Developing Decision Support Tools for Optimizing Retention and Placement of Conservation Reserve Program Grasslands in the Northern Great Plains for Grassland Birds

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ABSTRACT

The U.S. Department of Agriculture Conservation Reserve Program (CRP) has provided important nesting habitat in the Northern Great Plains for grassland birds, one of the fastest declining groups of birds in North America. However, the amount of land enrolled in the CRP has been declining due to retired contracts coupled with lower nation-wide enrollment caps. To maximize the benefits of CRP for grassland birds, we developed decision-support tools to guide retention and enrollment. We used stop-level data from The North American Breeding Bird Survey to create density and distribution models for eight species of grassland birds across the Prairie Pothole Joint Venture and Northern Great Plains Joint Venture. We used covariates derived from land cover, climatic, and topographic datasets. Species were selected based on joint venture priorities and included Baird's Sparrow, Bobolink, Chestnut-collared Longspur, Dickcissel, Grasshopper Sparrow, Lark Bunting, Ring-necked Pheasant, and Sprague's Pipit. Generally all species showed a negative association with water, forest, and/or developed areas, and a positive association with grasslands. Six species were positively associated with managed grasslands and generally occurred at higher densities in the west, while Bobolink, Dickcissel, and Ring-necked Pheasant occurred at higher densities in the east and were more associated with a diversity of cover types including cropland, pasture/hay, CRP or alfalfa. Five species were positively associated with CRP, while Sprague's Pipit, Chestnut-collared Longspur, and Lark Bunting were negatively associated with CRP, and generally more strongly associated with drier managed grasslands of the west. In total, CRP supported ~5% (~720,000 birds) of the total estimated population for those that had positive associations with CRP. If CRP were treated as managed grasslands, we estimated that populations of those species that had a negative association with CRP would increase 4%. Targeting areas for CRP enrollment based on density

models, and encouraging CRP management through grazing or haying would be most beneficial for grassland birds in this region.

INTRODUCTION

The Conservation Reserve Program (CRP) of the 1985 Food Security Act (Public Law 99-198) is the largest private lands conservation program in the United States and is implemented by the U.S. Department of Agriculture (USDA) Farm Services Agency (FSA). Lands enrolled in the CRP provide habitat for a variety of grassland bird species, typically at higher densities than adjacent croplands (Johnson and Schwartz 1993, Reynolds et al. 1994, Johnson and Igl 1995, Best et al. 1997, Herkert 1998). In addition to providing habitat that harbors high densities of birds, CRP grasslands also provide secure nesting cover for many species of grassland-nesting birds (Best et al. 1997, Koford 1999, Reynolds et al. 2001).

The CRP may be particularly important in the Northern Great Plains, as populations of grassland birds are declining at a steeper rate than any other group of North American birds (Knopf 1994, Herkert 1995) and the Northern Great Plains has the highest diversity of grassland bird species on the continent (Figure 1; Peterjohn and Sauer 1999). Unfortunately for conservation, nation-wide enrollment of CRP lands by FY18 has been capped at 24 million acres, a 25% decrease from the previous cap of 32 million acres, which will reduce benefits for grassland birds. However, the development and use of spatial decision-support tools can minimize effects of the reduced acreage cap and maximize benefits for grassland birds by prioritizing existing CRP parcels for retention and assessing new parcels for future enrollment of CRP lands.

Spatial decision-support tools have been successfully used to guide conservation of grassland nesting birds in many locations and situations, including prioritization of land parcels for CRP enrollment (e.g. Reynolds et al. 2006). Given the need to maximize benefits of CRP lands for grassland birds as CRP acreage declines, we had three main objectives: 1) develop species-specific density and/or distribution models with each species' response to CRP and other landscape predictors using methods that can be applied throughout the conterminous United States; 2) develop spatial decision-support tools (i.e. maps) that will help the FSA prioritize CRP parcels for retention and acquisition in the Northern Great Plains; and 3) provide recommendations from technical experts and land managers on CRP policy and management to optimize the program for grassland nesting birds. The final objective is included in this interim report as Appendix C.

METHODS

Study Area

Models were developed for the Prairie Pothole Joint Venture and Northern Great Plains Joint Venture administrative areas of North Dakota, South Dakota, Montana, Wyoming, Minnesota, and Iowa (Figure 1). The study area covers approximately 332,000 square miles and is comprised of three grassland ecoregions following an east– west gradient, with higher precipitation in the east (Wiens 1974): tallgrass prairie, mixed grass prairie, and dry mixed grass prairie (Figure 2). The precipitation gradient greatly influences land use, vegetation composition and structure, and bird communities (Wiens 1974, Samson et al. 1998, Niemuth et al. 2008). Much native grassland has been converted to crop production, with losses of native prairie exceeding 99% in the eastern tallgrass prairie portion of the study area (Samson and Knopf 1994, Licht 1997). Recent high commodity prices and biofuel mandates for corn and soybeans have driven a westward surge of grassland loss across the central Northern Great Plains (Wright and Wimberly 2013, Lark et al. 2015). However, the relatively dry conditions in western dry-mixed grass prairie ecoregion are not conducive to growing those row crops. Instead, dryland agriculture in this region is dominated by small grains such as wheat and barley, with relatively large expanses of grassland and sagebrush-steppe supporting cattle ranching.

BBS Data

Species-specific density and distribution models for grassland birds were developed using stop-level observations from The North American Breeding Bird Survey (BBS) following methods adapted from Niemuth et al. (2017). The BBS is an annual, continent-wide survey that is the primary source of information regarding North American bird populations, relying on the efforts of thousands of volunteer observers combined with the scientific rigor of the survey and analysis of resulting data (Bystrak 1981, Sauer et al. 2017). We used stop-level data (individual survey points along a BBS route) from 2008-2016 downloaded from the U.S. Geological Survey Patuxent Wildlife Research Center, Laurel, Maryland, USA (Pardieck et al. 2017); this timespan was appropriate as it overlapped with the time period of land cover data collection. We obtained data for 11,228 stops collected on 229 routes in the Prairie Pothole and Northern Great Plains Joint Ventures for a total of 71,774 observations by 197 observers (Figure 2).

Stop coordinates for BBS routes were not available for download and were created using one of three methods. The preferred method was to obtain stop coordinates collected by observers using GPS devices; this method accounted for 32% of our stops used in our analysis. If these data were not available, we digitized stops in a Geographic Information System (GIS) using stop descriptions from the BBS database with current USDA National Agricultural Imagery Program aerial photography (41%). If neither stop coordinates nor stop descriptions were available, we produced stop locations in a GIS at 0.5 mi spacing along the route (27%). BBS protocol indicates that when a route is first developed an observer should establish stops at

0.5 mi intervals measured via an odometer; however, BBS protocol allows stops to be within 0.5-0.7 mi from the previous stop to allow for placement near a recognizable landmark and/or a safe location. Stop locations produced in a GIS at 0.5 mi intervals could lack accuracy for certain routes; however given the flat topography and landscape-scale modeling techniques we used, the potential lack of accuracy should have minimal influence on model estimates.

We selected 17 potential grassland bird species for model development, representing a large portion of the grassland-dependent species breeding in the study area (Table 2). We then selected a subset of species for modeling analysis that breed across the study area and are either species of conservation concern or JV priority species. Initial models for this interim report were developed for the following eight species: Grasshopper Sparrow (*Ammodramus savannarum*), Baird's Sparrow (*Ammodramus bairdii*), Chestnut-collared Longspur (*Calcarius ornatus*), Sprague's Pipit (*Anthus spragueii*), Bobolink (*Dolichonyx oryzivorus*), Dickcissel (*Spiza Americana*), Lark Bunting (*Calamospiza melanocorys*), and Ring-necked Pheasant (*Phasianus colchicus*).

Predictor Variables

We developed models from a suite of candidate predictor variables that characterized landscape composition and configuration, weather and climate, daily and seasonal changes in bird activity and detectability, topographic variation, and survey structure, all of which have been well supported by previous research (Niemuth et al. 2017; Table 1). Model covariates were derived using 2011 National Land Cover Dataset (NLCD; Homer et al 2015), PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group data (Daly et al. 2008), and the USGS National Elevation Dataset (NED; Gesch et al. 2002). NLCD 2011 has overall agreement of 82% between classified satellite data and a primary or alternate land cover class visually interpreted from aerial photography, although accuracy has been consistently lower among grass-dominated classes (Wickham et al. 2017). To improve thematic resolution and classification accuracy of grass-associated land cover data, we incorporated spatial data from the USDA National Agricultural Statistics Service identifying alfalfa (*Medicago sativa*) fields (Boryan et al. 2011), as well as data delineating 5.2 million acres of land enrolled in CRP grasslands, which were mapped rather than interpreted from remotely sensed imagery. All predictor data were processed at a spatial resolution of 30 m.

We extracted data for the following land cover types: grass/herb, pasture/hay, CRP, alfalfa, crop, shrub, bare, open water, emergent wetland, and woody wetland. Additionally, we aggregated the following land cover variables: all developed (low, medium, and high); all forest (coniferous, deciduous, and mixed); all woody vegetation (forest and shrub); all grass (grass/herbaceous, pasture/hay, CRP, and alfalfa); and all water (open water, emergent wetland, and woody wetland). Aggregated variables are beneficial for reducing model complexity when individual land cover components have similar effects on abundance. We defined land cover patches as contiguous land cover types. We used a spatial moving windows analysis in a GIS to calculate focal statistics for each aggregated land cover class using the following landscape scales (i.e. radius of moving window): 400 m, 800 m, 1200 m, 1600 m, 2400 m, and 3200 m. Using this technique, we calculated the percentage of land area and number of patches of each land cover class within the moving window at each scale. We obtained climatic data for 30-year mean minimum temperature, mean maximum temperature, and precipitation. In addition, we obtained annual sum precipitation from 2008-2016, and subtracted the 30-year mean precipitation data from the annual precipitation data, which represented annual precipitation anomalies. We used a similar moving window analysis approach with the NED data to calculate the elevation mean and standard deviation at each landscape scale. In addition, we subtracted the mean elevation from the raw elevation to create a covariate that estimates if a point on the landscape is higher or lower than the surrounding mean elevation at each landscape scale. Last, we extracted the values for all raster datasets at each stop location and joined these data to BBS observational data. BBS observational data were included in models to account for factors that could influence detection including observer identity, day of year, stop number (as a proxy for daily time), and wind speed. We scaled and centered all continuous model covariates by subtracting the mean and dividing by the standard deviation to optimize model convergence.

Model Development

We developed generalized linear mixed-effects regression models with a Poisson distribution and log link function for abundance models in program R version 3.4.0 (R core team 2017) using the lme4 package (Bates et al. 2015). If we could not develop an abundance model that performed well, we used logistic regression with a binomial distribution and logit link function to model probability of occurrence in the lme4 package. We used route, route:observer, and year as random intercepts. While change in observed counts over time can be a function of change in population size, it can also be a function of many other confounding variables, such as different observers surveying a route (i.e., skill), day of year, or weather. Unique combination of route:observer were included as a random intercept to account for the effect of different skills of multiple observers for a route . This random effects structure complements the experimental design of the BBS and has been implemented in other models examining BBS data (Sauer and Link 2011). If a bird had an observation in a state within the study area then we used all routes in that state in the model. We evaluated competing models for model development and selection (Burnham and Anderson 2002). Migratory breeding birds settle on the landscape in a hierarchical process that occurs at different landscape scales (Block and Brennan 1993). To determine the landscape scale that best fit the data, we first developed global models at each landscape scale that contained a maximum number of covariates with reduced multicollinearity; global models contained variables with Pearson's $r < |0.7|$ and a variance inflation factor (VIF) < 3 (Zuur et al 2010). We used AIC values of competing models to select the landscape scale that best fit the data (i.e. Δ AIC < 2). We then used exploratory analyses to further guide model development, including factored box plots, line graphs, and univariate models that included covariate transformations (log and square root) and quadratic terms. Covariates were transformed to improve the linear relationship with the response variable or to improve the distribution of covariate residuals. We discriminated among reduced versions of the full model, holding out one parameter or set of parameters at a time and assessing improvements in AIC values to select a best approximating model (Burnham and Anderson 2002, Crawley 2007) and to remove uninformative covariates (Arnold 2010). The utility of these models for conservation planning and delivery are maximized if grass, CRP, and crop are all included in the model. Multicollinearity could influence results using this method; however, we did not pursue this approach if inclusion of one of these covariates had a large influence on coefficient estimates (e.g. reversed coefficient signs). After selecting the most parsimonious model we forced any of these three covariates lacking back into the model if necessary. The best model was validated by testing for overdispersion and/or zero-inflation, spatial autocorrelation, comparing the AIC of the top model to the null model AIC (i.e. only random effects included), and comparing observed to predicted values to see if they followed a 1:1 ratio. If spatial autocorrelation was detected in model residuals we reduced or eliminated it by including an autoregressive term that indicated the presence of the target species at adjacent stops to improve model fit and reduce local autocorrelation (Augustin et al. 1996). We further evaluated logistic regression models by calculating the area under the curve (AUC) of receiver operating characteristics (ROC; Hosmer and Lemeshow 2000) using 10-fold cross validation (Stone 1974).

Models were spatially applied in a GIS to estimate the CRP's overall and marginal effects on bird populations using two scenarios: 1) applying each model with 2016 CRP data, and 2) applying each model with all CRP fields converted to crop. For those species that showed a negative association with CRP we applied each model with all CRP fields converted to grass/herb. We summarized total population estimates for each state in the study area with and without CRP (Appendix B); the difference between these two estimates indicates the number of birds CRP supported, or conversely, the number of birds potentially lost if CRP were converted back to cropland (i.e., overall effect). We also summarized the number of birds predicted within CRP fields for each state; the difference between the number of birds CRP supported and the number of birds in CRP fields provides an estimate of the marginal benefits of CRP surrounding the parcel at a distance of the landscape scale used. Using this method, we can also estimate the number of birds lost per acre of CRP lost for each state. Model results were scaled using Partner's in Flight inflation factors that included estimates of species' detection distance and pair adjustments (Blancher et al. 2013). This approach provides biologically relevant and reasonable predictions; however, it can also have a large effect on predictions and an accurate assessment and understanding of detection distance and pair adjustments are paramount (Thogmartin et al. 2006b).

We developed pseudo-abundance models from occurrence models to estimate population loss within CRP fields. This was accomplished by calculating the proportion of probability of occurrence relative to the sum of all values (i.e., divide probability of occurrence by the sum of all probability of occurrence values) and then multiplying these values by the PIF population estimates. Forcing the population to sum to the PIF population estimate does not allow the calculation of marginal benefits, however.

RESULTS

Predictive Models

Landscapes surrounding BBS stops throughout our study region varied considerably in type and distribution of land cover (Table 3). Data were dominated by zeroes for all species; however, final models predicted zeros adequately (Table 4). Given the complexity of the model and number of variables considered, the Ring-necked Pheasant model did not successfully converge, even when the number of maximum likelihood iterations was increased to 500,000. Authors of the lme4 package have debated the limit for convergence warnings and have suggested in cases where the maximum absolute scaled gradient >0.001 to double check calculations by comparing it to the absolute gradient and hessian to obtain parallel minimums. In both cases when doing this the minimum was 0.00004 and since coefficient estimates were reasonable, we did not proceed with reducing the model to eliminate warnings.

Best-supported models characterizing bird/environmental relationships indicated that occurrence of all species was influenced by climate, weather, or topography as well as landscape composition and configuration (Table 5 and Table 6). Habitat and observed bird numbers showed strong positive spatial autocorrelation, but spatial autocorrelation was greatly reduced or eliminated in model residuals for all species we assessed (Figure 3). Climate and land cover variables accounted for much spatial autocorrelation, but observer and time variables were necessary to remove remnant spatial autocorrelation. Models for Chestnut-collared Longspur and Lark Bunting required the addition of an autoregressive term to remove remnant positive spatial autocorrelation from model residuals. Improvements in AIC values over the null model indicated substantial support for the best-supported model for all species, and R^2 values for abundance models ranged from 0.22 – 0.54. The AUC value for both Baird's Sparrow and Chestnut-collared Longspur occurrence models was 0.93 (Table 4), indicating outstanding discrimination (Hosmer and Lemeshow 2000). Species showed similar responses to landscape characteristics, with consistent negative association with trees, shrub, water and urban areas; positive and varying association with grassland cover classes; and a negative, weak positive, or curvilinear response to cropland (Table 5 and Table 6).

CRP response was positive for five of the eight species in the analysis with decreased predicted numbers following simulated conversion of CRP fields to cropland in the landscape (Table 7, Appendix A, Appendix B). Chestnut-collared Longspur, Lark Bunting, and Sprague's Pipit had weak negative associations with CRP; abundance for these species increased following simulated conversion of CRP fields to grass/herb (Table 7, Appendix A, and Appendix B). Partial plots (Appendix B) showing marginal effects of CRP indicate varied response curves, and were spatially varied, where the greatest effect of CRP often occurred in areas of greatest estimated density. For example, Baird's Sparrow and Chestnut-collared Longspur were both most abundant in Montana, and the greatest effect of CRP occurred in Montana. However, Baird's Sparrow had a positive exponential response curve with most of the gain in abundance occurring in the first 25% increase of CRP, while Chestnut-collared Longspur had a negative exponential response curve with most loss occurring in the first 25% increase of CRP. Ring-necked Pheasant had the greatest response to CRP in Minnesota with a quadratic response curve, where the greatest increase in abundance occurred at ~13% CRP (i.e. 1,033 acres CRP).

Precipitation influenced occurrence or abundance of four of the eight species, with three influenced by long-term (30-year mean) precipitation and one influenced by short-term (current-year) precipitation. Occurrence or abundance of seven of the eight species was strongly associated with mean long-term (30-year max or 30-year min) temperature. Occurrence or abundance of all species was strongly related to elevation. Detection of all species was influenced by survey structure, including observer, year, and route effects, and all but Sprague's Pipit and Chestnut-collared Longspur were influenced by daily and/or seasonal timing of surveys (Table 5).

Spatial patterns in predicted occurrence and abundance of grassland birds reflected regional climatic patterns, land forms, and cover classes. Sprague's Pipit, Chestnut-collared Longspur, Grasshopper Sparrow and Lark Bunting selected higher elevation areas in the west; Bobolink and Dickcissel selected lower elevation areas in the east; and Ring-necked Pheasant was found throughout much of the study area. Predicted abundance/occurrence at each BBS stop was positively correlated with observed numbers for all species (Table 4).

Field Validation

Efforts to validate model results with field visits will occur during the 2018 field season. Validation design, analysis, and results will be included in the 2018 final report.

Decision Support Tools

The Duck Nesting Habitat Initiative (CP-37) prioritization for CRP contract enrollment and retention has proven to be biologically sound and easily implemented by USDA field offices. For the final project report, we will develop decision-support tools by combining the best areas for CRP retention and enrollment for individual species into a single map. Final combined priority areas will also include waterfowl priority areas identified by Drum et al. (2015) to optimize CRP plantings for multi-species benefits. For this interim report, we provide an example with the combined top 25% of all 8 species predicted populations identifying areas to target for CRP retention and enrollment and retention (Figure 4). Decision support tools can be provided in the form of single-species or multi-species maps at the appropriate scape for USDA field station application (e.g., county, district, region, etc.). However, caution is recommended when prioritizing CRP enrollment for multiple species benefits as some of the best habitat for declining species may not coincide with priority habitats for other, generalist species.

DISCUSSION

Similar with Niemuth et al. (2017), our results demonstrate that analyses using stop-level BBS data and environmental data with high thematic resolution were able to describe habitat relationships often associated with fine-grained local studies, but across broad spatial extents and at scales relevant to local conservation actions. For example, our models indicated that Dickcissel was positively associated with a diversity of grassland habitats including pasture/hay, CRP, and alfalfa, all of which are consistent with previous findings of selection for tall, dense cover, and exotic grasses (Sample 1989, Klute et al. 1997, Best et al. 1997, Overmire 1962, Wiens 1973, Frawley and Best 1991). Bobolink showed a similar response, again consistent with previous findings, selecting a diversity of grassland habitats including CRP, alfalfa, and grassland/herbaceous (Renken and Dinsmore 1987, Delisle and Savidge 1997). Conversely, the strong association of Sprague’s Pipit, Grasshopper Sparrow, Lark Bunting, Chestnut-collared Longspur, and Baird’s Sparrow with the grassland/herbaceous cover class, which was found primarily in the central and western portion of our study region, is consistent with previous findings that these species generally select drier sites with relatively short or sparse vegetation (Davis et al. 1999, Madden et al. 2000, Lueders et al. 2006); however, Baird’s Sparrow and

Grasshopper sparrow did demonstrate a positive association with CRP, indicating a broader preference to a range of grassland structure. As expected, most of the species we assessed showed a quadratic or negative association with cropland, which is consistent with previous findings of lower density or likelihood of occurrence in cropland than grasslands (Johnson and Igl 1995, Kirsch and Higgins 1976). In addition, most grassland birds in this study showed a negative association with developed areas, woody vegetation, and water; this is expected and consistent with other studies in this region (e.g., Bakker et. al 2002, Tack et. al 2017).

