

**A Comparison of Acoustic and Point Count Monitoring with Respect to
Historical Records to Determine Avian Migration Phenology in the
Great Plains**



A cooperative research project between the Desert Southwest Cooperative Ecosystem Studies
Unit, the National Park Service, and Rocky Mountain Bird Observatory

May 2015



ROCKY MOUNTAIN BIRD OBSERVATORY

Mission: *To conserve birds and their habitats*

Vision: *Native bird populations are sustained in healthy ecosystems*

Core Values: *(Our goals for achieving our mission)*

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2. **Education** is critical to the success of bird conservation.
3. **Stewardship** of birds and their habitats is a shared responsibility.

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Executive Summary

In 2011, the Desert Southwest Cooperative Ecosystem Studies Unit, the National Park Service, and Rocky Mountain Bird Observatory initiated a project comparing acoustic and point count monitoring techniques to investigate the migration phenology of grassland birds. A goal of the project was to determine if climate change was responsible for declines in grassland bird species by causing a mismatch in spring arrival dates and food availability. Another goal of the study was to measure the effectiveness of automated recording units for surveying birds. Automated recording units were deployed at four study sites (Badlands and Wind Cave National Parks in South Dakota and Lake Meredith National Recreation Area and Rita Blanca National Grassland in Texas) and point count surveys were conducted at the same locations to compare the two methodologies during 2011 and 2012 field seasons. We used 15 years of eBird data to investigate temporal and spatial trends in the arrival dates of the grasshopper sparrow in the Great Plains. We discovered that the detection rates of acoustic monitoring units and point counts were similar for the long-billed curlew, Cassin's sparrow, grasshopper sparrow and brown-headed cowbird. In contrast, the detection rates for the acoustic method were lower than the point count method for the vesper sparrow, lark sparrow and lark bunting. Acoustic monitoring performed equal to point count methods for estimating the arrival dates of the grasshopper sparrow, lark sparrow and lark bunting. Conversely, acoustic monitoring detected arrival on the breeding grounds before the territorial establishment of the long-billed curlew, Cassin's sparrow and brown-headed cowbird. Interestingly, acoustic monitoring detected arrival on the breeding ground after territorial establishment of the vesper sparrow. Our results suggested that the grasshopper sparrow may be able to alter migration timing to match early onset of spring conditions. Because this species demonstrated flexibility in migration timing, climate change and associated changes to the timing of resource availability may not be a large contributor to ongoing population declines of this species.

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Introduction

The grassland ecosystem in North America has been altered significantly by human activities since settlement. At least 97% of native prairies have vanished, mostly due to conversion to agriculture (US NABCI Committee 2011). Grassland bird species have suffered considerable population declines because of the loss of habitat and currently 48% of the North American grassland-breeding bird species are listed as species of conservation concern (Berlanga et al. 2010, US NABCI Committee 2011). Very little research has been conducted on the effects of climate change on grassland birds, but this is a threat to their continued survival (US NABCI Committee 2010). The State of the Birds Report released in 2010 states that 57% of all grassland birds show “medium vulnerability” to the effects of climate change (US NABCI Committee 2010). The classic example of how disparities in migration timing and prey availability displayed by the European Pied Flycatcher well illustrates how climate change can cause population declines (Both and Visser 2001). Understanding the timing of migration with respect to prey availability may be important for the conservation of North American grassland birds and, therefore warrants further research.

In 2011, we initiated a collaborative project between the National Parks Service and Rocky Mountain Bird Observatory to investigate the migratory arrival dates for grassland birds of conservation concern. We used acoustic monitoring to estimate spring arrival dates and population monitoring to determine territory occupancy through time for seven species of grassland in southern and northern study areas during 2011 and 2012. The objectives of the project were to 1) estimate the spring arrival dates for migratory grassland birds of conservation concern, 2) compare detection and occupancy rates for acoustic and point count monitoring and 3) compare the arrival times to historical records and population declines for the grasshopper sparrow. We compared acoustic arrival data and territory occupancy from point count data to evaluate the effectiveness of acoustic monitoring for estimating spring arrival times. We used eBird data (Sullivan et al. 2009) to discover discrepancies between modern and historical arrival dates for the grasshopper sparrow (*Ammodramus savannarum*), and we used population trends from the Breeding Bird Survey (BBS) (Robbins et al. 1986) to evaluate potential relationships between climate change and population declines for this species. We compared acoustic monitoring arrival dates to eBird arrival dates for the grasshopper sparrow to evaluate the performance of eBird for estimating arrival dates of grassland birds. A better understanding of how migration phenology and climate change may influence population declines of grassland birds will help inform conservation actions for species recovery.

Study Area

Arrival dates

To estimate the arrival times of grassland birds, we selected two study areas in South Dakota, Badlands and Wind Cave National Parks, and two study areas in Texas, Lake Meredith National Recreation Area and Rita Blanca National Grasslands (Fig. 1). The South Dakota study sites are located in the Badlands and Prairies Bird Conservation Region (BCR 17) and the Texas study sites are in the Shortgrass Prairie Bird Conservation Region (BCR 18) (US NABCI Committee 2000b;a) (Fig. 2). The vegetation at Badlands and Wind Cave National Park is mixed-grass prairie, but survey locations at Wind Cave were often located near stands of

ponderosa pine (*Pinus ponderosa*). The latitude of the South Dakota study sites is 44° (Fig. 2), with an elevation of ~870 m and annual precipitation of 44 cm for Badlands National Park, and an elevation of ~1,300 m and annual precipitation of 50 cm for Wind Cave National Park. The vegetation at Rita Blanca National Grassland was exclusively shortgrass prairie and Lake Meredith National Recreation Area is shortgrass prairie with juniper (*Juniperus monosperma*) and mesquite (*Prosopis glandulosa*). Some of the survey locations at Lake Meredith National Recreation Area were located near eastern cottonwood (*Populus deltoides*) galleries. The latitude of the Texas study sites is 36° (Fig. 2), with an elevation of ~1,250 m and annual precipitation of 40 cm for Rita Blanca National Grassland, and an elevation of ~900 m and annual precipitation of 59 cm for Lake Meredith National Recreation Area.

Historical records

The study area to compare the arrival times to historical records for the grasshopper sparrow, included the Prairie Potholes (BCR 11), Badlands and Prairies (BCR 17), Shortgrass Prairie (BCR 18) and Central Mixed-grass Prairie (BCR 19) Bird Conservation Regions (US NABCI Committee 2000b;a) (Fig. 2). The four BCRs represented the Great Plains and Central Flyway, which corresponded to the hypothesized migratory pathways for grassland birds. To evaluate changes in migration timing with respect to regional population declines of the grasshopper sparrow, we used BBS trend data from the Central Region, which extended from the Mississippi River to the edge of the Rocky Mountains (Sauer et al. 2014).

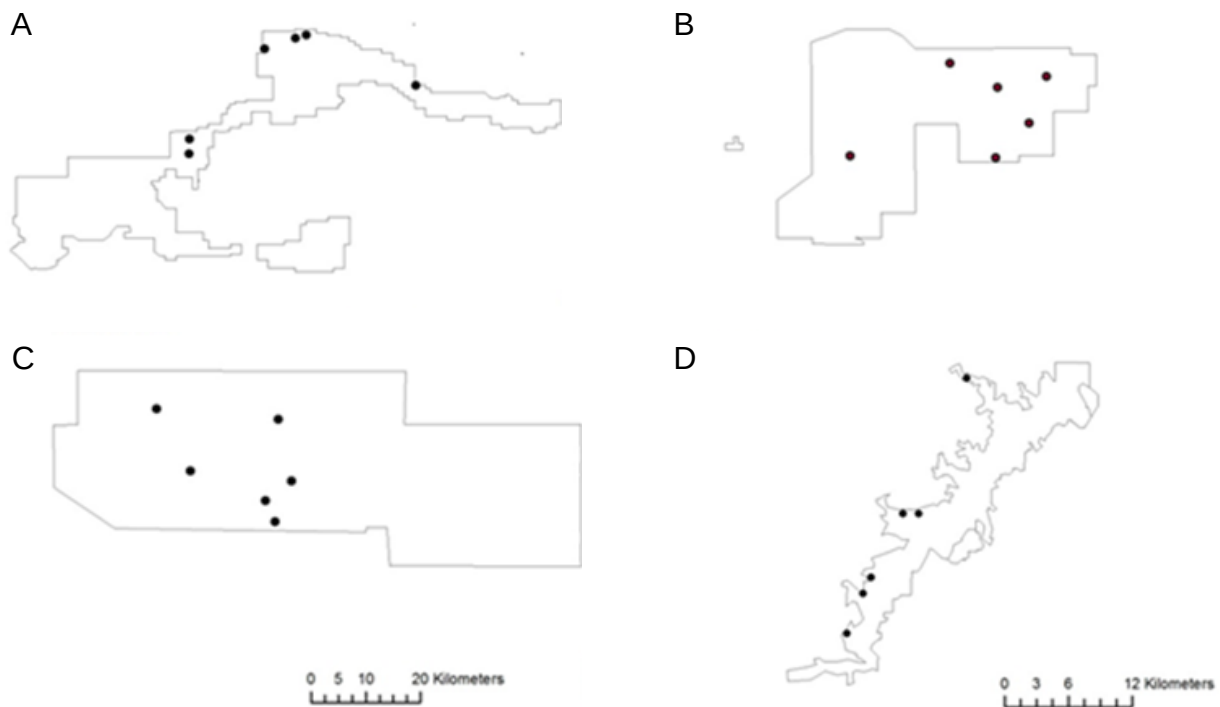


Figure 1. The A) Badlands, B) Wind Cave, C) Rita Blanca and D) Lake Meredith study areas and the location of the selected sampling grids in South Dakota, Texas, and Oklahoma, 2011-2012.

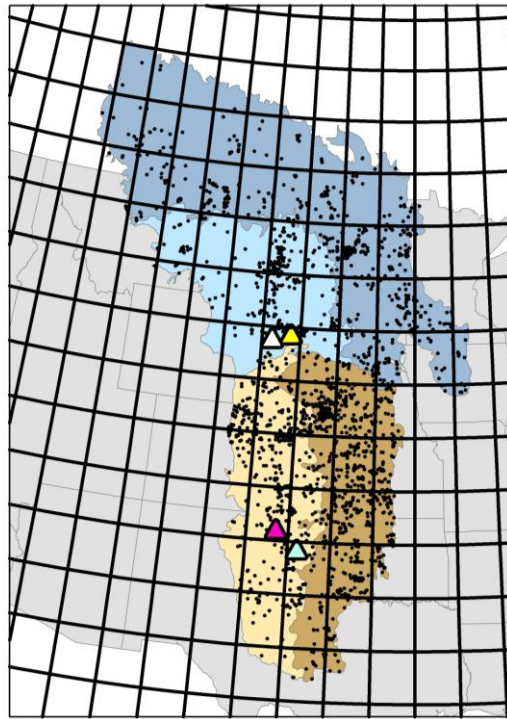


Figure 2. The Great Plains study area showing the Bird Conservation Regions (BCR), 2° latitude-longitude grid, and the Grasshopper Sparrow eBird locations in small black symbols. The Prairie Potholes BCR (11) is shown in dark blue, Badlands and Prairies BCR (17) in light blue, and Shortgrass Prairie BCR (18) in light brown and Central Mixed-grass Prairie BCR (19) in dark brown. The Badlands study site is depicted by the white triangle, Wind Cave by the yellow triangle, Rita Blanca by the maroon triangle and Lake Meredith by the light blue triangle.

Methods

Sampling design

Arrival dates.—To estimate the arrival times of grassland birds, we constructed the sampling frame for the study by superimposing a 750 m x 750 m grid over the study areas within a Geographic Information System (ArcGIS Version 10.0, Environmental Systems Research Institute, Redlands, CA). At Badlands National Park, only lands in the north management unit of the park were available for selection because of access issues and to minimize travel time between survey sites. During initial visits, we deemed some available survey sites inaccessible because access roads crossed private lands and we selected back-up survey sites in these cases. This occurred exclusively at the Texas study sites where many of the federal lands are only accessible via roads through private lands. The sampling unit for the study was the 750 m x 750 m (0.56 km²) grid cell. Within each 750 m x 750 m grid cell, we positioned nine, evenly-spaced sample points 250 m apart and 125 m from the edge of the grid. The circular point count plots (4.9 ha) had a radius of 125 m and were centered on the point count locations. We used a spatially balanced sample design (Stevens and Olsen 2004) to randomly select 6 grid cells from the four study areas (Fig. 1).

Historical records.—To compare the arrival times to historical records for the grasshopper sparrow, we superimposed a 2° latitude-longitude grid over the Great Plains study region (Fig. 2).

Data collection

ARU surveys.—To monitor the arrival dates of birds, we deployed Acoustic Monitoring Units (ARU) at the center point of each survey grid. If the center point was located in a depression on the landscape, the recording station was placed above the surrounding terrain where recording quality would be improved. To record bird vocalizations, we used a Song Meter terrestrial recording system (SM2+, Wildlife Acoustics Inc., Concord, MA) mounted on a tripod. In 2011, we used a vertical nocturnal flight call microphone (SMX-NFC) and in 2012 we used a horizontal microphone (SMX-II) for each ARU.

In Texas and Oklahoma, we collected six weekly samples of ARU recordings between 10 April and 23 May 2011, and five weekly samples between 28 March and 16 May 2012. In South Dakota, we collected six weekly samples of ARU recordings between 30 March and 8 June 2011, and eight weekly samples between 10 April and 5 June 2012. We randomly selected the recording dates for each week during the time frame of the point count surveys. Overall, we collected 300 ARU samples over the course of the study with 40 for Badlands in 2011, 54 for Badlands in 2012, 36 for Lake Meredith in 2011, 31 for Lake Meredith in 2012, 37 for Rita Blanca in 2011, 26 for Rita Blanca in 2012, 29 for Wind Cave in 2011 and 47 for Wind Cave in 2012.

We programmed the ARUs to record eight 2-min time intervals beginning 0.5 hr before sunrise. An experienced ornithologist (J. Beason) used Raven Pro software (Raven Pro Versions 1.3 & 1.4, <http://www.birds.cornell.edu/brp/raven/RavenVersions.html>, accessed 1 July 2012) to identify and document bird detections for the 2-min time intervals of the weekly recordings.

