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Predicted avian responses to bioenergy development scenarios in an intensive agricultural landscape

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Abstract

Conversion of native prairie to agriculture has increased food and bioenergy production but decreased wildlife habitat. However, enrollment of highly erodible cropland in conservation programs has compensated for some grassland loss. In the future, climate change and production of second-generation perennial biofuel crops could further transform agricultural landscapes and increase or decrease grassland area. Switchgrass (*Panicum virgatum*) is an alternative biofuel feedstock that may be economically and environmentally superior to maize (*Zea mays*) grain for ethanol production on marginally productive lands. Switchgrass could benefit farmers economically and increase grassland area, but there is uncertainty as to how conversions between rowcrops, switchgrass monocultures and conservation grasslands might occur and affect wildlife. To explore potential impacts on grassland birds, we developed four agricultural land-use change scenarios for an intensively cultivated landscape, each driven by potential future climatic changes and ensuing irrigation limitations, ethanol demand, commodity prices, and continuation of a conservation program. For each scenario, we calculated changes in area for landcover classes and predicted changes in grassland bird abundances. Overall, birds responded positively to the replacement of rowcrops with switchgrass and negatively to the conversion of conservation grasslands to switchgrass or rowcrops. Landscape context and interactions between climate, crop water use, and irrigation availability could influence future land-use, and subsequently, avian habitat quality and quantity. Switchgrass is likely to provide higher quality avian habitat than rowcrops but lower quality habitat than conservation grasslands, and therefore, may most benefit birds in heavily cultivated, irrigation dependent landscapes under warmer and drier conditions, where economic profitability may also encourage conversions to drought tolerant bioenergy feedstocks.

Keywords: cellulosic ethanol, climate, conservation reserve program, geographic information systems, grassland birds, rowcrops, scenario planning, switchgrass

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Introduction

Since 19th Century European settlement, agriculture has replaced native grassland throughout the North American Great Plains (Weaver, 1968; Samson *et al*., 2004), increasing food production but decreasing wildlife habitat. A large proportion of the Great Plains is either farmed or grazed (Forrest *et al*., 2004), and remaining grasslands are fragmented (White *et al*., 2000; Grant *et al*., 2004). As global food and bioenergy demands rise, additional land-use conversions occur (Tilman *et al*., 2002; Fargione *et al*., 2008). In addition to prairie remnants, North American grasslands include rangelands, grassland buffers along water bodies, and Conservation Reserve Program (CRP) grasslands (Delisle & Savidge, 1997; Utrup & Davis, 2007). The CRP provides landowners with monetary incentives for removing highly erodible croplands from production and seeding them with conservation plantings, which in addition to reducing soil erosion, benefit water resources and wildlife [Ribaudo, 1989; Dunn *et al*., 1993; United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS), 2012].

Grassland birds have been negatively impacted by reductions and fragmentations of native grasslands

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during the past several centuries (Samson & Knopf, 1994; White *et al.*, 2000; Grant *et al.*, 2004), experiencing steep and widespread population declines (Sauer *et al.*, 2011). Remnant and restored grasslands provide grassland birds with crucial feeding and breeding habitat (Johnson & Igl, 1995; Rahmig *et al.*, 2009; Ramirez-Yanez *et al.*, 2011), and effective grassland conservation, restoration and management are paramount to reversing declines in avian populations. Heterogeneous landscape-level grassland management regimes contribute to the conservation of various avian species with different habitat requirements (Powell & Busby, 2013), and even small prairie fragments can contribute to grassland bird habitat conservation (Walk *et al.*, 2010).

Recent demands for clean, renewable energy have resulted in widespread efforts to utilize maize (*Zea mays*) grain for ethanol production. Despite extensive development of the starch-based ethanol industry, ethanol production from maize grain remains controversial, due to uncertainties over its net energy production (Tilman *et al.*, 2009), water use efficiency (Berndes, 2008), ability to reduce atmospheric greenhouse gas emissions and concentrations (Searchinger *et al.*, 2008), and competition with food production for land-use (Dale *et al.*, 2010). These have led to an increasing promotion of the benefits of second-generation biofuels (Tilman *et al.*, 2009).

One alternative bioenergy feedstock promoted for large-scale cellulosic ethanol production in the Great Plains is switchgrass (*Panicum virgatum*) (Mitchell *et al.*, 2012). Switchgrass is a perennial, C4 grass species, native to the Great Plains (Vogel, 2004) and endorsed as a bioenergy feedstock because of its potential economic (Kiniry *et al.*, 2008; Sarath *et al.*, 2008; Schmer *et al.*, 2008) and environmental (McLaughlin *et al.*, 2002; McLaughlin & Kszos, 2005; Adler *et al.*, 2007) benefits. Simple sugars from switchgrass cell walls can be fermented to produce cellulosic ethanol (Dein *et al.*, 2006), and the species thrives in rain-fed systems east of the 100th Meridian (Vogel, 2004) where non-irrigated (dryland) farming can be conducted in most years (Mitchell *et al.*, 2010). Switchgrass is typically harvested once yearly through traditional haying methods in the late summer, autumn, or winter, after grassland birds have nested (Mitchell *et al.*, 2010). Grassland birds are capable of achieving high reproductive success in prairies hayed late in the growing season (Rahmig *et al.*, 2009).