The association between area of land enrolled in CRP grasslands and occurrence or abundance of Baird's Sparrow, Dickcissel, Grasshopper Sparrow, Bobolink, and Ring-necked Pheasant reinforces previous findings as well as the importance of that program to grassland bird populations in the Great Plains (Johnson and Igl 1995, Delisle and Savidge 1997, Koford 1999, Johnson 2005, Niemuth et al. 2007, Nielson et al. 2008). The negative association between CRP grassland and abundance or occurrence of Sprague's Pipit, Lark Bunting, and Chestnut-collared Longspur reflects those species selection for native grasslands of short to intermediate stature (Davis and Duncan 1999, Davis et al. 1999, Madden et al. 2000). Only 24% of the CRP grassland conservation practices in the study area are associated with native grass seed mixes; furthermore, many CRP lands are not regularly disturbed through grazing, haying, or fire, and generally have a dense structure unsuitable for these species. Therefore, we conducted a simulation for these species where all CRP was replaced with grassland/herbaceous cover, mimicking native grassland CRP enrollment with management, such as grazing (Table 8, Figure A3, Figure A6, Figure A8). As expected, these species responded positively to this change in landcover. It should be noted that our estimates of overall and marginal CRP benefits were lower than similar studies (e.g., Johnson 2005, Niemuth et al. 2007), however given the length of time that has passed since these studies and the considerable amount of CRP loss during that time (~50%), our results are suitable and congruent with trends. Adopting a CRP policy that can better serve the needs of grassland birds in this region is discussed in detail in Appendix C.

Response to elevation and climate varied among species but, similar to other studies (i.e., Thogmartin et al. 2006a, Ahlering et al. 2009, Albright et al. 2010, Lipsey et al. 2015), elevation, precipitation, and/or temperature were strong predictors of abundance or occurrence for most species. The biological significance of topographic and climatic variables is unclear, as they are likely correlates of other factors (e.g., plant community composition and structure, primary and secondary productivity) that more directly influence species occurrence, likely in concert with other factors such as soils and landform (Guisan and Zimmerman 2000, Niemuth et al. 2008). Regardless of mechanism, weather and climate in our study region are highly variable and strongly affect bird occurrence, whether directly or indirectly.

Similar to Niemuth et al. 2017, we did not find support for associations between occurrence of Sprague’s Pipit and number of patches in the landscape, even though previous analyses have found Sprague’s Pipit to be sensitive to landscape fragmentation (Davis 2004, Lipsey et al. 2015); however, it should be noted that as a univariate model there was a negative association with the number of grass/herb patches and Sprague’s Pipit abundance. Due to high collinearity, the sign of the coefficient for grass/herb patches switched (i.e. became positive) when it was incorporated into the model, and therefore we did not keep it in the model.

We also did not find associations between Sprague’s Pipit and stop number or ordinal date, which were present for most of the other species we considered except Chestnut-collared Longspur. Both species have been noted to sing into late afternoon, which could account for the lack of association between stop number, and Chestnut-collared Longspur will typically have two broods and sing throughout the breeding season, which could account for a lack of association with ordinal date (Davis et al. 2014, Bleho et al. 2015). Furthermore, lack of support for these relationships may be a function of the relatively small number of observations for Sprague's Pipit. Sprague's Pipit is simply an uncommon species throughout much of its range, but the problem of small number of detections was addressed in part by the 2015 addition of 42 BBS routes in Montana, which had the lowest BBS route density (1 route per degree block) and highest density of Sprague's Pipit in the United States.

The BBS only provides an index to bird presence and numbers, as existing protocols provide no mechanism for assessing and correcting for detectability, and some unknown fraction of the birds present at each stop is not recorded (Sauer et al. 2013). Nevertheless, uncorrected data can still provide useful estimates of relative density or probability of occurrence (Johnson 2008, Etterson et al. 2009), and spatial models developed from BBS data have been useful for providing ecological insights, guiding conservation, and providing spatially explicit minimum estimates of population size and distribution (e.g., Flather and Sauer 1996, Newbold and Eadie 2004, Thogmartin et al. 2006a, Niemuth et al. 2017). Predicted occurrence was positively and significantly correlated with observed counts for all species we developed occurrence models for, suggesting that the two occurrence models we present are also useful for identifying areas of high density. A drawback of producing occurrence models and applying them to estimate pseudo-abundance is not being able to calculate marginal effects outside the CRP field. This is because the population estimate is always being forced to equal the PIF population estimate. Birds that are lost within the CRP parcel when it is converted to crop are then added somewhere else on the landscape, and the total population never declines from converting CRP to crop. This approach is a tradeoff between spatial accuracy in distribution and accuracy in developing a model with a reasonable population estimate. Products from this study will be used to target CRP and spatial accuracy is paramount. It should be noted that for many models in this study, the marginal effect was highest outside the CRP field, and pseudo-abundnace models could only be capturing a fraction of the total change in population and should be considered conservative estimates of population change.

Our models included several variables (i.e., stop number, ordinal date, autoregressive) that were applied to spatial data as inflation factors to create maps showing relative probability of occurrence or abundance. These variables explained spatio-temporal or fine-grained spatial variation in bird abundance or occurrence that improved estimates for variables that were in line with our goal of developing landscape-scale predictive models over broad spatial and temporal extents. Models that include variables to accommodate observer and route effects as well as daily and seasonal timing can have AIC values >100 points lower than models without such variables (unpublished data), indicating that models that do not accommodate sampling and design issues have essentially zero support for adequately describing the data relative to models that contain those variables (Burnham and Anderson 1998). In addition, elimination of spatial autocorrelation of residuals when timing and observer variables were included suggests that our modeling process accounted for spatio-temporal patterns in detection caused by observer and timing effects.

The radius of the sampling window for which landscape data best described bird occurrence was ≤ 800 m for five of the seven species we evaluated, but extended out to 1,600 m for Sprague’s Pipit and 3,200 m for Lark Bunting and Ring-necked Pheasant. Our findings are consistent with other studies showing that landscape characteristics influence occurrence or density of grassland birds and that the scale of landscape influence varies among species (Ribic and Sample 2001, Cunningham and Johnson 2006, Thogmartin et al. 2006a, Niemuth et al. 2017). Birds likely respond to different landscape features (i.e., trees vs. wetlands) at different scales, but we did not assess landscape characteristics at multiple scales within individual species' models due to the absence of *a priori* information about selection preferences by each species.

For all species but Dickcissel, our abundance models consistently under-predicted and produced lower population estimates relative to those of Blancher et al. (2013). This is not surprising as we are incorporating species/habitat relationships which may have great influence compared to population estimates without habitat relationships. Our results demonstrate the utility of using spatially explicit models to evaluate a conservation program, as the landscape relationships incorporated into the models provide a mechanism for examining effects of conversion of CRP grasslands to cropland.

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Figure 1. The study area includes the Prairie Pothole Joint Venture (PPJV) and Northern Great Plains Joint Venture (NGPJV), both of which have high richness of grassland bird species.

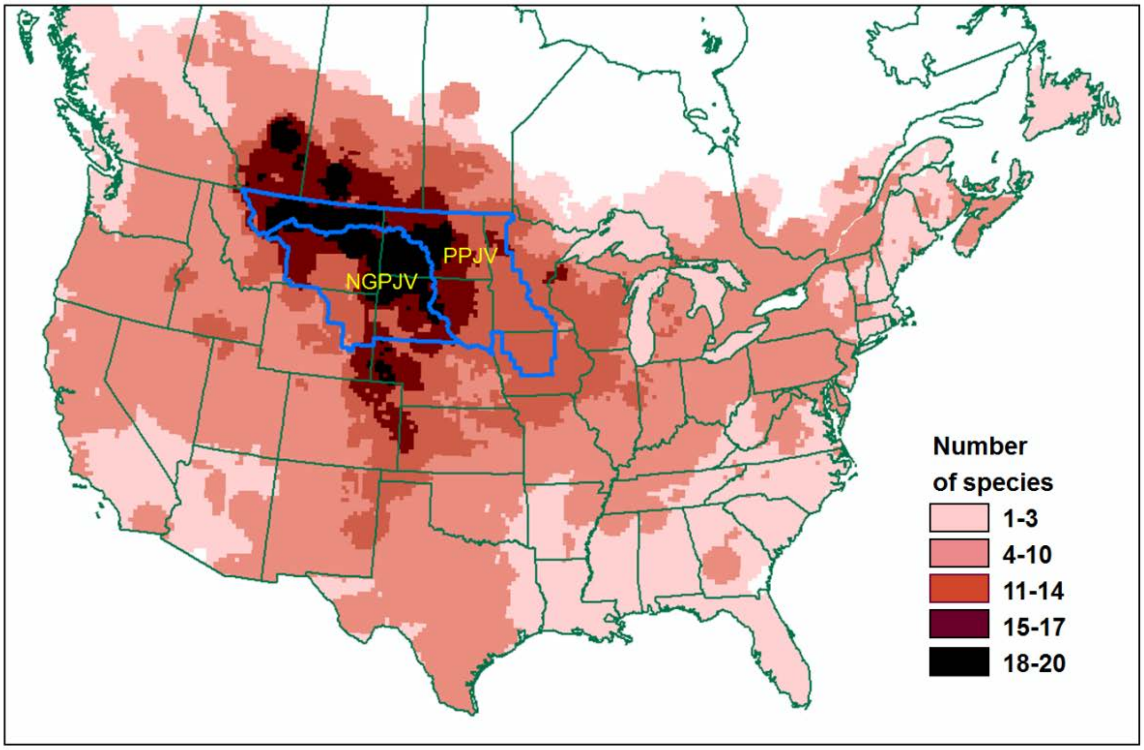


Figure 2. Grassland biomes in the PPJV and NGPJV study area (adapted from Wright and Bailey 1982). Tallgrass Prairie (green), Mixed-grass Prairie (brown), Dry Mixed-grass Prairie (yellow). Red lines represent BBS routes (n = 229) included in the analysis.

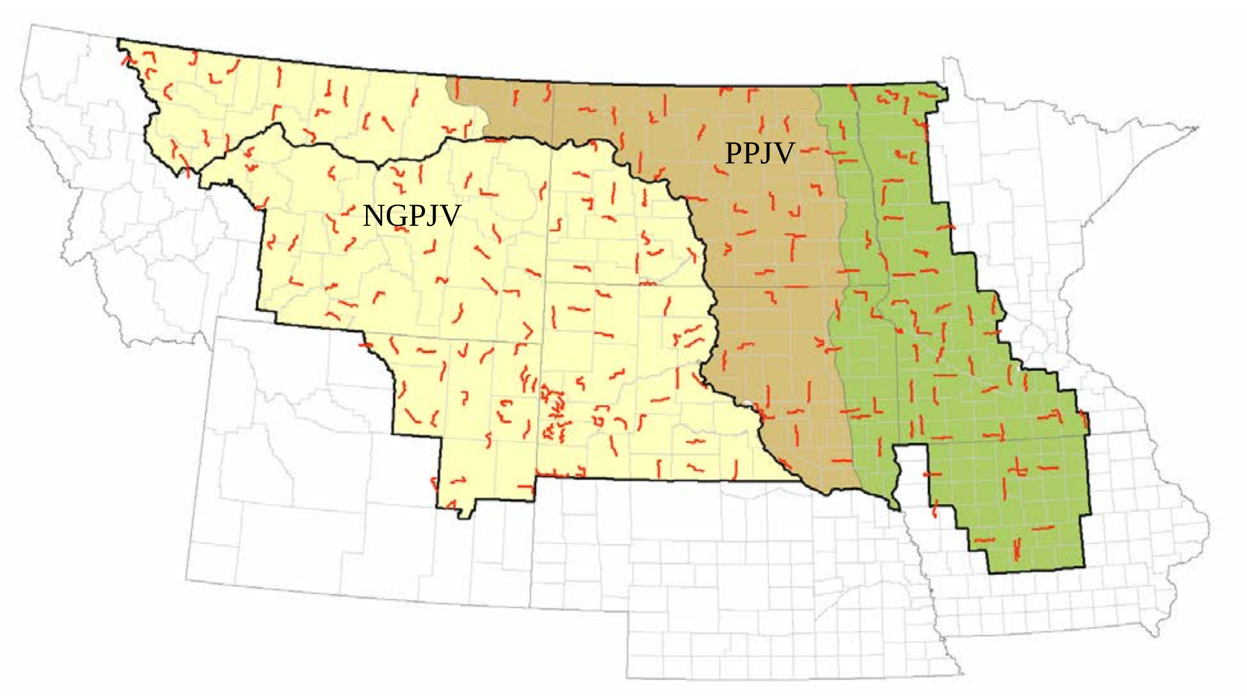


Figure 3. Positive spatial autcorrelation was evident in amount of grassland in the landscape surrounding BBS stops (A) and number of Grasshopper Sparrows recorded at BBS stops in the study area (B). Positive spatial autcorrelation was eliminated in residuals of model predicting occurrence of Grasshopper Sparrows that included habitat, climatic, topographic variables, observer, stop, and date (C). Center lines represent estimated autocorrelation; Outer lines indicates 95% confidence intervals. Data and models for other species and geographic extents showed similar patterns. All distances are in meters.

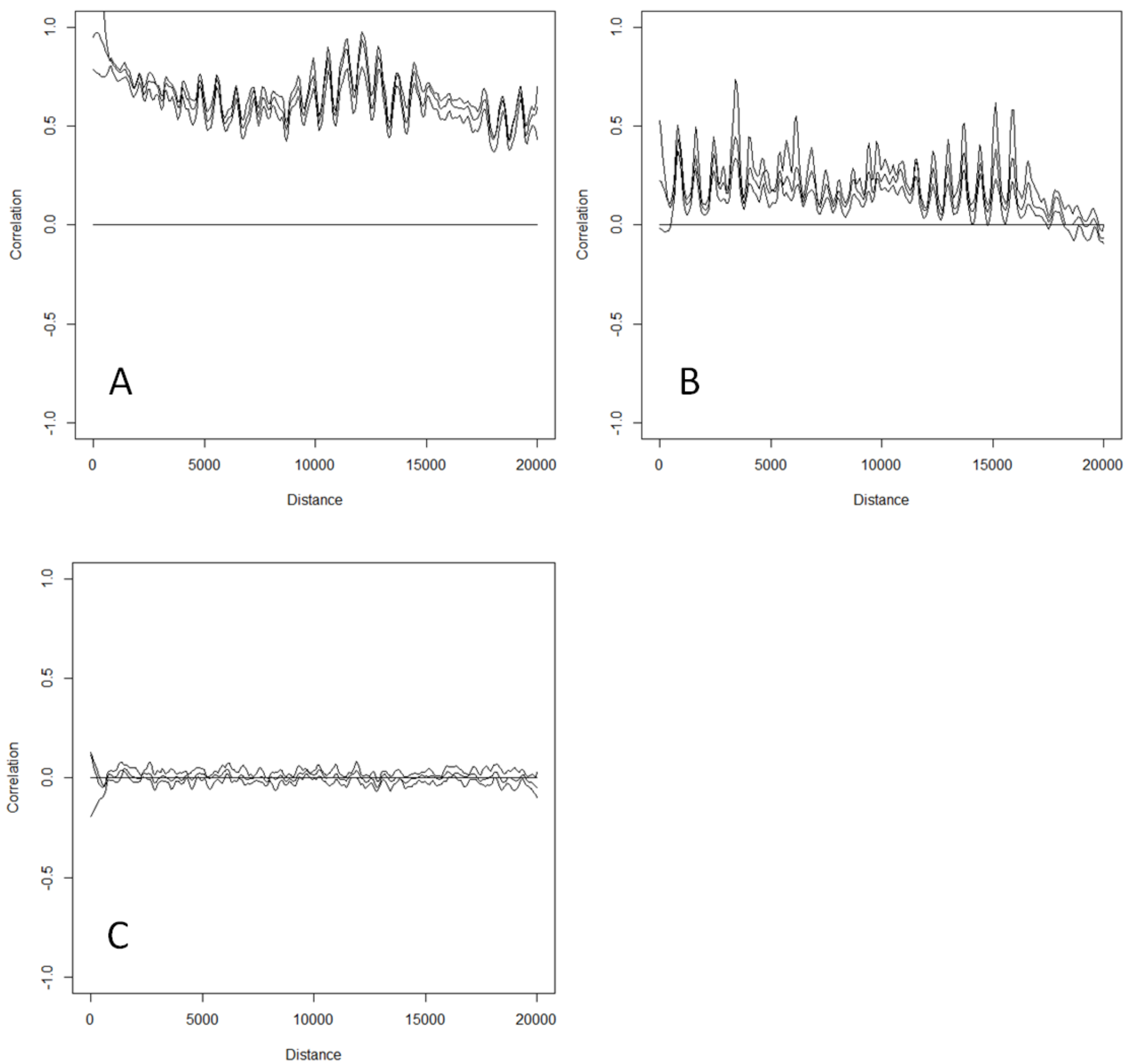
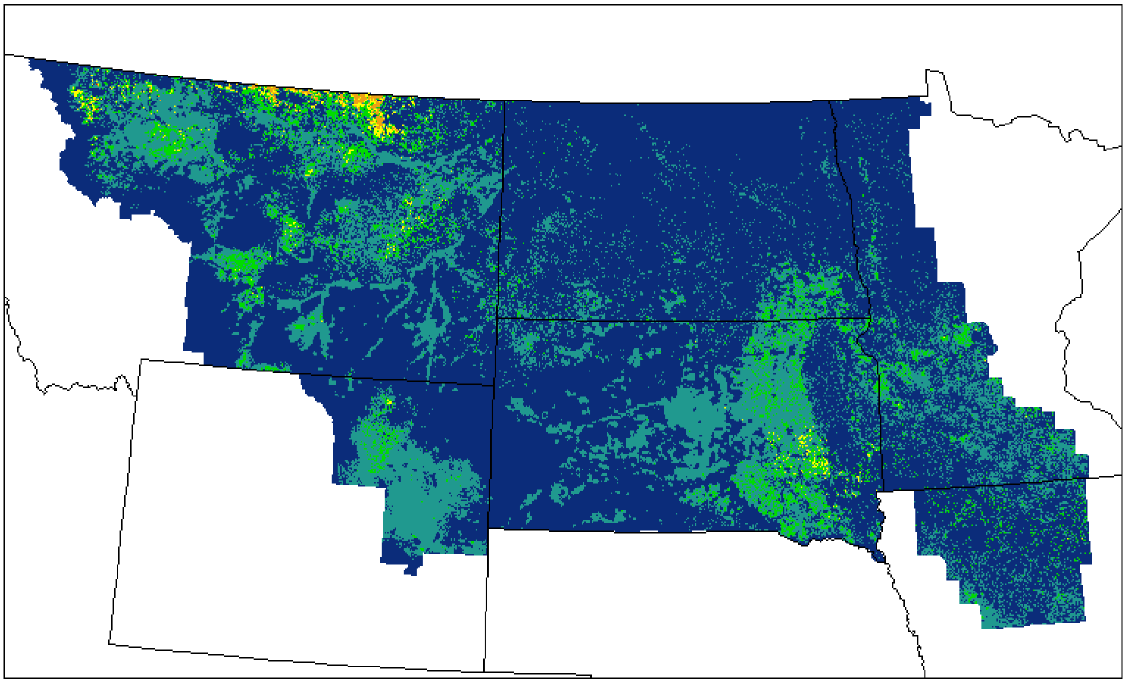


Figure 4. Multi-species overlay identifying areas of 8 grassland bird species' top 25% population cores (A) throughout the study area and (B) in a Glacier County, Montana township.

