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Alternative scenarios of bioenergy crop production in an agricultural landscape and implications for bird communities

Peter J. Blank,[1,5] Carol L. Williams,[2] David W. Sample,[3] Timothy D. Meehan,[4,6] and Monica G. Turner[1]

[1]*Department of Zoology, University of Wisconsin, Madison, Wisconsin 53706 USA*
[2]*Department of Agronomy, University of Wisconsin, Madison, Wisconsin 53706 USA*
[3]*Wisconsin Department of Natural Resources, Madison, Wisconsin 53716 USA*
[4]*Department of Entomology, University of Wisconsin, Madison, Wisconsin 53706 USA*

Abstract. Increased demand and government mandates for bioenergy crops in the United States could require a large allocation of agricultural land to bioenergy feedstock production and substantially alter current landscape patterns. Incorporating bioenergy landscape design into land-use decision making could help maximize benefits and minimize trade-offs among alternative land uses. We developed spatially explicit landscape scenarios of increased bioenergy crop production in an 80-km radius agricultural landscape centered on a potential biomass-processing energy facility and evaluated the consequences of each scenario for bird communities. Our scenarios included conversion of existing annual row crops to perennial bioenergy grasslands and conversion of existing grasslands to annual bioenergy row crops. The scenarios explored combinations of four biomass crop types (three potential grassland crops along a gradient of plant diversity and one annual row crop [corn]), three land conversion percentages to bioenergy crops (10%, 20%, or 30% of row crops or grasslands), and three spatial configurations of biomass crop fields (random, clustered near similar field types, or centered on the processing plant), yielding 36 scenarios. For each scenario, we predicted the impact on four bird community metrics: species richness, total bird density, species of greatest conservation need (SGCN) density, and SGCN hotspots (SGCN birds/ha ≥ 2). Bird community metrics consistently increased with conversion of row crops to bioenergy grasslands and consistently decreased with conversion of grasslands to bioenergy row crops. Spatial arrangement of bioenergy fields had strong effects on the bird community and in some cases was more influential than the amount converted to bioenergy crops. Clustering grasslands had a stronger positive influence on the bird community than locating grasslands near the central plant or at random. Expansion of bioenergy grasslands onto marginal agricultural lands will likely benefit grassland bird populations, and bioenergy landscapes could be designed to maximize biodiversity benefits while meeting targets for biomass production.

Key words: bioenergy crops; grass biomass; grassland birds; landscape scenarios; land-use change; row-crop agriculture; species of greatest conservation need

Introduction

Agricultural landscapes are under increasing pressure to produce multiple ecosystem goods and services, with implications for farmland biodiversity (Jordan and Warner 2010). Increased demand and government mandates for bioenergy crops in the United States will require a large allocation of agricultural land to bioenergy feedstock production (U.S. Congress 2007, U.S. EPA 2011). Bioenergy landscapes (i.e., landscapes that produce bioenergy feedstocks) represent novel agroecosystems, and understanding the ecological consequences of these new land-use patterns will provide guidance to optimize benefits at multiple spatial scales (Dale et al. 2010b, 2011, Dauber et al. 2010). Incorporating bioenergy landscape design into land-use decision making could minimize trade-offs among alternative land uses (Webster et al. 2010, Werling et al. 2014).

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[5]Present address: American Bird Conservancy, Alabama Ecological Services Field Office, Daphne, Alabama, 36526, USA. E-mail: pblank@abcbirds.org

[6]Present address: National Ecological Observatory Network, Boulder, Colorado, 80301, USA.

Recent increases in agricultural commodity prices, demand for corn ethanol, and crop insurance subsidies have created incentives for converting natural habitats, such as perennial grasslands, shrublands, and wetlands, to annual bioenergy row crops (Faber et al. 2012, Wright and Wimberly 2013). Conversion rates of grasslands, such as those enrolled in the Conservation Reserve Program (CRP), to annual crops have been particularly high in the Upper Midwest and Great Plains (Fargione et al. 2009, Swinton et al. 2011, Faber et al. 2012). For example, nearly 530000 ha of grassland habitat was converted to corn/soy production in the Western Corn Belt from 2006 to 2011 (Wright and Wimberly 2013). This widespread conversion of grasslands to row crops is expected to have numerous environmental impacts, such as increased soil erosion and carbon emissions and decreased water quality (Fargione et al. 2009). Expansion of row crop agriculture could also result in smaller and more fragmented natural habitat patches leading to a decrease in biodiversity and area-sensitive habitat specialists (Webster et al. 2010).