Rowcrop fields are intensively managed, low diversity plant communities that typically support very low avian densities (Best *et al.*, 1997). Switchgrass stands could provide grassland birds with habitat that annual rowcrops do not, but this is still largely uncertain. Most studies addressing the impacts of switchgrass monocultures on wildlife are conducted in CRP switchgrass plantings, which are managed less intensively and are generally more structurally and florally diverse than bioenergy switchgrass stands (McCoy *et al.*, 2001; Gardiner *et al.*, 2010). Diverse grasslands provide high quality habitat for multiple grassland bird species, whereas more homogeneous grasslands may benefit only select species (Robertson *et al.*, 2010).

The willingness of farmers to convert lands to switchgrass production or enroll them in conservation programs could increase or decrease with changes in growing conditions, irrigation availability, and commodity prices; thereby affecting grassland bird communities. The effects of climate change are largely uncertain, but substantial changes are expected to occur [Intergovernmental Panel on Climate Change (IPCC), 2007], as are agricultural policy adjustments (Olesen & Bindi, 2002). Scenario planning is useful for addressing key uncertainties through the exploration of plausible, alternative futures (Peterson *et al.*, 2003), and is especially appropriate when high levels of uncertainty accompany uncontrollable future events (Williams *et al.*, 2009). We questioned how biofuel-based land-use change, as influenced by climate, agricultural policies, commodity prices, and continuation of conservation programs, might impact grassland bird populations in intensively cultivated agricultural landscapes. To explore potential consequences, four agricultural land-use change scenarios were proposed for the rowcrop dominated Rainwater Basin region of south-central Nebraska, USA, under which changes in abundance for a suite of grassland bird species were predicted.

Materials and methods

Study area

This study was conducted for the Rainwater Basin, a region that covers 15 800 km^2 in all, or portions of, 21 south-central Nebraska counties (LaGrange, 2005; Fig. 1). In this intensively farmed landscape, maize and soybean (*Glycine max*) production dominate land-use, and water for irrigation is obtained from surface and groundwater sources (Dunnigan *et al.*, 2011).

Ethanol plant service areas

Agricultural fields in close proximity to existing starch-based ethanol plants could be suitable for growing alternative bioenergy feedstocks because of the availability of infrastructure that could be modified for cellulosic ethanol production (Mitchell *et al.*, 2012). Therefore, geographic coordinates of 10 starch-based ethanol plants currently servicing the Rainwater Basin were collected from Google Earth (Google Inc, 2011) satellite imagery and digitized in a geographic information system (GIS) [Environmental Systems Research Institute (ESRI), 2011]. Forty kilometers (km) is recognized as the approximate

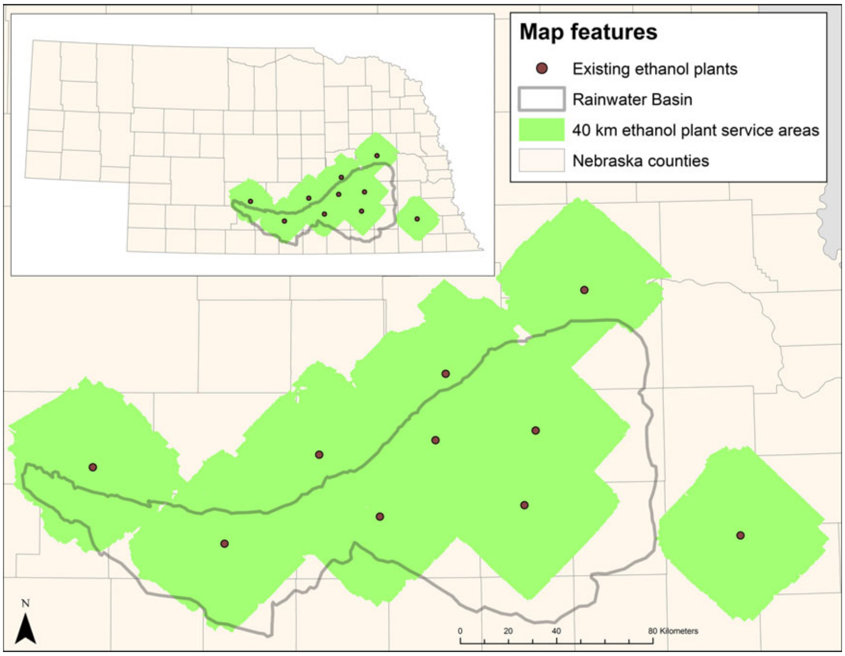

Fig. 1 Location of the Rainwater Basin in south-central Nebraska, USA, displaying starch-based ethanol plants and 40 kilometer ethanol plant road network service areas. This figure was created in ArcGIS [Environmental Systems Research Institute (ESRI), 2011].

maximum distance producers may be willing to transport feedstocks to biorefineries for processing (Khanna *et al.*, 2008), so we generated a 40 km network service area for each plant, using Nebraska roads as travel corridors (Fig. 1), and restricted land-cover to the combined service areas.