(A)



(B)

Township: 35 N, Range: 7 W

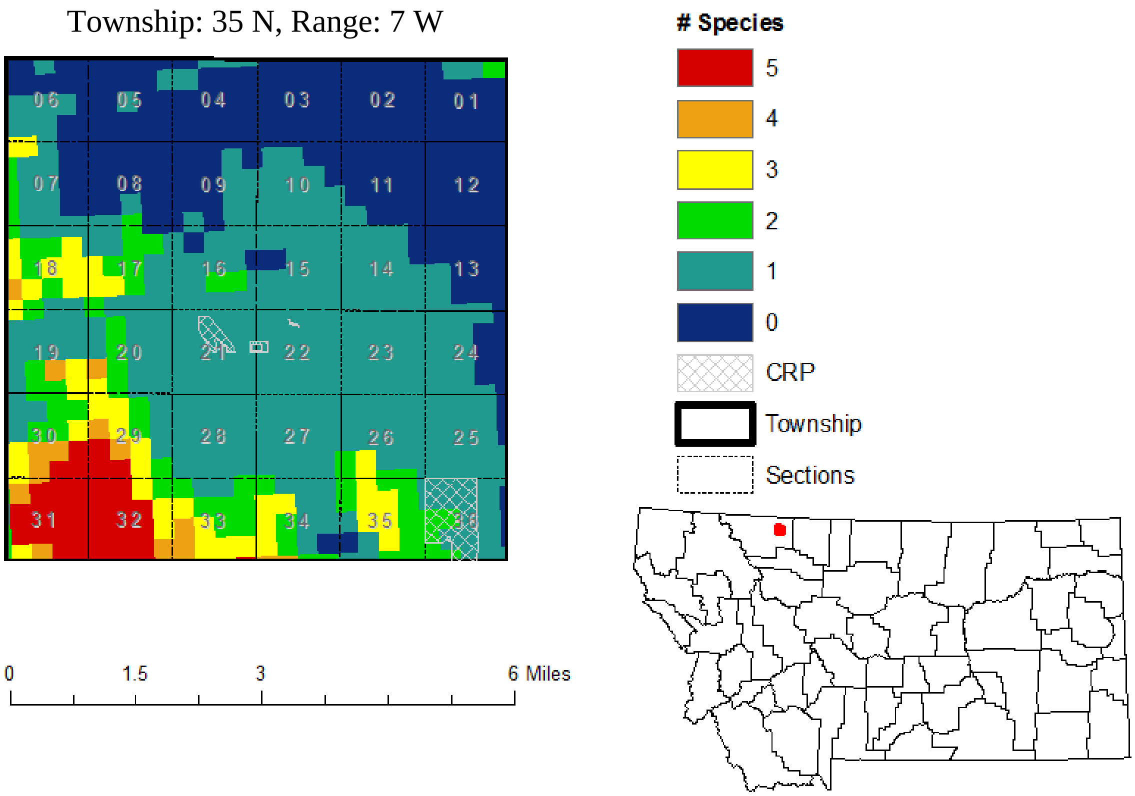


Table 1. Predictor variables considered in development of models predicting occurrence and abundance of grassland birds in the U.S. Northern Great Plains were selected based on documented associations with bird presence, density, or detection. All predictors were treated as continuous variables unless otherwise noted. Adapted from Niemuth et al. 2017.

Variable type	***Predictor variable***	***Definition***	***Justification***
Landscape composition and configuration	Grassland/herbaceous (%)	Areas dominated by graminoid or herbaceous vegetation; may be used for grazing. NLCD class 71.	Presence or density of many species positively associated with area of grasslands (Madden et al. 2000, Ribic and Sample 2001, Bakker et al. 2002, Davis 2004, Greer et al. 2016).
	Pasture/hay (%)	Area of grasses, legumes, or grass-legume mixtures planted for livestock grazing or production or seed or hay crops. NLCD class 81.	Grassland bird response to hay varies among species (Dale et al. 1997, Davis et al. 1999a, Madden et al. 2000); densities differ between mowed and unmowed fields (Dale et al. 1997).
	CRP (%)	Area of grassland enrolled in the United State Department of Agriculture Conservation Reserve Program in 2016.	CRP grasslands substantially affect distribution and density of many species of grassland birds (Johnson and Igl 1995, O'Connor et al. 1999, Herkert 1998, Johnson 2005).
	Alfalfa (%)	Areas identified as alfalfa in 2011 by the USDA National Agricultural Statistics Service.	Grassland bird response to alfalfa varies among species (Renken and Dinsmore 1987, Dale et al. 1997, Ribic and Sample 2001).
	All grass (%)	Combination of grass/herb, pasture/hay, CRP, and alfalfa.	Presence or density of many species positively associated with area of grasslands (Madden et al. 2000, Ribic and Sample 2001, Bakker et al. 2002, Davis 2004, Greer et al. 2016).
	Grass Diversity (n)	A count of the different grass types (0-4); grass/herb, pasture/hay, CRP, and alfalfa.	Some species of birds may prefer a variety of grass (i.e. structural) types (personal communication Neal Neimuth).

Cropland (%)	Areas used for production of annual crops such as corn, soybeans, wheat, and sunflowers. NLCD class 82.	Grassland loss is likely the ultimate factor driving declines of grassland bird populations (Knopf 1994, Vickery et al. 1999, Brennan and Kuvlesky 2005); grassland bird numbers lower on cropland than grassland (Johnson and Schwartz 1993, Davis et al. 1999a, DeJong et al. 2004).
Bare (%)	Areas with < 15% vegetation (i.e., bedrock). NLCD class 31.	Grassland bird occurrence is generally low in areas of bare ground.
Open water (%)	Areas of open water, generally with less than 25% of total cover of vegetation or soil. NLCD class 11.	Open water will not be occupied by grassland birds.
Emergent herbaceous wetlands (%)	Areas where herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. NLCD class 95.	Grassland bird species may be positively or negatively associated with wetlands or mesic sites, depending on habitat preferences and water conditions (Hubbard 1982, Cody1985, Cunningham and Johnson 2006).
Woody wetlands (%)	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. NLCD class 90.	Grassland bird species may be positively or negatively associated with wetlands or mesic sites, depending on habitat preferences and water conditions (Hubbard 1982, Cody1985, Cunningham and Johnson 2006).
All water (%)	Combination of open water, woody wetlands, and emergent wetlands. NLCD classes 11, 90, and 95.	
Forest (%)	Areas dominated by trees > 5 m tall. Includes deciduous	Many species of grassland birds avoid trees, which create visual obstructions as well as harbor predators and brood

		and coniferous forest. NLCD classes 41, 42, and 43.	parasites (Coppedge et al. 2001, Ribic and Sample 2001, Grant et al. 2004, Thompson et al. 2014).
	Shrub (%)	Areas dominated by shrubs <5 m tall with shrub canopy >20% of total vegetation. NLCD class 52.	Presence and density of grassland birds are influenced by amount and structure of sage brush and associated short-grass prairie (Kantrud and Kologiski 1983, Rotenberry and Wiens 1980).
	All Woody Vegetation (%)	Combination of Forest and Shrub. NLCD classes 41, 42, 43, and 52.	
	Developed (%)	Areas characterized by constructed materials and impervious surfaces as well as open space and lawns. NLCD classes 21, 22, 23, and 24.	Presence and density of grassland birds are influenced by amount of development in the surrounding landscape (Bock et al. 1999, Jongsomjit et al. 2013, Wood et al. 2014).
	Patches (n)	Number of disjunct patches of specified land cover classes	Presence and density of grassland birds are influenced by degree of habitat fragmentation (Helzer and Jelinski 1999, Coppedge et al. 2001).
Climatic	Long-term minimum temperature (°C)	Long-term (1981-2010) mean minimum temperature from PRISM data	Temperature affects avian physiology and vegetation communities upon which birds depend, thereby influencing bird distribution and density (Cody 1985, Wiens 1989, O’Connor et al. 1999, Thogmartin et al. 2006a).
	Long-term maximum temperature (°C)	Long-term (1981-2010) mean maximum temperature from PRISM data.	Temperature affects avian physiology and vegetation communities upon which birds depend, thereby influencing bird distribution and density (Cody 1985, Root 1988, Wiens 1989, O’Connor et al. 1999, Thogmartin et al. 2006a).
	Long-term precipitation (mm)	Long-term (1981-2010) mean precipitation from PRISM data.	Long-term precipitation influences structure and composition of vegetation communities with corresponding effects on distribution and density of grassland birds (Wiens 1974, Cody 1985, Wiens 1989, Thogmartin et al. 2006a).
	Current-year precipitation (mm)	Annual mean precipitation for each year (2008-2016)	Distribution and density of grassland birds are influenced by current-year precipitation (Wiens 1974, Cody 1985,

		from PRISM data.	George et al. 1992, Niemuth et al. 2008, Ahlering et al. 2009).
	Current-year precipitation anomaly (mm)	Difference between precipitation for the year in which data were collected and long-term mean precipitation.	Distribution and density of grassland birds are influenced by current-year precipitation (Wiens 1974, Cody 1985, George et al. 1992, Niemuth et al. 2008, Ahlering et al. 2009).
Topography	Mean elevation	Mean elevation of the sampling window, calculated from digital elevation model (Gesch et al. 2002).	Elevation influences many physical and ecological processes that shape or limit bird communities (Wiens 1989).
	Elevation	Elevation of BBS stop at 30m resolution given by a digital elevation model.	Elevation influences many physical and ecological processes that shape or limit bird communities (Wiens 1989).
	Elevation difference	Difference between elevation and mean elevation of sampling window.	Some species may prefer to settle in areas that are higher or lower than the surrounding landscape (personal communication Neal Neimuth).
	Topographic variation	Standard deviation of elevation around each survey point, calculated from a digital elevation model.	Topographic variation may influence detection (Dawson 1981) or densities of birds (Renfrew and Ribic 2002).
Detection	Route	Categorical variable with unique identifier for each route.	Inclusion of route number as a random effect accommodated reduced variance associated with repeated sampling (Crawley 2007).
	Observer	Categorical variable identifying observer for each route. Treated as random effect.	Bird detection ability differs among observers (Sauer et al. 1994); we included observer identify as a random effect to accommodate variance associated with observer differences (Crawley 2007).
	Stop number	Number (1-50) of stop within each route, serving as a proxy for time of day.	Detection of some species of birds varies substantially during the daily survey period (Robbins 1981, Rosenberg and Blancher 2005).
	Ordinal date	Integer representing number of days since	Detection of some species of birds varies substantially during the annual survey

		the beginning of the count year. Also included as a quadratic to characterize seasonal changes in detection.	period (Anderson et al. 1981, Skirvin 1981).
	Wind (Beaufort scale)	Categorical variable representing Beufort scale wind speed at the start of the survey.	Aural detection of some birds decreases as wind speed increases (Simons et al. 2007).
	Year	Categorical variable accounting for inter-annual variation in population size and distribution. Treated as random effect.	Population size and distribution vary among years (Anderson et al. 1981, Niemuth et al. 2008); we included year as a random effect to accommodate variance associated with inter-annual changes (Crawley 2007).

Table 2. Candidate species for model development (n = 17). A species was considered of conservation concern if it is on the 2016 Partners in Flight Watch List or 2008 USFWS Birds of Conservation Concern list. Bold font species were selected for model development. Grassland ecoregion abbreviations include TG (tallgrass prairie); MG (mixed-grass prairie); and DMG (dry mixed-grass prairie).

Species	***Conservation Concern***	***JV Priority***	***Grassland Ecoregion***
Grasshopper Sparrow	**X**	**X**	**TG, MG**
Baird's Sparrow	**X**	**X**	**MG, DMG**
Vesper Sparrow			TG, MG, DMG
Savannah Sparrow			TG, MG, DMG
LeConte's Sparrow			TG, MG
Sedge Wren			TG, MG
Chestnut-collared Longspur	**X**	**X**	**MG, DMG**
McCown's Longspur	X	X	MG, DMG
Sprague's Pipit	**X**	**X**	**MG, DMG**
Western Meadowlark		X	TG, MG, DMG
Bobolink	**X**	**X**	**TG, MG**
Dickcissel	**X**		**TG, MG**
Lark Bunting	**X**	**X**	**DMG**
Upland Sandpiper	X	X	TG, MG, DMG
Willet		X	MG, DMG
Ring-necked Pheasant		**X**	**TG, MG, DMG**
Northern Harrier			TG, MG, DMG

Table 3. Means, standard deviations (SD), minimum, and maximum values for continuous predictor variables at 11,228 Breeding Bird Survey (BBS) stops (individual survey points). Values for land cover and digital elevation model data were derived from a sampling window with 800-m radius. Land cover data were static, but climatic and temporal data varied among years. See Table 1 for variable definitions.

Variable	***Mean***	***SD***	***Minimum***	***Maximum***
Grass/Herb (n)	12.85	13.86	0.00	95.00
Grass/Herb (%)	29.46	32.86	0.00	100.00
Pasture/Hay (n)	4.55	9.09	0.00	94.00
Pasture/Hay (%)	5.86	12.53	0.00	97.00
CRP (n)	0.84	2.95	0.00	74.00
CRP (%)	2.2	7.2	0.00	97.00
Alfalfa (n)	7.1	11.86	0.00	105.00
Alfalfa (%)	2.62	6.51	0.00	79.00
All Grass (n)	12.7	12.3	0.00	102.00
All Grass (%)	40.17	32.94	0.00	100.00
Grass Diversity (n)	2.11	1.02	0.00	4.00
Crop (n)	6.64	8.02	0.00	96.00
Crop (%)	38.32	35.86	0.00	98.00
Bare (n)	0.43	2.04	0.00	33.00
Bare (%)	0.38	3.86	0.00	90.00
Open Water (n)	1.07	2.5	0.00	30.00
Open Water (%)	1.25	4.28	0.00	59.00
Emergent Wetland (n)	4.53	8.08	0.00	73.00
Emergent Wetland (%)	2.14	5.35	0.00	86.00
Woody Wetland (n)	2.51	5.75	0.00	86.00
Woody Wetland (%)	1.2	3.78	0.00	59.00
All Water (n)	5.85	8.32	0.00	72.00
All Water (%)	4.62	8.52	0.00	99.00
Forest (n)	3.45	6.88	0.00	73.00
Forest (%)	6.44	18.8	0.00	100.00
Shrub (n)	9.56	17.36	0.00	115.00
Shrub (%)	5.55	12.9	0.00	92.00
All Woody Vegetation (n)	9.63	15.13	0.00	115.00
All Woody Vegetation (%)	12	24.28	0.00	100.00
Developed (n)	4.19	5.3	0.00	53.00
Developed (%)	4.48	6.31	0.00	100.00

Long-term Minimum Temperature ('C)	-0.02	1.45	-5.39	3.68
Long-term Maximum Temperature ('C)	12.99	1.92	5.17	17.16
Long-term Precipitation (mm)	522.46	154.61	262.97	2223.40
Current-year Precipitation (mm)	577.08	196.7	112.22	3680.05
Current-year Precipitation Anomaly (mm)	54.62	123.01	-439.63	2202.92
Elevation (m)	746.61	439.82	240.00	2833.00
Mean Elevation (m)	748.38	443.91	240.00	2833.00
Elevation Difference (m)	-1.77	11.47	-138.57	58.81
Topographic Variation (m)	8.56	11.02	0.00	250.10

Table 4. Species, states included in analysis, scale of model, AIC difference from null model (Δn), model performance (R2 for abundance models/area under curve [AUC] of receiver operator characteristics for occurrence models), the ratio of observed vs predicted zeros, number of stops included in analysis (n), number of counts during which each species was detected (Detections), and the number of stops that had CRP within landscape scale distance used (CRP Stops) for best-supported models predicting occurrence of eight species of grassland birds in the Northern Great Plains, 2008-2016. Variables are defined in Table 1.

Species	***States***	***Scale***	***Δ_nAIC***	***R^2/AUC****	***Zeros***	***n***	***Detections***	***CRP Stops***
Baird's Sparrow	MT, ND, SD	800	317.57	0.93*	*NA**	47,008	484	1,052
Bobolink	ALL	400	3760.33	0.22	1.10	71,774	7,802	1,451
Chestnut-collared Longspur	MT, ND, SD, WY	400	1883.65	0.93*	*NA**	54,142	2,123	664
Dickcissel	ALL	400	2131.33	0.31	1.01	71,774	5,311	1,451
Grasshopper Sparrow	ALL	400	3419.99	0.32	1.02	71,774	9,097	1,451
Lark Bunting	MT, ND, SD, WY	3200	19149.32	0.50	0.97	54,142	8,821	3,529
Ring-necked Pheasant	ALL	3200	11744.54	0.54	0.95	71,774	18,328	5,959
Sprague's Pipit	MT, ND, SD	1600	451.73	0.27	1.01	47,008	432	2,014

* Occurrence models for Chestnut-collared Longspur and Baird's Sparrow include AUC values. The ratio of observed vs predicted zeros are not calculated for the occurrence models.

Table 5. Variables and estimated coefficients (and standard errors) for landscape models predicting the occurrence of 8 grassland bird species in the U.S. Northern Great Plains, 2008–2016. Variables are defined in Table 1.

	Coefficient (SD)							
Variable	Baird's Sparrow	Bobolink	Chestnut-collared Longspur	Dickcissel	Grasshopper Sparrow	Lark Bunting	Ring-necked Pheasant	Sprague's Pipit
Intercept	-6.46 (0.43)	-3.12 (0.16)	-4.04 (0.26)	-4.36 (0.27)	-3.13 (0.15)	-4.37 (0.18)	-2.45 (0.18)	-7.61 (0.45)
Grass/herb	0.93 (0.18)		0.73 (0.08)		0.32 (0.036)	0.23 (0.38)		
Grass/herb^2	-0.36 (0.082)					-0.008 (0.018)	-0.11 (0.021)	
log Grass/herb								1.50 (0.27)
Grass/herb Patches			-0.21 (0.043)					
All grass		0.11 (0.045)						
All grass patches$^{0.5}$						0.085 (0.016)		
Pasture/hay				0.12 (0.012)	0.07 (0.017)			
log Grass Diversity		0.072 (0.011)		0.11 (0.018)				
CRP		0.06 (0.006)			0.11 (0.011)	-0.047 (0.010)	0.12 (0.013)	-0.072 (0.064)
CRP^2							-0.023 (0.003)	
CRP Patches^2							0.045 (0.009)	
log CRP	0.13 (0.056)		-0.070	0.084				

			(0.033)	(0.012)				
Alfalfa				0.18 (0.015)			0.14 (0.011)	
Alfalfa$^{0.5}$	-0.19 (0.073)	0.12 (0.009)			-0.044 (0.013)			
Alfalfa Patches						0.02 (0.010)		
Alfalfa Patches$^{0.05}$				0.10 (0.016)				
Cropland	-0.11 (0.16)	-0.20 (0.047)	0.25 (0.082)	0.15 (0.025)	-0.19 (0.040)	0.22 (0.032)	0.16 (0.024)	-0.42 (0.15)
Cropland^2			-0.19 (0.044)	-0.17 (0.02)	-0.10 (0.019)	0.057 (0.020)	-0.18 (0.016)	
All water			-0.26 (0.06)	-0.055 (0.017)		-0.16 (0.02)		0.36 (0.12)
All water^2								-0.62 (0.13)
All water$^{0.5}$	-0.36 (0.10)	-0.10 (0.01)			-0.25 (0.015)			
Woody Wetland		-0.081 (0.013)						
Forest		-1.12 (0.054)						
Forest$^{0.5}$	-1.93 (0.50)		-1.02 (0.24)		-0.40 (0.04)		-0.22 (0.026)	
Shrub								
Shrub^2		-0.55 (0.079)						
Log All Woody Vegetation				-0.21 (0.031)		-0.25 (0.029)		
Developed		-0.32 (0.020)	-0.30 (0.07)	-0.12 (0.017)	-0.19 (0.021)	-0.33 (0.024)	-0.22 (0.015)	-0.69 (0.16)
Long-term maximum temperature	-1.80 (0.30)	-0.83 (0.092)	-1.18 (0.16)		-0.23 (0.080)		0.67 (0.069)	-2.77 (0.33)
Long-term maximum temperature^2	-0.84 (0.26)	0.49 (0.062)	-0.83 (0.15)			0.35 (0.066)		-1.44 (0.32)
Long-term minimum temperature	-0.64 (0.24)	0.46 (0.081)		1.71 (0.14)			-0.17 (0.059)	

Long-term minimum temperature^2				-0.29 (0.059)			-0.24 (0.30)	
Precipitation Anomaly						0.17 (0.010)		
Long-term precipitation					-0.77 (0.11)	-0.66 (0.064)		-1.55 (0.31)
Current-year precipitation				0.26 (0.02)				
Topographic roughness	-1.03 (0.19)	-0.37 (0.031)	-0.62 (0.11)	0.17 (0.036)				-0.66 (0.18)
Mean elevation		-1.02 (0.11)					-0.63 (0.11)	
Elevation	3.03 (0.40)		0.38 (0.23)	-1.09 (0.16)	0.53 (0.11)	0.66 (0.092)		
Elevation^2	-1.43 (0.25)		-2.35 (0.27)	-1.18 (0.16)	-0.33 (0.063)			
log Elevation								1.17 (0.26)
Elevation Difference					0.12 (0.016)	0.18 (0.015)		
Elevation Difference^2						-0.16 (0.013)		
Stop number	-0.22 (0.055)	0.045 (0.008)		-0.14 (0.011)	-0.22 (0.009)	0.045 (0.006)	-0.53 (0.006)	
Ordinal date		-0.16 (0.011)		0.26 (0.13)		-0.049 (0.009)	-0.14 (0.007)	
Ordinal date^2								
Wind		-0.061 (0.01)		-0.051 (0.012)	-0.075 (0.011)	-0.026 (0.007)	-0.16 (0.006)	
Autoregressive			1.67 (0.06)			2.20 (0.024)		

Table 6. General model based descriptions summarizing covariate associations for eight species of grassland birds in the PPJV and NGPJV.

