M.L. 2019, Chp. 4, Sec. 2, Subd. 03j **Project Abstract**
For the Period Ending June 30, 2022

PROJECT TITLE: Red-headed Woodpeckers: Indicators of Oak Savanna Health
PROJECT MANAGER: David Andersen
AFFILIATION: U.S. Geological Survey (USGS), Minnesota Cooperative Fish and Wildlife Research Unit (MN CFWRU) and University of Minnesota
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2019, Chp. 4, Sec. 2, Subd. 03j

APPROPRIATION AMOUNT: $171,000
AMOUNT SPENT: $171,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results

Our project results provide important information on the factors associated with red-headed woodpecker habitat use, survival, and productivity in savanna ecosystems, which can aid ongoing habitat management and conservation efforts intended to conserve and restore this species in Minnesota.

Overall Project Outcome and Results

Red-headed Woodpeckers (*Melanerpes erythrocephalus*) are charismatic cavity-nesters that breed in savannas and open forest systems across the eastern and Midwestern United States and south central and eastern Canada. Historically, they were common across the Midwest, but populations have experienced dramatic regional declines. Habitat restoration initiatives have been challenged by a general lack of information on the factors that make savannas desirable for this species. With collaborators from the University of Toledo in Ohio, we studied red-headed woodpecker demography, habitat associations, and migration ecology from 2017 – 2020 in Ohio and Minnesota to elucidate critical periods, locations, life stages, and habitat characteristics associated with population growth rates and to provide habitat restoration and management recommendations for land managers and the public (separate funding sources for research in Ohio). Our results indicate that red-headed woodpecker productivity is higher in landscapes with both open and closed-canopy forest and that even in large stands of oak savanna, productivity near the center of those stands is predicted to be lower than in savanna closer to other forest types. GPS tracking data show detailed information on the migratory and overwintering locations and behaviors of adult red-headed woodpeckers, which, to our knowledge is the first reported data of its kind for this species in Minnesota. Our results provide information on snag density around nest trees, the importance of nest tree wood hardness, and habitat use by adult and fledgling woodpeckers. We have also gained considerable information on the community of predators that may impact red-headed woodpecker nest survival through our trail camera project, now hosted on Zooniverse. We have engaged with thousands of volunteers from around the world to share more about our research through our cavity camera project. Our best management practices are based on current results and we intend to update our recommendations in consultation with collaborators and other experts.

Project Results Use and Dissemination

We presented our research at professional conferences (the Annual meeting of the Minnesota Ornithologist's Union, the American Ornithological Society Annual Conference, and at the Toledo Museum of Natural History Forum on Local Natural History and Research). We also presented eight invited talks to public audiences through the University of Minnesota, Cedar Creek Ecosystem Science Reserve, multiple local Audubon Chapter organizations, and a Naturalist club in Brandon Manitoba in Canada. Our research project was featured in articles in the following newspapers and magazines: ***Terrain.org***, ***University of Minnesota College of Biological Sciences***, *and the* ***Minneapolis Star and Tribune***.

We are also currently in the process of preparing three manuscripts for publication in the peer-reviewed, scientific literature focused on red-headed woodpecker nest survival and nest site selection, landscape productivity, and mating system:

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2018 ENRTF Work Plan Final Report

Date of Report: 30 June 2022

Date of Final Report: 30 June 2022

Date of Work Plan Approval: 5 June 2019

Project Completion Date: 30 June 2022

Does this submission include an amendment request? No

PROJECT TITLE: Red-headed Woodpeckers: Indicators of Oak Savanna Health

Project Manager: David E. Andersen

Organization: U.S. Geological Survey (USGS), Minnesota Cooperative Fish and Wildlife Research Unit (MN CFWRU) and University of Minnesota

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Web Address: http://mncoopunit.cfans.umn.edu/

Location: Anoka and Isanti Counties, Minnesota

Total Project Budget: $171,000

Amount Spent: $171,000

Balance: $0

Legal Citation: M.L. 2019, Chp. 4, Sec. 2, Subd. 03j

Appropriation Language: $171,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate red-headed woodpecker survival and habitat needs and to use this data to develop and disseminate a long-term oak savanna management plan that supports red-headed woodpeckers and other oak savanna habitat-dependent species.

I. PROJECT STATEMENT:

The red-headed woodpecker (*Melanerpes erythrocephalus*) is the flagship species of the oak savanna ecosystem. It plays a crucial role in maintaining healthy oak savanna by creating habitat for other species in live and dead trees. Red-headed woodpeckers are considered ecosystem engineers and a keystone species, and their presence may have far-reaching effects on species richness and ecosystem health. Historically, red-headed woodpeckers were common across the Midwest, but populations have experienced dramatic regional declines estimated at 67% since 1970. The situation in Minnesota is even grimmer: since 1967, this species has experienced an average annual decline of 6%, representing a cumulative loss of nearly 95% of the population. Although the rate at which red-headed woodpeckers are declining has slowed since 1990, **populations in Minnesota do not appear to have stabilized**.

Fragmented patches of oak savanna exist across Minnesota, and there is considerable interest and effort from public and private land managers to preserve and restore this rare ecosystem. Efforts to support red-headed woodpeckers and other oak savanna specialists through habitat restoration are ongoing at a number of sites, but these initiatives have been challenged by **a general lack of information on the factors that make savannas desirable for this species**. Fortunately, red-headed woodpeckers occur in relatively stable numbers (>100 breeding adults annually) at the Cedar Creek Ecosystem Science Reserve (hereafter "Cedar Creek") despite dramatic declines in surrounding areas. Since 2008, a citizen-driven initiative of the Audubon Chapter of Minneapolis has been monitoring this species at Cedar Creek, and has generated some basic information on population size and nest cavity use. In 2017, a formal research collaboration was established with partners at the University of Minnesota and the University of Toledo in Ohio to address key information gaps about red-headed woodpecker ecology, with a particular emphasis on identifying the aspects of oak savanna habitat that support nest success, survival, and migration patterns. **Our GOALS** are to address population declines in a charismatic species of great conservation concern, to assess the outcomes of ongoing management and conservation efforts in an endangered ecosystem, and to develop a unified management plan for restoring oak savanna for red-headed woodpeckers and other oak habitat specialist species in Minnesota and throughout the Midwest.

The OUTCOMES we plan to achieve are to:

1. Identify oak savanna habitat characteristics and adult condition and behaviors associated with successful production of young, the factors related to whether and where individuals migrate, and the consequences of migratory status on productivity and survival.
2. Develop a long-term management plan for restoring oak savanna to support red-headed woodpeckers and other oak-savanna habitat specialists in Minnesota and the Midwest.

II. OVERALL PROJECT STATUS UPDATES:

Project Status as of *31 March 2020:* We captured a total of 72 red-headed woodpeckers at Cedar Creek during the 2019 field season. Of this total we equipped 21 adults with GPS tracking units and geolocators and 10 adults with radio-transmitters and geolocators. Of the total birds captured we also equipped 15 nestling woodpeckers with radio-transmitters. We also monitored 36 individual nest cavities once they were confirmed as active. Each nest cavity was visited a minimum of three times per week until nest failure (eggs or nestlings depredated or missing) or fledglings left the nest.

Project Status as of *30 September 2020:* We captured 62 red-headed woodpeckers at Cedar Creek during the 2020 field season. We marked 24 adults with GPS tracking units and geolocators and 6 adults with radio-transmitters and geolocators. We also equipped 9 nestling woodpeckers with radio-transmitters. We monitored 69 individual nest cavities once they were confirmed as active. Each nest cavity was visited a minimum of three times per week until nest failure (eggs or nestlings depredated or missing) or fledglings left the nest. We also completed a project to examine the role of wood density in nest site selection by woodpeckers. Data analyses have been delayed due to safety and other constraints related to Covid-19 and are beginning Fall 2020.

AMENDMENT REQUEST November 13, 2020
We are requesting funds be shifted from the supplies budget line to personnel and travel.

- Supplies budget would be reduced by $3,246 to a revised budget of $1,700
- Personnel budget would increase by $2,925 to a revised budget of $152,409
- Travel budget would increase by $321 to a revised budget of $2,841

These changes are being requested because mileage costs were higher than anticipated this summer, as Covid-related safety protocols required single occupants in vehicles, and we were therefore required to support multiple vehicles this summer to complete field work. We did not spend all of the funds we had budgeted for field supplies, in part because we were able to cover some of those costs with in-kind support from the Minnesota Cooperative Fish and Wildlife Research Unit and the Minneapolis Chapter of the Audubon Society. We therefore plan to use remaining funds to extend the appointments of our technicians to assist with data entry and other project-related tasks.

We are requesting a 1-year time extension to submit the final report for this project. We do not require a budget extension and anticipate being able to complete the data collection portion of the project as currently scheduled. However, due in part to issues related to Covid-19 and the extra effort required to conduct field work in 2020 to conform to University of Minnesota and Centers for Disease Control safety policies, we anticipate requiring additional time to complete the final project report.
Amendment Approved by LCCMR 12/2/2020

Project Status as of *31 March 2021:* We are currently focusing project efforts on processing and analyzing movement data from GPS Pinpoint devices and radio-transmitters, analyzing nest survival data, and writing up results for publication in peer-review scientific journals and our best management plan.

Final Report Draft between project end (30 June) and 15 August 2021: We completed final field work in May and June 2021. We are continuing to process and analyze movement data from GPS Pinpoint devices and radio-transmitters, analyze nest survival data, and write up results for publication in peer-review scientific journals and our best management plan for final submission by 30 June 2022.

Final Report 30 June 2022
Red-headed Woodpeckers (*Melanerpes erythrocephalus*) are charismatic cavity-nesters that breed in savannas and open forest systems across the eastern and Midwestern United States and south central and eastern Canada. Historically, they were common across the Midwest, but populations have experienced dramatic regional declines. Habitat restoration initiatives have been challenged by a general lack of information on the factors that make savannas desirable for this species. With collaborators from the University of Toledo in Ohio, we studied red-headed woodpecker demography, habitat associations, and migration ecology from 2017 – 2020 in Ohio and Minnesota to elucidate critical periods, locations, life stages, and habitat characteristics associated with population growth rates and to provide habitat restoration and management recommendations for land managers and the public (separate funding sources for research in Ohio). Our results indicate that red-headed woodpecker productivity is higher in landscapes with both open and closed-canopy forest and that even in large stands of oak savanna, productivity near the center of those stands is predicted to be lower than in savanna closer to other forest types. GPS tracking data show detailed information on the migratory and overwintering locations and behaviors of adult red-headed woodpeckers, which, to our knowledge is the first reported data of its kind for this species in Minnesota. Our results provide information on snag density around nest trees, the importance of nest tree wood hardness, and habitat use by adult and fledgling woodpeckers. We have also gained considerable information on the community of predators that may impact red-headed woodpecker nest survival through

our trail camera project, now hosted on Zooniverse. We have engaged with thousands of volunteers from around the world to share more about our research through our cavity camera project. Our best management practices are based on current results and we intend to update our recommendations in consultation with collaborators and other experts.

