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

Final Report Prepared for the United States Department of Agriculture Farm Service Agency

Reimbursable Fund Agreement 16-IA-MRE CRP TA 5

October 2018

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ABSTRACT

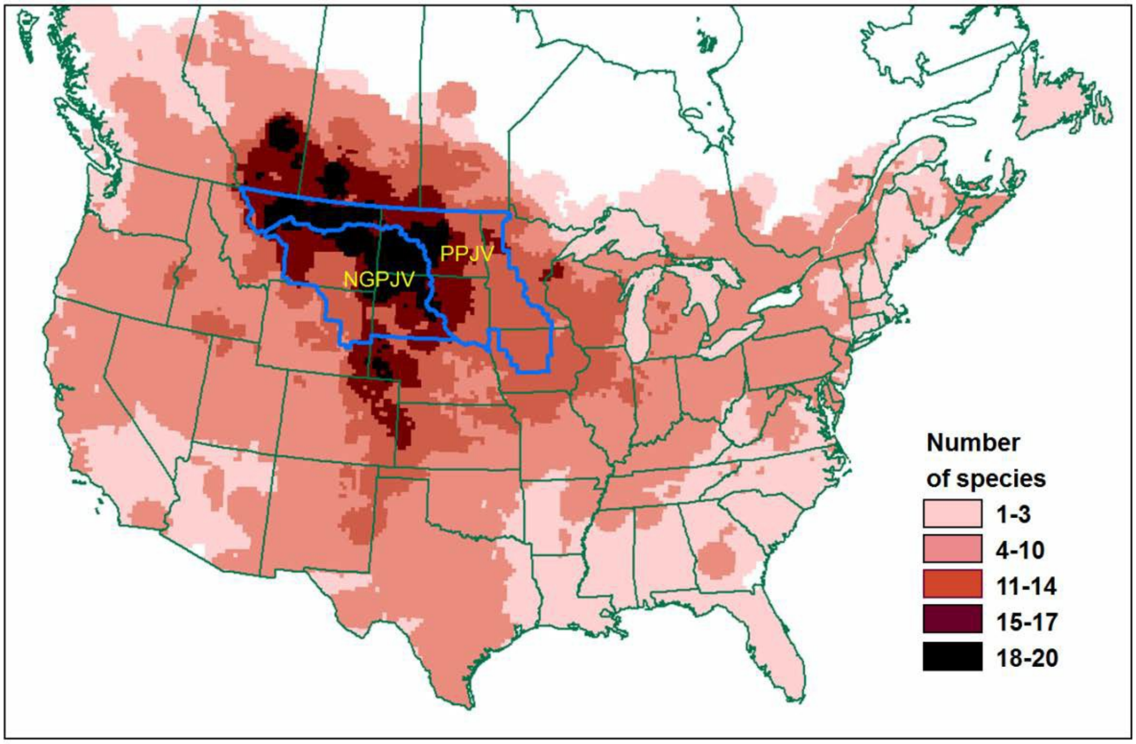
The U.S. Department of Agriculture Conservation Reserve Program (CRP) has provided important nesting habitat in the Northern Great Plains for grassland birds, one of the fastest declining groups of birds in North America. However, the amount of land enrolled in CRP has been declining due to retired contracts coupled with lower nation-wide enrollment caps. To maximize the benefits of the CRP for grassland birds, we developed decision-support tools to guide retention and enrollment of CRP grasslands. We used stop-level data from The North American Breeding Bird Survey and covariates derived from land cover, climatic, and topographic datasets to create density and distribution models for nine species of grassland birds across the Prairie Pothole Joint Venture and Northern Great Plains Joint Venture. Species were selected based on joint venture priorities. Endemic grassland birds included Baird's Sparrow, Chestnut-collared Longspur, Lark Bunting, and Sprague's Pipit. More widespread species included Bobolink, Clay-colored Sparrow, Dickcissel, Grasshopper Sparrow, and Sedge Wren. Generally, all species showed a negative association with water, forest, and/or developed areas, and a positive association with grasslands. The more widespread grassland birds in this study generally occurred at higher densities in the east and were more positively associated with a diversity of cover types including grassland/herbaceous cover, pasture/hay, CRP, and/or alfalfa. All widespread grassland birds and Baird's Sparrow were positively associated with CRP, while Chestnut-collared Longspur, Lark Bunting, and Sprague's Pipit had no association or a weak negative association with CRP. Endemic grassland bird species had a stronger association with the drier managed grasslands of the west (i.e. grassland/herbaceous cover) than CRP or other grass cover types. In total, CRP supported 8.61% of the total estimated population for those species that had positive associations with CRP. If CRP were treated as managed grasslands and grazed or hayed, we estimated that populations of endemic grassland birds

in our study region would increase 5.00%. 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 (US Congress 1985; Public Law 99-198), which is administered by the U.S. Department of Agriculture (USDA) Farm Services Agency (FSA), is the largest private lands conservation program in the United States. Lands enrolled in CRP provide habitat for a variety of grassland bird species. CRP is particularly important in the Northern Great Plains because this region has the highest diversity of grassland bird species on the continent, and populations of grassland birds are declining at a steeper rate than those of any other group of North American birds (Figure 1; Knopf 1994, Herkert 1995, Peterjohn and Sauer 1999). For example, results from the North American Breeding Bird Survey indicate total population declines since the 1960s for McCown's Longspur, Lark Bunting, Chestnut-collared Longspur, Baird's Sparrow, and Sprague's Pipit to be 94%, 86%, 85%, 75%, and 71%, respectively (Partners In Flight Science Committee 2013).

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.



Grassland birds in the Northern Great Plains evolved to use vegetation structure and composition that was ultimately the result of soil, climate, and ecological drivers such as grazing and fire; however, since European settlement, grasslands have been converted and degraded at an alarming rate, and ecological drivers have been largely suppressed (Knopf 1994, Askins et al. 2007). Cropland expansion is one major contributing factor of grassland bird declines due to the replacement of ecologically relevant cover with foreign monocultures, such as row crops and small grains, which have a structure and composition different than what was historically present and what grassland birds evolved to utilize. However, the CRP program has been able to provide sufficient vegetation structure and composition for some grassland birds and has helped stem population declines.

The CRP is a particularly important conservation tool because much of the land in this region is privately owned. An increase in commodity prices, coupled with crop insurance, advances in biotechnology, and biofuel mandates have incentivized cultivation even on marginal lands, and have created high land values that are cost-prohibitive for conservation efforts such as fee-title acquisition (Rashford et al. 2010, Hertel and Beckman 2011, Claassen 2012, Wright and Wimberly 2013). CRP has provided a mechanism for land owners to benefit from marginal cropland without cultivation by leasing these lands for a 10-15 year period and establishing non-agricultural perennial cover. CRP enrollment applications are ranked using an environmental benefits index, which ranks lands according to the wildlife benefits they will provide, as well as the benefits to soil, air, and water quality, the enduring benefits beyond the contract period, and the cost (USDA-FSA 2013).

There are many types of plantings that landowners can enroll in, which are generally associated with the type of cover being established (USDA-FSA 2018a). For example, CP1 and CP2 are introduced grasses and legumes, and native grasses and forbs, respectively. Generally landowners are not permitted to graze or hay CRP lands except during extreme conditions. However, weed control and mid-contract management obligations are becoming common.

Unfortunately for conservation, the total acreage of CRP in the US has declined drastically over the past decade, with greatest losses in the Northern Great Plains states of Montana and North Dakota (UDS-FSA 2018b). This situation is unlikely to improve, as the 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 assessing existing CRP parcels for retention and assessing new parcels for future enrollment and prioritizing those CRP lands that provide highest benefits for grassland birds.

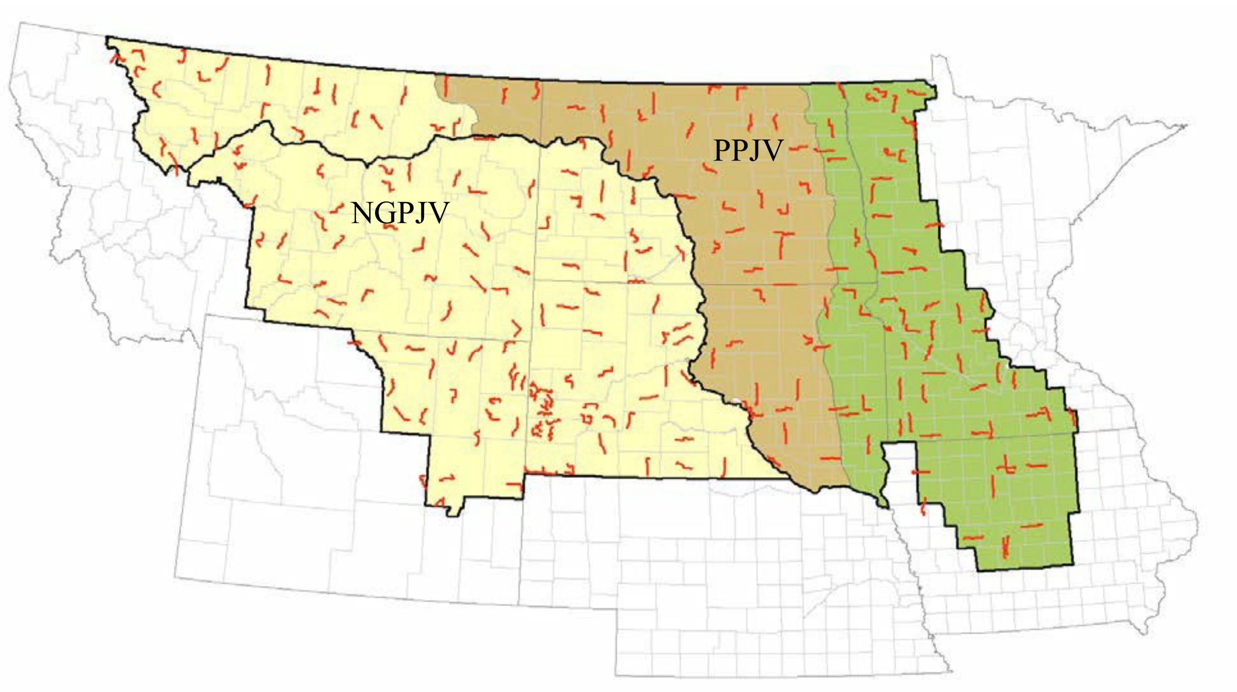
Spatial decision-support tools have been successfully used to guide conservation of grassland nesting birds in many locations and situations, including prioritization of land parcels for CRP enrollment (e.g. Reynolds et al. 2006). Given the need to maximize benefits of CRP lands for grassland birds as CRP acreage declines, we initiated a spatial analysis project with 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 targeting and management to optimize the program for grassland nesting birds.

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 and 2). 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). Soil composition and climate greatly influence land use and vegetation composition and structure, and ultimately bird communities (Wiens 1974, Samson et al. 1998, Niemuth et al. 2008).

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 = 221) included in the analysis.



In addition to soil and climate, historically the vegetation structure and composition within the short grass prairie were largely influenced by free-roaming grazers, whereas in the tall grass prairie vegetation was influenced more by fire and to a lesser degree grazing. The replacement of free-roaming grazers with moderate grazing regimes, suppression of fires, and the introduction of non-native vegetation have created a taller and denser vegetation structure than what was historically present in the shortgrass prairie region, and has also allowed woody vegetation encroachment and a dense litter layer in the east (Wright and Baily 1982, Truett 2003, Askins et al. 2007).

Endemic grassland birds of the Great Plains evolved in the short grass prairie region and utilized different vegetation structure and composition than what was available (Knopf 1994, Askins et al. 2007). For example, McCown's Longspur, Lark Bunting, Chestnut-collared Longspur, Sprague's Pipit, and Baird's Sparrow settle on their breeding grounds in locations that range from very short and sparse to relatively taller and denser vegetation, respectively. Other, more widespread grassland birds often occur in areas of taller and denser vegetation compared to the shortgrass prairie region but still utilized different vegetation structure and composition. For example, Grasshopper Sparrow, Dickcissel, Bobolink, and Sedge Wren settle in areas on their breeding grounds with vegetation composition and structure that range from moderate height and density to greater height and density with a well defined litter layer, respectively.

Since European settlement 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 the 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.

Landcover changes from 2008 to 2016 have been extensive. Area of CRP has declined 48%, making up 3% of the study area in 2016 (USDA-FSA 2018b). According to time series land cover data from the Cropland Data Layer (CDL) developed by the United States Department of Agriculture National Agriculture Statistics Service (USDA NASS 2011), grassland/pasture has declined 16% during this period, making up 38% of the study area in 2016, and cropland has increased 9%, making up 39% of the study area in 2016. Other research also reports annual grassland declines in the Great Plains of 1-2% in the last decade (Rashford et al. 2010, Wright and Wimberly 2013, Gage et al. 2016).

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). Standard survey routes were randomly established with uniform densities per 1 degree block within states. Routes consist of 50 roadside stops that are 0.5 mi apart. Surveys are conducted by one individual in good weather (i.e., limited rain, and wind less than Beufort 4) and start 30 min prior to sunrise. At each stop surveyors record all the birds they hear and all the birds they see within ~0.25 mi of the stop during a 3 minute period. Birds that are heard but not seen are counted despite distance; however, surveyors make efforts to avoid double counting individuals.

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 10,859 stops collected on 221 routes in the Prairie Pothole and Northern Great Plains Joint Ventures for a total of 66,180 observations by 186 observers (Figure 2).

Stop coordinates for BBS routes were identified 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 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 or 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 for a portion of our stops should have minimal influence on model estimates.

We selected 18 potential grassland bird species for model development, representing a large portion of the grassland-dependent species breeding in the study area (Table 1). We then selected nine species for model development and analysis that are either species of conservation concern or JV priority species. Endemic species included Baird's Sparrow (*Ammodramus bairdii*), Chestnut-collared Longspur (*Calcarius ornatus*), Lark Bunting (*Calamospiza melanocorys*), and Sprague's Pipit (*Anthus spragueii*). More widespread species included Bobolink (*Dolichonyx oryzivorus*), Clay-colored Sparrow (*Spizella pallida*), Dickcissel (*Spiza Americana*), Grasshopper Sparrow (*Ammodramus savannarum*), and Sedge Wren (*Cistothorus platensis*).

Table 1. Candidate species for model development (n = 18). 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**
Clay-colored Sparrow			**TG, MG, DMG**
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
Northern Harrier			TG, MG, DMG

Predictor Variables

We developed models from a suite of candidate predictor variables that characterized landscape composition and configuration, weather and climate, topography, daily and seasonal changes in bird activity and detectability, and survey structure, all of which have been well supported by previous research (Niemuth et al. 2017; Table 2). Model covariates were derived using 2011 National Land Cover Dataset (NLCD; Homer et al. 2015), 2011 NASS CDL, 2016 CRP dataset provided by FSA, 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 an 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 2011 CDL 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.

Table 2. 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.

Type	Variable	Definition	Justification
Land cover composition and configuration	Grassland & herbaceous (%, n)	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 (%, n)	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. 1999, Madden et al. 2000); densities differ between mowed and unmowed fields (Dale et al. 1997).
	CRP (%, n)	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 (%, n)	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).
	Grass Diversity (n)	A count of the different grass types (0-4); grassland/herbaceous, pasture/hay, CRP, and alfalfa.	Some species of birds may prefer a variety of grass (i.e. structural) types.
	Cropland (%, n)	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.1999, DeJong et al. 2004).
	Bare (%, n)	Areas with < 15% vegetation (i.e., bedrock). NLCD class 31.	Grassland bird occurrence is generally low in areas of bare ground.
	Open water (%, n)	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.

Land cover composition and configuration	Emergent herbaceous wetlands (%, n)	Areas where herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or coverd 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 (%,n)	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 (%,n)	Combination of open water, woody wetlands, and emergent wetlands. NLCD classes 11, 90,and 95.	See open water and wetland justifications.
	Forest (%,n)	Areas dominated by trees > 5 m tall. Includes deciduous and coniferous forest. NLCD classes 41, 42, and 43. Forest (%)	Many species of grassland birds avoid trees, which create visual obstructions as well as harbor predators and brood parasites (Coppedge et al. 2001, Ribic and Sample 2001, Grant et al. 2004, Thompson et al. 2014).
	Shrub (%, n)	Areas dominated by shrubs < 5 m tall with shrub canopy > 20% of total vegetation. NLCD calss 52.	Presence and density of grassland birds are influenced by amount and structure of sage brush and association short-grass prairie (Kantrud and Kologiski 1983, Rotenberry and Wiens 1980).
	All Woody Vegetation (%, n)	Combination of forest and shrub. NLCD classes 41, 42, 43, 52.	See forest and shrub justifications.
	Developed (%, n)	Areas characterized by construction materials and impervious surfaces as well as open spaces and lawns. NLCD 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, Jongsomjjit et al. 2013, Wood et al. 2014)
Climate	Long-term minimum temperature (°C)	Long-term (1981-2010) mean minimum temperature data 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'Conner et al. 1999, Thogmartin et al. 2006b).
	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, Wiens 1989, O'Conner et al. 1999, Thogmartin et al. 2006b).

Climate	Long-term precipitation (mm)	Long-term (1981-2010) mean sum precipitation from PRISN 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. 2006b).
	Annual Precipitation	Annual precipitation (2008-2016) from PRISM data	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).
	Annual Precipitation Anomaly	Annual precipitation minus Long-term 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 NED digital elevation model	Elevation influences many physical and ecological processes that shape or limit bird communities (Wiens 1989).
	Elevation	Elevation of BBS stop at 30 m resolution given by NED digital elevation model	Elevation influences many physical and ecological processes that shape or limit bird communities (Wiens 1989).
	Topographic Position	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 Niemuth).
	Topographic variation	Standard deviation of elevation around each survey point, calculated from NED 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 tha groups data by BBS route. Treated as random effect.	Inclusion of route number as a random effect accommodated reduced variance associated with repeated sampling (Crawley 2007).
	Observer	Categorical variable grouping data by route observer (route:observer). Treated as random effect.	Bird detection ability differs among observers (Sauer et al. 1994); we included as random effect to accommodate variance associated with observer differences (Crawley 2007)
	Year	Categorical variable identifying that groups data by year. Treated as random effect	Population size and distribution vary among years (Anderson et al. 1981, Niemuth et al. 2008); we included as a random effect to accommodate variance associated with inter-annual changes (Crawley 2007).
	Stop	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 daily survey period (Robbins 1981, Rosenberg and Blancher 2005).
	Ordinal Date	Integer representing number of days since beginning of count year.	Detection of some species of birds varies substantially during the annual survey period (Anderson et al. 1981, Skirvin 1981).
	Wind	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).

We extracted data for the following land cover types: grassland/herbaceous, 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 (grassland/herbaceousaceous, 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 (Table 3).

Table 3. Means, standard deviation (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 2 for variable definitions.

Variable	***Mean***	***SD***	***Minimum***	***Maximum***
Grassland/herbaceous (n)	12.85	13.86	0.00	95.00
Grassland/herbaceous (%)	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

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 total precipitation. In addition, we obtained annual total 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 (henceforth topographic position). 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 fixed effect 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 using the lme4 package (Bates et al. 2015) in program R version 3.4.0 (R core team 2017). 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 with 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, Zuur et al. 2009, Zuur et al. 2010).

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. 2009, 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; Table 4). We then used exploratory analyses to further guide model development, including factored box plots, line graphs, and univariate models that included quadratic terms and covariate transformations (log, square, and square root). Quadratic terms and covariate transformations better characterized the relationship between the response and predictor variable and improved the fit of the model, VIF, the distribution of model residuals, and/or model convergence. To select a best-approximating model 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, VIF, model convergence, and overdispersion estimates (Burnham and Anderson 2002, Crawley 2007, Arnold 2010).

Table 4. Species, states included in analysis, scale of model, 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 density or occurrence of nine species of grassland birds in the Northern Great Plains, 2008-2016.

Species	**States**	**Scale**	**n**	**Detections**	**CRP-Stops**
Baird's Sparrow	MT, ND, SD	800	42,744	479	5,947
Bobolink	ALL	400	66,180	7,489	8,567
Chestnut-collared Longspur	MT, ND, SD, WY	400	49,598	2,035	3,912
Clay-colored Sparrow	MN, MT, ND, SD, WY	400	62,929	6,233	7,624
Dickcissel	ALL	400	66,180	4,861	8,567
Grasshopper Sparrow	ALL	400	66,180	8,138	7,079
Lark Bunting	MT, ND, SD, WY	3,200	49,598	7,802	18,922
Sedge Wren	IA, MN. MT, ND, SD	400	59,326	1,770	8,567
Sprague's Pipit	MT, ND, SD	1,600	42,744	425	11,359

* Occurrence models for Chestnut-collared Longspur and Baird's Sparrow

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 (i.e., reversed coefficient signs). After selecting the most parsimonious model we forced any of these three covariates lacking back into the model if necessary.

Model performance was assessed by testing for spatial autocorrelation (Figure 3), overdispersion, zero-inflation, the difference in AIC from the null model (i.e. only random effects included), and calculating the marginal and conditional R^2 (Table 5; Nakagawa and Schielzeth2013). 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). If overdispersion was detected we included an observation-level random effect to model the extra-Poisson variation (Figure 4; Harrison 2014). We further evaluated logistic regression models by calculating the area under the curve (AUC) of receiver operating characteristics (ROC; Hosmer and Lemeshow 2000) using predictions from10-fold cross validation (Stone 1974).

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 abundance 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.

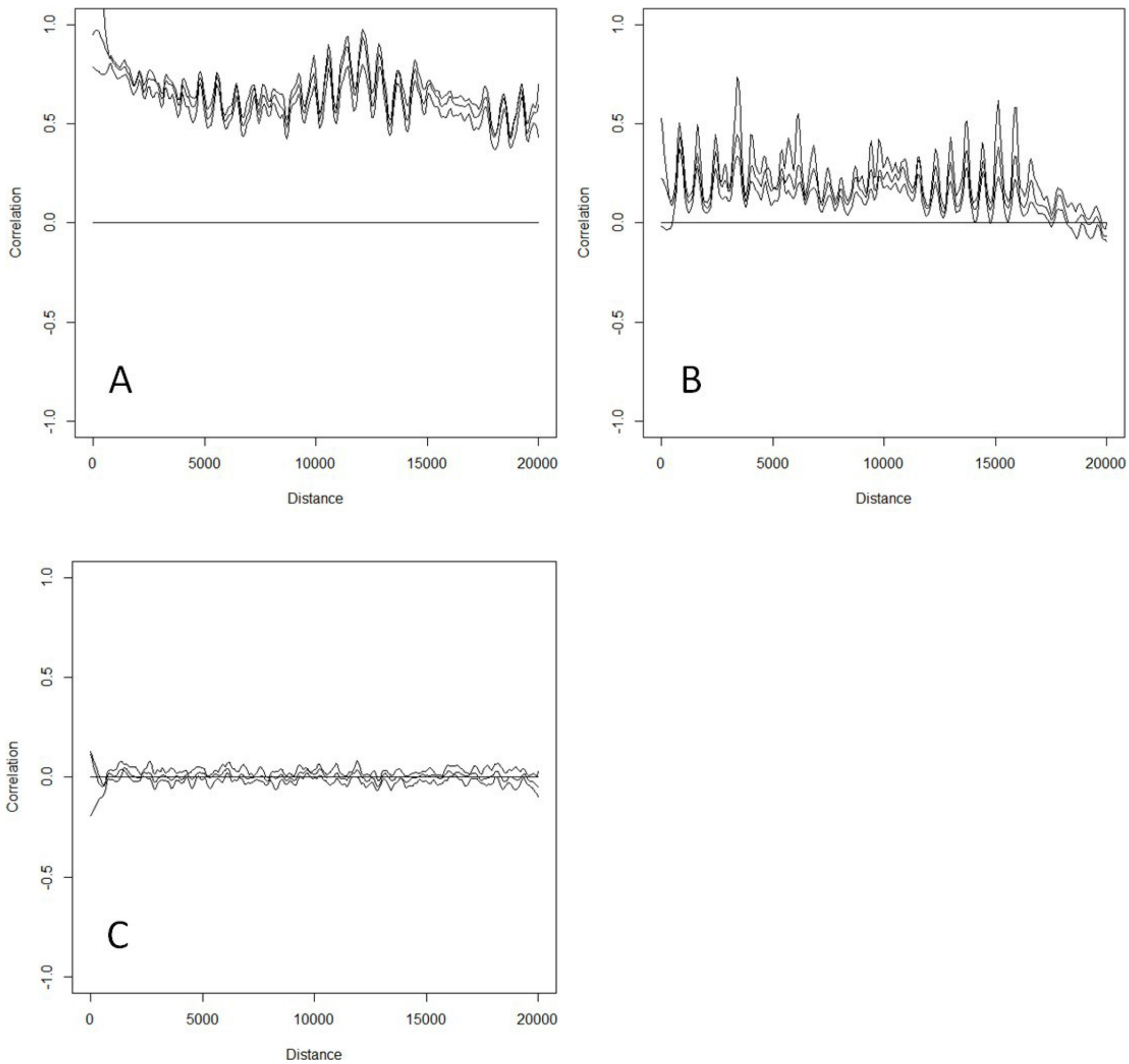
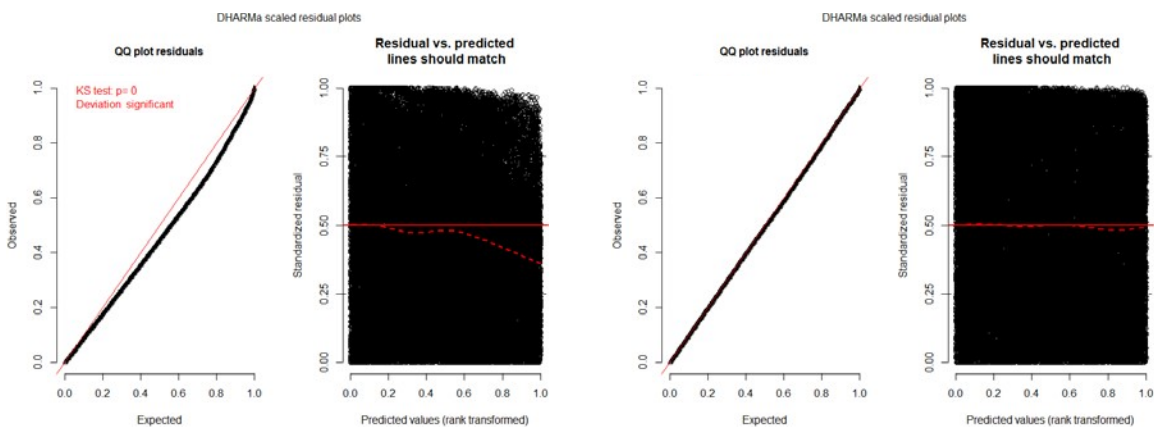


Table 5. Model performance and validation for best-supported models predicting density or occurrence of nine species of grassland birds in the Northern Great Plains, 2008-2016. Model performance metrics include AIC difference from null model (Δn), marginal R^2 (R^2m), conditional R^2 (R^2c), area under the curve (AUC) of receiver operator curves for occurrence models. Model validation metrics represent observed vs. predicted values of an independent test set using methods from Johnson et al. 2006. Model validation metrics include R^2, y-intercept, slope, and spearman's rank correlation for the proportion of observations within 10 approximately equal-area-slice bins of distribution models compared to the expected utilization proportion within those bins. See Apendix B for validation figures.