Species	***General Model-based Description***
Grasshopper Sparrow	Colder, drier areas at relatively high to mean elevations, and located upslope. Associated with grass/herb and dense grass (CRP & pasture/hay, grass/herb). Not associated with water, crop, forest, and developed areas.
Baird's Sparrow	Colder, flatter areas at relatively higher elevations. Associated with grasslands with some dense cover (CRP and grass/herb). Not associated with water, crop, and forest.
Sprague's Pipit	Colder, drier, and flatter areas at relatively higher elevations. Strongly associated with grass/herb. Not associated with water, crop, and developed areas.
Chestnut-collared Longspur	Colder, drier, and flatter areas at mean elevations. Strongly associated with grass/herb but tolerant of some crop. Not associated with water, forest, shrub, and developed areas.
Lark Bunting	Warmer, annually wet areas at relatively higher elevations, and located upslope. Associated with a grass/herb and crop mosaic. Not associated with some wetland types (i.e. no effect with emergent wetlands), and developed areas.
Ring-necked Pheasant	Warmer areas at lower elevations. Associated with crop, alfalfa & CRP mosaic. Not associated with forest and developed areas.
Bobolink	Warmer, flatter areas at lower elevations. Associated with a grassland mosaic with some dense cover (grass/herb, alfalfa, CRP). Not associated with some wetland types (i.e. no effect with emergent wetlands), crop, forest, shrub, and developed areas.
Dickcissel	Warmer, wetter areas with rough terrain and at lower elevations. Associated with a grassland mosaic with dense cover (alfalfa, pasture hay, CRP). More tolerant of crop. Not associated with some wetland types (i.e. no effect with emergent wetlands), and developed areas.

Table 7. Overall and marginal CRP effects on population estimates for grassland birds in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
Species	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
Bobolink	2,761,331	2,613,430	-147,901	-5.4	-75,473	-72,429	-2.7	-2.6
Grasshopper Sparrow	5,836,067	5,544,209	-291,858	-5.0	-157,933	-133,925	-2.7	-2.3
Lark Bunting	2,252,899	2,350,506	+ 97,607	4.3	+15,728	+81,879	+ 0.7	+ 3.6
Ring-necked Pheasant	3,030,637	2,898,428	-132,209	-4.4	-8,415	-123,794	-0.3	-4.1
Dickcissel	2,591,737	2,453,412	-138,325	-5.3	-26,185	-112,140	-1.0	-4.3
Sprague's Pipit	160,527	160,293	-233	-0.1	-53	-180	0.0	-0.1
Baird’s Sparrow	599,700*	NA	NA	NA	-12,422	NA	-2.07	NA
Chestnut-collared Longspur	1,930,000*	NA	NA	NA	+10,810	NA	0.56	NA

Table 8. Overall and marginal CRP effects on population estimates for grassland birds in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to grass/herb in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
Species	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
CCLO	1,930,000	NA	NA	NA	+71,403	NA	+3.70	NA
LARB	2,252,898	2,334,816	+81,917	+3.64	+12,899	+69,017	+0.57	+3.06
SPPI	160,526	174,960	+14,434	+8.99	+4,728	+9,705	+2.95	+6.05

APPENDIX A. Maps of predicted bird distributions

Figure A1. Predicted pseudo-abundance of Baird's Sparrows per 4.9 ha in the PPJV and NGPJV (A), and in portions of Daniels and Valley counties, MT with CRP (B) and with CRP converted to crop (C).

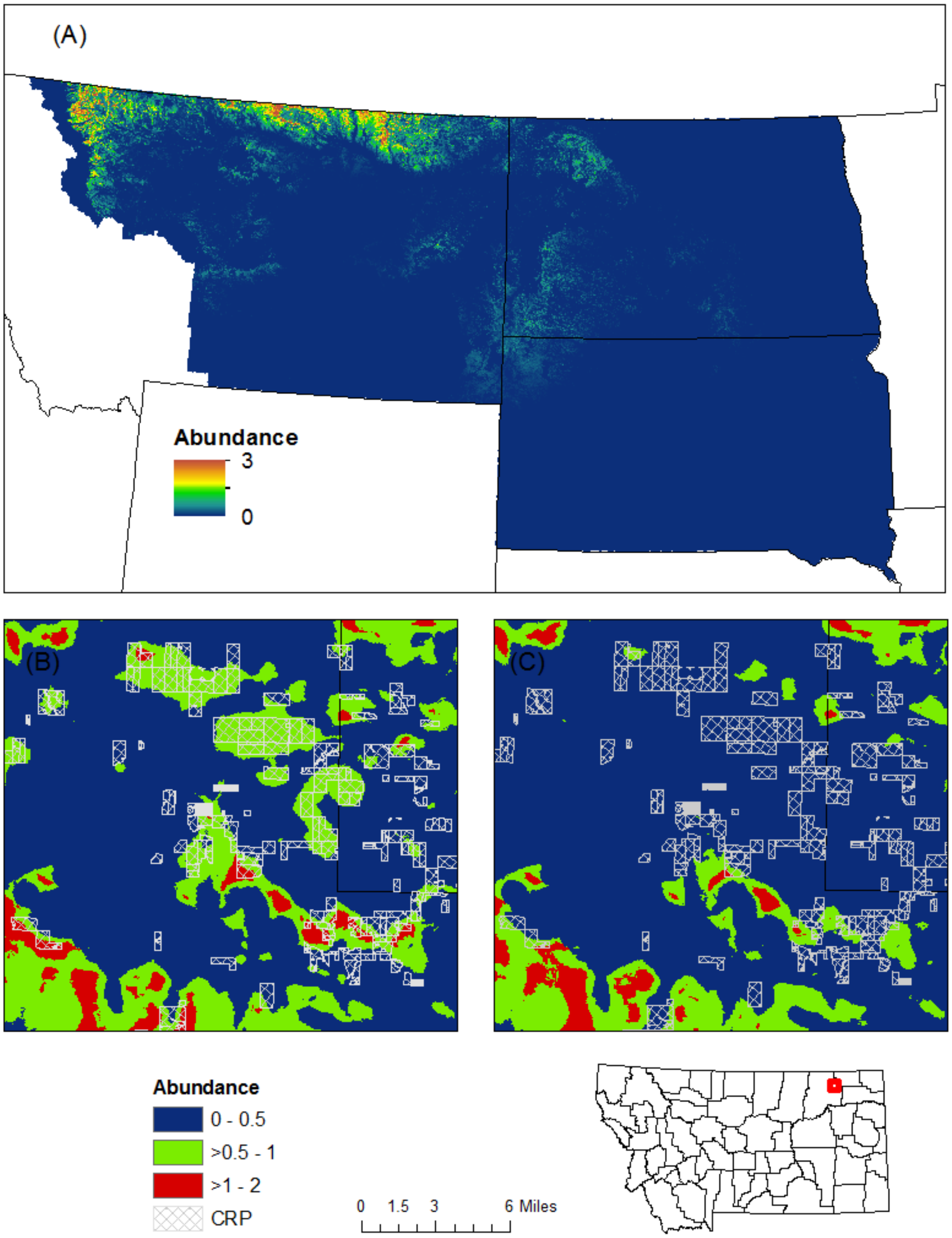


Figure A2. Predicted abundance of Bobolinks per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Grand Forks County, ND with CRP (B) and with CRP converted to crop (C).

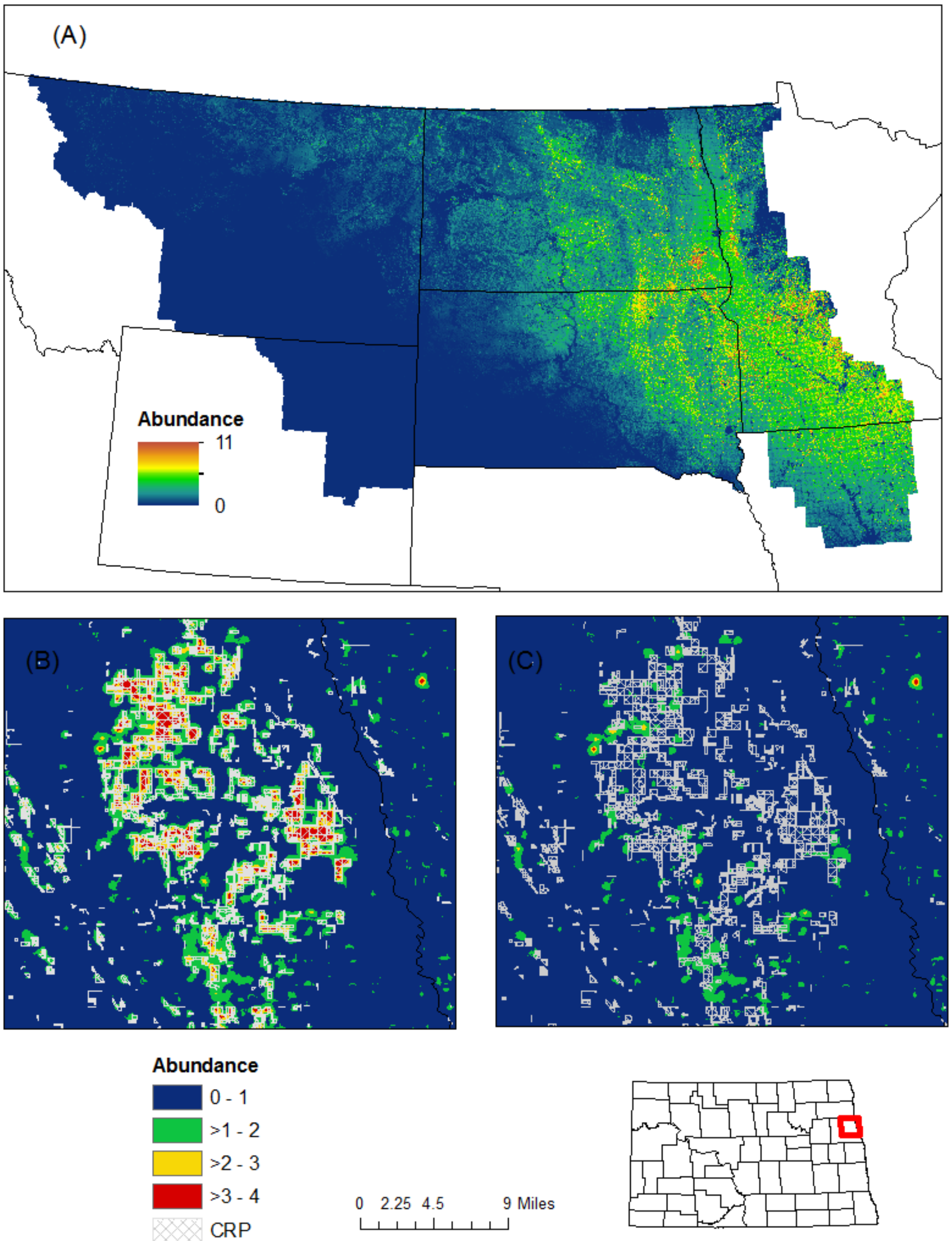


Figure A3. Predicted pseudo-abundance of Chestnut-collared Longspurs per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Daniels County, MT with CRP (B) and with CRP converted to grass/herb (C).

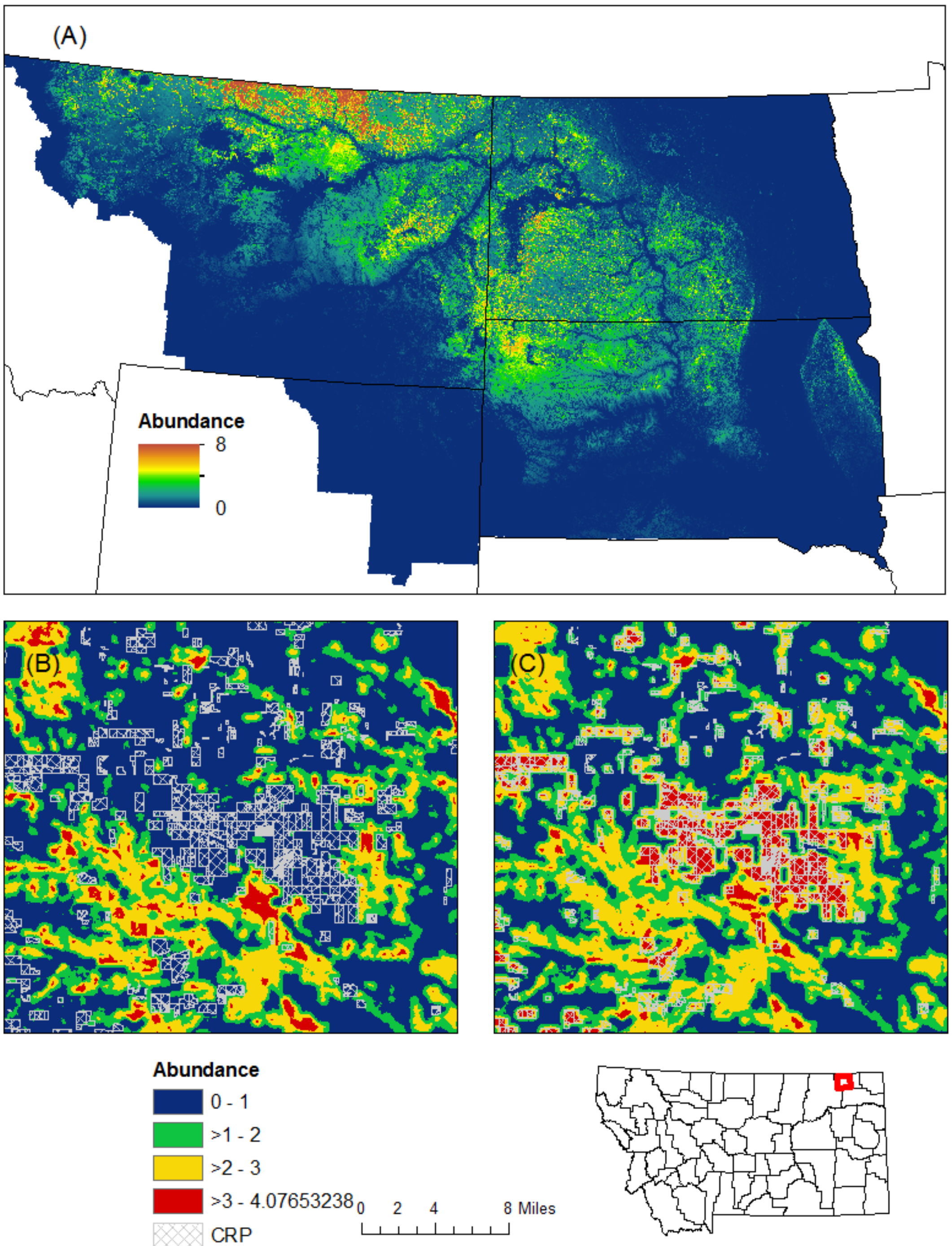


Figure A4. Predicted abundance of Dickcissels per 12.6 ha in the PPJV and NGPJV (A), and in portions of Pocahontas and Calhous counties, IA with CRP (B) and with CRP converted to crop (C).

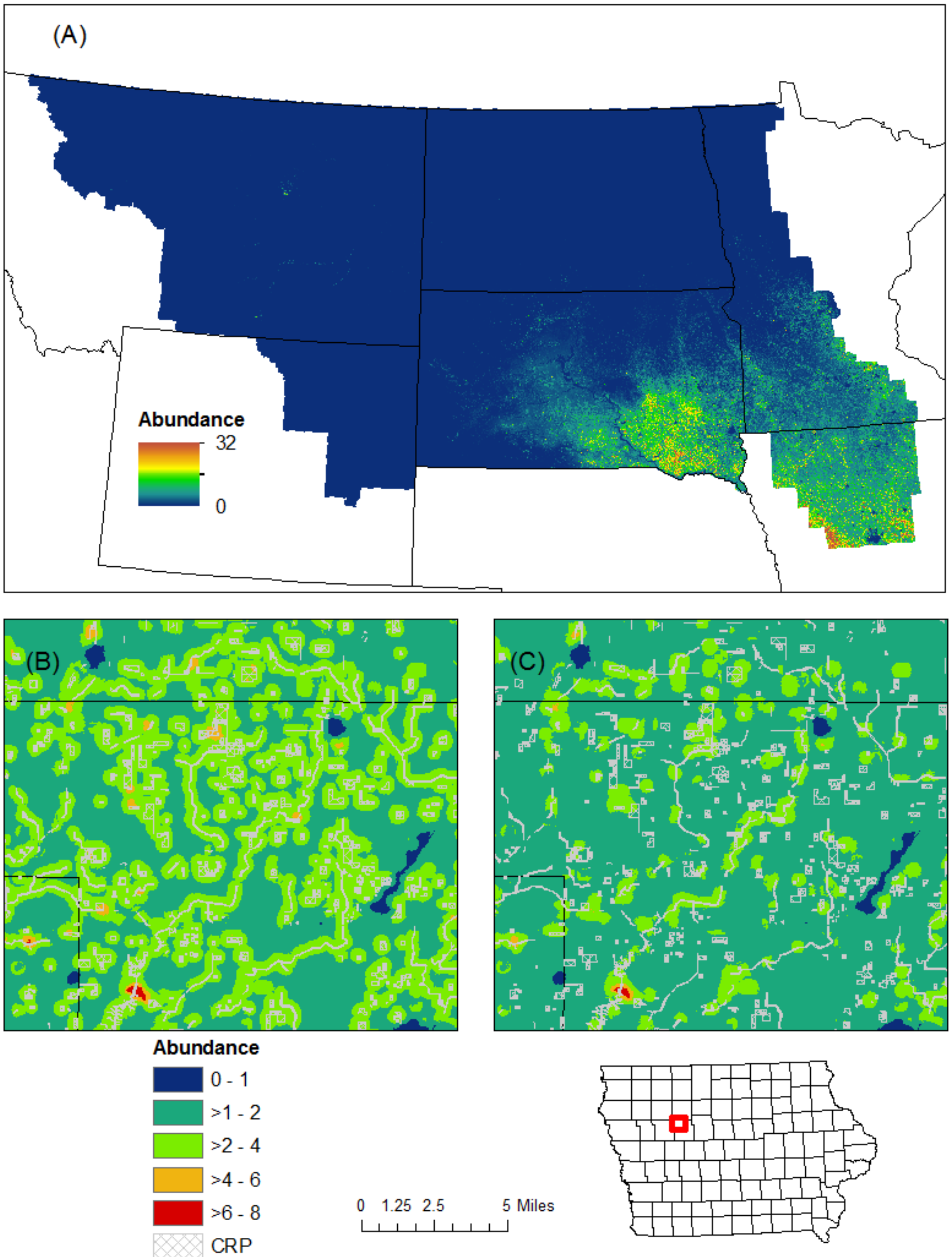


Figure A5. Predicted abundance of Grasshopper Sparrows per 4.9 ha in the PPJV and NGPJV (A), and in a portion of Daniels County, MT with CRP (B) and with CRP converted to crop (C).

