Demographic monitoring of breeding grassland birds in the Northern Great Plains

Bird Conservancy of the Rockies
2018 Annual Report
March 06, 2019

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

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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

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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.

Meet Bird Conservancy's Demographic Monitoring Team

Jacy Bernath-Plaisted, M.N.R.M.: Jacy joined the Science Team at Bird Conservancy in 2017 and coordinates the field effort for this demographic work. He also manages and analyzes the project's data. Jacy came to his position with a background in grassland bird demographic work from his master's thesis at the University of Manitoba, where he examined the effects of oil and gas infrastructure on mixed-grass prairie songbirds in southern Alberta.

Dr. Maureen Correll: Mo joined the Science Team at Bird Conservancy in 2016 and is the principle investigator of Bird Conservancy's full-annual-cycle study of grassland bird demographics. Mo's interest in remote sensing has also driven her to explore the use of UASs (drones)as tools to collect habitat information for grassland birds on the breeding and wintering grounds.

Nicole Guido, M.S. candidate: Nicole joined the Bird Conservancy team in 2016 as a crew leader for our demographic site in eastern Montana. Nicole returned in 2017 as a crew leader and a graduate student investigating the use of UASs as tools for collecting habitat information on nest site selection and juvenile habitat use in grassland songbirds. Nicole is pursuing her degree at the University of Maine, co-advised by Mo Correll and Kate Ruskin.

Arvind O. Panjabi, MS: Arvind holds a senior position as an Avian Conservation Biologist at Bird Conservancy. His efforts to explore the demographics of grassland songbirds across their full annual cycle have provided a conceptual vision for the full annual cycle analysis and conservation of Baird's and grasshopper sparrows. Through Arvind's leadership, Bird Conservancy also maintains a stewardship program on the wintering grounds in Mexico and Texas.

Erin H. Strasser, MS: Erin leads our winter demographic work in the Chihuahuan Desert in Mexico, a project initiated in 2012. Erin has provided transmitter attachment and telemetry training to the NGP project, and she has also participated in the deployment and recovery of light-level geolocator units on the breeding grounds. Field technicians in the NGP follow the same telemetry protocols as those Erin implements in the Chihuahuan Desert.

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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 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 sparrow in western North Dakota. In 2016, we expanded the project, establishing a new site in eastern Montana. We also began monitoring juvenile survival of Baird's and grasshopper sparrow, and deploying (2016-2017) light-level geolocator units on adult of both species at our sites, as well as a collaborator site operated by the University of Manitoba, located in southern Alberta, Canada. In 2017, we continued research activities at all sites, 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. During the 2017-18 seasons, we also introduced collection of imagery and habitat data via Unmanned Aircraft Systems (drones) in an effort to better quantify environmental conditions. We also successfully 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 all 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, though Sprague's pipit nesting success was influenced by visual obstruction (VOR). Juvenile survival of Baird's and grasshopper sparrow was lower and more variable than adult survival and driven primarily by effects of fledgling age, with additional variation explained by vegetation height and dead grass cover.

Highlights of 2018

Juvenile survival analysis

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

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 for juvenile survival in the species.

***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 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 the 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. Additionally, thanks to funding from the North Dakota Natural Resources Trust (NDNRT) we were able to provide our grazing lessee partners from the Little Missouri Grazing Association in North Dakota with drone-collected imagery of the pastures on which our research activities occur.

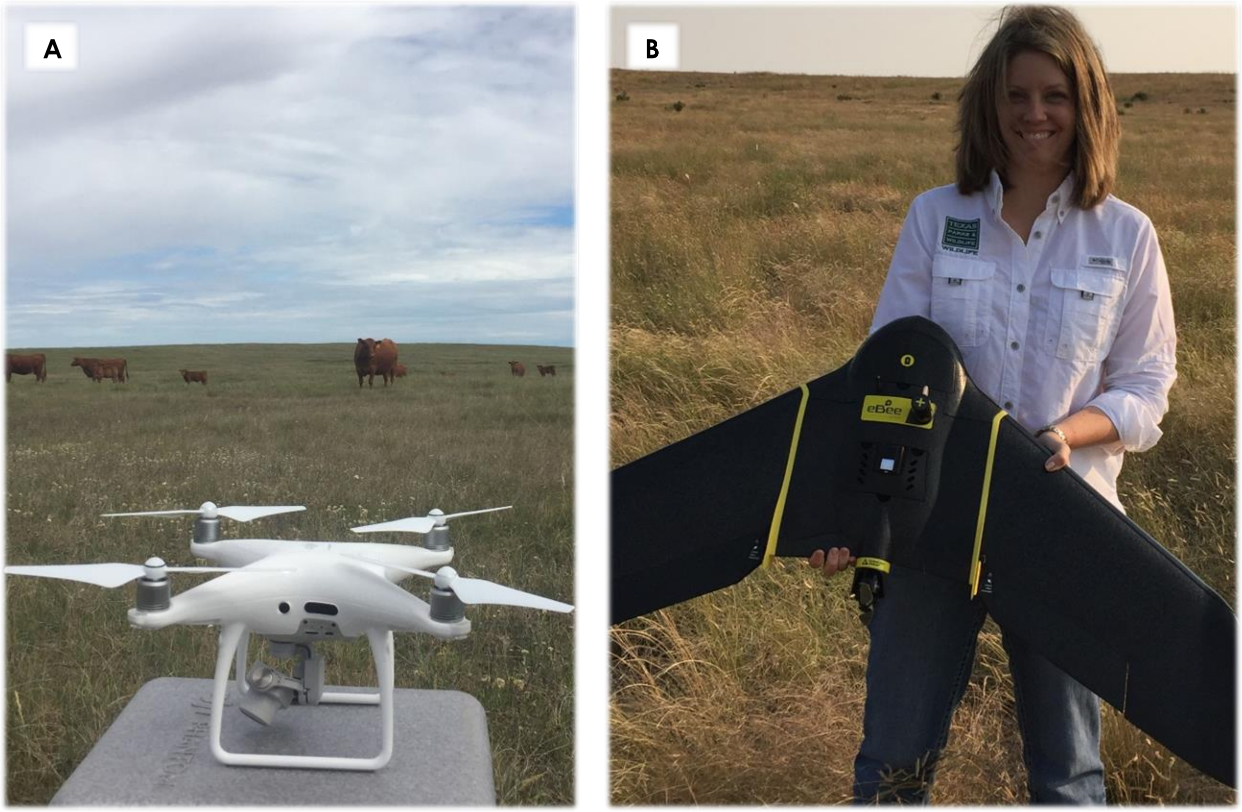

Figure 4: ***A)*** *A quadcopter drone used to collect vegetation data at Bird Conservancy's NGP field sites.* ***B)*** *A Fixed-wing drone recently purchased by Bird Conservancy held by a collaborator at Bird Conservancy's winter demography site near Marfa Texas. Photos by M. Correll.*

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 the NGP 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 NGP began in 2015 and largely concluded in 2018. However, we will conduct a final season in 2019 focusing on the adult survival of Sprague's pipit.

***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

We seek to quantify nesting success, adult and juvenile survival, and home range patterns in multiple breeding populations of declining grassland songbirds that breed in the NGP. We will also assess the influence of vegetation, climate, and other parameters on these vital rates to inform grassland management in the NGP.

The specific objectives for our demographic work in the NGP are to:

1) Estimate baseline rates of reproduction (nesting success and productivity) in Baird's and grasshopper sparrows and other focal species as allowed by sample size.

2) Estimate baseline rates of survival in adult and juvenile Baird's and grasshopper sparrows, and adult Sprague' pipits as allowed by sample size.

3) Examine the influence of vegetation characteristics, climate, and other environmental factors on demographic rates.

4) Track course routes of stopover, migration, and wintering geography for Baird's and grasshopper sparrows

5) Develop recommendations to share with Bird Conservancy's stewardship program and other organizations to inform management strategies for grassland songbirds breeding in the NGP.

6) Inform an integrated population model to assess how vital rates during various stages of the life cycle influence population size and growth across years.

Field sites

Little Missouri National Grasslands – Western North Dakota

Our demographic monitoring site in North Dakota on the Little Missouri National Grasslands (Figure 5) was established in 2015 under a 3-year grant (since renewed into 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, this site experienced moderate drought relief.

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

Eastern Montana

Northeastern Montana is a high-density area for grassland songbirds (Sauer et al. 2017). Added in 2016 using funding from the National Fish and Wildlife Foundation Conoco Phillips SPIRIT award (renewed through 2018), this site (Figure 6) expanded the geographic scope of the project and helps our study capture potential regional variation in demographic rates. Different from our North Dakota plots, the vegetation on our Montana plots is predominantly native. One plot is managed by the Bureau of Land Management (BLM) and leased by grazers, and the other is privately owned by local ranchers. During the fall of 2018, approximately 30% of our BLM plot suffered a complete burn, and had to be shifted slightly for the 2018 season. Our Montana site also experienced severe drought in 2017, but recovered in 2018.

***Figure 6**: Bird Conservancy study site in eastern Montana. Photo by K. Bell.*

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 site and year.

***Figure 7**: 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 (2017-2018) using targeted mist-netting techniques (Figure 8A). 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 8B). We also fitted captured birds with USGS aluminum bands

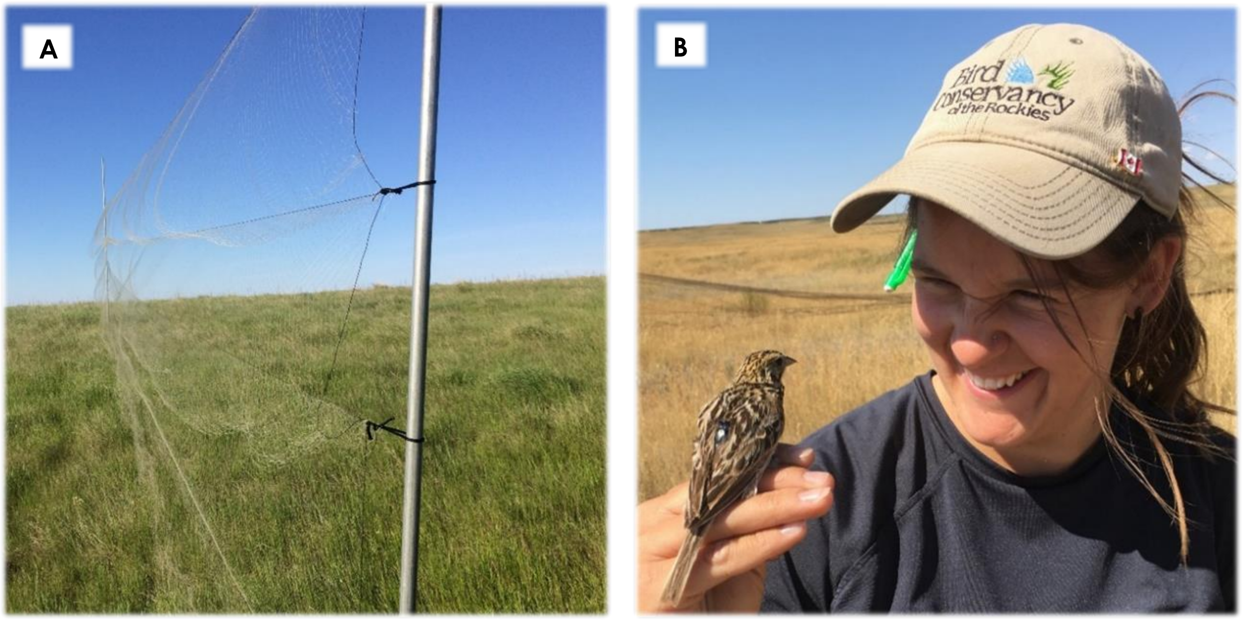

***Figure 8**: **A)** A mist net used to capture grassland songbirds for banding and transmitter attachment; **B)** Bird Conservancy crew lead Kelsey Bell holding a Baird's sparrow outfitted with a radio transmitter. Photos by J. Bernath-Plaisted.*

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 7) 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.