	Model Performance				**Model Validation**			
Species	**Δ_nAIC**	**R^2m**	**R^2c**	**AUC**	**R^2**	**y-int**	**slope**	**Cor**
Baird's Sparrow	323.77	0.58	0.78	0.89	0.99	-0.02	1.19	0.93
Bobolink	1,914.62	0.39	0.60	NA	0.79	0.05	0.53	0.98
Chestnut-collared Longspur	1,836.04	0.81	0.90	*NA*	0.99	-0.01	1.12	0.87
Clay-colored Sparrow	2,458.18	0.35	0.81	0.90	0.91	0.03	0.70	1.00
Dickcissel	2,033.72	0.39	0.86	NA	0.98	-0.004	1.04	0.99
Grasshopper Sparrow	3,131.7	0.26	0.62	NA	0.43	0.05	0.47	0.84
Lark Bunting	7,012.4	0.59	0.68	NA	0.93	0.02	0.82	0.95
Sedge Wren	2,233.11	0.86	0.91	NA	0.96	0.02	0.77	0.99
Sprague's Pipit	455.14	0.52	0.68	NA	1.00	-0.003	1.03	0.81

Figure 4. Models residuals were graphically examined for heteroscedacticity using the DHARMa package in R. Overdispersion was detected for two models and was corrected by included an observation-level random effect. Diagnostic tests show overdispersion in Bobolink model (A), and elimination of dispersion in a Bobolink model where the extra-Poisson variation was modeled by including and observation-level random effect (B).

(A) (B)



Model analysis and application

We created partial plots that depicted the effect of the percentage of CRP, crop, and grassland/herbaceous cover in the landscape on abundance or occurrence. This was accomplished by sequencing these cover types from 0 to 100 by 0.01 and for each cover type predicting abundance or occurrence using model coefficient estimates and the mean of all other fixed effects. We also calculated the effect of CRP within each state using the methods previously described but holding all other fixed effects at their respective state means (Appendix B).

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 or grassland/herbaceous (Appendix A and B). We also 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 acres of CRP lost.

Model results were scaled using Partner's in Flight adjustment factors that included estimates of species' detection distance and pair adjustments (Blancher et al. 2013). This approach provided biologically relevant and reasonable adjustments to predictions; however, it can also have a large influence on predictions and an accurate assessment and understanding of detection distance and pair adjustments are paramount (Thogmartin et al. 2006a). Specifically, model predictions went through a proportional conversion to maintain a cell size of 30 m. We multiplied predictions in each cell by the area of the cell (i.e. 900 m), then divided by the area of the detection distance (pi*(distance^2)), and finally multiplied these values by pair adjustment values.

We developed pseudo-abundance models from occurrence models for Baird's Sparrow and Chestnut-collared Longspur to estimate population loss within CRP fields. This was accomplished by scaling predictions, then calculating the proportion of probability of occurrence values 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 for the region. This is essentially a spatially applied Fermi approximation, which is adjusted based on probability of occurrence. This method assumes a linear relationship with density and probability of occurrence and forces the total population to equal the PIF population estimate for the region. To determine the change in population estimates under model scenarios where CRP is converted to crop or grassland/herbaceous cover we used a proportional conversion based on the relationship of probability of occurrence values and their respective pseudo-abundance values. Specifically, the probability of occurrence for a model scenario where CRP was converted to crop was multiplied by the original pseudo-abundance model and then divided by the original probability of occurrence model.

Model Validation

We validated models using an independent test dataset which was not used in model development. The test dataset included 2017 BBS data and 20 BBS-like routes that we created in new locations throughout the study region and surveyed in June of 2018 (8,447 observations). We established new routes using a GIS process within a 30 mi x 30 mi grid that extended throughout the study region. Each route was established diagonally across the grid using a cost layer. The cost layer was a rasterized version of the TIGER census transportation layer (Topologically Integrated Geographic Encoding and Referencing; USCB-TIGER 2018). Routes were established based on minimizing the distance traveled and a penalty incurred via the cost layer. An extreme penalty was given for not being on a road and a large penalty was given for not being on a local road (e.g., highway). Routes were then split into 30 mi segments and points were established every 0.5 mi along the route. We used optimal allocation analysis to select 20 routes that adequately sampled target birds given the variance of predictions within population percentiles (Lohr 2010). Surveys were conducted following BBS protocol. Some routes had to be augmented in the field due to ownership and/or safety issues that could not be accounted for using an automated process of route establishment.

We used methods from Johnson et al. (2006) to determine if the proportion of observed species was proportional to the expected utilization proportion (Appendix B). This is not an assessment of prediction accuracy but an assessment of a model's ability to identity areas of low to high density proportionally to observed density proportion. For each species we divided density and distribution models into 10 approximately equal area bins of increasing density. For each bin we calculated the number of observed birds, the area, and the midpoint density value. Observed proportion of birds was calculated for each bin by dividing the sum of birds in each bin by the total sum of birds in all bins. The expected utilization proportion was calculated for each bin by multiplying the midpoint density value by the area of the bin, and dividing by the total sum of all bins. We then compared observed proportion to expected utilization proportion using Spearman's rank correlation and linear regression. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1 and a y-intercept of 0.

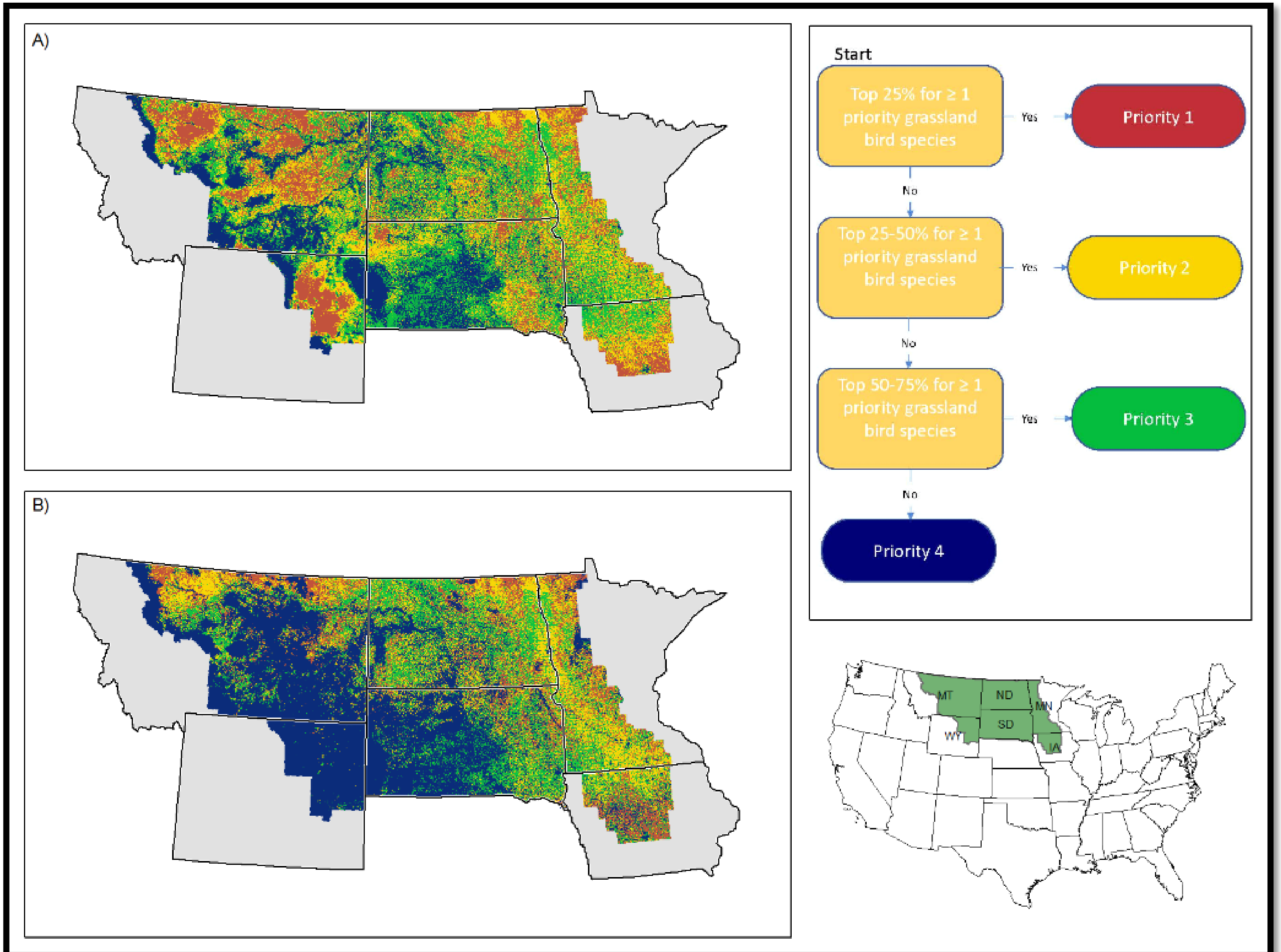
Decision Support Tools

We developed two decision-support tools to benefit the birds in this study (Figure 5). These map-based raster tools prioritize landscapes for CRP retention and enrollment, respectively. Landscapes were given a value of one to four; one being the highest priority areas and four being the lowest priority areas. These raster tools can be used to rank competing parcel boundaries using spatial tools such as zonal statistics.

The CRP retention tool was derived from predicted density and distribution models for all the birds in this study. Each density and distribution model was reclassified based on its top 25^{th}, 25^{th}-50^{th}, 50^{th}-75^{th}, and 75^{th}-100^{th} population percentiles. We determined cutpoints for population percentiles by collapsing the density and distribution rasters into a numeric vector, dividing values by the sum of all values, sorting from maximum to minimum, and calculating cumulative sums until the thresholds of 0.25, 0.50, and 0.75 were reached. The values associated with these thresholds were then back transformed and used as cutpoints to reclassify density and distribution models according to their population percentiles. Population percentile rasters for all birds were then stacked and collapsed into one raster so priority was given to the model with the highest population percentile. That is if any location had a species that was in the top 25^{th} percentile, then that location was given a priority of 1; a priority of 2 was given if the highest percentile was the 25^{th}-50^{th} for any species; a priority of 3 was given if the highest percentile was the 50^{th}-75^{th} for any species; and lastly, a priority of 4 was given if the highest percentile was the 75^{th}-100^{th} for any species.

The CRP enrollment tool is a scenario-based tool derived from the predicted change in density given a change in CRP or grass/herb. We first hypothetically created a landscape without CRP by converting all CRP to crop and re-applying the models. Next we converted 1% of this new hypothetical crop layer to CRP or grass/herb at each bird's respective landscape scale and re-applied the models. We then calculated the difference, or gain in density, between these two hypothetical models. Using the same methods previously stated for the retention tool, we derived percentiles for each bird's change in density, and collapsed the models into one map-based tool depicting priority areas. This method is congruent with our CRP policy recommendation to target areas for enrollment that are already near large blocks of grasslands. Sprague's Pipit and Chestnut-collared Longspur models indicated a weak negative association with CRP; therefore, for these species we ran scenarios where 1% crop was converted to grass/herb cover. This scenario is congruent with our CRP policy recommendation for native endemic grassland birds in this study, which would benefit more from managed grasslands. Lark Bunting was not included in this tool because its model indicated a slightly stronger association with crop than grass/herb and had a negative association with CRP, making it illogical to include given this scenario-based approach.

Figure 5. Hierarchical decision support tools for targeting A) CRP enrollment, and B) CRP retention. The CRP enrollment tool is based on multi-species overlay of tiered population percentiles for nine grassland bird species in the Prairie Pothole Joint Venture and Northern Great Plains Joint Venture administrative areas. Species include Baird's Sparrow, Chestnut-collared Longspur, Lark Bunting, Sprague's Pipit, Bobolink, Clay- colored Sparrow, Dickcissel, Grasshopper Sparrow, and Sedge Wren. The CRP retention tool is based on multi-species overlay of tiered population gain percentiles from scenario-based models that calculated the population gain from converting 1% of crop to CRP or grass/herb. All species except Lark Bunting were included in the enrollment tool.


A)
B)
Start
Top 25% for ≥ 1 priority grassland bird species
Yes
Priority 1
No
Top 25-50% for ≥ 1 priority grassland bird species
Yes
Priority 2
No
Top 50-75% for ≥ 1 priority grassland bird species
Yes
Priority 3
No
Priority 4
MT
ND
MN
SD
WY
IA

RESULTS

Predictive Models

Landscapes surrounding BBS stops throughout our study region varied considerably in type and distribution of land cover (Table 3). In addition, modeling species only in states in which there were detected created modeling datasets that varied among study species (Table 4). For example, Bobolink, Dickcissel, and Grasshopper Sparrow were observed in all states in our study region and had 66,180 data points, whereas Baird's Sparrow and Sprague's Pipit were observed only in Montana, North Dakota and South Dakota and had 42,744 data points. The percentage of data points with species-specific observations varied from 1% for Sprague's Pipit to 16% for Lark Bunting. The 400-m landscape scale was best supported by the data for all species except Baird's Sparrow, Sprague's Pipit, and Lark Bunting, which were best supported by data at the 800, 1600, and 3200 scales, respectively. The percentage of data points that had CRP within the modeling landscape scale varied from 8% for Chestnut-colored Longspur to 38% for Lark Bunting. In 2016, 97% of CRP had a CP type that consisted of non-woody cover. Of the 97%, the 3 most common CP types by area throughout the study region were vegetation cover already established (CP10, 17%), introduced grass and legumes (CP1, 13%), and permanent wildlife habitat non-easement (CP4D, 10%). The three most common CP types that were within a 3200 m landscape scale of route stops were the same three CP types previously mentioned at 18%, 15%, and 12%, respectively.

Best-supported models characterizing bird/environmental relationships indicated that occurrence or abundance of all species was influenced by climate, topography and landscape composition and configuration (Table 5 and Table 6). Climate and land cover variables accounted for much spatial autocorrelation, but route, observer and time variables were necessary to remove remnant spatial autocorrelation. 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). Chestnut-collared Longspur and Lark Bunting models showed some spatial autocorrelation, and the addition of an autoregressive term removed remnant positive spatial autocorrelation from model residuals. Bobolink and Lark Bunting models were overdispered, and the addition of an object-level random effect adequately modeled the extra-Poisson variation (Figure 4). Data were dominated by zeroes for all species; however, final models predicted zeros adequately. All models had a ΔAIC $\geq$ 323.8 from the null model containing only random effects, indicating substantial support for the best-supported model for all species (Burnham and Anderson 2002). Marginal R^2, the proportion of variance explained by the fixed factors alone, ranged from 0.26 for Grasshopper Sparrow to 0.81 for Chestnut-collared Longspur. Conditional $R^{2,}$ the proportion of variance explained by both the fixed and random factors, ranged from 0.60 for Bobolink to 0.90 for Chestnut-collared Longspur. The random effects in Clay-colored Sparrow, Dickcissel, and Grasshopper Sparrow models explained more of the variance than the fixed effects, indicating fixed effect variables lacked the information necessary to better explain the variance of bird abundance. The AUC values for Baird's Sparrow and Chestnut-collared Longspur occurrence models were 0.89 and 0.90, respectively (Table 4), indicating very good discrimination (Hosmer and Lemeshow 2000).

Table 6. Variables and estimated coefficients (and standard errors) for landscape models predicting the density or occurrence of nine grassland bird species in the U.S. Northern Great Plains, 2008–2016. Superscript for estimates indicate the following variable transformations: [a] – quadratic term (variable coefficient estimate, followed by squared variable coefficient estimate), [b] – square, [c] - square root, [d] – logarithmic. Variables are defined in Table 2.

	Coefficient (SE)								
Variable	Baird's Sparrow	Bobolink	Chestnut-collared Longspur	Clay-colored Sparrow	Dickcissel	Grasshopper Sparrow	Lark Bunting	Sedge Wren	Sprague's Pipit
Intercept	-6.56 (0.45)	-3.64 (0.15)	-3.86 (0.26)	-4.14 (0.17)	-5.14 (0.26)	-3.10 (0.15)	-4.61 (0.18)	-5.94 (0.24)	-7.55 (0.46)
% Crop	-0.20 (0.17)[b]	-0.42 (0.03)	0.25 (0.08), -0.21 (0.05)[a]	-0.23 (0.02)	-0.23 (0.02)[b]	-0.22 (0.04), -0.11 (0.02)[a]	0.49 (0.07)	-0.46 (0.06)[b]	-0.43 (0.15)
% CRP	0.10 (0.06)	0.08 (0.01)	-0.08 (0.03)[d]	0.04 (0.01)[b]	0.03 (0.01)[d]	0.11 (0.01)	-0.03 (0.02)	0.25 (0.02)[d]	-0.07 (0.06)
CRP Patches				0.04 (0.01)[b]					
% Grassland/herbaceous	0.85 (0.21), -0.34 (0.09)[a]	0.13 (0.04), -0.20 (0.03)[a]	0.73 (0.08)	0.10 (0.02)[d]	-0.33 (0.01)[b]	0.30 (0.04)	0.45 (0.07)	0.41 (0.07), -0.09 (0.04)[a]	1.50 (0.28)[d]
Grassland/herbaceous Patches			-0.22 (0.04)						
% Alfalfa	-0.20 (0.08)[c]	0.15 (0.02)[c]		0.03 (0.01)[b]	0.12 (0.02)	-0.04 (0.01)[c]			
Alfalfa Patches					0.09 (0.02)[c]				
% Pasture/Hay						0.07 (0.02)		0.11 (0.03)	
Grass Type Count		0.07 (0.02)[d]		0.23 (0.01)	0.12 (0.02)				
% All Water	-0.36 (0.10)		-0.25 (0.06)		-0.18 (0.02)	-0.26 (0.02)[c]	-0.13 (0.04)		0.35 (0.12), -0.64 (0.14)[a]
% Open Water		-0.15 (0.01)c		-0.10 (0.01)					
% Woody Wetland		-0.10 (0.02)							

% Emergent Wetlands				-0.07 (0.01)				0.31 (0.03), -0.02 (.003)[a]	
% Forest	-1.99 (0.05)[c]	-1.21 (0.08)	-1.04 (0.24)[c]	-0.23 (0.04)[b]		-0.44 (0.04)[c]	-1.04 (0.14)	-0.81 (0.15)[b]	
Forest Patches				0.03 (0.01)[b]					
% Shrub		-0.64 (0.09)[b]		0.11 (0.04)[d]			0.16 (0.04)		
% All Woody Vegetation					-0.29 (0.03)[d]				
% Developed	-0.45 (0.16)	-0.40 (0.03)	-0.28 (0.07)	-0.12 (0.02)	-0.19 (0.02)	-0.22 (0.02)	-0.23 (0.05)	-0.29 (0.04)	-0.73 (0.17)
30yr Max Temperature	-1.59 (0.29) , -0.77 (0.25)[a]	-0.78 (0.11), -0.48 (0.08)[a]	-1.12 (0.16), -0.85 (0.15)[a]	-1.44 (0.10)		-0.20 (0.08)	0.94 (0.11), -0.55 (0.08)[a]	-0.64 (0.14)	-2.63 (0.33), -1.47 (0.32)[a]
30yr Min Temperature	-0.63 (0.25)	0.28 (0.11)			1.70 (0.15), -0.29 (0.06)[a]				
30yr Precipitation						-0.68 (0.11)	-0.87 (0.10)		-1.37 (0.28)
Annual Precipitation					0.23 (0.02)				
Precipitation Anomaly							0.17 (0.02)		
Elevation	3.07 (0.41), -1.28 (0.24)[a]		0.58 (0.23), -2.36 (0.28)[a]	-0.94 (0.12)	-0.70 (0.14)	0.46 (0.11), -0.32 (0.06)[a]	0.94 (0.14), -0.19 (0.10)[a]		1.28 (0.27)[d]
Mean Elevation		-0.86 (0.13)						-4.00 (0.46), -1.46 (0.45)[a]	
Topographic Variation	-0.81 (0.15)	-0.44 (0.05)	-0.55 (0.10)	0.69 (0.03), -0.23 (0.02)[a]	0.16 (0.03)			-0.49 (0.08)	-0.47 (0.12)
Elevation Difference						0.12 (0.02)	0.18 (0.03), -0.12 (0.02)a		
Stop	-0.23 (0.06)	0.06 (0.01)		-0.16 (0.01)	-0.11 (0.01)	-0.22 (0.01)	0.07 (0.01)	-0.42 (0.02)	
Start Wind		-0.07 (0.02)		-0.04 (0.13)	-0.09 (0.01)	-0.06 (0.01)	-0.04 (0.01)	-0.07 (0.02)	
Ordinal Date		-0.13 (0.02)		0.05 (0.01)	0.28 (0.01)		-0.05 (0.02)	0.10 (0.02)	
Auto-regressive			1.68 (0.06)				2.29 (0.04)		

Validation showed that models performed well, with Spearman's rank correlation for all species ranged from 0.81 to 1 indicating a high level of correlation between observed proportion and expected utilization proportion. The R^2 and slope for Grasshopper Sparrow and Bobolink were 0.43 and 0.47, and 0.53 and 0.79, respectively. Generally these models under-predicted low density areas and over predicted high density areas. The remaining models performed quite well, with R^2 and slope values ranging from 0.91 – 1.0 and 0.77 – 1.19, respectively.

Species showed similar responses to some landscape characteristics. Generally, all species had a negative association with woody vegetation, water and developed areas. However, there were some exceptions. For example, Sedge Wren showed the greatest response at intermediate percentages of emergent wetland. In addition, Clay-colored Sparrow, an ecotone species, had a negative association with the percentage of forest, but a positive association with shrubs and forest patches.

Endemic grassland birds were strongly associated with the grassland/herbaceous cover classes and less so with other cover types, whereas more widespread grassland birds showed varied positive associations with multiple grassland cover classes such as CRP, grassland/herbaceous, pasture/hay and alfalfa (Table 6, Appendix B). Generally there was a negative association or quadratic association with cropland. Lark bunting was the only species to have a positive association with crop, and Chestnut-collared Longspur had quadratic effects with cropland. Dickcissel was the only species to have a negative association with grassland/herbaceous cover class, and Baird's Sparrow, Bobolink, and Sedge Wren had quadratic effects with the grassland/herbaceous class.

All widespread grassland birds and Baird's sparrow had a positive association with CRP.

The remaining endemic grassland birds had either a weak negative response or no association with CRP, indicated by a weak negative coefficient estimate and large standard error. Partial plots (Appendix B) showing the effects of CRP cover indicated response curves that varied among species and across space where the greatest effect of CRP often occurred in areas of greatest estimated density. Baird's Sparrow, Bobolink, Clay-colored Sparrow, and Grasshopper Sparrow had curvilinear responses where the greatest increase in abundance or occurrence was between ~50-100% CRP cover; Sedge Wren had the greatest increase in abundance within the first ~0-25% CRP cover, and Dickcissel within the first ~0-15% cover.