Landcover classes

Together, different rowcrops and grassland types account for the majority of landcover within the study area, and maize and soybeans account for the strong majority of rowcrops grown (Bishop & Vrtiska, 2008); therefore, we did not distinguish between crop types, but did differentiate between irrigation types. Spatially explicit irrigation type rowcrop field data [Rainwater Basin Joint Venture (RWBJV), 2006] was grouped into four irrigation types: center-pivot irrigated, pivot corners, gravity irrigated and dryland fields. Crops on center-pivot and gravity irrigated fields are provided water throughout the growing season, but dryland fields are not. Pivot corners are the non-irrigated, peripheral portions of center-pivot irrigated fields that result from the circular motion of center-pivots in square-shaped fields. In years with adequate growing season precipitation, dryland field and pivot corner grain yields are comparable with irrigated fields; however, they tend to yield less in drier years.

Grasslands consist of CRP enrolled grasslands, non-CRP grasslands, and wet meadows (RWBJV, 2010). CRP grasslands are highly erodible croplands that have been removed from production and seeded with various conservation plantings, the most common of which are nonnative grass and legume [Conservation Planting 1 (CP1)] or native tallgrass [Conservation Planting 2 (CP2)] plantings (King & Savidge, 1995; Delisle & Savidge, 1997; USDA NRCS, 2012). We did not differentiate between CRP plantings, because many additional conservation plantings that cannot be easily classified as CP1 or CP2 were present in the study area. Non-CRP grassland includes remnant grasslands, pastures, restored grasslands, grass buffers surrounding restored wetland sites, and linings of road ditches and canals (Utrup & Davis, 2007; Ramirez-Yanez *et al.*, 2011). Wet meadows are commonly flooded and hayed riparian grasslands dominated by sedges (*Carex* spp.), rushes (*Juncus* spp.), and other native mixedgrass prairie plants (Currier, 1989).

Identifying rowcrop fields suitable for conversion

Switchgrass is most likely to replace rowcrops on marginally productive lands (Varvel *et al.*, 2008), which can include small, complexly shaped, non-irrigated portions of agricultural fields located on unproductive soils, in addition to remnant and restored grasslands (Mitchell *et al.*, 2012). Five marginal characteristics making rowcrop fields better suited to raising switchgrass over maize and soybeans in the Great Plains are (i) lack of irrigation infrastructure; (ii) reduced soil productivity; (iii) small size/complex shape; (iv) reduced mean annual precipitation; and (v) regional implementation of irrigation limitations (Uden *et al.*, 2013). From combinations of these characteristics, 24 marginality classes were developed for grouping rowcrop fields, according to the number of marginal characteristics they possessed.

Non-irrigated fields were considered more marginal than irrigated rowcrop fields, and therefore more suitable for conversion, due to the increased drought tolerance of switchgrass over rowcrops (Kiniry *et al.*, 2008; Uden *et al.*, 2013).

Agricultural soil suitability was determined according to USDA NRCS land capability classes. Soils in classes 1 and 2 are considered most suitable for agriculture, while soils in classes 7 and 8 are completely unsuitable (USDA NRCS, 2011a,b). Soils in classes 3–6 can be described as marginally productive and may be better suited to less intensive forms of land-use, like seeding with perennial grasses. Switchgrass remains productive on marginally productive soils, with ethanol yields comparable to or greater than that of combined maize grain and stover on similar soils (Varvel *et al*., 2008). Rowcrop fields with center points located on soils in NRCS land capability classes 3–6 were considered more suitable for conversion than fields with soils in classes 1 or 2.

Small and complexly shaped rowcrop fields were identified using field areas and shape indices, with greater shape indices indicating more complexly shaped fields. This shape index was calculated in Fragstats (McGarigal *et al*., 2002) by dividing field perimeter by the perimeter of the most compact form of a field of equal size. Raising rowcrops on small, complexly shaped fields with increasingly large, modern farm equipment can be inconvenient and time consuming, and these fields could be better suited to raising less management intensive crops. All rowcrop pivot corners, dryland fields with areas less than the mean pivot corner area [3.7 hectares (ha)], and dryland fields with areas greater than 3.7 ha but less than the 25th percentile value for dryland field area (4.7 ha) and with a shape index greater than the 75th percentile value for dryland field shape index (1.56), were considered suitable for conversion to switchgrass.