Perennial grasslands dedicated to biomass production have high bioenergy potential (Mulkey et al. 2008, Schmer et al. 2008, Miesel et al. 2012) and would provide greater ecosystem services and support for biodiversity compared to annual crops (Paine et al. 1996, Tilman et al. 2006, Fargione et al. 2009, Dauber et al. 2010, Werling et al. 2014). Perennial grasslands managed as bioenergy crops could be grown on marginal agricultural lands (e.g., highly erodible soils) that are not suitable for annual crops, thereby reducing the competition between food and fuel production. Due to technological and commercial challenges associated with conversion of grass biomass to bioenergy and the scarcity of perennial biomass feedstock markets, perennial grassland cropping systems are uncommon (Dauber et al. 2010, Mitchell et al. 2012, Williams et al. 2013). As a consequence, there is little empirical information on the ecological consequences of perennial grass biomass production in agricultural landscapes.

The type, amount, and spatial arrangement of bioenergy crops will have strong effects on biodiversity, and may particularly affect grassland bird populations (Paine et al. 1996, Dauber et al. 2010, Fletcher et al. 2010, Engel et al. 2012). Grassland birds, which are of high conservation concern due to substantial population declines (Askins et al. 2007), could gain habitat from an increase in perennial grassland bioenergy crops and lose habitat from an increase in annual bioenergy row crops (Murray et al. 2003, Fletcher et al. 2010, Meehan et al. 2010, Webster et al. 2010, Robertson et al. 2011a, b, Uden et al. 2014). In the short-term, relatively small proportions of farmland are likely to be converted to perennial bioenergy crops due to conflicts with on-going land uses, which could lead to a highly fragmented pattern of cultivation (Mooney et al. 2013). Spatially clustered bioenergy crops would be more economical for biomass-processing plants and would reduce habitat fragmentation in local landscapes (Dauber et al. 2010, Bailey et al. 2011, Mooney et al. 2013). Concentrating perennial grassland bioenergy crops near other grasslands (e.g., CRP fields) could increase grassland bird use of smaller habitat patches and create larger habitat patches that could benefit area-sensitive bird species (Robertson et al. 2012). However, many uncertainties remain about how birds will respond to perennial bioenergy crops, and most research has focused on local habitat associations instead of regional effects of bioenergy development on bird communities (Fargione 2010, Werling et al. 2014).

Previously, we reported on a field study of the bird community response to vegetation characteristics of potential bioenergy grasslands and the immediate landscapes surrounding those grasslands (Blank et al. 2014). We found that bioenergy grasslands could provide habitat for several bird Species of Greatest Conservation Need (SGCN) and that forb cover, vegetation density (an indicator of biomass yields), and the landscape composition within 1 km of grassland fields influenced bird community assemblages. In the current study we extend those results into a modeling environment and address the potential effects of bioenergy development on bird communities at a regional scale. We asked how bioenergy crop type, percent conversion to bioenergy crops, and the spatial arrangement of bioenergy crops influenced bird communities around a hypothetical biomass-processing energy facility in an agricultural landscape.

We used spatially explicit scenarios of alternative land-cover patterns, which can be used to evaluate possible futures and uncertainties (Nassauer and Corry 2004, Thompson et al. 2012) and have been used previously to study the implications of bioenergy development policies on bird populations (Murray et al. 2003, Meehan et al. 2010, Engel et al. 2012, Uden et al. 2014). We explored a range of possible variations of converting existing row crops to bioenergy grasslands or converting existing grasslands to annual bioenergy row crops. The scenarios included combinations of four bioenergy crop types (three potential grassland crops along a gradient of plant diversity and one annual row crop [corn]), three land conversion percentages to bioenergy crops (10%, 20%, or 30% of existing row crops or grasslands to the alternative), and three spatial arrangements of bioenergy crop fields (random, clustered near similar field types, or closest to a central processing plant), yielding 36 scenarios. For each scenario we predicted the impact on four bird community metrics: species richness, total bird density, SGCN density, and SGCN hotspots (SGCN birds/ha $\geq$ 2).