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1 Title: *Capture and mark 70 red-headed woodpeckers with tracking units in Minnesota, acquire movement and habitat use data for marked birds.*

Description: *We will mark 20 adult red-headed woodpeckers with GPS units during the summer 2019 breeding season at Cedar Creek. Each GPS unit will collect up to 300 precise locations on a pre-programmed schedule throughout the year. Those data will be downloaded when the woodpeckers are recaptured the following year (2020) and used to estimate survival and dispersal. We will mark an additional 50 woodpeckers (15 nestlings and 10 adults each in 2019 and 2020) with radio-transmitters to study fledgling survival, behavior, and habitat associations. Capture, marking, and tracking will be conducted by the postdoctoral researcher (Dr. Elena West) and field technicians assisted by volunteers coordinated by Keith Olstad of the Audubon Chapter of Minneapolis.*

Summary Budget Information for Activity 1:	**ENRTF Budget:**	**$ 85,500**
	Amount Spent:	**$ 85,500**
	Balance:	**$ 0**

Activity Completion Date: August 2020

Outcome	Completion Date
1. Mark 20 woodpeckers with GPS tracking units	*September 2019*
2. Acquire high-resolution GPS tracking data from marked woodpeckers	*May 2020*
3. Mark 25 woodpeckers with radio-transmitters, acquire habitat data	*August 2019*
4. Mark 25 woodpeckers with radio-transmitters, acquire habitat data	*August 2020*

Activity Status as of *31 March 2020:* During our 2019 field season we captured a total of 72 red-headed woodpeckers at Cedar Creek. We banded woodpeckers with an aluminum U.S. Geological Survey band and a unique combination of three colored leg bands and collected blood and feather samples. We also weighed and took morphological measurements from each captured woodpecker (tarsus length and wing chord). We equipped 21 adult woodpeckers with GPS tracking units and geolocators (the two devices were glued together) designed by Lotek Wireless. We also equipped 10 adult and 15 juvenile woodpeckers with radio-transmitters, designed by Blackburn Transmitters. Adults equipped with radio-transmitters were also equipped with geolocators. We used a handheld telemetry receiver to relocate focal individuals through daily ground-based telemetry surveys, which were conducted by walking trails and driving roads in search of signals emanating from radio-marked individuals. We also monitored 36 individual nest cavities once they were confirmed as active. Each nest cavity was visited a minimum of three times per week until nest failure (eggs or nestlings predated or missing) or fledglings left the nest. We are currently waiting to receive laboratory results to determine the sex of each woodpecker (based on DNA analysis from blood samples). We also prepared woodpecker blood and prey samples for stable isotope analysis and are awaiting those results, which will provide information on woodpecker diet.

During the 2019 field season we also recovered 4 GPS tracking units and 8 geolocators from woodpeckers that had been equipped with these devices in 2018, as part of our collaborative work with our partner organizations. Data from devices recovered in 2018 showed that all of the woodpeckers equipped with GPS units overwintered in and around Cedar Creek. Interestingly, data from one of the GPS units recovered in 2019 indicate that a woodpecker migrated to southeast Iowa in September 2018, remaining in this location until late December, 2018 when the device's battery apparently failed and it stopped collecting location data. This bird's overwintering locations appear to be in small, dense forest patches within landscapes dominated by agricultural fields, within a few miles of the Mississippi River (Fig. 1).

Activity Status as of *30 September 2020*: We completed field work for the 2020 field season on 28 September 2020. We captured 62 red-headed woodpeckers at Cedar Creek, following banding and measurement methods mentioned above (March 2020 update). We equipped 24 adult woodpeckers with GPS tracking units and geolocators (the two devices were glued together) designed by Lotek Wireless. These devices were purchased by our partner organization, the Audubon Chapter of Minneapolis, in an effort to collect additional data on migratory movements by red-headed woodpeckers, given that very few woodpeckers have migrated during previous years of our study. We also equipped 6 adult and 9 juvenile woodpeckers with radio-transmitters, designed by Blackburn Transmitters. Adults equipped with radio-transmitters were also equipped with geolocators. Birds equipped with radio-transmitters were tracked following methods described above (March 2020 update). We also recovered 13 GPS tracking units and 15 geolocators from woodpeckers that had been equipped with these devices in 2019.

We monitored 68 individual nest cavities once they were confirmed as active. Each nest cavity was visited a minimum of three times per week until nest failure (eggs or nestlings depredated or missing) or fledglings left the nest. We are currently waiting to receive laboratory results to determine the sex of each woodpecker (based on DNA analysis from blood samples). Finally, we completed a project to examine the role of wood density in nest site selection by woodpeckers. The method involves measuring the wood mass density, which is proportional to the torque required to spin an increment borer into a pre-drilled hole. We collected density data from 38 woodpecker nest cavities from 34 trees and a sample of 34 random trees that were not used by woodpeckers for nesting. We plan to begin data analyses fall 2020.

Activity Status as of *31 March 2021*: We are currently processing and analyzing data from GPS Pinpoint and radio-tracking devices. Data from GPS Pinpoint devices is being used to determine non-breeding season movements by red-headed woodpeckers, including migratory movements. Data from the 19 GPS devices we have recovered to date show that all but one red-headed woodpecker overwintered at Cedar Creek. We will capture adults marked with GPS devices during the 2020 field season during the upcoming 2021 field season and these data will be combined with the data we have to date for completion of this aspect of the project. Data from radio-tracking devices are currently being analyzed to determine breeding season home range and habitat use patterns and post-fledgling survival.

Final Report Draft between project end (30 June) and 15 August 2021: Between May and June 2021, we recovered 9 of the 24 GPS Pinpoint devices from red-headed woodpeckers marked during the field season in 2020. We are analyzing the data downloaded from these devices as part of our work to understand the non-breeding season movements of red-headed woodpeckers, including migratory movements and timing. These data will be combined with data from previously recovered GPS Pinpoint devices. Over the course of our study we have recovered 29 GPS Pinpoint devices.

Final Report Summary: We captured a total of 88 adult red-headed woodpeckers during the breeding season (May – September) from 2017 – 2020 at the Cedar Creek Ecosystem Science Reserve. Field work in 2017 and 2018 was conducted with funding from our collaborators. We captured adult woodpeckers using box traps baited with peanuts. Captured woodpeckers were banded with an aluminum U.S. Geological Survey metal band and a unique combination of three colored leg bands. We collected blood samples in lysis buffer for genetic-based sex determination as red-headed woodpeckers are sexually monomorphic. To examine migratory patterns and behaviors, we marked 51 adult woodpeckers with 1.5-g backpack-mounted archival GPS tags (n = 29 females, n = 22 males). Fifteen woodpeckers were marked with GPS tags over multiple years (n = 81 GPS tags across all study years; n = 20 in 2017, n = 12 in 2018, n = 21 in 2019, n = 24 in 2020). We programmed GPS tags to record location estimates, hereafter "locations," once per week during the summer and winter months (May

– August and December – February) and once every three days during the months in which we expected migration might occur (September – November and March – April). We conducted site-wide surveys during the breeding season (1 survey/week during April – September) and wintering season (2 surveys/month during October – February) to verify which individuals remained during the winter (i.e., did not migrate). Archival GPS tags store data collected throughout their deployment and must be recovered to download locations; therefore, each subsequent field season after device deployments we prioritized site-wide surveys in April and May to locate and attempt to recapture birds that were marked the previous year.

We used radio-telemetry to track the movements and habitat use of adult red-headed woodpeckers. During the breeding season (May – September) between 2018 – 2020, we marked woodpeckers with 2.5-g backpack-mounted radio-transmitters (n = 7 females, n = 23 males). We tracked woodpeckers from May – September by conducting ground-based telemetry surveys, relocated adult birds approximately every 2-3 days and confirmed individuals by their unique combination of colored leg bands. We recorded the date, time, and location of each adult observation using a handheld global positioning system (GPS) unit. We estimated woodpecker home-range size as the area (ha) based on 95% utilization distributions derived using fixed kernel density estimates (Kernohan et al. 2001). We used the plugin method for bandwidth (i.e., smoothing parameter) estimation (Gitzen et al. 2006) in the Geospatial Modeling Environment for ArcGIS (Beyer 2012). We tested whether home-range size was influenced by the density of live and dead trees within each bird's home range, sex, age, and total years an individual spent on the same territory using a generalized linear modeling approach in R (R Core Team 2021).

We studied fledgling red-headed woodpeckers from nests we monitored during each breeding season from 2017 – 2020. We found nests by observing and following adult birds until it appeared a pair was focused on one cavity and confirmed active nests by using a wireless cavity inspection camera attached to a telescoping 50-ft pole. Once confirmed active, we visited nests approximately every 2–3 days until documenting a failure (eggs or nestlings abandoned, disappeared, or destroyed in cavity) or success, i.e., at least one nestling fledged (cavity found empty in the appropriate date range for fledging, confirmed by observation or radio telemetry when possible). Red-headed woodpeckers are known to re-nest after failure or after a successful first nest (Frei et al. 2020); therefore, we monitored pairs for a second brood and observed these using the same methods. To mark nestling woodpeckers, we installed small doors in accessible cavities after clutches were laid and prior to hatching. When we determined fledglings were within 1–2 days of an estimated fledge date, we accessed cavities using an extendable ladder, secured in place using climbing ropes. We removed nestlings from each nest cavity through doors and transported nestlings in a soft cloth bag from the nest cavity to a nearby processing station in a field vehicle. Nestlings were banded and marked with radio-transmitters (n = 55 individuals across all study years; n = 15 in 2017, n = 16 in 2018, n = 15 in 2019, n = 9 in 2020) using the same methods used for adults (see above). We also collected blood samples in lysis buffer for genetic-based sex determination as juvenile red-headed woodpeckers are sexually monomorphic. We observed no apparent effects of transmitter attachment on fledglings in comparison to observed unmarked fledglings. Once marking and sampling were completed, we returned all nestlings to the nest cavity.

Following marking, we monitored the location of radio signals (i.e., still in the nest or not) daily until birds fledged from the nest. After fledging, we located fledglings at least four times per week using ground-based telemetry from late June through mid-September, or until the radio signal was lost, which we assumed indicated winter migration or dispersal had occurred. We recorded the date, time, and location of each fledgling observation using a handheld global positioning system (GPS) unit. During each monitoring event, we attempted to visually confirm identity of each individual and we assumed that individuals that we could not observe (e.g., occupying dense canopy and not moving) were alive until we were unable to detect a bird at the same location for >3 days or signs of predation were apparent (e.g., feathers on the ground, damaged transmitter recovered). When a bird not observed visually remained in the same location for three days with no other evidence of fate, we assumed mortality occurred on the first day at that location.

We modeled fledgling survival based on logistic exposure models (Shaffer 2004) built in R (R Core Team 2021) to estimate fledgling daily survival rates and the relationships between daily survival and explanatory variables. We considered the variables year, site, age (i.e., days since fledging), fledge date, precipitation events (binary; days where rainfall > 1.27 cm indicating an above-average rainfall event), and nest cover-type (oak savanna or other). All models included a random effect of brood to avoid psuedoreplication due to non-independence of siblings. We ranked models using Akaike's Information Criterion corrected for sample size and we considered any model with ΔAICc < 4 to be potentially competitive. We calculated a period survival estimate for the dependent fledgling period as the product of all daily survival estimates for the first 28 days after fledging.

To examine red-headed woodpecker nest success and nest site selection, we monitored 135 nest attempts (*n* = 90 individual nest trees) from 2018 – 2020. After nests failed or fledged, we measured multiple features of each nest tree and the habitat surrounding each nest. At the nest tree, we recorded cavity height and orientation, diameter of each cavity entrance hole, tree diameter at breast height (DBH), percentage of the bole (trunk) that was visibly burned, percentage of remaining bark on the bole, and whether the tree was alive or dead. For habitat characteristics surrounding the nest (within a 10-m radius), we counted the number of snags and live trees with DBH >10 cm, measured canopy closure (the proportion of sky obscured by vegetation when viewed from a single point) around nest trees using a spherical densiometer at four cardinal points, counted trees with at least one cavity present, and estimated percent woody understory.