Bird surveys.—Field technicians conducted point counts (Buckland 2006) following the Integrated Monitoring in Bird Conservation Regions protocols (Hanni et al. 2013). Observers conducted surveys in the morning, beginning 0.5 hr before sunrise and concluding no later than five hr after sunrise. For every bird detected during the 6-min period, observers recorded species, sex; radial distance from the observer; minute, type of detection (e.g., call, song, visual), whether the bird was thought to be a migrant, and whether or not the observer was able to visually identify each record. We truncated the data, using only detections <126 m of the sample points. Truncating the data at 125 m allowed us to use bird detections over a consistent plot size and ensured that the points were independent (points were spaced 250 m apart). Using the six 1-min intervals recorded during sampling, we binned min 1 and 2, min 3 and 4, and min 5 and 6, resulting in three 2-min time intervals.

In Texas and Oklahoma, we conducted two bi-weekly surveys of the 9-point grid between 13 April and 23 May 2011, and three bi-weekly surveys of the 9-point grid between 25 March and 16 May 2012. In South Dakota, we conducted five bi-weekly surveys of the 9-point grid between 30 March and 8 June 2011, and four bi-weekly surveys of the 9-point grid between 10 April and 5 June 2012. Overall, we surveyed 161 grids and 1,273 point count locations over the course of the study with 29 grids and 210 points in Badlands during 2011, 27 grids and 214 points in Badlands during 2012, ten grids and 63 points in Lake Meredith during 2011, 17 grids and 150 points in Lake Meredith during 2012, ten grids and 65 points in Rita Blanca during

2011, 15 grids and 129 points in Rita Blanca during 2012, 27 grids and 228 points in Wind Cave during 2011 and 26 grids and 214 points in Wind Cave during 2012.

eBird surveys.—We summarized 15 years of eBird data (1999-2013) for the study area, resulting in sample size of 30 2° grid cells per year and a mean of 27 eBird records of the grasshopper sparrow for each 2° grid cell. We used the earliest record of the grasshopper sparrow for each 2° latitude-longitude grid and year to estimate the arrival time for each grid cell.

Statistical analyses

Arrival dates.—The sampling situation for the ARU survey method included song-meter recordings at eight two-min time occasions. Consider an example encounter history for the ARU method $H_{\text{ARU}} = 10100010$. In this example, the species was detected at time occasions 1, 3 and 7, and was not detected at time occasions 2, 4, 5, 6 and 8. The sampling situation for the point count survey method followed a removal design for three two-min intervals of the point count. According to the removal design, we set all subsequent time occasions at a point to “missing data” after the target species was detected at a time occasion (MacKenzie et al. 2006). Consider an example encounter history for the point count method $H_{\text{PT}} = 001.....$. In this example, the species was detected at time occasion 3, and was not detected at time occasions 1 and 2. The subsequent five time intervals were considered missing data to make the point count encounter history compatible with the ARU encounter history. The model appropriately accommodated missing observations by omitting the missing time occasions from the likelihood of the model (MacKenzie et al. 2006).

We estimated the detection and occupancy rates for the bird species using the single season occupancy model (MacKenzie et al. 2002). We used the implicit dynamics formulation of the single season occupancy model (MacKenzie et al. 2006) to estimate the daily trend in occupancy during the migratory season. The occupancy rates for the ARU stations corresponded to daily occupancy rate at the center point of each grid. The occupancy rates for the point counts corresponded to the fraction of nine points in each grid that were occupied each day. When no detections occurred at a Site, we fixed the parameter for that site to zero. The parameters of the model were the probability of detection p_i for point i and the probability of occupancy ψ_i for point i . We fitted the models in tandem with package RMark (RMark Version 2.1.7, <http://cran.r-project.org/mirrors.html>, accessed 18 Mar 2014), program R (R Version 3.0.2, <http://cran.r-project.org/bin/windows/base/>, accessed 10 Jan 2014) and program MARK (MARK Version 6.1, <http://www.phidot.org/software/mark/downloads/>, accessed 25 Nov 2013).

We considered five covariates for the probability of detection, including categorical group covariates for survey method (Method), State (State), study site (Site) and year (Year), as well as a continuous covariate for ordinal date (Date). Method was a group covariate with two levels for ARU and point count methods. State was a group covariate with two levels for Texas and South Dakota that corresponded to the southern and northern study areas. Study site was a group covariate with four levels for the Lake Meredith, Rita Blanca, Badlands and Wind Cave study sites. For species with < 10 detections in a level, we pooled the Lake Meredith and Rita Blanca, or Badlands and Wind Cave study sites, resulting in a study site covariate with three levels. Year was a group covariate with two levels for 2011 and 2012. Ordinal date was a continuous covariate starting at day 1, which corresponded to the earliest survey date on 26 March 2012. We considered the same four covariates for the probability of occupancy, but used a nonlinear transformation for the functional form ordinal date covariate [$\log_e(\text{ordinal date})$].

For the detection parameter we considered all-subsets of two-covariate models, an intercept only model and a $p(\text{Method} \times \text{Year})$ model for a total of 16 detection models. We hypothesized that detection rates may have varied by Date, Site, State, Method and or Year. The $p(\text{Method} \times \text{Year})$ model evaluated the hypothesis that detection rates were different for ARUs in 2011 than ARUs in 2012 due to a change from vertical to horizontal microphones in 2012. For the occupancy parameter we considered eight main effects models and eight interaction models for the $\log_e(\text{Date})$, Site, State, Method, Year covariates (Table 1). The occupancy analysis was similar to an Analysis of Covariance, to evaluate relative importance of main effects of $\log_e(\text{Date})$, Site, State, Method and Year, and interactions between the continuous $\log_e(\text{Date})$ covariate and the categorical covariates (Table 1). The final candidate set of 352 models was developed by all-subsets of the 16 detection and 22 occupancy models.

We used information-theoretic model selection to rank models according to the Akaike Information Criterion (Akaike 1973) adjusted for sample size (AIC_c) (Hurvich and Tsai 1989), evaluated the magnitude of information loss using the change in AIC_c (ΔAIC_c), measured strength of evidence for alternate models using AIC_c weights (w_i), and quantified the likelihood of the models using evidence ratios (w_i / w_j) Burnham and Anderson 2002). We model averaged the predictions and estimated unconditional standard errors from candidate sets of models with $\Delta AIC_c < 2$ (Burnham and Anderson 2002). We considered models with $\Delta AIC_c < 2$ to have substantial support and we used these models to make inference (Burnham and Anderson 2002). We assessed the strength of evidence for effect sizes by evaluating beta parameter estimates with respect to zero using conditional 90% or 95% Confidence Intervals (CI) (Burnham and Anderson 2002).

Table 1. Occupancy models, number of model parameters (K) and hypotheses associated with each model for the arrival dates of grassland birds, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Models	K	Hypotheses
$\ln\text{Date} + \text{Site}$	5	Occupancy differed by Site and the slopes for $\ln\text{Date}$ were the same for each Site
$\ln\text{Date} \times \text{Site}$	8	Occupancy differed by Site and the slopes for $\ln\text{Date}$ differed by Site
$\ln\text{Date} + \text{State}$	3	Occupancy differed by State and the slopes for $\ln\text{Date}$ were the same for each State
$\ln\text{Date} \times \text{State}$	4	Occupancy differed by State and the slopes for $\ln\text{Date}$ differed by State
$\ln\text{Date} + \text{Method}$	3	Occupancy differed by Method and the slopes for $\ln\text{Date}$ were the same for each Method
$\ln\text{Date} \times \text{Method}$	4	Occupancy differed by Method and the slopes for $\ln\text{Date}$ differed by Method
$\ln\text{Date} + \text{Year}$	3	Occupancy differed by Year and the slopes for $\ln\text{Date}$ were the same for each Year
$\ln\text{Date} \times \text{Year}$	4	Occupancy differed by Year and the slopes for $\ln\text{Date}$ differed by Year

Historical records.—We modeled the arrival date (ordinal date) of the grasshopper sparrow in 2° latitude-longitude grids using a generalized linear mixed model (Bolker et al. 2009) with a normal distribution and identity link function weighted by effort within the grid (PROC GLIMMIX, SAS/STAT, Version 9.3, SAS Institute, Inc., Cary, NC). The random

effects assumed a normal distribution with a mean of zero and variance matrix G with block covariance structure for the interaction between Grid ID and Year. The covariance structure for the random effect of Grid ID by Year allowed the investigation of covariates for the north-south, latitude effect on arrival date as well as an annual trend in arrival date. We fit a single model including the effects of latitude and year and evaluated the strength of evidence for these effects using 95% confidence intervals.

Results

Detection rates

Long-billed curlew.—The best detection models, $p(\text{Date})$, and $p(\text{Date} + \text{Site})$, were 2 times more probable than the next best models containing the Year or Method covariates (Appendix A, Table A1), providing little support for the effects of survey method on the detection of the long-billed curlew (*Numenius americanus*). The detection rate of the long-billed curlew declined with increasing Date (Appendix A, Table A2; Fig. 3) and was lower in Wind Cave than in Badlands (Appendix A, Table A3; Fig. 3).

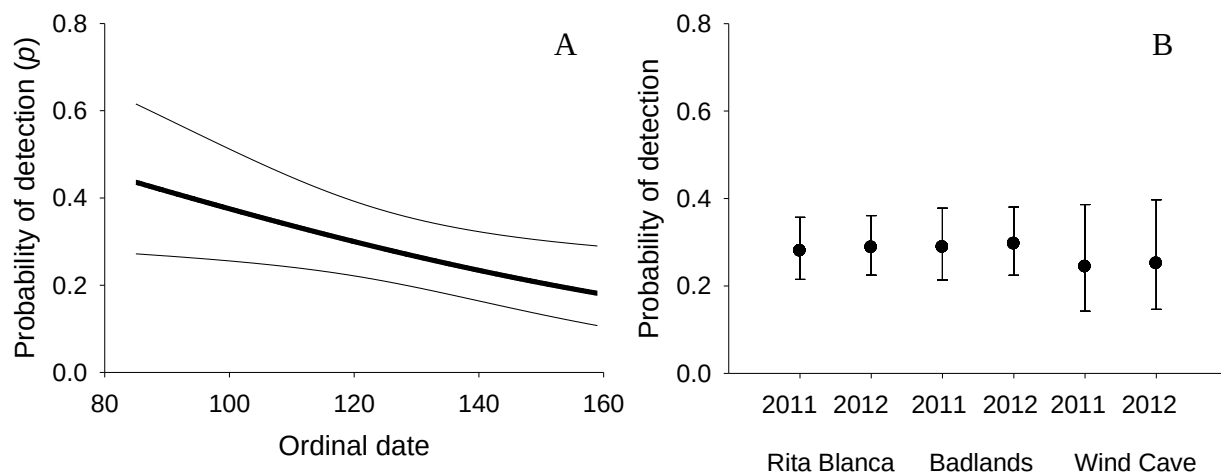


Figure 3. The estimated detection rates of the long-billed curlew during migration by A) ordinal date in Badlands during 2011 and B) study site at the mean ordinal date, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, and Badlands and Wind Cave National Parks, South Dakota, USA, 2011-2012. The bold lines and symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

Cassin's sparrow.—The best detection model for the Cassin's sparrow (*Peucaea cassinii*), $p(\text{Date} + \text{Year})$, was 97 times more probable than the next best detection model containing the Method covariate (not shown), providing very little support for the effect of survey method on the detection rate of this species. The detection rate of the Cassin's sparrow increased with increasing Date and was lower in 2012 than in 2011 (Appendix B, Table B1; Fig. 4).

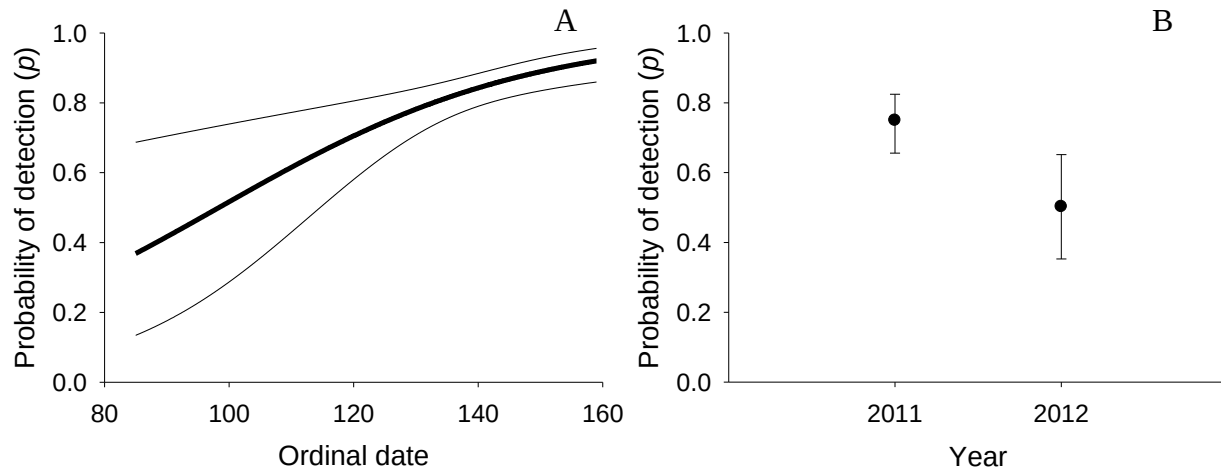


Figure 4. The estimated detection rates of the Cassin's sparrow during migration by A) ordinal date in 2011 and B) year at the mean ordinal date, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The bold lines and symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

Vesper sparrow.—The best detection models for the vesper sparrow (*Pooecetes gramineus*), $p(\text{State} + \text{Method})$ and $p(\text{State} + \text{Year})$, were 3 and 4 times more probable than the $p(\text{Year} * \text{Method})$ model (not shown), providing little support for different detection rates for ARUs in 2011 and 2012 (Appendix C, Table C1). The detection rates of the vesper sparrow were greater for point counts than for ARUs, lower in Texas than in South Dakota (Appendix C, Table C2; Fig. 5) and were lower in 2012 than in 2011 (Appendix C, Table C3; Fig. 5).