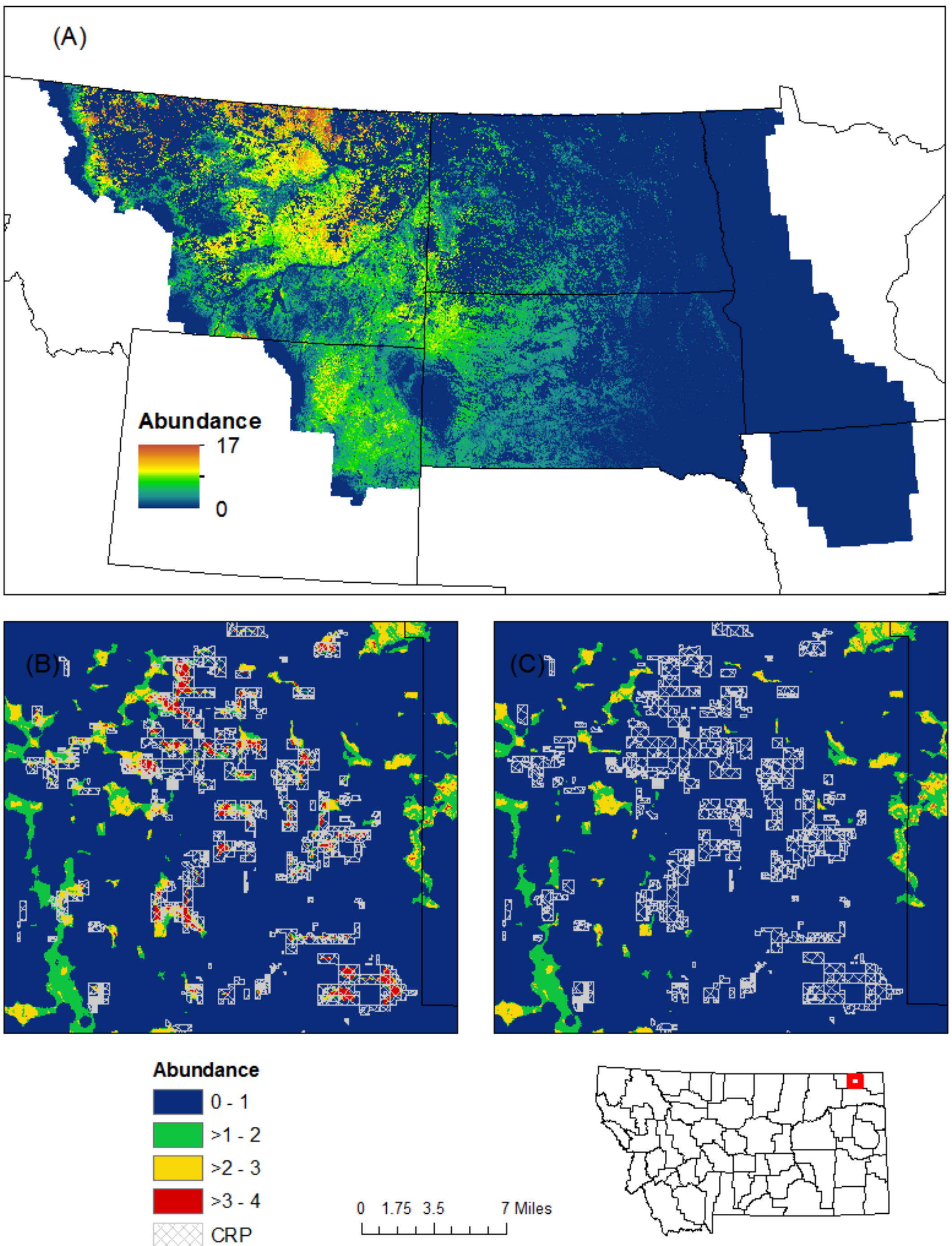


Figure A6. Predicted abundance of Lark Buntings per 12.6 ha in the PPJV and NGPJV (A), and in portions of Teton, Cascade, and Pondera counties, MT with CRP (B) and with CRP converted to grass/herb (C).

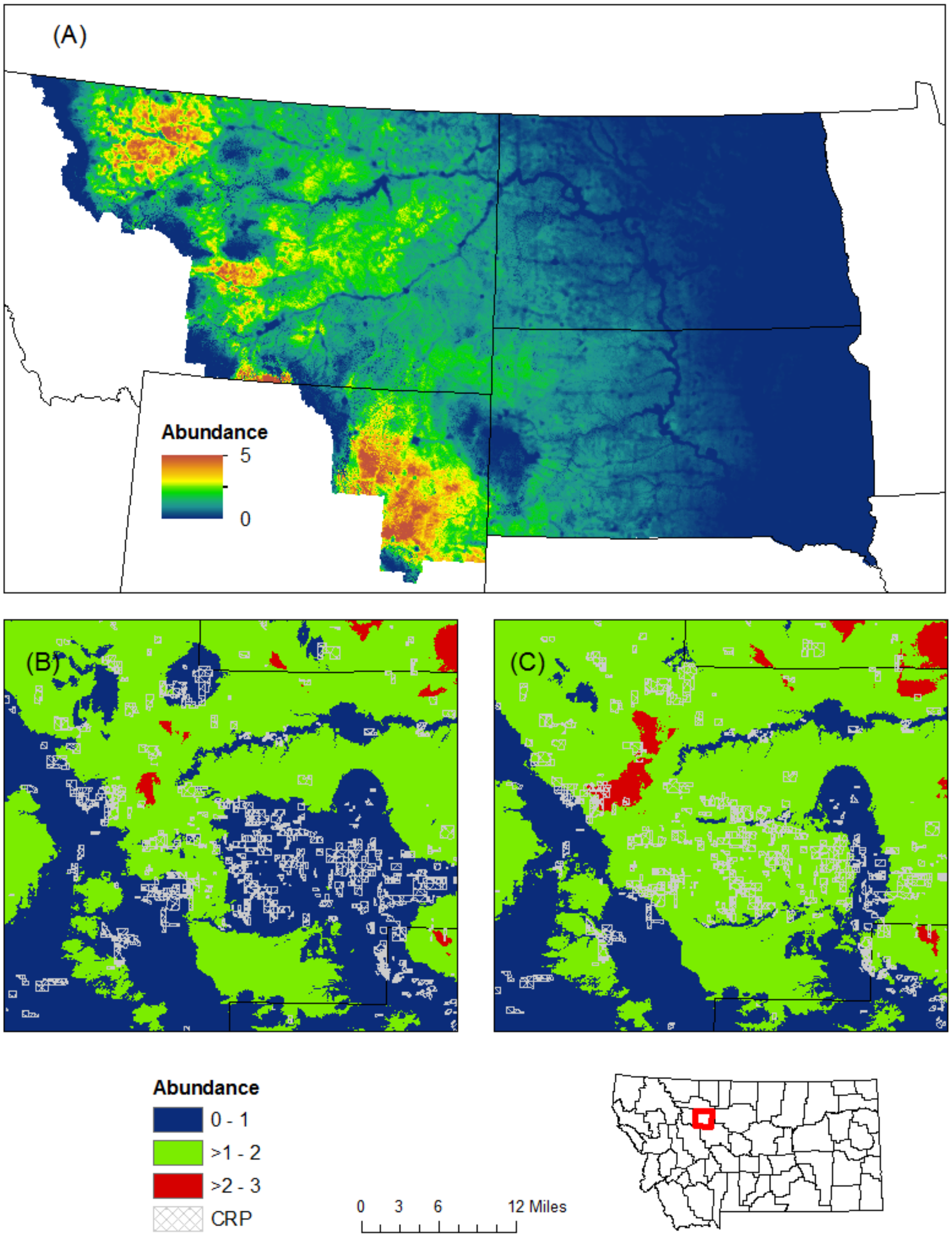


Figure A7. Predicted abundance of Ring-necked Pheasants per 28.3 ha in the PPJV and NGPJV (A), and in a portion of Brown County, SD with CRP (B) and with CRP converted to crop (C).

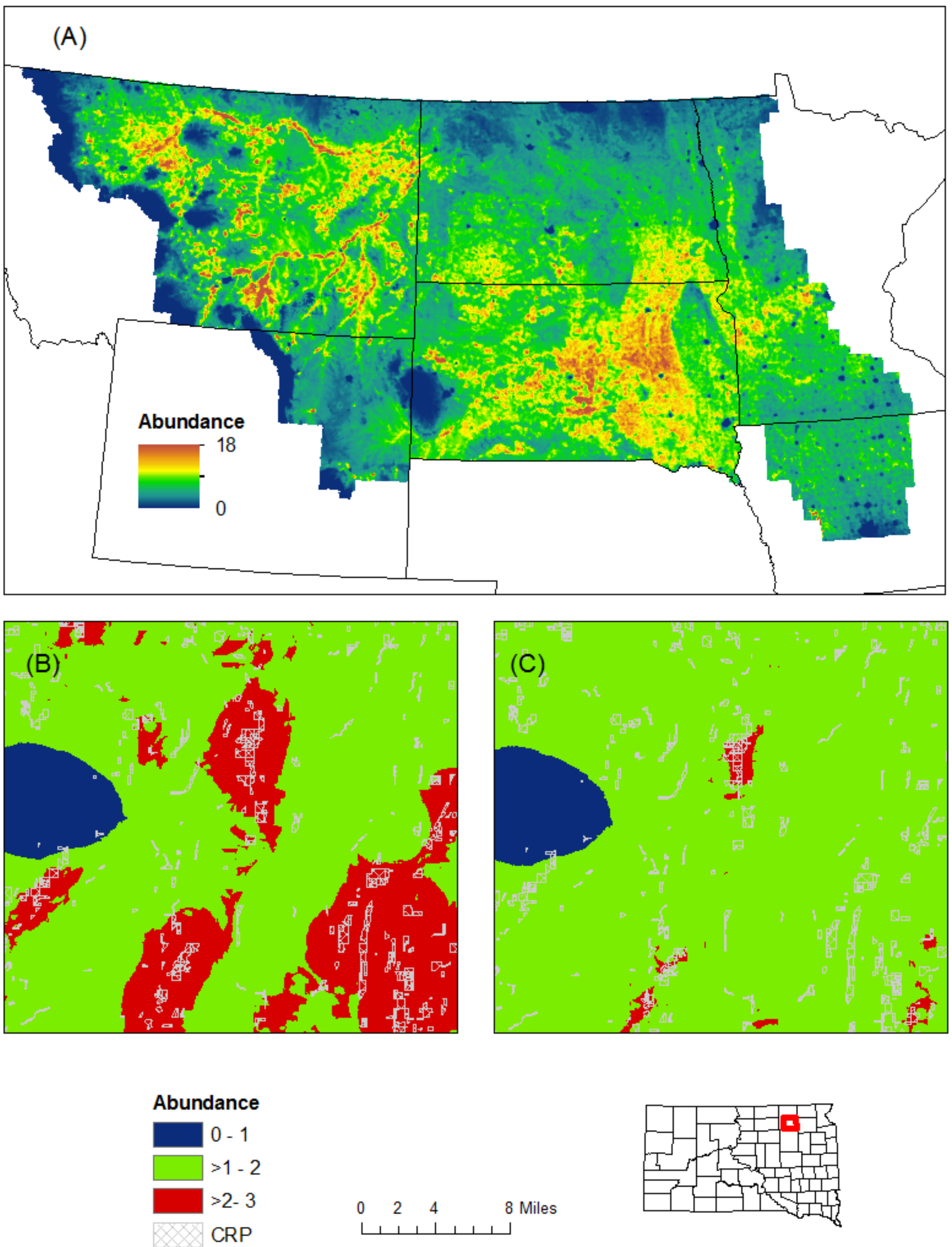
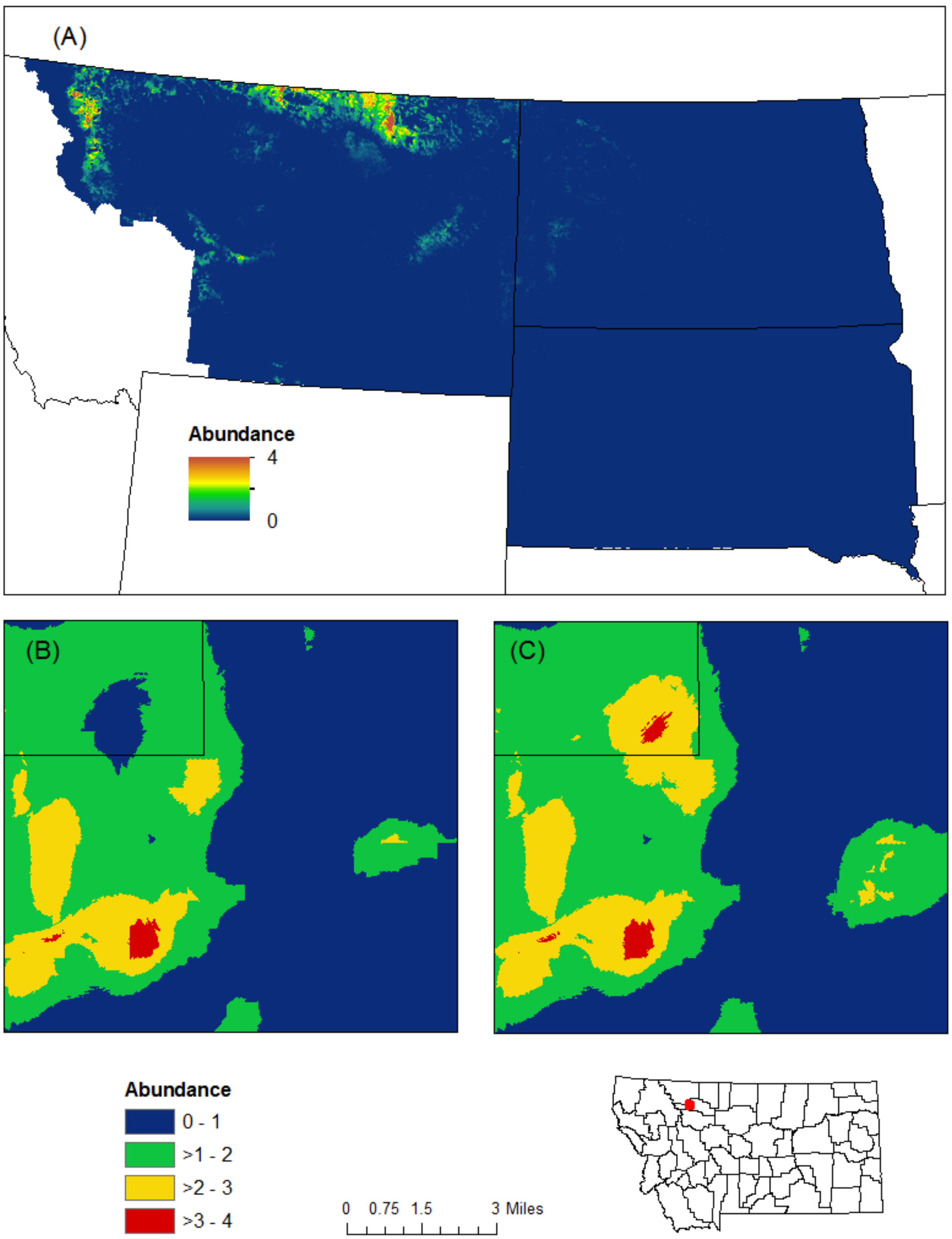


Figure A8. Predicted abundance of Sprague's Pipits per 12.6 ha in the PPJV and NGPJV (A), and in portions of Glacier and Pondera counties, MT with CRP (B) and with CRP converted to crop (C).



APPENDIX B. Overall and marginal CRP effects by state

Table B1. Marginal CRP effects on pseudo-population estimates of Baird's Sparrow by state in the PPJV and NGPJV areas of the Northern Great Plains. Marginal CRP effects include field-specific effects only and are based on modeled population estimates following simulated conversion of CRP fields to cropland in the landscape. Other estimates could not be calculated due to using a pseudo-abundance model where overall population estimates are forced to equal a specified value.

Overall CRP Effects					Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Differen ce in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	599,700	NA	NA	NA	-12,422	NA	-2.07	NA
MT	470,025	NA	NA	NA	-10,259	NA	-2.18	NA
ND	99,826	NA	NA	NA	-1,981	NA	-1.98	NA
SD	29,847	NA	NA	NA	-181	NA	-0.61	NA

Figure B1. Effect of CRP within a 800 m landscape scale on Baird's Sparrow probability of occurrence within a 5.9 ha area (based on detection distance of 125 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

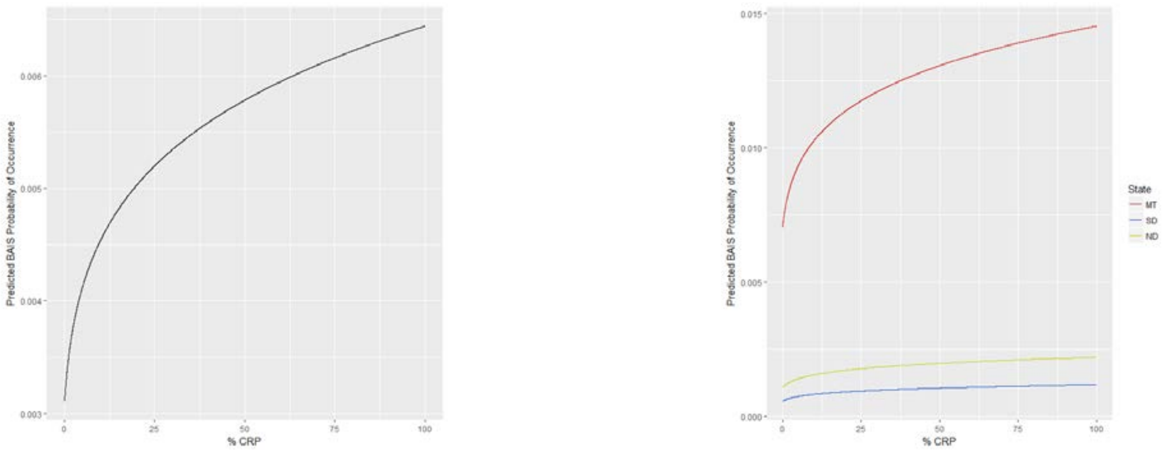


Figure B2. Change in Baird's Sparrow pseudo-abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A) (B)

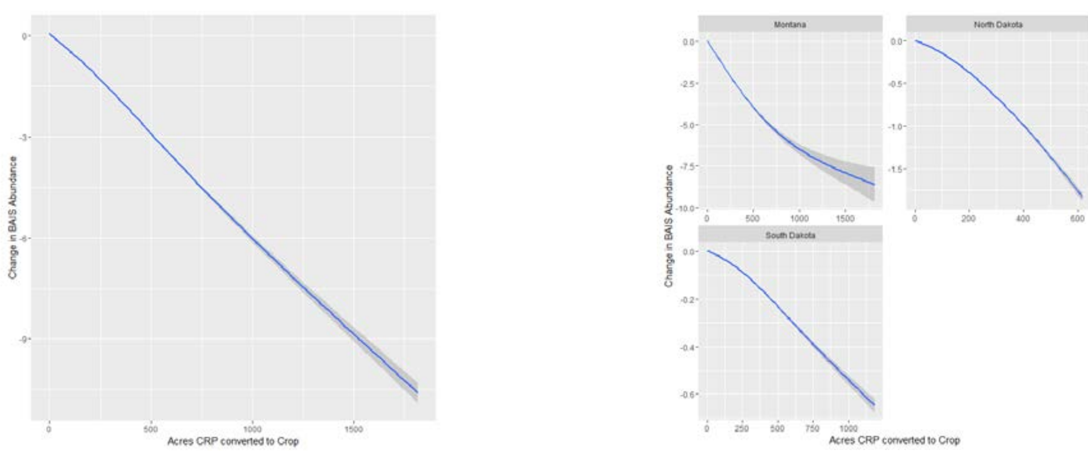
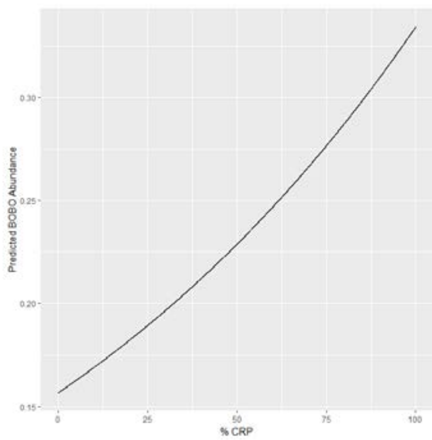


Table B2. Overall and marginal CRP effects on population estimates of Bobolink by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	2,761,331	2,613,429	-147,901	-5.36	-75,472	-72,428	-2.73	-2.62
IA	305,690	289,075	-16,615	-5.44	-5,981	-10,633	-1.96	-3.48
MN	785,199	741,439	-43,760	-5.57	-19,639	-24,120	-2.50	-3.07
MT	222,506	211,015	-11,491	-5.16	-8,137	-3,353	-3.66	-1.51
ND	757,100	710,779	-46,321	-6.12	-26,905	-19,415	-3.55	-2.56
SD	684,646	654,961	-29,685	-4.34	-14,786	-14,898	-2.16	-2.18
WY	6,187	6,159	-27	-0.45	-21	-6.80	-0.34	-0.11

Figure B3. Effect of CRP within a 400-m landscape scale on Bobolink abundance within a 12.6-ha area (based on detection distance of 200 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