In addition to habitat variables collected in the field, we used a high-resolution (10-m) ecological land-type data layer (MN DNR) in ArcGIS 10.8 to measure the distance from each nest to the nearest wetland and closed canopy forest. We also compiled data on burn frequency surrounding nest trees from a record of prescribed burn history for Cedar Creek; however, we ultimately did not include these data in our models because the scale of this variable was larger than the scale of habitat selection measured by our use vs. available dataset. In addition to characteristics of nests and surrounding habitat, we also measured climatic and temporal variables that may impact nest survival rate, including high temperature anomalies and nest initiation date. Temperature anomalies may reduce nest survival. Socoloar et al. (2017) show warm temperature anomalies are associated with nest success in cold parts of a species' range, and the opposite holds true in warm parts of a species' range. East-central Minnesota is the northern region of the year-round range for red-headed woodpeckers but is not the northernmost extent of their breeding range (Frei et al. 2020). We investigated both cold and warm temperature anomalies in the nesting period to account for the unique location of the study site. We subtracted the mean max temperature of the 45-day nest period following initiation from the max temperatures experienced in the previous interval to account for high temperature anomalies, and subtracted the interval minimum temperature from the mean minimum of the same 45-day period to account for low temperature anomalies (Stillman et al. 2019, Socolar et al. 2017).

We modeled red-headed woodpecker daily nest survival (the probability that a given nest survives from day_x to day_{x+1}) using logistic exposure models fit within a Bayesian framework. We used logistic regression in a Bayesian framework to evaluate the biotic factors that influence nest-site selection by comparing used nest locations to a sample of available nest locations within a 65-m radius buffer around each nest. This buffer encompassed an area of 1.3 hac, which is the average minimum convex polygon home range size for red-headed woodpecker in our study population. Our nest-tree-selection model contained 3 available locations (snags that had no visible cavities) for each nest location. We selected only snags (rather than live trees) in our sample of available trees, because only a small proportion of nests occurred in live trees (in dead branches).

We also evaluated the role of interior wood hardness using a subset of nests and available trees for which we had wood hardness data, as we were unable to access all nest and available tree cavities because they were beyond the height of our ladders or because certain trees were too decayed to safely access cavities. At each nest site we measured the hardness of wood using a method developed by Matsuoka (2000) in which wood mass density is proportional to the torque required to spin an increment borer into a pre-drilled hole 5-cm above the nest cavity entrance at 1-cm increments into the tree. We used torque measured in newton meters

(Nm) for all statistical analysis involving wood hardness. For available sites, we measured wood hardness at a random height and orientation on each snag.

As part of our collaborative work with Dr. Henry Streby at the University of Toledo, we built spatially explicit models of full-season productivity (young raised to independence per breeding pair) for red-headed woodpeckers and applied these models to the broader landscape using data from Cedar Creek and study sites in Ohio and Michigan (separate funding sources). These models use landscape composition and configuration to predict productivity in any area with similar cover types to that of the study areas. To estimate the effect(s) of cover types on nest success and fledgling survival, we began with initial landcover classification layers that contained 20 cover types for each site. We collapsed those 20 cover types into six broad categories, which included savanna, grassland, forest, water, developed, road, and agriculture. For each of the six model covariates (hereafter, landscape variables), we used model ranking to determine an impact radius, which defined the scale at which that landscape variable was most strongly associated with survival in each period (i.e., nests and fledglings). To determine the impact radius for each landscape variable, we buffered each nest location with circular radii at 50, 100, 250, and 500 m. We summed the total area for each cover type for each buffer distance around each nest location to model the relationships between the area of each landscape variable at each scale (i.e., impact radii) and survival. We estimated survival using each combination of scale and polynomial function (i.e., linear, quadratic, or cubic relationships) for each variable by fitting logistic exposure models (Shaffer 2004) to survival data from each site for nest and fledgling survival in R (R Core Team, 2020). We included brood as a random effect in all juvenile survival models to account for non-independent survival of brood mates (x^2 = 138.6489, p=0.0056; Winterstein 1992).

For all candidate impact radii for each habitat variable, we ranked models of nest and fledgling survival rate using Akaike's Information Criterion adjusted for sample size (AICc; Burnham and Anderson, 2002). We selected cover types and impact radii as covariates in productivity models using a combination of AICc rankings and biologically informed predictions. If none of candidate impact radii models outperformed the null model for a given habitat variable within a survival period, then there was no discernable influence of that habitat variable at any scale on that survival period, and it was not included in the final predictive productivity surface model.

Following the selection of model covariates, we built logistic exposure survival rate models (Shaffer 2004) for each potential combination of important landscape components at their determined impact radius (Table 4) to estimate daily survival rate for each pixel (i.e., $1m^2$) on the digitized landscape informed by the landscape composition and configuration surrounding that pixel. We predicted daily survival rate (*S*) for each observed combination of landscape structure and composition (*l*) and survival period (*p*; e.g., nest period) as:

$$Slp = exp(\alpha_{lp} + \beta_{1lp}x_{1lp} + \beta_{2lp}x_{2lp} + \beta_{3lp}x_{3lp} ...) / (1 + exp(\alpha_{lp} + \beta_{1lp}x_{1lp} + \beta_{2lp}x_{2lp} + \beta_{3lp}x_{3lp}...))$$

where α is the estimated intercept and βi is the estimated coefficient for the landscape variable *xi*.

For each landscape variable, we built a landscape variable map that delineated the area over which that variable was related to each component of productivity (nest survival, fledgling survival). We used the vector cover-type layers delineated using satellite imagery and isolated each cover type. We converted all landscape variable maps to 1 x 1-m resolution raster layers and then used a neighborhood function in ArcGIS 10.8 to calculate a value at every 1 x 1-m pixel on the map equal to the quantity (i.e., area) of each landscape variable within its impact radius for each survival period. For example, area of savanna was related to nest survival at a 500-m scale; we therefore created a variable quantity map that for each pixel contained a value equal to the number of ha of savanna within 500 m of that pixel.

To estimate survival probability over each period (i.e., nest and fledgling), we used our estimate of daily survival rate raised to a power equal to the number of days in the period (45 days for the nest period and 12 days for the fledgling period). We applied these logistic exposure survival rate equations to the landscape surface using the amount of each landscape variable surrounding a given pixel at the previously determined impact radius and the β-coefficients from the logistic exposure survival rate equations for each appropriate landscape variable to estimate survival rates of nests and fledglings. Nest productivity (i.e., the number of juvenile red-headed woodpeckers leaving the nest; NP) was calculated given the assumed ability for one renesting attempt (i.e., one additional nesting attempt following previous nest failure), using a mean brood of two juveniles as:

$$NP = (NS + (1 - NS) * NS) * 2$$

where NS is nest success probability. Productivity (i.e., the number of fledglings raised to 12 days post-fledging; P) was calculated as:

$$P = NP * JS$$

where JS is juvenile [fledgling] survival probability from hatch day to day 12. We applied these equations to the digitized landscape to produce raster surfaces containing values for productivity of hypothetical red-headed woodpeckers nests placed within each pixel ($1m^2$) of each study area.

ACTIVITY 2 Title: *Develop and share long-term plan for managing oak savannas in Minnesota to support red-headed woodpeckers*

Description: *We will evaluate red-headed woodpecker survival, movement patterns, and habitat use, and use these data to develop a long-term management plan for restoring oak savanna and supporting red-headed woodpecker populations. Dr. Elena West will lead data analysis, writing and dissemination of management plan to local, state, and federal management agencies and the public, assisted by Dr. Caitlin Barale Potter, education and community engagement coordinator at Cedar Creek and Dr. Henry Streby of the University of Toledo.*

Summary Budget Information for Activity 2: **ENRTF Budget: $ 85,500**
Amount Spent: $ 85,500
Balance: $ 0

Activity Completion Date: June 2021

Outcome	Completion Date
1. Assess survival, year-round habitat use and selection patterns of RHWO	*September 2020*
2. Dissemination of findings to management agencies and the public	*June 2021*

Activity Status as of *31 March 2020*: We are currently in the first year of our 2-year study that is the continuation of a long-term study funded by The Audubon Chapter of Minneapolis and other partners. We are currently working to obtain spatial habitat data layers that will be used in future habitat selection analyses as a part of Activities 1 and 2. We will be collecting a final year of survival data during our 2020 field season and these data will be used as part of our assessment of red-headed woodpecker survival.

Activity Status as of *30 September 2020*:
We are in the process of analyzing survival and habitat use data collected as part of this study. After completing data analyses we will compile our results into research articles and as part of a best management plan for agencies and the public. We plan to begin dissemination of the best management plan in 2021.

Activity Status as of *31 March 2021*:
We are continuing to analyze survival and habitat use data collected as part of this study. We are working to complete an analysis to determine how the landscape surrounding red-headed woodpecker nests impacts nest and post-fledging survival. We are working on this analysis with our collaborator at the University of Toledo, Dr.

Henry Streby. The results from this analysis will inform our best management recommendations for land managers in Minnesota and throughout the red-headed woodpecker's Midwest range.

Final Report Draft between project end (30 June) and 15 August 2021: We are in the process of completing an analysis to determine how the landscape surrounding red-headed woodpecker nests affects nest and post-fledging survival. We are nearing completion of the analyses associated with this particular effort, which we will complete as part of a manuscript submission for a peer-reviewed journal. Results from this project will also be included in the best management plan we are developing as part of the final report for this project.

Final Report 30 June 2022: We have completed data collection and analyses and we have summarized our findings below. Final tables and figures are included at the end of our summary (page 16).

Migratory movements and winter habitat use

Following recapture of GPS-tagged individuals during each subsequent breeding season from 2018 – 2021, we downloaded and analyzed GPS data using the software provided from the manufacturer. We recaptured 41 adult woodpeckers marked with GPS tags during each subsequent breeding season (n = 9 marked in 2017, n = 8 marked in 2018, n = 15 marked in 2019, n = 9 marked in 2020). Of this total, 12 birds were missing their devices and two devices were damaged such that data could not be extracted from them. Due to substantially shorter battery life than expected in these newly developed tags, only 3 tags lasted through the full programmed schedule and 11 tags stopped collecting data between October and March after deployment.

We plotted locations for each individual and determined the predominant land cover-type in ArcGIS 10.8 using the National Land Cover Dataset and satellite imagery in Google Earth Pro. We then determined migration status (i.e., migratory or sedentary), departure date, minimum distance traveled, sites used during migration, and wintering sites for each individual. We categorized individuals as migratory if they left the breeding site and were not observed on the study site during winter surveys. We categorized individuals as sedentary if they were present on the breeding site during winter surveys. We estimated departure date to be the midpoint date between the last location taken on the breeding site and the first location away from the breeding site. We calculated minimum distance traveled as the distance between chronological points and defined migratory locations as single locations away from the breeding site. We defined wintering sites as sites away from the breeding site where ≥ 2 consecutive GPS locations were recorded, indicating the individual had settled for a period > 1 week.

Of the 25 GPS tags recovered with enough data to estimate non-breeding season movement patterns, nine included data indicating that migration had occurred during the prior year (n = 1 in 2018, n = 8 in 2020). GPS data for the remaining 16 individuals (n = 3 in 2017, n = 2 in 2018, n = 11 in 2019) indicated that these birds remained on the study site for the duration of the breeding season and wintering season. Locations from the 9 birds that migrated indicated that those individuals departed the breeding site (Cedar Creek) during the first three weeks of September and arrived at their respective wintering sites nine to 29 days after departure (Table 1).

Location data for birds that migrated indicated that all individuals departed from the breeding site to the southeast, towards the Mississippi River. One bird moved approximately 51 km to the northwest after an initial movement away from the breeding site to the southeast. From there, this individual traveled approximately 101 km north before making migratory movements to the southeast again, ultimately overwintering in Indiana (Figure 1). The distance traveled between 3-day locations varied by individual, with the longest averaging 288 km and the shortest averaging 166 km between locations. The distance between locations ranged from 5 km to 720 km. Woodpecker locations during migration spanned five states (Iowa, Kansas, Missouri, Wisconsin, and Illinois). Sites occupied during migration were primarily hardwood forest patches within landscapes dominated by agricultural fields (n = 53 locations, 98%; Figure 2) with the single remaining location in oak barrens (n = 1, 2%). Sites occupied during winter were small (mean = 2.1 ha, range = 0.08 – 12 ha) and were located primarily in hardwood forest patches surrounded by agriculture. Data from two birds indicates that spring migration movements took place over approximately 3 and 7 days (small sample size of spring migration data was due to battery failure on the majority of the GPS tags on birds that migrated), with both birds arriving at Cedar Creek by May 3 (Figure 3). The average distance traveled between 3-day locations by these birds during spring migration was 313 and 664 km.