Under simulation where CRP was converted to crop, we estimated that CRP supports 8.61% of the total population of all species that had a positive association with CRP. If CRP were converted to a grassland/herbaceous cover class we estimated the total endemic grassland bird population in this study would increase 5.00%. If all CRP were converted to cropland we estimated that populations of Sedge Wren, Bobolink, Clay-colored Sparrow, Baird's Sparrow, Dickcissel, and Grasshopper Sparrow would decline 28.0%, 10.6%, 7.1%, 6.0%, 4.6%, 4.4%, respectively (Table 7). If CRP were converted to a grassland/herbaceous cover class we estimated Sprague's Pipit, Chestnut-collared Longspur, Lark Bunting, and Baird's sparrow populations would increase 8.7%, 6.9%, 4.3%, and 2.1%, respectively (Table 8).

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 (%)
Sedge Wren	1,741,937	1,254,131	-487,806	-28.00	-193,824	-293,983	-11.1	-16.9
Bobolink	938,394	839,348	-99,046	-10.55	-56,249	-42,797	-5.99	-4.56
Clay-colored Sparrow	2,014,080	1,870,821	-143,259	-7.11	-76,597	-66,662	-3.80	-3.31
Baird's Sparrow	599,700	563,451	-36,249	-6.04	-18,266	-17,983	-3.05	-3.00
Dickcissel	2,080,101	1,983,909	-96,192	-4.62	-28,891	-67,302	-1.39	-3.24
Grasshopper Sparrow	7,166,164	6,848,780	-317,385	-4.43	-216,335	-101,050	-3.02	-1.41
Sprague's Pipit	177,830	177,187	-643	-0.36	-147	-496	-0.08	-0.28
Chestnut-collared Longspur	1,930,000	1,964,798	34,798	1.80	11,615	23,183	0.60	1.20
Lark Bunting	3,517,710	3,685,681	167,972	4.78	27,847	140,125	0.79	3.98

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 grassland/herbaceous cover class 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 (%)
Sprague's Pipit	177,830	193,276	15,445	8.69	5,114	10,331	2.88	5.81
Chestnut-collared Longspur	1,930,000	2,063,359	133,359	6.91	78,982	54,378	4.09	2.82
Lark Bunting	3,517,710	3,667,589	149,879	4.26	-30,491	180,370	-0.87	5.13
Baird's Sparrow	599,700	612,403	12,703	2.12	8,333	4,370	1.39	0.73

Topographic and climatic related variables had a strong influence on species density and distribution. Every model had at least one topographic and one climatic related variable. Depending on a species distribution, elevation had either a positive, negative, or quadratic effect where the greatest response was at intermediate values. For example Sprague's Pipits are generally found in northern Montana and had a positive association with elevation relative to the study area; Chestnut-collared Longspurs range from Montana into North and South Dakotas and had a quadratic relationship with elevation; and Sedge Wren is typically found in the eastern dakotas, Minnesota and Iowa and had a negative effect with elevation. The only models that did not retain the variable topographic roughness were those for Chestnut-collared Longspur and Grasshopper Sparrow. Dickcissel was the only species to have a positive association with topographic roughness and is the only model to not retain the 30-year mean maximum temperature covariate. The 30-year mean minimum temperature covariate was included in best-supporting models for four species, and precipitation related covariates were included in best-supporting models for five species. Generally, Baird's Sparrow, Chestnut-collared Longspur, Clay-colored Sparrow, Grasshopper Sparrow, and Sprague's Pipit were associated with cooler regions, whereas the remaining species were associated with warmer regions. In addition, Dickcissel was positively associated with wetter regions, lark bunting was associated with dry regions but positively associated with precipitation anomalies, and Chestnut-collared Longspur, Grasshopper Sparrow, and Sprague's Pipit were associated with drier regions (Table 9).

Detection of all species was influenced by survey structure, including observer, year, and route effects. However the variance estimated for the random effect year was generally quite low. All but Sprague's Pipit and Chestnut-collared Longspur were influenced by daily and/or seasonal timing of surveys (Table 5). Baird's Sparrow only retained the variable stop, and Grasshopper Sparrow only retained the variables stop and wind. The remaining species retained all detection-related variables.

Table 9. General model based descriptions summarizing covariate associations for nine species of grassland birds in the PPJV and NGPJV.

Species	***General Model-based Description***
Grasshopper Sparrow	Cooler, drier areas at relatively high to mean elevations, and located upslope. Associated with grassland/herbaceous and dense grass (CRP & pasture/hay, grassland/herbaceous). Not associated with water, crop, forest, and developed areas.
Baird's Sparrow	Cooler, flatter areas at relatively mean to higher elevations. Associated with grasslands with some dense cover (CRP and grassland/herbaceous). Not associated with water, alfalfa, crop, and forest.
Sprague's Pipit	Cooler, drier, and flatter areas at relatively higher elevations in the study area. Strongly associated with grassland/herbaceous. Not associated with crop, developed areas, and an abundance of water.
Chestnut-collared Longspur	Cooler, drier, and flatter areas at mean to lower elevations. Strongly associated with grassland/herbaceous but tolerant of some crop. Not associated with CRP, water, forest, shrub, and developed areas.
Clay-colored Sparrow	Cooler areas at lower elevations with some topographic roughness. Associated with grassland with some dense cover (i.e., grassland/herbaceous, alfalfa, and CRP) and patchy forest and shrubs. Not associated with some wetland types (i.e. no effect with woody wetlands), crop, developed areas, and a high percentage of forest.
Sedge Wren	Cooler flat areas at lower elevations. Associated with grasslands with some dense cover (i.e. grassland/herbaceous, CRP, and pasture/hay) and emergent wetlands. Not associated with crop, forest, and developed areas.
Lark Bunting	Warmer, annually wet areas at relatively higher elevations, and located on flat terrain or slightly upslope. Associated with a grassland/herbaceous, crop, and shrub mosaic. Not associated with water, CRP, and developed areas.
Bobolink	Warmer, flatter areas at lower elevations. Associated with a grassland mosaic with some dense cover (grassland/herbaceous, 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 (i.e., alfalfa, CRP). Not associated with some wetland types (i.e. no effect with emergent wetlands), crop, and developed areas.

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. We developed similar decision-support tools by combining the best areas for CRP retention and enrollment for individual species into single maps based on species' densities or change in densities in response to CRP added to the landscape. Priority areas range from high (1) to low (4). Areas of importance in this region included locations such as southern Iowa, northeastern Minnesota, eastern Dakotas, northwestern South Dakota, southwestern North Dakota, and northern Montana. We recommend developing a CP program for grassland birds that is similar to the Duck Nesting Habitat Initiative. We provided further recommendations in Appendix C.

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, CRP, and alfalfa, all of which are consistent with previous findings of selection for tall, dense cover, and exotic grasses (Overmire 1962, Wiens 1973, Sample 1989, Frawley and Best 1991, Klute et al. 1997, Best et al. 1997). 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, Leuders et al. 2006); however, Baird's Sparrow and Grasshopper sparrow demonstrated 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). 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 density of Baird's Sparrow, Bobolink, Clay-colored Sparrow, Dickcissel, Grasshopper Sparrow, and Sedge Wren 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, Drum et al. 2015, Niemuth et al. 2007). 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 9, 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.

Response to elevation and climate varied among species but, similar to other studies (i.e., Thogmartin et al. 2006b, 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.

We did not find associations between Sprague's Pipit or Chestnut-collared Longspur and stop number or ordinal date, which were present for most of the other species we considered. 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. 2006b, 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.

Our models included several variables (i.e., stop number, ordinal date, wind, year, and autoregressive terms) 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 $\leq$800 m for seven of the nine species we evaluated, but extended out to 1,600 m for Sprague's Pipit and 3,200 m for Lark Bunting. 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. 2006b, 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.

Grasshopper Sparrow and Bobolink models did not validate as well as the other models. This is likely because these species are responding to features on the landscape that remotely sensed data could not identify at a 30 m scale, or they are settling in small areas of appropriate habitat in largely fragmented areas. For instance, Grasshopper Sparrow will occasionally utilize roadside grass in areas dominated by cropland, or Bobolink will be associated with a small buffer of grass around a wetland that has not been plowed. However, based on Spearman's rank correlation estimates these models are useful in decision support tools.

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 because we are incorporating species/habitat relationships that 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.

AKNOWLEDGMENTS

We thank the many BBS observers who collected data and helped identify stop locations; Beth Madden (current MT BBS Coordinator), Dan Sullivan (former MT BBS Coordinator), Dan Bachen, and Bryce Maxwell from Montana Natural Heritage program for helping establish new BBS routes in Montana and providing BBS stop data; Sasha Auer, Tyler Harms, and Chris Ensminger for their help in the conducting bird survey for the independent validation dataset. This work was supported by a grant from the U.S. Department of Agriculture Farm Service Agency.

LITERATURE CITED

Ahlering, M. A., D. H. Johnson, and J. Faaborg. 2009. Factors associated with arrival densities of Grasshopper Sparrow (Ammodramus savannarum) and Baird's sparrow (A. bairdii) in the upper Great Plains. The Auk 126:799-808.

Albright, T. P., A. M. Pidgeon, C. D. Rittenhouse, M. K. Clayton, B. D. Wardlow, C. H. Flather, P. D. Culbert, and V. C. Radeloff . 2010. Combined effects of heat waves and droughts on avian communities across the conterminous United States. Ecosphere 1:art12.

Anderson, B. W., R. D. Ohmart, and J. Rice. 1981. Seasonal changes in avian densities and diversities. In Estimating Numbers of Terrestrial Birds (C. J. Ralph and J. M. Scott, Editors). Studies in Avian Biology 6:262–264.

Arnold, T. W., 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management, 74(6), pp.1175-1178.

Askins, R. A., F. Chávez-Ramírez, B. C. Dale, C. A. Haas, J. R. Herkert, F. L. Knopf, and P. D. Vickery. 2007. Conservation of grassland birds in North America: understanding ecological processes in different regions. Ornithological Monographs 64:1-46.

Augustin, N. H., M. A. Mugglestone, and S. T. Buckland. 1996. An autologistic model for the spatial distribution of wildlife. Journal of Applied Ecology 33:339–347.

Bakker, K. K., D. E. Naugle, and K. F. Higgins. 2002. Incorporating landscape attributes into models for migratory grassland bird conservation. Conservation Biology 16:1638–1646.

Bates, D., M. Machler, B. M. Bolker, and S. C. Walker . 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1–48.

Best, L. B., H. Campa, K. E. Kemp, R. J. Robel, M. R. Ryan, J. A. Savidge, H. P. Weeks, and S. R. Winterstein. 1997. Bird abundance and nesting in CRP fields and cropland in the Midwest: a regional approach. Wildlife Society Bulletin 25:864-877.

Blancher, P. J., K. V. Rosenberg, A. O. Panjabi, B. Altman, A. R. Couturier, W. E. Thogmartin and the Partners in Flight Science Committee. 2013. Handbook to the Partners in Flight Population Estimates Database, Version 2.0. PIF Technical Series No 6.

Bleho, B., K. Ellison, D. P. Hill, and L. K. Gould. 2015. Chestnut-collared Longspur (*Calcarius ornatus*), The Birds of North America. Ithaca: Cornell Lab of Ornithology.

Block, W. M., and L. A. Brennan. 1993. The habitat concept in ornithology: Theory and applications. Current Ornithology 11:35-91

Bock, C. E., J. H. Bock, and B. C. Bennett. 1999. Songbird abundance in grasslands at a suburban interface on the Colorado High Plains. Studies in Avian Biology 19:131-136.

Boryan, C., Z. Yang, R. Mueller, and M. Craig. 2011. Monitoring US agriculture: The US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program. Geocarta International 26:341–358.

Brennan, L. A., and W. P. Kuvlesky, Jr. 2005. North American grassland birds: An unfolding conservation crisis? The Journal of Wildlife Management 69:1–13.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, 320pp.

Bystrak, D. 1981. The North American Breeding Bird Survey. Studies in Avian Biology 6:34-41.

Claassen, R. L. 2012. Grassland to Cropland Conversion in the Northern Plains: The Role of Crop Insurance, Commodity, and Disaster Programs. Darby, PA: Diane Publishing.

Cody, M. L. 1985. Habitat selection in grassland and open-country birds, p. 191–226. In M. L. Cody (ed.), Habitat selection in birds. Academic Press, New York.

Coppedge, B. R., D. M. Engle, R. E. Masters, and M. S. Gregory. 2001. Avian response to landscape change in fragmented southern Great Plains grasslands. Ecological Applications 11:47-59.

Crawley, M. J. 2007. The R book. John Wiley & Sons, West Sussex, England.

Cunningham, M., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Application 16:1062-1075.

Dale, B. C., P. A. Martin, and P. S. Taylor. 1997. Effects of hay management on grassland songbirds in Saskatchewan. Wildlife Society Bulletin 25:616-626.

Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology 28:2031–2064.

Davis, S. K. 2004. Area sensitivity in grassland passerines: Effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. The Auk 121:1130–1145.

Davis, S. K., and D. C. Duncan. 1999. Grassland songbird occurrence in native and crested wheatgrass pastures of southern Saskatchewan. Studies in Avian Biology 19:211-218.

Davis, S. K., D. C. Duncan, and M. Skeel. 1999. Distribution and habitat associations of three endemic grassland songbirds in southern Saskatchewan. Wilson Bulletin 111:389-396

Davis, S. K., M. B. Robbins, and B. C. Dale. 2014. Sprague's Pipit (*Anthus spragueii*), The Birds of North America (p. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology.

Delisle, J. M., and J. A. Savidge. 1997. Avian use and vegetation characteristics of Conservation Reserve Program fields. Journal of Wildlife Management 61:318-325.

Dawson, D. K. 1981. Sampling in rugged terrain. Studies in Avian Biology 6:311-315.

DeJong, J. R., D. E. Naugle, K. K. Bakker, F. R. Quamen, and K. F. Higgins.2004. Impacts of agricultural tillage on grassland birds in western South Dakota. Proceedings of the North American Prairie Conference 19:76–80.

Drum, R. G., C. R. Loesch, K. M. Carrlson, K. E. Doherty, and B. C. Fedy. 2015. Assessing the biological benefits of the USDA-Conservation Reserve Program (CRP) for waterfowl and grassland passerines in the Prairie Pothole Region of the United States: spatial analyses for targeting CRP to maximize benefits for migratory birds. Final Report for USDA–FSA Agreement: 12-IA-MRE-CRP-TA. Prairie Pothole Joint Venture, Denver, Colorado.

Etterson, M. A., G. J. Niemi, and N. P. Danz. 2009. Estimating the effects of detection heterogeneity and overdispersion on trends estimated from avian point counts. Ecological Applications 19:2049–2066.

Flather, C. H. and J. R. Sauer. 1996. Using landscape ecology to test hypotheses about large scale abundance patterns in migratory birds. Ecology 77:28-35.

Frawley, B. J., and L. B. Best. 1991. Effects of mowing on breeding bird abundance and species composition in alfalfa fields. Wildlife Society Bulletin 19:135-142.

Gage, A. M., S. K. Olimb, and J. Nelson. 2016. Plowprint: tracking cumulative cropland expansion to target grassland conservation. Great Plains Research, 26:107-116.

George, T. L., A. C. Fowler, R. L. Knight, and L. C. McEwen. 1992. Impacts of a severe drought on grassland birds in North Dakota. Ecological Applications 2:275-284.

Gesch, D., Oimoen, M., Greenlee, S., Nelson, C., Steuck, M. and Tyler, D., 2002. The national elevation dataset. Photogrammetric engineering and remote sensing, 68(1), pp.5-32.

Grant, T. A., E. Madden, and G. B. Berkey. 2004. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. Wildlife Society Bulletin 32:807-818.

Greer, M. J., K. K. Bakker, and C. D. Dieter. 2016. Grassland bird response to recent loss and degradation of native prairie in central and western South Dakota. The Wilson Journal of Ornithology 128:278-289.

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147–186.

Harrison, X. A. 2014. Using observation-level random effects to model overdispersion in count data in ecology and evolution. PeerJ 2:e616 https://doi.org/10.7717/peerj.616.

Herkert, J. R. 1995. An analysis of Midwestern breeding bird population trends: 1966-1993. American Midland Naturalist 134:41-50.

Herkert, J. R. 1998. The influence of the CRP on grasshopper sparrow population trends in the mid-continental United States. Wildlife Society Bulletin 26:227-231.

Hertel T. W., and J. Beckman. 2011 The Intended and unintended effects of US agricultural and biotechnology policies. Chicago, IL: University of Chicago Press pp 189–221.

Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354

Hosmer, D. W., and S. Lemeshow. 2000. Applied Logistic Regression, second edition. John Wiley & Sons, New York, NY, USA.

Hubbard, D. E. 1982. Breeding birds in two dry wetland in eastern South Dakota. The Prairie Naturalist 14:6-8.

Johnson, D. H., and M. D. Schwartz. 1993. The Conservation Reserve Program and grassland birds. Conservation Biology 7:934-937.

Johnson, D. H., and L. D. Igl. 1995. Contributions of the Conservation Reserve Program to populations of breeding birds in North Dakota. Wilson Bulletin 107:709-718.

Johnson, D. H. 2005. Grassland bird use of Conservation Reserve Program fields in the Great Plains. Pages 17-32 in J. B. Haufler, editor. Fish and wildlife benefits of Farm Bill conservation programs: 2000-2005 update. The Wildlife Society Technical Review 05-02.

Johnson, D. H. 2008. In defense of indices: The case of bird surveys. The Journal of Wildlife Management 72:857–868

Johnson, C. J., S. E. Nielsen, E. H. Merrill, T. L. McDonald, and M. S. Boyce. 2006. Resource Selection Functions Based on Use Availability Data: Theoretical Motivation and Evaluation Methods. The Journal of Wildlife Management 70: 347-357.

Kantrud, H. A., and R. L. Kologiski. 1983. Avian associations of the Northern Great Plains grasslands. Journal of Biogeography 10:331-350.

Klute, D. S., R. J. Robel, and K. E. Kemp. 1997. Will conversion of Conservation Reserve Program (CRP) lands to pasture be detrimental for grassland birds in Kansas? American Midland Naturalist 137:206-212.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247 257.

Koford, R. R. 1999. Density and fledging success of grassland birds in Conservation Reserve Program fields in North Dakota and west-central Minnesota. Studies in Avian Biology 19:187-195.

Lark, T. J., J. M. Salmon, and H. K Gibbs. 2015. Cropland expansion outpaces agriculture and biofuel policies in the United States. Environmental Research Letters 10:044003

Leuders, A. S., P. L. Kennedy, and D. H. Johnson. 2006. Influences of management regimes on breeding bird densities and habitat in mixed-grass prairie: an example from North Dakota. Journal of Wildlife Management 70:600-606.

Licht, D. S. 1997. Ecology and Economics of the Great Plains. Lincoln: University of Nebraska Press.

Lipsey, M. K., K. E. Doherty, D. E. Naugle, S. Fields, J. S. Evans, S. K. Davis, and N. Koper. 2015. One step ahead of the plow: Using cropland conversion risk to guide Sprague's Pipit conservation in the Northern Great Plains. Biological Conservation 191:739–749

Lohr, S. L. 2010. Sampling: Design and analysis. Pacific Grove, CA: Brooks/Cole.

Madden, E. M., R. K. Murphy, A. J. Hansen, and L. Murray. 2000. Models for guiding management of prairie bird habitat in northwestern North Dakota. The American Midland Naturalist 144:377–392.

Nakagawa, S. and H. Schielzeth. 2013. A general and simple method for obtaining R^2 from generalized linear mixed-effects models. Methods in Ecology and Evolution, 4:133–142.

Newbold, S. C. and J. M. Eadie. 2004. Using species-habitat models to target conservation: A case study with breeding mallards. Ecological Applications 14:1384-1393.

Nielson, R. M., L. L. McDonald, J. P. Sullivan, C. Burgess, D. S. Johnson, D. H. Johnson, S. Bucholtz, S. Hyberg, S. Howlin. 2008. Estimating the response of ring-necked pheasants (Phasianus colchicus) to the Conservation Reserve Program. Auk 125, 434–444.

Niemuth N. D., F. R. Quamen, D. E. Naugle, R. E. Reynolds, M. E. Estey, T. L. Shaffer. 2007. Benefits of the Conservation Reserve Program to Grassland Bird Populations in the Prairie Pothole Region of North Dakota and South Dakota. US Department of Agriculture RFA OS-IA-04000000-N34, Bismarck, North Dakota.

Niemuth, N. D., R. E. Reynolds, D. A. Granfors, R. R. Johnson, B. Wangler, and M. E. Estey. 2008. Landscape-level Planning for Conservation of Wetland Birds in the U.S. Prairie Pothole Region. Pages 533-560 in Models for Planning Wildlife Conservation in Large Landscapes, J. J. Millspaugh and F. R. Thompson, III, eds. Elsevier Science.

Niemuth, N. D., M. E. Estey, S. P. Fields, B. Wangler, A. A. Bishop, P. J. Moore, R. C. Grosse, and A. J. Ryba. 2017. Developing spatial models to guide conservation of grassland birds in the US Northern Great Plains. The Condor, 119(3), pp.506-525.

O'Connor, R. J., M. T. Jones, R. B. Boone, and T. B. Lauber. 1999. Linking continental climate, land use, and land patterns with grassland bird distribution across the conterminous United States. Studies in Avian Biology 19:45-59

Overmire, T. G. 1962. Nesting of the Dickcissel in Oklahoma. Auk 79:115-116.

Pardieck, K.L., D.J. Ziolkowski Jr., M. Lutmerding, K. Campbell and M.-A.R. Hudson. 2017. North American Breeding Bird Survey Dataset 1966 - 2016, version 2016.0. U.S. Geological Survey, Patuxent Wildlife Research Center. www.pwrc.usgs.gov/BBS/RawData/; doi:10.5066/F7W0944J.

Partners in Flight Science Committee. 2013. Population Estimates Database, version 2013. Available at http://pif.birdconservancy.org/PopEstimates. Accessed May 2018

Peterjohn, B. G., and J. R. Sauer. 1999. Population status of North American grassland birds from the North American Breeding Bird Survey, 1966-1996. Studies in Avian Biology 19:27-44.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rashford, B. S., J. A. Walker, and C. T. Bastian. 2010. Economics of grassland conversion to cropland in the Prairie Pothole Region. Conservation Biology 25:276-284.

Renfrew, R. B., and C. A. Ribic. 2002. Influence of topography on density of grassland passerines in pastures. American Midland Naturalist 147:315-325.

Renken, R. B., and J. J. Dinsmore. 1987. Nongame bird communities on managed grasslands in North Dakota. The Canadian Field-Naturalist 101:551-557.

Ribic, C. A., and D. W. Sample. 2001. Associations of grassland birds with landscape factors in southern Wisconsin. The American Midland Naturalist 146:105–121.

Reynolds, R. E., T. L. Shaffer, C. R. Loesch, and R. R. Cox Jr. 2006. The Farm Bill and duck production in the Prairie Pothole Region: increasing the benefits. Wildlife Society Bulletin, 34(4), 963-974.

Rosenberg, K. V., and P. J. Blancher. 2005. Setting numerical population objectives for priority landbird species. Pages 57-67 in Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference 2002 (C.J. Ralph and T.D. Rich, Eds.). U.S. Department of Agriculture, Forest Service General Technical Report PSW-191.

Robbins, C. S. 1981. Effect of time of day on bird activity. Studies in Avian Biology 6: 275-286.

Root, T. 1988. Environmental factors associated with avian distributional boundaries. Journal of Biogeography 15:489-505.

Rotenberry, J. T., and J. A. Wiens. 1980. Habitat structure, patchiness, and avian communities in North American steppe vegetation: a multivariate analysis. Ecology 61:1228-1250.

Sample, D. W. 1989. Grassland birds in southern Wisconsin: Habitat preference, populations trends, and response to land use changes. M.S. thesis. Univ. Wisconsin, Madison.

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American Breeding Bird Survey. The Auk 111:50–62.

Sauer, J. R., and W. A. Link. 2011. Analysis of the North American Breeding Bird Survey using hierachical models. The Auk 128:87-98.

Sauer, J. R., W. A. Link, J. E. Fallon, K. L. Pardieck, and D. J. Ziolkowski, Jr. 2013. The North American Breeding Bird Survey 1966–2011: Summary analysis and species accounts. North American Fauna 79:1–32.

Sauer, J. R., D. K. Niven, J. E. Hines, D. J. Ziolkowski, Jr, K. L. Pardieck, J. E. Fallon, and W. A. Link. 2017. The North American Breeding Bird Survey, Results and Analysis 1966 - 2015. Version 2.07.2017 USGS Patuxent Wildlife Research Center, Laurel, MD.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418–421.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 1998. Grasslands. In Status and trends of the nation's biological resources, vol. 2, eds. M. J. Mac, P. A. Opler, C. E. Pucket Haecker, and P. D. Doran, 437–72. Jamestown, North Dakota, Northern Prairie Wildlife Research Center.