Methods

Study Area

We selected a study landscape to represent potential bioenergy landscapes around biomass processing facilities, such as power plants and ethanol biorefineries that utilize lignocellulosic biomass. We chose a landscape centered on an existing centralized district power/heating/cooling plant in Madison, Wisconsin, USA. The plant was recently under consideration for a retrofit that would have included a biomass boiler capable of co-firing natural gas and biomass mixtures (Runge and Porter 2013). Although the biomass portion of the retrofit was canceled in 2011, the facility concept served as a driver of feasibility studies regarding biomass procurement and logistics, and generated interest in understanding subsequent impacts to socioeconomic and ecological systems in the surrounding landscape (Runge and Porter 2013). In this study, we explore how the landscape around the plant (referred to as a power plant), and subsequently the bird community, may have changed if the originally designed biomass boiler had been installed. We use this system as an example of how landscapes may change based on demand for biomass resources around a central processing plant.

We chose an 80-km radius circle around the plant to define our study landscape, which is considered an economically feasible area for transporting biomass feedstocks to a central processing plant (Paine et al. 1996, Bailey et al. 2011, Gelfand et al. 2013). This landscape also includes the majority of field sites where we conducted bird, vegetation, and biomass surveys in potential bioenergy grasslands and surveyed birds in nearby cornfields (Blank et al. 2014). Southern Wisconsin is well suited for this study because the central United States is predicted to have high local biomass production of switchgrass (Panicum virgatum) under future scenarios (Behrman et al. 2013), the region contains abundant marginal land ideal for bioenergy crops (Mooney et al. 2013), and several grassland bird species nesting in the study area are listed as Species of Greatest Conservation Need (SGCN) in Wisconsin (Wisconsin Department of Natural Resources 2005).

Scenarios and landscape analysis

We developed our scenarios in ArcGIS 10 (ESRI 2011). The 2011 Cropland Data Layer (CDL) was used to represent current land cover in the study area (data *available online*).[7] The land-cover raster was resampled (by using a majority rule) to a 180 × 180 m cell size (3.24 ha; hereafter, also referred to as a "field"), which approximates the area surveyed during bird point counts detailed in Blank et al. (2014). We reclassified the CDL land-cover types in the landscape into seven broader land-cover classes: grass/pasture (combining pasture/grass, grassland herbaceous, and pasture/hay), agriculture (all crops including grains, vegetables, fruits, hays, and seeds), forest (all forest categories including deciduous, evergreen, mixed, and woody wetlands), wetlands/water (wetlands, aquaculture, open water, and herbaceous wetlands), developed (developed open space and low-, medium-, and high-intensity development), shrubland, and barren land. Combining grassland and pasture land-cover types as grass/pasture is consistent with the 2011 CDL, which was recoded and rereleased in 2014 (see footnote 1). We refer to the grass/pasture category as grassland and use this category for subsequent analyses (as in Wright and Wimberly 2013, Werling et al. 2014).

We focused on plausible scenarios of bioenergy development involving the conversion of existing annual row crops to perennial bioenergy grasslands (hereafter, increasing grasslands scenarios) and the conversion of existing grasslands to annual bioenergy row crops (specifically, cornfields; hereafter, increasing row crops scenarios). All land-cover conversions were restricted to marginal land because marginal lands are well suited for bioenergy crops, such as native warm-season grasses, that grow well on highly erodible land or under low moisture conditions (Paine et al. 1996, Mulkey et al. 2008, Mitchell et al. 2012). Marginal lands were identified from the SSURGO soil geodatabase (USDA 2013) and were defined as soil capability classes 3–6 (as in Uden et al. 2013). We restricted conversions of grasslands to row crops in the increasing row crops scenarios to soil capability classes 3 and 4, because classes greater than 4 are considered unsuitable for cultivation of conventional row crops.

We assumed in our scenarios that no row crops or grasslands currently in the landscape were used for cellulosic feedstock production and that all land-cover conversions would be to produce dedicated herbaceous biomass crops. We included all cells classified as agriculture on marginal land for possible conversion to grassland crops in the increasing grassland scenarios, rather than allowing only cornfields to be converted, because most agricultural fields in the study landscape are cultivated in a corn/soy rotation. However, for the increasing row crops scenarios, we assumed all converted grasslands would be converted to cornfields because corn stover (i.e., leaves, stems, and stalks) is a potential cellulosic bioenergy feedstock (Graham et al. 2007). Because it is unclear if grassland bioenergy production systems will call for monotypic or mixed-species (i.e., polycultures) feedstocks (Fargione et al. 2009, Griffith et al. 2011, U.S. EPA 2011, Anderson-Teixeira et al. 2012), we considered three types of potential bioenergy grassland fields along a gradient of plant diversity (as in Blank et al. 2014) in the increasing grasslands scenarios: grass monocultures (e.g., monocultures of switchgrass), grass-dominated fields (grasslands with >50%

[7] http://nassgeodata.gmu.edu/CropScape/

live vegetation in grass), or forb-dominated fields (grasslands with <50% live vegetation in grass). We also assumed that only one biomass crop would be grown in each scenario (i.e., different biomass crop types were not grown in the landscape concurrently). While this is an obvious oversimplification, it made it possible to attribute results to specific crop types.