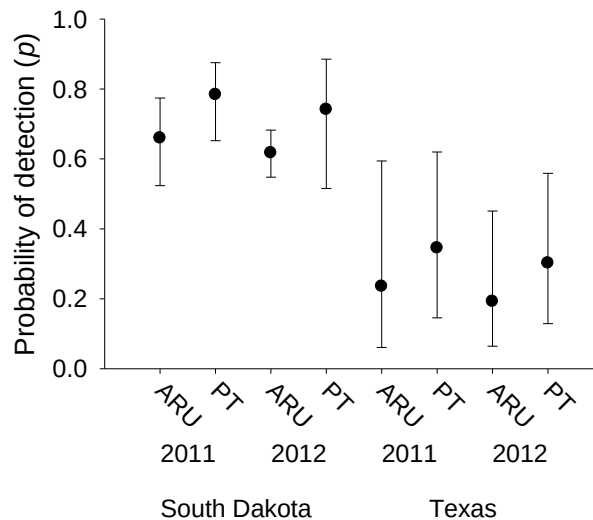


Figure 5. The estimated detection rates of the vesper sparrow during migration by survey method, State and year, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, and Badlands and Wind Cave National Parks, South Dakota, USA, 2011-2012. The symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

Lark sparrow.—The best detection model for the lark sparrow (*Chondestes grammacus*), $p(\text{Method} + \text{Year})$, was four times more probable than the next best model without the Method covariate (not shown), providing support for a large effect of survey method on detection (Appendix D, Table D1). The detection rates of the lark sparrow were greater for point counts than for ARUs and were greater in 2012 than in 2011 (Appendix D, Table D2; Fig. 6).

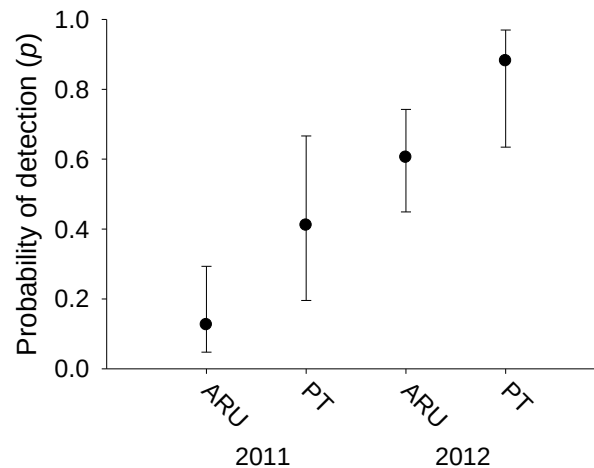


Figure 6. The estimated detection rates of the lark sparrow during migration by survey method and year, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, and Badlands and Wind Cave National Parks, South Dakota, USA, 2011-2012. The symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

Lark bunting.—The best detection models for the lark bunting (*Calamospiza melanocorys*) were $p(\text{Method} + \text{Year})$ and $p(\text{Method} * \text{Year})$, providing nearly equal support for the main and interaction effects of survey method and year (Appendix E, Table E1). The two best detection models were 2 times more probable than the next best model without the Method covariate, providing support for the effects of survey method (Appendix E, Table E1). The detection rates of the lark sparrow were greater for point counts than for ARUs, greater in 2012 than in 2011 (Appendix E, Table E2, E3; Fig. 7) and were greater at ARU stations in 2012 than in 2011 (Appendix E, Table E4; Fig. 7).

Grasshopper sparrow.—The best detection models for the grasshopper sparrow, $p(\text{Date} + \text{Site})$ and $p(\text{Date} + \text{Year})$, were 278 and 189 times more probable than the next best model with the Method covariate (not shown), providing very little support for an effect of survey method on detection (Appendix F, Table F1). The detection rates of the grasshopper sparrow increased with increasing ordinal date, were lower in Texas and Wind Cave than in Badlands (Appendix F, Table F2; Fig. 8) and were greater in 2012 than in 2011 (Appendix F, Table F3; Fig. 8).

Brown-headed cowbird.—There was nearly equal support for the two best detection models for the brown-headed cowbird (*Molothrus ater*), $p(\text{State})$ and $p(\text{Date})$ (Appendix G, Table G1). The best detection model was 2 times more probable than the next best model with the Method covariate (Appendix G, Table G1), providing little support for an effect of survey method on detection. The detection rates of the brown-headed cowbird were lower in Texas than in South Dakota (Appendix G, Table G2; Fig. 9) and increased with increasing ordinal date (Appendix G, Table G3; Fig. 9).

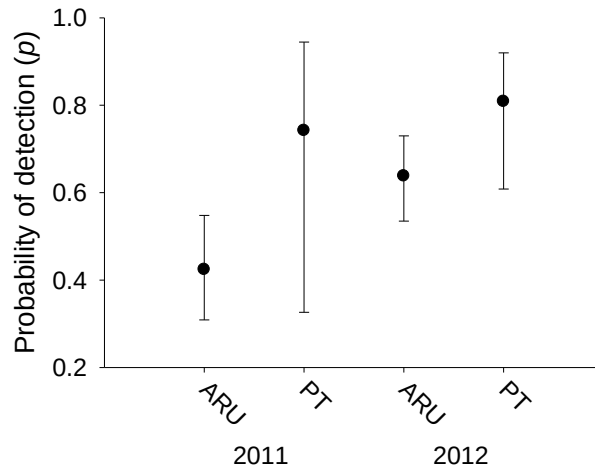


Figure 7. The estimated detection rates of the lark bunting during migration by survey method and year at the mean ordinal date, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

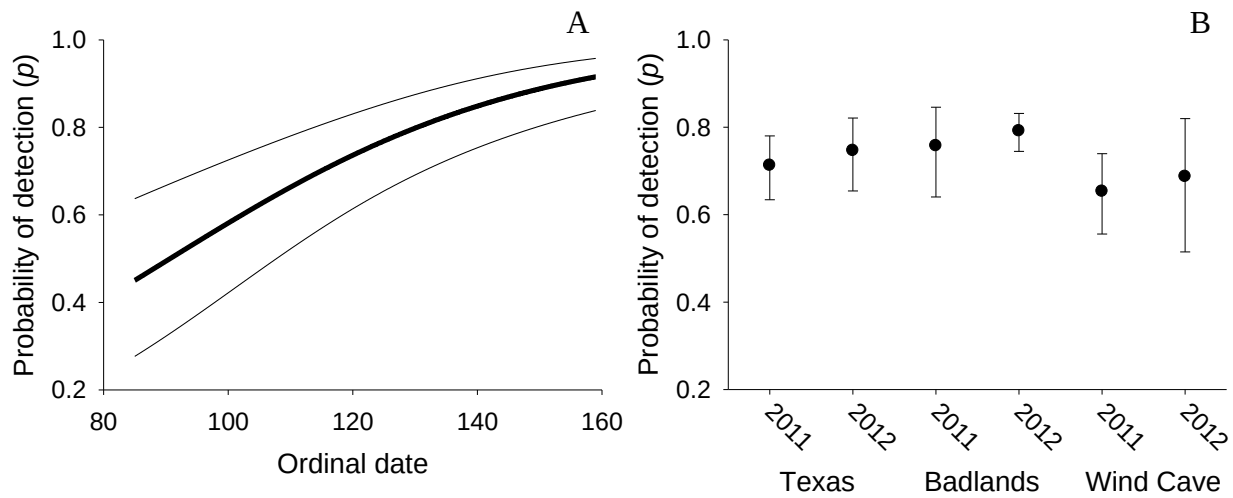


Figure 8. The estimated detection rates of the grasshopper sparrow during migration by A) ordinal date in Badlands during 2011 and B) study site and year at the mean ordinal date, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, and Badlands and Wind Cave National Parks, South Dakota, USA, 2011-2012. The bold lines and symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

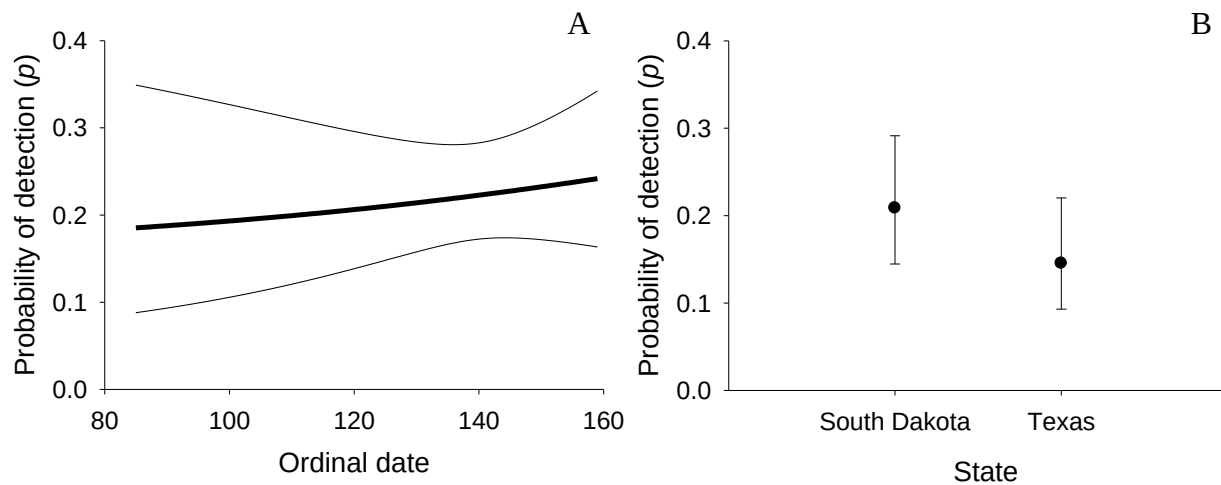


Figure 9. The estimated detection rates of the brown-headed cowbird during migration by A) ordinal date in South Dakota and B) study site and year at the mean ordinal date, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, and Badlands and Wind Cave National Parks, South Dakota, USA, 2011-2012. The bold lines and symbols are model averaged estimates of detection and the error bars are unconditional 95% confidence intervals.

Arrival dates

Long-billed curlew.—The best occupancy models for the daily trend in long-billed curlew occupancy, $\psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$ and $\psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{State})$, were 38 and 24 times more probable than the next best interaction model (not shown), providing very little support for interactions between $\ln\text{Date}$ and the categorical covariates (Appendix A, Table A1). The occupancy rates were lower for point counts than for ARUs, greater in Rita Blanca and lower in Wind Cave than in Badlands, greater in 2012 than in 2011 (Appendix A, Table A2; Fig. 10) and greater in Texas than in South Dakota (Appendix A, Table A3; Fig. 10). The 90% CI for the daily trend in occupancy did not cover zero, indicating a small effect size for the $\ln\text{Date}$ trend (Appendix A, Table A2, A3).

Based on the mean dates of first detection at each study site, the date of first detection of the long-billed curlew was 4 days earlier for ARU stations than for point count locations (Table 2). The daily trends in occupancy of the long-billed curlew at ARU stations and point count locations increased at the same rate, but the trend for point count occupancy lagged behind the trend for ARU occupancy due to the low occupancy rates at point count locations (Fig. 10). Based on the mean date that occupancy reached 10% ($\psi = 0.1$) at Rita Blanca, the long-billed curlew occupied 10% of the ARU stations 25 days before the species occupied 10% of the point count locations (Table 2; Fig. 10).

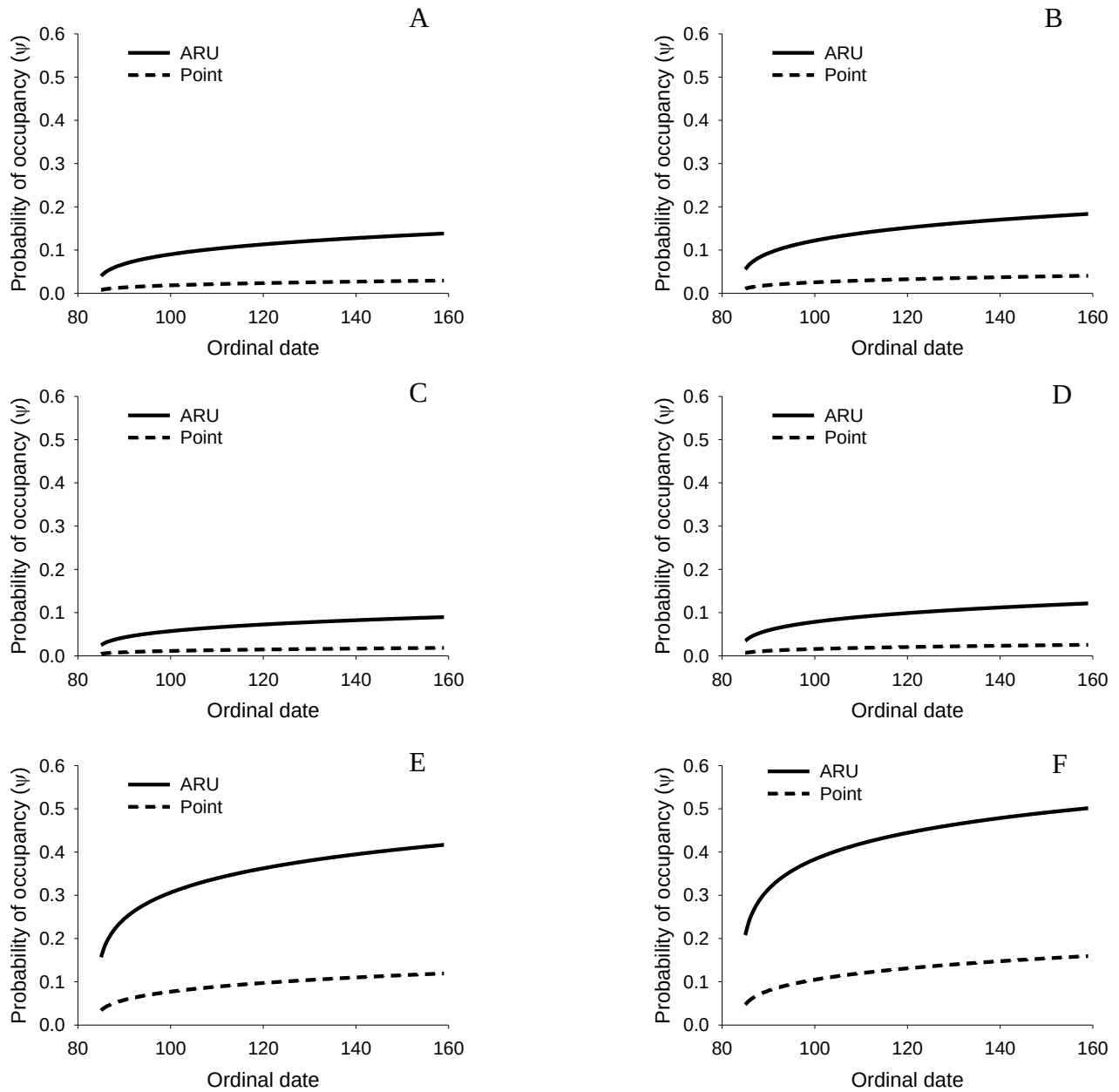


Figure 10. The predicted occupancy rates of the long-billed curlew at acoustic recording units (ARU) and point count stations (Point) for A) Badlands in 2011, B) Badlands in 2012, C) Wind Cave in 2011, D) Wind Cave in 2012, E) Rita Blanca in 2011 and F) Rita Blanca in 2012, Texas and South Dakota, USA, 2011-2012. The bold trend lines are model averaged estimates of occupancy.