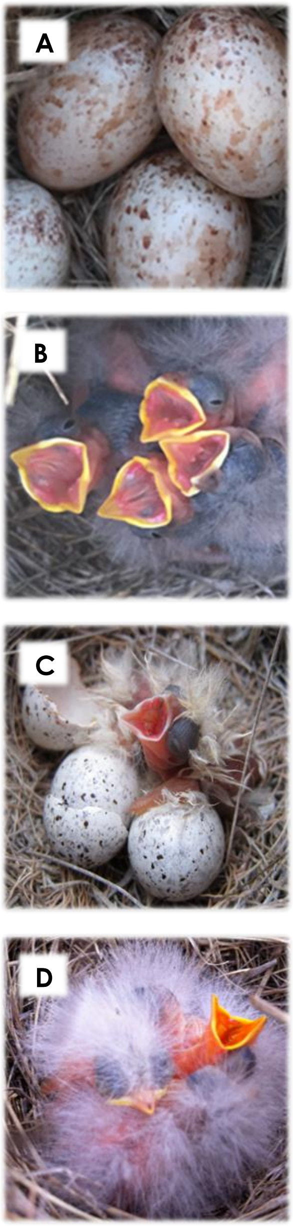

***Figure 9**: **A)** Baird's sparrow eggs; **B)** grasshopper sparrow nestlings; **C)** chestnut-collared longspur nestlings hatching; **D)** Sprague's pipit nestlings. Photos by J. Bernath-Plaisted*

Nest searching and monitoring

We monitored nests of Baird's sparrow, grasshopper sparrow, chestnut-collared longspur, and Sprague's pipit (Figure 9A-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 10A), 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 10B-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.

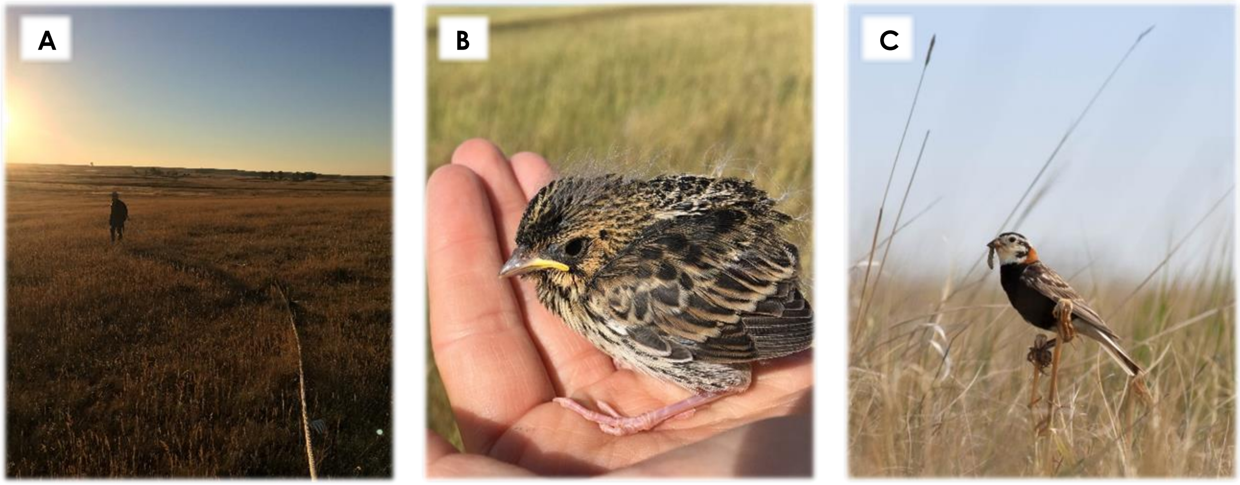

***Figure 10**: **A)** Technicians rope dragging for nests (photo by K. Bell); **B)** Recently fledged Baird's sparrow (photo by K. Bell); **C)** Adult male chestnut-collared longspur carrying food (photo by J. Horvat).*

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, 2015-2018), 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 11) 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, 2016-2018) to capture changes in vegetation structure, cover, and composition to assess the influence of seasonal changes and climate on vegetation.

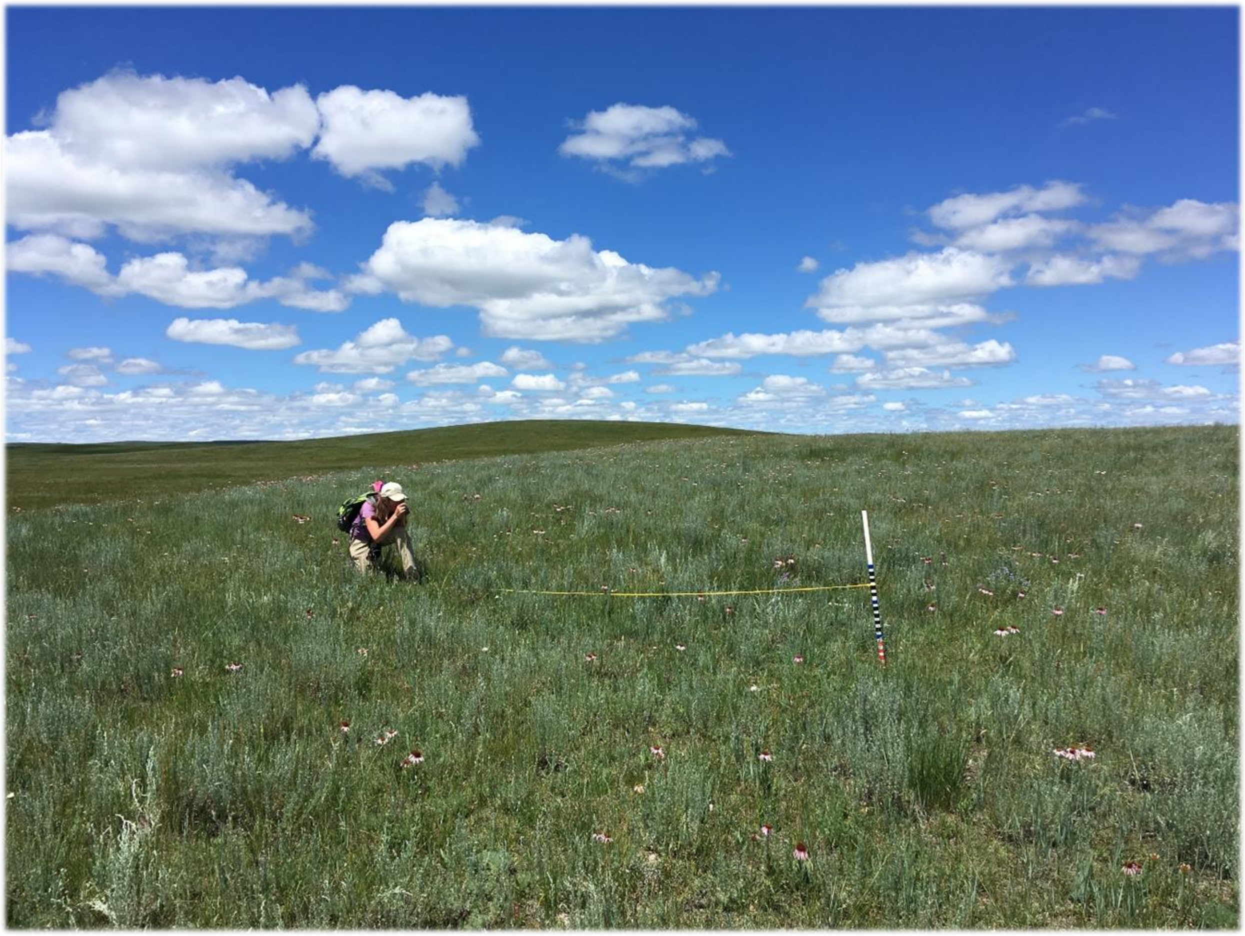

***Figure 11**: North Dakota crew lead Chistryne Callbeck conducts visual obstruction measurements in the field. Photo by J. Bernath-Plaisted*

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 12A-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.