The rain shadow effect of the Rocky Mountains causes precipitation to increase from west to east across the Rainwater Basin, with drier areas located in the western half (Ricketts *et al*., 1999; USDA NRCS, 2011c). Rowcrop fields in areas with a mean annual precipitation of at least 63.5 cm were considered more marginal and suitable for conversion to switchgrass than fields in areas with a mean annual precipitation greater than 63.5 cm, because rowcrop productivity tends to decrease under drier conditions (Kiniry *et al*., 2008).

In Nebraska, surface and groundwater withdrawal limitations are established by Natural Resource District(s) (NRD), according to the appropriation status of water resources (Dunnigan *et al*., 2011). In the event that water resources are determined to be fully or over-appropriated, the affected NRDs are required to develop integrated management plans for reducing water use, which can include withdrawal reduction incentives for farmers [Nebraska Department of Natural Resources (NE DNR), 2007]. Seven NRDs currently service the Rainwater Basin, and water resources in portions of three of them have previously been classified as fully appropriated (Dunnigan *et al*., 2011). If climatic changes increase crop water use and irrigation withdrawals but decrease groundwater recharge, NRDs previously determined to be fully appropriated may impose greater limitations than those where water resources have not been fully appropriated. Under a scenario of warmer and drier climatic conditions, irrigated rowcrop fields in the three NRDs with histories of imposing irrigation limitations were classified as being at higher risk for additional limitations and more suitable for conversion to switchgrass than fields in the other four NRDs.

Rowcrop fields classified as least productive for rowcrops and most suitable for conversion to switchgrass under present climatic conditions and irrigation policies were non-irrigated, complexly shaped dryland fields located on soils in NRCS land capability classes 3–6 and in areas with a mean annual precipitation less than or equal to 63.5 cm. Fields classified as least suitable were irrigated fields located on soils in NRCS land capability classes 1 or 2. Remaining fields were placed into intermediate marginality classes according to the number of marginal criteria they satisfied (Table 1).

We used these rowcrop field marginality classifications to identify individual fields most suitable for conversion to switchgrass under alternative land-use change scenarios. Predetermined percentages of rowcrop fields composing marginality classes were randomly converted to switchgrass, with greater conversion percentages assigned to classes with more marginal characteristics. We used the random assignment of percentages of fields to switchgrass to simulate the effects of marginal characteristics on land-use decisions at the landscape scale of observation, recognizing that land-use decisions can be driven by various factors. Under a scenario that assumed climatic changes and additional irrigation limitations, higher conversion percentages were assigned to most marginality classes, as a result of increased crop water use and decreased irrigation availability.

Land-use change scenarios

We developed four scenarios for considering the potential impacts of future changes on grassland bird populations. These scenarios encompass a range of possible futures for agricultural lands, with major drivers of change being climate, irrigation limitations, commodity prices, ethanol demand, and continuation of the CRP. Interactions between these and other drivers could influence future land-use alterations. These scenarios do not directly correspond to the Special Report on Emissions Scenarios put forth by the IPCC (2007) or downscaled regional climate change projections, but instead consider relative levels of change and their possible interactions with other driving factors of LULCC.

Scenario 1: Limited Rowcrops to Switchgrass. The 'Limited Rowcrops to Switchgrass Scenario' assumed status quo climatic conditions without additional irrigation limitations and an increased cellulosic ethanol demand. This scenario establishes a baseline for the adoption of switchgrass as a bioenergy crop under current conditions.

Scenario 2: Modest Rowcrops to Switchgrass. Under the 'Modest Rowcrops to Switchgrass Scenario', warmer and drier climatic conditions are projected for the Great Plains in the mid-21st Century (IPCC, 2007). As a result, additional irrigation limitations in 'high risk' NRDs and greater cellulosic ethanol demand than under Scenario 1 were assumed (Table 1).

Scenario 3: CRP to Switchgrass. Under the 'CRP to Switchgrass Scenario', increased cellulosic ethanol demand, high grain

Table 1 Percentages of rowcrop field marginality classes assigned to switchgrass conversion under Scenarios 1 and 2. Greater percentages were assigned to classes possessing more marginal characteristics, and assumed climatic changes and irrigation limitations increased percentages under Scenario 2. Lack of irrigation infrastructure, small field size and complex shape, low agricultural soil suitability, decreased precipitation, and high risk of additional irrigation limitations were considered marginal characteristics