GPS data indicated that sedentary birds were located primarily in oak savanna that overlapped the areas used during the breeding season. Sedentary individuals remained near their previous year's nest tree (mean = 44 m, range = 21 – 109 m; males = 31 m, females = 57 m) and close to nest trees used the following year if they differed from the previous year's tree (mean = 45 m; males = 35 m, females = 48 m). Sites used by sedentary individuals were small (mean = 0.67 ha; males = 0.43 ha, females = 0.92 ha). Six individuals made one-time movements (i.e., a single location recorded away from the winter site with locations prior to and after these movements on the wintering site). These movements often occurred in September – October or March – April. One individual made 5 one-time movements ranging from 0.3 km – 2.2 km to oak savanna or hardwood forest patches.

Breeding season home-range size and habitat use

We obtained an average of 40 tracking locations per individual adult woodpecker (range: 19–57). Adult woodpecker home-range size during the breeding season was small, with individuals generally occupying the area around their nest trees (mean = 0.02 km^2 based on the 95% UD, range: = 0.0031 – 0.05 km^2), primarily in oak savanna and hardwood forest. Nests located in hardwood forests were generally near forest edges and open grasslands. To explore patterns in adult home-range size, we tested nine model combinations that included live- and dead-tree density within each bird's home range, sex, age, and total years an individual spent on the same territory. Our top-performing model indicated that snag density is an important predictor of home-range size in red-headed woodpeckers (Figure 4). Our results also show a strong positive relationship between home-range size and distance to individual bird's nearest neighbor (Figure 5).

Nest and fledgling survival

We observed nest failure at 37 of 135 nests with known fates, yielding an apparent nest success rate of 0.72 (n = 98 nests that fledged ≥ 1 young). Although we were not able to confidently determine the cause of failure for most nests, we documented probable occurrences of nest predation by small mammals, including raccoons (*Procyon lotor*), flying squirrels (*Glaucomys sabrinus*), and bull snakes (*Pituophis catenifer*), and multiple occasions of nest eviction by flying squirrels. Mean clutch size was 4.4 eggs (SD = 1.06, SEM = 0.1). Of the 98 nests that fledged young, the average age from nest initiation to the first fledge event was 44.7 days (SD = 3.49, SEM = 0.35). The median nest initiation date was 21 May, and 75% of nests were initiated between 1 May and 27 June (Figure 6). Our top model for nest survival included live tree count within 10 m of nest trees, canopy closure, maximum temperature anomalies, and year (Figure 7). Tree count and year showed a strong effect on nest survival whereas canopy closure and temperature anomalies showed a weak positive relationship with nest survival (Table 3).

We estimated a mean of 2.1 fledglings produced per successful nest, and 70% of those fledglings survived to independence from adult care. Overall, mortality of fledglings was due to predation (86%) and exposure (14%). Daily survival rates were lowest in the first 5 days post-fledging at ~0.98 and increased to >0.99 at 12 days after fledging, well within the parental dependent phase, with no mortalities observed past 50 days.

Nest site selection

The majority of red-headed woodpecker nests (81%) occurred in northern pin oak (*Quercus ellipsoidalis*) trees and 77% of nests were located in dead trees. Woodpeckers nested at sites with a mean of 2 ± 1 snags within 10 m of the nest tree (range = 0 – 8 snags), and the average nest tree had a DBH of 35 cm (range = 25 – 76 cm; Figure 8). Mean nest cavity orientation was 83.4 degrees, and a Rayleigh test of uniformity indicated cavity orientation was randomly distributed (R = 0.05, p = 0.75). Our resource selection model showed significant positive selection for habitat patches with more dead trees and no effect of live trees (within a 10-m radius of each nest tree) on the relative probability of nest site selection (Table 3, Figure 9). Finally, torque measurements (wood density measures) were much lower in nest trees (mean = 5.37) compared to available trees (mean = 19.31; Figure 10), indicating that woodpeckers used nest trees with softer interior wood (effect of nest tree = -13.89; 95% CI = -16.60, -11.33).

Landscape productivity

Table 4 shows positive, negative, and neutral relationships, and the scales at which those relationships occurred, between the habitat variables and nest survival, fledgling survival, and full-season productivity. In general, full-season productivity in red-headed woodpeckers was positively associated with areas that contained both savanna and closed canopy forest types adjacent to one another but was negatively associated with larger areas (>50 ha) of only savanna (Figure 11). Even in large stands of oak savanna, with which woodpecker abundance is positively associated, productivity near the center of those stands is predicted to be lower than in savanna closer to other forest types. There was a positive association between full-season productivity and the area of the landscape that was water, which included shrubby and grassy wetlands, ephemeral wetlands, and open water (Figure 11). This relationship was apparently driven by the tendency for high productivity from nests near or in shallow or ephemeral wetlands and should not be misinterpreted as high productivity within areas of open water, where woodpeckers generally do not nest. There was a complicated relationship between full-season productivity and area of grassland, wherein small areas of grassland (i.e., narrow strips or patches of only 1–2 ha) had a positive effect, whereas larger areas of grassland had an increasingly negative effect on productivity. This relationship is likely driven by reduced fledgling survival from nests in snags that were not near live trees, as is the case in lone snags in grasslands away from forest or savanna edges. There was a slightly positive association between full-season productivity and roads, but that relationship should be viewed in the context of the negative effect of roads on abundance and adult survival, indicating that roads likely have an overall negative effect on red-headed woodpecker populations.

IV. DISSEMINATION:

Description: *Results from this project will provide information about red-headed woodpecker habitat needs that will be disseminated to local, state, and federal management agencies, published in the peer-reviewed literature, and made available to the general public via our project website (rhworesearch.org) and popular press articles.*

Status as of *31 March 2020*: Dr. West gave an invited 'lightning talk' on April 10, 2019 to approximately 100 people as part of the University of Minnesota's College of Biological Sciences SciSpark Women in Science event, aimed at raising awareness of women in science and a public outreach event. Dr. West's presentation provided a 5-minute overview of her current work on red-headed woodpeckers and previous work on Steller's jays. Dr. West also gave an invited talk to approximately 200 people on December 7, 2019 at the Minnesota Ornithologist's Union annual meeting in St. Paul, Minnesota. The presentation gave an overview of red-headed woodpecker research efforts and provided public outreach. We will also submit an abstract to present our preliminary results at the 2020 national meeting of The Wildlife Society in October 2020.

Status as of *30 September 2020*: Dr. West gave a one-hour presentation on the red-headed woodpecker project as part of Cedar Creek's *Lunch with a Scientist Speaker Series.* We also submitted an abstract to present our preliminary nonbreeding season habitat use and movement results at the Midwest Fish and Wildlife Conference in January 2021.

Status as of *31 March 2021*: Dr. West gave a one-hour presentation on the red-headed woodpecker project as part of Cedar Creek's *Lunch with a Scientist Speaker Series.* We also plan to submit an abstract to present findings from this project at the upcoming American Ornithologists' Union annual conference in August 2021.

Final Report Draft between project end (30 June) and 15 August 2021: On March 9 2021, Dr. West gave a one-hour presentation on the red-headed woodpecker project as part of Cedar Creek's *Lunch with a Scientist Speaker Series.* On 26 March 2021, Dr. West gave a presentation on red-headed woodpecker behavior to the University of Minnesota Department of Ecology and Evolutionary Biology Behavior Group.

In collaboration with our partner organization, the Audubon Chapter of Minneapolis, we developed a side project as part of our work to understand the nesting ecology of red-headed woodpeckers and the factors that may influence nest success and survival. To do this we set up a series of trail cameras outside red-headed woodpecker nest cavities and have since collected thousands of 10–30 second videos (some cameras are still running). These video clips have captured the behaviors and interactions of red-headed woodpeckers, but also the community of animals that depend on and compete for these cavities. With help from Audubon Chapter of Minneapolis volunteers and our partner, Dr. Caitlin Barale Potter, we launched this project on the online platform, Zooniverse, where volunteers from anywhere in the world can view these videos and classify the behaviors and interactions of the animals in them, which will allow us to turn the videos into data that we can analyze to further understand red-headed woodpecker ecology and behavior and the role that other animals play in nest predation and competition. After the launch of this project on Zooniverse in May 2021, 1,556 volunteers from all over the world have looked through 22,709 videos. Each video has received at least three independent classifications as to whether there are animals or not in the shot. Of those 22,709 videos, 15,296 (67%) have contained wildlife. Those 15,296 images are then getting additional looks and classification to species (along with behavioral data and numeric counts) from 3–10 independent classifiers. That task is partially done - 12,299 videos have been classified in that manner, with 2,997 currently in that section of the pipeline. Of those 12,299 videos of wildlife, 6,424 (52%) have contained red-headed woodpeckers, and volunteers are now combing back through those videos to give us data on bands, age classes, behaviors, and within-species interactions. One of the exciting aspects of this project has been the opportunity to engage with volunteers from around the world and share more about elements of animal life and ecosystems that many wouldn't otherwise see. It has also been a unique way to share more about our research on red-headed woodpeckers, conservation, and habitat restoration. The project can be accessed here: https://z.umn.edu/woodpeckercams.

Final Report 30 June 2022

We presented our research via one oral presentation and two poster presentations at professional conferences (the Annual meeting of the Minnesota Ornithologist's Union, the American Ornithological Society Annual Conference, and at the Toledo Museum of Natural History Forum on Local Natural History and Research). We also presented eight invited talks to public audiences through the University of Minnesota, Cedar Creek Ecosystem Science Reserve, multiple local Audubon Chapter organizations, and a Naturalist club in Brandon Manitoba in Canada. Our research project was featured in articles in the following newspapers and magazines:

Terrain.org
https://www.terrain.org/2022/lter/cedar-creek/

University of Minnesota College of Biological Sciences
https://cbs.umn.edu/blogs/cbs-connect/holey-homemakers

Minneapolis Star and Tribune
http://www.startribune.com/red-headed-woodpeckers-find-a-home-in-east-bethel-minnesota/490829251/

We are also currently in the process of preparing three manuscripts for publication in the peer-reviewed, scientific literature focused on red-headed woodpecker nest survival and nest site selection, landscape productivity, and mating system:

West, E. H., J. Howitz, E. Fountain, C. Barale Potter, and H. Streby. Mating system flexibility may buffer population decline in the red-headed woodpecker, *Melanerpes erythrocephalus*.

West, E. H., K. Carr, G. Kramer, K. Pagel, C. Barale Potter, D. Andersen, and H. Streby. Using spatially explicit models to assess the impact of landscape structure and composition to predict full season productivity in a species of conservation concern.

West, E. H., K. Carr, J. Howitz, C. Barale Potter, and A. Stillman. Nest site selection and nest survival of red-headed woodpeckers in a landscape managed with prescribed fire.

V. ADDITIONAL BUDGET INFORMATION:
A. Personnel and Capital Expenditures

Explanation of Capital Expenditures Greater Than $5,000: N/A

Explanation of Use of Classified Staff: N/A

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 2.77

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: N/A

VI. PROJECT PARTNERS:

A. Partners outside of project manager's organization receiving ENRTF funding N/A

B. Partners outside of project manager's organization NOT receiving ENRTF funding

Dr. Caitlin Barale Potter, Cedar Creek Ecosystem Science Reserve, University of Minnesota (Activity 2)
Keith Olstad, Chair, Audubon Chapter of Mpls Steering Committee (Activity 1)
Dr. Henry Streby, Associate Professor, University of Toledo (Activities 1 and 2)

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The proposed project will support and expand an ongoing collaborative partnership to 1) address critical knowledge gaps about the habitat needs of red-headed woodpeckers, and 2) inform oak savanna restoration activities to benefit this species and other oak habitat specialists. Following the completion of this specific effort supported through ENTRF funds, continuing data collection and information dissemination will be carried on by volunteers from the community.

