NORTH DAKOTA GAME AND FISH DEPARTMENT

FINAL REPORT

Full Annual Cycle Demographic Monitoring of Grassland Birds Nesting in the Northern Great Plains

Project T-46-R

March 1, 2015 – December 31, 2019

Terry Steinwand
Director

Submitted by
Greg Link
Chief, Conservation and Communications Division

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FULL ANNUAL CYCLE DEMOGRAPHIC MONITORING OF GRASSLAND BIRDS NESTING IN THE NORTHERN GREAT PLAINS
2015 - 2019

Final report to North Dakota Game and Fish

Bird Conservancy of the Rockies
July 11, 2019

Juvenile grasshopper sparrow outfitted with radio-transmitter, photographed on North Dakota's Little Missouri National Grassland, 2018. Photo by J. Bernath-Plaisted

Primary contact
Jacy Bernath-Plaisted, Avian Ecologist
Bird Conservancy of the Rockies
230 Cherry St. Ste. 150
Fort Collins, CO 80521
Jacy.bernath-plaisted@birdconservancy.org

Bird Conservancy of the Rockies

Connecting People, Birds and Land

BIRD CONSERVANCY OF THE ROCKIES

Mission: Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship and sustained through partnerships. Together, we are improving native bird populations, the land and the lives of people.

Vision: Native bird populations are sustained in healthy ecosystems

Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education, and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship, and sustained through partnerships. Together, we are improving native bird populations, the land, and the lives of people.

Core Values:

1. **Science** provides the foundation for effective bird conservation.
2. **Education** is critical to the success of bird conservation.
3. **Stewardship** of birds and their habitats is a shared responsibility.

Goals:

1. Guide conservation action where it is needed most by conducting scientifically rigorous monitoring and research on birds and their habitats within the context of their full annual cycle.
2. Inspire conservation action in people by developing relationships through community outreach and science-based, experiential education programs.
3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

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Executive Summary

Grassland songbirds are among the most rapidly declining avian assemblages in North America. Over half of these grassland populations show long-term negative trends, and species breeding in the Great Plains and wintering in the Chihuahuan desert have declined 70% since 1970. In 2015, Bird Conservancy initiated a comprehensive demographic monitoring program for several grassland songbird species that breed in the Northern Great Plains (NGP) in an effort to provide more targeted and effective management solutions to slow population declines. These species include the Baird's sparrow (*Centronyx bairdii*), grasshopper sparrow (*Ammodramus savannarum*), chestnut-collared longspur (*Calcarius ornatus*), and Sprague's pipit (*Anthus spragueii*). In 2015, we collected data on the abundance, nesting success, and habitat of all four species, as well as adult survival on radio-tagged Baird's and grasshopper sparrows in western North Dakota's Little Missouri National Grassland. In 2016, began monitoring juvenile survival of Baird's and grasshopper sparrow. In 2017, we continued research activities with the addition of adult survival monitoring of Sprague's pipit. In 2018, we continued nest monitoring for all species, as well as the survival of adult Sprague's pipit. However, following analysis of data from 2015-2017, we found high, invariant adult survival rates in our focal sparrow species, and thus ceased further adult survival monitoring for Baird's and grasshopper sparrow in 2018 to better focus on juvenile survival for these species. In 2019, we ceased the majority of our monitoring efforts, as we had adequate sample size for most species. However, we continued to monitor the adult survival of Sprague's pipit during the 2019 field season to boost our sample for this species. We also continued multi-species abundance sampling in 2019, as in previous year. During the 2017-18 seasons, we introduced collection of imagery and habitat data via Unmanned Aircraft Systems (drones) in an effort to better quantify environmental conditions. We also successfully deployed (2016-2017) and recaptured (2017-2018) light-level geolocators on individuals of both Baird's and grasshopper sparrow, revealing previously undocumented migratory routes for these species. Nesting success analyses for three of our four focal species showed variation across years but estimates fell within the previously established ranges for the species. Overall, nesting success was not explained well by climate and vegetation variables modeled. Juvenile survival of Baird's and grasshopper sparrow was lower and more variable than adult survival and driven primarily by effects of fledgling age.

Project highlights

Juvenile survival analysis

Post-fledgling, or juvenile survival is a critical and historically understudied phase for many avian species. During this period, fledglings (Figure 1) may have limited flight capability and be more vulnerable to predation (Figure 2) or extreme climatic events. Understanding mortality during this transitional period is therefore important both for developing season-specific management recommendations, and for informing population models that can make accurate predictions across the full life cycle of a species. For grasshopper sparrow (*Ammodramus savannarum*), Bird Conservancy's juvenile survival estimates contribute to a small existing body of literature on the topic. However, for Baird's sparrow (*Centronyx bairdii*; Figure 1*)*, our estimates are the first estimates of juvenile survival in the species.

Figure 1*: Recently fledged Baird's sparrow outfitted with a radio tag. Photo by K. Bell.*

Figure 2*: A Plains Garter snake, a frequently observed predator of fledglings at Bird Conservancy's demographic study sites. Photo by J. Bernath-Plaisted*

***Figure 3**: Radio-tagged adult Sprague's pipit ready to be released. Photo by K. Bell.*

Adult Sprague's pipit survival analysis

Like nesting success and juvenile survival, adult survival is another fundamental baseline component of demographic monitoring. In 2017, Bird Conservancy piloted the use of VHF radio tags on adult Sprague's pipits (*Anthus spragueii*; Figure 3) to monitor their survival. In 2018 and 2019, we expanded this effort and produced baseline adult survival estimates for this species. We found high, invariant survival, similar to our other grassland species. These are the first estimates of adult survival for the species and will help to shed light on the ecology of this cryptic and remarkable bird.

Application of UASs in vegetation mapping

We introduced Unmanned Aircraft Systems (UASs, commonly known as drones) to our data collection techniques in 2017. This technology is particularly helpful in measuring remote, expansive areas such as grasslands of the NGP. Data collected via UASs are especially promising due to the high spatial resolution of the resulting data when compared to other methods (e.g. satellite platforms such as MODIS, Landsat, or SPOT). UAS-collected data also allows us to collect data during specific periods of time; this is particularly important for grassland ecosystems where vegetation changes continuously throughout the summer months. In 2018 we piloted a new fixed-wing drone (Figure 4B) to maximize efficiency of data collection and successfully collected spectral data at all four study plots multiple times throughout the field season.

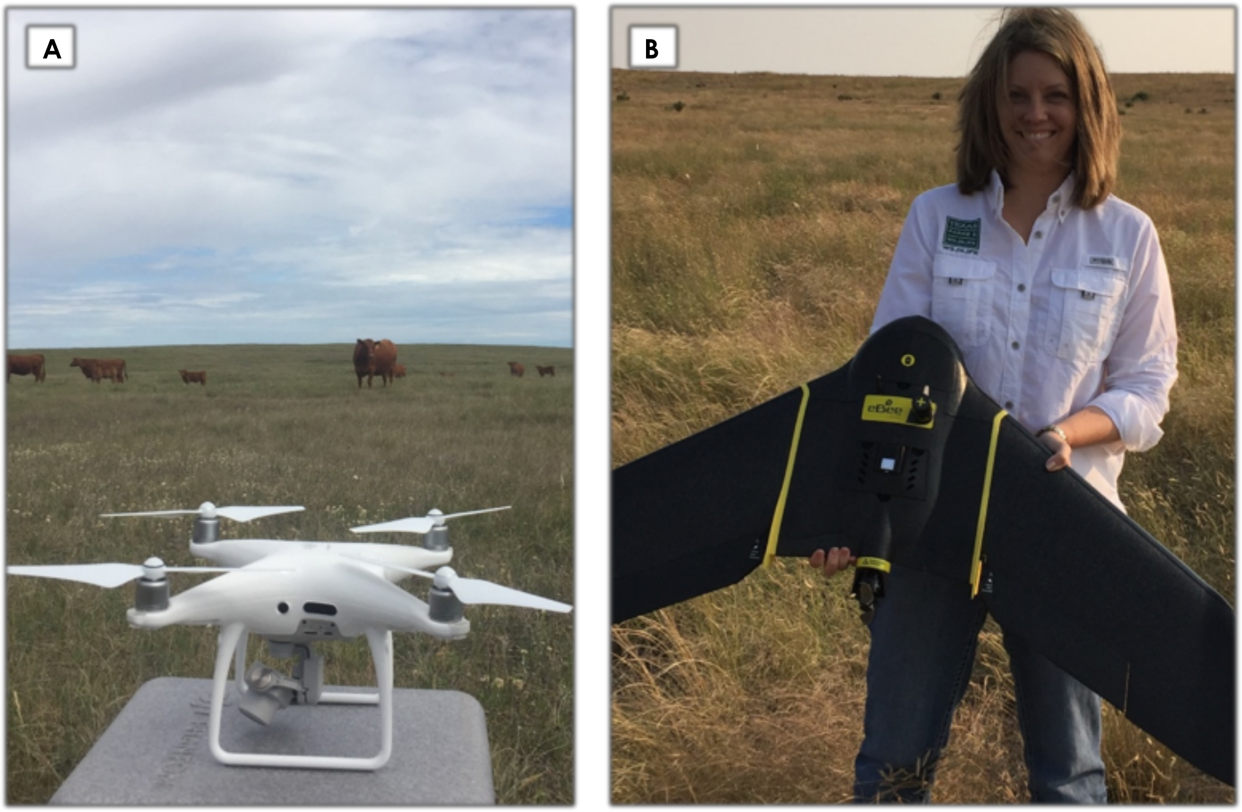

***Figure 4**: **A)** A quadcopter drone used to collect vegetation data at Bird Conservancy's North Dakota field sites. **B)** A Fixed-wing drone recently purchased by Bird Conservancy held by a collaborator. Photos by M. Correll.*

Project background

Grassland songbirds as a group are in steep decline. Specialist species reliant upon mixed-grass prairie habitat in the NGP have collectively experienced average population losses of >80% since 1966 (Sauer et al. 2017). Included in this group are the four focal species of Bird Conservancy's demographic monitoring project (Baird's sparrow, grasshopper sparrow, chestnut-collared longspur [*Calcarius ornatus*], and Sprague's pipit; see Table 1 for species population status). These species have all been identified as potential focal species for the National Fish and Wildlife Foundation (NFWF) NGP conservation business plan (NFWF 2016). Many conservation plans and initiatives including NFWF, North Dakota and Montana State Wildlife Action Plans, Partners in Flight (PIF), Northern Great Plains (NGPJV) and Prairie Potholes Joint Ventures (PPJV), and Region 6 of the US Fish and Wildlife Service (USFWS) identify the NGP as a critical breeding area for grassland birds of greatest conservation need. Although population declines in these species may be broadly attributed to the loss and degradation of grassland and rangeland habitat (*e.g.* Murphy 2003; Brennan and Kulvesky 2005; Askins et al. 2007), there is limited knowledge of how grassland conditions at a regional scale influence vital rates or what management practices should be implemented to optimize remaining habitat for these species. Over the last several years, Bird Conservancy has developed, and continued to refine, the study design and field protocols necessary to successfully carry out regional demographic monitoring for these species, with particular emphasis on Baird's and grasshopper sparrow.