Marginality class	Scenario 1%	Scenario 2%
Pivot corners + poor soils + drier	100	100
Pivot corners + poor soils + wetter	75	100
Pivot corners + good soils + drier	75	100
Pivot corners + good soils + wetter	50	75
Small dryland + poor soils + drier	100	100
Small dryland + poor soils + wetter	75	100
Small dryland + good soils + drier	75	100
Small dryland + good soils + wetter	50	75
Large dryland + poor soils + drier	25	50
Large dryland + poor soils + wetter	0	25
Large dryland + good soils + drier	0	25
Large dryland + good soils + wetter	0	0
Gravity + poor soils + drier + high risk irrigation	0	50
Gravity + poor soils + wetter + high risk irrigation	0	25
Gravity + good soils + drier + high risk irrigation	0	25
Gravity + good soils + wetter + high risk irrigation	0	0
Gravity + poor soils + wetter + low risk irrigation	0	0
Gravity + good soils + wetter + low risk irrigation	0	0
Pivots + poor soils + drier + high risk irrigation	0	25
Pivots + poor soils + wetter + high risk irrigation	0	0
Pivots + good soils + drier + high risk irrigation	0	0
Pivots + good soils + wetter + high risk irrigation	0	0
Pivots + poor soils + drier + low risk irrigation	0	0
Pivots + good soils + wetter + low risk irrigation	0	0

market prices and decreased CRP funding resulted in the conversion of all CRP grassland area to switchgrass. CRP grassland currently comprises ca. 0.2% of total landcover within the study area, making the sole conversion of CRP grassland to switchgrass for cellulosic ethanol production economically infeasible (Uden *et al.*, 2013). However, this scenario allows for consideration of the ecological impacts associated with converting CRP grasslands to switchgrass, without factoring in the impacts of rowcrops to switchgrass conversions.

Scenario 4: CRP to Rowcrops. Under the 'CRP to Rowcrops Scenario', all CRP grasslands were returned to rowcrop production, and presently farmed rowcrop fields remained in rowcrop production. This could occur if funding for the CRP decreases or is completely eliminated, the cellulosic ethanol industry fails to develop, and/or grain market prices remain high. Under these circumstances, farmers would have fewer incentives for enrolling marginally productive croplands in alternative biofuel feedstocks or conservation plantings.

Predicting avian abundances

A customized version of the Hierarchical All Birds Strategy (HABS) model [Playa Lakes Joint Venture (PLJV), 2007] was used to predict current abundances for a suite of grassland bird species, in addition to changes in abundance under each scenario. Existing scientific literature was used to populate the following landcover classes with breeding season bird density estimates: switchgrass, rowcrops, CRP grasslands, non-CRP grasslands, and wet meadows (Table 2). When available, density estimates were obtained from studies conducted in or near the study area, and estimates from other regions were used to fill information gaps. Because no bird density estimates in bioenergy switchgrass were available for the study area, density estimates were acquired from Murray & Best (2003), who conducted avian surveys in bioenergy switchgrass stands in southern Iowa, USA, approximately 300 km from the eastern edge of the Rainwater Basin.

Total abundance and percent change in abundance was calculated for the following species under the four land-use change scenarios: bobolink (*Dolichonyx oryzivorus*), dickcissel (*Spiza americana*), eastern kingbird (*Tyrannus tyrannus*), field sparrow (*Spizella pusilla*), grasshopper sparrow (*Ammodramus savannarum*), meadowlark (*Sturnella* spp.), ring-necked pheasant (*Phasianus colchicus*), sedge wren (*Cistothorus plantensis*), and upland sandpiper (*Bartramia longicauda*). No distinction was made between western (*S. neglecta*) and eastern meadowlarks (*S. magna*). Although many sedge wren range maps specify eastern Nebraska as the western edge of their range, they have been documented in and around the Rainwater Basin (Delisle & Savidge, 1997; Utrup & Davis, 2007; Kim *et al.*, 2008; Jorgensen, 2012), potentially due to the high density of wetlands and wet meadows in the area.

Abundances were calculated by multiplying individual species density estimates for each landcover class by the total number of ha in the class and summing abundances across classes. Lower and upper abundance estimates were calculated by multiplying mean bird densities for each landcover class with the standard errors of density estimates from Murray & Best (2003). This approach for modeling grassland bird abundances is simple and does not incorporate species minimum area requirements, sensitivities to edges and fragmentation, or various local and landscape factors known to influence grassland bird habitat utilization (Ribic *et al.*, 2009; Robertson *et al.*, 2010). Nevertheless, we believe that it is a useful and appropriate approach for considering grassland bird community responses to bioenergy development under alternative, plausible futures. Even if edge effects and other factors were to

Table 2 Grassland bird densities for bioenergy switchgrass, rowcrops, Conservation Reserve Program (CRP) grassland, non-CRP grassland and wet meadows input into the Hierarchical All Birds Strategy (HABS) model to predict grassland bird abundances. All rowcrop types were aggregated, but consisted primarily of maize and soybean fields, both of which support relatively low avian densities