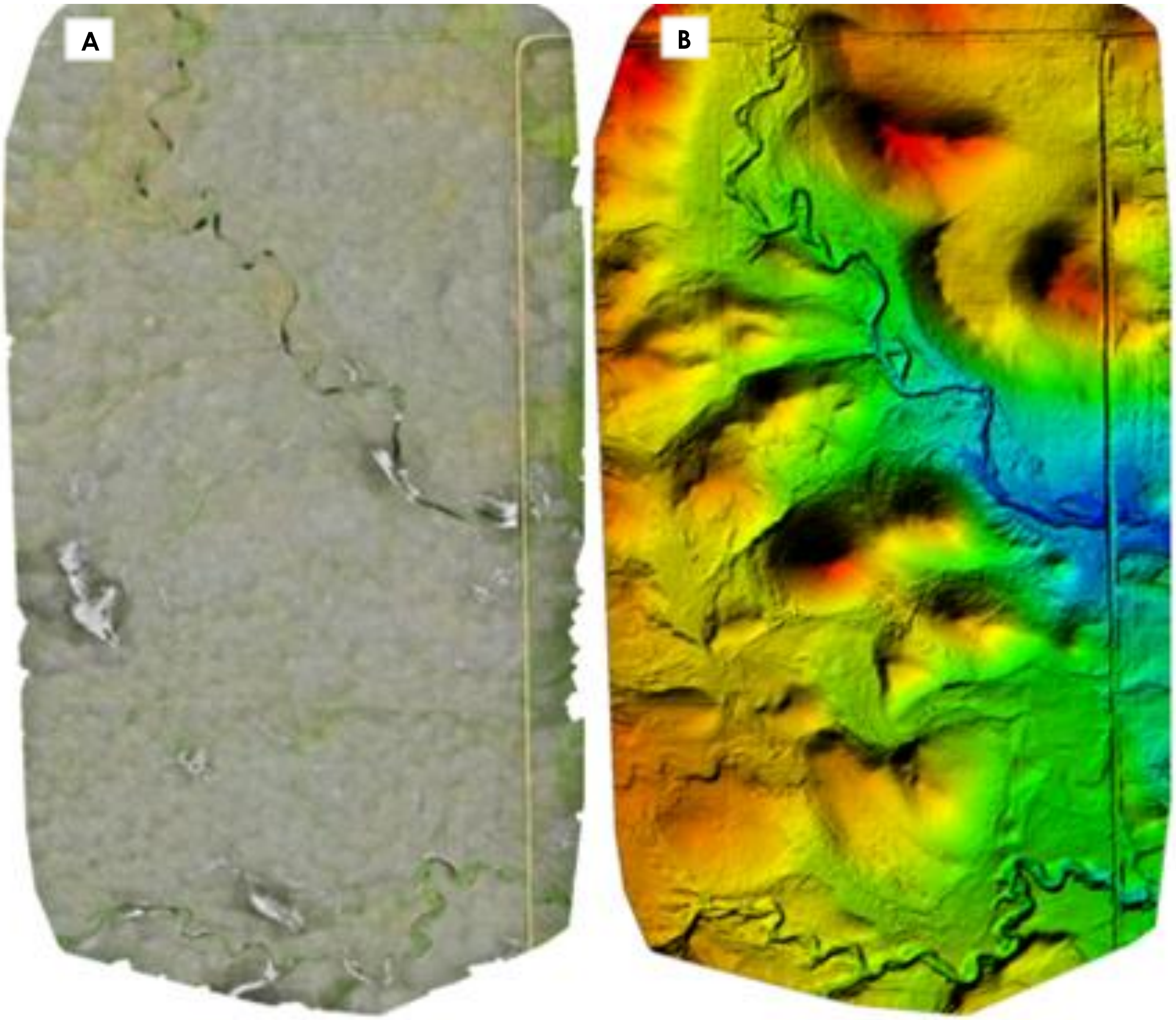

***Figure 12**: Resulting imagery at spatial resolution of 2.5 cm per pixel from our North Dakota study site collected with SODA camera and produced in Pix4D Mapper. **A)** Orthomosaic, a composite image of spatially corrected photos. **B)** Digital Surface Model (DSM), a raster that accounts for elevation 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 13) 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 sites in North Dakota and Montana, 2015-2018.*

Year	Site	Species	Nests (*n*)	Adults (*n*)	Juveniles (*n*)
2015	ND	Baird's sparrow	21	35	-
		Grasshopper sparrow	39	50	-
		Chestnut-collared longspur	10	-	-
		Sprague's pipit	1	-	-
2016	ND	Baird's sparrow	12	38	9
		Grasshopper sparrow	70	59	29
		Chestnut-collared longspur	50	-	-
		Sprague's pipit	-	-	-
	MT	Baird's sparrow	33	48	23
		Grasshopper sparrow	8	35	2
		Chestnut-collared longspur	64	-	-
		Sprague's pipit	16	-	-
2017	ND	Baird's sparrow	16	38	12
		Grasshopper sparrow	42	44	15
		Chestnut-collared longspur	66	-	-
		Sprague's pipit	3	7	-
	MT	Baird's sparrow	45	50	39
		Grasshopper sparrow	10	35	2
		Chestnut-collared longspur	81	-	-
		Sprague's pipit	14	8	-
2018	ND	Baird's sparrow	6	-	3
		Grasshopper sparrow	57	-	32
		Chestnut-collared longspur	94	-	-
		Sprague's pipit	2	10	-
	MT	Baird's sparrow	41	-	47
		Grasshopper sparrow	18	-	6
		Chestnut-collared longspur	120	-	-
		Sprague's pipit	13	10	-
Totals		Baird's sparrow	174	209	133
		Grasshopper sparrow	244	223	86
		Chestnut-collared longspur	485	-	-
		Sprague's pipit	49	35	-
		All	952	467	219

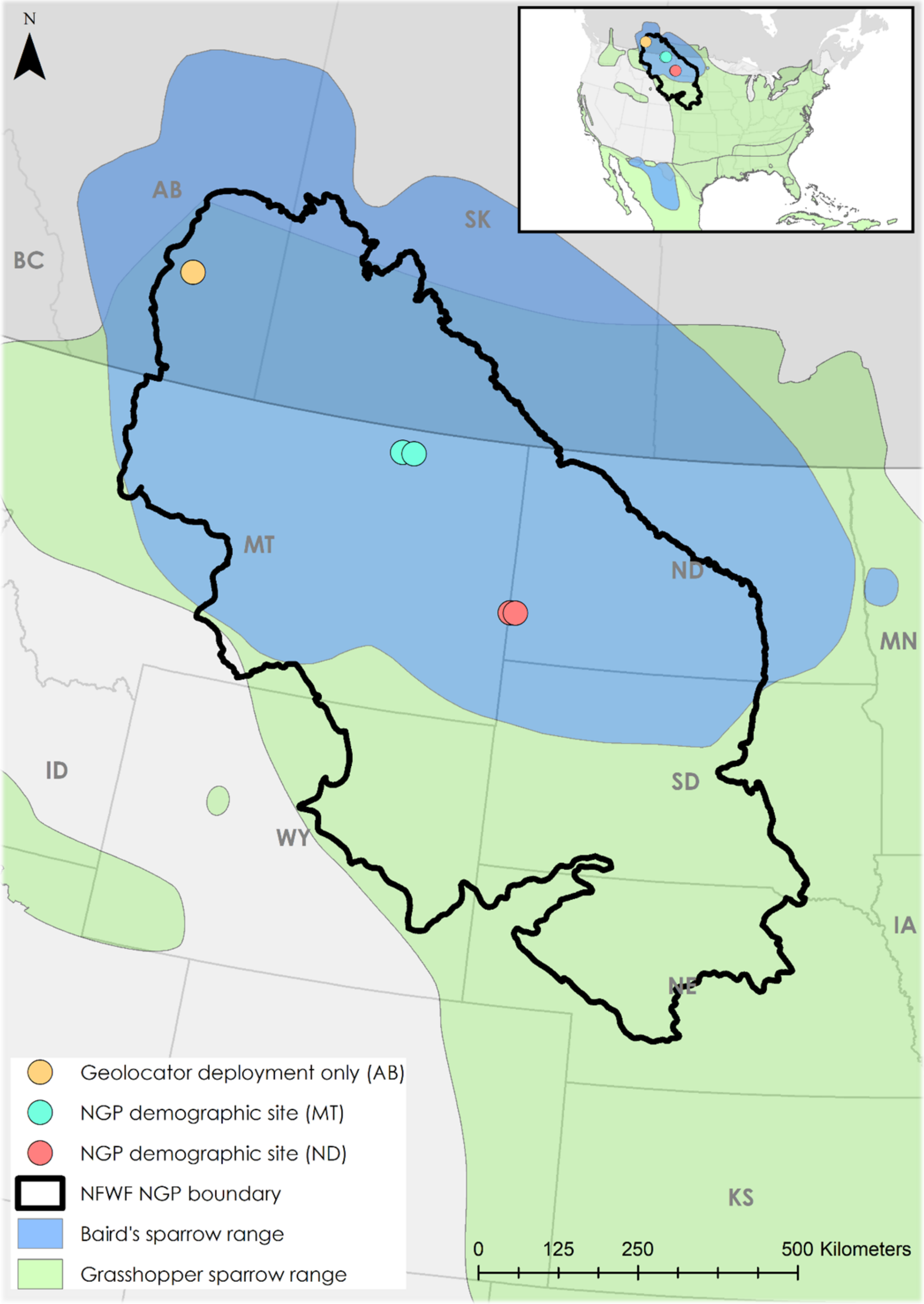

Figure 13*: Map showing the locations of Bird Conservancy's geolocator deployment sites in the NGP relative to the breeding ranges of Baird's and grasshopper sparrow.*

Analysis and results

Adult survival

We estimated adult survival (Figure 14) in male Baird's and grasshopper sparrow for the years of 2015-2017 in North Dakota and 2016-2017 in Montana. We also estimated adult survival of Sprague's pipit in North Dakota and Montana, 2017-2018. 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, site (North Dakota or Montana), 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, as well as to select between correlated variables; we did not include 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's pipit were 76% (46-91), 71%(36-89), 79%(16-96), 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 76%, 86%, 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. Our adult survival estimates were similar to those reported in adult males of similar species, such as Savannah sparrow (*Passerculus sandwichensis*; Perlut et al. 2008). Although annual adult survival is an important parameter affecting population recruitment in grassland songbirds (Fletcher et al. 2006), 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 at our sites, 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). However, it should be noted that our adult survival estimates are for males only, and survival in females may differ (Perlut et al. 2008). Mortality rates during migration for these species remain unknown. 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 sparrow 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).

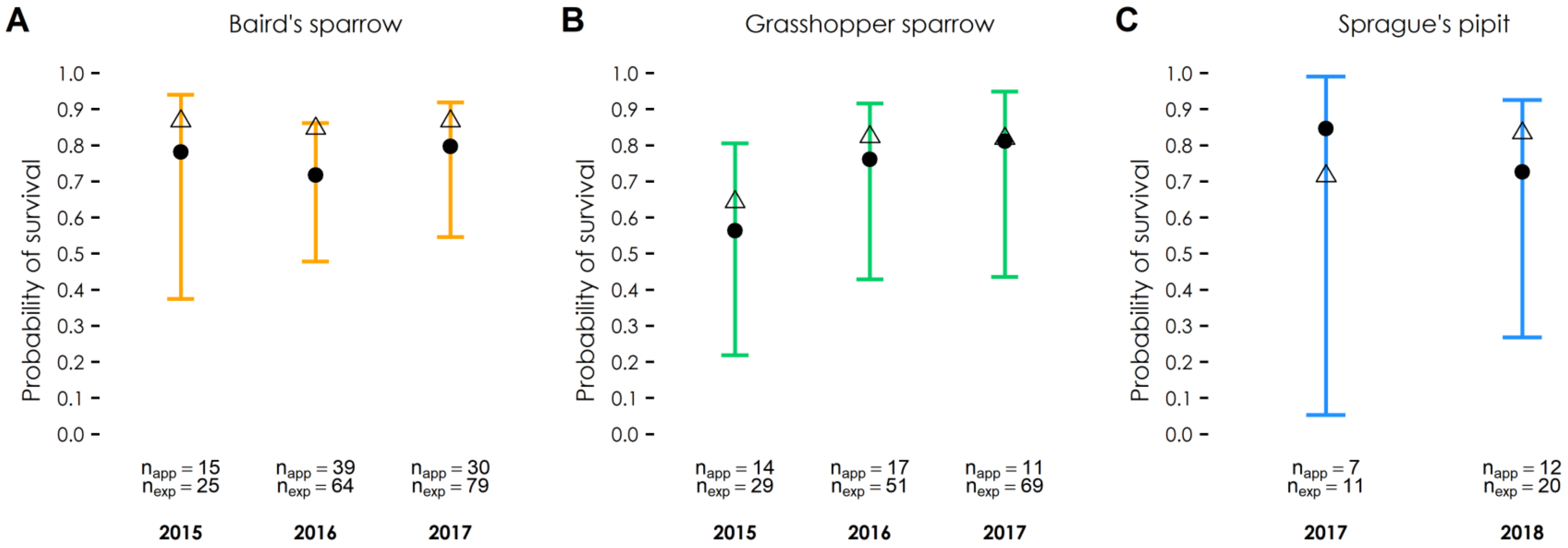

Figure 14: *Survival estimates for adult male* ***A)*** *Baird's sparrow,* ***B)*** *Grasshopper sparrow, and* ***C)*** *Sprague's pipit in North Dakota and Montana, 2015-2018. Filled circles indicate logistic exposure estimates over a period of 90 days, shown with 95% confidence intervals. Triangles indicate corresponding annual apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. 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 = 4) of adult Baird's sparrow survival in North Dakota and Montana, 2015-2017. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Max daily temp	-1.05	-7.03	4.93	0.36
Precip (interval)	-0.20	-3.94	3.53	0.33
Site (ref ND)	0.80	-4.64	6.23	0.27