Table 2. The ordinal dates (OD) and calendar dates when the modeled long-billed curlew occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting long-billed curlew occupancy. The dashes correspond to Site, Year and Method combinations where the estimated occupancy rate was < 0.1 .

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2011	ARU	107	17 April	116	26 April
Badlands	2011	PT	-	-	116	26 April
Badlands	2012	ARU	92	2 April	101	12 April
Badlands	2012	PT	-	-	114	25 April
Wind Cave	2011	ARU	-	-	127	7 May
Wind Cave	2011	PT	-	-	99	9 April
Wind Cave	2012	ARU	121	1 May	108	19 April
Wind Cave	2012	PT	-	-	122	3 May
Rita Blanca	2011	ARU	85	26 March	101	11 April
Rita Blanca	2011	PT	123	3 May	106	16 April
Rita Blanca	2012	ARU	85	26 March	90	1 April
Rita Blanca	2012	PT	98	8 April	107	18 April

Cassin's sparrow.—The best occupancy model for the daily trend in Cassin's sparrow occupancy, $\psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$, was 3 times more probable than the next best interaction model (not shown), providing little support for interactions between $\ln\text{Date}$ and the categorical covariates (Appendix B, Table B1). The occupancy rates of the Cassin's sparrow were lower for point counts than for ARUs, lower in Rita Blanca than in Lake Meredith and lower in 2012 than in 2011 (Appendix B, Table B2; Fig. 11). The 95% CI for the daily trend in occupancy did not cover zero, indicating a large effect size for $\ln\text{Date}$ (Appendix B, Table B2). Based on the mean dates of first detection at each study site, the date of first detection of the Cassin's sparrow was 8 days earlier for ARU stations than for point count locations (Table 3). The daily trends in occupancy for the Cassin's sparrow at ARU stations and point count locations increased at the same rate, but the trend for point count occupancy lagged behind the trend for ARU occupancy due to the low occupancy rates of the point count locations (Fig. 11). Based on the mean date that occupancy reached 10% ($\psi = 0.1$), the Cassin's sparrow occupied 10% of the ARU stations 22 days before the species occupied 10% of the point count locations (Table 3; Fig. 11).

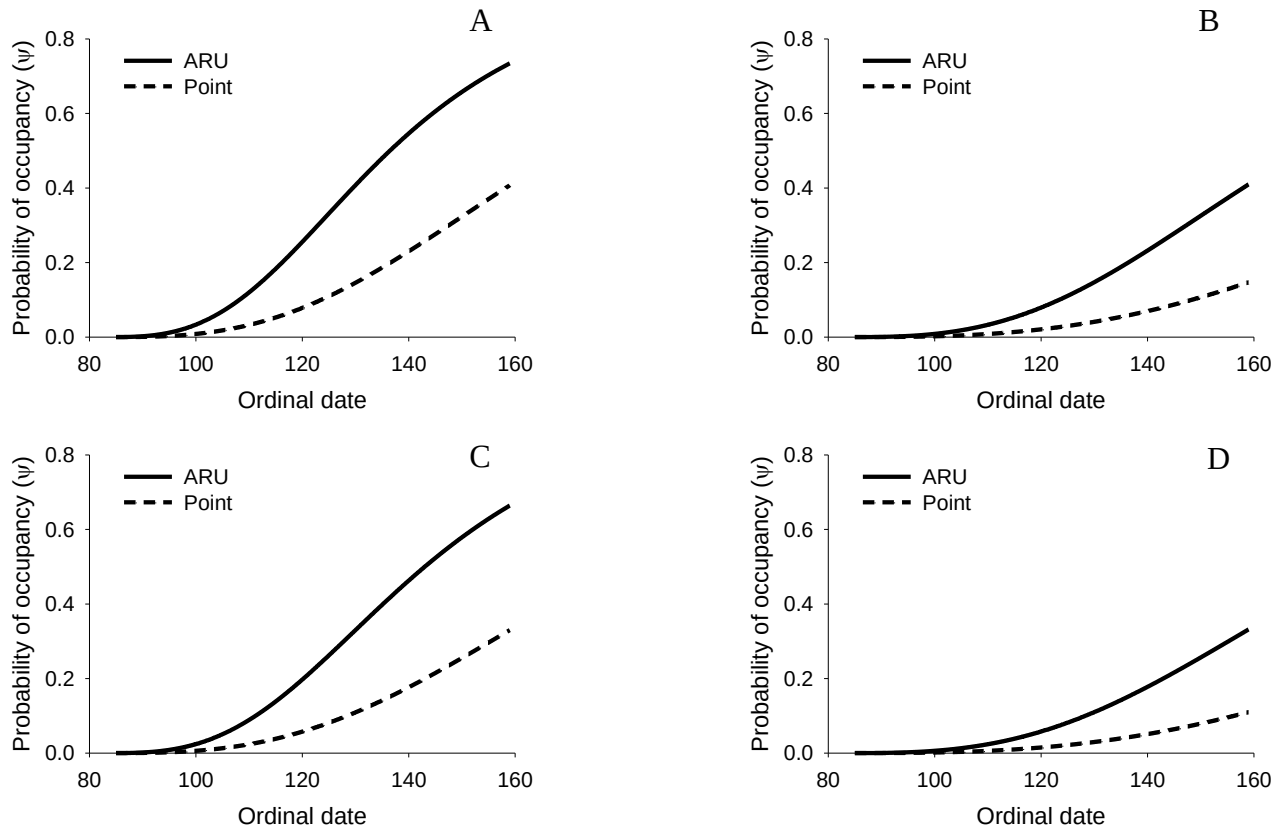


Figure 11. The predicted occupancy rates of the Cassin's sparrow at acoustic recording units (ARU) and point count stations (Point) for A) Lake Meredith in 2011, B) Lake Meredith in 2012, C) Rita Blanca in 2011 and D) Rita Blanca in 2012, Texas, USA, 2011-2012. The bold trend lines are model averaged estimates of occupancy.

Table 3. The ordinal dates (OD) and calendar dates when the modeled Cassin's sparrow occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top model predicting Cassin's sparrow occupancy.

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Lake Meredith	2011	ARU	108	18 April	111	21 April
Lake Meredith	2011	PT	123	3 May	111	21 April
Lake Meredith	2012	ARU	123	3 May	117	27 April
Lake Meredith	2012	PT	149	29 May	128	8 May
Rita Blanca	2011	ARU	111	21 April	104	14 April
Rita Blanca	2011	PT	129	9 May	119	29 April
Rita Blanca	2012	ARU	129	9 May	129	9 May
Rita Blanca	2012	PT	156	5 June	133	13 May

Vesper sparrow.—The best occupancy model for the daily trend in vesper sparrow occupancy, $\psi(\ln\text{Date} * \text{Method} + \ln\text{Date} * \text{Year})$ was 9 times more probable than the next best main effects model (not shown), providing little support for the additive effects of $\ln\text{Date}$, survey method and year (Appendix C, Table C1). The slope of the daily trend in occupancy was lower for point counts than ARUs (Appendix C, Table C2, C3; Fig. 12). The 90% CI for the interaction effect of $\ln\text{Date} * \text{Year}$ included zero, which indicated the slope of the daily trend in occupancy was marginally lower in 2012 than in 2011 (Appendix C, Table C2, C3; Fig. 12).

Based on the mean dates of first detection at each study site, the date of first detection of the vesper sparrow was 4 days later for ARU stations than for point count locations (Table 4). The daily trend in occupancy for the vesper sparrow was much greater for ARU stations than for point count locations (Fig. 12). Based on the dates that occupancy reached 10% ($\psi = 0.1$) at Wind Cave in 2011, the vesper sparrow occupied 10% of the ARU stations 41 days before the species occupied 10% of the point count locations (Table 4; Fig. 12).

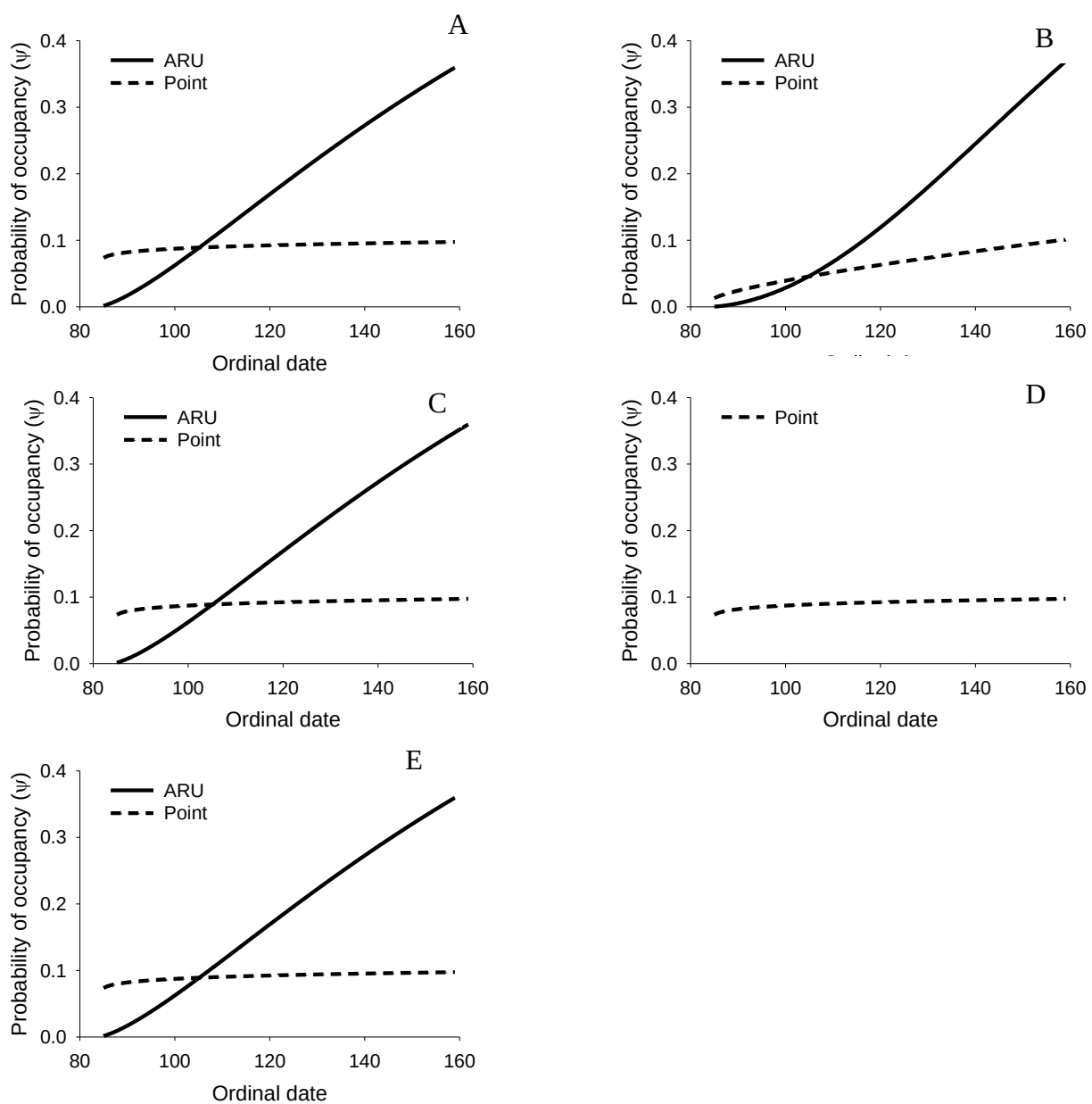


Figure 12. The predicted occupancy rates of the vesper sparrow at acoustic recording units (ARU) and point count stations (Point) for A) Badlands in 2012, B) Wind Cave in 2011, C) Wind Cave in 2012, D) Lake Meredith in 2012 and E) Rita Blanca in 2012, South Dakota and Texas, USA. The bold trend lines are model averaged estimates of occupancy.

Table 4. The ordinal dates (OD) and calendar dates when the modeled vesper sparrow occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting vesper sparrow occupancy. The dashes correspond to Site, Year and Method combinations where the estimated occupancy rate was < 0.1 .

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2012	ARU	107	17 April	113	23 April
Badlands	2012	PT	-	-	113	23 April
Wind Cave	2011	ARU	117	17 April	123	3 May
Wind Cave	2011	PT	158	7 June	123	3 May
Wind Cave	2012	ARU	107	17 April	114	24 April
Wind Cave	2012	PT	-	-	122	2 May
Lake Meredith	2012	PT	-	-	101	11 April
Rita Blanca	2012	ARU	107	17 April	122	2 May
Rita Blanca	2012	PT	-	-	99	9 April

Lark sparrow.—The best occupancy models for the daily trend in lark sparrow occupancy, $\psi(\ln\text{Date} + \text{State})$ was 2 times more probable than the next best model including the Method covariate, providing little support for the effect of survey method on occupancy (Appendix D, Table D1). The occupancy rates of the lark sparrow were greater in Texas than in South Dakota (Appendix D, Table D2; Fig. 13). The 95% CI for the daily trend in occupancy did not cover zero, indicating a large effect size for $\ln\text{Date}$ (Appendix D, Table D2).