	Landcover class				
Species	Switchgrass	Rowcrops	CRP grassland	Non-CRP grassland	Wet meadow
Bobolink	0.0240†	0.0245‡	0.1295¶	0.0541**	1.0645‡‡
Dickcissel	0.0751†	0.0079§	1.6741¶	0.0640**	0.4302‡‡
Eastern Kingbird	0.0200†	0.0079§	0.0146‖	0.0299**	0.0739**
*Field sparrow	0.0089†	0.0020§	0.0054‖	0.0200**	0.0000**
Grasshopper sparrow	0.3509†	0.0040§	0.5211¶	0.3600**	0.1843‡‡
Meadowlark	0.0499†	0.0040§	0.0694¶	0.3800**	0.2219‡‡
Ring-necked pheasant	0.0309†	0.0059§	0.0591¶	0.0040**	0.0000‡‡
Sedge wren	0.0739†	0.0000‡	0.1376¶	0.0334††	0.0418‡‡
Upland sandpiper	0.0069†	0.0040§	0.0030‖	0.0400**	0.2511‡‡

*There are no confirmed records of field sparrows breeding in the Rainwater Basin (Jorgensen, 2012). However, it does migrate through the Rainwater Basin, and was described by Faanes & Lingle (1995) as ‘a common migrant and fairly common summer resident’ in the immediately adjacent Platte River valley.
†Murray & Best (2003).
‡Johnson & Igl (1995).
§Best *et al.* (1997).
¶Delisle & Savidge (1997).
‖Delisle (1995).
**Faanes & Lingle (1995).
††Utrup & Davis, 2007.
‡‡Kim *et al.* (2008).

be incorporated, the spatial distribution of rowcrop fields, switchgrass stands, and conservation grasslands in the future Rainwater Basin landscape, an important determinant of avian utilization (Ribic *et al.*, 2009; Robertson *et al.*, 2012), is highly uncertain. Therefore, we utilized this broad scale approach to incorporate various important drivers and provide general, landscape-level conclusions.

Species were selected for inclusion in this study according to their documented presence in the Rainwater Basin during their respective breeding and/or migration seasons (Delisle, 1995; Faanes & Lingle, 1995; Best *et al.*, 1997; Delisle & Savidge, 1997; Utrup & Davis, 2007; Kim *et al.*, 2008; Jorgensen, 2012), as well as according to the availability of density estimates for them in major landcover classes, including bioenergy switchgrass (Murray & Best, 2003). The nine species we modeled meet these criteria, and also span three Orders and seven Families of birds. Because of their differential grassland habitat structure requirements and local abundances, we expect these species to serve as useful initial indicators of the potential effects of alternative forms and intensities of biofuel-based land-use change in the Rainwater Basin and surrounding Great Plains.

Results

Within the study area, rowcrops dominated land-use, occupying 1 010 180 ha, or ca. 74% of the study area (1 357 850 ha), while non-CRP grassland covered 188 930 ha (ca. 14%); wet meadows 13 718 ha (ca. 1%); and CRP grassland 2583 ha (ca. 0.2%). Grasshopper sparrows, bobolinks and dickcissels were predicted to be the most abundant species in the current landscape, and field sparrows, ring-necked pheasants and sedge wrens were predicted as least abundant (Fig. 2).

Under the ‘Limited Rowcrops to Switchgrass Scenario’ (Scenario 1), there were 53 672 marginally productive rowcrop ha converted to switchgrass, reducing rowcrop area to 956 509 ha, but allowing CRP grassland, non-CRP grassland and wet meadow areas to remain constant. The conversion of rowcrops to switchgrass positively impacted a variety of grassland birds, most notably sedge wrens, which exhibited a ca. 34–55% increase in abundance (Table 3). All other species besides bobolink increased, but less than sedge wrens.

In the ‘Modest Rowcrops to Switchgrass Scenario’ (Scenario 2), there were 121 141 marginally productive rowcrop ha converted to switchgrass, while 889 039 ha remained in rowcrop production, and CRP grassland, non-CRP grassland and wet meadow areas stayed constant. Avian responses were identical in direction, but greater in magnitude than those observed under Scenario 1, due to the 67 470 additional rowcrop ha converted to switchgrass. Sedge wrens showed the greatest percent increase in abundance (ca. 78–124%), with other species, excluding bobolinks, increasing to lesser degrees (Table 3).