Simons, T. R., M. W. Alldredge, K. H. Pollock, and J. M. Wettroth. 2007. Experimental analysis of the auditory detection process on avian point counts. The Auk 124:986-999.

Skirvin, A. A. 1981. Effect of time of day and time of season on the number of observations and density estimates of breeding birds. Studies in Avian Biology 6:271-274.

Stone, M. 1974. Cross-validatory choice and assessment of statistical predictions. Journal of the Royal Statistical Society B 36:111–147.Swets, J. A. 1988. Measuring the accuracy of diagnostic systems. Science 240:1285-1293.

Tack, J. D., F. R. Quamen, K. Kelsey, and D. E. Naugle. 2017. Doing more with less: Removing trees in a prairie system improves value of grasslands for obligate bird species. Journal of Environmental Management 198: 163-169.

Thogmartin, W. E., F. P. Howe, F. C. James, D. H. Johnson, E. T. Reed, J. R. Sauer, and F. R. Thompson, III. 2006a. A review of the population estimation approach of the North American Landbird Conservation Plan. The Auk 123:892–904.

Thogmartin, W. E., M. G. Knutson, and J. R. Sauer. 2006b. Predicting regional abundance of rare grassland birds with a hierarchical spatial count model. The Condor 108:25–46.

Thompson, S. J., T. W. Arnold, and C. L. Amundson. 2014. A multiscale assessment of tree avoidance by prairie birds. The Condor 116:303-315.

Truett, J. 2003. Migrations of grassland communities and grazing philosophies in the Great Plains: A review and implications for management. Great Plains Research 13:3-26.

United States Census Bureau Topologically Integrated Geographic Encoding and Referencing (USCB-TIGER). 2018. TIGER products. Availble at https://www.census.gov/geo/maps-data/data/tiger.html. Accessed May 2018.

United States Congress. 1985. Food security act of 1985. Public Law, 99, 198.

United States Department of Agriculture Farm Services Agency (USDA-FSA). 2013. Fact sheet: Conservation Reserve Program sign-up 45 environmental benefits index. Available at United States Department of Agriculture Farm Services Agency. Available at https://www.fsa.usda.gov/Internet/FSA_File/su45ebifactsheet.pdf. Accessed May 2018.

United States Department of Agriculture Farm Services Agency (USDA-FSA). 2018a. Conservation Reserve Program practices library. Available at https://www.fsa.usda.gov/programs-and-services/conservation-programs/crp-practices-library/index. Accessed May 2018.

United States Department of Agriculture Farm Services Agency (USDA-FSA). 2018b. Conservation Reserve Program statistics. Available at https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index. Accessed May 2018.

USDA National Agricultural Statistics Service Cropland Data Layer (USDA NASS). 2011. Published crop- specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/ (accessed 02/01/2017). USDA-NASS, Washington, DC.

Wiens, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3:385-397.

Vickery, P. D., P. L. Tubaro, J. M. Cardoso da Silva, B. G. Peterjohn, J. R. Herkert, and R. B. Cavalcanti. 1999. Conservation of grassland birds in the Western Hemisphere. In Ecology and Conservation of Grassland Birds of the Western Hemisphere (P. D. Vickery and J. R. Herkert, Editors). Studies in Avian Biology 19:2–26.

Wickham, J., S. V. Stehman, L. Gass, J. A. Dewitz, D. G. Sorenson, B. J. Granneman, R. V. Poss, L. A. and Baer. 2017. Thematic accuracy assessment of the 2011 National Land Cover Database (NLCD). Remote Sensing of Environment, 191, pp.328-341.

Wiens, J. A. 1973. Pattern and process in grassland bird communities. Ecological Monographs 43:236-270.

Wiens, J. A. 1974. Climatic instability and the ‘‘ecological saturation’’ of bird communities in North American grasslands. The Condor 76:385–400.

Wiens, J. A. 1989. The Ecology of Bird Communities, Volume 2: Processes and Variations. Cambridge University Press, Cambridge, UK.

Wright, H. A., and A. W. Bailey 1982. Fire ecology: United States and Southern Canada. John Wiley and Sons, New York, New York, USA.

Wright, C. K. and M. C. Wimberly. 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. 110, 4134–4139.Island Press, Covelo, CA, USA. pp. 739–749.

Wood, E. M., A. M. Pidgeon, V. C. Radeloff, D. Helmers, P. D. Culbert, N., S. Keuler, and C. H. Flather. 2014. Housing development erodes avian community structure in U.S. protected areas. Ecological Applications 24:1445-1462.

Zuur, A. F., E. N. Ieno, and C. S. Elphick. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, 1(1), pp.3-14.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Gail M, Krickeberg K, Samet JM, Tsiatis A, Wong W, editors. New York, NY: Spring Science and Business Media.

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 a portions of Valley County, MT with CRP (B) and with CRP converted to crop (C).

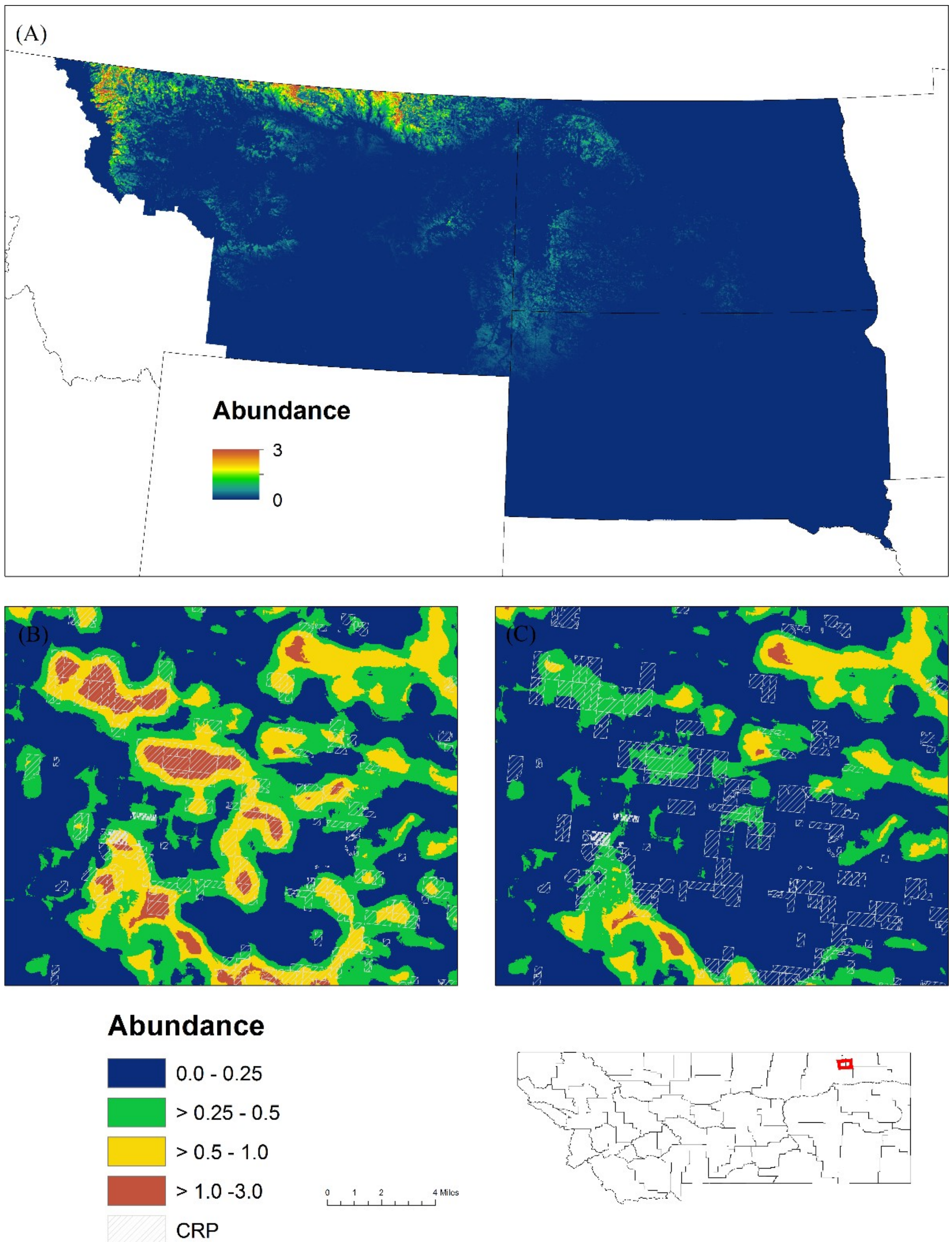


Figure A2. Predicted abundance of Bobolinks per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Ransom County, ND with CRP (B) and with CRP converted to crop (C).

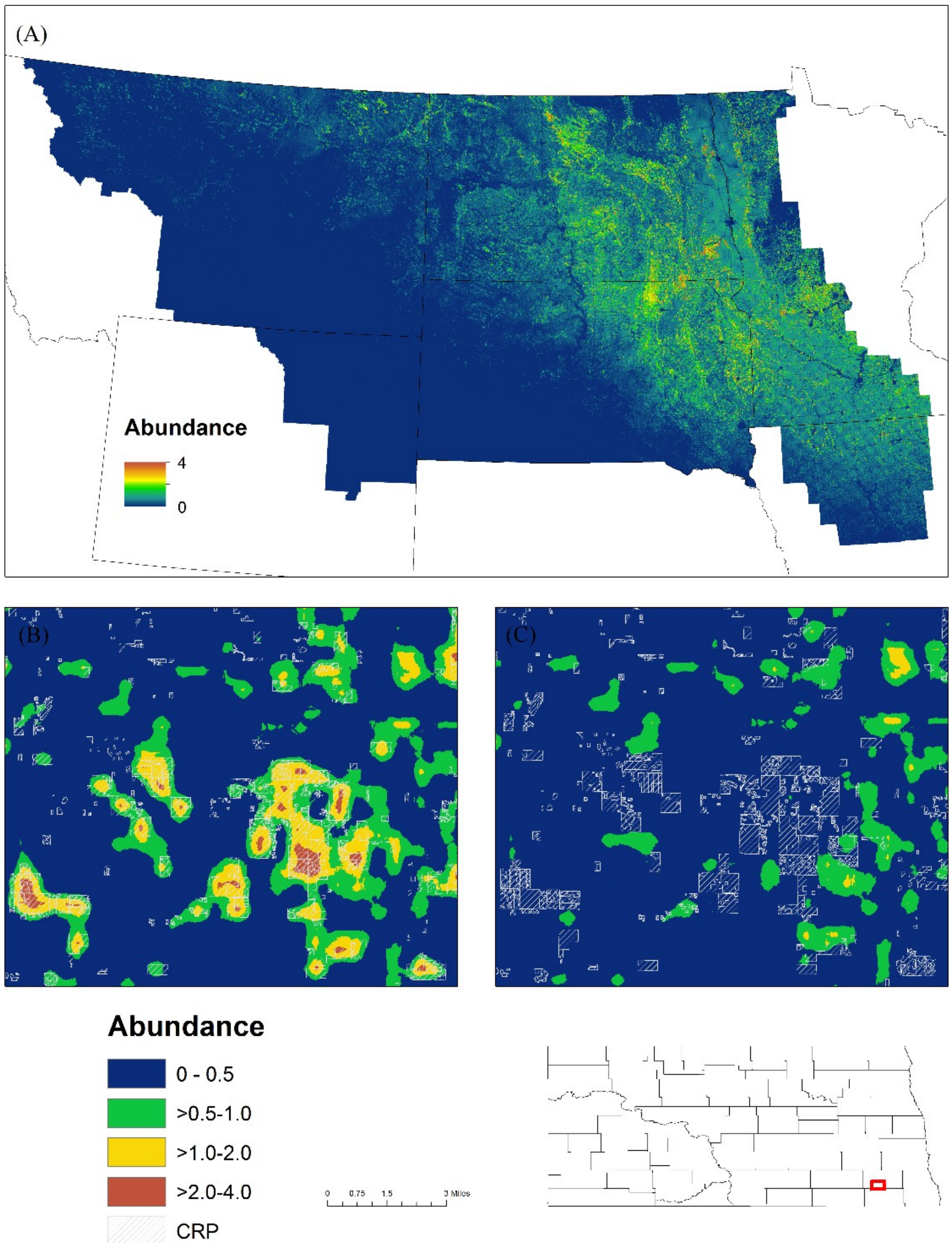


Figure A3. Predicted pseudo-abundance of Chestnut-collared Longspurs per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Daniels County, MT with CRP (B) and with CRP converted to grassland/herbaceous (C).

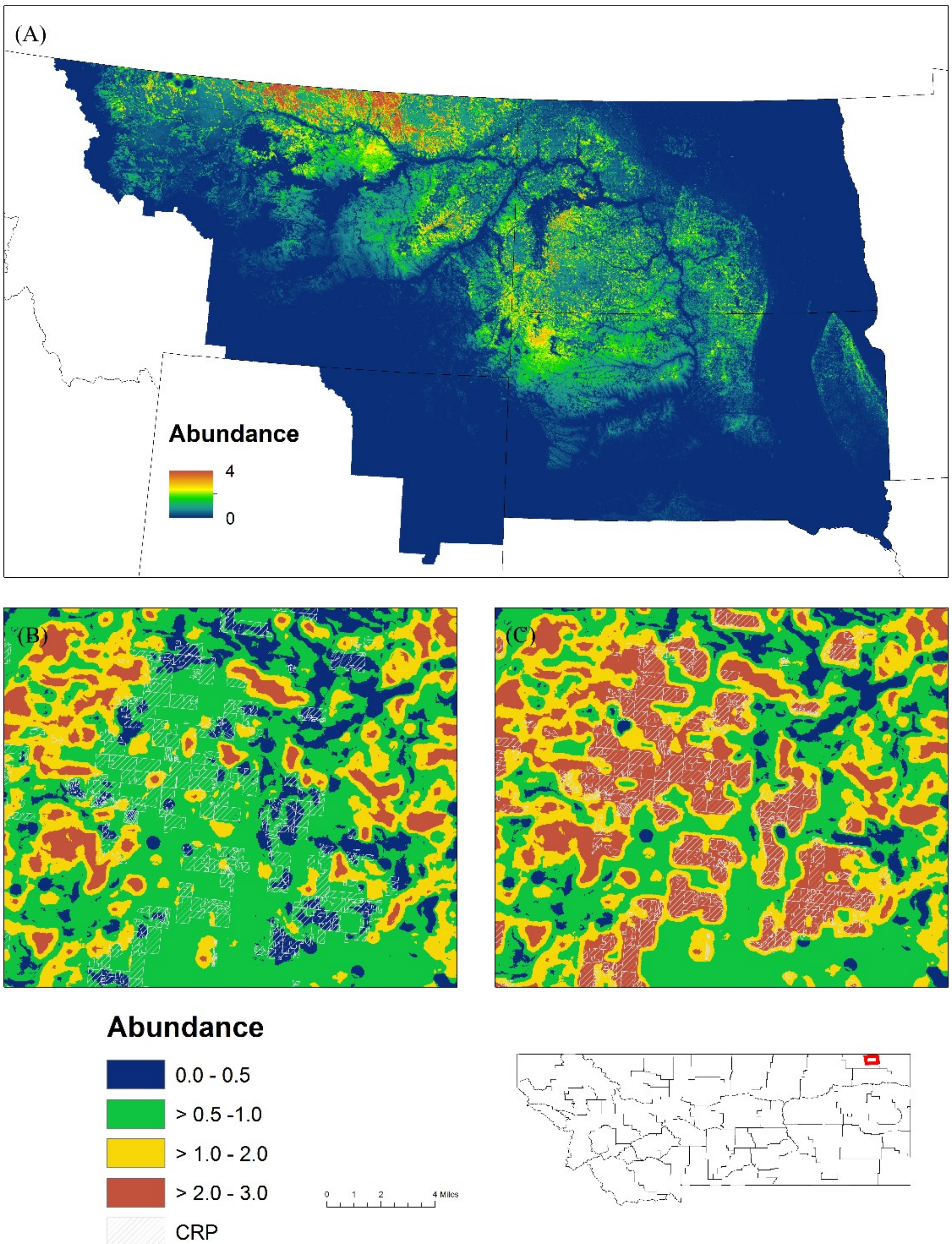


Figure A4. Predicted abundance of Clay-colored Sparrows per 4.9 ha in the PPJV and NGPJV (A), and in a portion of Kittson County, MN with CRP (B) and with CRP converted to grassland/herbaceous (C).

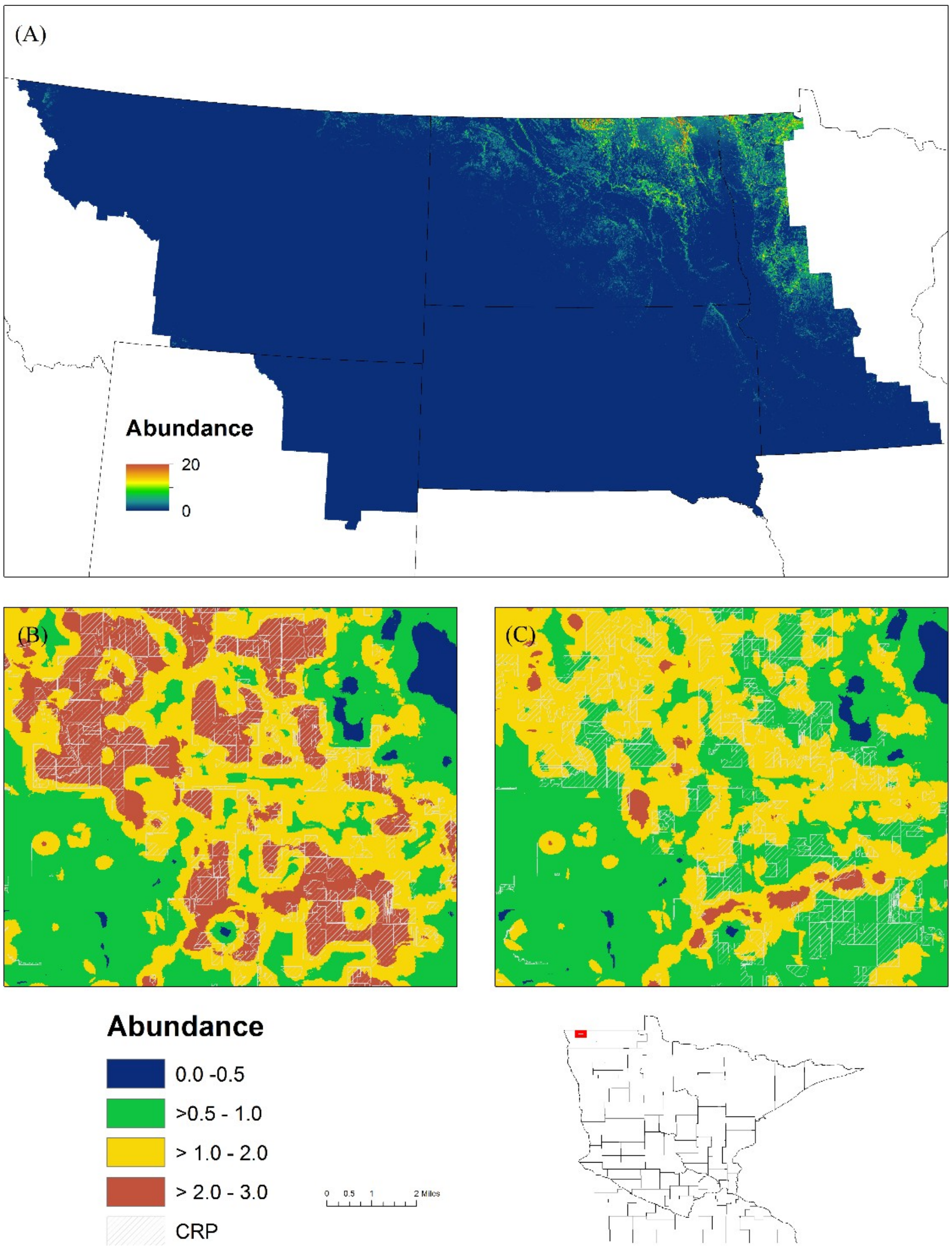


Figure A5. Predicted abundance of Dickcissels per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Palo Alto County, IA with CRP (B) and with CRP converted to crop (C).

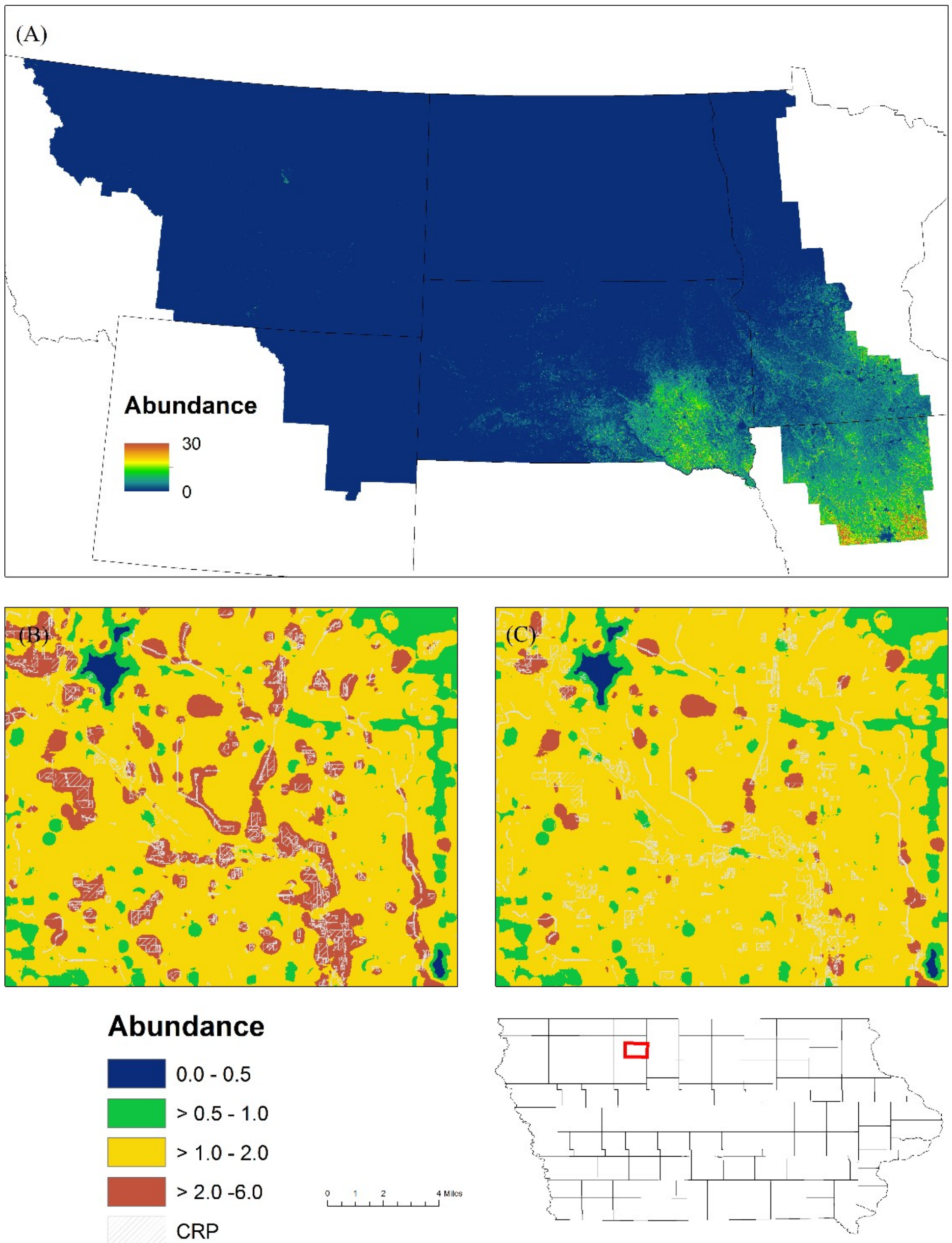


Figure A6. Predicted abundance of Grasshopper Sparrows per 4.9 ha in the PPJV and NGPJV (A), and in a portion of Valley County, MT with CRP (B) and with CRP converted to crop (C).