Bird Conservancy's monitoring efforts in North Dakota with respect to these two species are part of a larger effort to assess demographic rates across their full life cycles. We are taking a full-annual-cycle approach to conservation of these species through development of an integrated population model (e.g. Woodworth et al. 2017). Initially, we will develop a model for the Baird's sparrow, but we hope to include grasshopper sparrows and other species in the future. This approach will provide a holistic and powerful analysis framework that can help determine what demographic parameters most strongly influence population trends and what environmental factors in which geographies most strongly influence those parameters. Our research efforts in the North Dakota began in 2015 and concluded in 2019.

Table 1*: Current global population estimates (PIF Database), annual BBS trend 1970-2015, and total population declines derived from BBS trends for four species of grassland songbird breeding in the NGP.*

Species	Population	Annual decline (%/yr)	Total decline (%)
Baird's sparrow	3,200,000	2.74	71.4
Grasshopper sparrow	32,000,000	2.59	69.3
Chestnut-collared longspur	2,900,000	4.25	85.8
Sprague's pipit	1,200,000	3.10	75.8

Objectives

Declines in grassland songbirds breeding in North Dakota may be driven by several different factors within their life histories. Low nesting success and productivity, survival rates in juveniles and adults, and differences in these rates across different seasons can all contribute to the growth or decline of a population. Declines may also be driven by complex seasonal interactions among various phases of the annual cycle. Given the importance of North Dakota as a breeding area for grassland songbirds, knowledge of demographic rates in grassland songbird populations in this area and how they are influenced by various environmental parameters is needed to guide conservation and management in the region. However, data on vital rates are lacking or incomplete for many migratory grassland songbirds, as are data on factors influencing vital rates, site fidelity, and local movement patterns. With this project, we seek to quantify nesting success, adult and juvenile survival, and how home range patterns influence survival in breeding populations in North Dakota. We will also assess the influence of vegetation, climate, and other parameters on these vital rates to inform grassland management in the NGP region.

The objectives for our demographic work in North Dakota are to:

1) Estimate adult and juvenile survival, nesting success, and annual productivity of Baird's sparrow and grasshopper sparrow, as well as estimate adult survival of Sprague's pipit.

2) Estimate nesting success and productivity of chestnut-collared longspur, Sprague's pipit (pending sample size), and lark bunting (pending sample size).

3) Examine the influence of vegetation characteristics, climate, and other environmental factors on nesting success, and adult and juvenile survival.

4) Generate information for the future application of the full annual cycle integrated population models, needed to determine where and when populations are most limited, and what changes in vital rates are likely driving population declines for grassland songbird species of interest.

Field site

Little Missouri National Grasslands – Western North Dakota

Our demographic monitoring site in North Dakota in the Little Missouri National Grasslands (Figure 5) was established in 2015 under a 3-year grant (renewed through 2019) from North Dakota Game and Fish (NDGF) with additional support from U.S. Fish and Wildlife service (USFWS) Region 6, the Northern Great Pains Joint Venture (NGPJV) and North Dakota Natural Resources Trust (NDNRT). These lands are managed by the United States Forest Service (USFS) and grazed to varying extents by cattle ranchers of the Little Missouri Grazing Association holding leases administered by the USFS. Our field plots at this site are dominated by exotic grasses such as Kentucky bluegrass *(Poa pratensis*) and crested wheatgrass (*Agropyron cristatum*). Native vegetation typical of the mixed-grass prairie also occurs throughout the plots, particularly on hilltops. Our North Dakota field site experienced severe drought during both the 2016 and 2017 field seasons. In 2018 and 2019, this site experienced moderate drought. relief. Additionally, the region experienced a later winter in 2019, resulting in some intermittent snow cover during the first several weeks of the season.

Figure 5*: Bird Conservancy study site in western North Dakota. Photo by M. Derby.*

Field methods

Overview

We implement standardized field protocols across our study sites to quantify adult and juvenile survival, nesting success, species abundance, vegetation characteristics, and migratory connectivity for grassland songbirds. We based our protocols on review of existing literature, recommendations from other grassland ecologists, and our continued experiences in the field as the project has progressed. See table 2 for sampling effort by year.

***Figure 6**: Bird Conservancy crew lead Sasha Robin with 5-element antenna and extension pole, used to track tagged birds. Photo by N. Guido.*

Radio telemetry: tracking and transmitter attachment

Between mid-May and early-August, we captured adult male Baird's and grasshopper sparrow (2015-2017), as well as adult male Sprague's pipit (2017-2019) using targeted mist-netting techniques (Figure 7A). We outfitted captured individuals with a Lotek PicoPip Ag379 radio transmitter using an elastic leg-loop harness (Rappole and Tipton 1991) for tracking purposes (Figure 7B). We also fitted captured birds with USGS aluminum bands

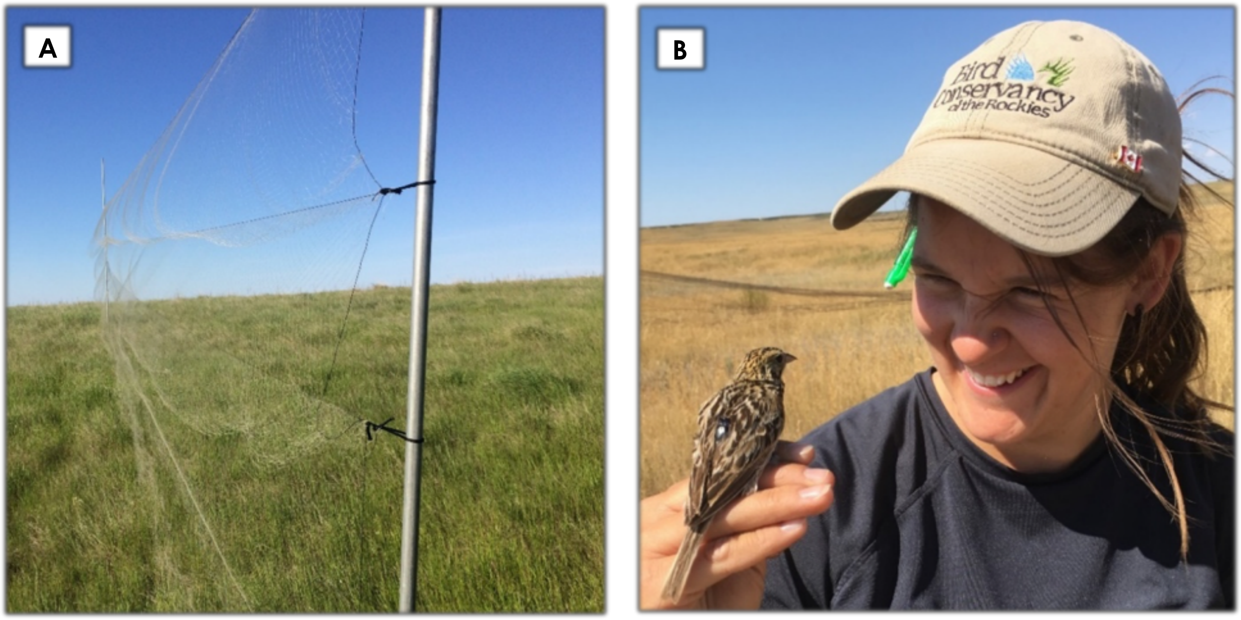

***Figure 7**: **A)** A mist net used to capture grassland songbirds for banding and transmitter attachment; **B)** Bird Conservancy crew lead Kelsey Bell holding a Baird's sparrow outfitted with a radio transmitter. Photos by J. Bernath-Plaisted.*

and one or more color bands, and measured them for standard morphometrics. In 2016, we also collected one primary feather (P1) and several body feathers from each bird for isotopic analyses to aid in assessing migratory connectivity (along with partners at University of Colorado-Denver and USGS). In 2017, we discontinued the capture of adult females on the nest because we found that it sometimes resulted in nest abandonment, despite attempts to refine methods by only capturing females during nestling stage. Instead, we continued to focus on survival of adult males and juveniles. We randomly selected two nestlings per nest and fitted them with smaller (0.4g) radio transmitters (Ag337) at 7-9 days of age, depending on development. We only tagged nestlings that weighed a minimum of 12g and displayed sufficient feather development (most pin and primary feathers beginning to unsheathe) to qualify. When possible, we recaptured tagged birds at the end of the season to remove tags prior to migration. We tracked all tagged birds daily (Figure 6) to monitor survival and identify causes of mortality, taking coordinates at each recorded bird location to estimate home ranges and movement patterns. In 2017, we introduced a brief vegetation survey at every tracking location, so that survival and habitat use could be linked to vegetation characteristics in analysis. In 2018, to provide more robust information on juvenile habitat selection, we also collected vegetation data at two random points associated with each known juvenile location.

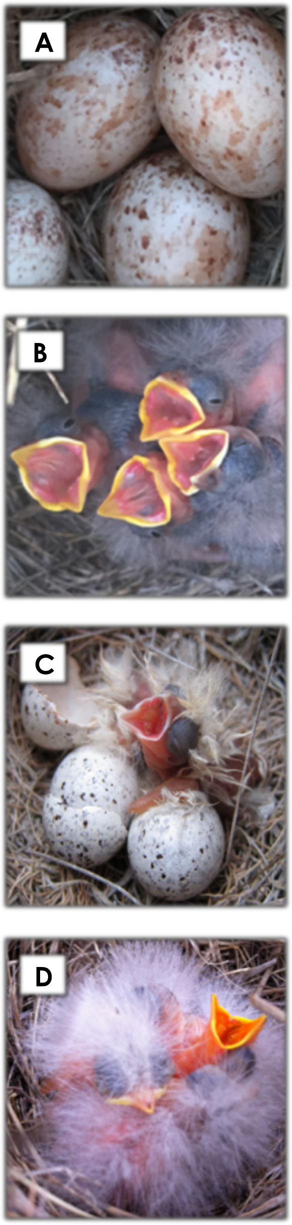

***Figure 8**: **A)** Baird's sparrow eggs; **B)** grasshopper sparrow nestlings; **C)** chestnut-collared longspur nestlings hatching; **D)** Sprague's pipit nestlings. Photos by J. Bernath-Plaisted*

Nest searching and monitoring

We monitored nests of Baird's sparrow, grasshopper sparrow, chestnut-collared longspur, and Sprague's pipit (Figure 8A-D) during the 2015-2018 breeding seasons. We located nests using a hybrid approach including rope-dragging and systematic walking (Winter et al. 2003; Figure 9A), behavioral observation (Martin 1993), and opportunistic discovery while traversing plots. Once located, we visited nests daily in 2015 and every 2-3 days in 2016-2018, occasionally with longer intervals between checks due to weather or logistic constraints. We visited nests more frequently (1-2 days) when near fledging age. At each visit we recorded and photographed nests contents and examined nests for evidence of predators or brood parasitism by brown-headed cowbirds (*Molothrus ater*). We also aged nests using egg floatation (Liebezeit et al. 2007) and nestling aging techniques based on physiological benchmarks (Jongsomjit et al. 2007). In 2017, to enhance our ability to discern nest fates accurately, we introduced 15 to 30-minute observation periods on potentially fledged nests. During observations, technicians watched for indicators of fledging, such as feeding of fledglings by parents (Figure 9B-C). We considered nests that fledged ≥1 young "successful". We also collected vegetation data at each nest within three days post-fledge or failure, as well as at a corresponding random point, for analysis of nest-site selection in these species.