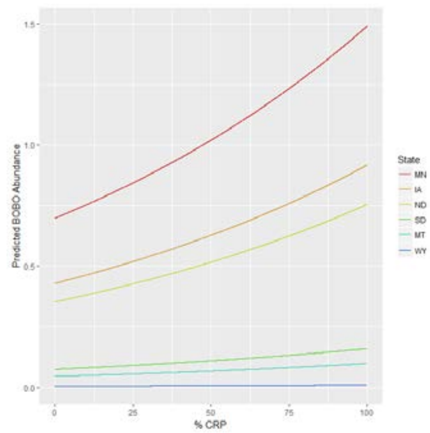
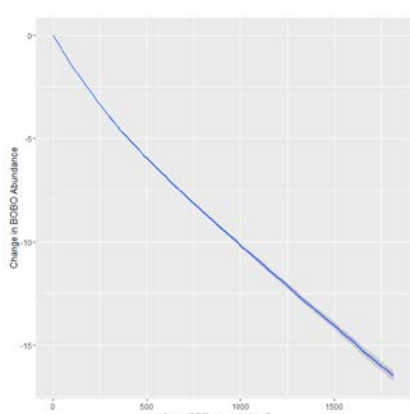


Figure B4. Change in Bobolink abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

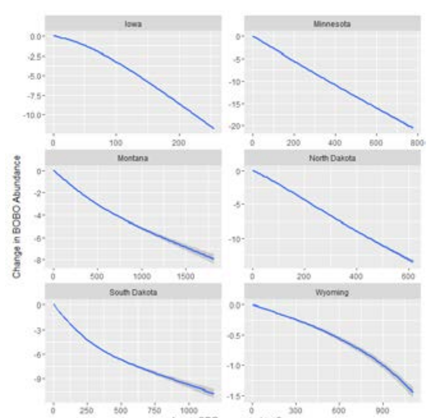


Table B3.1. Marginal CRP effects on pseudo-population estimates of Chestnut-collared Longpsur by state in the PPJV and NGPJV areas of the Northern Great Plains. Marginal CRP effects include field-specific effects only and are based on modeled population estimates following simulated conversion of CRP fields to cropland in the landscape. Other estimates could not be calculated due to using a pseudo-abundance model where overall population estimates are forced to equal a specified value.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	1,930,000	NA	NA	NA	10,809	NA	0.56	NA
MT	995,635	NA	NA	NA	5,706	NA	0.57	NA
ND	525,027	NA	NA	NA	3,797	NA	0.72	NA
SD	400,735	NA	NA	NA	1,302	NA	0.33	NA
WY	8,600	NA	NA	NA	3	NA	0.04	NA

Figure B5. Effect of CRP within a 400-m landscape scale on Chestnut-collared Longspur probability of occurrence within a 12.6 ha area (based on detection distance of 200 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A) (B)

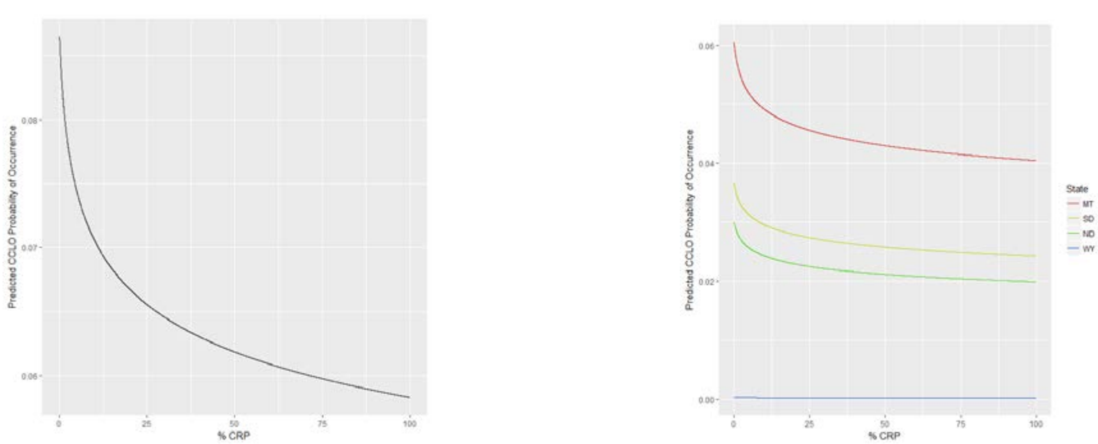


Figure B6.1 Change in Chestnut-collared Longspur pseudo-abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A) (B)

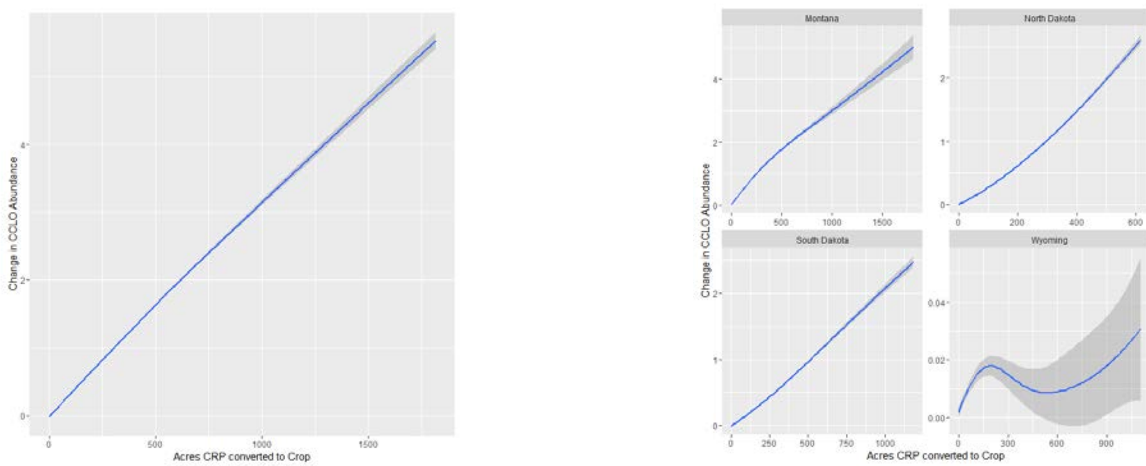
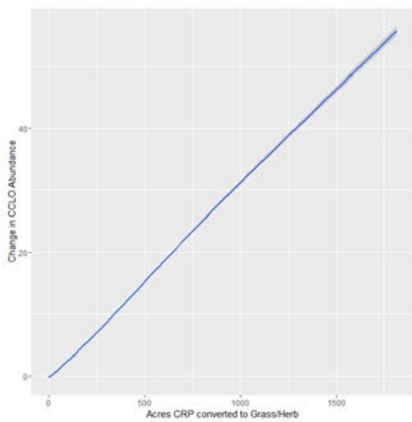


Table B3.2. Marginal CRP effects on pseudo-population estimates of Chestnut-collared Longpsur by state in the PPJV and NGPJV areas of the Northern Great Plains. Marginal CRP effects include field-specific effects only and are based on modeled population estimates following simulated conversion of CRP fields to grass/herb in the landscape. Other estimates could not be calculated due to using a pseudo-abundance model where overall population estimates are forced to equal a specified value.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	1,930,000	NA	NA	NA	71,403	NA	3.70	NA
MT	995,635	NA	NA	NA	45,468	NA	4.57	NA
ND	525,027	NA	NA	NA	19,798	NA	3.77	NA
SD	400,735	NA	NA	NA	6,123	NA	1.53	NA
WY	8,600	NA	NA	NA	12	NA	0.15	NA

Figure B6.2. Change in Chestnut-collared Longspur abundance within CRP fields converted to grass/herb vs. acres of CRP field converted to grass/herb within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

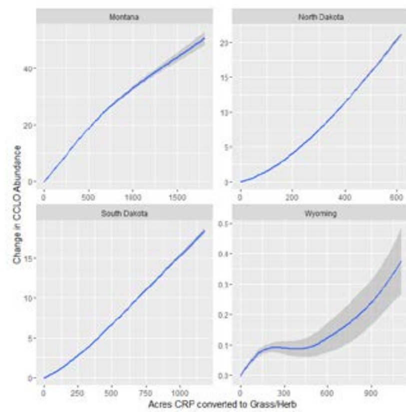
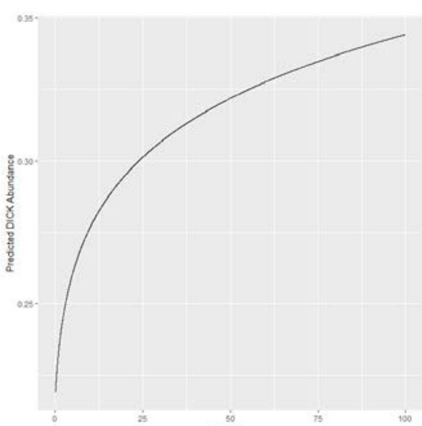


Table B4. Overall and marginal CRP effects on population estimates of Dickcissel by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

Overall CRP Effects					Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	2,591,736	2,453,411	-138,325	-5.34	-26,184	-112,140	-1.01	-4.33
IA	767,501	700,210	-67,291	-8.77	-11,318	-55,972	-1.47	-7.29
MN	486,245	454,263	-31,982	-6.58	-5,633	-26,348	-1.16	-5.42
MT	83,767	82,696	-1,070	-1.28	-482	-588	-0.58	-0.70
ND	80,475	77,678	-2,796	-3.48	-835	-1,961	-1.04	-2.44
SD	1,171,738	1,136,555	-35,183	-3.00	-7,915	-27,268	-0.68	-2.33
WY	2,008	2,007	-1	-0.05	-0.27	-0.69	-0.01	-0.03

Figure B7. Effect of CRP within a 400 m landscape scale on Dickcissel abundance within a 12.6 ha area (based on detection distance of 200 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

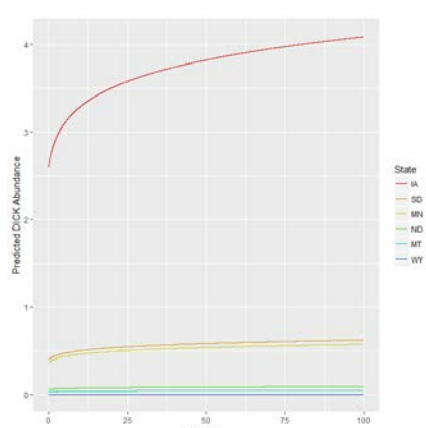
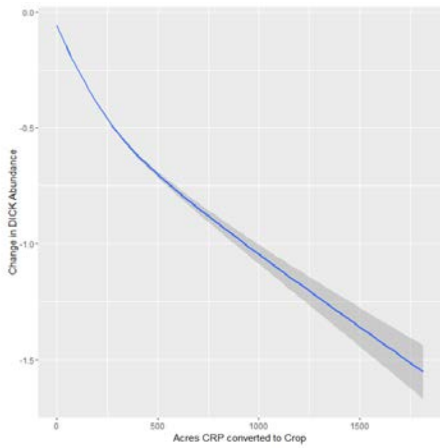


Figure B8. Change in Dickcissel abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

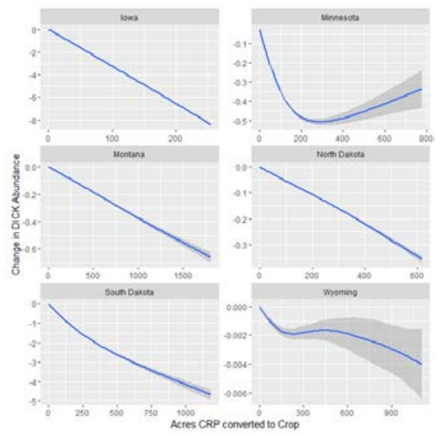
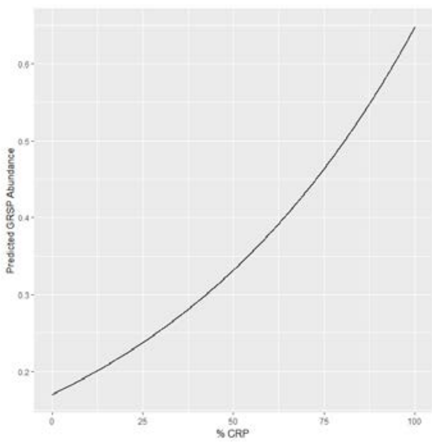


Table B5. Overall and marginal CRP effects on population estimates of Grasshopper Sparrow by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

Overall CRP Effects					Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	5,836,066	5,544,208	-291,858	-5.00	-157,933	-133,925	-2.71	-2.29
IA	158	92	-66	-41.75	-30	-35	-19.48	-22.27
MN	5,084	3,205	-1,878	-36.96	-1,254	-624	-24.67	-12.28
MT	3,376,689	3,192,999	-183,690	-5.44	-106,074	-77,615	-3.14	-2.30
ND	517,438	448,506	-68,932	-13.32	-33,915	-35,017	-6.55	-6.77
SD	1,072,932	1,040,726	-32,205	-3.00	-14,028	-18,177	-1.31	-1.69
WY	863,764	858,678	-5,085	-0.59	-2,630	-2,455	-0.30	-0.28

Figure B9. Effect of CRP within a 400 m landscape scale on Grasshopper Sparrow abundance within a 4.9 ha area (based on detection distance of 125 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

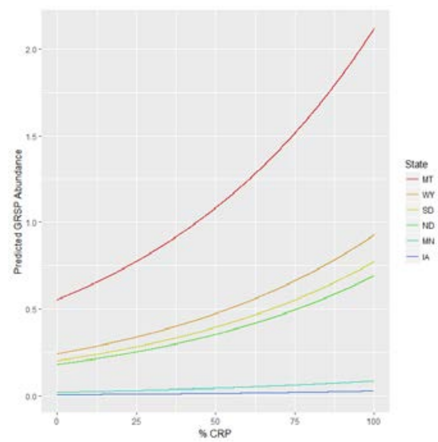
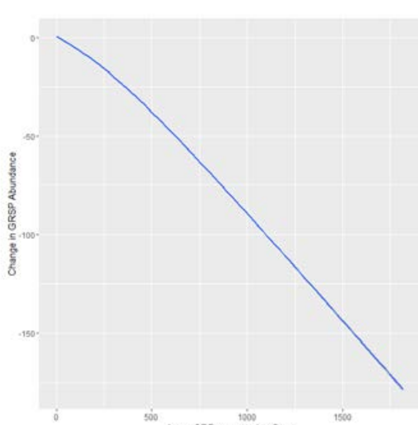


Figure B10. Change in Grasshopper Sparrow abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

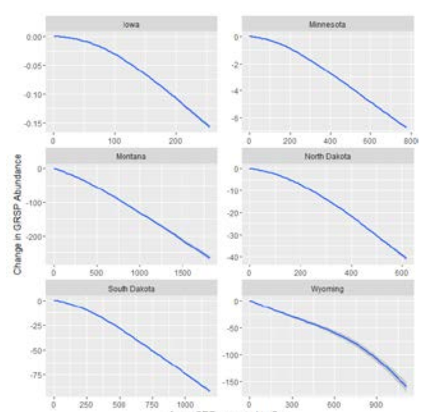
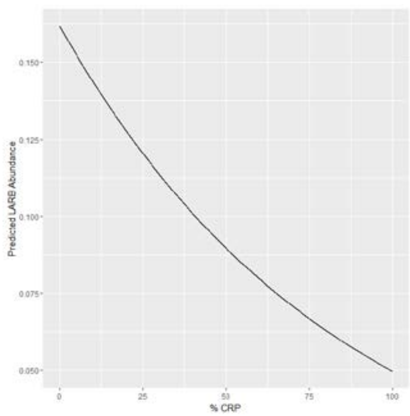


Table B6. Overall and marginal CRP effects on population estimates of Lark Bunting by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	2,252,898	2,350,505	97,606	4.33	15,728	81,878	0.70	3.63
MT	1,268,516	1,345,965	77,448	6.11	13,274	64,174	1.05	5.06
ND	190,757	202,401	11,643	6.10	1,349	10,294	0.71	5.40
SD	334,280	341,013	6,732	2.01	757	5,974	0.23	1.79
WY	459,343	461,124	1,781	0.39	346	1,434	0.08	0.31

Figure B11. Effect of CRP within a 3200 m landscape scale on Lark Bunting abundance within a 12.6 ha area (based on detection distance of 200 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

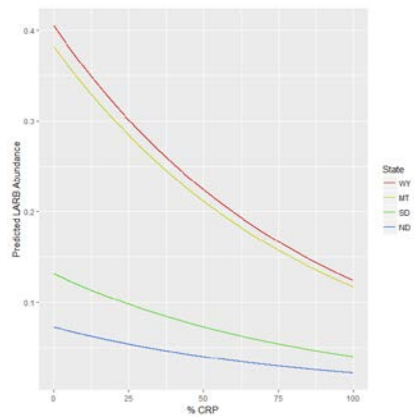
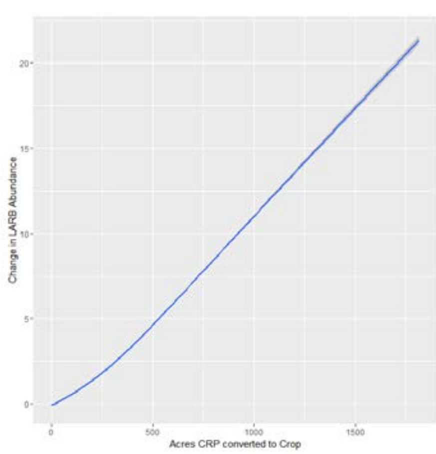


Figure B12.1 Change in Lark Bunting abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

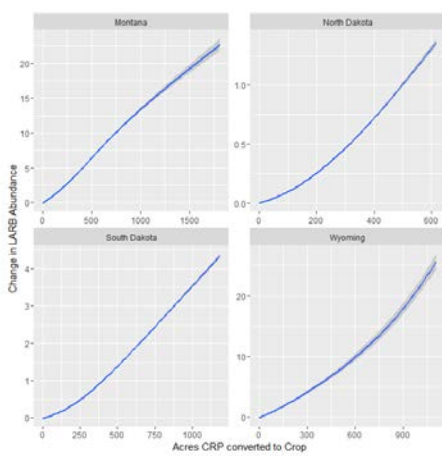


Table B6.2. Marginal CRP effects on pseudo-population estimates of Lark Bunting by state in the PPJV and NGPJV areas of the Northern Great Plains. Marginal CRP effects include field-specific effects only and are based on modeled population estimates following simulated conversion of CRP fields to grass/herb in the landscape. Other estimates could not be calculated due to using a pseudo-abundance model where overall population estimates are forced to equal a specified value.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	2,252,898	2,334,816	81,917	3.64	12,899	69,017	0.57	3.06
MT	1,268,516	1,332,138	63,621	5.02	10,657	52,963	0.84	4.18
ND	190,757	200,737	9,979	5.23	-3,367	13,347	-1.77	7.00
SD	334,280	340,652	6,371	1.91	718	5,653	0.21	1.69
WY	459,343	461,287	1,943	0.42	4,890	-2,946	1.06	-0.64

Figure B12.2. Change in Lark Bunting abundance within CRP fields converted to grass/herb vs. acres of CRP field converted to grass/herb within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A) (B)

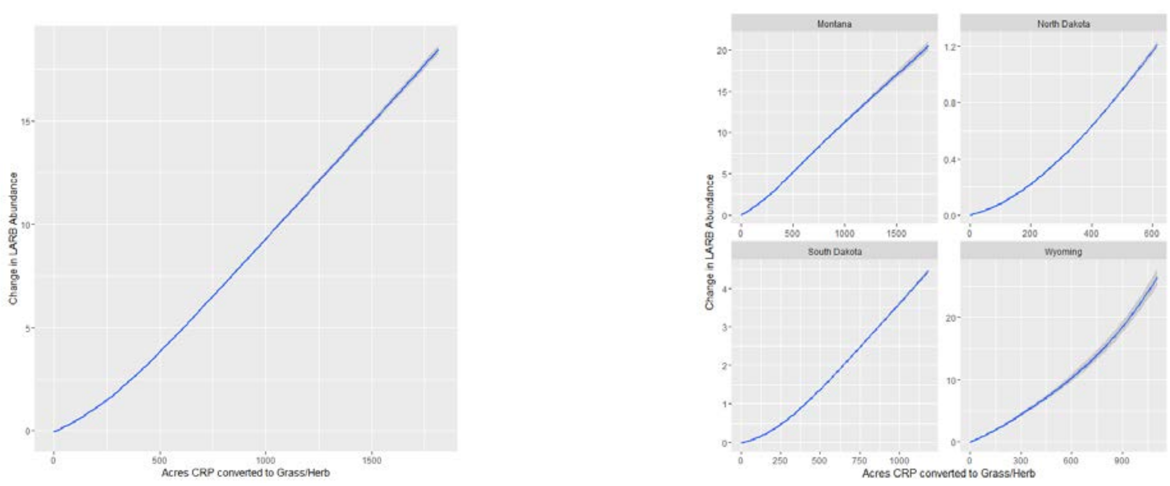
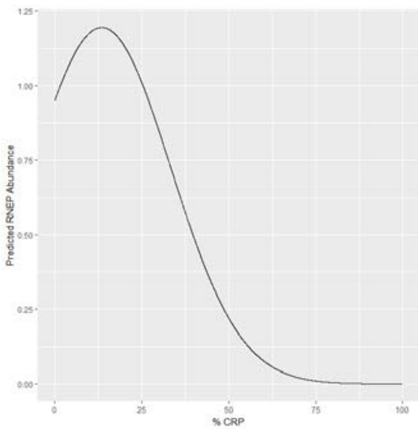