The percentages of land converted to bioenergy crops were based on estimates of the demand for biomass in the landscape and biomass yields of each crop type. The biomass boiler at the Madison energy plant would have required an estimated 230000 Mg/yr of biomass (Runge and Porter 2013). We assumed that all biomass would be harvested in the fall and that 30% of the biomass would not be available for processing because sustainable harvesting practices (e.g., leaving crop residue in the fields) would be used to prevent erosion and maintain soil nutrients, and because some biomass is lost during collection, transportation, storage, and preprocessing (Graham et al. 2007). Therefore, we assumed 329000 Mg/yr of dedicated biomass would need to be grown in the landscape under each scenario to meet the requirements for the plant. Fall biomass yields for each grassland crop type were obtained from Blank et al. (2014): grass monoculture (6.4 Mg/ha), grass-dominated (3.6 Mg/ha), and forb-dominated (4.7 Mg/ha). Corn stover yields were estimated at 7.5 Mg/ha (Graham et al. 2007). We calculated that at least 10% of all row crops would need to be converted to perennial grasslands, or 10% of all grasslands would need to be converted to annual row crops, to ensure the biomass requirement by the plant was met under all scenarios. Therefore, we chose 10% as the lowest level of conversion to bioenergy crops. We also developed scenarios of 20% and 30% conversions assuming demand for herbaceous biomass crops increased within the landscape. A 10–30% conversion of grasslands to row crops is similar to documented rates of conversion of grassland to row crops in the Upper Midwest from 2006 to 2011 (Wright and Wimberly 2013).

We considered three types of spatial arrangements for bioenergy crops: randomly converted fields, clustered near similar field cover types, and centered on the power plant. For the random scenarios, eligible fields across the entire landscape were converted at random. For the clustered scenarios, we calculated the percent of grassland and row crops within 1 km of each field and converted fields with more existing grasslands or row crops, and in the same land cover type as the target bioenergy crop, within 1 km first. In the power-plant centered scenarios, the distance of each field to the power plant was calculated and fields closest to the plant were converted first.

In total, we generated 36 possible bioenergy development scenarios for our study landscape (4 crop types × 3 conversion percentages × 3 spatial arrangements = 36 scenarios; Table 1). We calculated landscape metrics related to patch number and area for each scenario in Fragstats 4.1 (Appendix S1: Table S11; McGarigal et al. 2012).

TABLE 1. Descriptions of each variable used in the bioenergy scenarios.

Variable, conversion direction, and level	Description
Bioenergy crop type	
Increasing grasslands	
Grass monocultures	conversion of annual row crops to grass monocultures
Grass-dominated fields	conversion of annual row crops to grass-dominated fields
Forb-dominated fields	conversion of annual row crops to forb-dominated fields
Increasing row crops	
Annual row crop (corn)	conversion of grasslands to annual row crops (corn)
Conversion amount	
10%	10% of row crops or grassland fields converted
20%	20% of row crops or grassland fields converted
30%	30% of row crops or grassland fields converted
Spatial arrangement of converted fields	
Random	eligible fields converted randomly
Clustered	converted fields clustered near similar field types
Power-plant centered	eligible fields closest to the power plant converted first

Notes: The study included all combinations, resulting in 36 scenarios. All land-cover conversions were restricted to marginal lands.

Predicting bird response

We predicted the response of bird species richness, total bird density, and SGCN density to each bioenergy scenario in a two-step process. First, we developed empirical models for each bird metric based on field data and analyses detailed in Blank et al. (2014). This study indicated that two variables, bioenergy crop type and the amount of grassland within 1 km of each field, were strong predictors of bird response. Therefore, we modeled each bird metric as a function of these two variables (see Blank et al. [2014] for details about the data and model structure). The marginal R^2 values (i.e., variance explained by the fixed effects) of these models were species richness, $R^2 = 0.67$; total bird density, $R^2 = 0.76$; and SGCN density, $R^2 = 0.37$. The most common species observed during our field work in the three grassland crop types we model here were Song Sparrow (*Melospiza melodia*), Red-winged Blackbird (*Agelaius phoeniceus*), Common Yellowthroat (*Geothlypis trichas*), Dickcissel (*Spiza Americana*), and Grasshopper Sparrow (*Ammodramus savannarum*). We also observed several SGCNs in the landscape we modeled, including Dickcissel, Grasshopper

Sparrow, Henslow's Sparrow (*Ammodramus henslowii*), Eastern Meadowlark (*Sturnella magna*), and Bobolink (*Dolichonyx oryzivorus*), which are also considered area-sensitive grassland obligate species (Sample and Mossman 1997, Ribic et al. 2009).