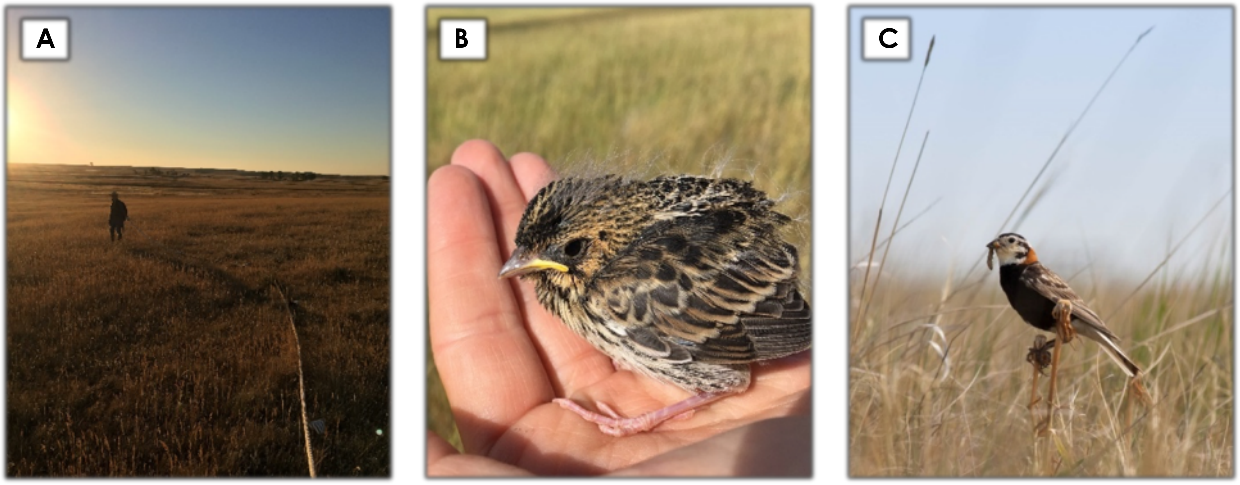

***Figure 9**: **A)** Technicians rope dragging for nests (photo by K. Bell); **B)** Recently fledged Baird's sparrow (photo by K. Bell); **C)** Adult male chestnut-collared longspur carrying food (photo by J. Horvat).*

Point Count Surveys

We followed point count protocol from Bird Conservancy's Integrated Monitoring of Bird Conservation Regions (IMBCR; Pavlacky et al. 2017) to estimate bird abundance within the study areas using 6-minute passive point count surveys that employ distance sampling (Buckland et al. 2001) and time-removal methods (Royle and Dorazio 2008). We selected point count locations using a 250-m grid across our study site; we then surveyed each point location twice during the breeding season (June, 2015-2019), leaving at least 10 days in between visits. We conducted 6-minute point counts at each selected location following IMBCR methods. These data allow us to estimate local abundance each year on the study plots to examine along with regional IMBCR estimates.

Vegetation surveys

In addition to vegetation surveys (Figure 10) we conducted at nest sites and bird locations (and associated random points), we also surveyed points on a 100-meter grid across each study plot to assess vegetation community composition and structure across the landscape. At each point, we employed a modified BBIRD Grasslands Protocol (Martin et al. 1997) using a Daubenmire frame (25 x 50 cm) and Robel pole to assess cover, structure, and composition. We collected data at each landscape grid point twice (early and late season, 2016-2019) to capture changes in vegetation structure, cover, and composition to assess the influence of seasonal changes and climate on vegetation.

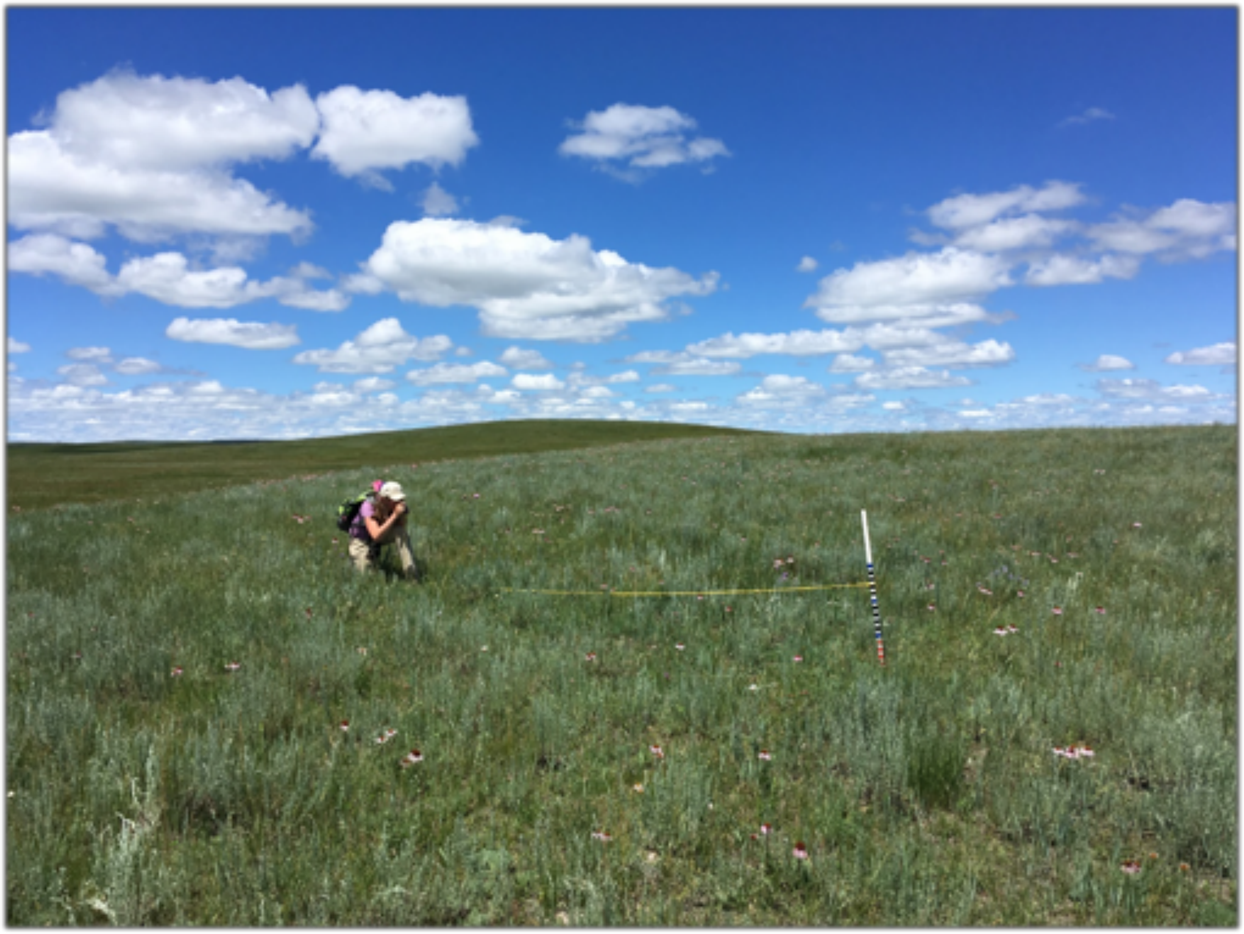

Figure 10*: North Dakota crew lead Chistryne Callbeck conducts visual obstruction measurements in the field. Photo by J. Bernath-Plaisted*

UAS imagery collection

In 2017, we used several DJI Phantom quad-copter drones to systematically survey the vegetation and surface features of each of our four plots. In 2018, we collected data using an eBee Plus fixed-wing drone equipped with specialized cameras. We recorded data that includes bandwidths within the visible light spectrum (red, green, blue, or RGB) using a Sensor Optimized for Drone Applications (SODA) and mutispectral (MSP) data that includes several infrared bands using a Parrot Sequoia sensor. We used Pix4D Mapper version 4.1 an imagery processing software, to align georeferenced images (raster images associated with spatial locations), generate point clouds, create orthomosaics and create Digital Surface Models (DSMs) from these UAS-collected data (Figure 11A-B). Ground control points were marked at each study site to confirm accuracy of georeferenced images. This processing resulted in RGB rasters (a grid of pixels) and elevation models at a resolution of 2-4 cm and MSP rasters at a resolution of 11-15 cm depending on altitude flown.