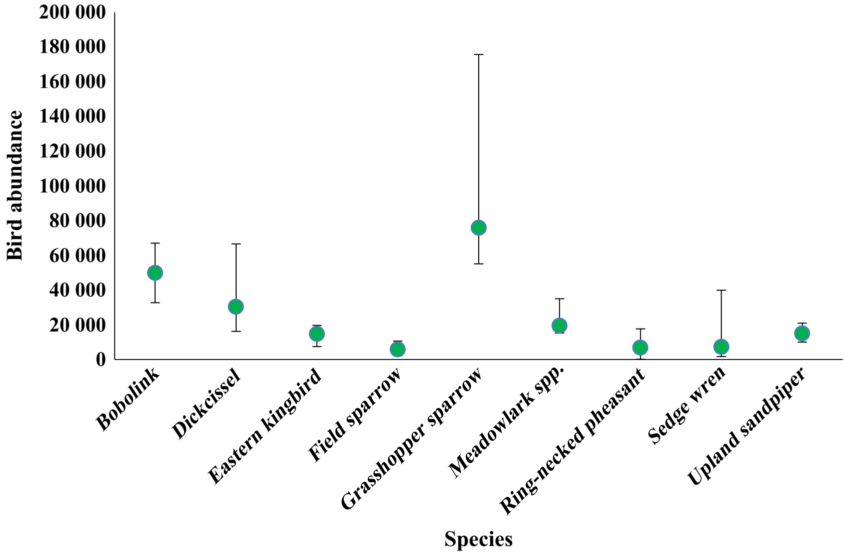

Fig. 2 Current predicted grassland bird abundances within 40 kilometer of existing starch-based ethanol plants. For abundance estimates, dots represent mean estimates and vertical bars represent confidence intervals. This figure was created in Microsoft Excel (Microsoft, 2010).

Table 3 Predicted lower and upper 95% confidence interval bounds for percent changes in grassland bird abundances under: Scenario 1 (limited rowcrops to switchgrass), which assumes the conversion of 53 672 rowcrop hectares (ha) to switchgrass; Scenario 2 (modest rowcrops to switchgrass), which assumes the conversion of 121 141 rowcrop ha to switchgrass; Scenario 3 [Conservation Reserve Program (CRP) to switchgrass], which assumes the conversion of all 2583 CRP grassland ha to switchgrass; and Scenario 4 (CRP to rowcrops), which assumes the return of all 2853 CRP grassland ha to rowcrops

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Species	pc low*	pc high†	pc low	pc high	pc low	pc high	pc low	pc high
Bobolink	−0.05	−0.05	−0.12	−0.12	−0.55	−0.55	−0.54	−0.54
Dickcissel	8.01	11.90	18.08	26.87	−13.63	−13.63	−14.01	−14.20
Eastern kingbird	4.42	4.42	9.99	9.99	0.10	0.10	−0.12	−0.12
Field sparrow	4.58	6.41	10.34	14.47	0.15	0.15	−0.07	−0.15
Grasshopper sparrow	19.01	24.54	42.92	55.38	−0.58	−0.58	−1.49	−1.76
Meadowlark spp.	9.61	12.67	21.68	28.60	−0.26	−0.26	−0.72	−0.87
Ring-necked pheasant	17.13	19.44	38.67	43.88	−1.06	−1.06	−1.88	−1.99
Sedge wren	34.85	54.84	78.66	123.78	−2.28	−2.28	−3.95	−4.92
Upland sandpiper	0.71	1.0	1.60	2.39	0.03	0.07	0.00	0.02

*pc low = lower 95% confidence interval bound for percent change in grassland bird abundance.
†pc high = upper 95% confidence interval bound for percent change in grassland bird abundance.

All 2583 ha of CRP grassland (ca. 0.2% of total land area) were converted to switchgrass under the 'CRP to Switchgrass Scenario' (Scenario 3). Rowcrop, non-CRP grassland, and wet meadow areas remained constant. Abundances of six of nine bird species decreased, and percent changes in abundance were less than 10% for all species except dickcissels, which displayed a ca. 14% decrease in abundance. Sedge wrens, ring-necked pheasants, grasshopper sparrows, bobolinks, and meadowlarks decreased less than dickcissels, whereas field sparrows, eastern kingbirds and upland sandpipers increased, but to even lesser degrees (Table 3).

In the 'CRP to Rowcrops Scenario' (Scenario 4), all 2583 currently enrolled CRP grassland was returned to rowcrop production, increasing total rowcrop area to 1 012 763 ha. Non-CRP grassland and wet meadow areas remained constant, and no ha were enrolled in bioenergy switchgrass. Dickcissels decreased by ca. 14%, and all other species, except upland sandpipers, decreased by less than 5% (Table 3).

Discussion

Fletcher *et al.* (2011) described ethanol production from maize grain as particularly detrimental to grassland birds when compared with less intensive land-use practices, and Robertson *et al.* (2012) noted that grassland bird species of conservation concern are most likely to benefit from switchgrass plantings that replace maize enrolled cropland. Our results from Scenarios 1 and 2 similarly suggest that the potential for bioenergy switchgrass to improve avian habitat may be greatest in intensively cultivated landscapes, where many rowcrop fields and few grasslands are available for conversion. The area of rowcrops converted to switchgrass could be greater under novel climatic conditions, due to the decreased profitability associated with raising rowcrops in warmer and drier conditions, especially in areas where water resources are already stressed. A daunting future for grassland birds entails the return of CRP grasslands to rowcrop production without the incorporation of additional grassland into landscapes via the replacement of rowcrops with switchgrass or prairie restorations. The negative responses we predicted under this form of change in Scenarios 3 and 4 could be even more extreme in landscapes with greater proportions of CRP or other higher diversity grassland available for conversion to alternative uses. The replacement of CRP grassland with switchgrass or rowcrops could offset, at least to some degree, habitat improvements associated with replacing rowcrops with switchgrass, even when CRP grassland comprises only a fraction of the landscape. Dickcissels and other species that rely on grassland forbs for nesting, perching and singing (Delisle & Savidge, 1997; Johnsgard, 2009; Rahmig *et al.*, 2009) may be especially vulnerable to decreases in CRP grassland area.