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 and Montana, 2015-2017. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-2.80	-12.06	6.45	0.46
Max daily temp	2.28	-6.77	11.33	0.43
Precip (interval)	-1.91	-8.27	4.45	0.42
Precip (weekly)	-0.67	-5.42	4.08	0.31
Site (ref ND)	-0.07	-2.36	2.22	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 = 7) of adult Sprague's pipit survival in North Dakota and Montana, 2017-2018. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-10.68	-25.78	4.43	0.62
Site (ref ND)	9.76	-5.89	25.40	0.60
Year (ref 2018)	0.57	-6.26	7.39	0.32
Min daily temp	0.47	-5.93	6.88	0.32
Precip (interval)	-0.89	-7.53	5.75	0.32
Precip (weekly)	-0.47	-7.08	6.14	0.28

Nesting success, clutch size, and nest initiation date

We monitored nests of grassland songbird species breeding in the mixed-grass prairie of North Dakota and Montana, including Baird's sparrow, grasshopper sparrow, chestnut-collared longspur, and Sprague's pipit from 2015-2018. 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 estimated nest initiation dates for all nests that could be back-dated from the end of lay period, hatch date, or from nestling age using known incubation and brooding periods for the species (e.g. Davis 2003, Jones et al. 2010) and assuming a single egg was laid during each day of the lay period. We did combined data across years, and did not account for variation in arrival dates. Nest initiations began in the first week of May and extended through July. Peak nesting dates differed among species (Figure 15A); both chestnut-collared longspur and Sprague's pipit began nesting in the first week of May and peaked in the third week of May, while Baird's sparrow peaked strongly in late May and early June, and grasshopper sparrow peaked during in mid-June (Figure 16). We estimated apparent clutch sizes from maximum egg and nestling content observed at each nest, as we did not check nests every day. We did not estimate clutch size for partially depredated or parasitized nests. We found that clutch sizes were similar among all four species (Figure 15B), averaging (±SD) 4.1 (± 0.83) in Baird's sparrow, 4.2 (± 0.85) in grasshopper sparrow, 3.7 (± 0.73) in chestnut-collared longspur, and 4.4 (± 0.77) in Sprague's pipit. Overall, brood parasitism by brown-headed cowbird (*Molothrus aeter*) was uncommon at our study sites, with parasitism documented at only 2% of total nests monitored. Of the 952 nests we monitored, 148 (15%) had unknown fates and 35 (4%) appeared to be abandoned as a consequence of research activities. Of the remaining 769 nests, 279 (36%) were successful, 474 (62%) failed, and 16 (2%) were abandoned for unknown reasons. Nest depredation was the largest driver of nest failure, and accounted for 90% of failures.

We analyzed nesting success for each species individually (Figure 17) 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; 22 days for chestnut-collared longspur, and 24 days for Sprague's pipit. 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 survival estimates and 95% confidence interval ranges averaged across the years for Baird's sparrow, grasshopper sparrow, chestnut-collared longspur, and Sprague pipit were 43% (31-59), 18%(8-31), 36%(21-52), and 19% (4-47) respectively. Apparent survival estimates averaged across years for the same species were 51%, 24%, 31%, and 18%, respectively. Our estimates for Baird's sparrow, grasshopper sparrow, and chestnut-collared longspur are consistent with estimates from other studies for 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). However, estimates of Sprague's pipit nesting success were lower than existing estimates (e.g. Davis 2003; Jones et al. 2010; Ludlow et al. 2014). Low estimates for this species may be a consequence of small sample size, or possibly drought conditions during some years of our study.

Overall, the climate and vegetation variables we modeled had relatively little influence on nesting success (Tables 6-9). The top model for Baird's sparrow included variables for date, precipitation (interval), VOR, and year. Although this model outperformed the constant survival model (ΔAICc = 3.57), there were 31 equivalent top models, and only the date variable appeared to be explanatory by weight and had confidence intervals not overlapping zero (Table 6). Daily nest survival decreased linearly as the season progressed for this species (Figure 18A). For grasshopper sparrow, the constant survival model performed best of all candidate models (Table 7). Nesting success in chestnut-collared longspur was best explained by a linear, negative effect of date (Table 8; Figure 18B), with the top model for this species including site, nest stage, date, vegetation height, and forb cover variables; this model substantially outperformed the constant survival model (ΔAICc = 42.6). However, as in Baird's sparrow, there were many equivalent top models (*n* = 18), and date was the only variable with confidence intervals not overlapping zero (Table 8). Finally, Sprague's pipit nesting success appeared to be driven both by a negative effect of maximum daily temperature and a quadratic effect of VOR (Table 9; Figure 19). The top model for this species outperformed the constant survival model (ΔAICc = 11.7), and also included precipitation (interval), but confidence intervals overlapped zero for this variable. There were 7 equivalent top models.

The overall 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 can occur rapidly in mixed-grass prairie from early May to June (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. Interestingly, nesting success in Sprague's pipit was influenced by a quadratic effect of VOR; nesting success was lower at intermediate vegetation densities around the nest site. This may be driven by the habitat preferences of nest predators and/or vigilance and foraging behavior trade-offs in nest predators (e.g. Dion et al. 2000; Klug et al. 2010). For example, small-rodent predators may avoid sparse cover, or spend more time being vigilant in sparse vegetation relative to foraging to mitigate risk from aerial predators (e.g. raptor species, shrike). Conversely, dense cover, while safer, may reduce foraging efficiency as a consequence of nest concealment, leaving intermediate vegetation cover as optimal foraging habitat for some nest predators.

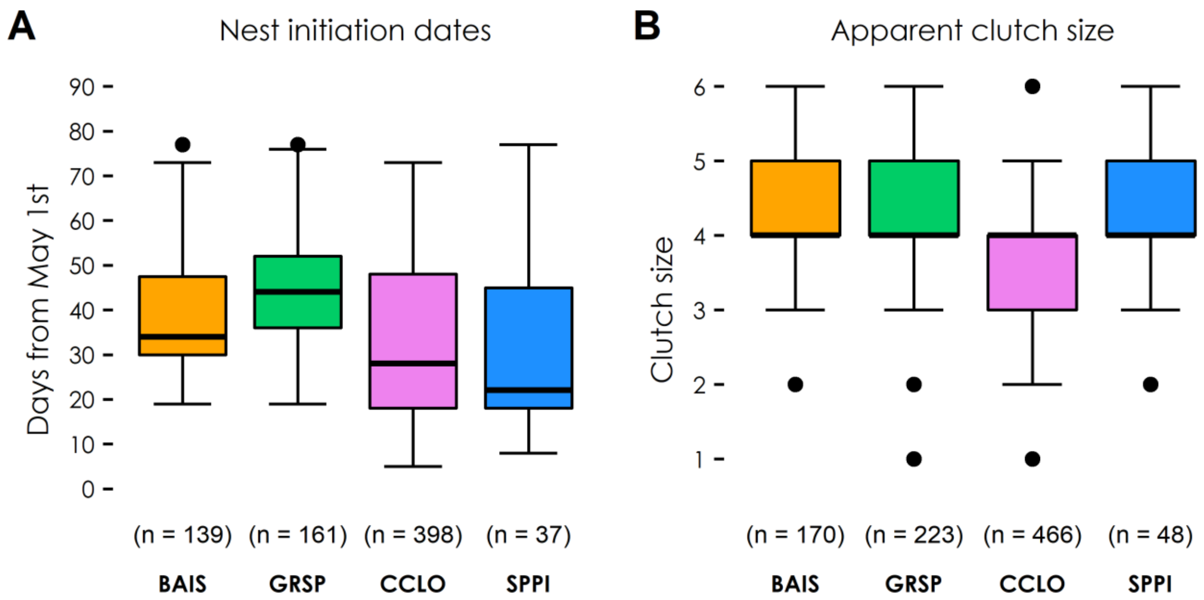

***Figure 15**: **A)** Nest initiation dates, and **B)** Apparent clutch sizes for four species of grassland songbird breeding in North Dakota and Montana, 2015-2018. Bold lines indicates median, and top and bottom hinges display first and third quartiles (25th and 75th percentiles); whiskers extend from quartiles to smallest/largest value that does not exceed 1.5*IQR; filled circles indicate outliers beyond this value.*

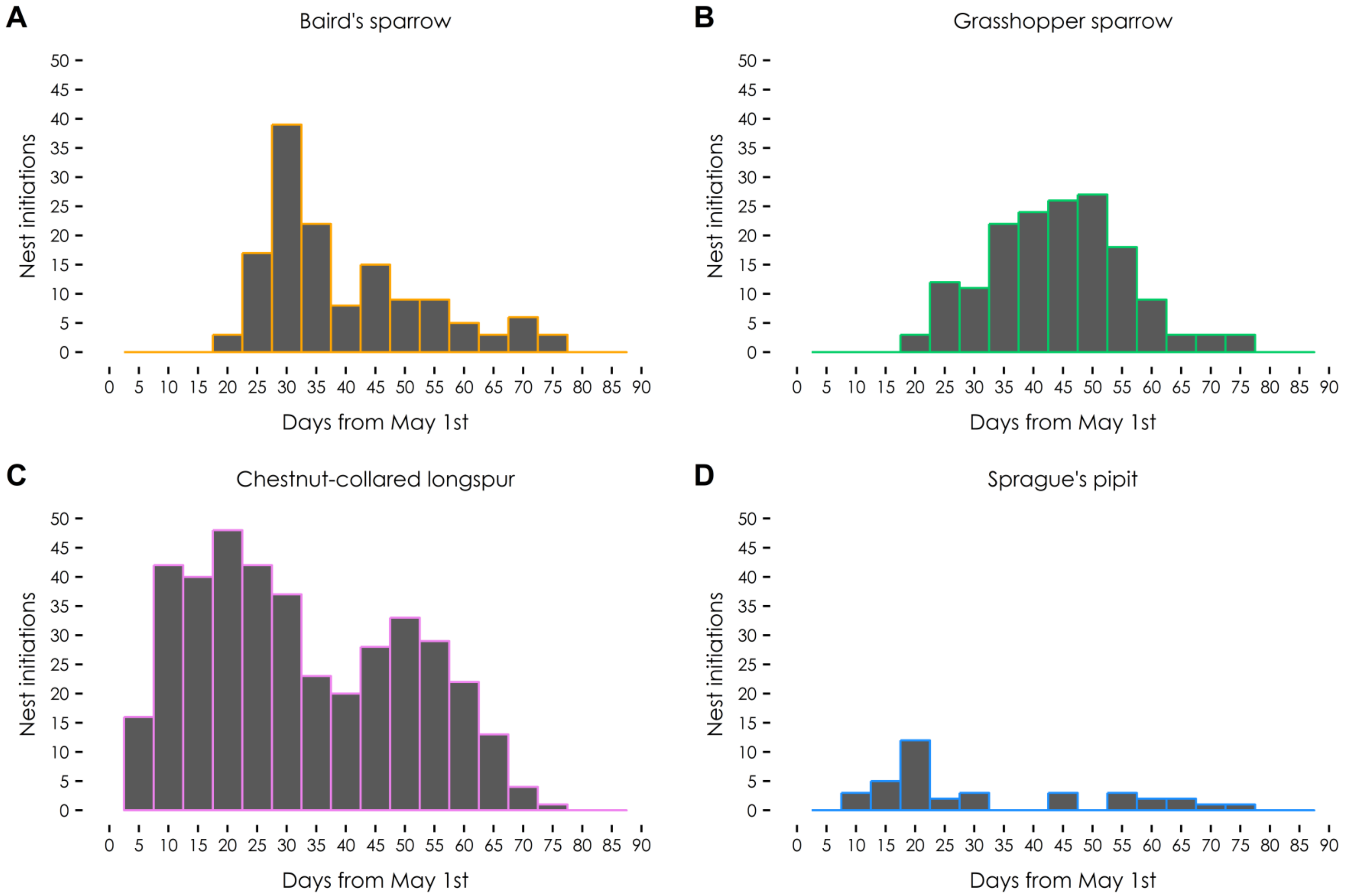

***Figure 16**: Nest initiation dates for **A)** Baird's sparrow, **B)** Grasshopper sparrow, **C)** Chestnut-collared longspur, and **D)** Sprague's pipit breeding in North Dakota and Montana, 2015-2018; initiations are binned by 5 day periods. Frequency of nest initiations is shown on the Y-axis and days from May 1st on the X-axis.*