Based on the mean dates of first detection at each study site, the date of first detection of the lark sparrow was 2 days later for ARU stations than for point count locations (Table 5). The daily trends in occupancy for the lark sparrow at ARU stations and point count locations increased at the same rate with only small differences in the occupancy rates of the two methods (Fig. 13). Based on the mean date that occupancy reached 10% ($\psi = 0.1$) at Lake Meredith in 2011, the lark sparrow occupied 10% of the ARU stations 1 day after the species occupied 10% of the point count locations (Table 5; Fig. 13).

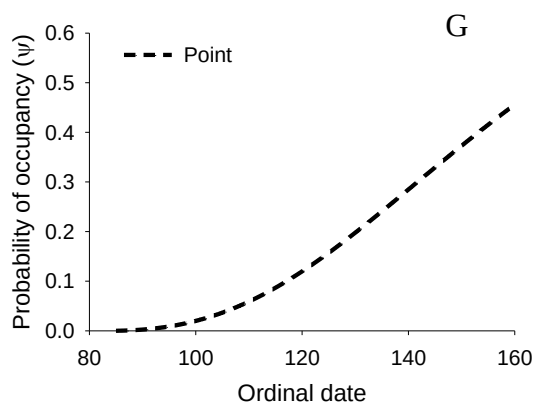
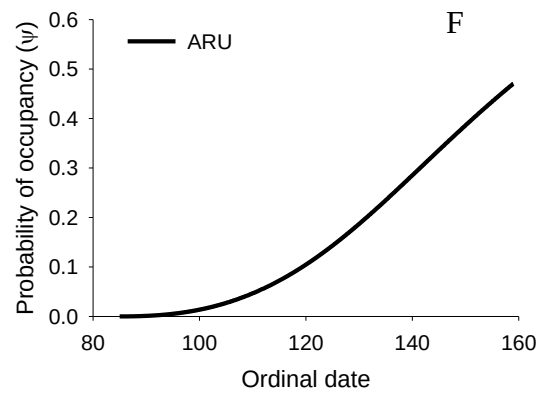
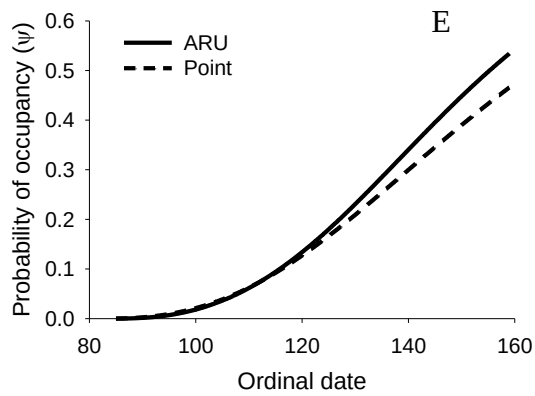
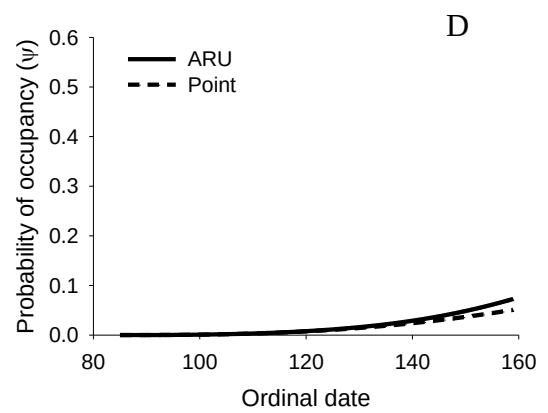
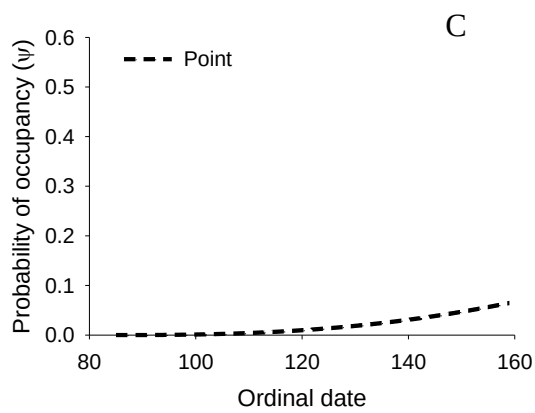
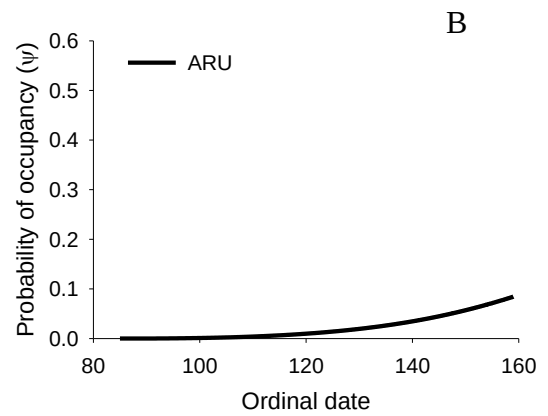
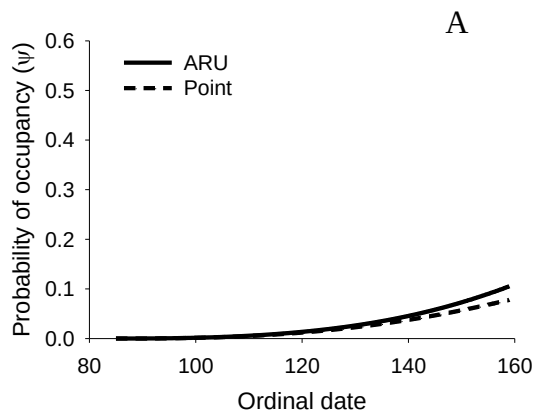


Figure 13. The predicted occupancy rates of the lark sparrow at acoustic recording units (ARU) and point count stations (Point) for A) Badlands in 2011, B) Badlands in 2012, C) Wind Cave in 2011, D) Wind Cave in 2012, E) Lake Meredith in 2011, F) Lake Meredith in 2012, and G) Rita Blanca in 2011, South Dakota and Texas, USA. The bold trend lines are model averaged estimates of occupancy.

Table 5. The ordinal dates (OD) and calendar dates when the modeled lark sparrow occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting lark sparrow occupancy. The dashes correspond to Site, Year and Method combinations where the estimated occupancy rate was < 0.1 .

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2011	ARU	158	7 June	145	25 May
Badlands	2011	PT	-	-	152	1 June
Badlands	2012	ARU	-	-	155	4 June
Wind Cave	2011	PT	-	-	148	28 May
Wind Cave	2012	ARU	-	-	122	2 May
Wind Cave	2012	PT	-	-	122	2 May
Lake Meredith	2011	ARU	117	27 April	127	7 May
Lake Meredith	2011	PT	116	26 April	114	24 April
Lake Meredith	2012	ARU	119	29 April	121	1 May
Rita Blanca	2011	PT	117	27 April	116	26 April

Lark bunting.—The best occupancy models for the daily trend in lark bunting occupancy were $\psi(\ln\text{Date} + \text{Site} + \text{Year})$ and $\psi(\ln\text{Date} + \text{Site} + \text{Year} + \text{Method})$, with nearly equal support for models with and without the Method covariate (Appendix E, Table E1). The best two occupancy models were 6 and 5 times more probable than the next best interaction models (not shown), providing little evidence for the interaction between $\ln\text{Date}$ and the categorical covariates. The occupancy rates of the lark bunting were greater in Rita Blanca than in Badlands and were greater in 2012 than in 2011 (Appendix E, Table E2; Fig. 14). The 90% CIs for the effects of Lake Meredith and Wind Cave covered zero, indicating the occupancy rates at Lake Meredith were marginally greater and those at Wind Cave were marginally lower than Badlands (Appendix E, Table E2; Fig. 14). The 90% CIs of the effect for survey method in the second best model covered zero, indicating that the occupancy rates of ARU stations were only marginally lower than those of point count locations (Appendix E, Table E3; Fig. 14). The 95% CI for the daily trend in occupancy did not cover zero, indicating a large effect size for $\ln\text{Date}$ (Appendix E, Table E2).

Based on the mean dates of first detection at each study site, the date of first detection of the lark bunting was 1 day earlier for ARU stations than for point count locations (Table 6). The daily trends in occupancy for the lark bunting at ARU stations and point count locations increased at the same rate with only small differences in the occupancy rates of the two methods (Fig. 14). Based on the mean date that occupancy reached 10% ($\psi = 0.1$), the lark bunting occupied 10% of the ARU stations 3 days before the species occupied 10% of the point count locations (Table 6; Fig. 14).

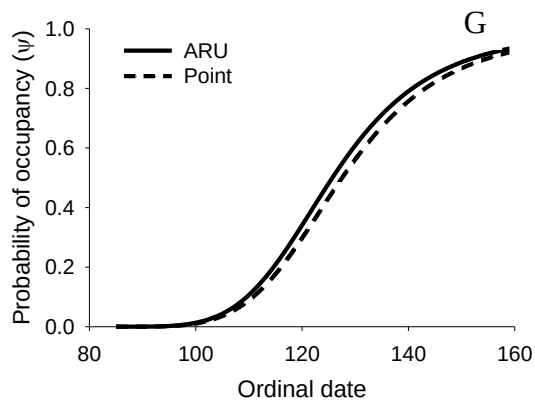
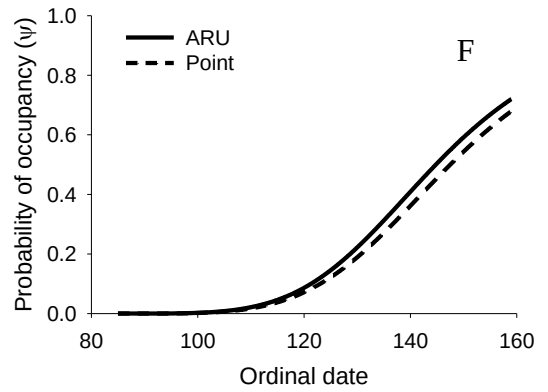
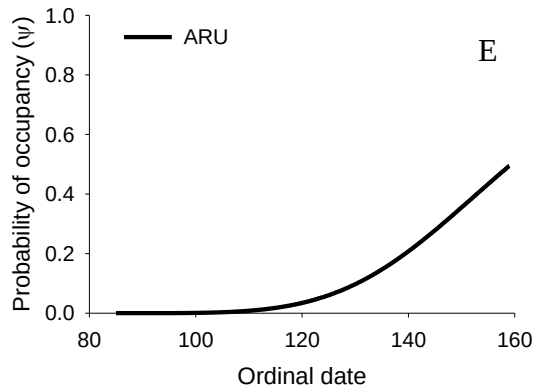
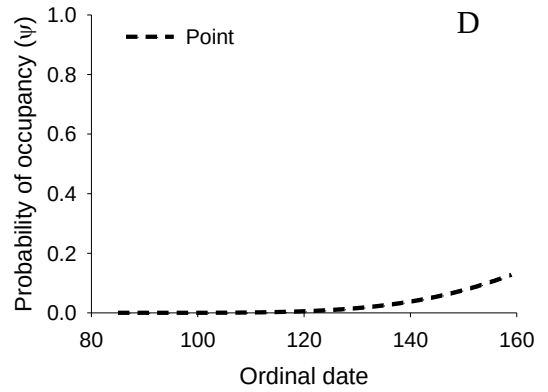
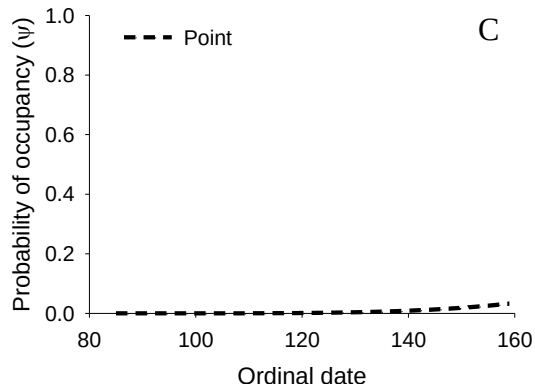
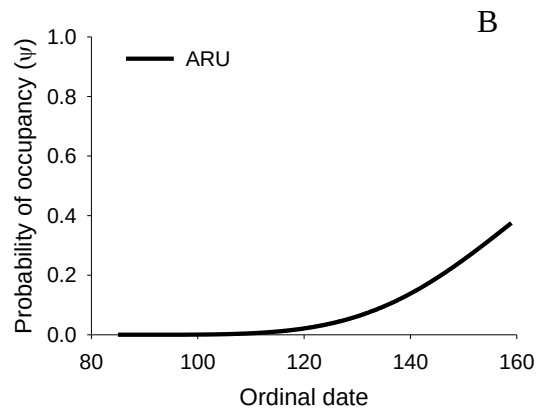
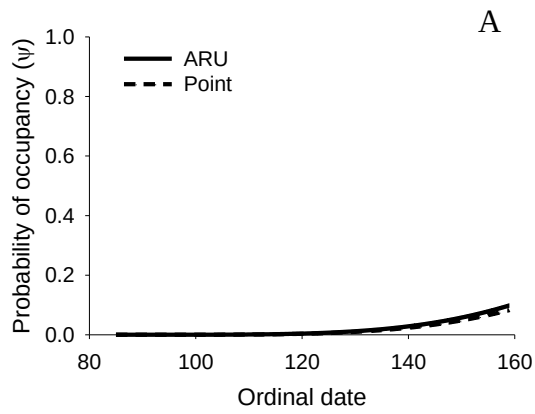


Figure 14. The predicted occupancy rates of the lark bunting at acoustic recording units (ARU) and point count stations (Point) for A) Badlands in 2011, B) Badlands in 2012, C) Wind Cave in 2011, D) Lake Meredith in 2011, E) Lake Meredith in 2012, F) Rita Blanca in 2011 and G) Rita Blanca in 2012, South Dakota and Texas, USA. The bold trend lines are model averaged estimates of occupancy.

Table 6. The ordinal dates (OD) and calendar dates when the modeled lark bunting occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting lark bunting occupancy. The dashes correspond to Site, Year and Method combinations where the estimated occupancy rate was < 0.1 .