Second, we used the parameter estimates from the models (Table 2) to predict each bird metric in each cell (i.e., field) in the 80-km radius landscape classified as either row crop or grassland (hereafter, focal cells). We assumed the bird communities in cells classified as other habitat types (e.g., forests, wetlands, and urban areas) remained constant. The model for predicting each bird metric in each focal cell was

$$\begin{aligned}\text{Bird community metric} &= \beta_1\,(\text{cornfield}) + \beta_2\,(\text{grass monoculture}) \\ &\quad + \beta_3\,(\text{grass- dominated field}) \\ &\quad + \beta_4\,(\text{forb- dominated field}) \\ &\quad + \beta_5\,(\text{grassland within 1 km})\end{aligned} \tag{1}$$

where the βs are the parameter estimates for the fixed effects (Table 2), the four possible crop types in a cell (cornfields, grass monocultures, grass- and forb-dominated fields) are binary indicator variables (0 = absent, 1 = present), and grassland within 1 km is a continuous covariate that describes the proportion of a 1-km radius landscape around each cell in grassland cover. Because cornfields had so few SGCNs we were unable to get reliable estimates of SGCNs in cornfields; therefore we assumed zero SGCNs in cornfields. We assumed that all currently existing grasslands in each scenario were grass-dominated fields, which we believe best characterizes the average grassland field in the landscape and is intermediate along the gradient of plant diversity among the grasslands considered in this study. As noted in Blank et al. (2014), bird detections during the field study used to inform the predictive models may have been <100%; therefore our predictions of bird community metrics are relative rather than absolute estimates. Predictions for each 3.24-ha focal cell were converted to a per hectare basis for further analysis.

We generated one map for each bird metric under each scenario because preliminary analyses indicated that multiple maps for the random scenarios yielded nearly identical results, and because our conversion rules for the clustered and power-plant centered scenarios required that fields with more grassland within 1 km and fields closest to the plant were converted first, respectively; thus there would have been no variation in the bird metrics if we had generated multiple maps for the clustered and power-plant centered scenarios. We calculated the mean of each bird community metric in each scenario across all focal cells in the landscape (n = 412707 cells) and then calculated the percent change from the mean of the focal cells in the current landscape. Therefore, the percent changes in mean bird metrics we report are relative to the current row crop and grassland cells only and not all habitat types in the landscape. We also estimated the number of cells in the landscape where SGCN density

Table 2. Parameter estimates (on a log scale) of bird species richness, total bird density, and species of greatest conservation need (SGCN) density.

Response and predictor variables	Estimate	SE	Z	P
Bird species richness				
Crop type				
Intercept (cornfields)	−1.21	0.29	−4.09	<0.001
Grass monocultures	1.73	0.34	5.11	<0.001
Grass-dominated fields	2.05	0.31	6.63	<0.001
Forb-dominated fields	2.22	0.31	7.20	<0.001
Grassland within 1 km (%)	0.67	0.34	1.98	0.047
Total bird density				
Crop type				
Intercept (cornfields)	−0.82	0.26	−3.14	0.002
Grass monocultures	1.40	0.34	4.07	<0.001
Grass-dominated fields	2.20	0.29	7.61	<0.001
Forb-dominated fields	2.58	0.30	8.72	<0.001
Grassland within 1 km (%)	1.54	0.50	3.06	0.002
SGCN density				
Crop type				
Intercept (grass monocultures)	−0.43	0.45	−0.96	0.336
Grass-dominated fields	0.49	0.44	1.12	0.262
Forb-dominated fields	−1.13	0.48	−2.34	0.019
Grassland within 1 km (%)	2.68	0.93	2.88	0.004

Notes: Additional details on field data and analysis are reported in Blank et al. (2014). Parameter estimates were generated from generalized linear models, specifying Poisson distributions, and including random effects of site and year.