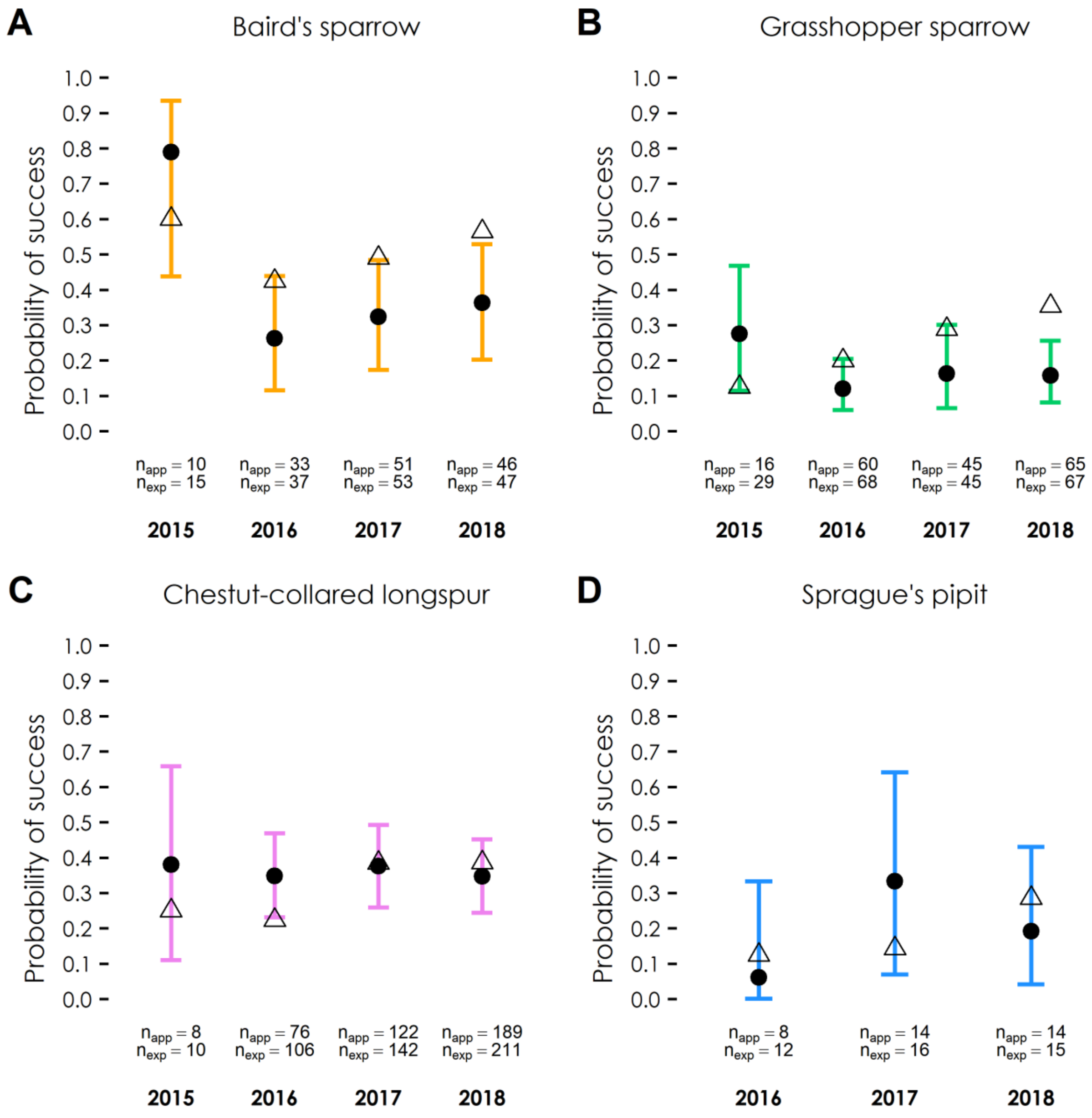

Figure 17: *Nesting success estimates for* ***A)*** *Baird's sparrow,* ***B)*** *Grasshopper sparrow,* ***C)*** *Chestnut-collared longspur, and* ***D)*** *Sprague's pipit in North Dakota and Montana, 2015-2018. Filled circles indicate logistic exposure estimates for the nesting period of each species, shown with 95% confidence intervals. Triangles indicate corresponding annual apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. Probability of nesting success is shown on the Y-axis and year on the X-axis.*

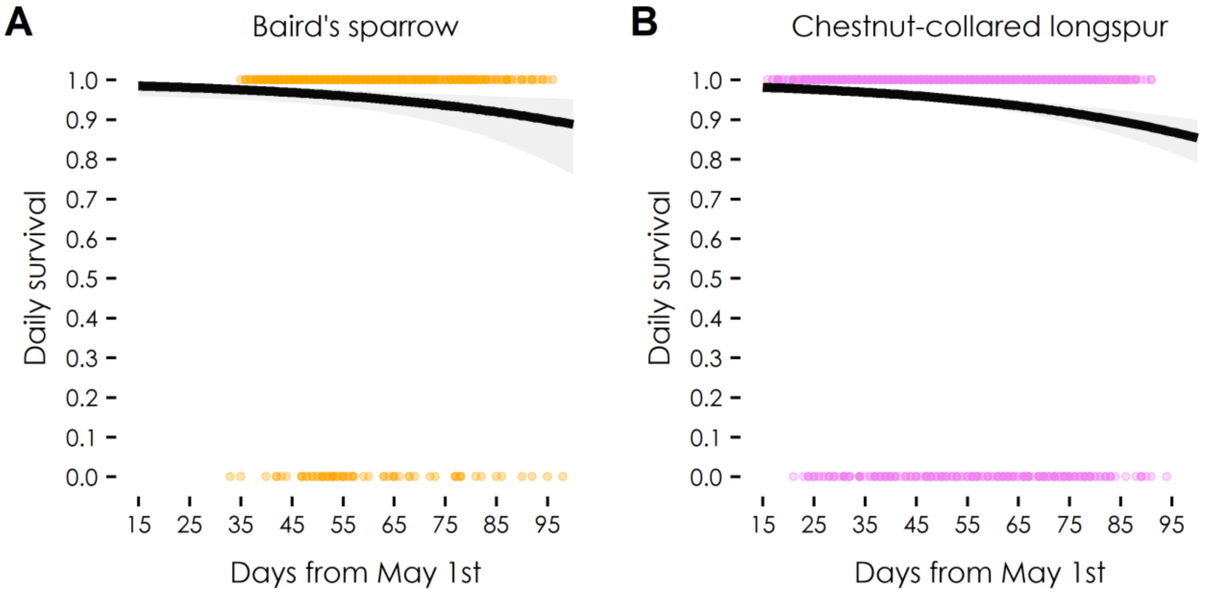

Figure 18: *Effect of date on logistic exposure daily survival rates of nests of* ***A)*** *Baird's sparrow, and* ***B)*** *Chestnut-collared longspur in North Dakota and Montana, 2015-2018. Shading indicates 95% CIs. Colored circles display raw data (1= success, 0= failure). DSR is displayed on the Y-axis, and days from May 1st on the X-axis. Points are transparent for display.*