VIII. REPORTING REQUIREMENTS:

- Project status update reports will be submitted 31 March each year of the project and 30 September 2020
- A first draft of the final report will be submitted between 30 June and 15 August 2021
- A final draft of the final report and associated products will be submitted by 30 June 2022

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet

B. Visual Component or Map
C. Parcel List Spreadsheet N/A
D. Acquisition, Easements, and Restoration Requirements N/A
E. Research Addendum *completed September 2018*

Final Tables and Figures

Table 1. Autumn migration movements by red-headed woodpeckers breeding in east-central Minnesota.

Tag ID	Sex	Departure date	Arrival date	Mean 3-day distance traveled (km)[a]	Distance from wintering site to breeding site (km)
49963	M	9/11/20	10/8/20	238	742
49968	F	9/2/20	10/1/20	286	1194
49959	F	9/5/20	9/20/20	255	768
49960	M	9/11/20	10/7/20	178	1596
49971	F	9/11/20	10/5/20	166	1324
49974	F	9/2/20	9/19/20	265	1214
49979	F	9/5/20	9/20/20	288	779
49969	M	9/14/20	10/5/20	267	1612
48733	F	9/2/18	9/11/20	201	602

[a]Distances are minimum distances measured between GPS locations during autumn migration

Table 2. One-time movements made by red-headed woodpeckers overwintering at their breeding site.

Tag ID	Sex	Date of aberrant location	Distance from wintering site	Cover type
49454	F	4/6/2020	0.58 km	Hardwood forest
49445	F	11/29/2019	0.2 km	Oak savanna
49450	F	10/14/2018	1.3 km	Hardwood forest
49450	F	10/23/2018	0.35 km	Oak savanna
49450	F	3/7/2019	0.31 km	Oak savanna
49450	F	3/16/2019	0.66 km	Hardwood forest
49450	F	3/22/2019	2.17 km	Hardwood forest
41903	M	10/3/2017	0.24 km	Oak savanna
41903	M	10/9/2017	7.56 km	Agriculture
41903	M	10/27/2017	2.3 km	Hardwood forest
41903	M	10/30/2017	2.6 km	Hardwood forest
49453	M	9/10/2019	0.21 km	Hardwood forest
49438	M	9/16/2019	0.48 km	Oak savanna
49438	M	3/22/2020	0.27 km	Hardwood forest

Table 3. Posterior means and 95% Bayesian credible intervals for standardized parameter estimates in three models describing red-headed woodpecker nesting ecology at Cedar Creek Ecosystem Science Reserve, Minnesota. Estimates in bold indicator 95% credible intervals that do not overlap zero.

Covariate	Parameter estimate
Best-supported nest survival model	
Intercept	4.58 (4.02, 5.21)
Year-2019	**1.62 (0.43, 3.13)**
Year-2020	-0.02 (-0.73, 0.68)
Live trees within 10 m	**-0.6 (-0.99, -0.22)**
Canopy closure	0.38 (-0.04, 0.87)
High temperature anomaly	0.32 (-0.02, 0.66)
Tree reuse	0.33 (-0.41, 1.13)
Stand-level habitat selection model	
Intercept	-1.19 (-1.45, -0.93)
Woody understory	0.2 (-0.07, 0.46)
Live trees within 10 m	0.03 (-0.23, 0.29)
Dead trees within 10 m	**0.31 (0.06, 0.57)**
Trees with cavities within 10 m	0.13 (-0.11, 0.37)
Canopy closure	0.16 (-0.08, 0.42)
Distance to water	-0.19 (-0.49, 0.10)
Distance to forest	0.0 (-0.29, 0.28)
Tree-level habitat selection model	
Intercept	-1.05 (-1.33, -0.77)
DBH	0.18 (-0.11, 0.47)
DBH^2	-0.08 (-0.25, 0.08)
Percent bark remain	-0.13 (-0.41, 0.16)
Area burned	-0.15 (-0.44, 0.13)

Table 4. General associations between area of habitat variables (consolidated cover type classifications) on the landscape and nest success, fledgling survival, and full-season productivity (number of young raised to independence) of red-headed woodpeckers. Note that these relationships are for each habitat variable in isolation and that the direction of the effect can change in different landscape contexts. For example, Forest alone is negatively associated with full-season productivity, but when adjacent to Savanna, the effect of Forest is slightly positive. Blank cells indicate no discernable effect of a cover type at any relevant scale. In the cases of Agriculture and Development, the lack of relationship is likely driven by insufficient data because these cover types were not common in proximity to most birds we studied.

Cover Type	Nest Survival	Fledgling Survival	Seasonal Productivity
Savanna	500^2 (+)	50 (+)	(+)
Forest	NA	500 (-)	(-)
Grassland	50^2 (+)	100^2 (-)	(-)
Water	50^3 (-)	500 (+)	(+)
Agriculture	NA	NA	NA
Developed	NA	NA	NA
Road	NA	100^2 (+)	(+)

Figure 1. Autumn migratory movements of a female red-headed woodpecker from the breeding site to overwintering location showing an initial movement to the southeast followed by movements north and west before migrating south.

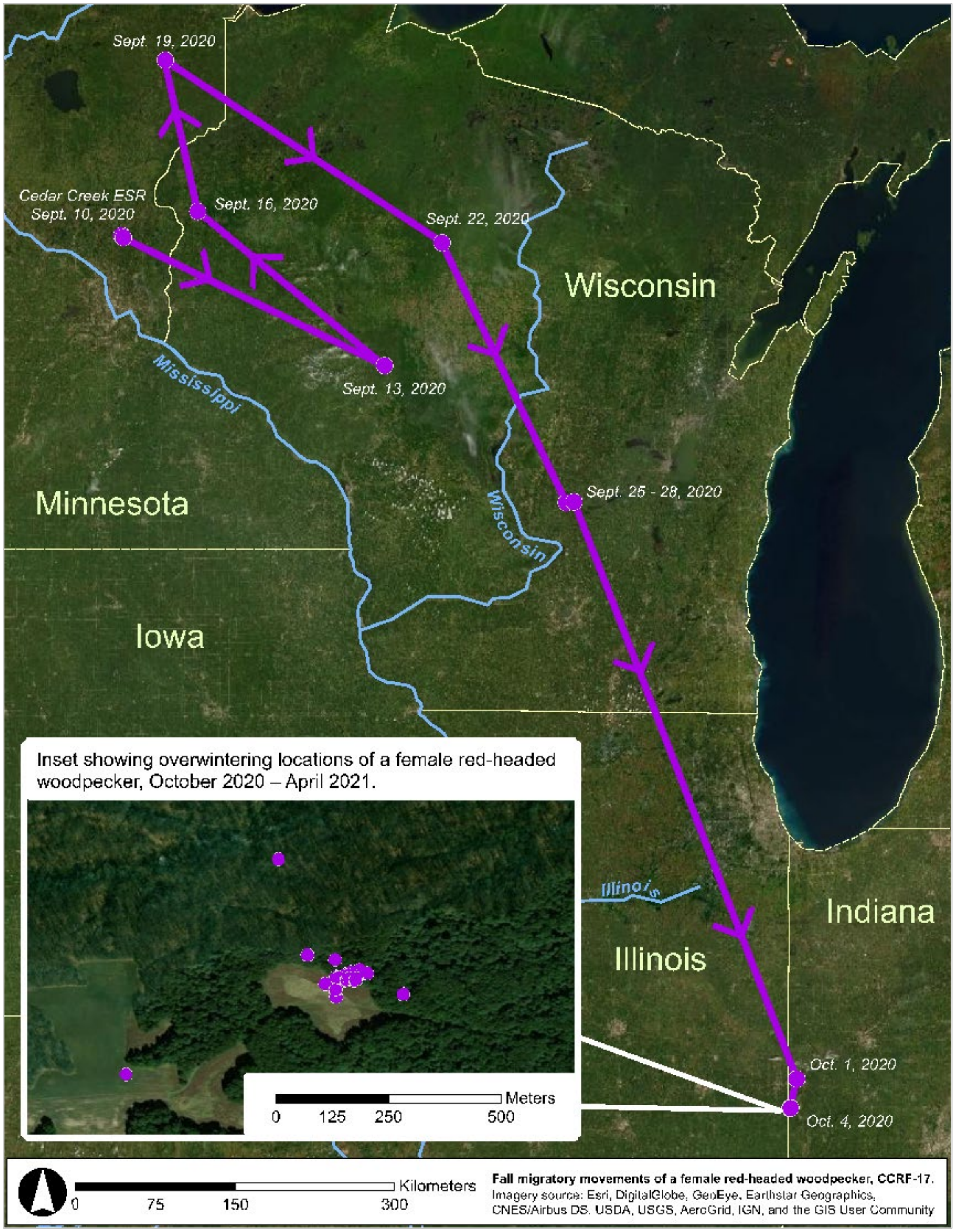


Figure 2. Autumn migratory movements of a male and female red-headed woodpecker from the breeding site to overwintering locations showing winter locations in hardwood forest patches surrounded by agriculture fields.

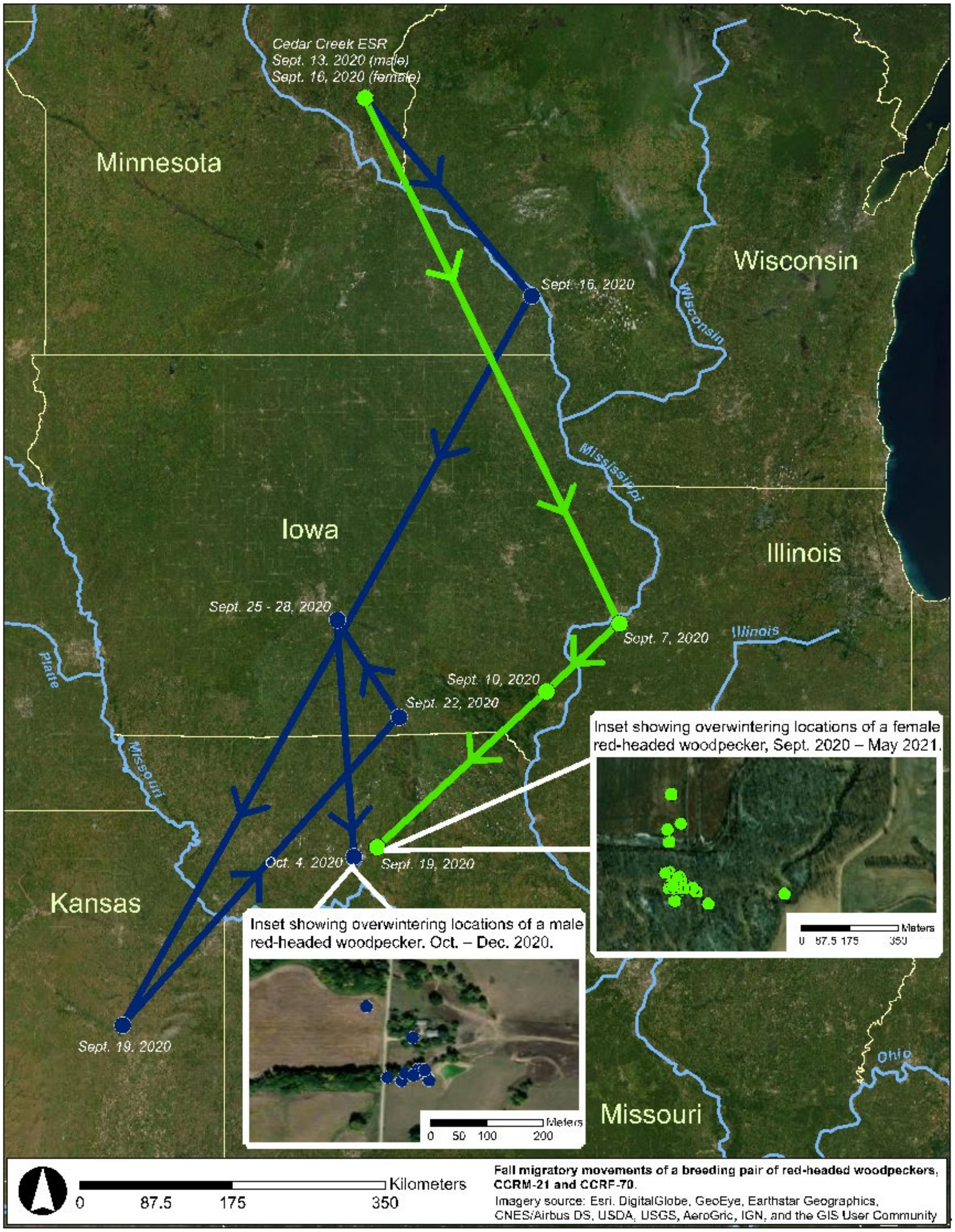


Figure 3. Spring migratory movements of a male and female red-headed woodpecker from their winter locations to their breeding site at the Cedar Creek Ecosystem Science Reserve, east-central Minnesota.