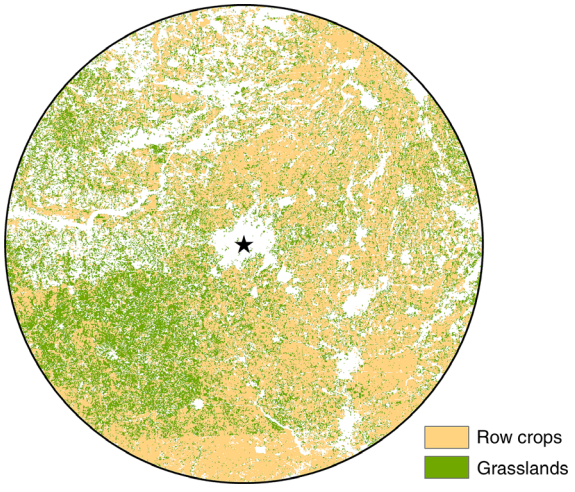

FIG. 1. Row crop and grassland land cover (i.e., focal cells) in the current landscape, an 80-km radius centered on an existing centralized district power/heating/cooling plant in Madison, Wisconsin, USA. The white cells represent non-focal land-cover types, such as forest, wetlands/water, and developed land. The central star is the location of the potential biomass-processing energy facility.

was ≥2 birds/ha, which we refer to as SGCN hotspots, because we believe it is a biologically meaningful threshold based on evaluating the distribution of SGCN densities among all focal cells in the landscape. We then calculated the percent change in the area occupied by SGCN hotspots for each scenario compared to the current landscape.

RESULTS

Baseline landscape conditions

Of the total area in the 80-km radius study landscape under the current land cover, 45% were row crops (902557 ha) and 22% were grasslands (434613 ha; Fig. 1). Thirty-eight percent of the row crops were on land capability classes 3–6 (342927 ha) and 52% of the grasslands were on classes 3 and 4 (225998 ha); these were the marginal lands we considered for land-cover conversions in our scenarios. For the current land cover, predicted mean bird population metrics among the focal cells (row crop and grassland cells) in the landscape were 1.07 species/ha, 1.77 total birds/ha, and 0.49 SGCN birds/ha, and 8% of the landscape had ≥2 SGCN birds/ha.

Increasing grasslands scenarios

In the increasing grasslands scenarios, grasslands increased from 22% of the landscape under current land cover to 35% under a 30% conversion of row crops to grasslands (Fig. 2A). Area-weighted mean patch size increased under all increasing grassland scenarios, but was highest when grasslands were clustered and lowest when row crops were converted to grasslands at random (Appendix S1: Table S11; Fig. 3).

Bird community metrics increased under all increasing grasslands scenarios (Appendix S2: Tables S21 and S22; Fig. 4). Bird species richness and total bird density were consistently higher under the forb-dominated fields scenarios, regardless of the conversion percentage or spatial arrangement of bioenergy grasslands. SGCN density was consistently higher under the grass-dominated fields scenarios. All bird community metrics increased as the conversion percentage from row crops to bioenergy grasslands increased. Bird species richness, total bird density, and SGCN density increased by up to 87%, 138%, and 159%, respectively, under the 30% conversion scenarios. Spatial arrangement of bioenergy crops had a strong influence on the bird community. The clustered scenarios consistently led to the greatest increases in bird community metrics, and the power-plant centered scenarios increased bird metrics more than the random scenarios.

SGCN hotspots (≥2 SGCN birds/ha) increased under all of the increasing grasslands scenarios (Fig. 5). SGCN hotspots increased up to 268% under the 30% conversion of row crops to grass-dominated fields when those fields were clustered near other grasslands. Spatial arrangement had a strong effect on SGCN hotspots. For example, SGCN hotspots increased more from a 10% conversion of row crops to grass-dominated fields clustered near other grasslands (131%) than under a 20% conversion to grass-dominated fields when the converted fields were randomly assigned (94%).

Increasing row crops scenarios

The increasing row crops scenarios increased row crops from 45% under current land cover to 51% under a 30% conversion of grasslands to row crops (Fig. 2B). Area-weighted mean patch size increased for row crops and decreased for grasslands under all conversion percentages (Appendix S1: Table S11). Area-weighted mean patch sizes of grasslands were greatest when bioenergy row crops were clustered; clustering row crops kept grasslands from being fragmented, as in the random scenarios.