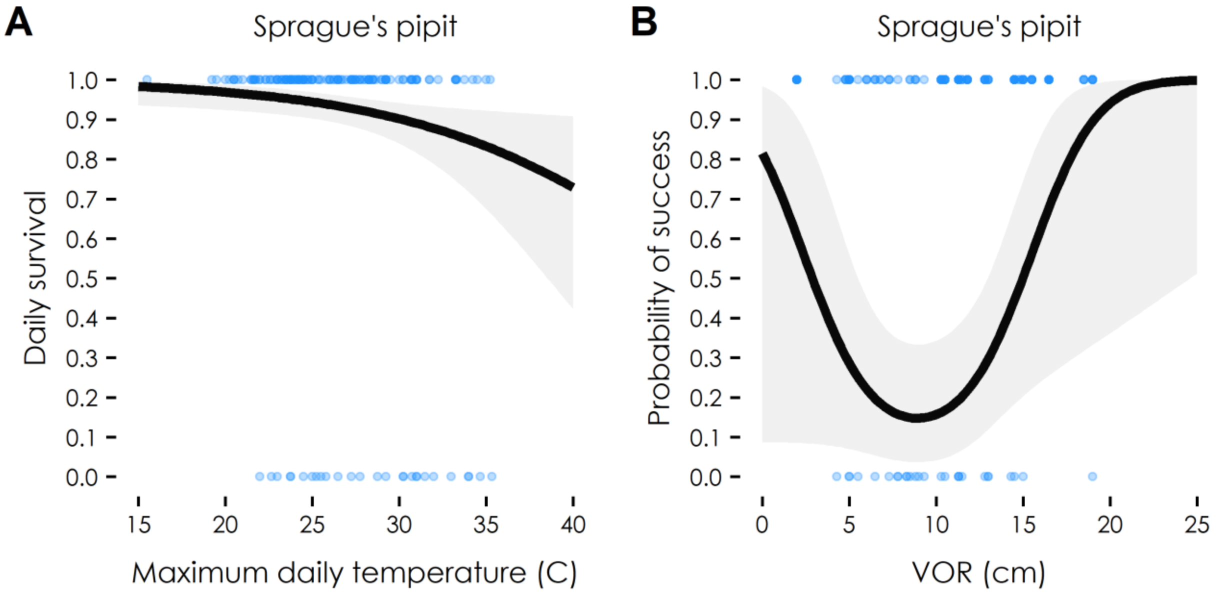

Figure 19*: Results of logistic exposure modelling of nest survival rates in Sprague's pipits breeding in the NGP (2016-2018), including effects of* ***A)*** *Maximum daily temperature and* ***B)*** *Visual obstruction (VOR). Grey shading indicates 95% CIs and colored circles display raw data (1= success, 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 = 31) of Baird's sparrow nesting success in North Dakota and Montana, 2015-2018. The constant survival model was not among top models (ΔAICc = 3.57).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-0.95	-1.82	-0.07	0.85
Precip (interval)	0.54	-0.64	1.73	0.56
Year (ref 2018)	-	-	-	0.52
2015	0.79	-0.91	2.50	-
2016	-0.24	-1.05	0.57	-
2017	-0.17	-1.02	0.67	-
VOR	0.52	-0.82	1.86	0.47
Vegetation height	0.11	-0.51	0.72	0.38
Litter cover	0.11	-0.48	0.70	0.37
Bare ground cover	-0.01	-0.17	0.15	0.29
Forb cover	-0.03	-0.33	0.28	0.29
Site (ref ND)	-0.01	-0.23	0.20	0.29
Stage (ref egg)	0.02	-0.25	0.29	0.28
Dead grass cover	0.00	-0.12	0.13	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 = 17) of grasshopper sparrow nesting success in North Dakota and Montana, 2015-2018. All models were equivalent or inferior to the constant survival model.*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Bare ground cover	-0.28	-0.73	0.16	0.63
Vegetation height	0.18	-0.31	0.67	0.50
Date	-0.05	-0.30	0.22	0.39
Site (ref ND)	-0.04	-0.27	0.20	0.37
Stage (ref egg)	0.02	-0.16	0.20	0.34
VOR	-0.04	-0.30	0.22	0.34
Live grass cover	0.01	-0.10	0.12	0.32
Precip (weekly)	0.02	-0.16	0.19	0.32
Forb cover	0.00	-0.08	0.08	0.29

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 = 18) of chestnut-collared longspur nesting success in North Dakota and Montana, 2015-2018. The constant survival model was not among top models (ΔAICc = 42.6).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Date	-1.28	-1.66	-0.89	1.00
Forb cover	0.37	-0.06	0.79	0.71
Vegetation height	0.25	-0.20	0.70	0.61
Site (ref ND)	0.21	-0.22	0.64	0.58
Stage (ref egg)	-0.21	-0.64	0.22	0.57
Live grass cover	-0.04	-0.27	0.19	0.36
Bare ground cover	0.03	-0.17	0.22	0.33
Precip (weekly)	-0.01	-0.15	0.12	0.31
Litter cover	0.00	-0.07	0.07	0.30

Table 9*: 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 = 7) of Sprague's pipit nesting success in North Dakota and Montana, 2016-2018. The constant survival model was not among top models (ΔAICc = 11.7).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Max daily temp	-1.41	-2.52	-0.30	0.92
VOR	-7.32	-15.04	0.39	0.87
VOR^2	10.49	0.65	20.34	0.87
Precip (interval)	1.19	-0.80	3.17	0.71
Stage (ref egg)	-0.25	-1.23	0.73	0.43
Live grass cover	-0.05	-0.61	0.51	0.28
Dead grass cover	0.04	-0.46	0.55	0.27
Year (ref 2018)	-	-	-	0.22
2016	-0.07	-0.65	0.52	-
2017	0.06	-0.49	0.61	-

Juvenile Survival and Movements

We monitored the post-fledgling survival and movement of juvenile Baird's sparrow and grasshopper sparrow in North Dakota and Montana, 2016-2018. The two species showed similar movement patterns, steadily moving away from the nest, and gradually moving further from the previous day's location with age. However, despite a clear increase in the range of distances moved in older fledglings, fledglings consistently moved <150 m from the previous day's location regardless of their age, even when they were likely capable of substantially longer flight (Figures 20-21). Grasshopper sparrow appeared to develop mobility (or show mobile behavior) slightly earlier than Baird's sparrow; we recorded occasional long lights at 10 days post-fledge for this species, while Baird's sparrow did display this behavior until 13 days post-fledge (Figures 20-21).

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. Secondly, 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 10-11; Figure 22), 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 (Appendix I). Therefore, all results we report are derived from analysis of the full dataset. We also modeled the effects of vegetation variables on survival of each species (Table 12-13; Figure 23), 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.

Logistic exposure cumulative survival estimates and 95% confidence interval ranges were 20% (7-37) for Baird's sparrow and 52% (24-75) for grasshopper sparrow (averaged across sites and years). Apparent survival for the two species averaged 18% and 29% 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 Baird's sparrow appear low relative to similar species, and are below the 40% survival threshold theorized 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 sparrows was best explained by age (ΔAICc = 98.8), 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 10; Figure 22C). Grasshopper sparrows exhibited a similar trend (Table 11; Figure 23D; ΔAICc = 43.7), 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 in both species at our sites (Tables 12-13). However, vegetation height explained some additional variation in juvenile Baird's sparrow survival, with survival increasing with greater height (Table12; Figure 23A). This suggests that cover and concealment may also play a role in survival, and that grazing practices and management could potentially influence survival rates to some extent. In grasshopper sparrow, juvenile survival declined with increasing dead grass cover (Table 13; Figure 23B). 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.

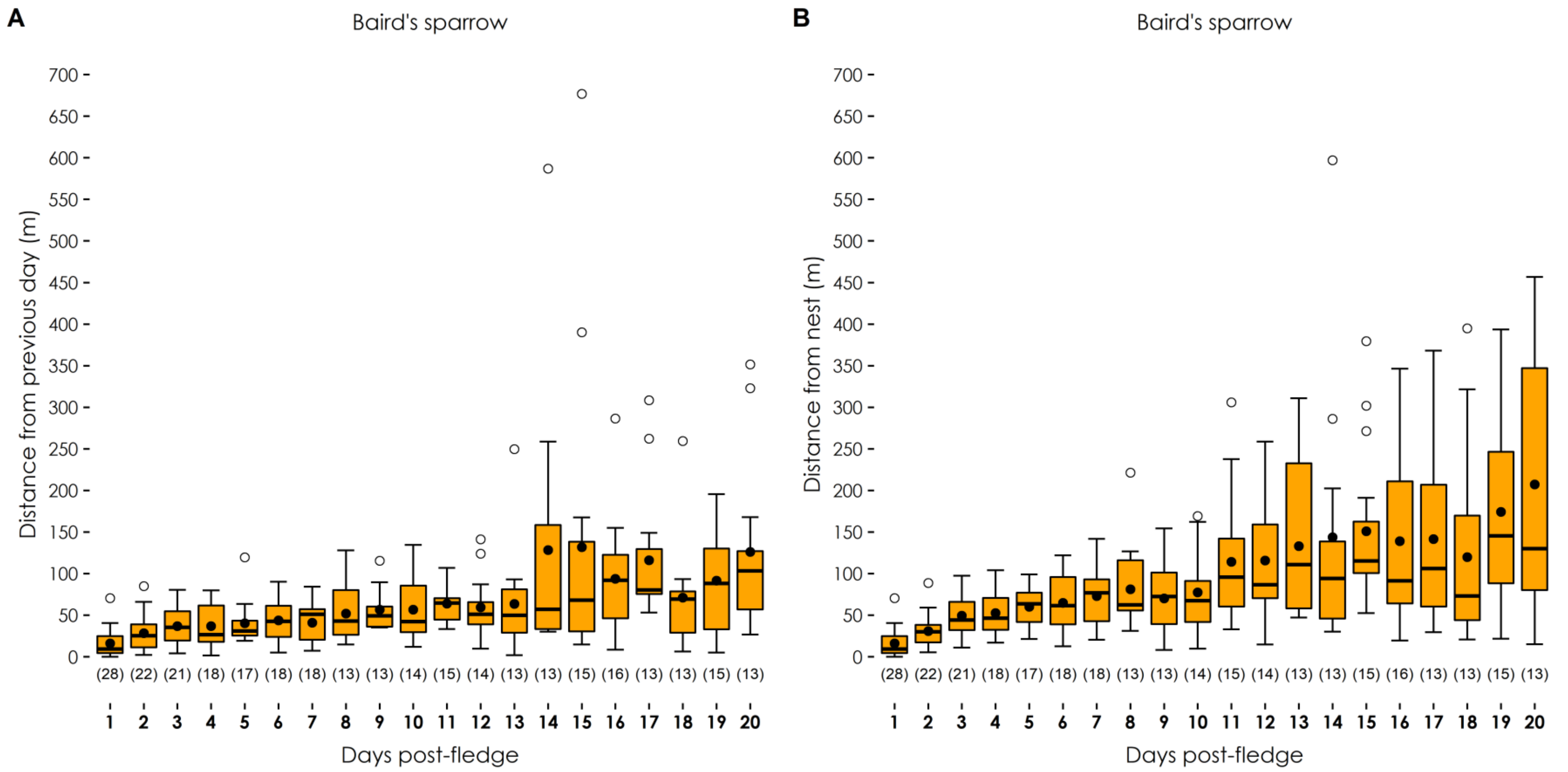

***Figure 20**: **A)** Mean distance traveled from previous location by age, and **B)** Mean cumulative distance traveled from nest by age for juvenile Baird's sparrow in North Dakota and Montana, 2016-2018. Bold lines indicates median, filled circles indicate mean, and top and bottom hinges display first and third quartiles (25th and 75th percentiles); whiskers extend from quartiles to smallest/largest value that does not exceed 1.5*IQR; open circles indicate outliers beyond this value. Distance in meters is shown on the Y-axis, and age in days post-fledge on the X-axis, with sample sizes given in parentheses.*