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2011	ARU	-	-	153	2 June
Badlands	2011	PT	-	-	152	1 June
Badlands	2012	ARU	135	15 May	137	17 May
Wind Cave	2011	PT	-	-	146	26 May
Lake Meredith	2011	PT	155	4 June	114	24 April
Lake Meredith	2012	ARU	130	10 May	123	3 May
Rita Blanca	2011	ARU	121	1 May	119	29 April
Rita Blanca	2011	PT	123	3 May	131	11 May
Rita Blanca	2012	ARU	109	19 April	122	2 May
Rita Blanca	2012	PT	111	21 April	121	1 May

Grasshopper sparrow.—The best occupancy model for the daily trend in grasshopper sparrow occupancy, $\psi(\ln\text{Date}*\text{Site} + \ln\text{Date}*\text{Year})$, was 2 times more probable than the next best model including the Method covariate, providing little support for the effect of survey method on the occupancy rates (Appendix F, Table F1). The best model with the multiplicative effects of $\ln\text{Date}*\text{Site}$ and $\ln\text{Date}*\text{Year}$ was 67 times more probable than the next best model with the additive effects of $\ln\text{Date}$, Site and Year (not shown), providing very little support for the additive model. The slope of the daily trend in occupancy was greater for Wind Cave than for Badlands (Appendix F, Table F2, F3; Fig. 15). The 90% CI for the interaction between $\ln\text{Date}$, and Lake Meredith and Rita Blanca, and $\ln\text{Date}$ and Year included zero, which indicated small effect sizes for these interactions (Appendix F, Table F2, F3; Fig. 15).

Based on the mean dates of first detection at each study site, the date of first detection of the grasshopper sparrow was 1 day earlier for ARU stations than for point count locations (Table 7). The daily trend in occupancy for the grasshopper sparrow was greater in Wind Cave than in Badlands with only small differences in the occupancy rates of the two survey methods (Fig. 15). Based on the mean date that occupancy reached 10% ($\psi = 0.1$), the grasshopper sparrow occupied 10% of the ARU stations 3 days before the species occupied 10% of the point count locations (Table 7; Fig. 15).

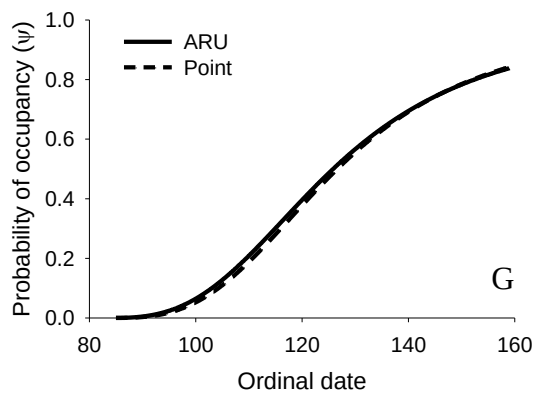
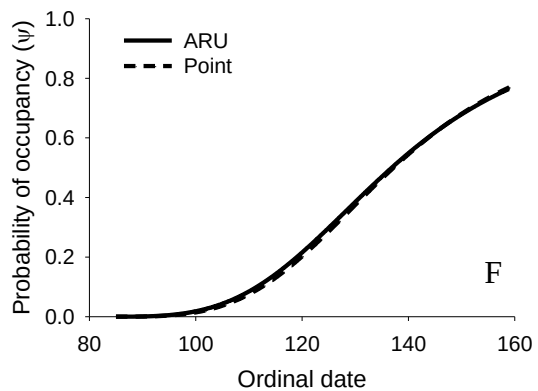
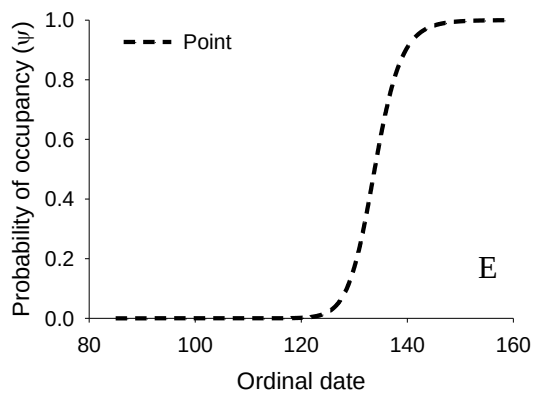
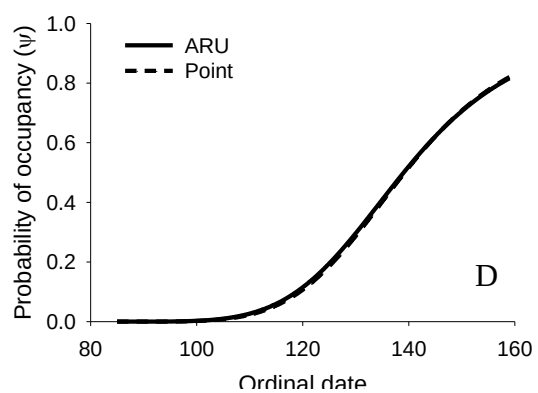
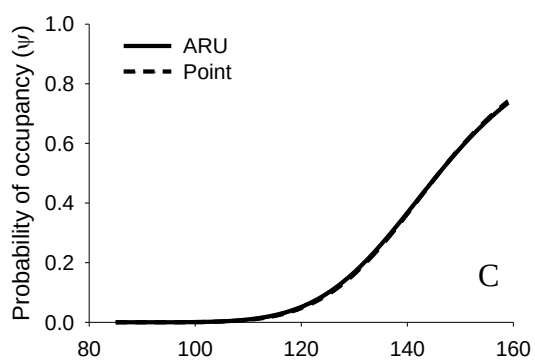
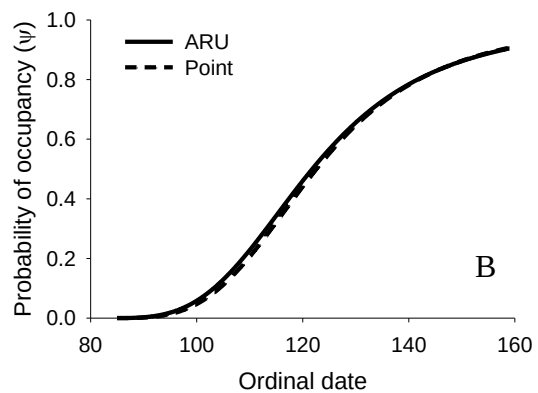
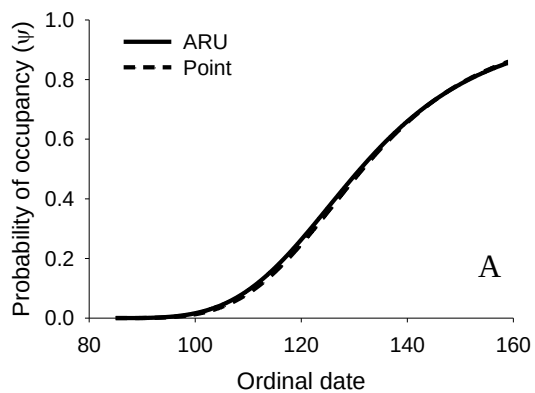


Figure 15. The predicted occupancy rates of the grasshopper sparrow at acoustic recording units (ARU) and point count stations (Point) for A) Badlands in 2011, B) Badlands in 2012, C) Wind Cave in 2011, D) Wind Cave in 2012, E) Lake Meredith in 2012, F) Rita Blanca in 2011, and G) Rita Blanca in 2012, South Dakota and Texas, USA. The bold trend lines are model averaged estimates of occupancy.

Table 7. The ordinal dates (OD) and calendar dates when the modeled grasshopper sparrow occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting grasshopper sparrow occupancy.

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2011	ARU	110	20 April	103	13 April
Badlands	2011	PT	112	22 April	117	27 April
Badlands	2012	ARU	104	14 April	110	20 April
Badlands	2012	PT	104	14 April	113	23 April
Wind Cave	2011	ARU	125	5 May	125	5 May
Wind Cave	2011	PT	126	6 May	125	5 May
Wind Cave	2012	ARU	119	29 April	123	3 May
Wind Cave	2012	PT	120	30 April	122	2 May
Lake Meredith	2012	PT	129	9 May	130	10 May
Rita Blanca	2011	ARU	112	22 April	112	22 April
Rita Blanca	2011	PT	112	22 April	116	26 April
Rita Blanca	2012	ARU	103	13 April	123	3 May
Rita Blanca	2012	PT	104	14 April	119	29 April

Brown-headed cowbird.—The best occupancy model for the daily trend in brown-headed cowbird occupancy, $\psi(\ln\text{Date}*\text{Method} + \ln\text{Date}*\text{Year})$, was 3 times more probable than the next best additive model for $\ln\text{Date}$, Method and Year (not shown), providing little support for the additive trend model (Appendix G, Table G1). The best occupancy model including the interaction between $\ln\text{Date}*\text{Method}$ was 2 times more probable than the fifth best model without this interaction (Appendix G, Table G1), providing support for the survey method interaction. The slope of the daily trend in occupancy was lower for point count locations than for ARU stations and was lower for 2012 than for 2011 (Appendix G, Table G2, G3; Fig. 16).

Based on the mean dates of first detection at each study site, the date of first detection of the brown-headed cowbird was 4 days earlier for ARU stations than for point count locations (Table 8). The daily trend in occupancy for the brown-headed cowbird was greater for ARU locations than for point count locations and was greater in 2011 than in 2012 (Fig. 16). Based on the mean date that occupancy reached 10% ($\psi = 0.1$), the brown-headed cowbird occupied 10% of the ARU stations 19 days before the species occupied 10% of the point count locations (Table 8; Fig. 16).

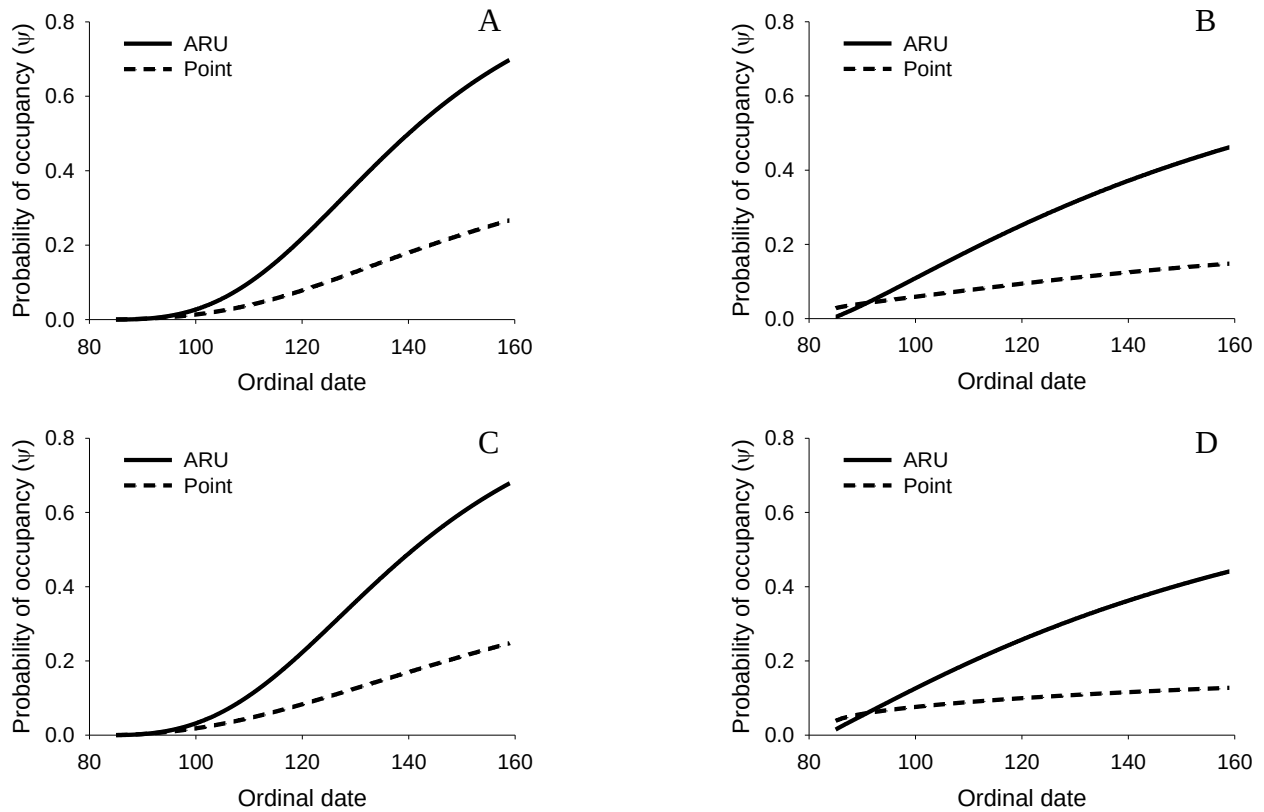


Figure 16. The predicted occupancy rates of the brown-headed cowbird at acoustic recording units (ARU) and point count stations (Point) for A) South Dakota in 2011, B) South Dakota in 2012, C) Texas in 2011 and D) Texas in 2012, USA. The bold trend lines are model averaged estimates of occupancy.

Table 8. The ordinal dates (OD) and calendar dates when the modeled brown-headed cowbird occupancy reached 10% ($\psi = 0.1$) and the dates when the species was first detected for acoustic recording units (ARU) and point count stations (PT) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012. The dates are model averaged estimates from the top models predicting brown-headed cowbird occupancy.

Site	Year	Method	OD ($\psi = 0.1$)	Date ($\psi = 0.1$)	OD detected	Date detected
Badlands	2011	ARU	110	20 April	117	27 April
Badlands	2011	PT	124	4 May	117	27 April
Badlands	2012	ARU	99	9 April	119	29 April
Badlands	2012	PT	124	4 May	142	22 May
Wind Cave	2011	ARU	110	20 April	145	25 May
Wind Cave	2011	PT	124	4 May	125	5 May
Wind Cave	2012	ARU	99	9 April	118	28 April
Lake Meredith	2011	ARU	109	19 April	108	18 April
Lake Meredith	2011	PT	124	4 May	139	19 May
Lake Meredith	2012	ARU	96	6 April	100	10 April
Lake Meredith	2012	PT	121	1 May	88	29 March
Rita Blanca	2011	ARU	117	27 April	141	21 May

Historical records

We discovered a negative trend in the arrival dates of the grasshopper in the Great Plains over the last 15 years (Appendix H, Table H1; Fig. 17). The 95% CI for the effect of year did not cover zero, indicating a large temporal trend in arrival date (Appendix H, Table H1). In addition, we found the expected correlation between arrival date and latitude, where the grasshopper sparrow arrived on the breeding later at high latitudes than at low latitudes (Appendix H, Table H1; Fig. 17). The 95% CI for the effect of latitude excluded zero, indicating a large spatial trend from south to north (Appendix H, Table H). The predicted arrival dates from the eBird analysis suggested that the grasshopper arrived on the breeding grounds in South Dakota on average 16 days after they arrived on the breeding grounds in Texas (Fig. 17, Table 9).