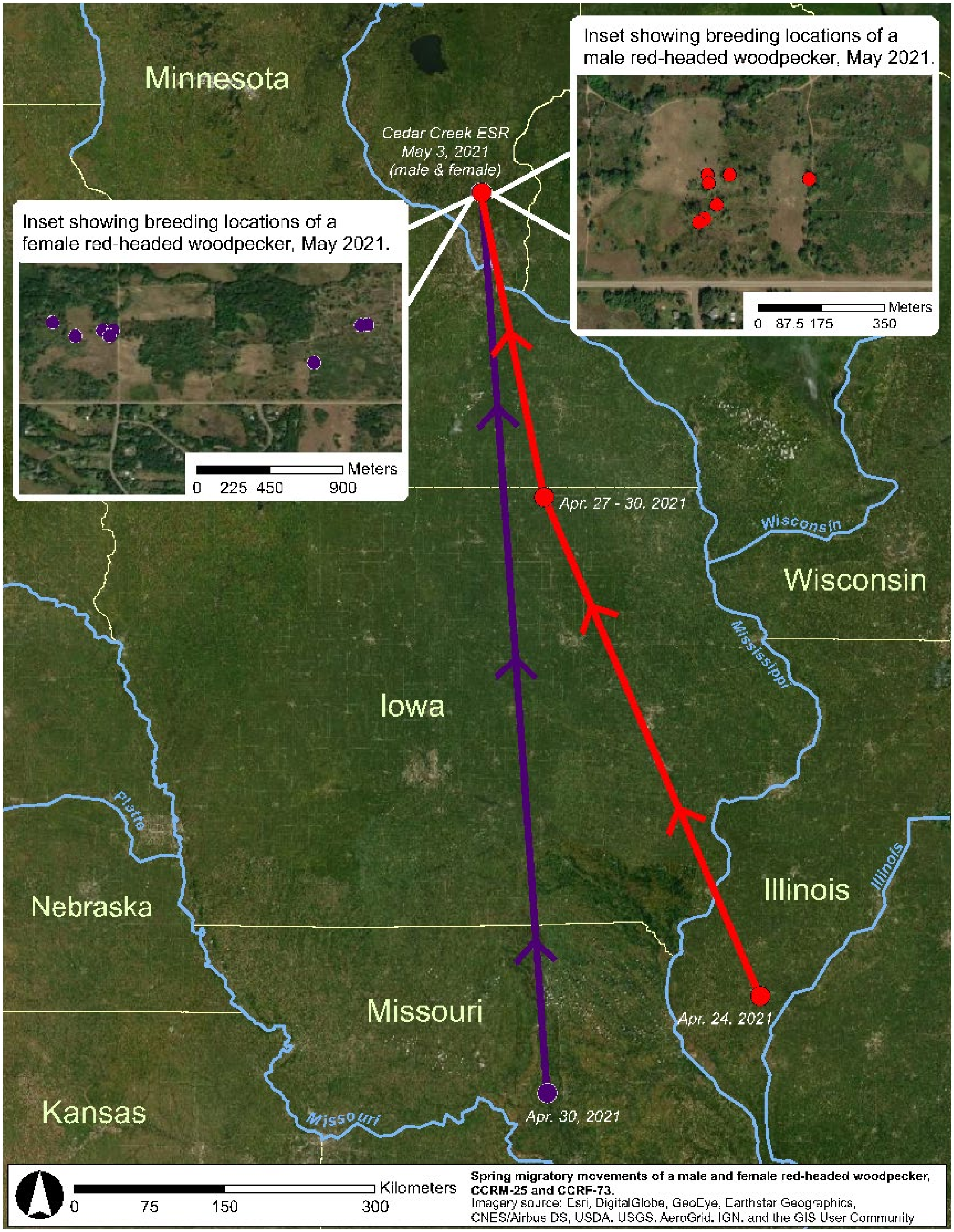


Figure 4. Relationship between red-headed woodpecker home-range size (ha) and snag density (count of snags per home range) at the Cedar Creek Ecosystem Science Reserve, Minnesota. Home ranges are based on the 95% utilization distribution.

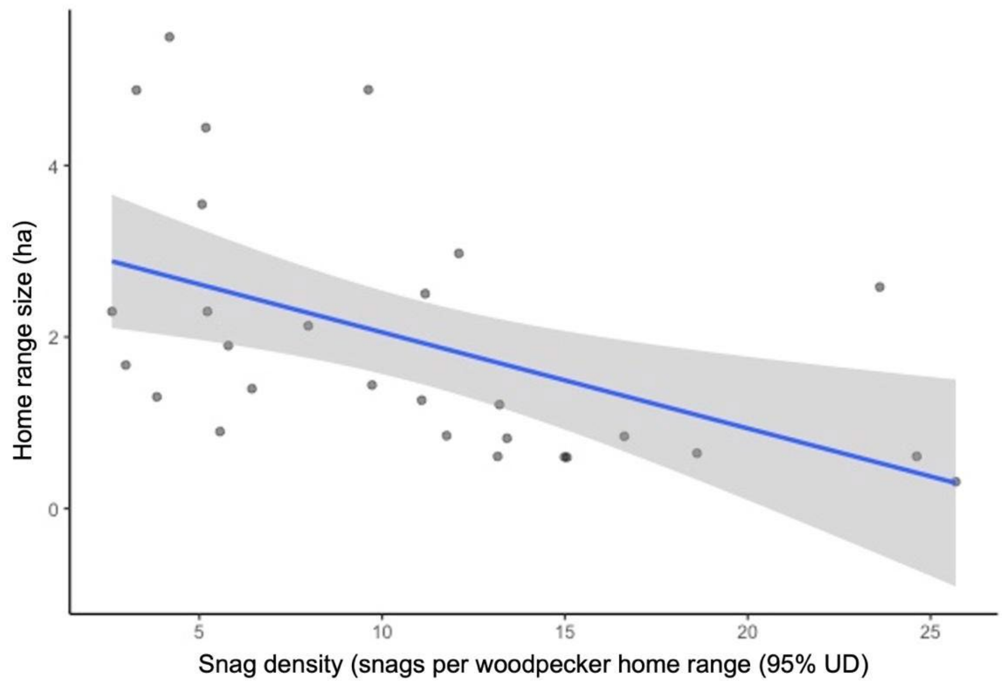


Figure 5. Relationship between red-headed woodpecker home-range size (ha) and distance (m) to the nearest nesting red-headed woodpecker at the Cedar Creek Ecosystem Science Reserve, Minnesota. Home ranges are based on the 95% utilization distribution.

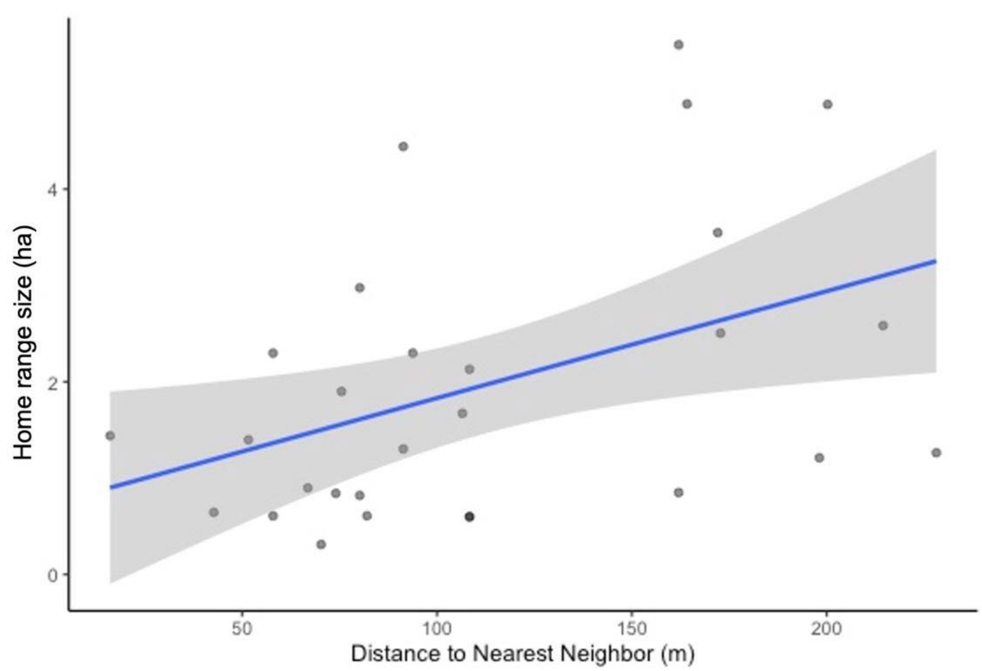


Figure 6. Initiation dates for 135 red-headed woodpecker nest attempts from 2018 – 2020 at the Cedar Creek Ecosystem Science Reserve, Minnesota.

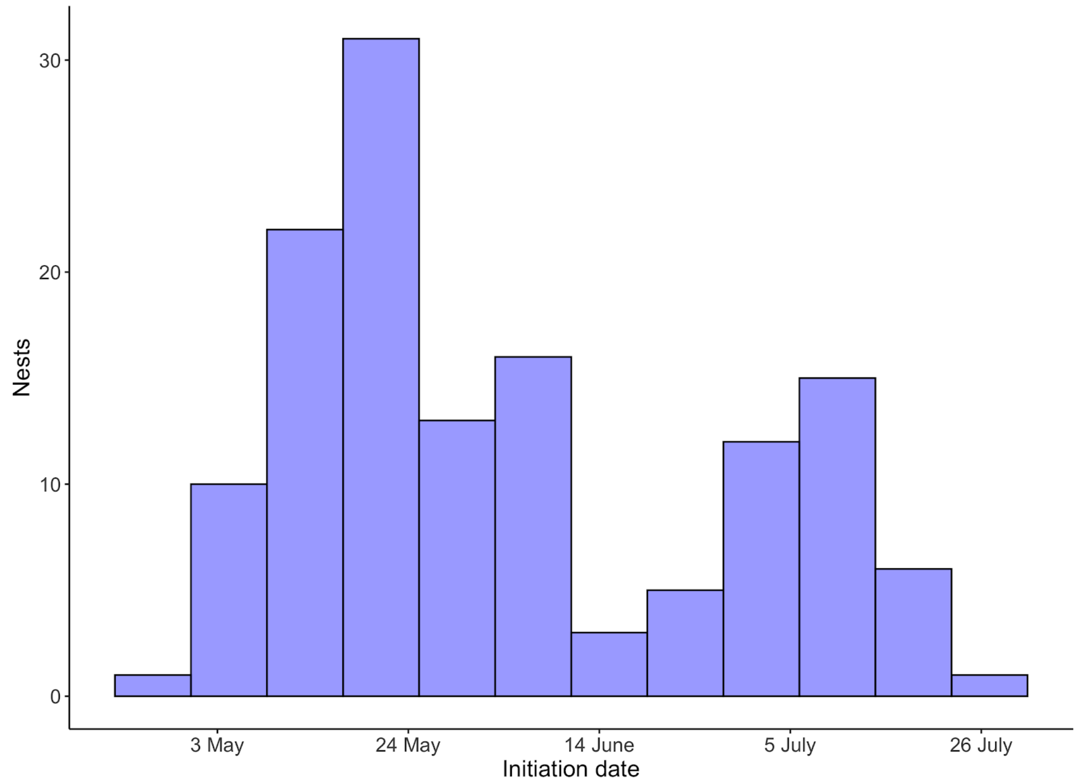


Figure 7. Histogram of red-headed woodpecker nest-tree size (diameter at breast height) used from 2018 – 2020 at the Cedar Creek Ecosystem Science Reserve, Minnesota.