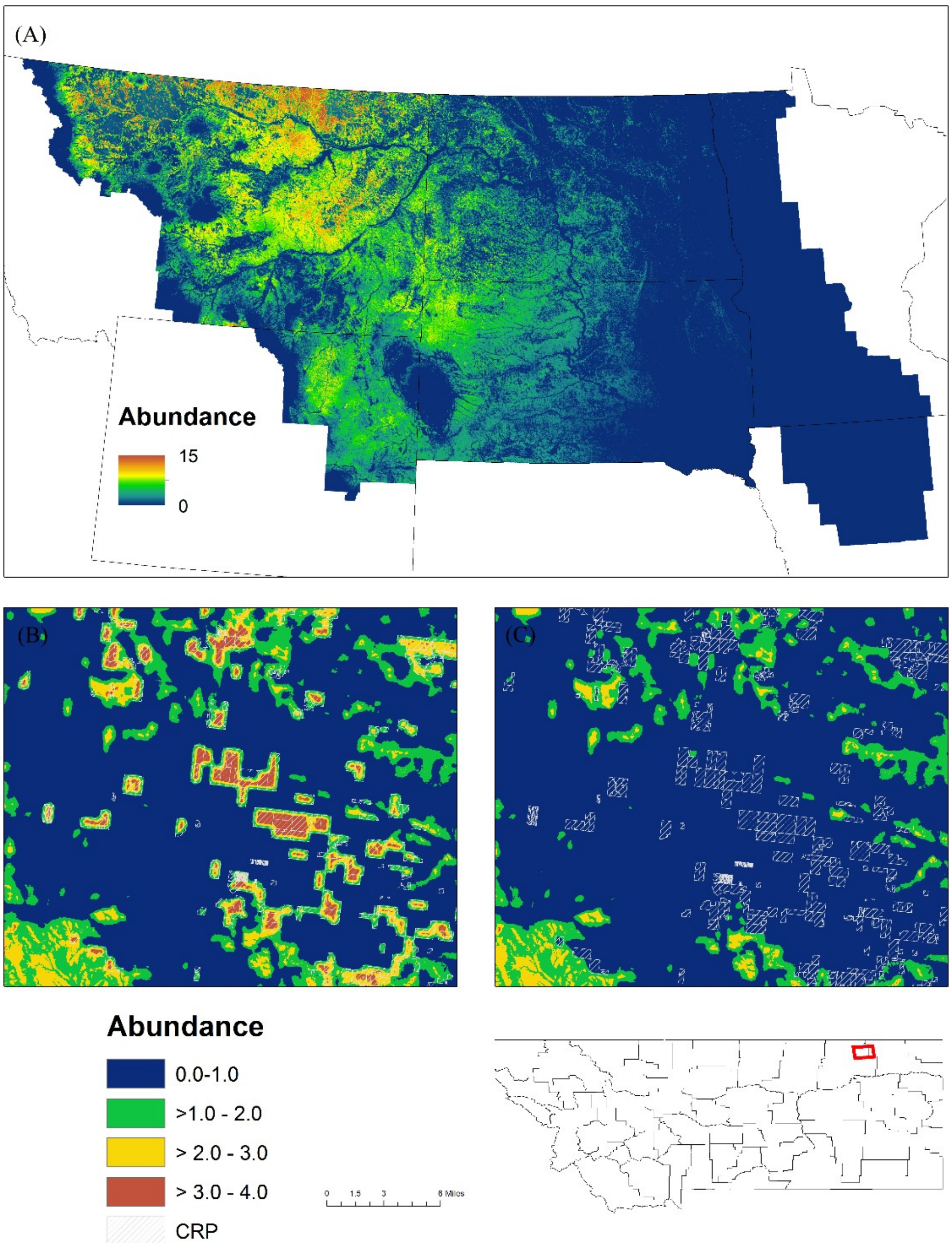


Figure A7. Predicted abundance of Lark Buntings per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Sillwater County, MT with CRP (B) and with CRP converted to grassland/herbaceous (C).

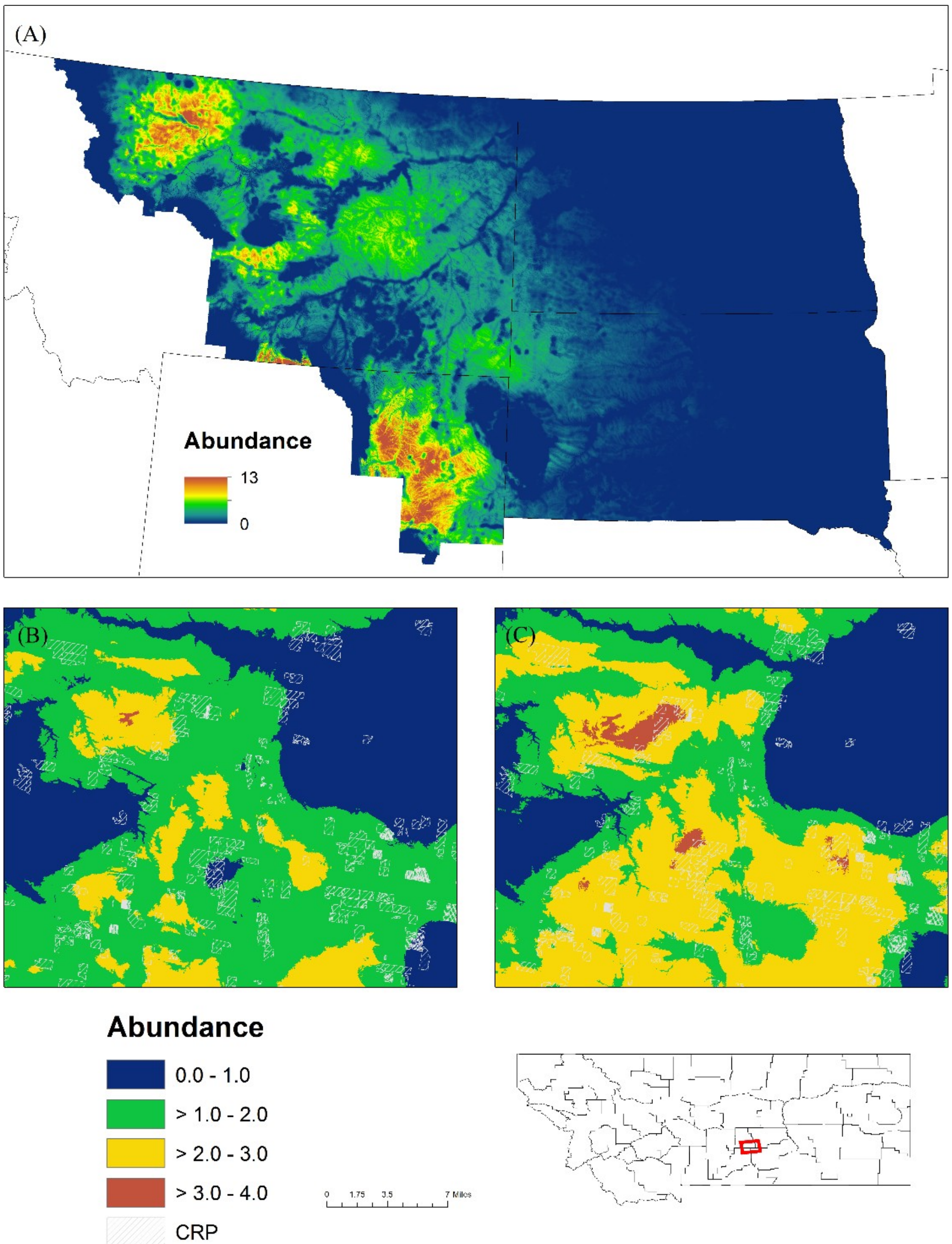


Figure A8. Predicted abundance of Sedge Wren per 4.9 ha in the PPJV and NGPJV (A), and in a portion of Ramsey County, ND with CRP (B) and with CRP converted to crop (C).

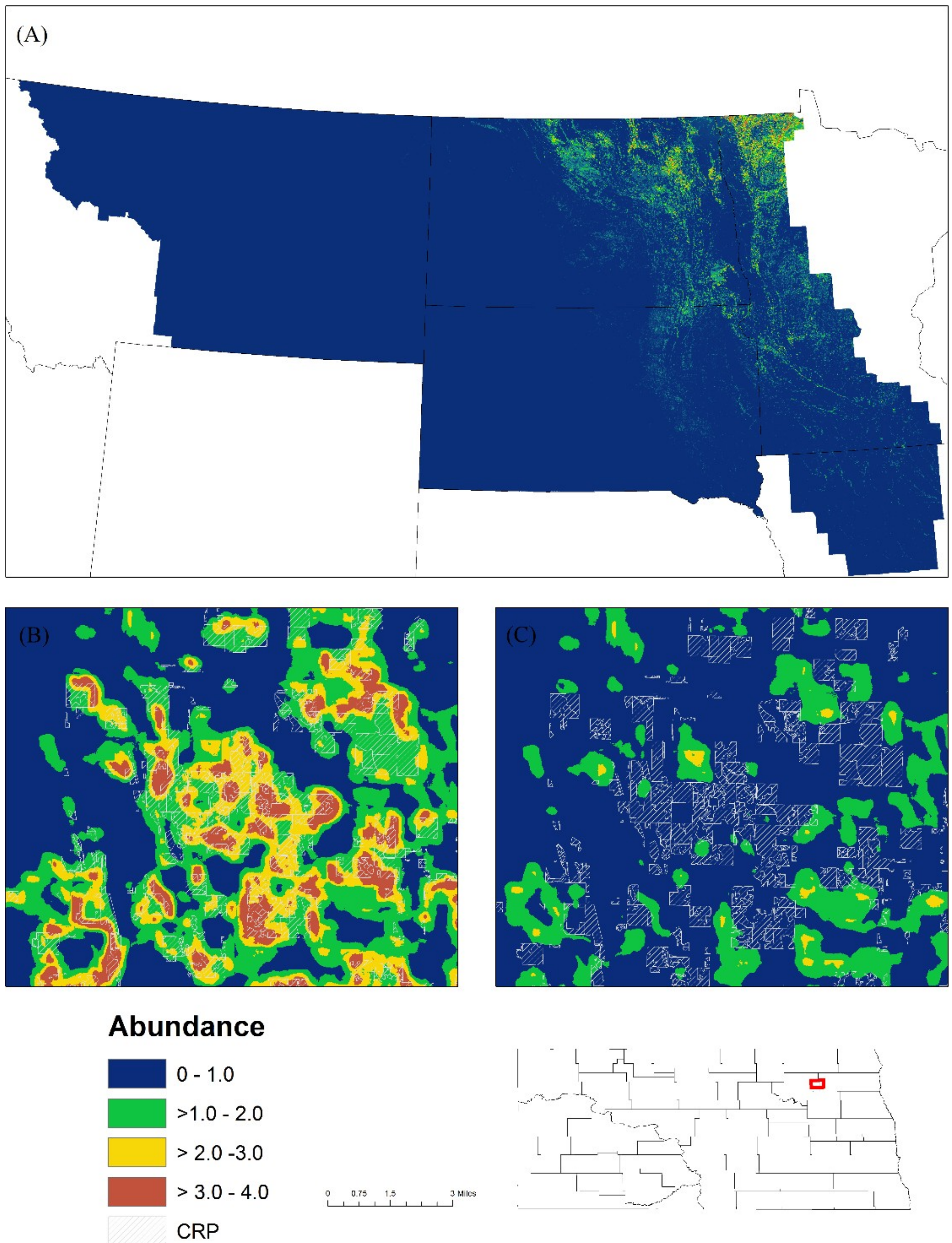
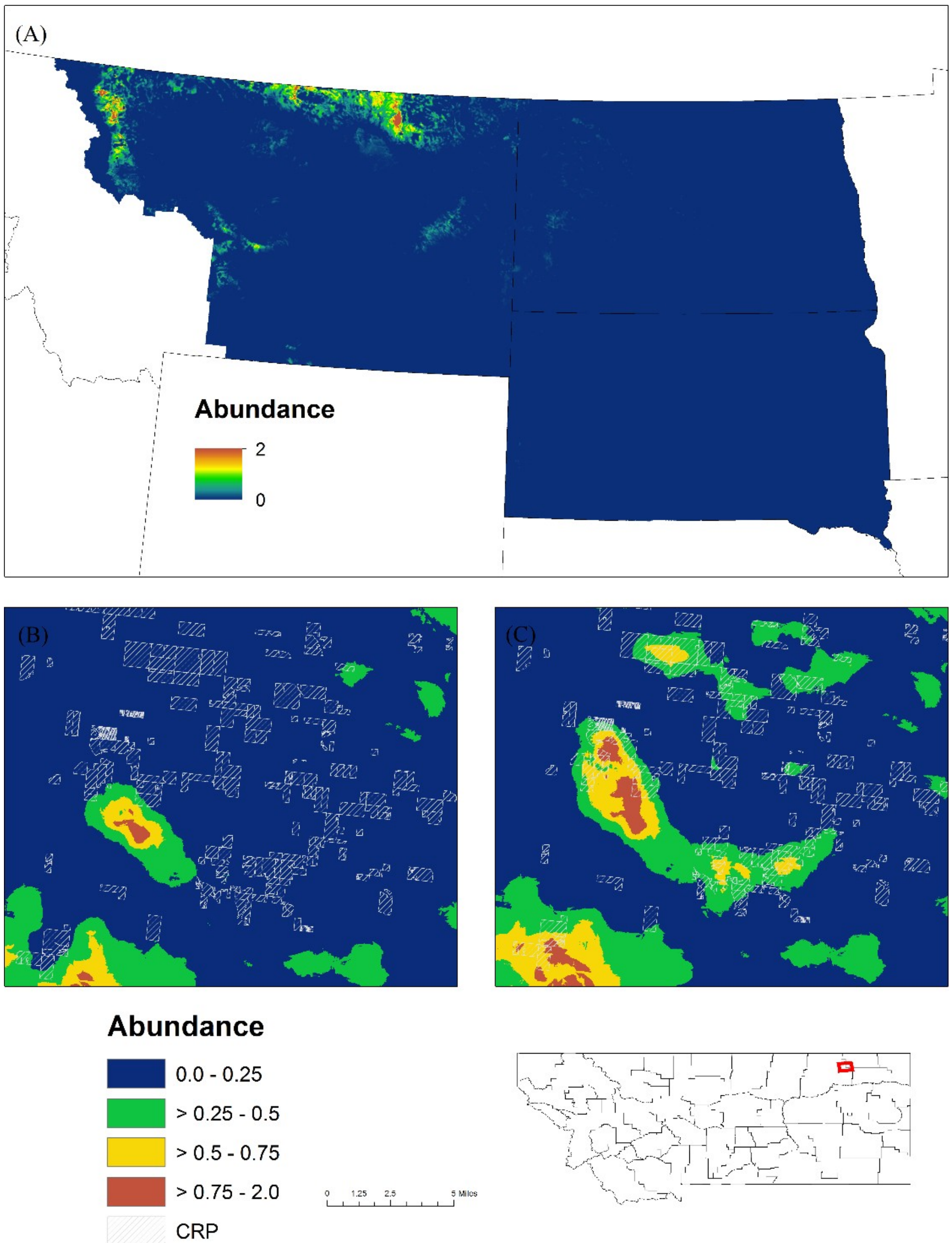


Figure A9. Predicted abundance of Sprague's Pipits per 12.6 ha in the PPJV and NGPJV (A), and in a portion of Valley County, MT with CRP (B) and with CRP converted to crop (C).



APPENDIX B. Overall and marginal CRP effects by state

Table B1. Overall and marginal CRP effects on pseudo-population estimates of Baird's 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 (A) or grassland/herbaceous (B) in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field-specific effects and surrounding landscape effects.

(A)

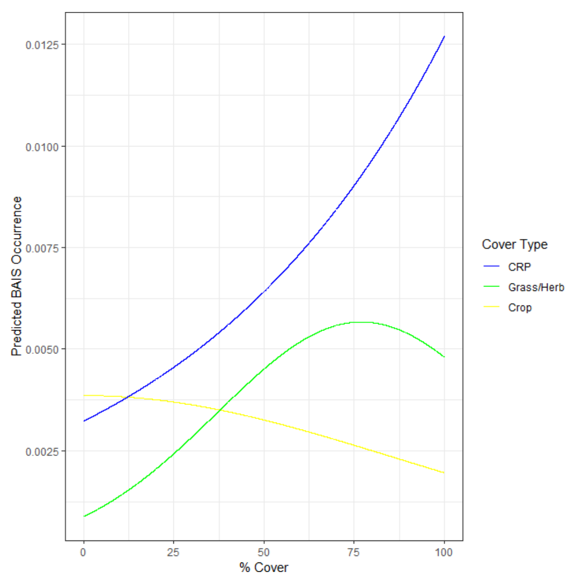
	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	599,700	563,451	-36,249	-6.04	-18,266	-17,983	-3.05	-3.00
MT	477,960	448,141	-29,819	-6.24	-15,840	-13,980	-3.31	-2.92
ND	90,099	84,240	-5,859	-6.50	-2,214	-3,644	-2.46	-4.04
SD	31,641	31,070	-571	-1.81	-212	-359	-0.67	-1.13

(B)

	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	599,700	612,403	12,703	2.12	8,333	4,370	1.39	0.73
MT	477,960	488,915	10,955	2.29	7,443	3,512	1.56	0.73
ND	90,099	91,934	1,835	2.04	901	934	1.00	1.04
SD	31,641	31,554	-87	0.27	-11	-76	-0.03	-0.24

Figure B1. Marginal effects of CRP, grassland/herbaceous, and cropland on Baird's Sparrow probability of occurrence within a 4.9 ha area (based on detection distance of 125 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A)



(B)

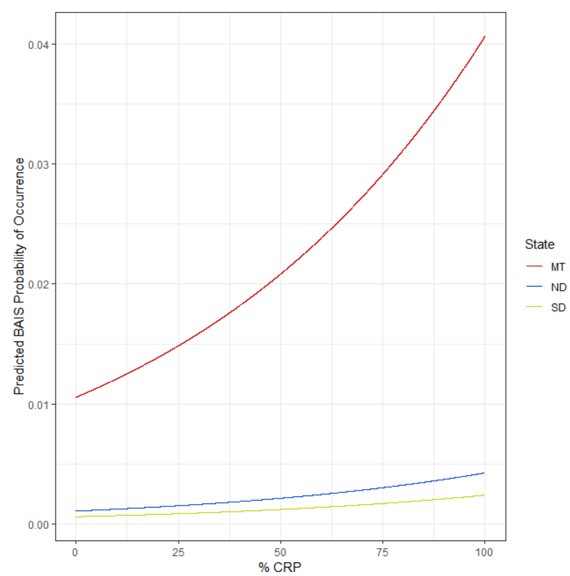
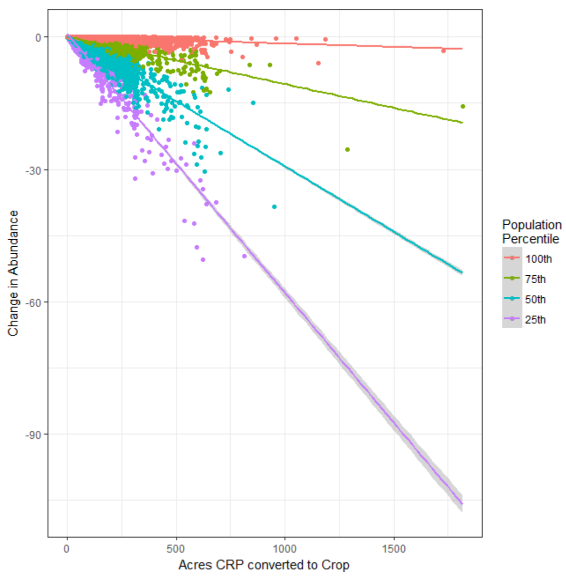


Figure B2. Change in Baird's Sparrow pseudo-abundance within CRP fields converted to crop (A) and grassland/herbaceous (B) vs. acres of CRP field converted to crop or grassland/herbaceous within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

(A)



(B)

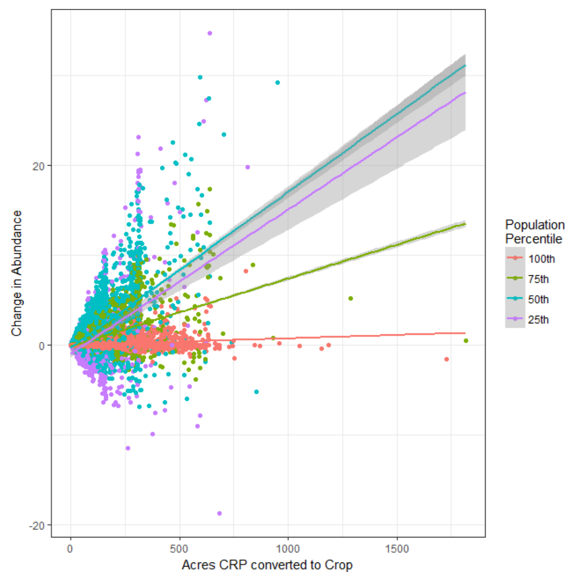


Figure B3. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Baird's Sparrows are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

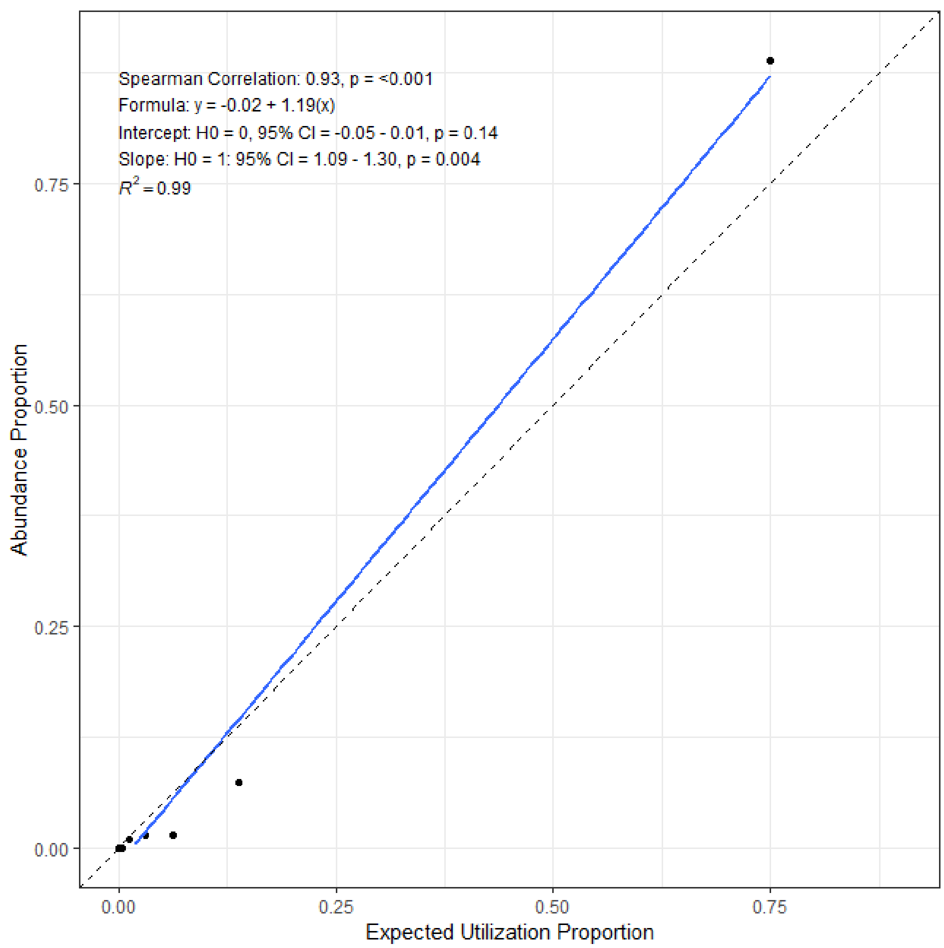


Table B2. Overall and marginal CRP effects on population estimates of Bobolink by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute 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	938,394	839,348	-99,046	-10.55	-56,249	-42,797	-5.99	-4.56
IA	67,021	60,340	-6,681	-9.97	-2,655	-4,026	-3.96	-6.01
MN	231,648	206,277	-25,371	-10.95	-12,842	-12,529	-5.54	-5.41
MT	96,616	85,489	-11,128	-11.52	-8,176	-2,951	-8.46	-3.05
ND	319,443	281,986	-37,457	-11.73	-22,773	-14,684	-7.13	-4.60
SD	220,798	202,420	-18,378	-8.32	-9,780	--8,598	-4.42	-3.89
WY	2,868	2,837	-31	-1.07	-24	-7	-0.83	-0.24

Figure B4. Marginal effects of CRP, grassland/herbaceous, and crop within a 400 m landscape scale on Bobolink abundance within a 12.6 ha area (based on detection distance of 200 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A) (B)