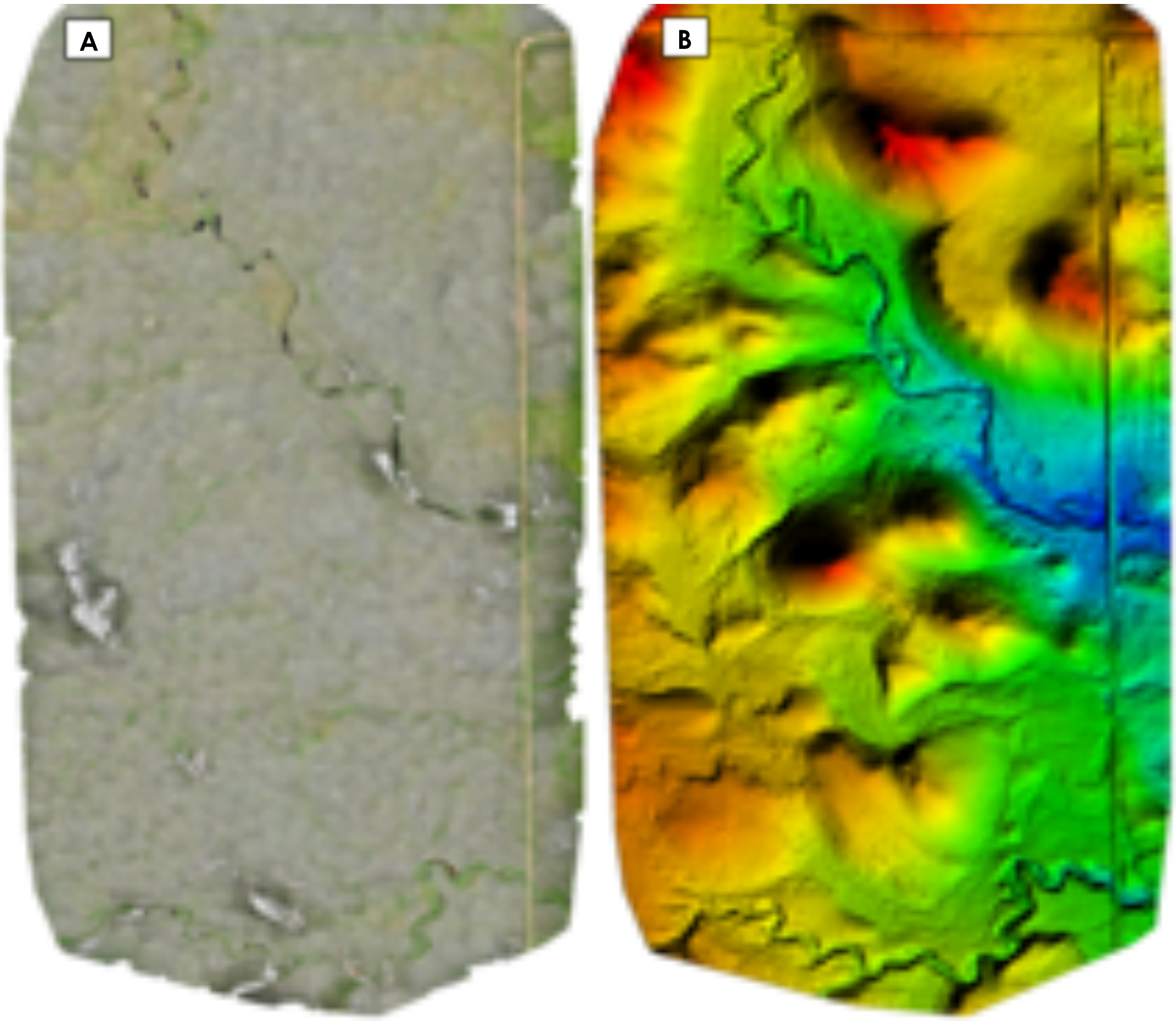

Figure 11**: Resulting imagery at spatial resolution of 2.5 cm per pixel from our North Dakota study site collected with SODA camera and produced in Pix4D Mapper.* ***A) *Orthomosaic, a composite image of spatially corrected photos.* ***B)*** *Digital Surface Model (DSM), a raster that accounts for elevation and topographic features.*

Geolocator deployment and recovery

In partnership with the National Audubon Society, University of Oklahoma, and the University of Manitoba, we deployed geolocators on adult Baird's and grasshopper sparrows across their breeding ranges in the NGP (Figure 12) to map migratory pathways and connectivity between breeding populations and wintering grounds (e.g., Bridge et al. 2013). Geolocators were produced by Migrate Tech or Eli Bridge, and attached using leg-loop harnesses constructed from StretchMagic plastic cord and crimp beads. We recaptured tagged individuals in following years by a concentrated re-sighting effort, and by systematically revisiting capture locations and conducting target netting.

***Table 2**: Numbers of nests monitored and adult and juvenile birds tagged with radio transmitters for four species of grassland songbird at Bird Conservancy study site in North Dakota, 2015-2019.*

Year	Species	Nests (*n*)	Adults (*n*)	Juveniles (*n*)
2015	Baird's sparrow	21	35	-
	Grasshopper sparrow	39	50	-
	Chestnut-collared longspur	10	-	-
	Sprague's pipit	1	-	-
2016	Baird's sparrow	12	38	9
	Grasshopper sparrow	70	59	29
	Chestnut-collared longspur	50	-	-
	Sprague's pipit	-	-	-
2017	Baird's sparrow	16	38	12
	Grasshopper sparrow	42	44	15
	Chestnut-collared longspur	66	-	-
	Sprague's pipit	3	7	-
2018	Baird's sparrow	6	-	3
	Grasshopper sparrow	57	-	32
	Chestnut-collared longspur	94	-	-
	Sprague's pipit	2	10	-
2019	Baird's sparrow	-	-	-
	Grasshopper sparrow	-	-	-
	Chestnut-collared longspur	-	-	-
	Sprague's pipit	-	12	-
Totals	Baird's sparrow	55	111	24
	Grasshopper sparrow	208	153	76
	Chestnut-collared longspur	220	-	-
	Sprague's pipit	6	29	-
	All	489	293	100

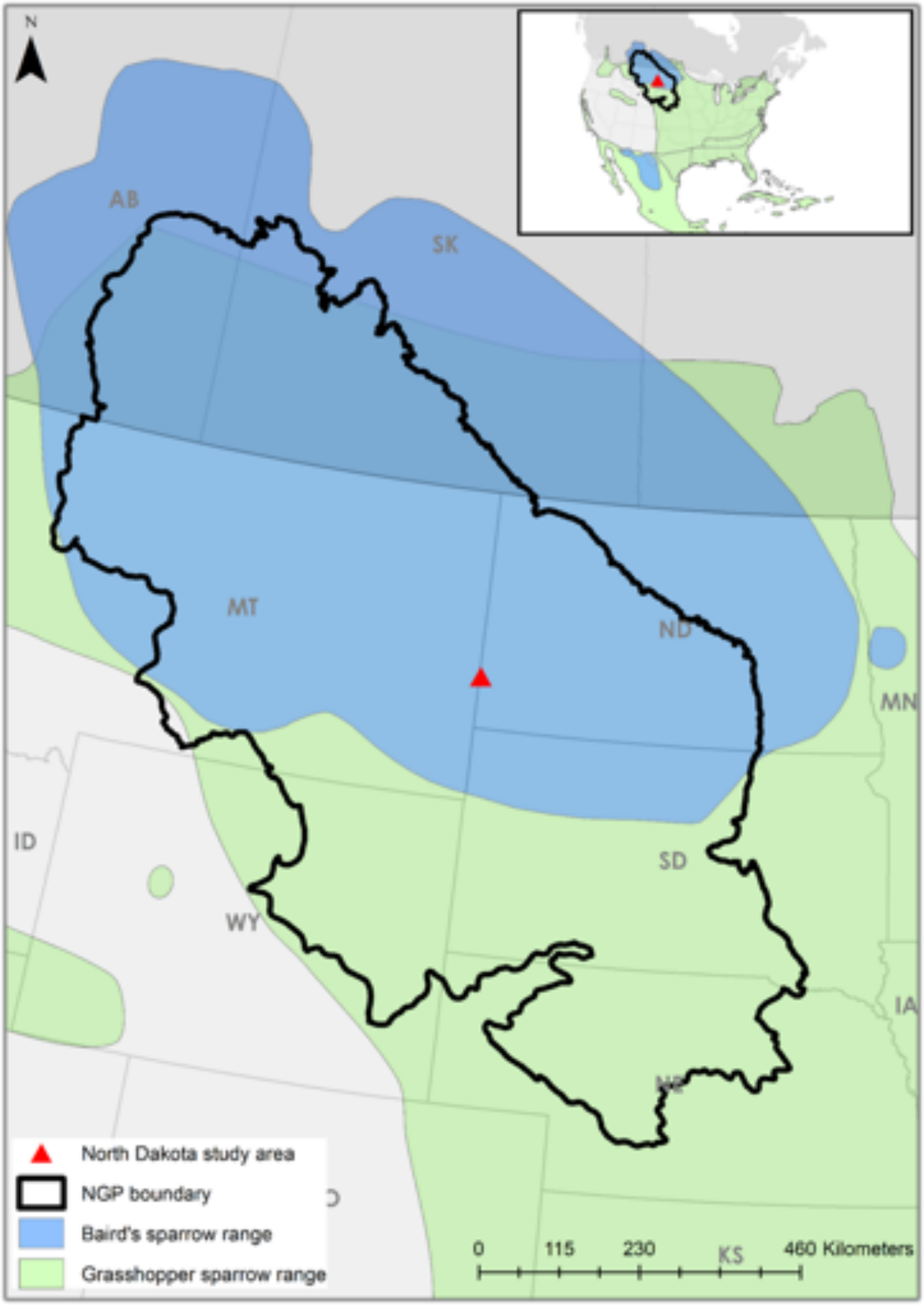

***Figure 12**: Map showing the locations of Bird Conservancy's North Dakota study site in the NGP relative to the breeding ranges of Baird's and grasshopper sparrow.*

Analysis and results

Adult survival

We estimated adult survival (Figure 13) in male Baird's and grasshopper sparrows in North Dakota, 2015-2017. We also estimated adult survival of Sprague's pipit in North Dakota, combining data from 2017-2019 due to small sample size. We estimated survival using logistic exposure (Shaffer 2004) and evaluated models using an information theoretic approach (AICc; Anderson and Burnham 2002). We considered individual birds dead when we recovered a carcass or when we discovered transmitters with evidence of depredation (e.g., blood, feathers, damage to unit, buried). We extrapolated daily survival rates (DSR) generated by logistic exposure over a 90-day cumulative survival period, roughly estimating the length of time an adult bird must survive on the breeding grounds. Logistic exposure assumes intervals to be independent and does not require known fates, therefore we were able to include unknown fates in our analysis. To provide validation for modeled estimates, we also calculated apparent survival, (using only individuals with known fates) as a proportion of individuals that survived the monitoring period to total number of individuals with known fates. We assigned deaths using the same criteria described for logistic exposure above, while we defined survival as an individual surviving a monitoring period of 30 days, after which point transmitter failure became likely. We considered individuals that went missing during the monitoring period, but could never be confirmed as dead, to have an unknown fate, and excluded them from apparent survival calculation.

We conducted logistic exposure analysis in Program R (R Core Team 2018) using the lme4 package (Bates et al. 2014) combined with a modified logit-link function provided by Shaffer (2004). We tested for environmental effects on survival by using exploratory model selection to compare models containing variables for year, plot, time of season (days from May 1st), temperature (daily average over interval length), and precipitation (daily average over interval length, and daily average over previous week). For well-distributed continuous variables, we tested for standard and quadratic effects. We used univariate modeling to select either linear or quadratic variables to include in the global models, and did not including any variables in the same global models with a collinearity of > 0.4. After we identified variables for inclusion in our models, we used package MuMIn (Barton 2018) to run all subsets and select top models. We model-averaged (full) across top models (ΔAICc<2) to generate parameter estimates (Tables 3-5). However, we generated predicted values (Figure 14) using only the top model for each species, with the addition of year if it was not already included. We also calculated variable weights (Tables 3-5) summed across all subsets for all variables appearing in the top model set. Our resulting logistic exposure survival estimates and 95% confidence intervals averaged across the years for Baird's sparrow, grasshopper sparrow, and Sprague pipit were 71% (29-89), 78%(20-96), 55%(5-89), respectively. Large confidence intervals around the estimate of Sprague's pipit survival are likely driven by small sample size for this species, as well as lack of explanatory variables. Apparent survival estimates for the same species averaged across years were 86%, 76%, and 77%, respectively. Overall, the constant survival model outperformed all other candidate models for each species.