The BBS data showed a negative trend of the grasshopper sparrow in the Central Region (Fig. 18). The 95% credible interval for the trend did not cover zero, indicating a large negative trend in the index of grasshopper sparrow abundance (trend estimate = -2.59, 95% credible interval = -3.27, -2.02).

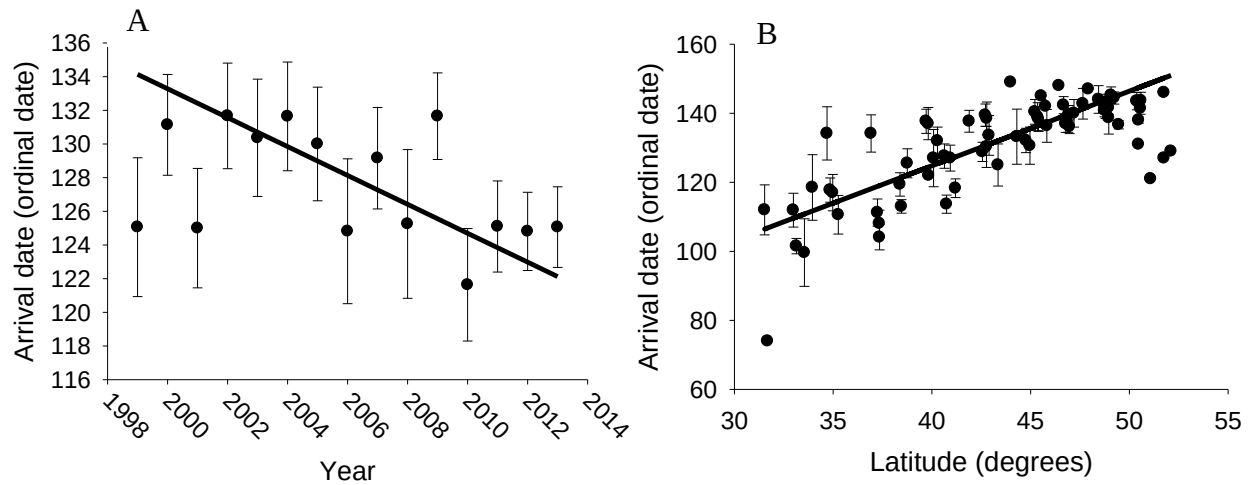


Figure 17. The predicted arrival dates of the grasshopper sparrow by A) year and B) latitude within the two degree latitude-longitude grid at the mean value of the other covariates in the model. The filled symbols are mean arrival dates, the error bars are one standard error of the mean arrival dates and the bold lines are the predicted trends in the arrival dates.

Table 9. The predicted ordinal dates (OD) and calendar dates of first arrival of the grasshopper sparrow from the eBird analysis.

Site	Year	OD	Date
Badlands	2011	128	8 May
Badlands	2012	128	8 May
Wind Cave	2011	128	8 May
Wind Cave	2012	127	7 May
Lake Meredith	2011	112	22 April
Lake Meredith	2012	112	22 April
Rita Blanca	2011	111	21 April
Rita Blanca	2012	110	20 April

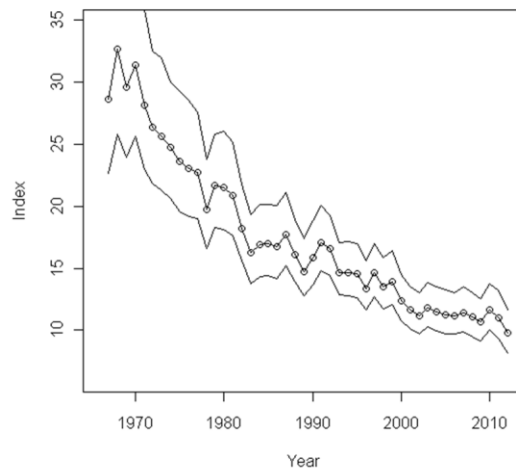


Figure 18. The BBS trend in the index of grasshopper sparrow abundance for the BBS Central Region. The symbols are the annual estimates of the index of grasshopper sparrow abundance, and the bounding lines are 95% Credible Intervals.

Discussion

In this study, we monitored the arrival dates of seven migratory species of grassland birds on the breeding grounds. In addition, we compared acoustic and point count methods to evaluate the effectiveness of acoustic monitoring for estimating migratory arrival times of grassland birds. We compared the detection rates of acoustic and point count methods to determine the ability of survey methods to detect the bird species when they were actually present on the breeding grounds. The comparison of acoustic and point count methods allowed us to determine how arrival dates estimated from acoustic monitoring compared to territory occupancy through the spring migratory season. Finally, we used historical eBird data to investigate temporal and spatial trends in arrival dates for the grasshopper sparrow. We compared the arrival dates estimated from the regional eBird data to the arrival dates estimated from the local acoustic and point count surveys to evaluate the consistency of the methods. Finally, we discuss variation in arrival date in context with climate change and long-term population declines of the grasshopper sparrow.

We found the detection rates for acoustic monitoring and point count methods were similar for the long-billed curlew, Cassin's sparrow, grasshopper sparrow and brown-headed cowbird. In contrast, the detection rates for the acoustic method were lower than the point count method for the vesper sparrow, lark sparrow and lark bunting. This suggested that acoustic monitoring performed well for four of the seven species, but acoustic monitoring exhibited a higher rate of false absences for the vesper sparrow, lark sparrow and lark bunting than the point count methods when monitoring the arrival of grassland birds on the breeding grounds. The differences in detection between the monitoring methods may due to differences in the life history, behavior and abundance of the species. Although the long-billed curlew exhibited low abundance, loud vocalizations may have allowed similar detection rates for both point count and acoustic monitoring. In contrast, although the grasshopper sparrow exhibited soft vocalizations, high abundance may have allowed similar detection rates for both point count and acoustic monitoring. The three species in the family Emberizidae (vesper sparrow, lark sparrow, lark

bunting) may have variable singing rates and greater number of visual detections than other species, resulting in that higher detection rates for point counts than acoustic monitoring.

By comparing the occupancy rates of the two methods, we discovered that acoustic monitoring performed just as well as point count methods for estimating the arrival dates of the grasshopper sparrow, lark sparrow and lark bunting. Conversely, acoustic monitoring detected arrival on the breeding grounds well before the territorial establishment of the long-billed curlew, Cassin's sparrow and brown-headed cowbird. Interestingly, acoustic monitoring detected arrival on the breeding ground after territorial establishment of the vesper sparrow.

The comparison of arrival dates from the eBird data and local surveys showed important differences in the estimates of arrival dates for the grasshopper sparrow. The eBird data suggested the grasshopper sparrow arrived on the breeding grounds in South Dakota in 2011 and 2012 on average 16 days after arriving on the breeding grounds in Texas. In contrast, the acoustic and point count data showed greater variability in arrival dates of the grasshopper sparrow. In 2011, the local ARU and point count surveys indicated the grasshopper sparrow arrived at the Badlands site in South Dakota before the species arrived at the Rita Blanca site in Texas, but the grasshopper sparrow arrival at the Wind Cave site in South Dakota 14 days after they arrived at the Rita Blanca site. In 2012, the arrival dates of the grasshopper sparrow at the Badlands site in South Dakota and Rita Blanca site in Texas were similar, but the arrival date at the Wind Cave site in South Dakota was 16 days later. The eBird migration data have high value for education and increasing understanding of avian migration ecology (Sullivan et al. 2009), especially for species of grassland birds with limited data during the migration life cycle. However, the migration timing for local populations of grassland birds may be more complex than the latitudinal arrival dates observed in the eBird data. Our results suggested the eBird data may be better suited for generating hypotheses that can be evaluated using a well designed monitoring program. Complex patterns of migratory connectivity with breeding populations linked to different wintering populations may explain the variability in arrival dates for the grasshopper sparrow (Norris and Marra 2007).

The eBird data indicated a negative annual trend in arrival dates of the grasshopper sparrow, suggesting this species is arriving on the breeding grounds earlier each year. According to the BBS, the grasshopper sparrow is undergoing a long-term population decline. One prediction from the hypothesis for a mismatch in migration timing is that certain species are vulnerable to climate change because they are unable to alter migration timing to match peak resource availability (Both and Visser 2001). Our results suggest that the grasshopper sparrow may be able to alter migration timing to match early onset of spring conditions. Because this species demonstrated flexibility in migration timing, climate change and associated changes to the timing of resource availability may not be a large contributor to ongoing population declines of this species. Future research to investigate the correlation between spring green-up and the arrival dates of the grasshopper sparrow may be useful for predicting the response of this species to climate change. In addition, future research is needed to investigate the extent that migration timing and climate change may influence population persistence for other grassland species of conservation concern.

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Appendices

Appendix A. Model selection and parameter estimate tables for the migratory arrival dates of the long-billed curlew, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table A1. Model selection for the detection (p) and occupancy (ψ) rates of the long-billed curlew for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC _c	ΔAIC_c^a	w_i
$p(\text{Date}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-424.86	8	865.82	0.00	0.097
$p(\text{Date} + \text{Site}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{State})$	-424.27	9	866.65	0.83	0.064
$p(\text{Date}) \psi(\ln\text{Date} + \text{Method} + \text{Site})$	-426.33	7	866.73	0.91	0.061
$p(\text{Date}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{State})$	-426.63	7	867.34	1.52	0.045
$p(\text{Date} + \text{Year}) \psi(\ln\text{Date} + \text{Method} + \text{Site})$	-425.69	8	867.48	1.66	0.042
$p(\text{Date} + \text{Site}) \psi(\ln\text{Date} + \text{Method} + \text{State})$	-425.70	8	867.49	1.67	0.042
$p(\text{Date} + \text{Year}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-424.70	9	867.51	1.69	0.042
$p(\text{Date} + \text{Site}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-423.80	10	867.73	1.91	0.037
$p(\text{Date} + \text{State}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-424.84	9	867.79	1.97	0.036
$p(\text{Date} + \text{Method}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-424.84	9	867.79	1.97	0.036

^a Models with $\Delta\text{AIC}_c < 2$ are shown.

Table A2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting long-billed curlew detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.278	0.301	-0.867	0.312
$p(\text{Date})$	-0.017	0.007	-0.031	-0.002
$\psi(\text{Intercept})$	-3.190	0.946	-5.045	-1.335
$\psi(\text{Site} - \text{Rita Blanca})$	1.448	0.317	0.826	2.071
$\psi(\text{Site} - \text{Wind Cave})^a$	-0.764	0.419	-1.586	0.058
$\psi(\text{Method} - \text{Point})$	-1.681	0.286	-2.242	-1.119
$\psi(\text{Year} - 2012)^a$	0.491	0.291	-0.079	1.062
$\psi(\ln\text{Date})$	0.307	0.248	-0.179	0.794

^a The 90% confidence interval does not cover zero.

Table A3. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the second best model predicting long-billed curlew detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.029	0.434	-0.879	0.822
$p(\text{Site} - \text{Rita Blanca})$	-0.169	0.320	-0.797	0.459
$p(\text{Site} - \text{Wind Cave})$	-0.967	0.453	-1.855	-0.079
$p(\text{Date})$	-0.018	0.008	-0.034	-0.003
$\psi(\text{Intercept})$	-3.444	0.970	-5.346	-1.543
$\psi(\text{State} - \text{Texas})$	1.611	0.318	0.988	2.234
$\psi(\text{Method} - \text{Point})$	-1.663	0.286	-2.225	-1.102
$\psi(\text{Year} - 2012)^a$	0.486	0.291	-0.085	1.057
$\psi(\ln\text{Date})$	0.331	0.255	-0.169	0.831

^a The 90% confidence interval does not cover zero.

Appendix B. Model selection and parameter estimate tables for the migratory arrival dates of the Cassin's sparrow, Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table B1. Model selection for the detection (p) and occupancy (ψ) rates of the Cassin's sparrow for acoustic recording units and point count stations during migration at Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC_c	ΔAIC_c^a	w_i
$p(\text{Date} + \text{Year}) \psi(\ln\text{Date} + \text{Method} + \text{Year} + \text{Site})$	-290.89	8	598.05	0.00	0.431
$p(\text{Date} + \text{Year}) \psi(\ln\text{Date} + \text{Method} + \text{Year})$	-292.43	7	599.07	1.03	0.258

^a Models with $\Delta AIC_c < 2$ are shown.

Table B2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting Cassin's sparrow detection (p) and occupancy (ψ) at Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.589	0.691	-1.943	0.766
$p(\text{Year} - 2012)$	-1.087	0.321	-1.716	-0.457
$p(\text{Date})$	0.051	0.016	0.020	0.083
$\psi(\text{Intercept})$	-10.588	2.171	-14.843	-6.333
$\psi(\text{Site} - \text{Rita Blanca})^a$	-0.537	0.308	-1.142	0.068
$\psi(\text{Method} - \text{Point})$	-1.407	0.315	-2.024	-0.790
$\psi(\text{Year} - 2012)$	-1.380	0.338	-2.043	-0.716
$\psi(\ln\text{Date})$	2.870	0.584	1.725	4.016

^a The 90% confidence interval does not cover zero.

Appendix C. Model selection and parameter estimate tables for the migratory arrival dates of the vesper sparrow, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table C1. Model selection for the detection (p) and occupancy (ψ) rates of the vesper sparrow for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC_c	ΔAIC_c a	w_i
$p(\text{State} + \text{Method}) \psi(\ln\text{Date} * \text{Method} + \ln\text{Date} * \text{Year})$	- 519.49	9	1057.10	0.00	0.174
$p(\text{State} + \text{Year}) \psi(\ln\text{Date} * \text{Method} + \ln\text{Date} * \text{Year})$	- 519.85	9	1057.81	0.71	0.122
$p(\text{State} + \text{Method}) \psi(\ln\text{Date} * \text{Method})$	- 521.92	7	1057.91	0.81	0.116

^a Models with $\Delta AIC_c < 2$ are shown.

Table C2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting vesper sparrow detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012 .