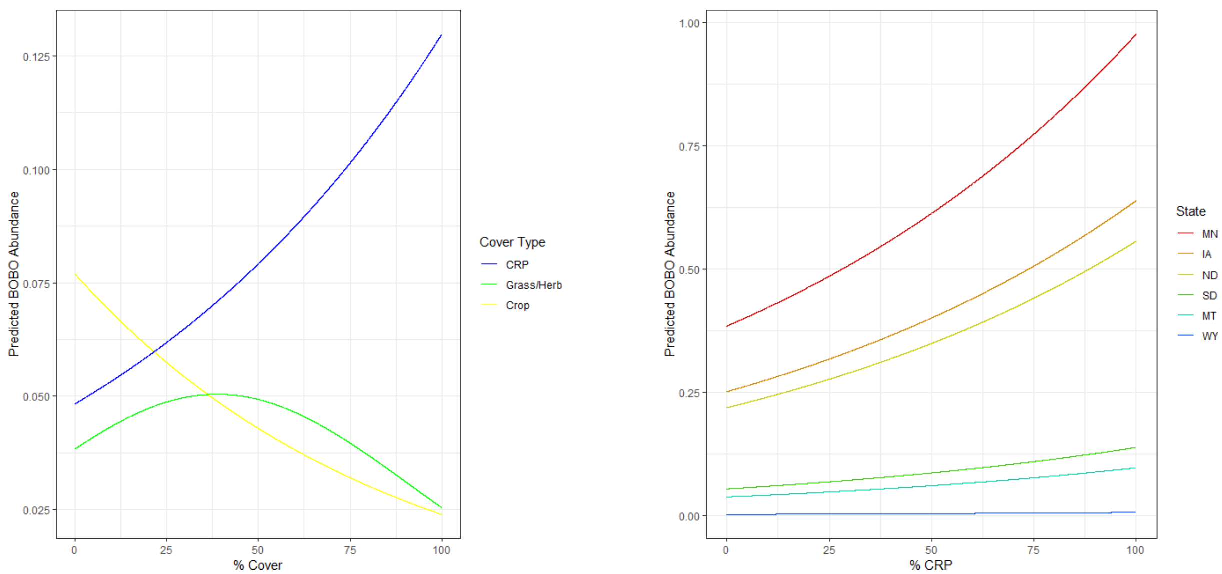


Figure B5. Change in Bobolink abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

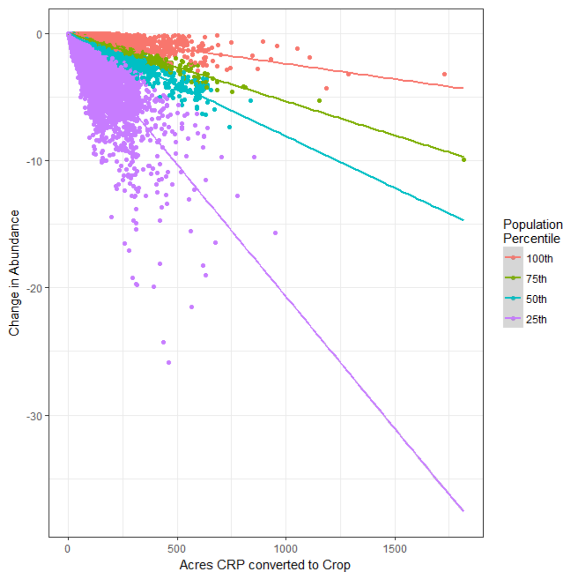


Figure B6. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Bobolink are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

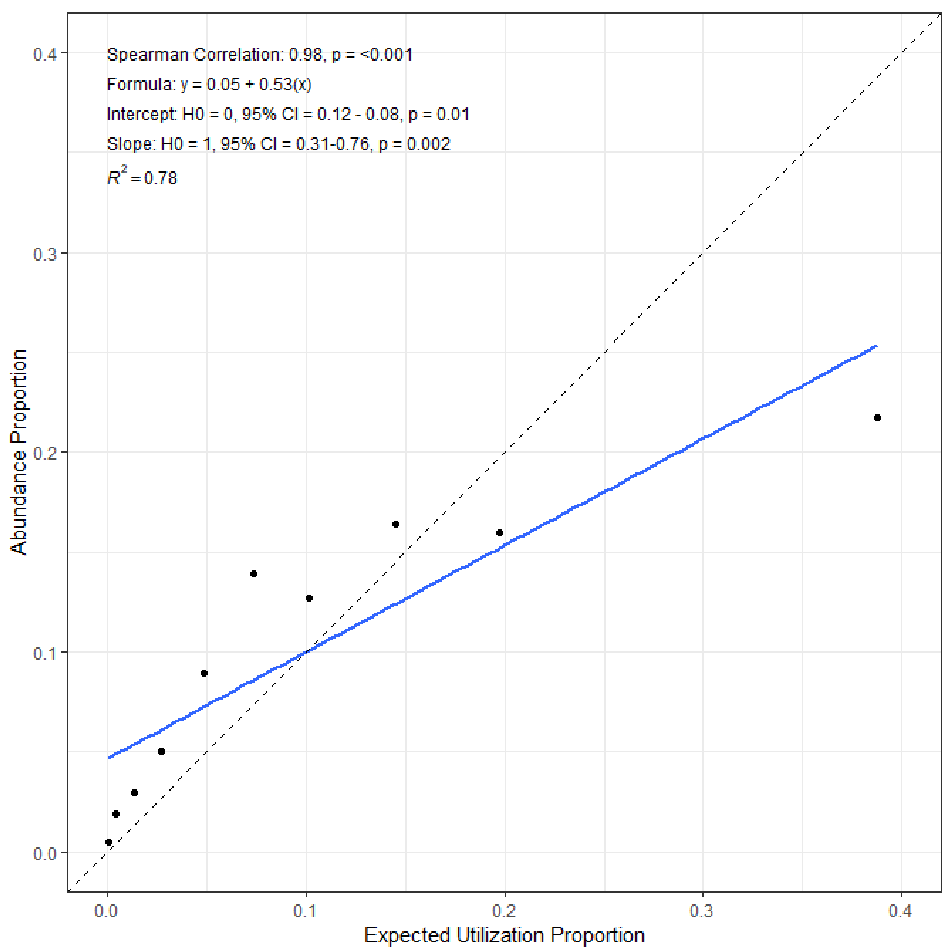


Table B3.Overall and marginal CRP effects on pseudo-population estimates of Chestnut-collared Longpsur by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland (A) or grassland/herbaceous (B) in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field- specific effects and surrounding landscape effects.

(A)

	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	1,964,798	34,798	1.80	11,615	23,183	0.60	1.20
MT	999,960	1,016,747	16,788	1.68	6,152	10,636	0.62	1.06
ND	525,975	538,793	12,818	2.44	4,070	8,748	0.77	1.66
SD	395,804	400,984	5,179	1.31	1,390	3,789	0.35	0.96
WY	8261	8,274	13	0.15	3	10	0.04	0.12

(B)

	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	2,063,359	133,359	6.91	78,982	54,378	4.09	2.82
MT	999,960	1,077,700	77,740	7.77	50,359	27,381	5.04	2.74
ND	525,975	567,339	41,363	7.86	21,856	19,507	4.16	3.71
SD	395,804	410,034	14,229	3.60	6,754	7,476	1.71	1.89
WY	8261	8,288	27	0.32	13	13	0.16	0.16

Figure B7. Marginal effects of CRP, grassland/herbaceous, and crop 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). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A) (B)

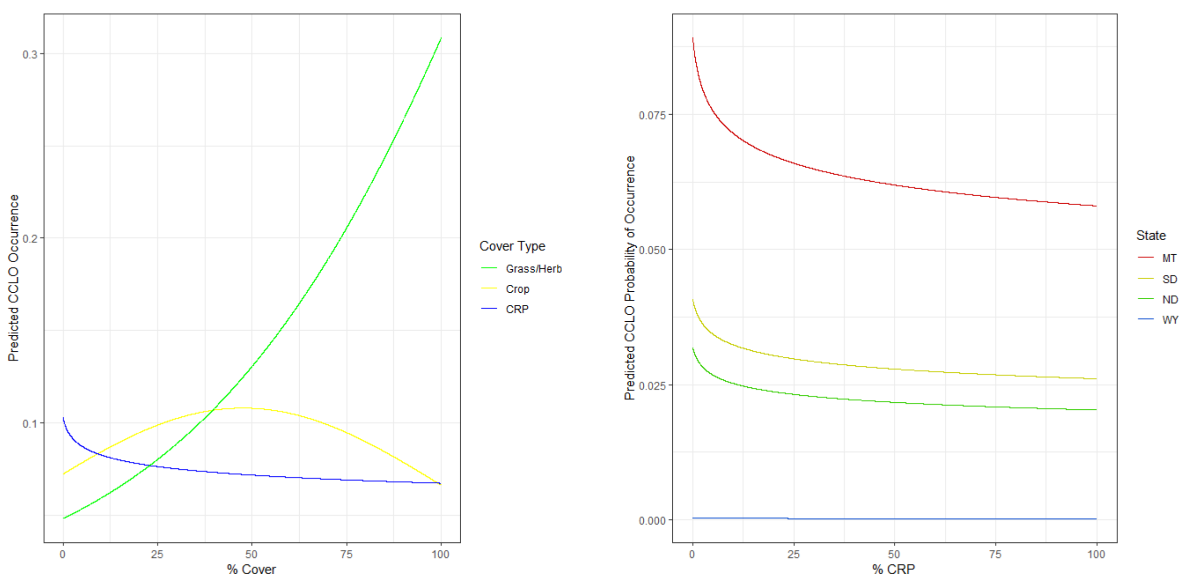


Figure B8. Change in Chestnut-collared Longspur pseudo-abundance within CRP fields converted to crop (A) and grassland/herbaceous (B) vs. acres of CRP field converted to crop or grassland/herbaceous within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

(A) (B)

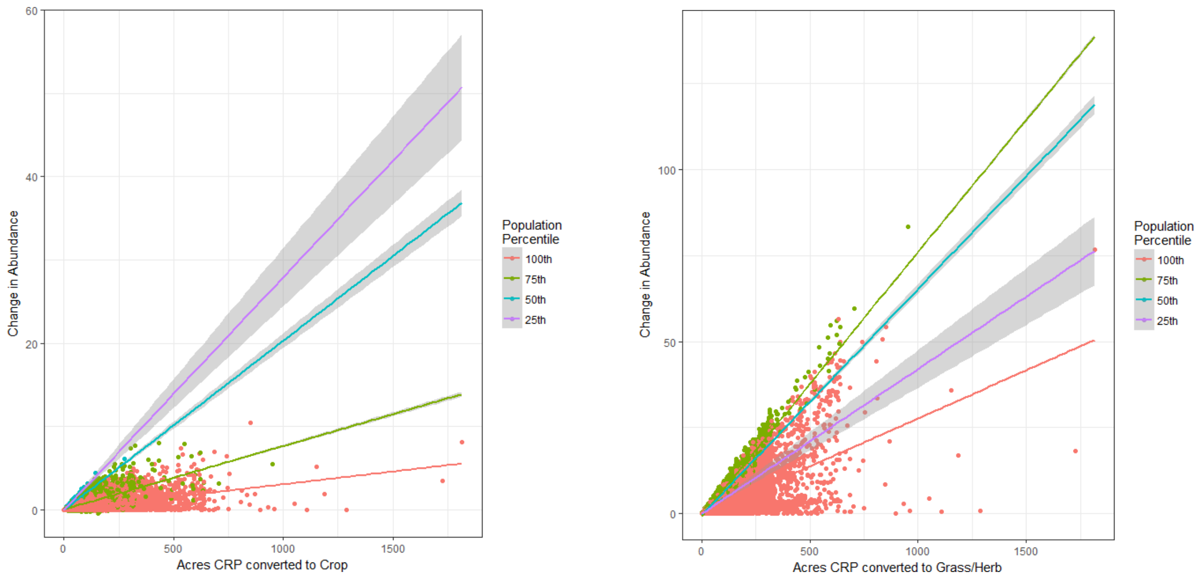


Figure B9. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Chestnut-collared Longspur are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

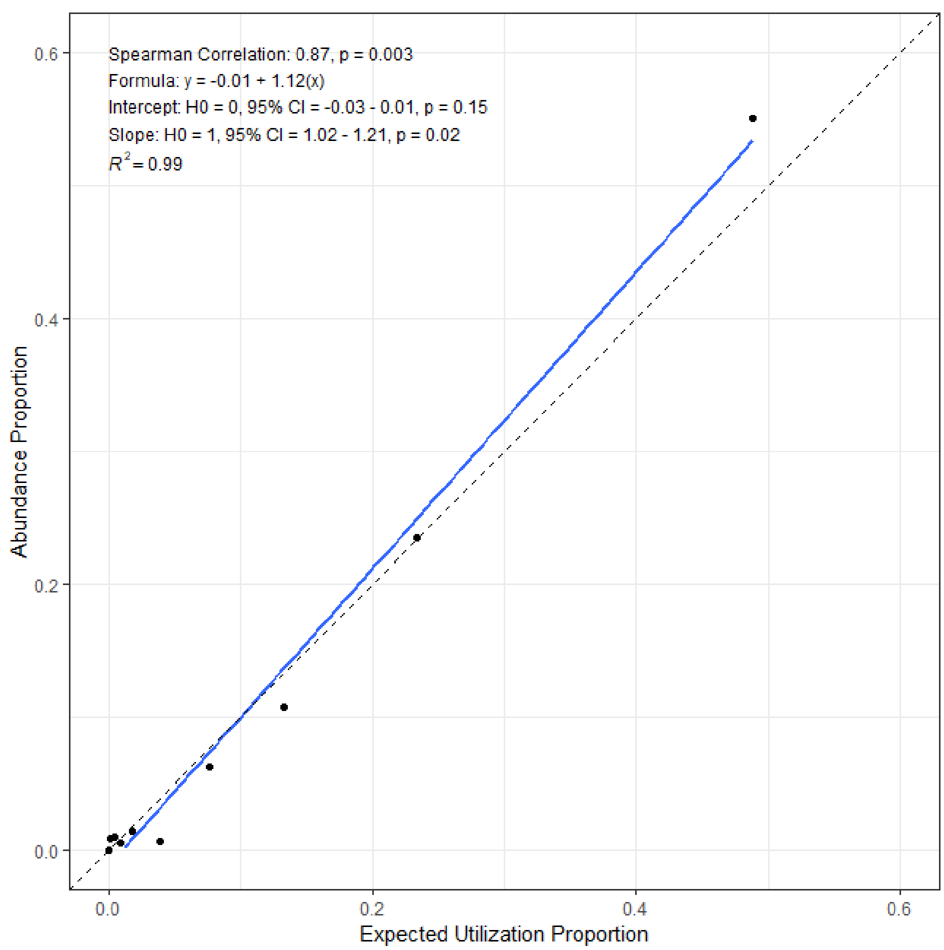


Table B4. Overall and marginal CRP effects on population estimates of Clay-colored Sparrow by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (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	2,014,080	1,870,821	-143,259	-7.11	-76,597	-66,662	-3.80	-3.31
MN	596,783	539,686	-57,097	-9.57	-29,377	-27,220	-4.92	-4.64
MT	199,250	190,289	-8,961	-4.50	-5,629	-3,332	-2.83	-1.67
ND	1,040,989	971,351	-69,638	-6.69	-38,321	-31,317	-3.68	-3.01
SD	165,366	157,881	-7,485	-4.52	-3,259	-4,226	-1.97	-2.56
WY	11,692	11,614	-77	-0.66	-10	-67	-0.09	-0.57

Figure B10. Marginal effects of CRP, grassland/herbaceous, and crop within a 400 m landscape scale on Clay-colored Sparrow abundance within a 4.9 ha area (based on detection distance of 125 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A) (B)

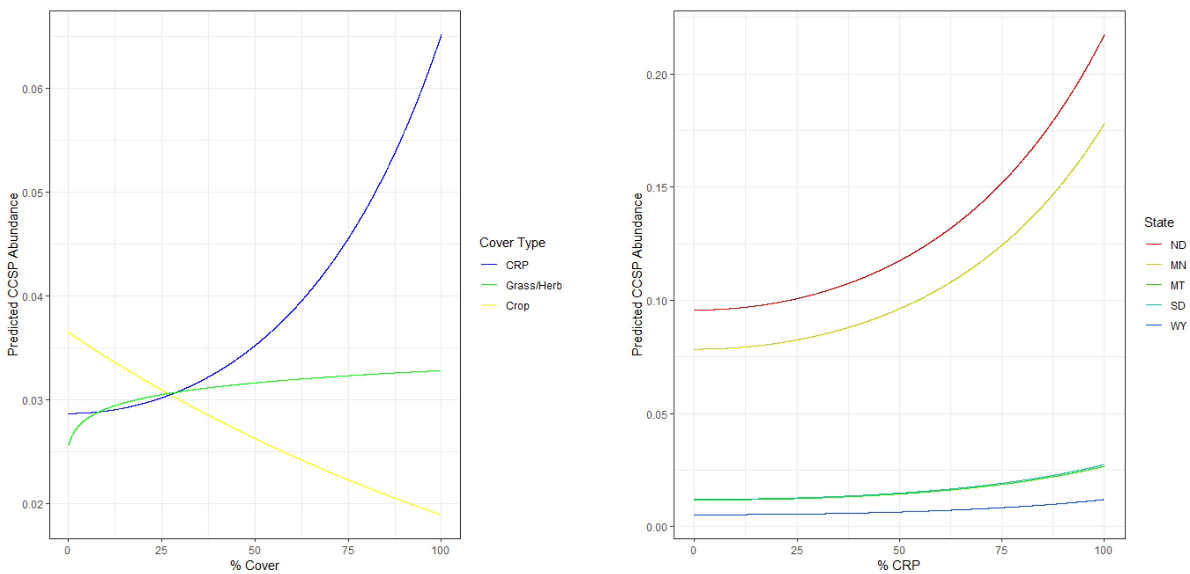


Figure B11. Change in Clay-colored Sparrow abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

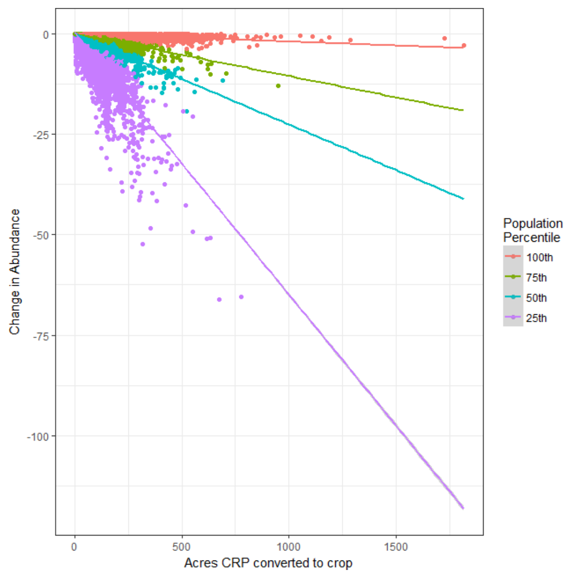


Figure B12. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Clay-colored Sparrows are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

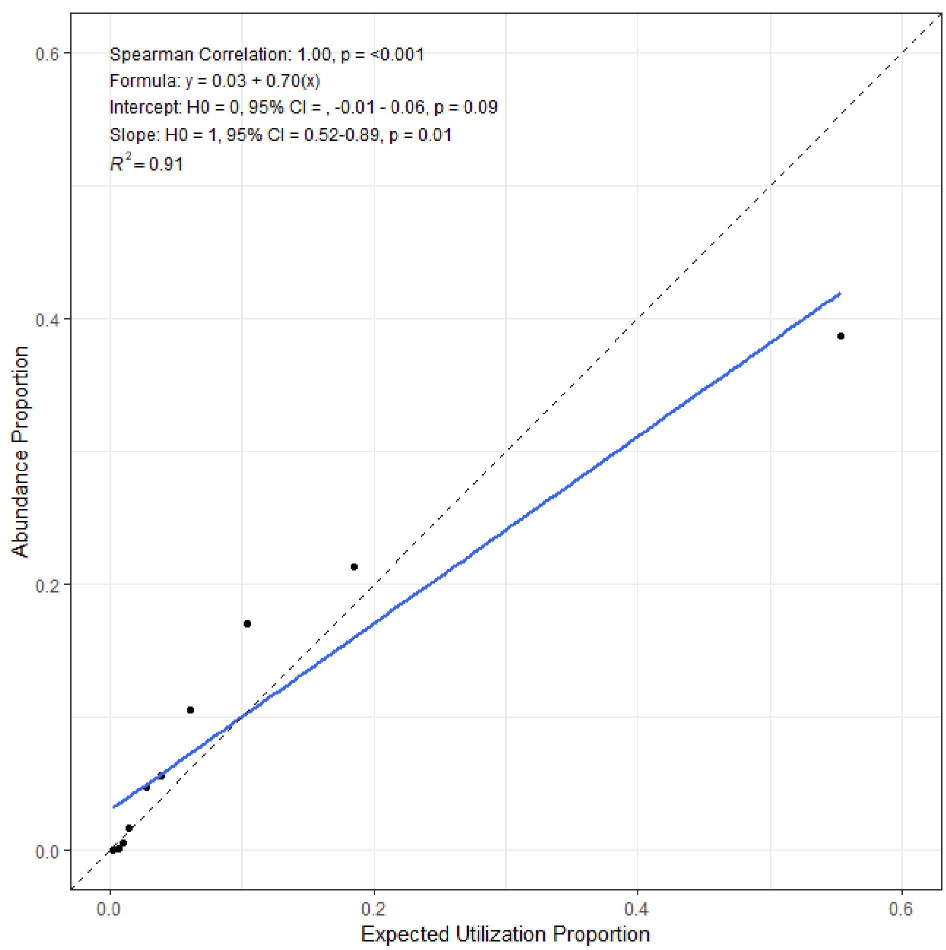
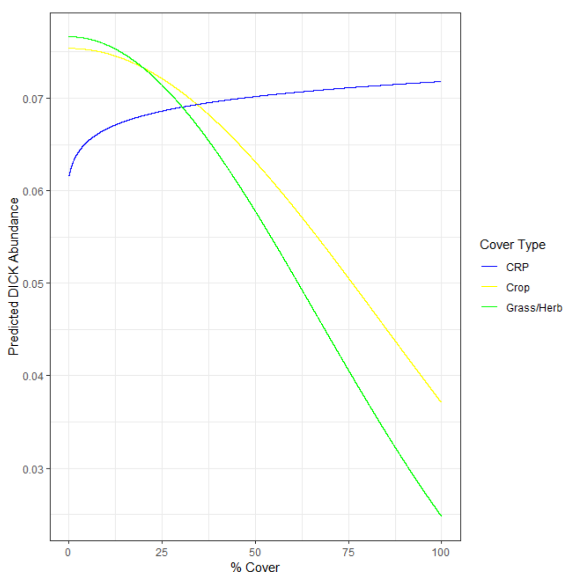


Table B5. Overall and marginal CRP effects on population estimates of Dickcissel by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute 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	2,080,101	1,983,909	-96,192	-4.62	-28,891	-67,301	-1.39	-3.24
IA	727,925	681,647	-46,279	-6.36	-11,460	-34,819	-1.57	-4.78
MN	439,084	417,409	-21,675	-4.94	-5,770	-15,905	-1.31	-3.62
MT	87,174	85,401	-1,773	-2.03	-1,160	-613	-1.33	-0.70
ND	58,690	56,014	-2,676	-4.56	-1,312	-1,364	-2.24	-2.32
SD	754,910	731,141	-23,769	-3.15	-9,175	-14,595	-1.21	-1.93
WY	12,317	12,297	-20	-0.16	-14	-6	-0.11	-0.05

Figure B13. Marginal effects of CRP, grassland/herbaceous, and crop within a 400 m landscape scale on Dickcissel probability of occurrence within a 12.6 ha area (based on detection distance of 200 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A)



(B)

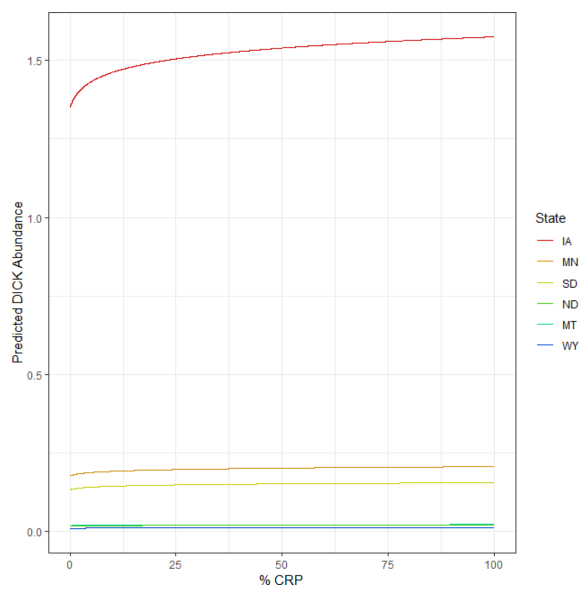


Figure B14. Change in Dickcissel abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

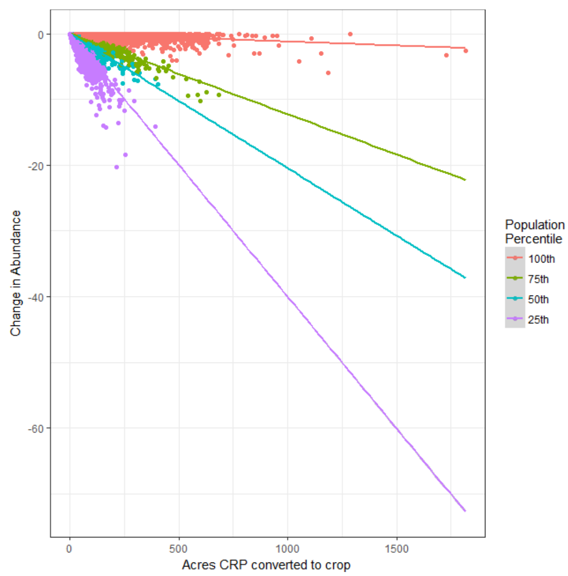


Figure B15. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Dickcissels are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