We did not explore a scenario involving the enrollment of additional rowcrop ha in the CRP, but species responses are expected to be opposite those of Scenario 3. Although more CRP grassland area would benefit grassland birds in rowcrop dominated landscapes, farmers generally engage in land-uses that secure the greatest profit, and therefore, most fields are likely to remain in rowcrop production while grain prices are high. However, increasing cellulosic ethanol demand, changing climate, and agricultural policy adjustments could increase the economic viability of commercial switchgrass production in these areas.

Grassland bird utilization of switchgrass stands will be influenced both by feedstock management practices (Murray & Best, 2003; Robertson *et al.*, 2010; Fletcher *et al.*, 2011) and the spatial extent and distribution of bioenergy feedstocks and other land-uses (Robertson *et al.*, 2012). We obtained bird density estimates in bioenergy switchgrass from Murray & Best (2003), where switchgrass harvest was conducted after a killing frost. Accordingly, our predictions under scenarios assuming the conversion of rowcrops to switchgrass showed notable percent increases in abundance for grasshopper sparrows, which prefer the short, sparse habitat (Johnsgard, 2009) afforded by winter switchgrass harvests (Murray & Best, 2003; Murray *et al.*, 2003). However, because the patch size of switchgrass stands in our analysis was biased toward small and complexly shaped field portions, benefits for area dependent grasshopper sparrows may not be as great (Herkert, 1994; Murray *et al.*, 2003; Ribic *et al.*, 2009), especially if switchgrass harvests are conducted at anthesis, instead of post-frost. We also predicted substantial percent increases in abundance for sedge wrens, which prefer tall, dense grassland structure during the breeding season (Delisle & Savidge, 1997; Renfrew & Ribic, 2002; Johnsgard, 2009), and ring-necked pheasants, which rely on residual vegetation for winter cover and early season nest construction (Haensly *et al.*, 1987; Murray & Best, 2003). These presently less abundant species could secure additional benefits from late summer or autumn harvests, given that other requirements for their survival and successful reproduction are satisfied. Although the introduction of small patches of perennial bioenergy feedstocks may provide limited benefits to area dependent species in agricultural landscapes, several studies caution against automatically categorizing all small prairie fragments as unsuitable grassland bird habitat (Winter *et al.*, 2006; Ribic *et al.*, 2009), including those bisected by cropland (Walk *et al.*, 2010).

Heterogeneous grassland management regimes have been shown to increase the benefits provided to the most species (Powell & Busby, 2013), and bioenergy feedstock harvest management strategies could be developed to increase habitat diversity at the field and landscape scales (Wiens *et al.*, 2011; Robertson *et al.*, 2012). For example, harvesting fields at different times of the year (e.g., late summer and post-frost) could increase habitat diversity in landscapes, and different harvest heights could increase local habitat heterogeneity and provide specific habitat structure not afforded by existing remnant or restored grasslands. Apart from management, improved switchgrass hybrids could influence switchgrass stand structure (Vogel & Mitchell, 2008), to the benefit or detriment of different species. To cope with the various social-ecological drivers of bioenergy production and best apply incentives for development, Wiens *et al.* (2011) recommend applying comprehensive cost–benefit analyses to proposed land-use changes.

Land-use change modeling results for Scenarios 1 and 2 were derived from separate model runs, which due to the random conversion component of the model, are likely to produce slightly different results in total land area converted from rowcrops to switchgrass. However, given the previously described aggregation of fields according to marginal characteristics, we do not expect these differences to be substantial enough to alter study conclusions. Slight variations in converted land area are acceptable, given our objective of simulating the effects of different intensities of biofuel-based land-use change at the landscape scale of observation. Furthermore, differences in converted land area between Scenarios 1 and 2 do not affect the direction of avian responses, only their magnitude.

Future studies could focus on the incorporation of additional landscape specific information and factors into models, as well as field evaluations of grassland bird use in switchgrass demonstration sites. This study predicted abundances of species for which density estimates in local major landcover classes were available. As additional density information becomes available, abundances of other grassland birds, including the following, could be modeled: red-winged blackbird (*Agelaius phoeniceus*), common yellowthroat (*Geothlypis trichas*), northern bobwhite (*Colinus virginianus*), brown-headed cowbird (*Molothrus ater*), and swamp sparrow (*Melospiza georgiana*).

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