These results are not surprising given that survival estimates were relatively constant among sites and years and individual deaths were uncommon in all species, leaving little variation in the data set. Adult survival for grassland songbirds on the breeding grounds varies among species, but typically ranges from 50-75% for similar species, such as savannah sparrow (*Passerculus sandwichensis*) and dickcissel (*Spiza americana*; Fletcher et al. 2006; Perlut et al. 2008). The estimates we present here help rule out adult breeding-season survival as an important contributor to population declines for Baird's and grasshopper sparrow relative to other parameters like nesting success, juvenile survival (discussed below), and adult survival on the wintering grounds, which is more variable (Strasser et al. 2018). Interestingly, at our sites, a large number of individuals for all three species appeared to emigrate during the monitoring period (e.g., birds that could not be located on plot, and were never confirmed dead). This suggests that a large proportion of these species' populations may be semi-nomadic throughout the season, perhaps in response to shifting climate and grassland conditions during the breeding period, or intraspecific changes in social hierarchy and dominance. This is consistent with existing literature on the movements of grasshopper sparrows on the breeding grounds showing that individuals habitually change territories throughout the season and sometimes range up to 9km from original locations (Williams and Boyle 2017).

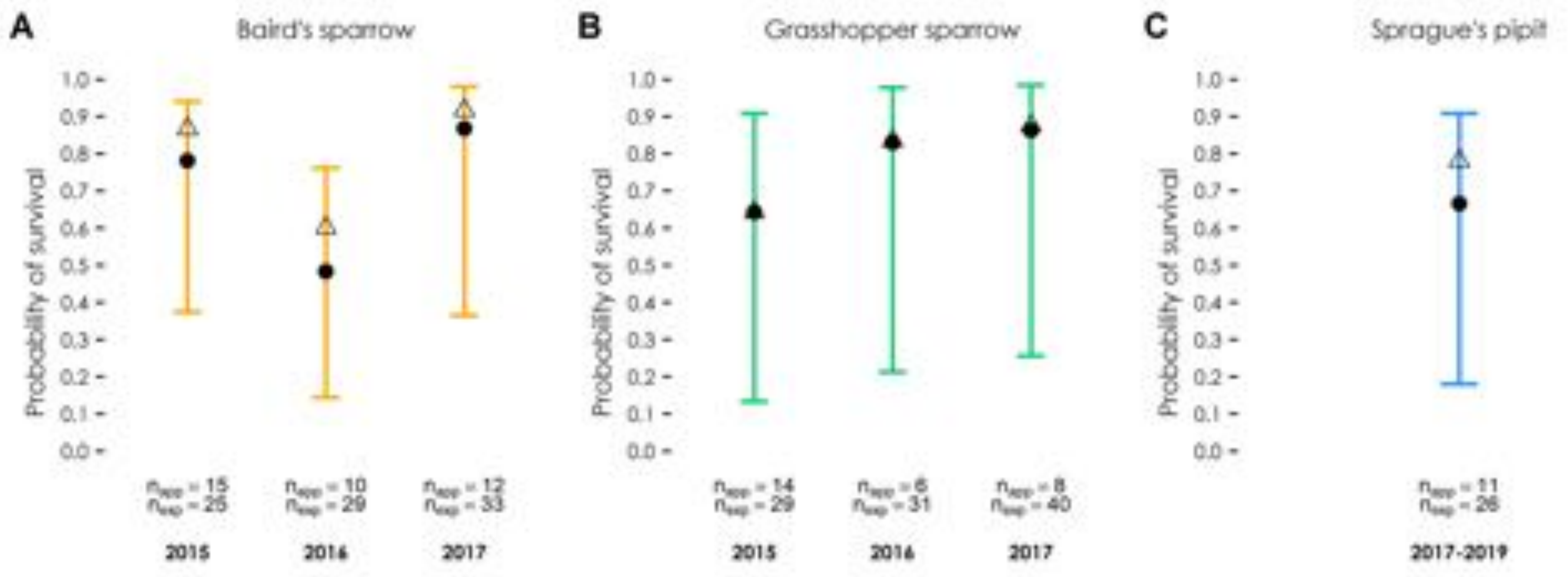

Figure 13: *Survival estimates for adult male* ***A)*** *Baird's sparrow,* ***B)*** *grasshopper sparrow, and* ***C)*** *Sprague's pipit in North Dakota, 2015-2019. Filled circles indicate logistic exposure estimates over a period of 90 days, shown with 95% confidence intervals. Triangles indicate corresponding apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. Cumulative probability of survival is shown on the Y-axis and year on the X-axis.*

***Table 3**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental variables appearing in top logistic exposure models (ΔAICc <2; n = 7) of adult Baird's sparrow survival in North Dakota, 2015-2017. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Year	-	-	-	0.40
2015	-1.52	-12.53	9.50	-
2016	-3.56	-17.34	10.23	-
Precip (weekly)	1.24	-6.66	9.14	0.33
Min daily temp	-0.34	-4.90	4.22	0.27
Plot	0.13	-3.94	4.20	0.26
Precip (interval)	-0.06	-3.67	3.54	0.25

***Table 4**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental variables appearing in top logistic exposure models (ΔAICc <2; n = 12) of adult grasshopper sparrow survival in North Dakota, 2015-2017. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-70.36	-254.37	113.65	0.55
Date^2	57.41	-101.92	216.74	0.55
Precip (interval)	-4.03	-13.07	5.01	0.52
Max daily temp	4.74	-11.07	20.55	0.42
Precip (weekly)	1.02	-6.60	8.64	0.35
Plot	0.44	-5.46	6.33	0.29

***Table 5**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental variables appearing in top logistic exposure models (Δ AICc<2; n = 8) of adult Sprague's pipit survival in North Dakota, 2017-2019. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Precip (interval)	-3.70	-11.05	3.66	0.59
Date	-3.72	-14.03	6.60	0.52
Max daily temp	0.71	-7.56	8.97	0.32
Precip (weekly)	0.33	-3.27	3.93	0.28

Nesting success

We monitored nests of grassland songbird breeding in the mixed-grass prairie of North Dakota including Baird's sparrow, grasshopper sparrow, and chestnut-collared longspur, from 2015-2018. Sprague's pipit sample size was insufficient for analysis. While explicit estimation of nest density was not possible through our study, chestnut-collared longspur appeared to be the most abundant nester in our study area and Sprague's pipit the sparsest (Table 2).

We analyzed nesting success for the three species individually (Figure 14) using the same logistic exposure methods described for adult survival. Nests with unknown fates were included in analyses but truncated to the interval of last known activity as suggested by Manolis et al. (2000). We defined a successful nest as any nest fledging at least one host young, while we considered any nest that was destroyed by a predator, lost to weather, fledged only cowbird young, or was abandoned, as a failure. For abandoned nests, we assumed failure occurred either during the interval containing the date following the last day of the expected incubation period for the species, or during the interval in which a triggering event occurred (e.g. partial predation), if no activity was observed at the nest following the event. We excluded research-related abandonments from analyses. We calculated cumulative survival based on established nesting periods for each species: 21 days for Baird's sparrow and grasshopper sparrow, and 22 days for chestnut-collared longspur. We also estimated apparent survival by calculating the proportion of successful nests to total known-fate nests. We followed the same model-selection, model-averaging, and variable weight calculation methods described for adult survival. However, for nesting success, in addition to environmental variables discussed for adult survival, we also included nest stage (egg or nestling), and a suite of vegetation variables collected at nest sites including: average vegetation height, visual obstruction reading (VOR), total vegetation cover, total grass cover, live grass cover, dead grass cover, forb cover, bare ground cover, and litter cover. Although vegetation data were collected in two schemes at nests sites, by Daubenmire frame, and 5-m radius ocular survey, we only used Daubenmire variables in analysis, as we did not collect 5-m data in 2015. Further, preliminary analysis of 2016-2017 data suggested 5-m variables were not explanatory. All well-distributed continuous variables were modeled as both standard and quadratic terms and compared in univariate modeling, as described for adult survival.

Logistic exposure nesting success estimates and 95% confidence interval ranges averaged across the years for Baird's sparrow, grasshopper sparrow, and chestnut-collared longspur were 40% (10-71), 16%(6-31), and 33%(18-49), respectively. Apparent success estimates averaged across years for the same species were 47%, 26%, and 27%, respectively. Our estimates for Baird's sparrow, grasshopper sparrow, and chestnut-collared longspur are consistent with estimates from other studies of the species, which range widely (e.g. DeLisle and Savidge 1996; Davis 2003; Lloyd and Martin 2005; Jones et al. 2010, Hovick et al. 2012; Ludlow et al. 2014).

Overall, the climate and vegetation variables we modeled had little influence on nesting success (Tables 6-8). The top model for Baird’s sparrow included variables for both interval and weekly precipitation. Although this model outperformed the constant survival model (ΔAICc = 3.70), there were 22 equivalent top models, and only weekly precipitation appeared to be explanatory by weight and confidence intervals (Table 6). Precipitation had a negative, linear effect on DSR in nests of this species (Figure 15A), and it’s possible that exposure and flooding events associated with precipitation may play a role in nest failure. However, inference based on this result should be made cautiously, given the limited sample size. For grasshopper sparrow, the top model contained only the plot variable, but this model only marginally outperformed the constant survival model (ΔAICc = 3.1), and confidence intervals for the variable overlapped zero (Table 7). Nesting success in chestnut-collared longspur was best explained by a linear, negative effect of date (Table 8; Figure 15B), with the top model for this species including date and vegetation height; this model substantially outperformed the constant survival model (ΔAICc = 26.3). However, there were many equivalent top models (*n* = 16), and date was the only variable with confidence intervals not overlapping zero (Table 8).

The general lack of vegetation effects on the nesting success of grassland songbirds at our study sites is not unusual for mixed-grass prairie species (e.g. Davis 2005; Lusk and Koper 2013). It is possible that selection pressure to avoid nest depredation risk is strong enough in these species that nest-site selection is already optimal, thus negating effects of vegetation structure on nesting success (Davis 2005). Another possibility is that temporal mismatch in vegetation sampling at nest sites obscures trends, as nest vegetation cannot be measured while nests are active (Davis 2005). Therefore, the conditions measured after the nest has been depredated or fledged may be substantially different from those at the nest during site selection and activity. Vegetation growth and green-up that occurs in mixed-grass prairie from early May to June can be very rapid (Rigge et al. 2013). This rate of change combined with the >20-day active period for successful nests leaves much room for discrepancy between the nest vegetation characteristics selected by breeding birds and those that we are able to measure explicitly.