Table B7. Overall and marginal CRP effects on population estimates of Ring-necked Pheasant by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	3,030,636	2,898,427	-132,209	-4.36	-8,414	-123,794	-0.28	-4.08
IA	141,929	115,426	-26,502	-18.67	-1,425	-25,076	-1.00	-17.67
MN	332,016	300,135	-31,880	-9.60	-2,011	-29,869	-0.61	-9.00
MT	928,429	910,588	-17,841	-1.92	-1,097	-16,744	-0.12	-1.80
ND	551,829	521,990	-29,839	-5.41	-2,246	-27,593	-0.41	-5.00
SD	940,834	912,915	-27,918	-2.97	-1,670	-26,247	-0.18	-2.79
WY	135,598	137,372	1,773	1.31	36	1,737	0.03	1.28

Figure B13. Effect of CRP within a 3200 m landscape scale on Ring-necked Pheasant abundance within a 28.3-ha area (based on detection distance of 300 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

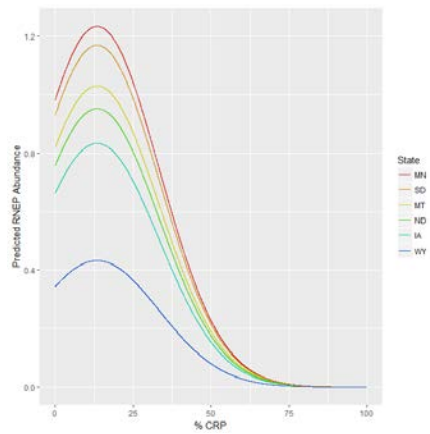
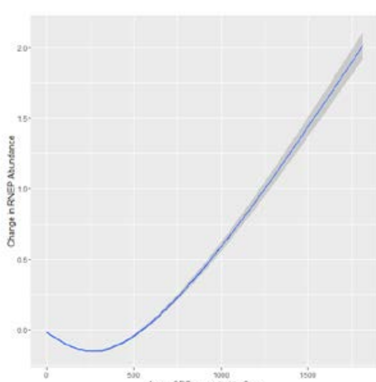


Figure B14. Change in Ring-necked Pheasant abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

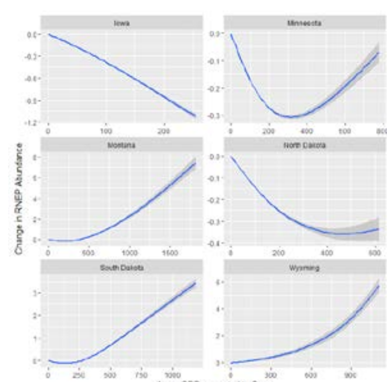
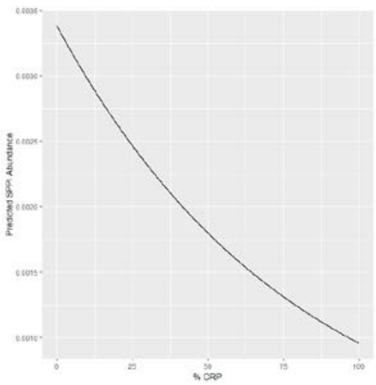


Table B8.1. Overall and marginal CRP effects on population estimates of Sprague's Pipit by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	160,526	160,293	-233	-0.15	-52	-180	-0.03	-0.11
MT	138,356	138,159	-197	-0.14	-46	-151	-0.03	-0.11
ND	18,195	18,162	-33	-0.18	-6	-27	-0.03	-0.15
SD	3,974	3,972	-2	-0.06	0	-2	-0.01	-0.05

Figure B15. Effect of CRP within a 1600 m landscape scale on Sprague's Pipit abundance within a 12.6-ha area (based on detection distance of 200 m). Effects were estimated using model predictions when CRP was increased from zero to 100 percent and all other covariates were held at their overall mean (A) or mean by state (B).

(A)



(B)

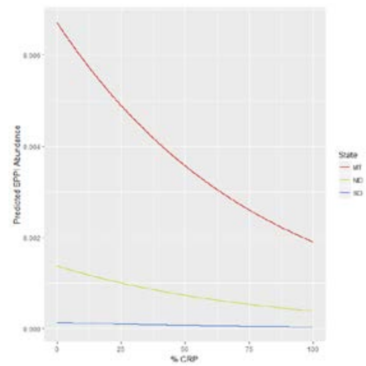
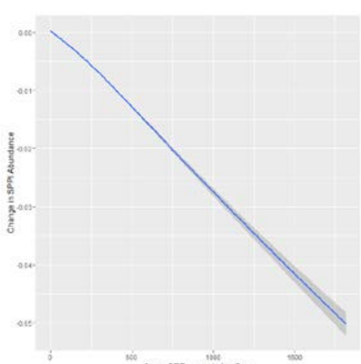


Figure B16.1. Change in Sprague's Pipit abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)

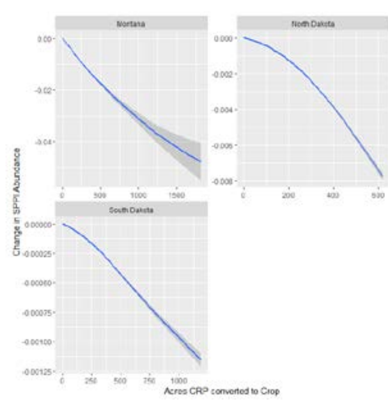
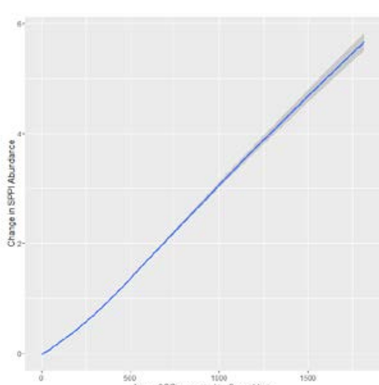


Table B8.2. Marginal CRP effects on pseudo-population estimates of Lark Bunting by state in the PPJV and NGPJV areas of the Northern Great Plains. Marginal CRP effects include field-specific effects only and are based on modeled population estimates following simulated conversion of CRP fields to grass/herb in the landscape. Other estimates could not be calculated due to using a pseudo-abundance model where overall population estimates are forced to equal a specified value.

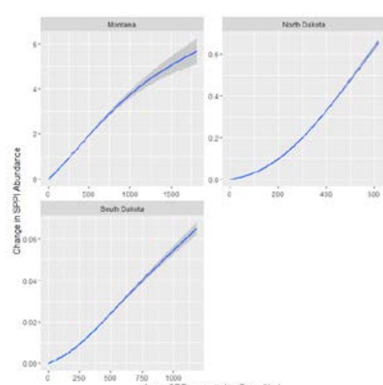
	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	160,526	174,960	14,434	8.99	4,728	9,705	2.95	6.05
MT	138,356	150,828	12,471	9.01	4,279	8,192	3.09	5.92
ND	18,195	20,058	1,862	10.24	432	1,430	2.38	7.86
SD	3,974	4,073	99	2.50	16	82	0.42	2.08

Figure B16.2. Change in Sprague's Pipit abundance within CRP fields converted to grass/herb vs. acres of CRP field converted to grass/herb within the PPJV and NGPJV (A), and by state (B). Fitted lines were derived using a Generalized Additive Model with a P-spline and lambda of 0.6.

(A)



(B)



APPENDIX C. Policy recommendations to optimize CRP for grassland birds

We consulted the Prairie Pothole Joint Venture Technical Committee and conservation professionals working in the Prairie Pothole Joint Venture and Northern Great Plains Joint Venture administrative areas about specific recommendations for optimizing USDA Conservation Reserve Program (CRP) cover for grassland nesting birds. Prioritization of fields for enrollment and retention in the CRP should be guided by:

1. Density thresholds derived from the eight species-specific models, similar to recommendations for prioritization of sites for the Duck Nesting Habitat Initiative (CP37).
2. Management practices and seeding prescriptions that increase the biological benefits for grassland birds, with special attention on grazing practices and infrastructure.
3. Targeting enrollment of lands that create large contiguous blocks of grassland.

The following recommendations are intended to streamline CRP program delivery and inform USDA financial and technical assistance.

- **Priority grassland bird species models provide density-based priority areas for CRP targeting and retention within the PPJV and NGPJV administrative areas.**

Targeting of individual tracts should be at the CRP field scale guided by thresholds identified by the individual models (see Results section in report). Although county-level summaries are useful for USDA resource allocation, grassland bird species generally respond to landscapes at biologically-relevant scales. The Duck Nesting Habitat Initiative (CP-37) example for prioritizing CRP contract enrollment and retention has proven to be biologically sound and easily implemented by USDA field offices. Final combined priority areas will include waterfowl priority areas identified by Drum et al. (2015) to optimize CRP plantings for multi-species benefits. However, caution is recommended when prioritizing CRP enrollment for multiple species benefits as some of the best habitat for declining species may not coincide with priority habitats for other generalist species.

- **Native grasses and forb species seed mixes should be planted with geographically-specific seeding prescriptions adapted to the ecological site. Seed mixes should be designed to represent natural conditions in the local landscape using existing Conservation Practice types for native seed planting (e.g., CP 2, CP4D, CP25).**

Grassland birds nesting in the northern Great Plains have evolved with the various grassland ecosystems: tallgrass, mixed grass, and dry mixed grass prairies. Grassland restorations and reconstruction should strive to replicate the native herbaceous vegetation composition within these ecosystems. By establishing CRP fields with geographically appropriate grass and forb seed mixes, the resulting herbaceous vegetation will be beneficial to other species of conservation concern, especially pollinators and butterflies.

- **Recommendations for management practices to maintain grassland productivity and structure include grazing, haying, and prescribed fire. Grazing is the preferred management practice, including the development of rangeland infrastructure (e.g., fencing and stock watering systems).**

Grassland birds in the northern Great Plains have evolved with grazers (e.g., bison, prairie dogs, etc.), wildland fires, and weather events affecting grassland productivity and structure. Grassland birds are among the least philopatric avian groups, shifting distributions annually in response to local and regional conditions (Jones et al. 2007). These nomadic behaviors provide flexibility in grassland management prescriptions intended to benefit breeding grassland birds.

To facilitate grazing in CRP fields, we recommend the installation of exterior and interior fencing with adequate livestock watering systems to achieve grazing prescriptions. Establishing these infrastructures will increase the probability the restored herbaceous cover will remain on the landscape post-CRP contract expiration, thus making grazing the preferred management practice. In areas of the northern Great Plains where sufficient livestock numbers are not available for grazing management, prescribed fire and haying can be used to maintain grassland productivity and structure.

Rotational, deferred, or continuous gazing should be conducted to benefit both forage quality and grassland bird habitat. Using a range of management prescriptions, rangelands can be maintained in good condition, providing quality livestock forage and suitable grassland bird habitat for many species. To facilitate CRP grassland management by agricultural producers, we recommend broad guidelines in management plans to maintain grassland productivity rather than applying grazing prescriptions to achieve a specific grassland structure. Although stocking rates and grazing regimes can influence grassland structure which in turn influences grassland bird distribution, the effect of grazing on herbaceous cover and birds can be highly dependent on precipitation (Lipsey and Naugle 2017), requiring periodic monitoring of CRP fields to provide information on grassland response.

- **Site-specific management plans should be developed to include detailed seeding prescriptions and required grassland management and monitoring activities.**

Consistent with current CRP policy, site-specific management plans should be developed to include detailed information regarding required grass and forb seed mixes, sowing rates, and management and monitoring actions. The plans should include adequate information for producers to successfully accomplish seeding and management prescriptions, but not so cumbersome as to inhibit landowner interest in the program. Management actions prescribed to achieve specific herbaceous vegetation objectives should be monitored across adequate timeframes to assess vegetation response and inform subsequent management actions.

- **In general, larger blocks of grass are preferred over smaller blocks for area-sensitive grassland bird species.**

Many “area-sensitive” grassland bird species require a minimum amount of habitat to be present, occur in high densities, or successfully reproduce (Ribic et al. 2009), usually in contiguous patches or unbroken blocks, before individuals will occupy a given site. Habitat fragmentation is likely to have caused grassland bird population declines, especially for area-sensitive species (Herkert 1994, Winter and Faaborg 1999). Grassland area strongly influences bird community composition in the northern Great Plains (Madden et al. 2000, Bakker et al. 2002, Davis 2004, Greer et al. 2016, Lipsey et al. 2017), and CRP grasslands substantially affect distribution and density of many grassland bird species (Johnson and Igl 1995, O’Connor et al. 1999, Johnson 2005). Further, the amount of habitat at regional scales may influence a species response to local grassland blocks. Lipsey et al. (2017) estimated that the Sprague’s Pipit was three times more likely to occupy 1 mi^2 block of grass if situated in landscapes with a high versus low proportion of grass at the township and quadrangle scale.

Estimates of the minimum size of suitable grassland habitat required to support breeding populations of grassland birds vary greatly among species. When targeting specific tracts for retention or inclusion in the CRP, the size of the resulting grassland block should be considered with emphasis on creating large continuous blocks of habitat. A general rule may be to maximize the size and interconnectedness of grassland habitat patches available

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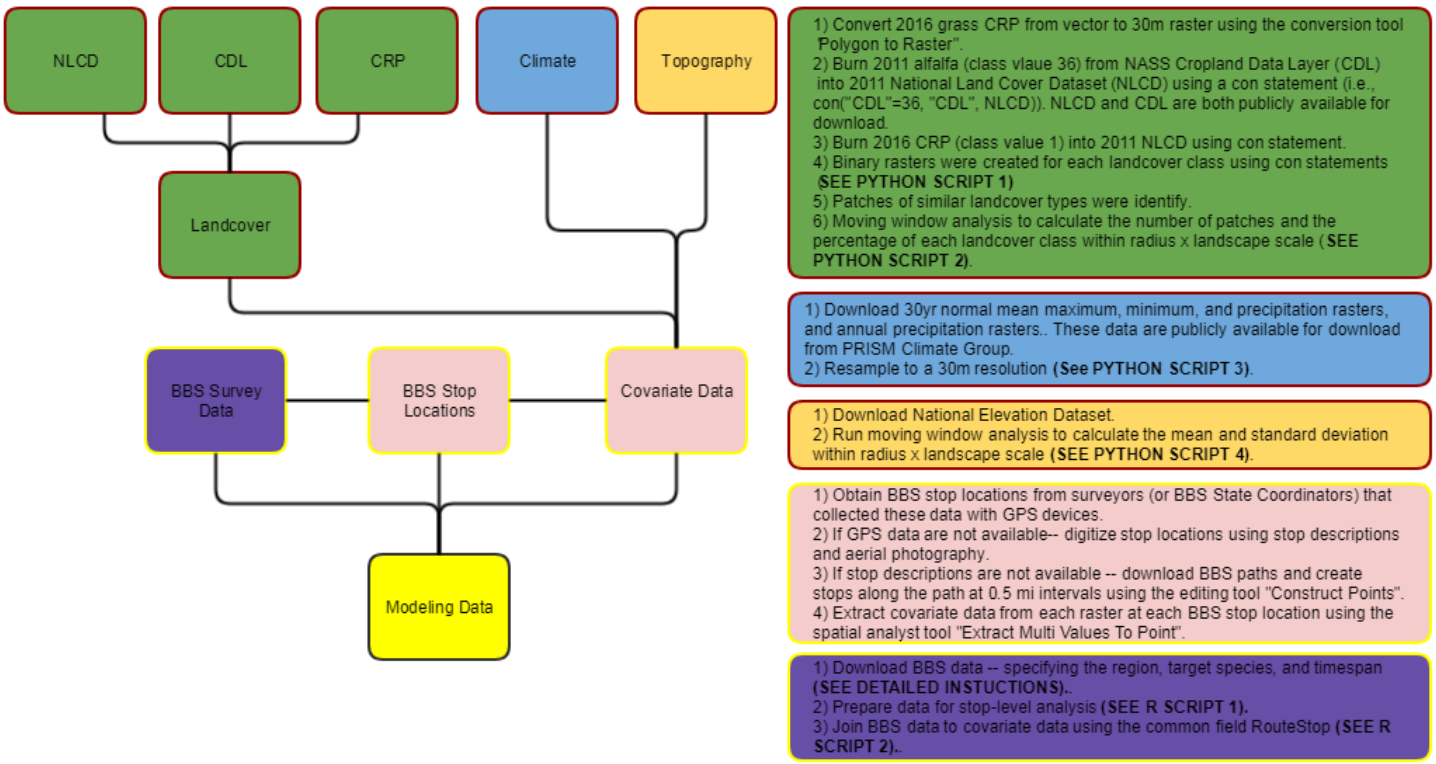
APPENDIX D. Detailed data preparation and modeling methods

Figure D1. Workflow and methods for building a data frame that contains Breeding Bird Survey data (observations of species' abundance and occurrence, survey conditions, and route, stop, and observer ID) and covariate data.