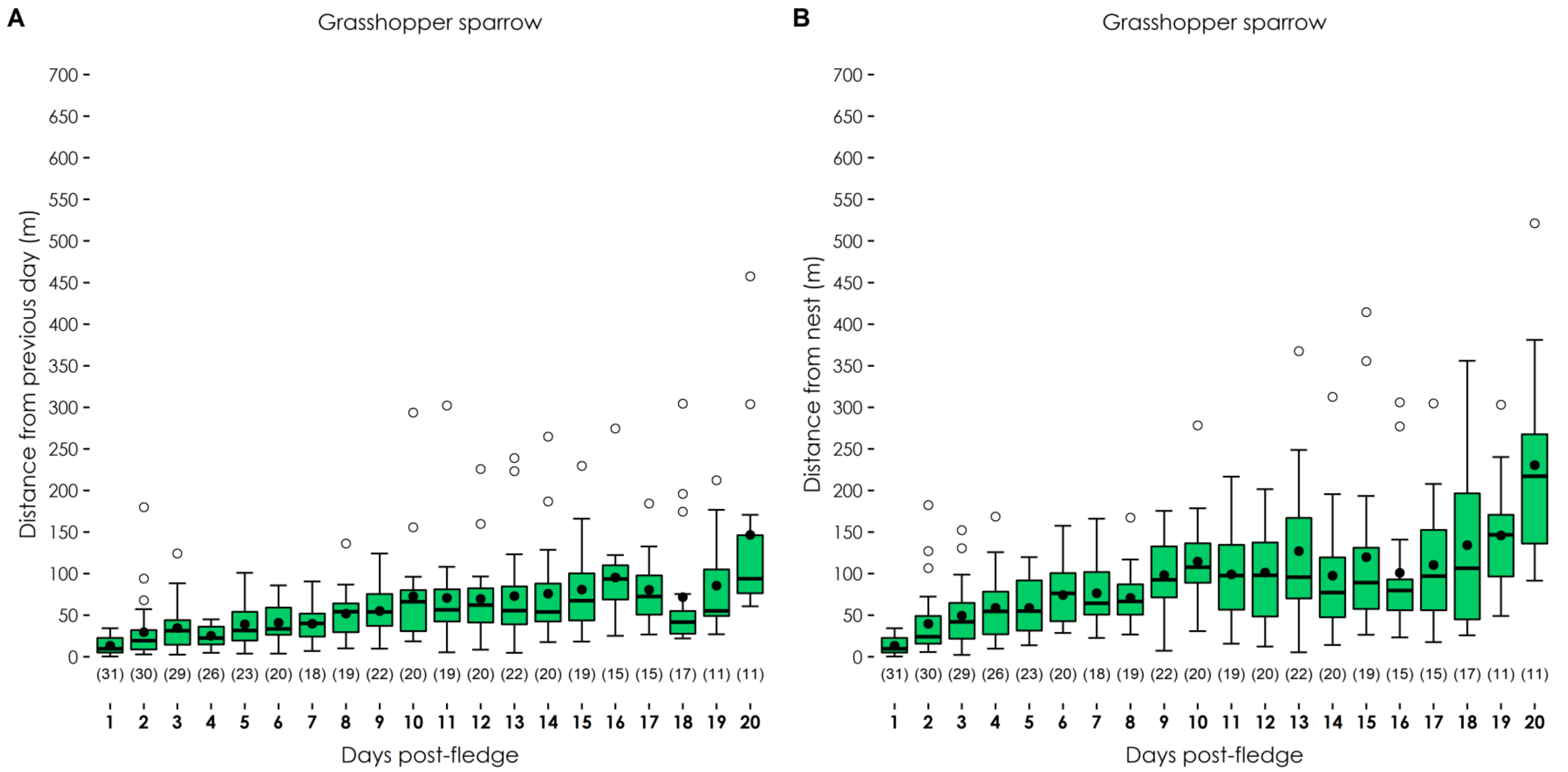

***Figure 21**: **A)** Mean distance traveled from previous location by age, and **B)** Mean cumulative distance traveled from nest by age for juvenile grasshopper sparrow in North Dakota and Montana, 2016-2018. Bold lines indicates median, filled circles indicate mean, and top and bottom hinges display first and third quartiles (25th and 75th percentiles); whiskers extend from quartiles to smallest/largest value that does not exceed 1.5*IQR, open circles indicate outliers beyond this value. Distance in meters is shown on the Y-axis, and age in days post-fledge on the X-axis, with sample sizes given in parentheses.*

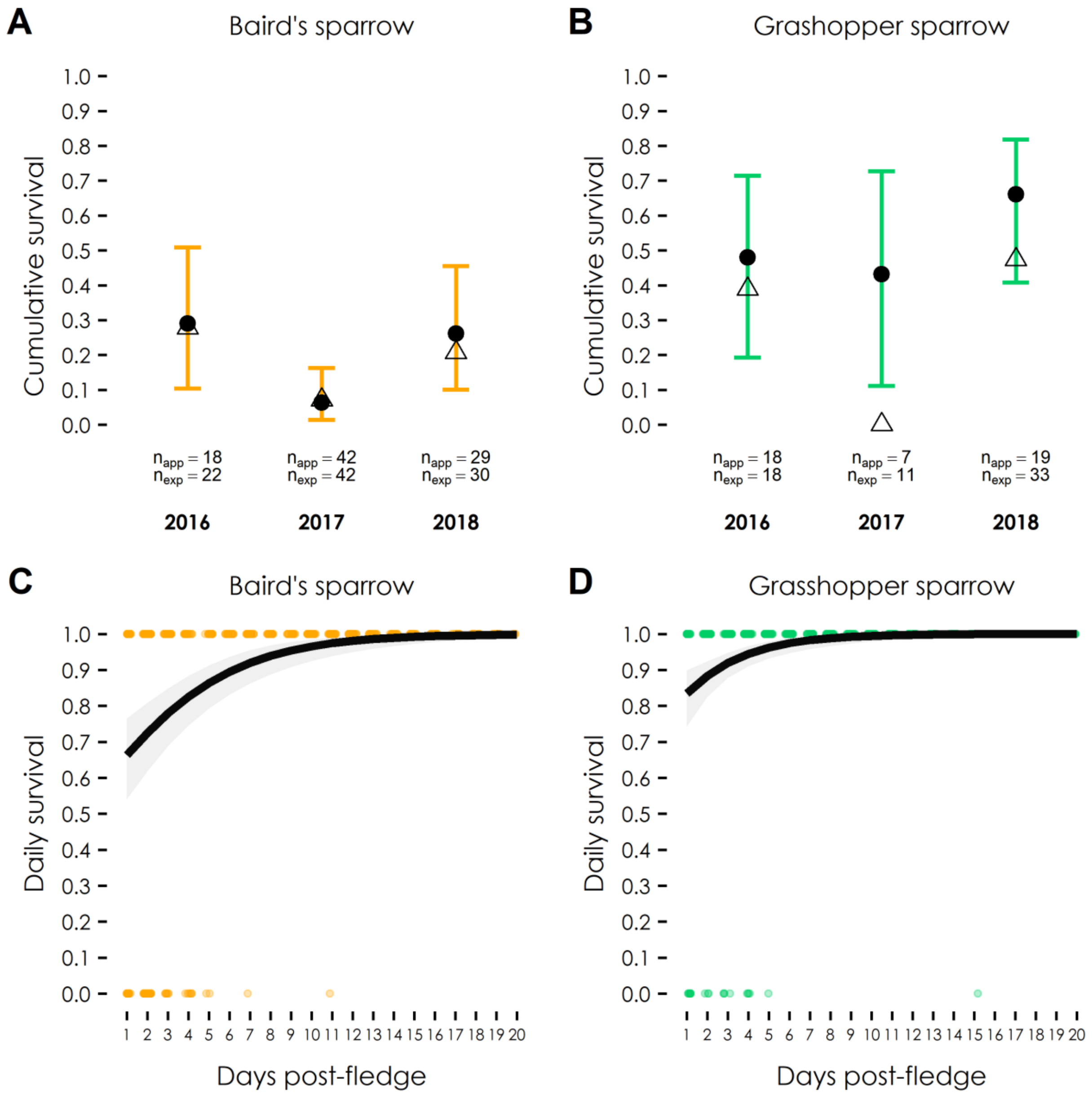

Figure 22: *Annual juvenile survival estimates for* ***A)*** *Baird's sparrow and* ***B)*** *Grasshopper sparrow in North Dakota and Montana, 2016-2018. Filled circles indicate logistic exposure estimates for a 20-day survival period, shown with 95% confidence intervals. Triangles indicate corresponding annual apparent survival estimates. Individual sample sizes for the two estimate types are given above each year. Probability of survival 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.*

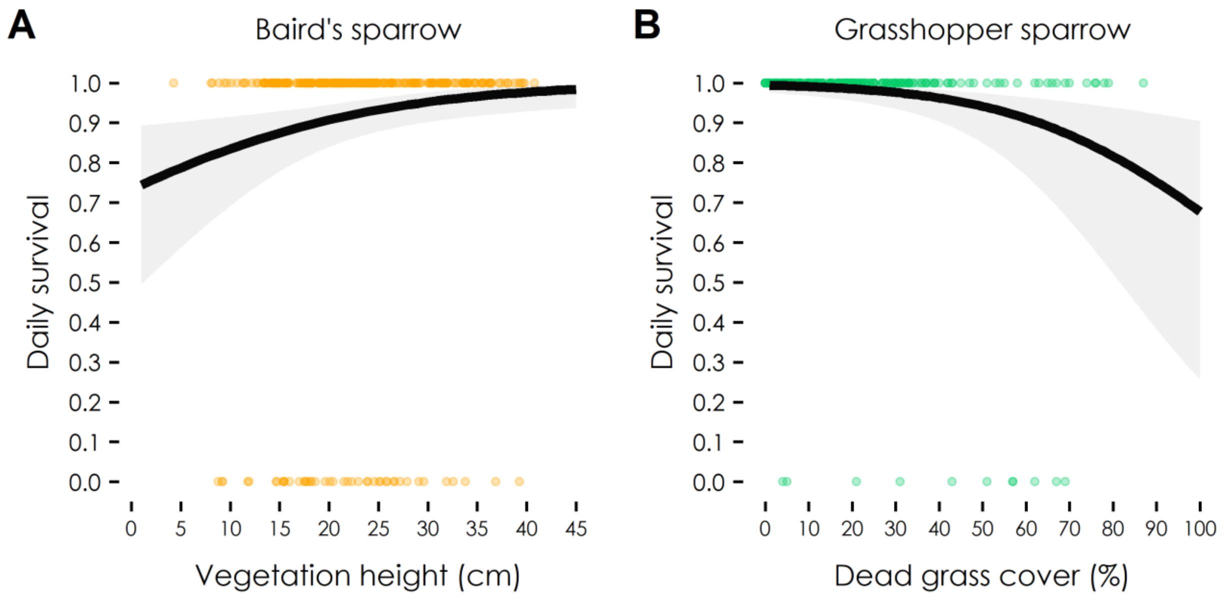

Figure 23: *Daily survival of juvenile grassland birds in response to vegetation variables in North Dakota and Montana, 2016-2018. Shading indicates 95% confidence intervals. Colored circles display raw data (1 = success, 0 = failure). Points are jittered and transparent for display purposes.* ***A)*** *Effects of vegetation height on juvenile Baird's sparrow DSR, and* ***B)*** *Effects of dead grass cover on juvenile grasshopper sparrow DSR.*

***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 = 3) of Baird's sparrow juvenile survival in North Dakota and Montana, 2016-2018. The constant survival model was not among top models (ΔAICc = 98.8).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	6.20	4.16	8.24	1.00
Year (ref 2018)	-	-	-	0.82
2016	0.10	-0.92	1.13	-
2017	-1.08	-1.95	-0.21	-
Precip (daily)	-0.12	-0.78	0.53	0.36
Min daily temp	0.05	-0.37	0.48	0.33

***Table 11**: 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 = 6) of grasshopper sparrow juvenile survival in North Dakota and Montana, 2016-2018. The constant survival model was not among top models (ΔAICc = 43.7).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	12.10	6.48	17.73	1.00
Precip (weekly)	1.40	-1.34	4.13	0.61
Year (ref 2018)	-	-	-	0.38
2016	-0.39	-2.05	1.28	-
2017	-0.38	-1.87	1.11	-
Min daily temp	-0.08	-0.88	0.71	0.31
Precip (daily)	-0.03	-0.74	0.69	0.27

***Table 12**: 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 = 9) of Baird's sparrow juvenile survival in North Dakota and Montana, 2017-2018. The constant survival model was not among top models (ΔAICc = 62.4).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	4.45	2.29	6.61	1.00
Vegetation height	1.69	0.46	2.91	0.93
Year (ref 2018)	-1.25	-2.66	0.15	0.78
Exotic cover	-0.97	-2.10	0.15	0.72
Live grass	-0.44	-1.72	0.84	0.46
Average daily temp	0.25	-0.73	1.24	0.44
Precip (weekly)	0.04	-0.42	0.49	0.34
Litter cover	-0.08	-0.64	0.49	0.31

***Table 13**: 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 = 11) of grasshopper sparrow juvenile survival in North Dakota and Montana, 2017-2018. The constant survival model was not among top models (ΔAICc = 20.7).*

Variable	Beta	Lower 95% CI	Upper 95% CI	Variable Weight
Age	8.48	1.55	15.41	0.96
Dead grass cover	-4.76	-7.73	-1.80	0.85
Litter cover	0.73	-2.48	3.95	0.44
Vegetation height	-6.34	-33.50	20.81	0.43
Vegetation height^2	6.87	-23.50	37.24	0.43
Grass cover	-0.19	-2.22	1.84	0.38
Year (ref 2018)	-0.07	-1.23	1.09	0.37
Precip (interval)	-0.16	-1.50	1.18	0.34
Max daily temp	3.71	-18.20	25.63	0.33
Max daily temp^2	-3.71	-25.60	18.18	0.33
Exotic cover	0.05	-0.94	1.05	0.33

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 sparrow 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 24). 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 sparrow 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.