All bird community metrics decreased as the conversion percentage from grasslands to bioenergy row crops increased (Appendix S3: Tables S31 and S32). Bird species richness, total bird density, and SGCN density (Fig. 6) decreased by up to 32%, 39%, and 53%, respectively, under the 30% conversion of grasslands to row crops scenarios. Clustered row crops led to smaller decreases in bird community metrics compared to the power-plant centered and random scenarios. For example, SGCN hotspots decreased up to 92% under a 30% random conversion of grasslands to row crops, but only decreased by 51% under a 30% conversion when bioenergy row crops were clustered.

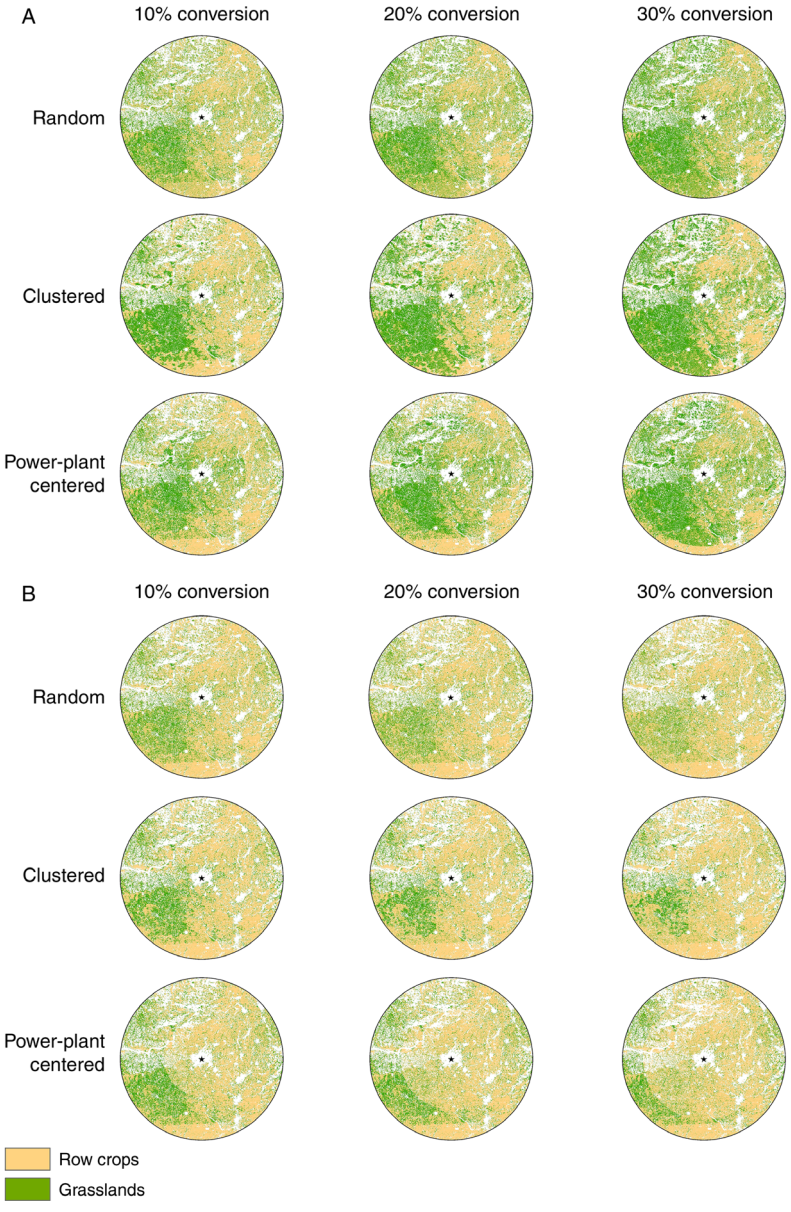

FIG. 2. Projected landscape patterns of row crops and grasslands under (A) increasing grasslands scenarios and (B) increasing row crops scenarios. The white cells represent non-focal land-cover types, such as forest, wetlands/water, and developed land. The central star is the location of the potential biomass-processing energy facility.

DISCUSSION

This study suggests that increased conversion of annual row crops to perennial grassland bioenergy crops would have strong positive influences on grassland bird populations in agricultural landscapes, and that increased conversion of perennial grasslands to annual bioenergy row crops would be detrimental to bird populations. Further, we show that spatial arrangement of bioenergy fields can have strong effects and that clustering bioenergy fields near similar field types could benefit bird populations substantially. In some cases, spatial arrangement of bioenergy fields had stronger effects than the percent of land converted to bioenergy crops. These results have implications for how grassland bird populations may be affected by many types of bioenergy development projects in agricultural landscapes, such as ethanol plants and coal plants co-fired with biomass, and may be particularly relevant for regions experiencing high demand for bioenergy feedstocks such as the U.S. Corn Belt (Wright and Wimberly 2013).