Python Script 1

```
#This script was created by Kevin Barnes (USFWS PPJV/HAPET, kevin_barnes@fws.gov)to automate
#the processing of NLCD data for the CRP grassland bird modeling project. In this script NLCD is
#seperated out into individual landcover classes as binary rasters through the use of con statements
#involving NLCD landcover class values. These are stored in a geodatabase with the suffix "_bin".

import arcpy
import time
from arcpy.sa import *
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput=True
start=time.time()
```

```
#Enter workspace. Workspace should hold the complete 2011 NLCD raster with crp burnt in
(i.e.PPNGPJV_NLCD)
arcpy.env.workspace=r"?:\Enter\WorkspaceHere.gdb"

#nlcd 2011 file
nlcd="PPNGPJV_NLCD"

#2011 NLCD Values are:
#open water=11, woody wetland=90, emergent wetland=95
#Developed, Open space= 21, Developed, Low intensity=22, Developed, Medium Intensity=23,
Developed, High Intensity=24
#Barren=31
#Deciduous Forest = 41, Coniferous Forest = 42, Mixed Forest = 43
#Scrub/Shrub = 52
#Grassland/Herbaceous = 71, Pasture/Hay =81, CRP=1, Alfalfa=36
#Crop=82


#Con statements
wtrALL=Con(nlcd, 1, 0, "VALUE=11 OR VALUE=90 OR VALUE=95")
wtrALL.save("wtrALL_bin")

wtr=Con(nlcd, 1, 0, "VALUE=11")
wtr.save("wtr_bin")

wdyw=Con(nlcd, 1, 0, "VALUE=90")
wdyw.save("wdyw_bin")

emgw=Con(nlcd, 1, 0, "VALUE=95")
emgw.save("emgw_bin")

fors=Con(nlcd, 1, 0, "VALUE=41 OR VALUE=42 OR VALUE=43")
fors.save("fors_bin")

shrb=Con(nlcd, 1, 0, "VALUE=52")
shrb.save("shrb_bin")

phay=Con(nlcd, 1, 0, "VALUE=81")
phay.save("phay_bin")

gh=Con(nlcd, 1, 0, "VALUE=71")
gh.save("gh_bin")

crp=Con(nlcd, 1, 0, "VALUE=1")
gh.save("crp_bin")

alf=Con(nlcd, 1, 0, "VALUE=36")
alf.save("crp_bin")

grsALL=Con(nlcd, 1, 0, "VALUE=71 OR VALUE=81 OR VALUE=1 OR VALUE=36")
grsALL.save("grs_bin")
```

```
crop=Con(nlcd, 1, 0, "VALUE=82")
crop.save("crop_bin")

bare=Con(nlcd, 1, 0, "VALUE=31")
bare.save("bare_bin")

urb=Con(nlcd, 1, 0, "VALUE=21 OR VALUE=22 OR VALUE=23 OR VALUE=24")
urb.save("urb_bin")

end=time.time()
elapsed=end-start
print elapsed
```

Python Script 2

```
#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov)to automate
#the processing of NLCD data for the CRP grassland bird modeling project. In this script landcover
#binary rasters are processed to first identify landcover patches, then use a moving window analysis
#to calculate the number of patches and percent of each landcover. Region groups are stored with the
#suffix "_RG", patch counts are stored with the suffix "pa", and percentages are stored with the
#suffix "pr".


import arcpy
import time
from arcpy.sa import *
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput=True
start = time.time()

#Users will have to enter input workspace below, which will house binaries, snap, and mask.
#They will also need to define which binaries they will run using a wildcard:
#one binary layer (i.e. "*fors_bin") or all binaries (i.e. "*_bin")
arcpy.env.workspace=r"E:\KBarnes\crop_bin\crop.gdb"
mask="PPNGPJV_nobuf_albers"

#Define the binaries you will run.
rasterlist=arcpy.ListRasters("*_bin")
print rasterlist

#List of landscape scales.
ls=[400, 800, 1200, 1600, 2400, 3200]


#Region Group, note standardized suffix to use as wildcard later on (i.e., "*_RG") to run patches.
#Note setnull so you don't count the zero patches.
for i in rasterlist:
    ras=arcpy.Raster(i)
```

```
    rasrg=RegionGroup(ras, "FOUR", "", "", 0)
    rgnull=SetNull(rasrg, rasrg, "LINK = 0")
    rgnull.save(i[:-4]+"_RG")

#Proportions
for i in rasterlist:
    ras=arcpy.Raster(i)
    for s in ls:
        raspr=FocalStatistics(ras, NbrCircle(s, "MAP"), "MEAN")
        raspr100=raspr*100
        raspr8bit=arcpy.CopyRaster_management(raspr100,"deleteme","","","","","","8_BIT_UNSIGNED")
        arcpy.env.snapRaster = "snap"
        arcpy.env.extent = "snap"
        arcpy.Clip_management(raspr8bit, "",  i[:-4]+str(s)+"pr", mask, "", "ClippingGeometry")
        arcpy.Delete_management("deleteme")

#Patches
rasterlist=arcpy.ListRasters("*_RG")
print rasterlist
for i in rasterlist:
    ras=arcpy.Raster(i)
    for s in ls:
        raspa=FocalStatistics(ras, NbrCircle(s, "MAP"), "VARIETY")
        arcpy.env.snapRaster = "snap"
        arcpy.env.extent = "snap"
        fixedit=Con(IsNull(raspa), 0, raspa)
        arcpy.Clip_management(fixedit, "",  i[:-3]+str(s)+"pa", mask, "", "ClippingGeometry")

import winsound
winsound.Beep(600,1000)
end = time.time()
elapsed = end - start
print elapsed
```

Python Script 3

```
#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov)to automate
#the processing of PRISM climate data for the CRP grassland bird modeling project. In this script climate
#data are resampled to a 30 m resolution and clipped to the extent of the study area. Note that you #need
to have the first mask buffered by 4000m and in the projection GCS_NAD83, and the second #mask must
be in the projection Albers.

import arcpy
from arcpy.sa import *
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput=True

mask1=r"E:\Projects\CRPbirds_2016\StudyExtent.gdb\PPNGPJV_buf4000_GCSNAD83"
mask2=r"E:\Projects\CRPbirds_2016\StudyExtent.gdb\PPNGPJV_nobuf_albers"
```

```
arcpy.env.workspace=r"E:\Projects\CRPbirds_2016\ClimateData\Unprocessed.gdb"
rasterlist=arcpy.ListRasters()
print rasterlist

for raster in rasterlist:
    Ras=arcpy.Raster(raster)
    arcpy.env.snapRaster = r"E:\Projects\CRPbirds_2016\NLCD.gdb\PPNGPJV_NLCD11_alf11crp16"
    arcpy.env.extent = r"E:\Projects\CRPbirds_2016\NLCD.gdb\PPNGPJV_NLCD11_alf11crp16"
    clipraster1=arcpy.Clip_management(Ras, "", "E:/Projects/CRPbirds_2016/Climate.gdb/clip1", mask1,
"", "ClippingGeometry")
    inras=arcpy.ProjectRaster_management (clipraster1, "E:/Projects/CRPbirds_2016/Climate.gdb/prj1",
mask2, "", "30")
    clipraster2=arcpy.Clip_management(inras, "", "E:/Projects/CRPbirds_2016/Climate.gdb/"+raster
,mask2, "", "ClippingGeometry")


arcpy.Delete_management("clip1")
arcpy.Delete_management("prj1")


import winsound
winsound.Beep(600,1000)
```

Python Script 4

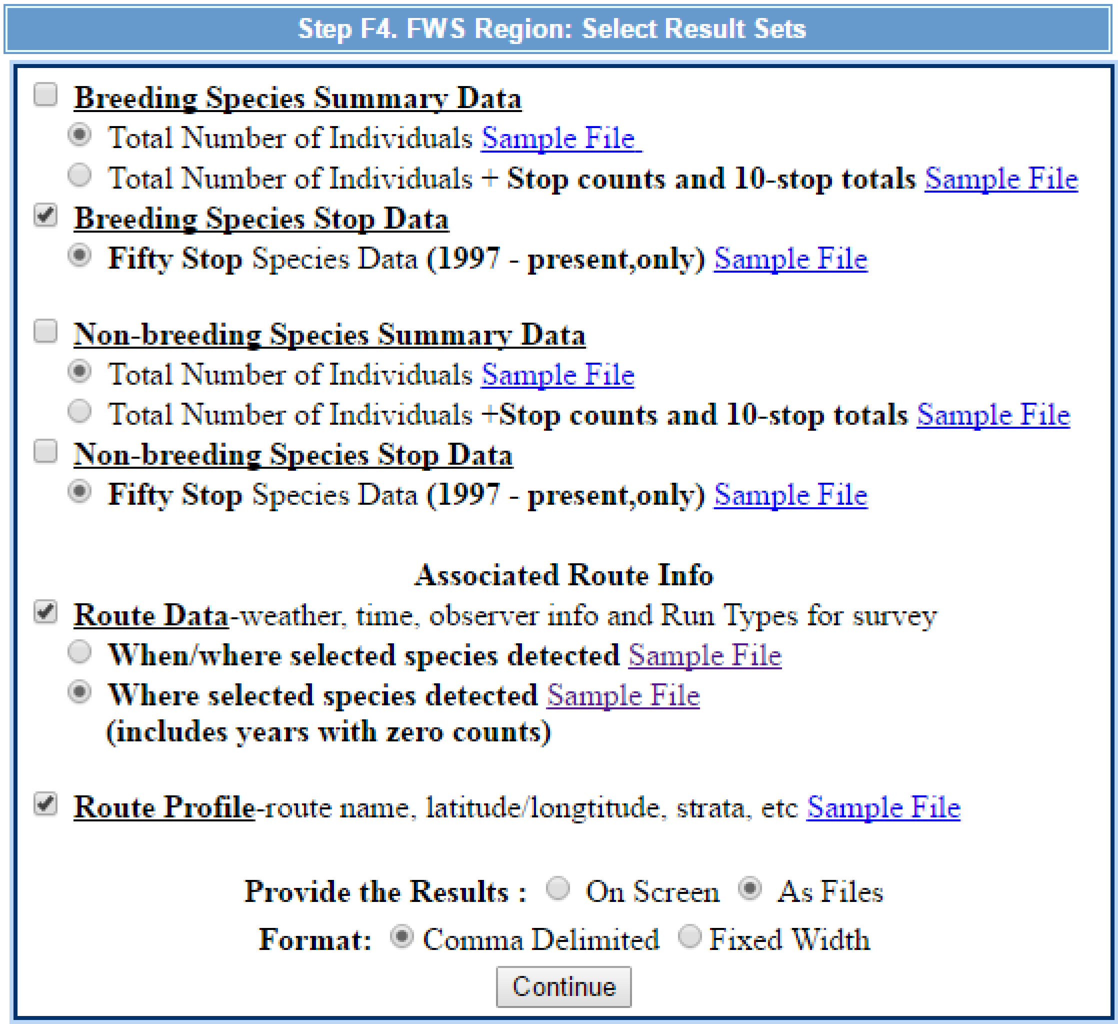
```
#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov)to automate
#the processing of DEM data for the CRP grassland bird modeling project. In this script DEM data are
#processed using a moving window analysis to calculate the mean elevation and the standard deviation
#(topographic roughness) for each landscape scale.


import arcpy
import time
from arcpy.sa import *
arcpy.CheckOutExtension("spatial")
arcpy.env.overwriteOutput=True
start = time.time()

#Users will have to enter input workspace below, which will house binaries, snap, and mask.
#They will also need to define which binaries they will run using a wildcard:
#one binary layer (i.e. "*fors_bin") or all binaries (i.e. "*_bin")
arcpy.env.workspace=r"E:\Projects\CRPbirds_2016\DEM.gdb"
mask="PPNGPJV_nobuf_albers"

#Define the binaries you will run.
rasterlist=arcpy.ListRasters()
print rasterlist

#List of landscape scales.
```

```
ls=[400, 800, 1200, 1600, 2400, 3200]


#Proportions Mean
for i in rasterlist:
    ras=arcpy.Raster(i)
    for s in ls:
        raspr=FocalStatistics(ras, NbrCircle(s, "MAP"), "MEAN")
        raspr100=raspr*100
        raspr8bit=arcpy.CopyRaster_management(raspr100,"deleteme","","","","","","8_BIT_UNSIGNED")
        arcpy.env.snapRaster = "Snap"
        arcpy.env.extent = "Snap"
        arcpy.Clip_management(raspr8bit, "",  i+str(s)+"x", mask, "", "ClippingGeometry")
        arcpy.Delete_management("deleteme")

#Proportions STD
for i in rasterlist:
    ras=arcpy.Raster(i)
    for s in ls:
        raspr=FocalStatistics(ras, NbrCircle(s, "MAP"), "STD")
        raspr100=raspr*100
        raspr8bit=arcpy.CopyRaster_management(raspr100,"deleteme","","","","","","8_BIT_UNSIGNED")
        arcpy.env.snapRaster = "Snap"
        arcpy.env.extent = "Snap"
        arcpy.Clip_management(raspr8bit, "",  i+str(s)+"sd", mask, "", "ClippingGeometry")
        arcpy.Delete_management("deleteme")



import winsound
winsound.Beep(600,1000)
end = time.time()
elapsed = end - start
print elapsed
```

DETAILED INSTRUCTIONS FOR DOWNLOADING BBS DATA

Download data from their database via https://www.pwrc.usgs.gov/BBS/PublicDataInterface/index.cfm.

I selected “Advanced Search”>”FWS Region”>”region 6” and then “region 3”>Selected multiple target species using the find function (cntrl+F) to locate it and using control+click to select multiple species>selected year 2008-2015 and standard method>then selected the following from the below image



Step F4. FWS Region: Select Result Sets

- [ ] Breeding Species Summary Data
  - (•) Total Number of Individuals Sample File
  - ( ) Total Number of Individuals + **Stop counts and 10-stop totals** Sample File
- [x] Breeding Species Stop Data
  - (•) **Fifty Stop** Species Data **(1997 - present,only)** Sample File

- [ ] Non-breeding Species Summary Data
  - (•) Total Number of Individuals Sample File
  - ( ) Total Number of Individuals +**Stop counts and 10-stop totals** Sample File
- [ ] Non-breeding Species Stop Data
  - (•) **Fifty Stop** Species Data **(1997 - present,only)** Sample File

Associated Route Info

- [x] Route Data-weather, time, observer info and Run Types for survey
  - ( ) **When/where selected species detected** Sample File
  - (•) **Where selected species detected** Sample File **(includes years with zero counts)**

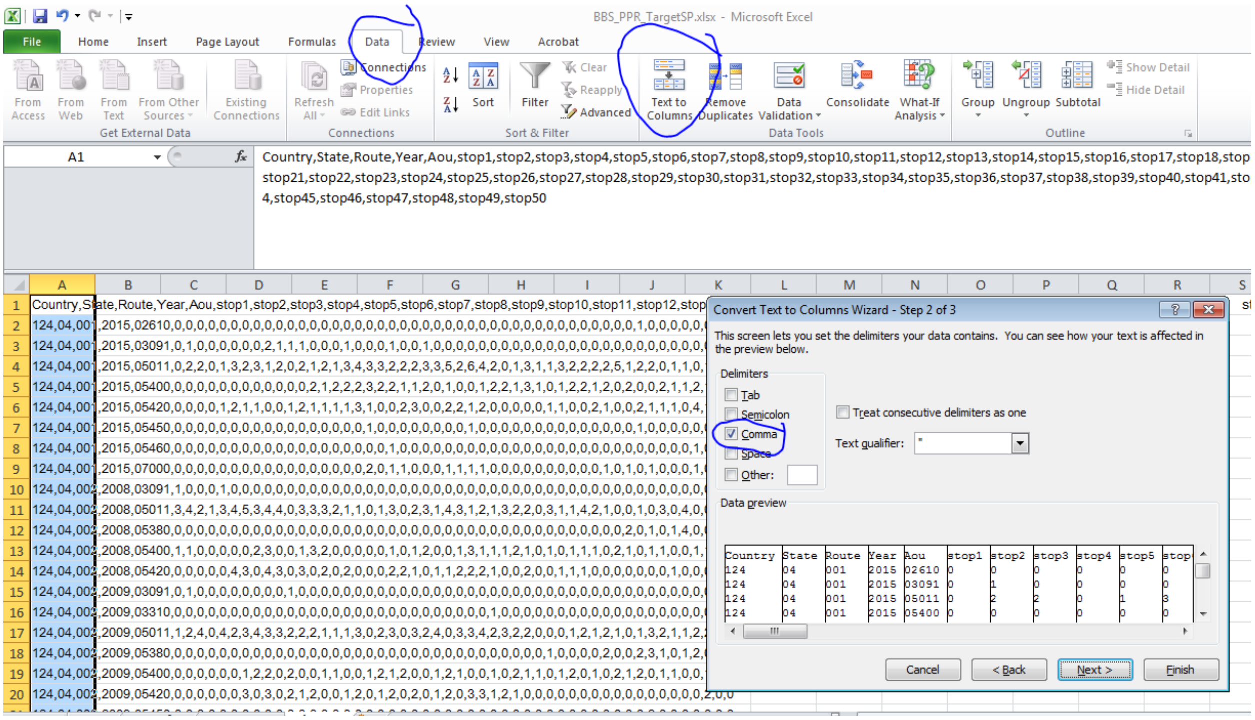
- [x] Route Profile-route name, latitude/longtitude, strata, etc Sample File

Provide the Results : ( ) On Screen (•) As Files

Format: (•) Comma Delimited ( ) Fixed Width

Continue

Access to data was available via three email links: stop data, route data, route profile. These were copy pasted into an excel document onto three different tabs in a worksheet. Data are comma delimited so I used “text to column” tool in excel with comma selected as the delimiter.



R Script 1

#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov)to automate #the processing of BBS data for the CRP grassland bird modeling project. In this script BBS data are #processed using the dplyr package to set up a data frame appropriate for stop level modeling.

```
#R code to process BBS data for modeling at the stop level
setwd("E:\\Projects\\CRPbirds_2016\\Rwd\\DataProcessing")
require(readxl)
require(dplyr)
require(tidyr)
require(ggplot2)
require(stringr)

#Import excel sheets
BBS1<-data.frame(read_excel("BBS_PPR_TargetSP3.xlsx", 7))
RouteInfo<-data.frame(read_excel("BBS_PPR_TargetSP3.xlsx", 8))
head(BBS1)
head(RouteInfo)

#Get route info assigned to each species. NOTE: “each=18” will need to be adjusted for the number of species if there are more or less than 18.
RouteInfo1<-data.frame(RouteInfo[rep(1:nrow(RouteInfo),each=18),], Aou=rep(c(2610, 3091, 3310, 4740, 4940,
                                                5011, 5380, 5390, 5400,
                                                5420, 5450, 5460, 5480, 5610,
                                                6040, 6050, 7000, 7240), nrow(RouteInfo)))
```

```
colnames(BBS1)
colnames(RouteInfo1)
head(RouteInfo1)

##join route info
BBS2<-left_join(RouteInfo1, BBS1, by=c("Country","state"="State", "route"="Route", "year"="Year",
"Aou"), match = "all")


#functions to convert abundance to occurrence and to fill NA values to zero
bin<-function(x) ifelse(x>0, 1, x)
na_to_zero<-function(x) ifelse(is.na(x), 0, x)

####BBS processing.
checkit<-BBS2%>%
  gather(Stop, Abundance, 21:70)%>%
  mutate(Stop=as.numeric(str_extract(Stop, "[[:digit:]]+")))%>%
  spread(Aou, Abundance)%>%
  mutate(Stop=str_pad(Stop, 2, pad = "0"), Route=str_pad(route, 3, pad = "0"))%>%
  mutate(RouteStop=as.numeric(paste0(state, Route, Stop)))%>%
  dplyr::rename(UPSA=`2610`, RNEP=`3091`, NOHA=`3310`, HOLA=`4740`, BOBO=`4940`,
WEME=`5011`,
            CCLO=`5380`, MCLO=`5390`, VESP=`5400`, SAVS=`5420`, BAIS=`5450`,
            GRSP=`5460`, LESP=`5480`, CCSP=`5610`, DICK=`6040`, LARB=`6050`, SPPI=`7000`,
            SEWR=`7240`)%>%
  mutate_at(21:38, funs(na_to_zero))%>%
  mutate_at(21:38, funs(occ=bin))
colnames(checkit)
summary(checkit)

write.csv(checkit, "ProcessedBBSdata3.csv")
```

R Script 2

```
#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov) to automate
#the processing of joining covariate data to BBS observational data for the CRP grassland bird modeling
#project. In this script data are processed using the dplyr package to set up a data frame appropriate for
#stop level modeling.


#R code to join covariate data to observational data

setwd("E:\\Projects\\CRPbirds_2016\\Rwd\\DataProcessing")
CRPbirds<-read.csv("ProcessedBBSdata2.csv")

require(lme4)
require(rgdal)
require(dplyr)
```

```
require(tidyr)
require(broom)

#geodatabase housing stop-level covariate data
fgdb2 = "E:/Projects/CRPbirds_2016/BBSdata.gdb"
#stop-level covariate data
Env = readOGR(dsn=fgdb2,layer="PPNGPJV_BBSstops_final")
Env<-data.frame(Env)
colnames(Env)
#Annual data needs to go from wide format to narrow format (i.e., stack each annual column according to
survey year).
Env2<-data.frame(Env[7], Env[140:148], Env[244])
colnames(CRPbirds)
colnames(Env2)

#melt annual precip data...convert wide to narrow
ppt07<-data.frame(Env2[1], Env2[2])
ppt08<-data.frame(Env2[1], Env2[3])
ppt09<-data.frame(Env2[1], Env2[4])
ppt10<-data.frame(Env2[1], Env2[5])
ppt11<-data.frame(Env2[1], Env2[6])
ppt12<-data.frame(Env2[1], Env2[7])
ppt13<-data.frame(Env2[1], Env2[8])
ppt14<-data.frame(Env2[1], Env2[9])
ppt15<-data.frame(Env2[1], Env2[10])
ppt16<-data.frame(Env2[1], Env2[11])
colnames(ppt07)[2]<-"ppt"
colnames(ppt08)[2]<-"ppt"
colnames(ppt09)[2]<-"ppt"
colnames(ppt10)[2]<-"ppt"
colnames(ppt11)[2]<-"ppt"
colnames(ppt12)[2]<-"ppt"
colnames(ppt13)[2]<-"ppt"
colnames(ppt14)[2]<-"ppt"
colnames(ppt15)[2]<-"ppt"
colnames(ppt16)[2]<-"ppt"
ppt07$year<-2007
ppt08$year<-2008
ppt09$year<-2009
ppt10$year<-2010
ppt11$year<-2011
ppt12$year<-2012
ppt13$year<-2013
ppt14$year<-2014
ppt15$year<-2015
ppt16$year<-2016
ppt<-rbind(ppt07,ppt08, ppt09, ppt10, ppt11,ppt12,ppt13,ppt14, ppt15, ppt16)

#Join static data
Env1<-data.frame(dplyr::select(Env, -ppt07, -ppt08, -ppt09, -ppt10, -ppt11, -ppt12,
                               -ppt13, -ppt14, -ppt15, -ppt16))
```

```
CRP<-left_join(CRPbirds, Env1, by=c("RouteStop"="st_rte_stop"))

#join annual data
CRP<-left_join(CRP1, ppt, by=c("RouteStop"="st_rte_stop", "year"), match="all")
colnames(CRP)


write.csv(CRP, "CRPbirds_modeldata.csv")
```