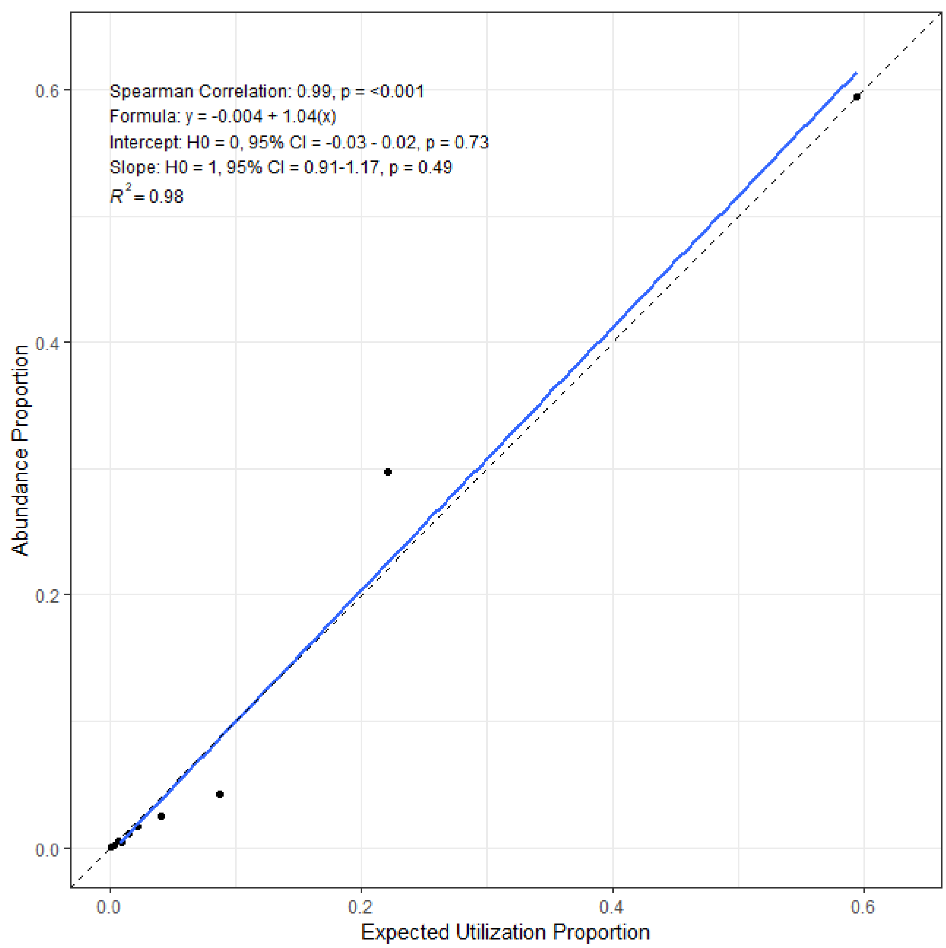


Table B6. Overall and marginal CRP effects on population estimates of Grasshopper Sparrow by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (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	7,166,164	6,848,780	-317,385	-4.43	-216,335	-101,050	-3.02	-1.41
IA	13,754	12,395	-1,359	-9.88	-509	-850	-3.70	-6.18
MN	69,003	59,400	-9,604	-13.92	-5,618	-3,986	-8.14	-5.78
MT	3,913,289	3,715,621	-197,668	-5.05	-143,864	-53,804	-3.68	-1.37
ND	1,134,155	1,056,682	-77,473	-6.83	-47,474	-30,000	-4.19	-2.65
SD	1,334,724	1,305,843	-28,880	-2.16	-17,098	-11,783	-1.28	-0.88
WY	701,240	698,839	-2,401	-0.34	-1,772	-629	-0.25	-0.09

Figure B16. Marginal effects of CRP, grassland/herbaceous, and crop within a 400 m landscape scale on Grasshopper Sparrow probability of occurrence within a 4.9 ha area (based on detection distance of 125 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

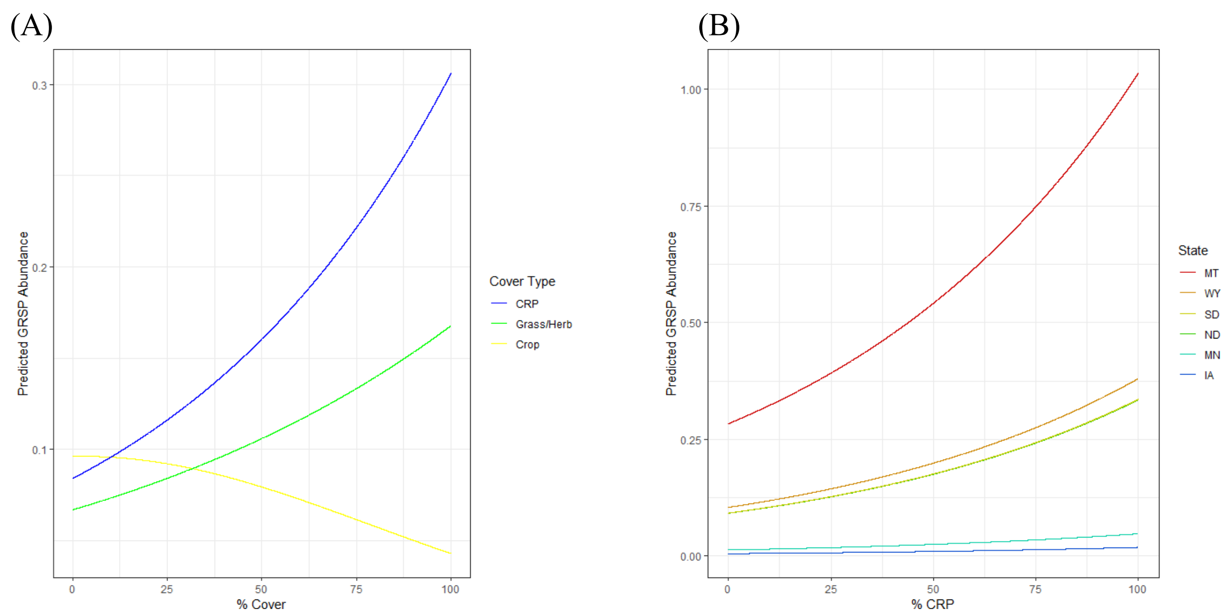


Figure B17. Change in Grasshopper Sparrow abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

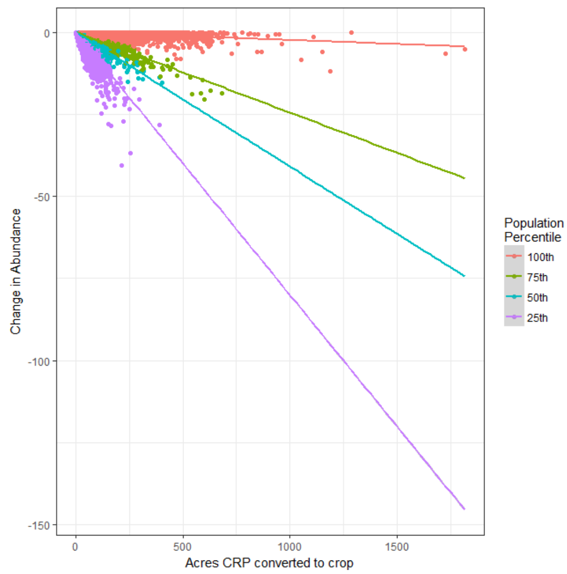


Figure B18. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Grasshopper Sparrows are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

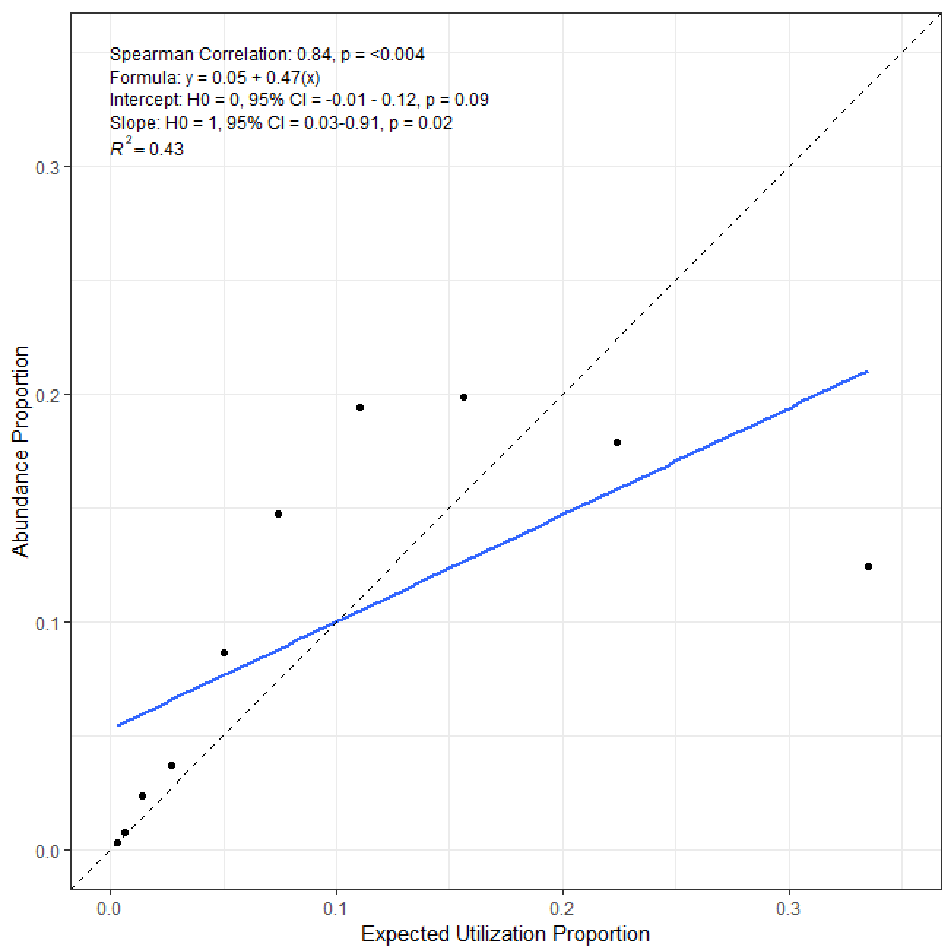


Table B7. Marginal CRP effects on pseudo-population estimates of Lark Bunting by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland (A) or grassland/herbaceous (B) in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field- specific effects and surrounding landscape effects.

(A)

	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	3,517,710	3,685,681	167,972	4.78	27,847	140,125	0.79	3.98
MT	2,172,428	2,318,742	146,315	6.74	24,775	121,540	1.14	5.59
ND	145,536	155,077	9,541	6.56	1,151	8,390	0.79	5.77
SD	326,887	334,025	7,139	2.18	906	6,233	0.28	1.91
WY	872,860	877,837	4,977	0.57	1,015	3,962	0.12	0.45

(B)

	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	3,517,710	3,667,589	149,879	4.26	30,491	180,370	-0.87	5.13
MT	2,172,428	2,302,928	130,500	6.01	-46,792	177,292	-2.15	8.16
ND	145,536	154,087	8,552	5.88	17,500	-8,949	12.02	-6.15
SD	326,887	333,285	6,398	1.96	457	5,941	0.14	1.82
WY	872,860	877,290	4,430	0.51	-1,656	6,085	-0.19	0.70

Figure B19. Marginal effects of CRP, grassland/herbaceous, and crop within a 3200 m landscape scale on Lark Bunting probability of occurrence within a 12.6 ha area (based on detection distance of 200 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A) (B)

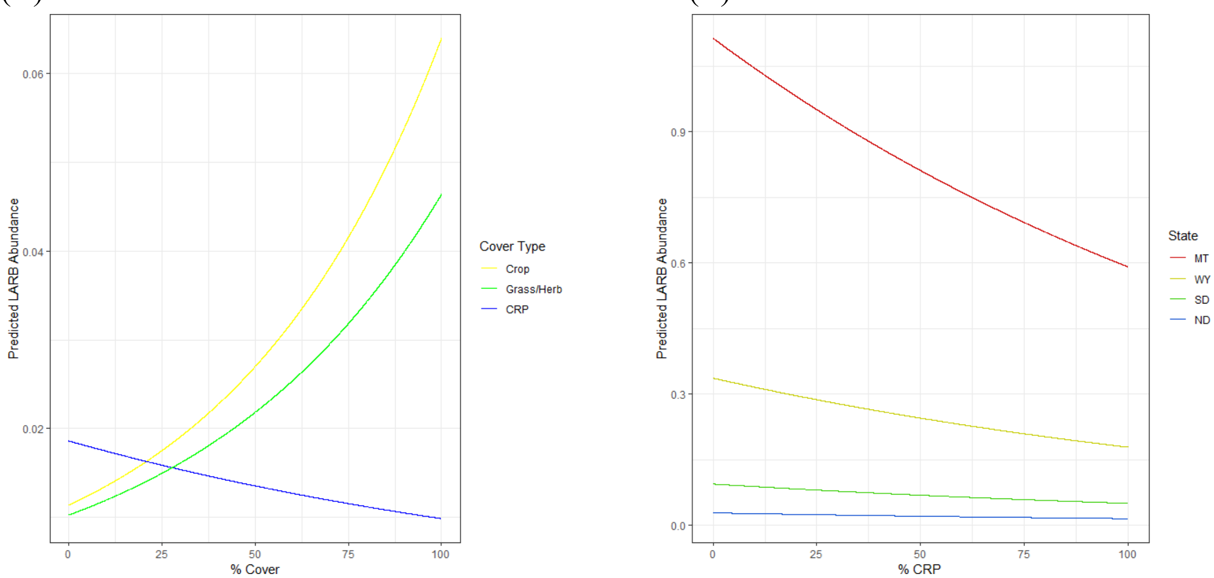
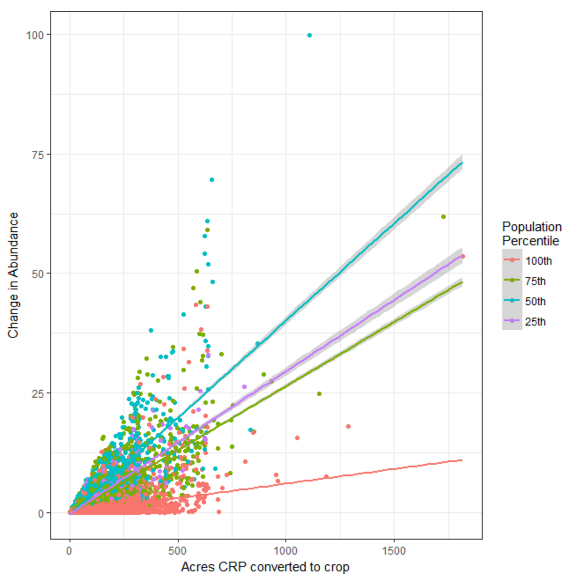


Figure B20. Change in Lark Bunting abundance within CRP fields converted to crop (A) and grassland/herbaceous (B) vs. acres of CRP field converted to crop or grassland/herbaceous within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

(A)



(B)

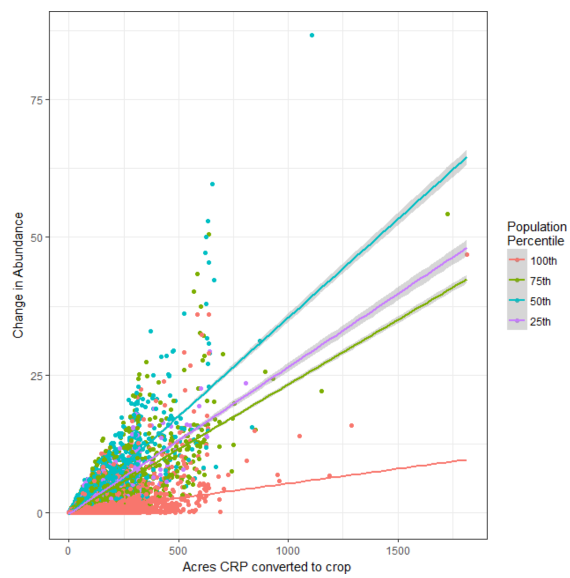


Figure B21. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Lark Buntings are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

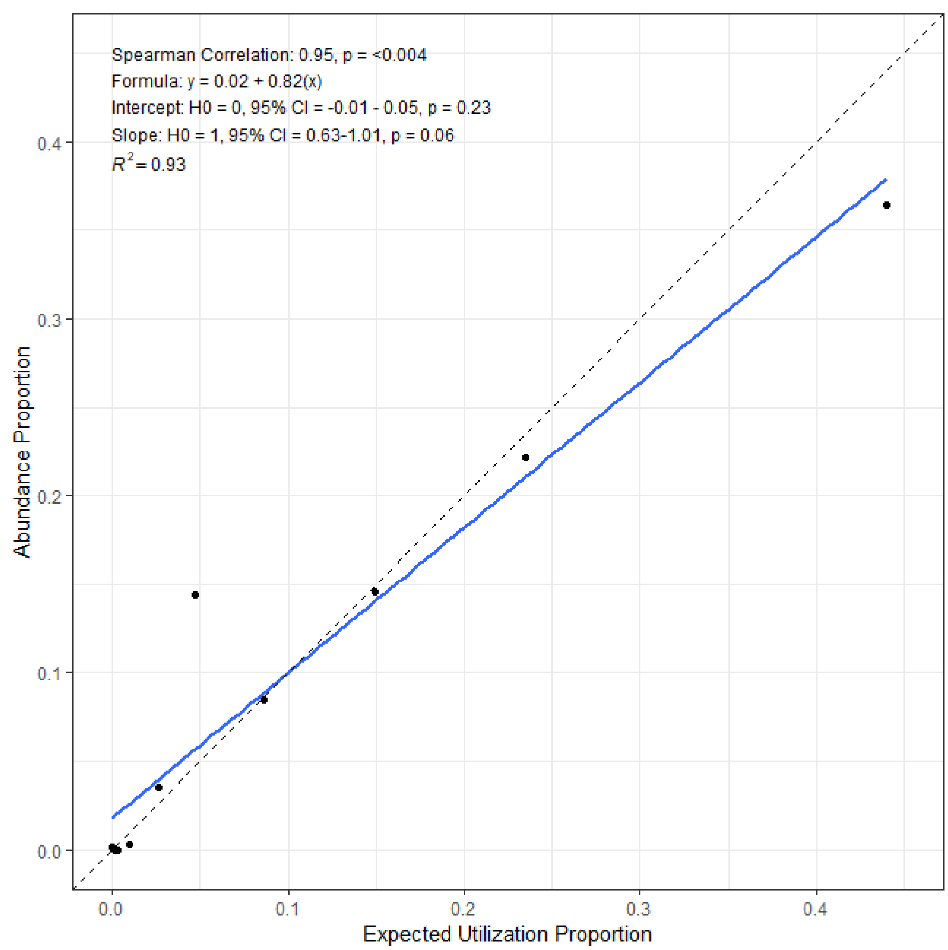


Table B8. Overall and marginal CRP effects on population estimates of Sedge Wren by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland in the landscape, and differences (absolute 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	1,741,937	1,254,131	-487,806	-28.00	-193,824	-293,983	-11.13	-16.88
IA	67,878	45,740	-22,138	-32.61	-5,940	-16,198	-8.75	-23.86
MN	708,698	491,476	-217,222	-30.65	-88,336	-128,886	-12.46	-18.19
MT	13,258	11,484	-1,773	-13.37	-873	-901	-6.58	-6.79
ND	722,490	521,757	-200,733	-27.79	-82,665	-118,068	-11.44	-16.34
SD	229,614	183,673	-45,941	-20.01	-16,010	-29,930	-6.97	-13.04

Figure B22. Marginal effects of CRP, grassland/herbaceous, and crop within a 400 m landscape scale on Sedge Wren abundance within a 4.9 ha area (based on detection distance of 125 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

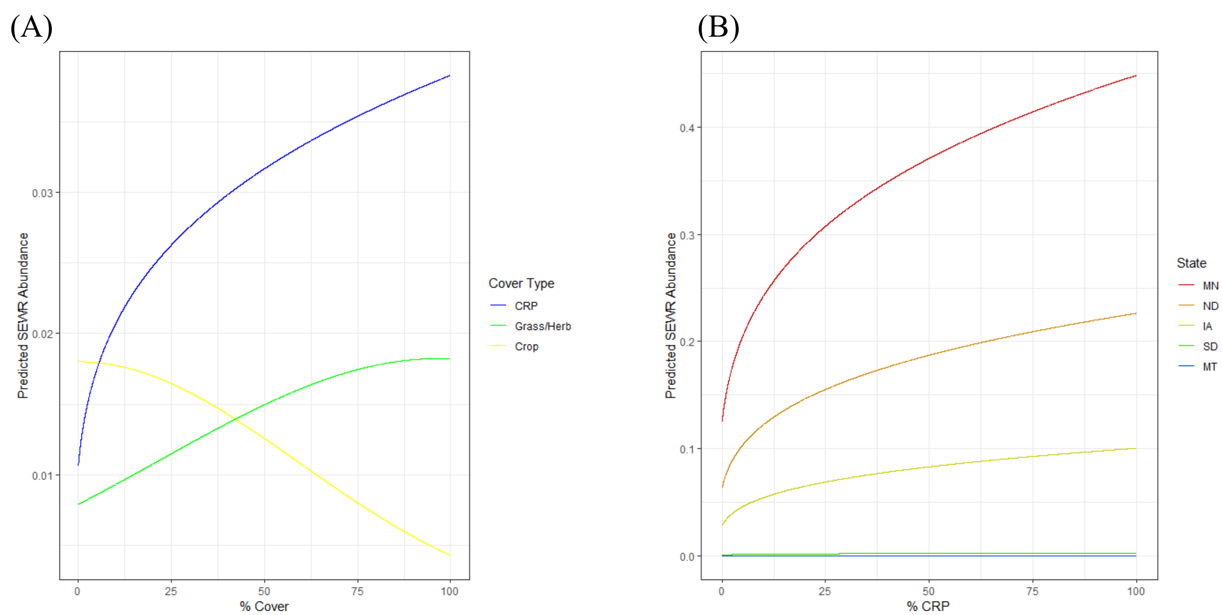


Figure B23. Change in Sedge Wren abundance within CRP fields converted to crop vs. acres of CRP field converted to crop within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

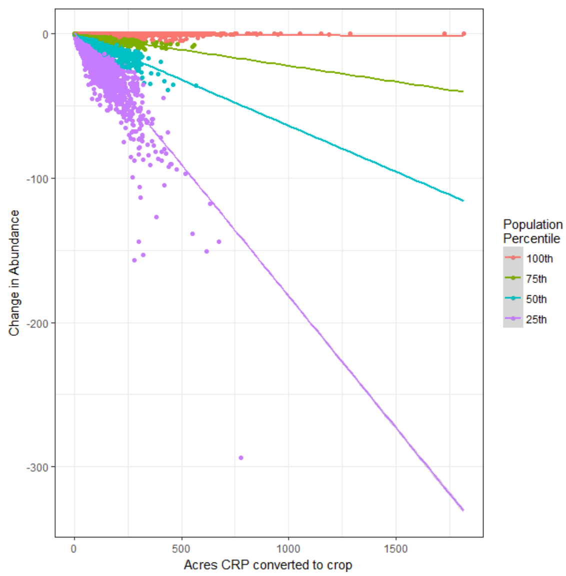


Figure B24. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Sedge Wren are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.