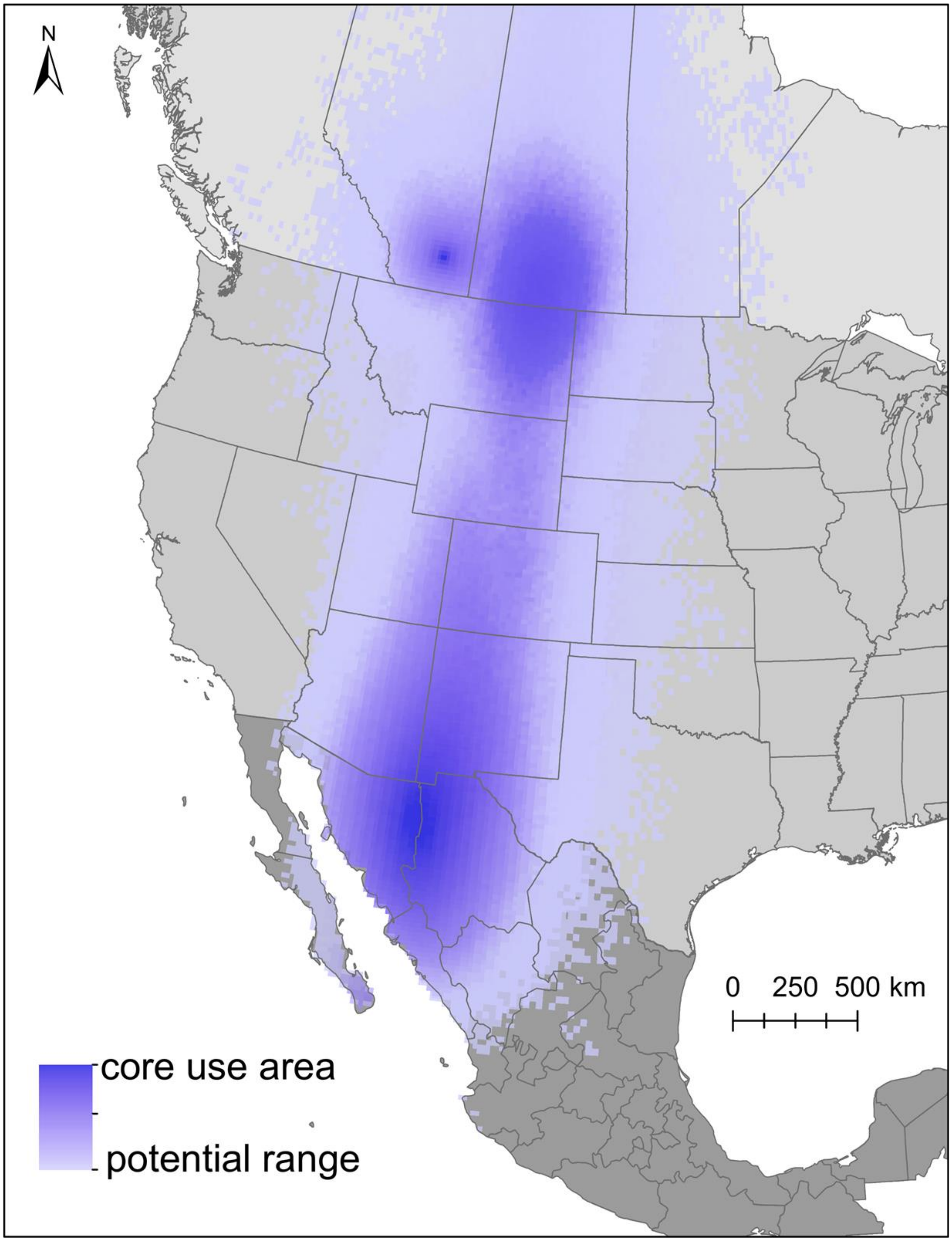

***Figure 24**: Coarse migratory route of a male Baird's sparrow captured and fitted with a light-level geolocator in Alberta, Canada.*

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.

In 2017, we used several DJI Phantom 4 Pro quad-copter drones to collect data once at the beginning of the field season in June and once at the end of the field season in August. With these data, we created DSMs (Figure 12) and calculated NDVI at our study sites in both North Dakota and Montana. We processed all collected imagery in Pix4D potogrammetry software to produce raster imagery. In 2018, we collected data using an eBee Plus fixed-wing drone. The fixed-wing drone is more adept to the windy conditions in the NGP and collects data more time-efficiently than the quadcopter drone. The efficiency of the fixed-wing drone allowed for additional data collection to measure change in NDVI at our study sites across the breeding season (Figure 25). We collected data at least three times per each study site (approximately every thirty days) from mid-May through early August. We produced rasters in 2018 that are comparable to those produced in 2017. 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.

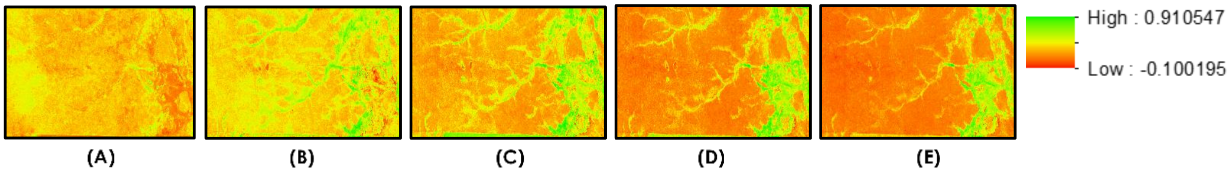

Figure 25: *Maps of the Normalized Vegetation Difference Index (NDVI) collected at a study site in Montana over the course of the 2018 breeding season. These maps demonstrate the change in vegetative productivity over the span of four months:* ***(A)*** *May 16th,* ***(B)*** *June 13th,* ***(C)*** *July 8th,* ***(D)*** *July 23rd, and* ***(E)*** *August 2nd.*

Future directions

Development of an IPM for the Baird's sparrow

We are in the beginning stages 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. 2011) 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 26). 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 a summit of the thought leaders for grassland bird conservation in the Great Plains, a gathering tentatively scheduled for mid-year 2020.

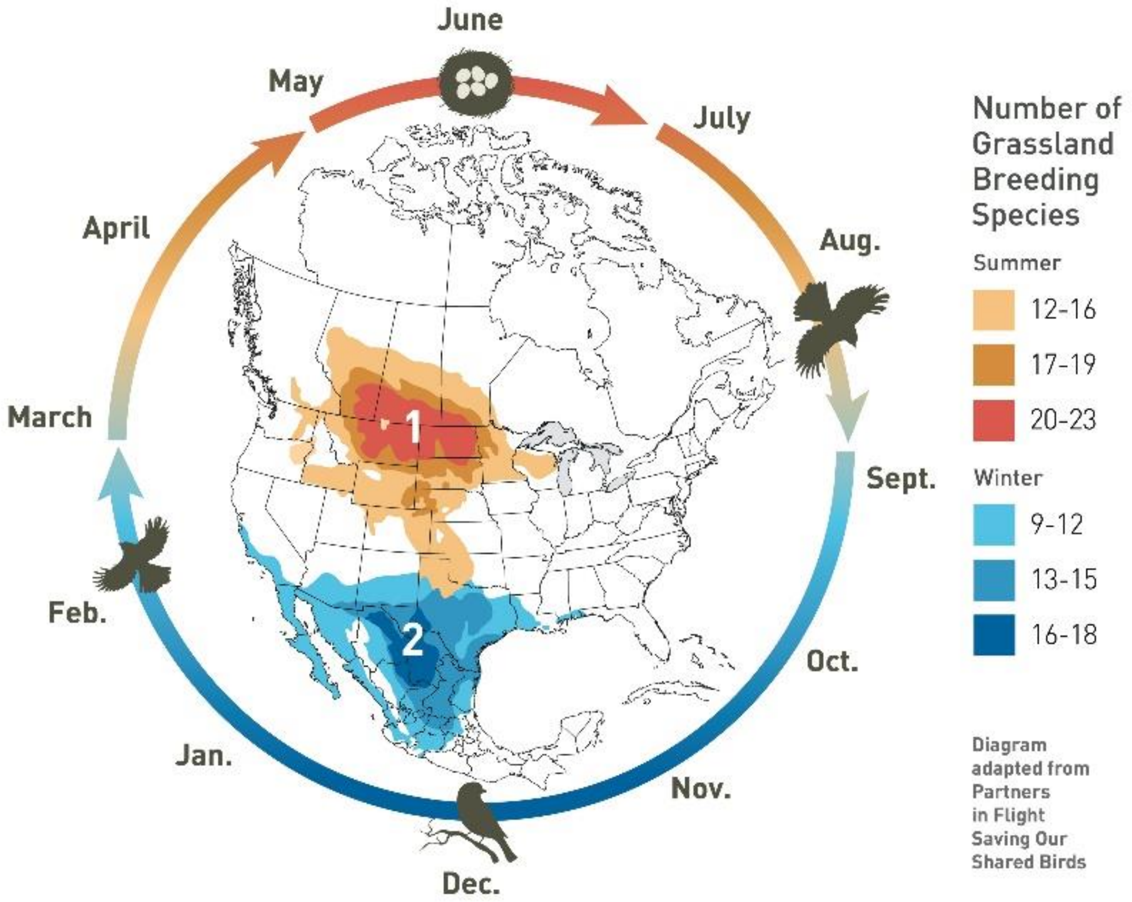

***Figure 26**: Visualization of the FAC monitoring approach, depicting the connection between grassland habitat on the breeding grounds in the NGP **(1)**, and wintering grounds in the southwestern United States and Mexico **(2)**.*

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***Appendix I**: Comparison of environmental parameter estimates derived from full data sets (colored) and data subsets including only one individual from each nest (grey)for logistic exposure juvenile survival of **A)** Baird's sparrow, and **B)** Grasshopper sparrow, in North Dakota and Montana, 2016-2018.*