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	0.499	0.138	0.229	0.769
$p(\text{Method} - \text{Point})$	0.874	0.361	0.167	1.581
$p(\text{State} - \text{Texas})$	-2.255	0.596	-3.424	-1.085
$\psi(\text{Intercept})$	-10.024	2.783	-15.479	-4.568
$\psi(\text{Method} - \text{Point})$ ^a	3.880	2.228	-0.486	8.248
$\psi(\text{Year} - 2012)$ ^a	3.741	2.185	-0.541	8.024
$\psi(\ln\text{Date})$	2.203	0.713	0.804	3.602
$\psi(\ln\text{Date} * \text{Method} - \text{Point})$	-1.283	0.580	-2.420	-0.145
$\psi(\ln\text{Date} * \text{Year} - 2012)$	-0.883	0.560	-1.982	0.216

^a The 90% confidence interval does not cover zero.

Table C3. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting vesper sparrow detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	1.097	0.258	0.591	1.602
$p(\text{Year} - 2012)$	-0.667	0.301	-1.257	-0.077
$p(\text{State} - \text{Texas})$	-1.484	0.527	-2.517	-0.450
$\psi(\text{Intercept})$	-10.357	2.801	-15.847	-4.866
$\psi(\text{Method} - \text{Point})^a$	4.237	2.235	-0.144	8.618
$\psi(\text{Year} - 2012)^a$	3.835	2.189	-0.455	8.125
$\psi(\ln \text{Date})$	2.272	0.717	0.866	3.679
$\psi(\ln \text{Date} * \text{Method} - \text{Point})$	-1.352	0.582	-2.492	-0.212
$\psi(\ln \text{Date} * \text{Year} - 2012)$	-0.897	0.561	-1.997	0.204

^a The 90% confidence interval does not cover zero.

Appendix D. Model selection and parameter estimate tables for the migratory arrival dates of the lark sparrow, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table D1. Model selection for the detection (p) and occupancy (ψ) rates of the lark sparrow for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC_c	ΔAIC_c^a	w_i
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{SD-TX})$	-201.38	6	414.82	0.00	0.126
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{SD-TX} + \text{Year})$	-200.61	7	415.28	0.46	0.100
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{Site})$	-199.81	8	415.71	0.88	0.081
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{SD-TX} + \text{Year} + \text{Method})$	-199.89	8	415.88	1.06	0.074
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} * \text{SD-TX} + \ln\text{Date} * \text{Method})$	-198.91	9	415.93	1.11	0.072
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} * \text{SD-TX})$	-201.14	7	416.35	1.53	0.059
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{SD-TX} + \text{Method})$	-201.27	7	416.62	1.80	0.051
$p(\text{Method} + \text{Year}) \psi(\ln\text{Date} + \text{Year} + \text{Site})$	-199.32	9	416.75	1.93	0.048

^a Models with $\Delta AIC_c < 2$ are shown.

Table D2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting lark sparrow detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-1.830	0.486	-2.783	-0.877
$p(\text{Year} - 2012)$	2.257	0.577	1.125	3.389
$p(\text{Method} - \text{Point})$	1.536	0.623	0.315	2.758
$\psi(\text{Intercept})$	-13.991	2.733	-19.348	-8.635
$\psi(\text{SD-TX} - \text{Texas})$	2.604	0.422	1.776	3.431
$\psi(\ln\text{Date})$	2.612	0.674	1.291	3.934

Appendix E. Model selection and parameter estimate tables for the migratory arrival dates of the lark bunting, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table E1. Model selection for the detection (p) and occupancy (ψ) rates of the lark bunting for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC_c	ΔAIC_c^a	w_i
$p(\text{Year} + \text{Method}) \psi(\ln\text{Date} + \text{Site} + \text{Year})$	-289.56	9	597.24	0.00	0.180
$p(\text{Year} + \text{Method}) \psi(\ln\text{Date} + \text{Site} + \text{Year} + \text{Method})$	-288.69	10	597.52	0.29	0.155
$p(\text{Year} * \text{Method}) \psi(\ln\text{Date} + \text{Site} + \text{Year})$	-288.74	10	597.62	0.39	0.148
$p(\text{Year} * \text{Method}) \psi(\ln\text{Date} + \text{Site} + \text{Year} + \text{Method})$	-287.83	11	597.83	0.59	0.133
$p(\text{Year} + \text{Date}) \psi(\ln\text{Date} + \text{Site} + \text{Year})$	-290.36	9	598.83	1.59	0.081

^a Models with $\Delta AIC_c < 2$ are shown.

Table E2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting lark bunting detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.235	0.215	-0.657	0.188
$p(\text{Year} - 2012)$	0.789	0.299	0.202	1.375
$p(\text{Method} - \text{Point})$	1.127	0.464	0.217	2.037
$\psi(\text{Intercept})$	-21.938	2.849	-27.523	-16.352
$\psi(\text{Site} - \text{Lake Meredith})$	0.451	0.838	-1.191	2.094
$\psi(\text{Site} - \text{Rita Blanca})$	3.078	0.475	2.146	4.010
$\psi(\text{Site} - \text{Wind Cave})$	-1.097	0.824	-2.712	0.518
$\psi(\text{Year} - 2012)$	1.719	0.348	1.036	2.402
$\psi(\ln\text{Date})$	4.553	0.671	3.236	5.869

Table E3. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the second best model predicting lark bunting detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.233	0.215	-0.655	0.189
$p(\text{Year} - 2012)$	0.783	0.297	0.201	1.365
$p(\text{Method} - \text{Point})$	1.157	0.451	0.272	2.042
$\psi(\text{Intercept})$	-21.671	2.841	-27.239	-16.103
$\psi(\text{Site} - \text{Lake Meredith})$	0.538	0.847	-1.123	2.198
$\psi(\text{Site} - \text{Rita Blanca})$	3.276	0.505	2.285	4.267
$\psi(\text{Site} - \text{Wind Cave})$	-0.778	0.872	-2.488	0.931
$\psi(\text{Method} - \text{Point})$	-0.474	0.359	-1.178	0.230
$\psi(\text{Year} - 2012)$	1.708	0.347	1.027	2.389
$\psi(\ln\text{Date})$	4.526	0.668	3.215	5.836

Table E4. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the third best model predicting lark bunting detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.283	0.218	-0.710	0.145
$p(\text{Year} - 2012)$	0.883	0.305	0.284	1.481
$p(\text{Method} - \text{Point})$	2.423	1.135	0.198	4.647
$p(\text{Method} - \text{Point} * \text{Year} - 2012)$	-1.527	1.229	-3.936	0.883
$\psi(\text{Intercept})$	-21.958	2.851	-27.547	-16.369
$\psi(\text{Site} - \text{Lake Meredith})$	0.448	0.837	-1.193	2.090
$\psi(\text{Site} - \text{Rita Blanca})$	3.078	0.475	2.146	4.009
$\psi(\text{Site} - \text{Wind Cave})$	-1.098	0.824	-2.713	0.516
$\psi(\text{Year} - 2012)$	1.746	0.347	1.065	2.427
$\psi(\ln\text{Date})$	4.552	0.671	3.235	5.868

Appendix F. Model selection and parameter estimate tables for the migratory arrival dates of the grasshopper sparrow, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table F1. Model selection for the detection (p) and occupancy (ψ) rates of the grasshopper sparrow for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC _c	ΔAIC_c^a	w_i
$p(\text{Date} + \text{Site}) \psi(\ln\text{Date}*\text{Site} + \ln\text{Date}*\text{Year})$	-1070.41	14	2169.09	0.00	0.393
$p(\text{Date} + \text{Year}) \psi(\ln\text{Date}*\text{Site} + \ln\text{Date}*\text{Year})$	-1071.82	13	2169.87	0.77	0.267
$p(\text{Date} + \text{Site}) \psi(\ln\text{Date}*\text{Site} + \ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-1069.11	16	2170.58	1.48	0.187

^a Models with $\Delta\text{AIC}_c < 2$ are shown.

Table F2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting grasshopper sparrow detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.113	0.355	-0.809	0.584
$p(\text{Site} - \text{Texas})^a$	-0.360	0.211	-0.774	0.053
$p(\text{Site} - \text{Wind Cave})$	-0.763	0.204	-1.164	-0.362
$p(\text{Date})$	0.037	0.007	0.023	0.051
$\psi(\text{Intercept})$	-15.279	1.703	-18.616	-11.941
$\psi(\text{Site} - \text{Lake Meredith})$	-64.712	50.251	-163.205	33.781
$\psi(\text{Site} - \text{Rita Blanca})$	1.455	2.282	-3.019	5.929
$\psi(\text{Site} - \text{Wind Cave})$	-7.358	2.449	-12.158	-2.558
$\psi(\text{Year} - 2012)$	2.929	1.831	-0.660	6.518
$\psi(\ln\text{Date})$	3.956	0.444	3.086	4.826
$\psi(\ln\text{Date}*\text{Site} - \text{Lake Meredith})$	16.328	13.090	-9.329	41.985
$\psi(\ln\text{Date}*\text{Site} - \text{Rita Blanca})$	-0.477	0.614	-1.681	0.726
$\psi(\ln\text{Date}*\text{Site} - \text{Wind Cave})$	1.530	0.619	0.315	2.744
$\psi(\ln\text{Date}*\text{Year} - 2012)$	-0.571	0.472	-1.497	0.355

^a The 90% confidence interval does not cover zero.

Table F3. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the second best model predicting grasshopper sparrow detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-0.523	0.329	-1.169	0.122
$p(\text{Year} - 2012)$	0.563	0.163	0.242	0.884
$p(\text{Date})$	0.033	0.006	0.021	0.045
$\psi(\text{Intercept})$	-15.120	1.714	-18.481	-11.759
$\psi(\text{Site} - \text{Lake Meredith})$	-64.673	50.243	-163.150	33.804
$\psi(\text{Site} - \text{Rita Blanca})$	1.311	2.278	-3.153	5.776
$\psi(\text{Site} - \text{Wind Cave})$	-7.589	2.440	-12.373	-2.806
$\psi(\text{Year} - 2012)$	2.751	1.834	-0.844	6.346
$\psi(\ln \text{Date})$	3.921	0.447	3.045	4.796
$\psi(\ln \text{Date} * \text{Site} - \text{Lake Meredith})$	16.316	13.088	-9.337	41.968
$\psi(\ln \text{Date} * \text{Site} - \text{Rita Blanca})$	-0.443	0.613	-1.645	0.758
$\psi(\ln \text{Date} * \text{Site} - \text{Wind Cave})$	1.582	0.618	0.371	2.793
$\psi(\ln \text{Date} * \text{Year} - 2012)$	-0.530	0.473	-1.458	0.397

Appendix G. Model selection and parameter estimate tables for the migratory arrival dates of the brown-headed cowbird, Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Table G1. Model selection for the detection (p) and occupancy (ψ) rates of the brown-headed cowbird for acoustic recording units and point count stations during migration at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Model	$\log(L)$	K	AIC_c	ΔAIC_c^a	w_i
$p(\text{State}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-518.12	8	1052.33	0.00	0.070
$p(\text{Date}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-518.44	8	1052.98	0.65	0.051
$p(\text{State} + \text{Date}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-517.64	9	1053.39	1.05	0.041
$p(\text{State} + \text{Method}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-517.78	9	1053.67	1.34	0.036
$p(\text{State} + \text{Method}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{State})$	-517.94	9	1054.00	1.67	0.030
$p(\text{State} + \text{Year}) \ \psi(\ln\text{Date}*\text{Year} + \ln\text{Date}*\text{Method})$	-517.98	9	1054.07	1.73	0.029
$p(\text{State} + \text{Method}) \ \psi(\ln\text{Date}*\text{Year})$	-520.00	7	1054.07	1.73	0.029

^a Models with $\Delta AIC_c < 2$ are shown.

Table G2. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the best model predicting brown-headed cowbird detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-1.251	0.151	-1.548	-0.955
$p(\text{State} - \text{Texas})$	-0.562	0.271	-1.094	-0.030
$\psi(\text{Intercept})$	-11.996	2.399	-16.698	-7.294
$\psi(\text{Method} - \text{Point})$	2.111	2.346	-2.488	6.709
$\psi(\text{Year} - 2012)$	6.097	2.472	1.251	10.942
$\psi(\ln\text{Date})$	2.995	0.633	1.754	4.237
$\psi(\ln\text{Date}*\text{Method} - \text{Point})^a$	-1.079	0.617	-2.289	0.132
$\psi(\ln\text{Date}*\text{Year} - 2012)$	-1.660	0.650	-2.933	-0.386

^a The 90% confidence interval does not cover zero.

Table G3. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits from the second best model predicting brown-headed cowbird detection (p) and occupancy (ψ) at Badlands and Wind Cave National Parks, South Dakota, and Lake Meredith National Recreation Area and Rita Blanca National Grassland, Texas, USA, 2011-2012.

Parameter	Estimate	SE	LCL	UCL
$p(\text{Intercept})$	-2.421	0.570	-3.538	-1.304
$p(\text{Date})^a$	0.020	0.011	-0.001	0.041
$\psi(\text{Intercept})$	-10.101	2.522	-15.046	-5.157
$\psi(\text{Method} - \text{Point})$	2.038	2.274	-2.420	6.497
$\psi(\text{Year} - 2012)$	5.325	2.422	0.578	10.071
$\psi(\ln \text{Date})$	2.477	0.654	1.195	3.759
$\psi(\ln \text{Date} * \text{Method} - \text{Point})^a$	-1.036	0.593	-2.198	0.126
$\psi(\ln \text{Date} * \text{Year} - 2012)$	-1.431	0.630	-2.667	-0.194

^a The 90% confidence interval does not cover zero.

Appendix H. Parameter estimate tables for the migratory arrival dates of the grasshopper sparrow in the Great Plains, USA, 1999-2013.

Table H1. The parameter estimates, standard errors (SE), and lower (LCL) and upper (UCL) 95% confidence limits for the arrival date of the Grasshopper Sparrow within the two degree latitude-longitude grid.

Parameter	Estimate	SE	LCL	UCL
Intercept	45.09	5.50	34.27	55.91
Year	-0.86	0.16	-1.17	-0.54
Latitude	2.16	0.13	1.90	2.43
Random effect (Year*Grid ID)	163.62	17.30	134.37	203.62
Residual error	68.79	46.33	25.60	490.84