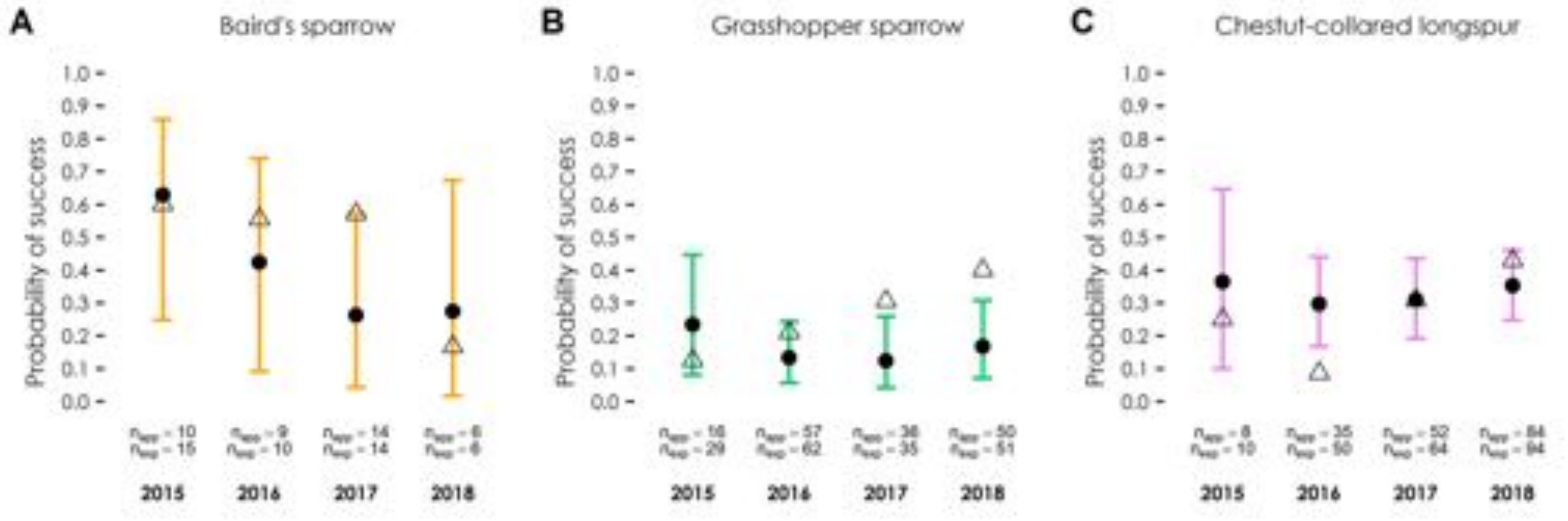

Figure 14: *Nesting success estimates for* ***A)*** *Baird's sparrow,* ***B)*** *grasshopper sparrow, and* ***C)*** *chestnut-collared longspur in North Dakota, 2015-2018. Filled circles indicate logistic exposure estimates for the nesting period of each species, shown with 95% confidence intervals. Triangles indicate corresponding apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. Cumulative probability of nesting success is shown on the Y-axis and year on the X-axis.*

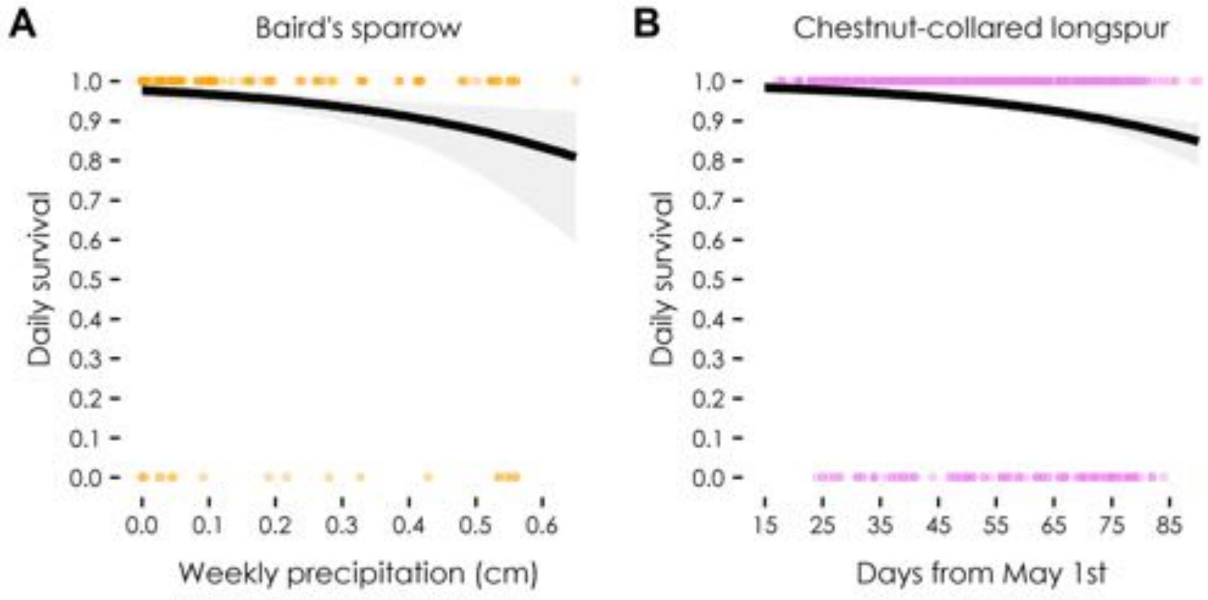

Figure 15: *Effect of environmental variables on logistic exposure DSR of nests of grassland songbird in North Dakota, 2015-2018.* ***A)*** *Effect of weekly precipitation on DSR of Baird's sparrow nests and* ***B)*** *Effect of time of season on DSR of chestnut-collared longspur nest**s**. Shading indicates 95% CIs. Colored circles display raw data (1= success, 0= failure). Points are transparent for display.*

***Table 6**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental and vegetation variables appearing in top logistic exposure models (ΔAICc<2; n = 22) of Baird's sparrow nesting success in North Dakota, 2015-2018. The constant survival model was not among top models (ΔAICc = 3.7).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Precip(weekly)	-1.87	-3.41	-0.33	0.80
Precip (interval)	1.06	-1.23	3.36	0.52
Live grass cover	-2.84	-11.69	6.01	0.51
Live grass cover^2	3.49	-7.29	14.28	0.51
Stage (ref egg)	0.08	-0.58	0.74	0.34
VOR	-0.06	-0.64	0.52	0.33
Litter cover	-0.07	-0.64	0.51	0.33
Bare ground cover	-0.12	-0.90	0.67	0.33
Max daily temp	0.04	-0.49	0.57	0.29
Plot	-0.06	-0.64	0.52	0.28

***Table 7**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental and vegetation variables appearing in top logistic exposure models (ΔAICc <2; n = 28) of grasshopper sparrow nesting success in North Dakota, 2015-2018. The constant survival model was not among top models (ΔAICc = 3.1).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Plot	-0.51	-1.04	0.03	0.71
Litter cover	0.15	-0.34	0.65	0.51
Precip (weekly)	0.12	-0.32	0.56	0.46
Vegetation height	0.12	-0.34	0.59	0.46
Forb cover	-0.08	-0.43	0.27	0.39
Bareground cover	-0.03	-0.25	0.19	0.32
Live grass cover	0.00	-0.09	0.09	0.31
Stage (ref egg)	0.01	-0.12	0.13	0.29
Avg daily temp	0.00	-0.08	0.09	0.27
VOR	-0.03	-0.43	0.38	0.25
VOR^2	0.03	-0.40	0.45	0.25

***Table 8**: Full model-averaged parameter estimates, 95% CIs, and cumulative AICc variable weights for environmental and vegetation variables appearing in top logistic exposure models (ΔAICc <2; n = 16) of chestnut-collared longspur nesting success in North Dakota, 2015-2018. The constant survival model was not among top models (ΔAICc = 26.3).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-1.55	-2.14	-0.96	1.00
Vegetation height	0.51	-0.13	1.14	0.72
Forb cover	0.22	-0.35	0.79	0.50
Litter cover	0.07	-0.30	0.44	0.40
Live grass cover	-0.06	-0.42	0.29	0.38
Bareground cover	0.03	-0.23	0.29	0.33
Stage (ref egg)	-0.02	-0.21	0.17	0.30
Plot	0.01	-0.16	0.18	0.29

Juvenile Survival and Movements

We monitored the post-fledgling survival and movement of juvenile Baird's sparrow and grasshopper sparrow in North Dakota, 2016-2018. We analyzed juvenile survival using the same logistic exposure and apparent survival methods described for adult survival. However, to avoid producing inflated survival estimates, we considered fledglings to be dead, rather than having an unknown fate, if they could not be located on plot while under 10 days post-fledge; fledglings under this age cap that went missing were most likely carried off by predators. Additionally, we used a 20-day period to define survival, and to calculate cumulative survival, instead of 30-day and 90-day periods, respectively, as we did for adults. Small juvenile transmitters have more limited battery life and begin to die after 20-days use, after which point fating birds could become inaccurate. Additionally, given that the period of time a fledgling must survive on the breeding grounds is variable, depending on whether it fledges from an earlier or later nesting attempt, a survival period based on this criterion would be somewhat arbitrary. Finally, fledglings all appeared to be mobile and independent by 20 days post-fledge. The exact age of independence is not known for either species, though fledgling Baird's sparrow were recorded to leave parental territories as early as 19 days old in one study (Cartwright et al. 1937).

We analyzed survival for each species independently (Tables 9-10; Figure 16), using the same set of environmental variables described for adult survival, in addition to an age (days post-fledge) variable. To test for pseudo-replication among fledglings from the same nest, we also analyzed survival using a dataset that included only one fledgling from each nest, and found that parameter confidence intervals overlapped those of parameters derived from the full dataset. Therefore, all results we report are derived from analysis of the full dataset. We also modeled the effects of vegetation variables on survival of for grasshopper sparrow (Table 11; Figure 17), for a subset of individuals for which these data were available (2017-2018). The vegetation variables we modeled were similar to those described for nesting success analyses, though the data were instead collected at a 5-m radius scale. We did not examine VOR for juvenile survival analyses, as we did not collect these data. We did not examine effects of vegetation on juvenile Baird's sparrow because sample size was limited.

Logistic exposure cumulative survival estimates and 95% confidence interval ranges were 20% (2-48) for Baird's sparrow and 49% (24-73) for grasshopper sparrow (averaged across years). Apparent survival for the two species averaged 21% and 32% respectively. Our estimates for grasshopper sparrow were within the range of established juvenile rates in grassland songbirds (e.g. Yackel Adams et al. 2001; Suedekamp et al. 2007; Fisher and Davis 2011, Hovick et al. 2011). Although no other juvenile survival estimates for Baird's sparrow currently exist to our knowledge, our estimates of juvenile survival in this species appear low relative to similar species, and are below the 40%

survival threshold theorized to be necessary to maintain population viability, given average winter survival rates (Cox et al. 2014). Low juvenile survival may therefore be contributing to overall Baird's sparrow declines.