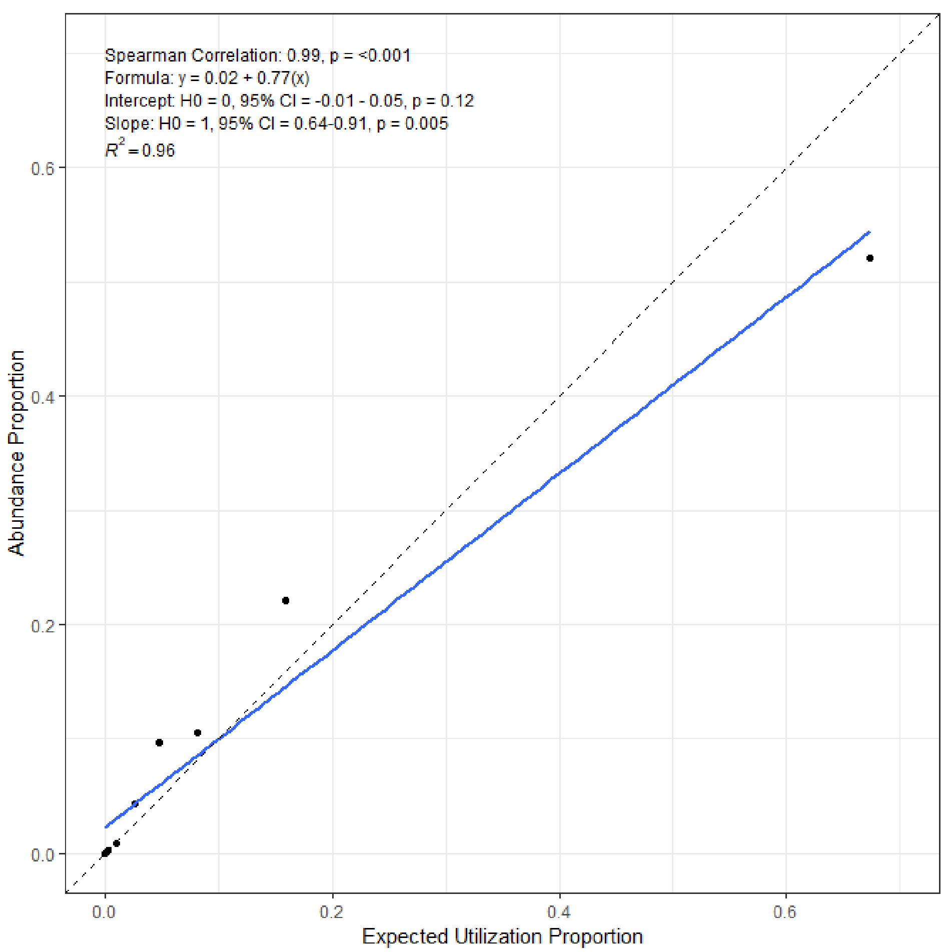


Table B9. Marginal CRP effects on population estimates of Sprague's Pipit by state in the PPJV and NGPJV areas of the Northern Great Plains. Overall CRP effects include modeled population estimates following simulated conversion of CRP fields to cropland (A) or grassland/herbaceous (B) in the landscape, and differences (absolute and percent) between estimates. Marginal CRP effects include field- specific effects and surrounding landscape effects.

(A)

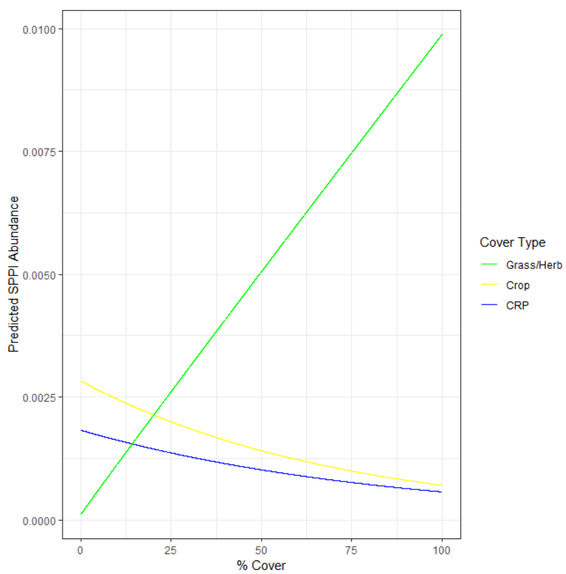
	Overall CRP Effects				Marginal CRP Effects			
State	Modeled estimate (n)	Estimate after loss of CRP (n)	Difference in estimate (n)	Difference (%)	Difference in CRP Fields (n)	Difference Outside of CRP Fields (n)	Difference in CRP Fields (%)	Difference outside CRP Fields (%)
All	177,831	177,187	-643	-0.36	-147	-496	-0.08	-0.28
MT	155,256	154,703	-553	-0.36	-131	-422	-0.08	-0.27
ND	18,577	18,493	-85	-0.45	-15	-69	-0.08	-0.37
SD	3,997	3,991	-6	-0.14	-1	-5	-0.02	-0.12

(B)

	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	177,831	193,276	15,445	8.69	5,114	10,331	2.88	5.81
MT	155,256	168,777	13,521	8.71	4,670	8,851	3.01	5.70
ND	18,577	20,406	1,828	9.84	427	1,401	2.30	7.54
SD	3,997	4,093	96	2.39	16	79	0.41	1.98

Figure B25. Marginal effects of CRP, grassland/herbaceous, and crop within a 1600 m landscape scale on Sprague's Pipit probability of occurrence within a 12.6 ha area (based on detection distance of 200 m). Marginal effects of cover were estimated using model predictions when cover was increased from zero to 100 percent and all other covariates were held at their overall mean (A); marginal effects of CRP using methods stated above but holding all other covariates at their respective state means (B).

(A)



(B)

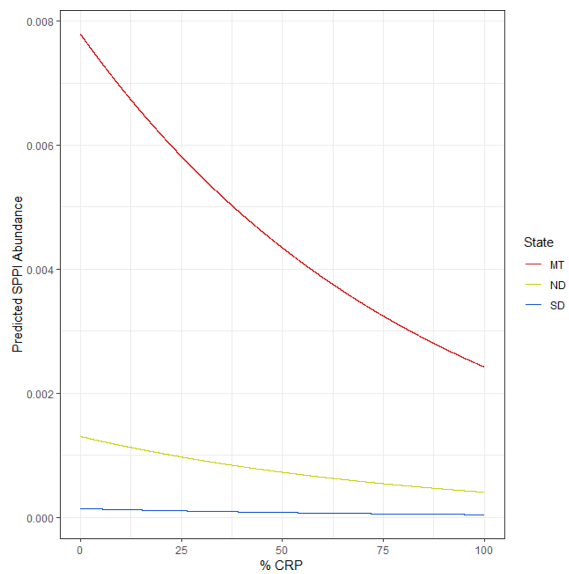
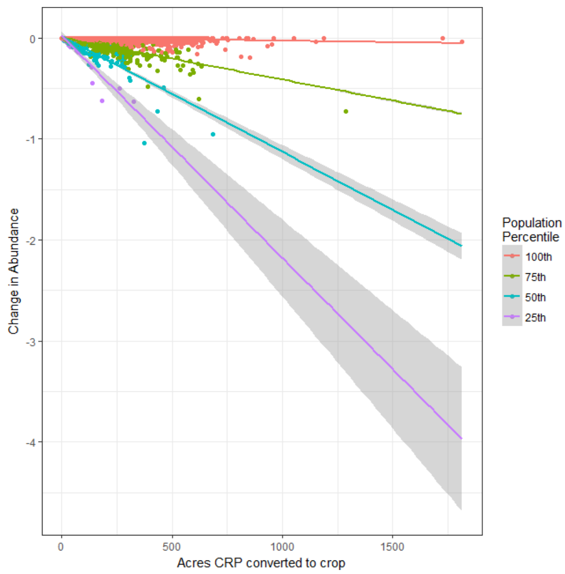


Figure B26. Change in Sprague's Pipit abundance within CRP fields converted to crop (A) and grassland/herbaceous (B) vs. acres of CRP field converted to crop or grassland/herbaceous within the PPJV and NGPJV. CRP fields are factored by the population percentile they are located in and regression lines are fitted for each population percentile.

(A)



(B)

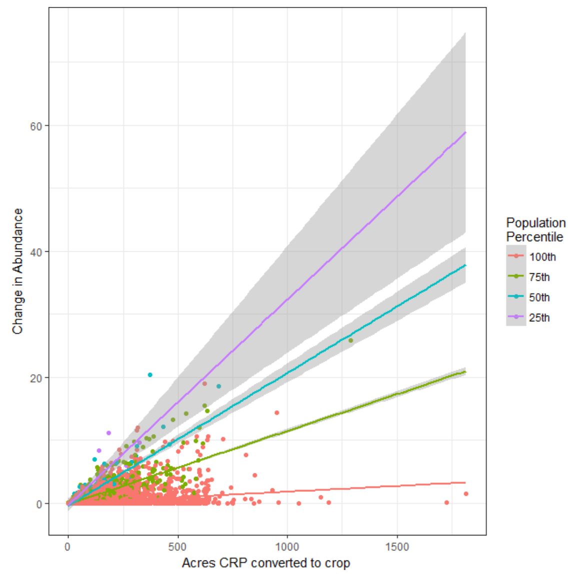
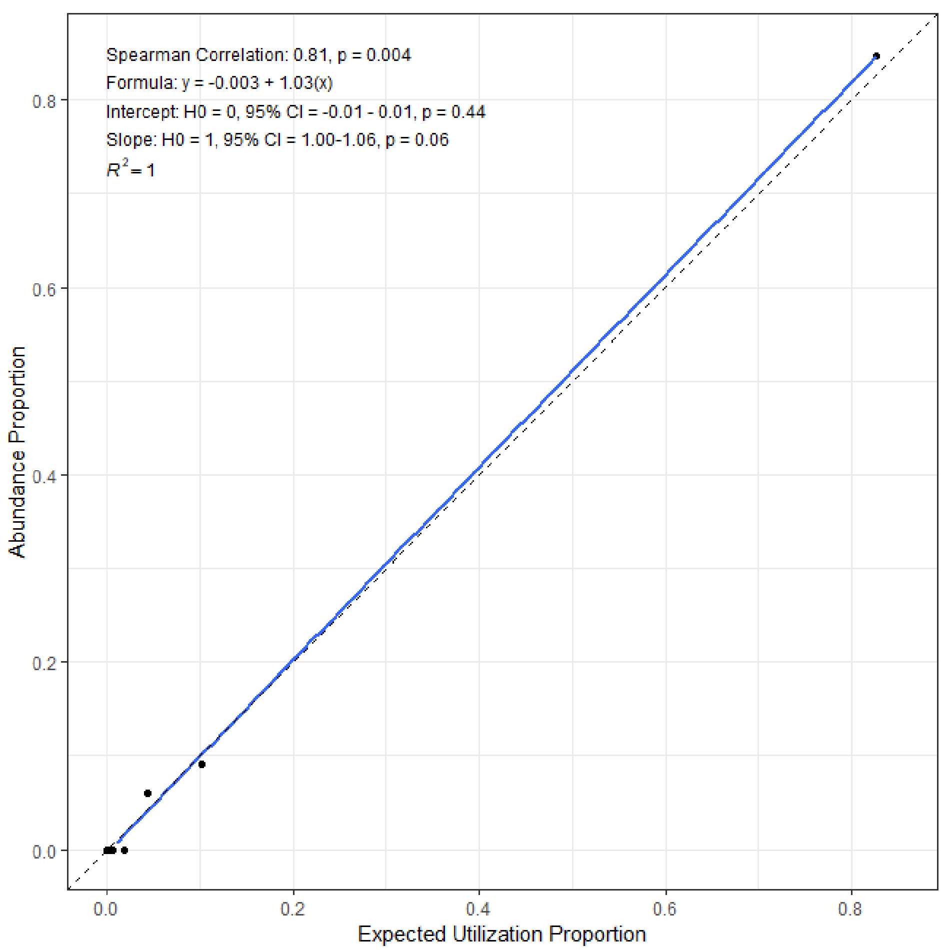


Figure B27. Model validation results using test data, which included 2017 BBS data and data from 20 new BBS-like routes collected throughout the study area in new locations in 2018. Validation results follow methods from Johnson et al. 2006, where density and distribution models are segmented in 10 approximately equal-area-slice bins and the proportion of observed Sprague's Pipit are compared to the expected utilization proportion for each bin. Validation metrics include Spearman's rank correlation (R^2 and p-value), y-intercept (estimate, 95% CI and p-value), slope (estimate, 95% CI and p-value), and R^2 values. The blue line is the regression line and the dotted line is a perfect fit with a slope of 1 and a y-intercept of 0. A perfect model will have a Spearman's rank correlation, slope, and R^2 of 1, and y-intercept of zero.



APPENDIX C. 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 nine 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 finer 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.

- **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. Bird communities and conservation treatments will vary greatly from western Montana to central Iowa. 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 that restored herbaceous cover will remain on the landscape after CRP contracts expire, 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, Drum et al. 2015). 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

Literature Cited

Bakker, K. K., D. E. Naugle, and K. F. Higgins. 2002. Incorporating landscape attributes into models for migratory grassland bird conservation. Conservation Biology 16:1638-1646.

Davis, S. K. 2004. Area sensitivity in grassland passerines: effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. The Auk 121:1130-1145.

Drum, R. G., Loesch, C. R., Carrlson, K. M., Doherty, K. E., & Fedy, B. C. 2015. Assessing the biological benefits of the USDA-Conservation Reserve Program (CRP) for waterfowl and grassland passerines in the Prairie Pothole Region of the United States: Spatial analyses for targeting CRP to maximize benefits for migratory birds. Final Report for USDA–FSA Agreement.

Greer, M. J., K. K. Bakker, and C. D. Dieter. 2016. Grassland bird response to recent loss and degradation of native prairie in central and western South Dakota. The Wilson Journal of Ornithology 128:278-289.

Herkert, J. R.1994. The effects of habitat fragmentation on midwestern grassland bird communities. Ecological applications, 4(3), 461-471.

Johnson, D. H. 2005. Grassland bird use of Conservation Reserve Program fields in the Great Plains. Pages 17-32 in Fish and wildlife Benefits of Farm Bill conservation programs: 2000-2005 update, J. B. Haufler, editor. The Wildlife Society Technical Review 05-2.

Johnson, D. H., and L. D. Igl. 1995. Contributions of the Conservation Reserve Program to populations of breeding birds in North Dakota. Wilson Bulletin 107:709-718.

Jones, S. L., J. S. Dieni, M. T. Green, and P. J. Gouse. 2007. Annual return rates of breeding grassland songbirds. Wilson Journal of Ornithology 119:89-94

Lipsey, M. K., and Naugle, D. E. 2017. Precipitation and soil productivity explain effects of grazing on grassland songbirds. Rangeland Ecology & Management, 70(3), 331-340.

Lipsey, M. K., Naugle, D. E., Nowak, J., & Lukacs, P. M. 2017. Extending utility of hierarchical models to multi-scale habitat selection. Diversity and Distributions, 23(7), 783-793.

Madden, E. M., R. K. Murphy, A. J. Hansen, and L. Murray. 2000. Models for guiding management of prairie bird habitat in northwestern North Dakota. American Midland Naturalist 144:377-392.

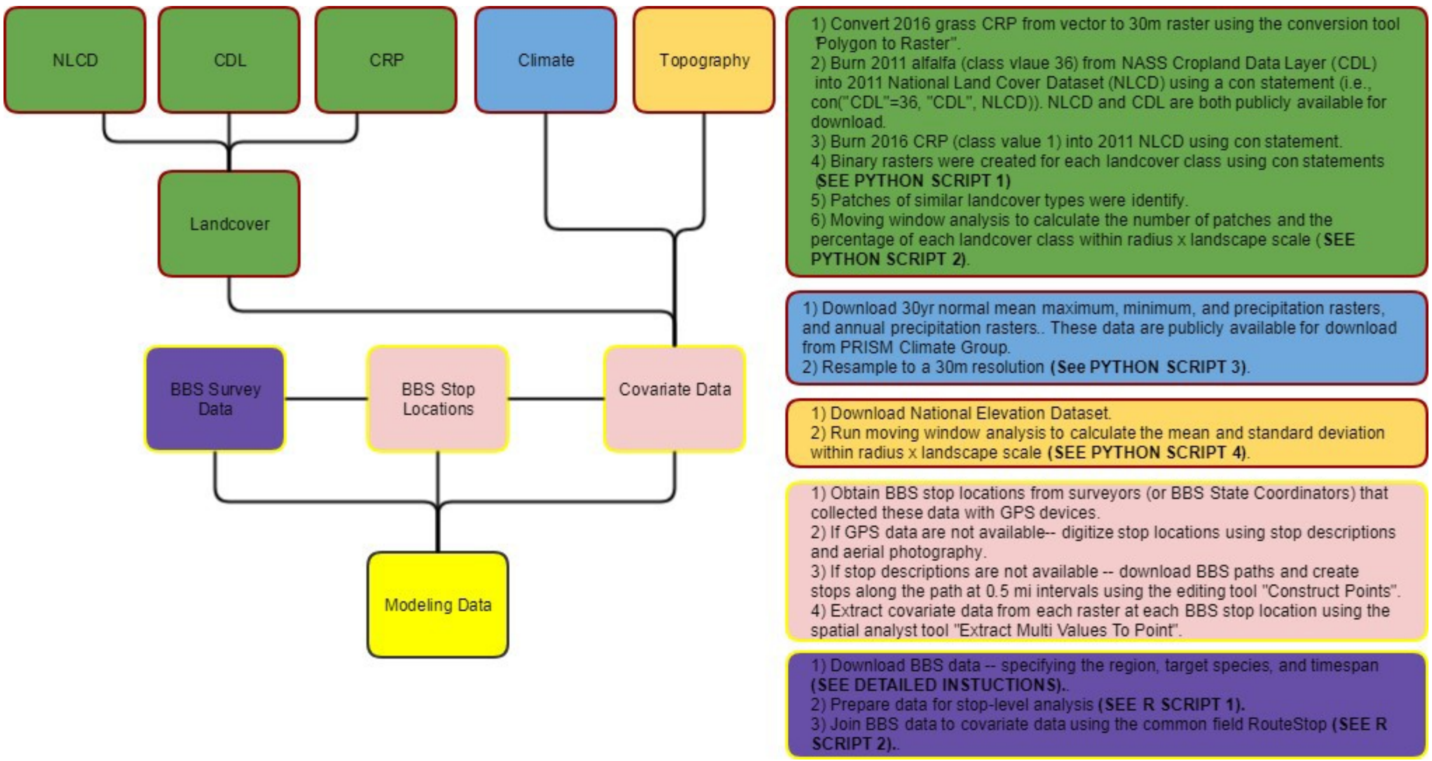
O’Connor, R. J., M. T. Jones, R. B. Boone, and T. B. Lauber. 1999. Linking continental climate, land use, and land patterns with grassland bird distribution across the conterminous United States. Studies in Avian Biology 19:45-59.

Ribic, C. A., R. R. Koford, J. R. Herkert, D. H. Johnson, N. D. Niemuth, D. E. Naugle, K. K. Bakker, D. W. Sample, and R. B. Renfrew. 2006.Area sensitivity in North American grassland birds: patterns and process. The Auk 126:233-244.

Winter, M., and J. Faaborg. 1999. Patterns of area sensitivity in grassland-nesting birds. Conservation Biology 13:1424-1436.

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
#separated 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

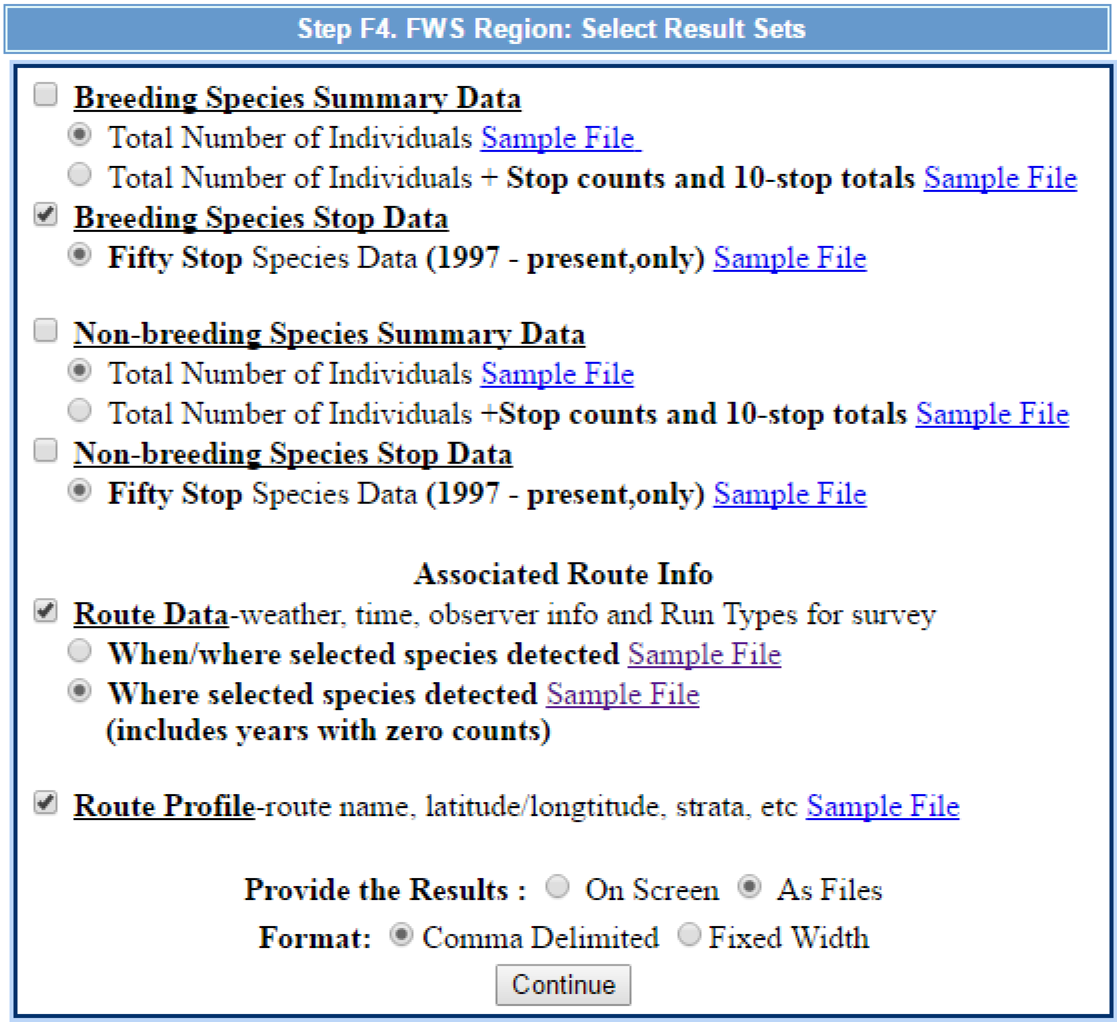
```
#This script was created by Kevin Barnes (USFWS/PPJV/HAPET, kevin_barnes@fws.gov) to automate
#the processing of DEM data for the CRP grassland bird modeling project. In this script DEM data are
#processed using a moving window analysis to calculate the mean elevation and the standard deviation
#(topographic 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
Breeding Species Stop Data
Fifty Stop Species Data (1997 - present,only) Sample File

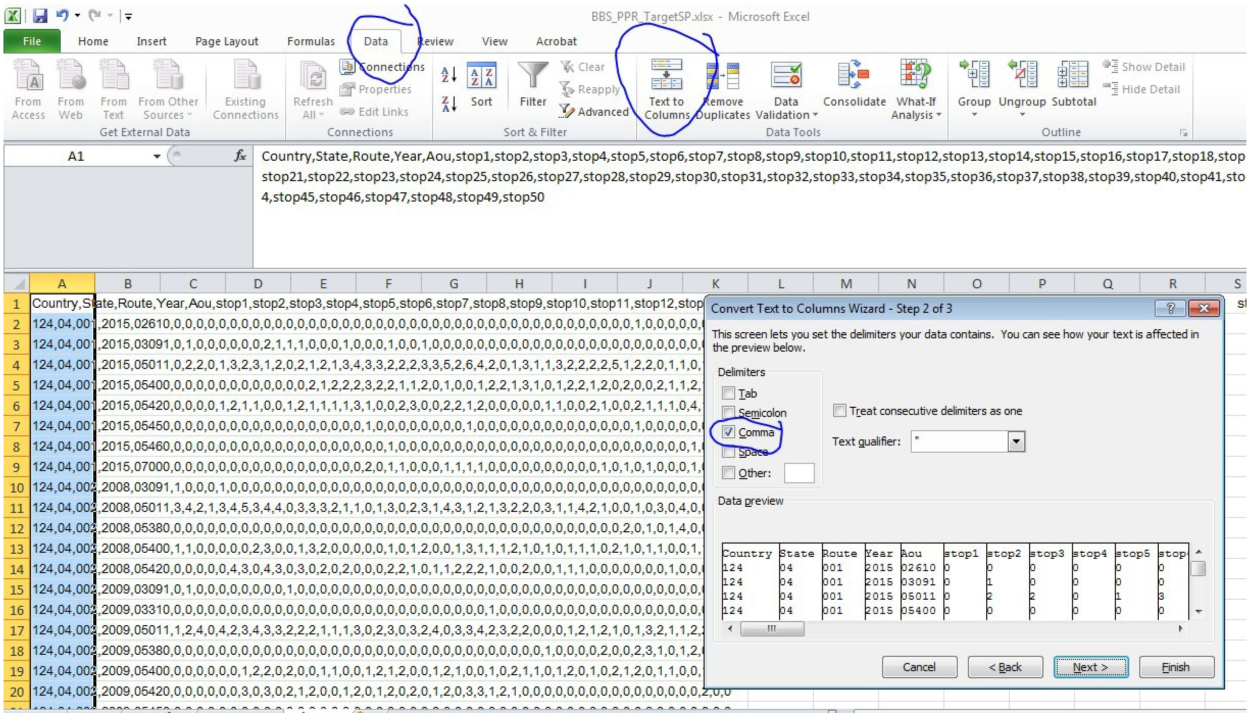
Non-breeding Species Summary Data
Total Number of Individuals Sample File
Total Number of Individuals +Stop counts and 10-stop totals Sample File
Non-breeding Species Stop Data
Fifty Stop Species Data (1997 - present,only) Sample File

Associated Route Info
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)

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")
```