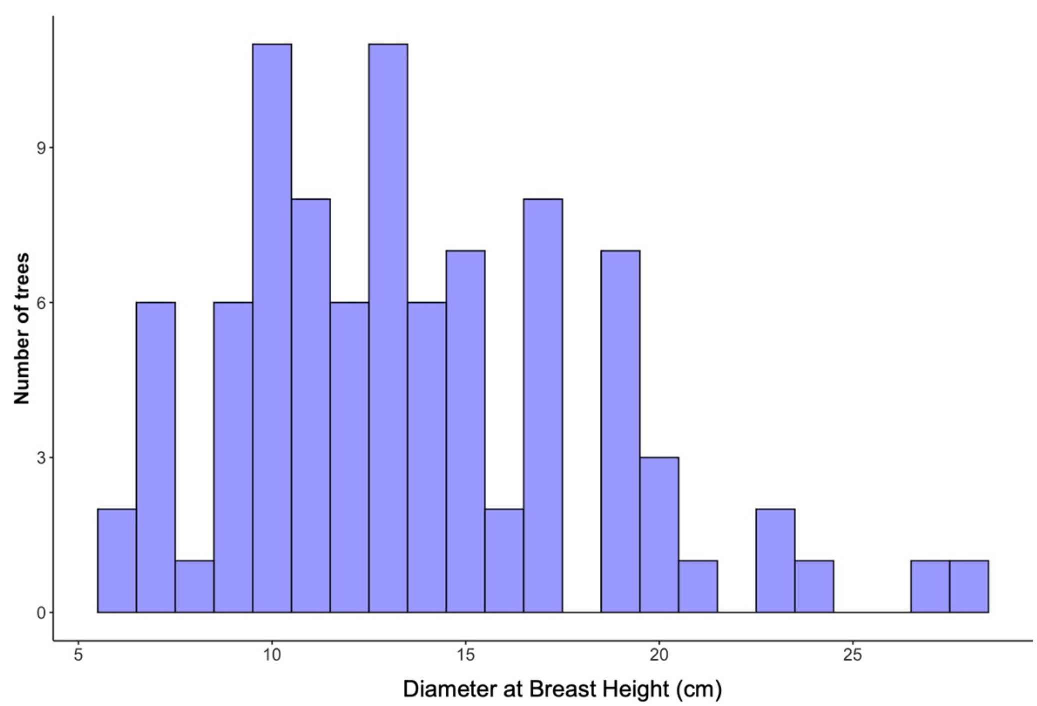


Figure 8. Probability of red-headed woodpecker nest success as a function of the number of live trees within a 10-m radius of nest trees (a), canopy closure within a 10-m radius of nest trees (b), high temperature anomalies (c), and year (d). Mean relationships are shown as dark red lines and shaded regions depict 95% CI. Predictions are shown from the best-supported nest survival model.

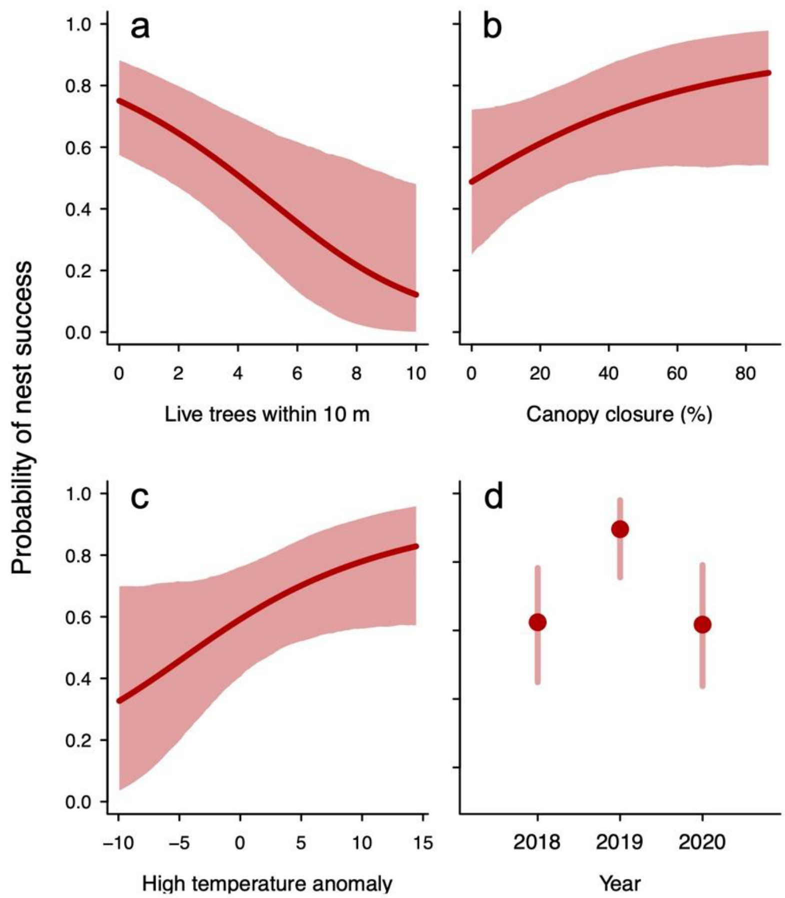


Figure 9. Modeled relationships for red-headed woodpecker nest stand selection (**a**, **b**) and nest tree selection. Dark lines show the mean response predicted by the model, and shaded regions show 95% CI.

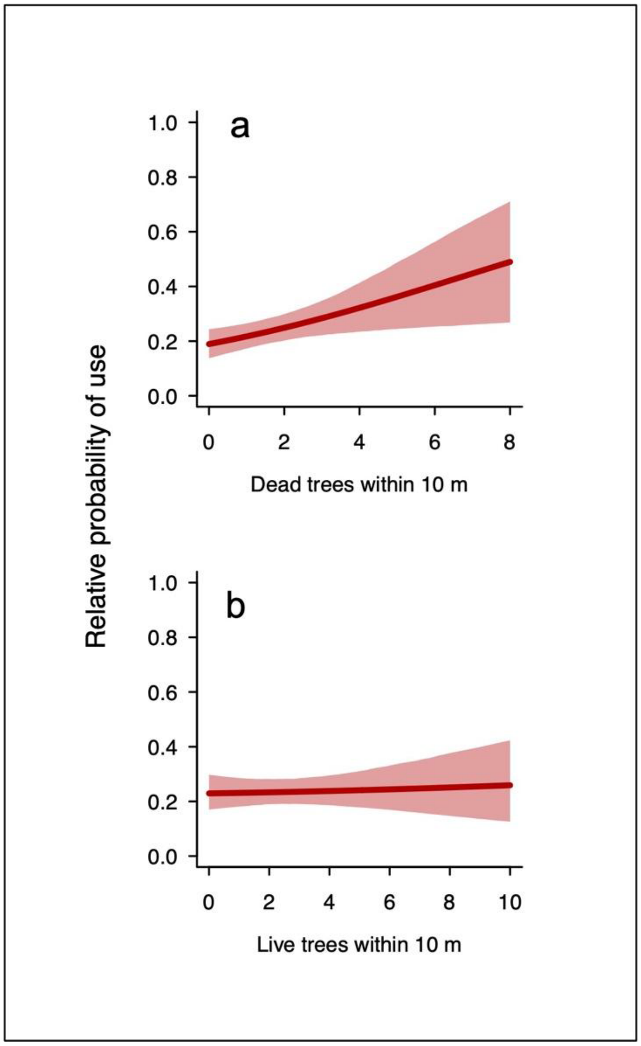


Figure 10. Hardness at red-headed woodpecker nest trees (red lines) and available trees (gray lines) at the Cedar Creek Ecosystem Science Reserve, Minnesota. Dark red and black lines are mean values for nest and available trees, respectively.

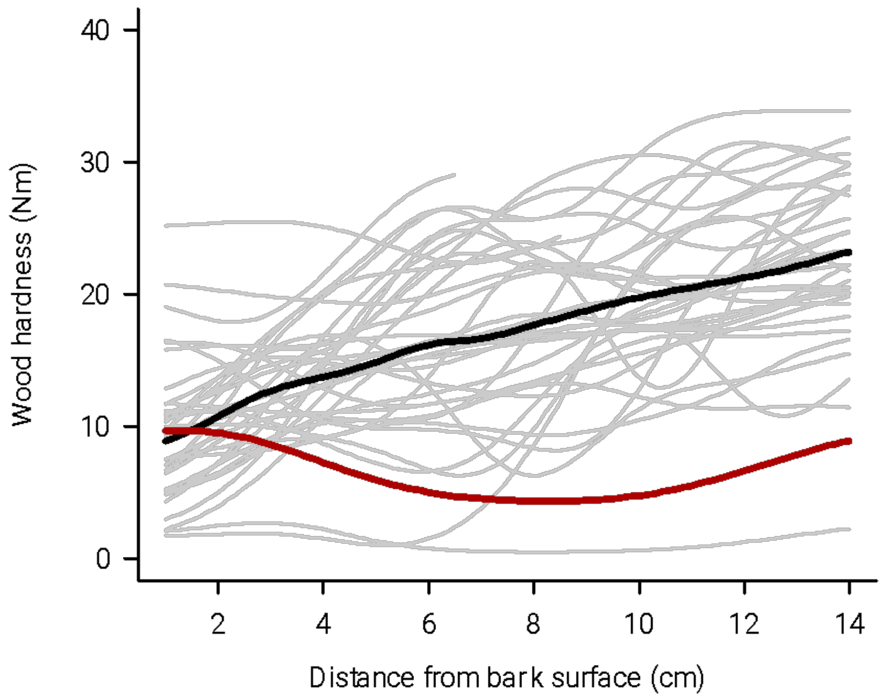
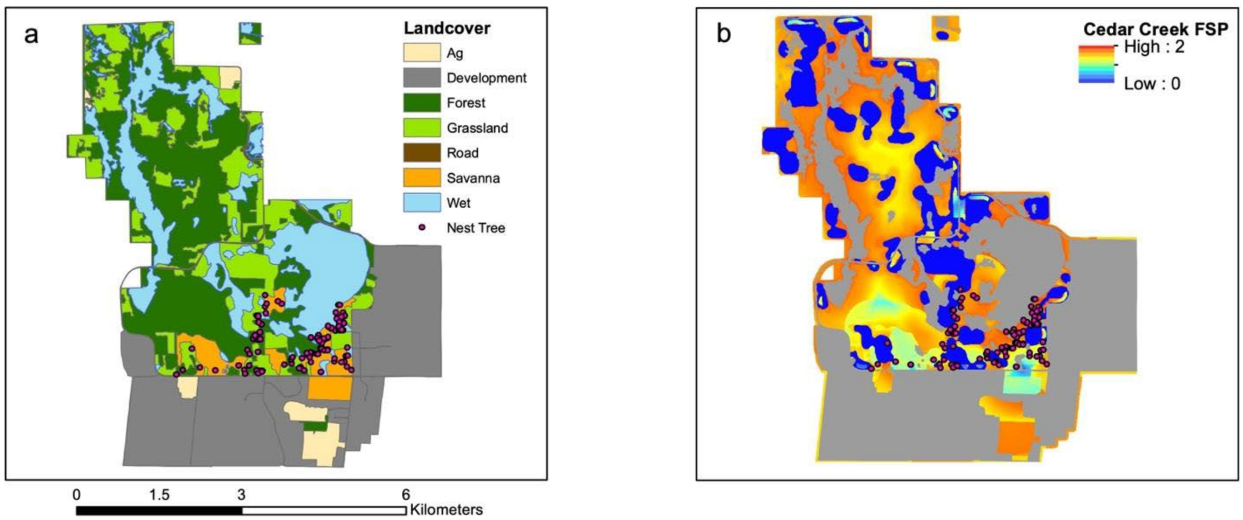


Figure 11. Spatially explicit model of red-headed woodpecker predicted full-season productivity (young raised to independence from adult care; FSP) at the Cedar Creek Ecosystem Science Reserve, Minnesota. Displayed are (a) landcover classification collapsed to seven cover types used in productivity surface modeling, and (b) productivity surface model visualizing areas of relatively high (red) and low (blue) full-season productivity. Red and orange areas near the edges of the modeled landscape are an artifact of under-informed cells near edges (i.e., missing data from outside the boundary) and should not be interpreted as predicting high productivity or any relationship between productivity and developed areas. Nest locations reflect only those for which sufficient monitoring data were available to inform survival models, and do not reflect all nests found.



Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Budget Spreadsheet
Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 03j
Project Manager: David E. Andersen
Project Title: Red-headed Woodpeckers: Indicators of Oak Savanna Health
Organization: U.S. Geological Survey Minnesota Cooperative Fish and Wildlife Research Unit and University of Minnesota
Project Budget: $171,000
Project Length and Completion Date: 2 years; 30 June 2022
Today's Date: 30 June 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET		Revised Budget (12/2/20)	Amount Spent	Balance
BUDGET ITEM				
Personnel (Wages and Benefits)		**$ 152,409**	**$ 152,409**	**$ -**
Elena West, Postdoctoral Researcher, $121,000 (100% FTE, 79% salary/21% fringe for 2 years)				
2 field technicians per year (2019 and 2020) @ 11 weeks per year $28,484 (42% FTE for each of 2 years, 92.1% salary, 7.9% fringe)				
Equipment/Tools/Supplies (for capturing and tracking woodpeckers):		**$ 15,750**	**$ 15,750**	**$ -**
GPS Pinpoint Units $7,800 (20 @ $390 each; deployed in 2019)		$ 7,800	$ 7,800	$ -
Radio transmitters $6,250 (50 @ $125 each; 25 deployed in 2019 and 25 deployed in 2020)		$ 6,250	$ 6,250	$ -
Miscellaneous supplies $4,946 (harnesses for GPS unit and transmitter device attachment, mist-nets, radio-telemetry receivers and antennas)		$ 1,700	$ 1,700	$ -
Travel expenses in Minnesota (field technicians and postdoc travel to capture RHWO at Cedar Creek):		**$ 2,841**	**$ 2,841**	$ (0)
4-wheel drive vehicle mileage $2,520 [1 (2019 and 2020) vehicle @ $0.56/mile x 25 miles/day x 90 days/year]				
COLUMN TOTAL		**$ 171,000**	**$ 171,000**	**$ (0)**

OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)		Spent	Balance
Non-State: Minneapolis Audubon (2017 - 2018 project support)	*Secured*	$ 40,000	$ 40,000	$ -
State:		$ -	$ -	$ -
In kind: Unrecovered indirect costs associated with this project ($92,340 - University of Minnesota); PI salary (U.S. Geological Survey, 1 month/year x 2 years x $14,000/month)	*Secured*	$ 120,340	$ 120,340	$ -

PAST AND CURRENT ENRTF APPROPRIATIONS	Amount legally obligated but not yet spent	Budget	Spent	Balance
Current appropriation:		$ -	$ -	$ -
Past appropriations:		$ -	$ -	$ -

Attachment B

Red-headed Woodpeckers: Indicators of Oak Savanna Health

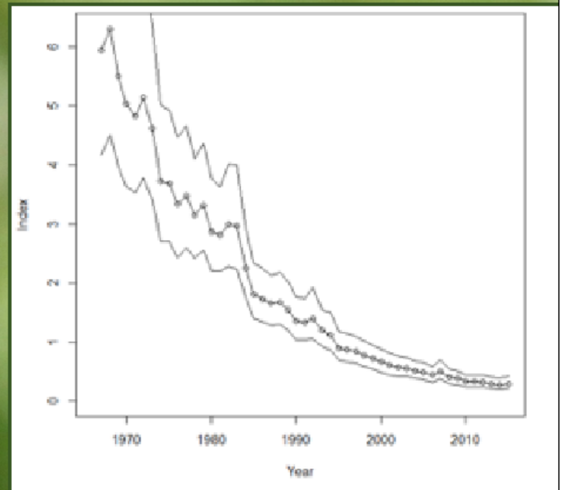


Figure 1. Breeding population trend for the Red-headed Woodpecker in Minnesota for 1967–2015 based on the federal Breeding Bird Survey (Sauer et al. 2017).

- Since 1967, red-headed woodpeckers have declined 6% annually statewide, representing a cumulative loss of nearly 95% of the population. Declines are believed to be due to habitat loss and degradation.
- Fragmented patches of oak savanna exist across Minnesota, and there is considerable interest and effort from land managers to preserve and restore this rare ecosystem, yet these initiatives are challenged by a lack of information on the factors that make savannas desirable for red-headed woodpeckers.
- **Our GOALS** are to address population declines in this species, assess the outcomes of ongoing habitat management and conservation efforts, and to develop a unified management plan for restoring oak savanna for red-headed woodpeckers and other oak habitat specialist species in Minnesota and throughout the Midwest.

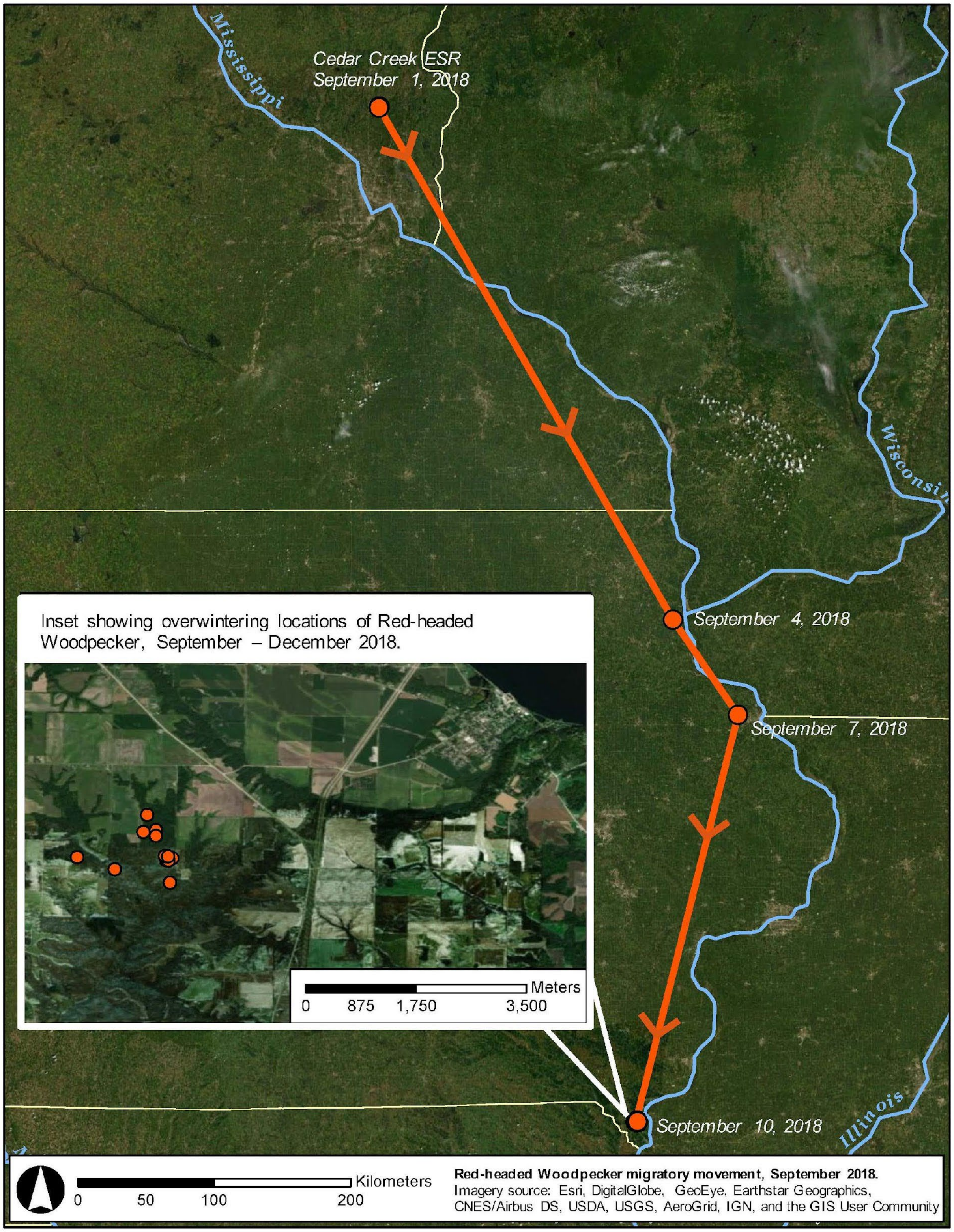


Figure 1. Autumn 2018 migration trajectory of a red-headed woodpecker captured at the Cedar Creek Ecosystem Science Reserve (Anoka and Isanti Counties), in Minnesota.

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Budget Spreadsheet
Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 03j
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PAST AND CURRENT ENRTF APPROPRIATIONS	**Amount legally obligated but not yet spent**	**Budget**	**Spent**	**Balance**
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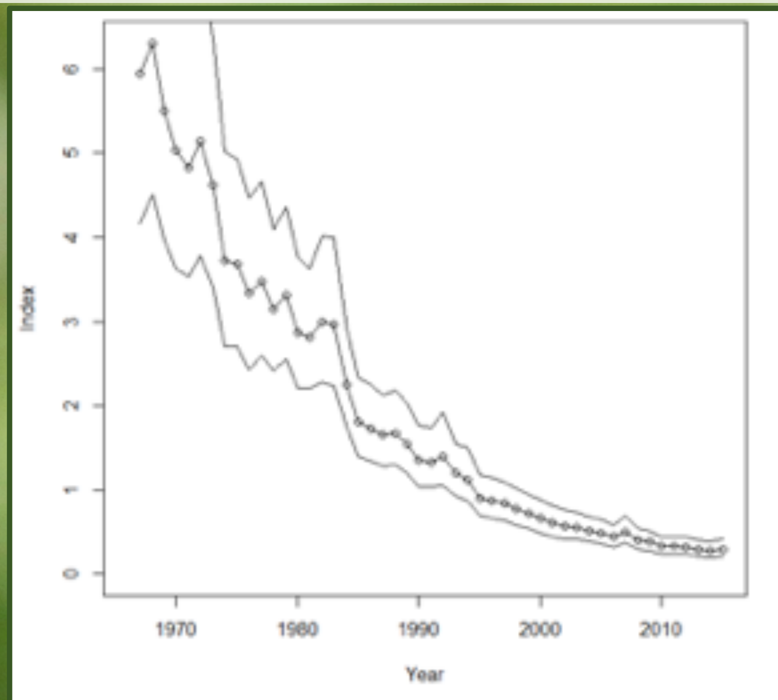
Past appropriations:		$ -	$ -	$ -

Red-headed Woodpeckers: Indicators of Oak Savanna Health



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