Survival of juvenile Baird's sparrow was best explained by age (ΔAICc = 18.0), where the vast majority of mortality occurred within the first 5 days post-fledge. After 5 days of age, the probability of survival increased substantially (Table 9; Figure 16C). Grasshopper sparrows exhibited a similar trend (Table 10; Figure 16D; ΔAICc = 42.6), reflecting patterns observed in previous studies (e.g. Hovick et al. 2011; Cox et al. 2014). Similar, recent research on post-fledgling survival in dickcissels found body condition and wing development prior to fledge were influential in survival (Jones et al. 2017). This pattern suggests that mobility and rate of physiological development are likely critical parameters affecting fledgling survival. Climate and vegetation variables had a limited effect on juvenile survival of grasshopper sparrow at our sites (Tables 11). However, survival declined with increasing dead grass cover (Table 11; Figure 17). It's unclear what effect dead grass might have on juvenile birds, but it could potentially relate to ease of movement, food availability, or dry conditions.

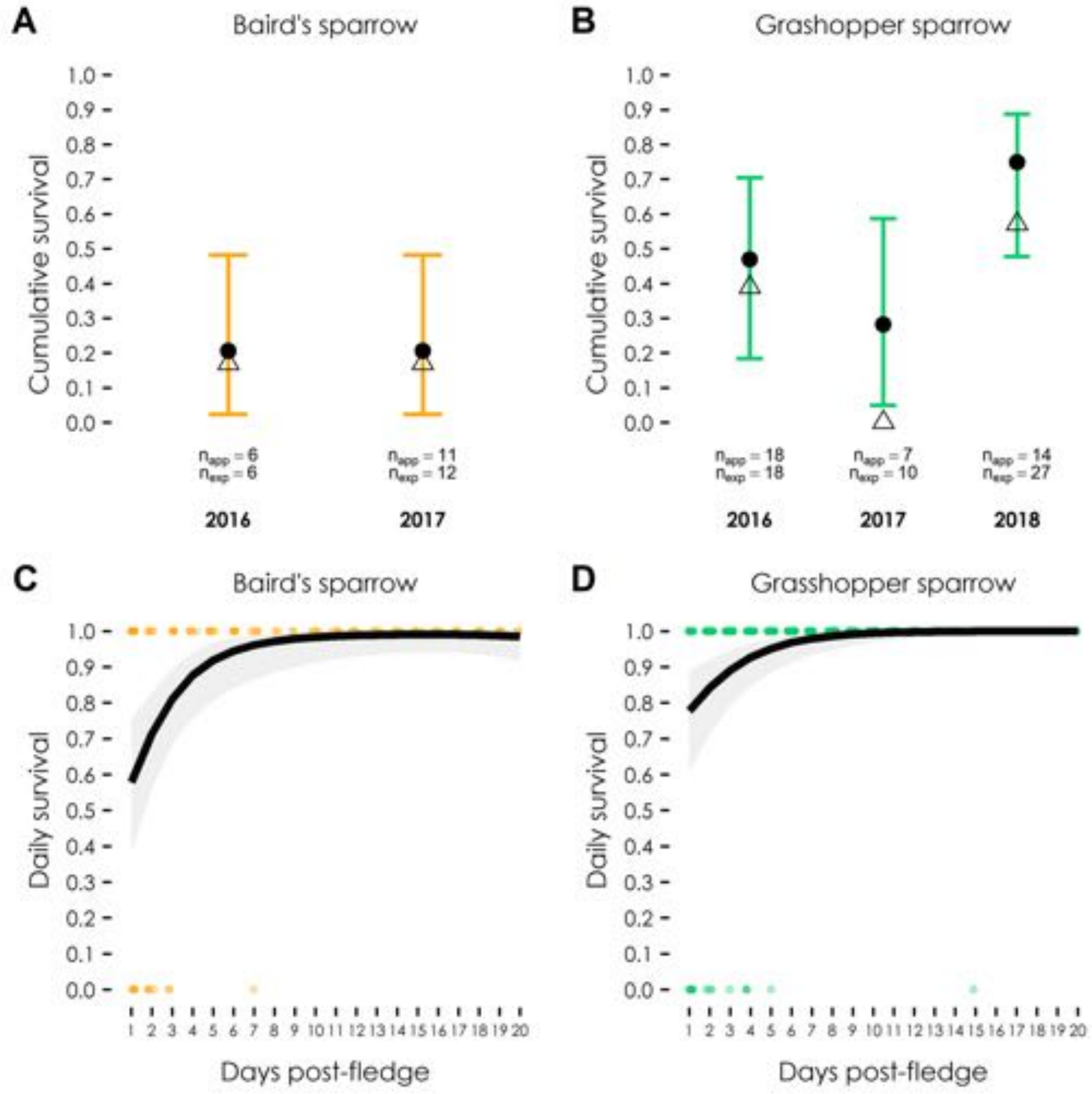

Figure 16: *Annual juvenile survival estimates for **A)** Baird's sparrow and **B)** grasshopper sparrow in North Dakota, 2016-2018. Filled circles indicate logistic exposure estimates for a 20-day survival period, shown with 95% confidence intervals. Triangles indicate corresponding apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. Cumulative probability of nesting success is shown on the Y-axis and year on the X-axis. Daily juvenile survival as a function of age for **C)** Baird's sparrow and **D)** grasshopper sparrow. Shading indicates 95% confidence intervals. Colored circles display raw data (1= success, 0 = failure), points are jittered and transparent for display purposes. DSR is displayed on the Y-axis, and age in days post-fledge on the X-axis.*

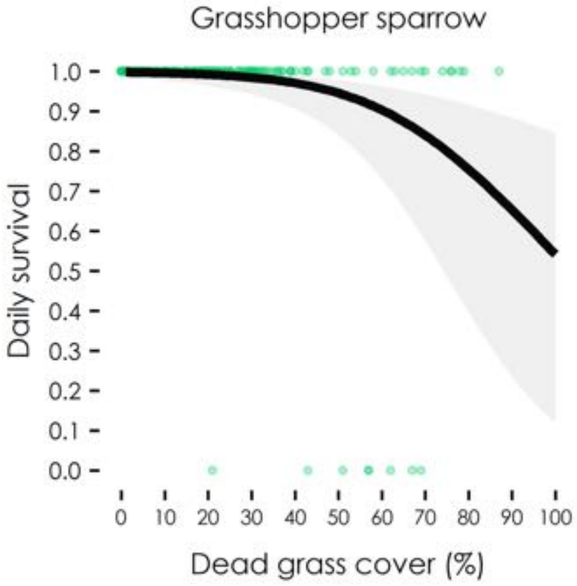

Figure 17: *Effect of dead grass cover on DSR of juvenile grasshopper sparrow in North Dakota, 2016-2018. Shading indicates 95% confidence intervals. Colored circles display raw data (1 = success, 0 = failure). Points are transparent for display purposes.*

***Table 9**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental variables appearing in top logistic exposure models (ΔAICc<2; n = 5) of Baird's sparrow juvenile survival in North Dakota, 2016-2018. The constant survival model was not among top models (ΔAICc = 18.0).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	14.26	5.46	23.07	1.00
Age^2	-10.96	-19.19	-2.73	1.00
Precip (weekly)	-0.18	-1.43	1.06	0.36
Year (ref 2018)	-0.16	-1.26	0.95	0.35
Precip(interval)	-0.17	-1.25	0.91	0.34
Min daily temp	0.07	-0.69	0.83	0.30

***Table 10**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental variables appearing in top logistic exposure models (ΔAICc<2; n = 7) of grasshopper sparrow juvenile survival in North Dakota, 2016-2018. The constant survival model was not among top models (ΔAICc = 42.6).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	13.48	6.89	20.07	1.00
Year	-	-	-	0.72
2016	-2.00	-4.90	0.89	-
2017	-2.05	-4.47	0.38	-
Precip (weekly)	1.09	-1.81	3.99	0.55
Max daily temp	-0.19	-1.37	0.99	0.33
Plot	0.28	-1.26	1.82	0.33

***Table 11**: Full model-averaged parameter estimates (Beta), 95% CIs, and cumulative AICc variable weights for environmental and vegetation variables appearing in top logistic exposure models (ΔAICc<2; n = 6) of Baird's sparrow juvenile survival in North Dakota, 2017-2018. The constant survival model was not among top models (ΔAICc = 23.3).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Dead grass cover	-6.76	-10.89	-2.62	0.93
Age	9.39	0.85	17.92	0.92
Max daily temp	2.23	-20.75	25.21	0.38
Max daily temp^2	-2.58	-25.55	20.39	0.38
Grass cover	-0.81	-6.02	4.40	0.37
Exotic cover	-0.45	-4.08	3.19	0.33
Litter cover	0.22	-1.81	2.25	0.29
Vegetation height	-0.17	-1.84	1.50	0.28

Mapping migratory pathways

Bird Conservancy deployed 215 light-level geolocator units on adult Baird's and grasshopper sparrow in 2016 and 2017 manufactured by Migrate Technology (58) and Dr. Eli Bridge at the University of Oklahoma (157). We recovered 6 units from returning Baird's Sparrows and 6 from returning grasshopper sparrows for a combined total of 12 geolocator units from returning birds in 2017 and 2018. Of the units recovered, we were able to extract data suitable for analysis from 10 of 12 units. We analyzed all geolocator data in Program R (R Core Team 2018) using the TwGeos (Wotherspoon et al. 2016) and GeoLight (Lisovski and Hahn 2013) packages. As a result of drift on the internal clocks of the University of Oklahoma units, all data from the University of Oklahoma units were calibrated to the internal clocks of the Migrate Technology units during analysis.

From the analyzed data, we observed that Baird's sparrows appear to maintain a dog-legged pattern at the beginning of their migratory route in the NGP, and then travel directly to their wintering grounds (Figure 18). This dog-leg pattern during fall stopover is exhibited in chestnut-collared longspurs as well (Ellison et al. 2017). Analysis of the migratory route of grasshopper sparrows is forthcoming, but generally seems to indicate a north-south trajectory after departure from their breeding grounds. We plan to combine our findings with isotope data recovered from feathers of breeding sparrows from both species.

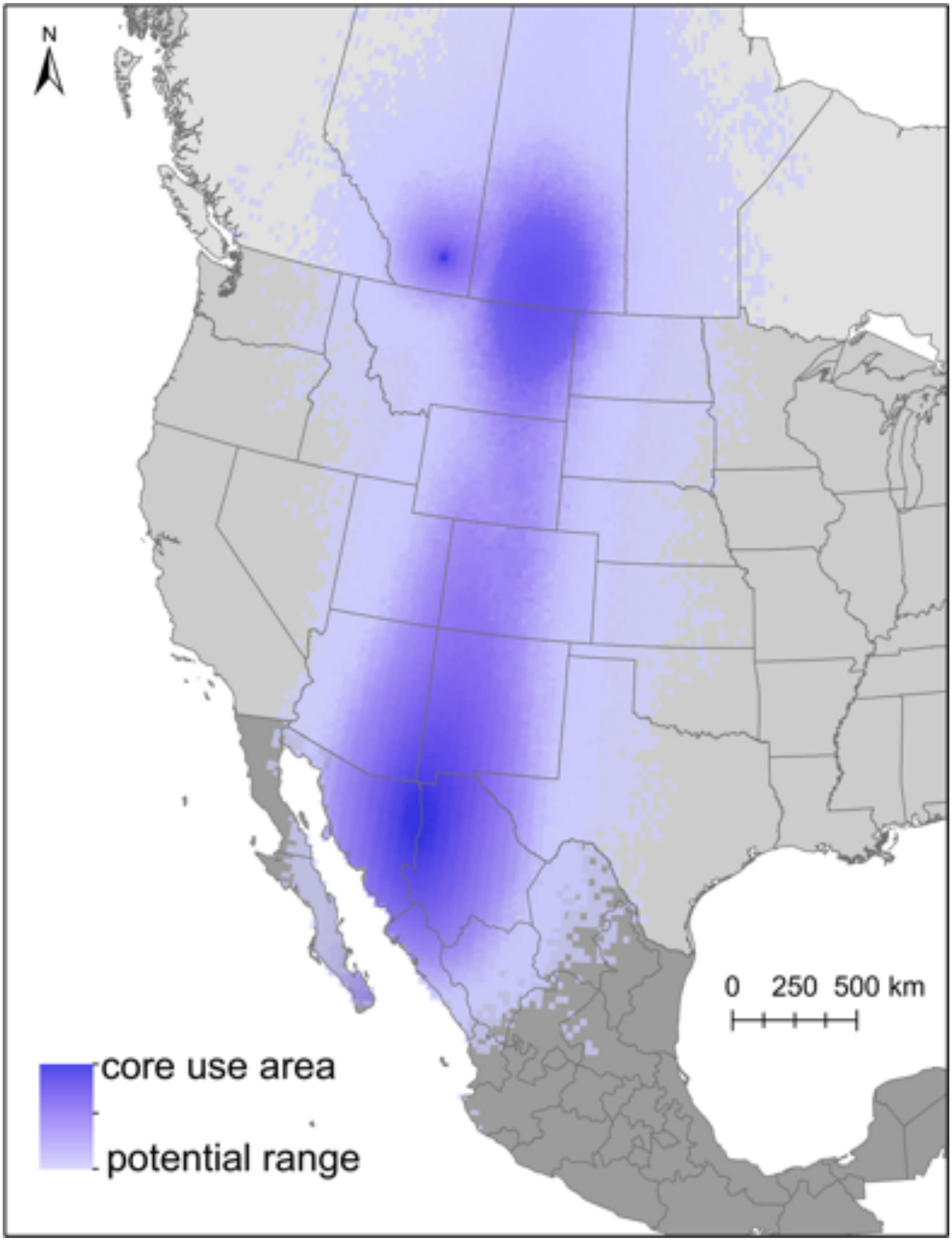

Figure 18: *Coarse migratory route of a male Baird's sparrow captured and fitted with a light-level geolocator.*

Mapping sparrow habitat using UASs

Spectral data collected with UASs can measure landscape characteristics through reflected radiation, adding insight into habitat conditions for many species including grassland birds. Characteristics such as bare ground, moisture, and vegetation absorb and emit specific wavelength values of the electromagnetic spectrum, and spectral vegetation indices (SVIs) such as Normalized Difference Vegetation Index (NDVI) can be calculated from UAS-sourced data that help measure these characteristics remotely. For example, measurements from NDVI can assess the amount of live vegetation on the ground by measuring chlorophyll content using the ratio of red and infrared light reflectance in a particular pixel. Low NDVI values could therefore correspond to bare ground or dead grass, and high values correspond to the presence of live vegetation. Other SVIs can also successfully quantify productivity and detect water stress, both potentially important factors in grassland systems. In addition to spectral data, UASs can create high-resolution Digital Surface Models (DSMs) that produce measurements for elevation, aspect, and topographical features that indicate direction of water flow.

We created DSMs (Figure 11) and calculated NDVI values for study sites in both North Dakota and Montana using imagery flown in August 2017 and throughout the breeding season in 2018 (Figure 19). We processed all collected imagery in Pix4D photogrammetry software to produce rasters of DSMs and NDVI with a horizontal accuracy of 5m. We produced rasters in 2018 that are comparable to those produced in 2017. The efficiency of the fixed-wing drone has allowed for additional data collection across the season to measure change in NDVI on our study sites across the breeding season (Figure 20). During the 2018 season, we collected imagery via UAS approximately every thirty days at each study site. All imagery processing in Pix4D Mapper will be complete by March of 2019. With these data, we will analyze various metrics such as elevation, NDVI, and other SVIs that are used by adult grassland songbirds at nest-sites and by juvenile birds that have recently fledged their nest to better understand habitat conditions that are suitable for breeding birds on the NGP.

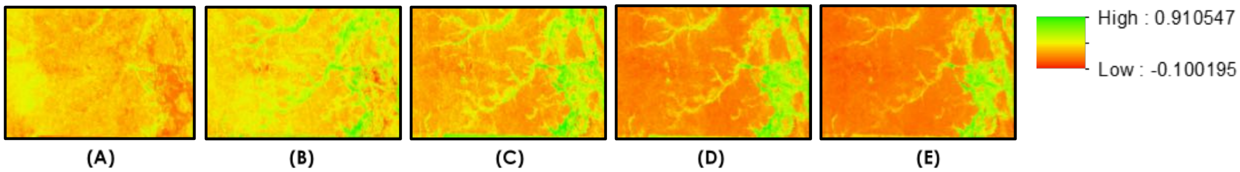

Figure 19: *Maps of the Normalized Vegetation Difference Index (NDVI) collected over the course of the 2018 breeding season. These maps demonstrate the change in vegetative productivity over the span of four months:* ***(A)*** *mid-May,* ***(B)*** *mid-June,* ***(C)*** *early-July,* ***(D)*** *late-July, and* ***(E)*** *early-august*

Future directions

Development of an IPM for the Baird's sparrow

We are in the middle of combining data presented in this report with similar demographic data from the wintering grounds (Strasser et al. 2018) and population data from the breeding (Pavlacky et al. 2017) and wintering (Macias-Duarte et al. 2018) grounds into an integrated population model for the Baird's sparrow. With input from state and federal agencies and other organizations involved with grassland bird conservation efforts in the NGP, we will seek to identify science-driven best management practices that will have implications across the Great Plains and Chihuahuan Desert (Figure 27). This project will be collaborative in nature and ideally will:

- Generate precise estimates of survival and fecundity on the breeding grounds, as well as survival during fall and spring migration with input from partners.
- Estimate the response of demographic parameters (e.g., survival, productivity), abundance, and population trends to covariates, such as habitat amount and fragmentation, management practices (e.g., CRP on breeding grounds, shrub removal on wintering grounds), etc.
- Identify phases of the annual cycle that are limiting population growth.
- Provide simulations of a range of future habitat conditions in different geographies to understand the resulting impact of management decisions on species decline.
- Produce geographically-explicit best management practices for grassland habitat to support this species, and similar species.

The ultimate outcome of this project will be the identification of specific actions and management practices needed to reduce the decline of the Baird's sparrow. Our results will complement investment across North America in grasslands protection and research, and contribute to a collaborative approach to grassland conservation. This will allow for the most efficient use of conservation dollars across regional conservation areas (USFWS Region 6), conservation business plans (e.g. the NGP business plan, NFWF 2016), and individual states that have identified the Baird's sparrow as a priority focal species. We hope to have preliminary results from the developed IPM and associated simulations to inform the Grassland Roadmap Summit in August 2020. This summit will be a combination of leaders in grassland conservation from state and federal government, non-profit, industry, and private entities held in Fort Collins, CO with the goal of creating continent-scale conservation plans to support working grasslands and their wildlife persist into the future.

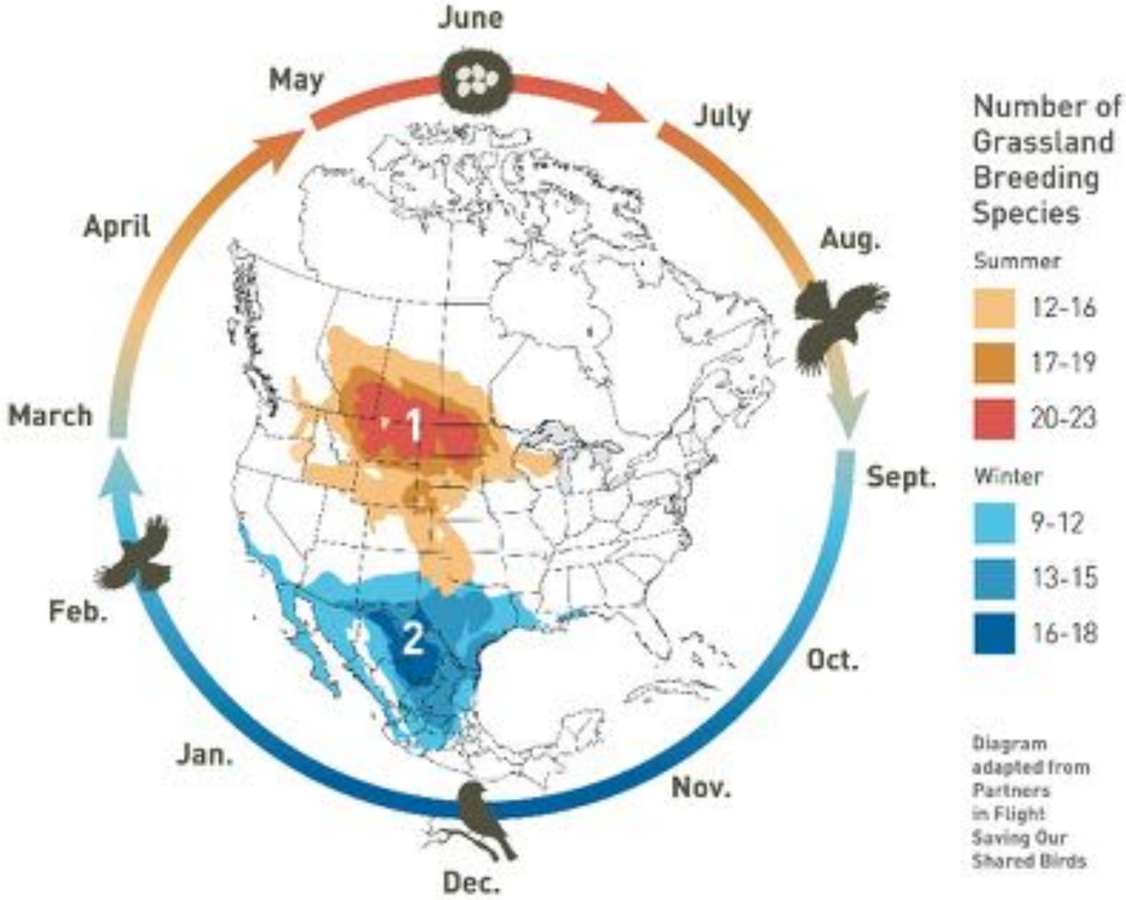

***Figure 20**: Visualization of the FAC monitoring approach, depicting the connection between grassland habitat on the breeding grounds in the NGP **(1)**, and wintering grounds in the southwestern United States and Mexico **(2)**.*

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