The choice of biomass crop types will have implications for grassland bird communities. We demonstrate that conversion of row crops to forb-dominated grassland

fields had the greatest positive impacts on bird species richness and total bird density, whereas conversion of row crops to grass-dominated fields had the greatest positive impacts on SGCN density. Comparing the results of our scenarios among bioenergy crop types allowed us to estimate the relative effects of crop type on the bird community. For example, a 10% conversion of row crops to forb-dominated grassland fields clustered near other grasslands increased bird species richness by 33%, whereas converting the same row crop fields to grass monocultures only increased bird species richness by an estimated 22%. Similarly, a 10% conversion of row crop fields to grass-dominated fields clustered near other grasslands increased SGCN hotspots by 131%, whereas a 10% conversion of row crop fields to grass monocultures only increased SGCN hotspots by an estimated 68%.

FIG. 3. Area-weighted mean patch size of grassland patches under the increasing grasslands scenarios.

Our results agree with previous studies suggesting that grassland biomass crops would benefit early-successional bird communities more than annual bioenergy row crops (Paine et al. 1996, Robertson et al. 2011a, b, Engel et al. 2012, Uden et al. 2014, Werling et al. 2014). For example, Murray et al. (2003) found that total bird abundance and abundance of grassland priority management species would increase if row crops on marginal land in Iowa were converted to grassland biomass crops. And Meehan et al. (2010) found that increasing bioenergy grasslands would lead to increased avian richness and abundance of grassland bird species of conservation concern in the Upper Midwest, whereas increasing bioenergy row crops would produce the opposite trends. While a few species that nest in row crop fields may benefit from additional row crops, such as Killdeer (Charadrius vociferus) and Horned Lark (Eremophila alpestris) (Murray et al. 2003, Robertson et al. 2011a), we find that most bird species in agricultural landscapes would gain habitat in bioenergy grasslands and lose habitat from increased row crop production.

Our study goes beyond the influence of crop type and demonstrates that spatial arrangement of bioenergy crop fields could have large effects on bird communities. Clustering grasslands had a stronger positive influence on the bird community than locating grasslands near the central plant or at random. We found that clustering bioenergy grasslands near existing grasslands led to landscapes with larger grassland patches and increases in all of the bird community metrics. Increasing grassland patch sizes benefits area-sensitive grassland specialists that are less abundant in highly fragmented landscapes and more common in larger grassland patches (Sample and Mossman 1997, Ribic et al. 2009). Although it is unknown why area-sensitive grassland birds occupy larger grassland patches, some factors influencing bird occupancy and density may include the minimum area requirements of individual species, social attraction among conspecifics, amount of edge habitat, and predation risk (Ribic et al. 2009). Clustering grasslands could increase their probability of colonization by grassland birds by reducing the distance between new patches and existing occupied patches (Ribic et al. 2009). Bioenergy grasslands planted close together could also be used as stepping-stone habitats or corridors for animals and enhance the provisioning of ecosystem services such as pest suppression and pollination (Dauber et al. 2010, Mitchell et al. 2013, Werling et al. 2014).

Notably, in some cases, spatial arrangement of bioenergy crops had similar or greater effects on the bird community than conversion percentage. For example, a 10% conversion of row crops to grass-dominated fields clustered near other grasslands increased SGCN density by 79%, whereas a 20% conversion to grass-dominated fields converted randomly only increased SGCN density by 68%. Similarly, a 20% conversion of row crops to grass-dominated fields clustered near other grasslands increased SGCN density by 125%, whereas a 30% conversion to grass-dominated fields converted at random increased SGCN density by 121%. Thus, landscape-level planning focused on the spatial arrangement of bioenergy grassland crops could have even greater effects on bird communities than the amount converted to crop production. Interestingly, in the increasing row crops scenarios, clustering bioenergy row crops near existing row crop fields increased row crop patch sizes and led to smaller decreases in bird community metrics. This is most likely because clustering bioenergy row crops decreased fragmentation of existing grasslands, preserving more habitat for grassland birds.

The majority of birds in our study were early-successional or grassland bird species that prefer open habitats (see species list in Blank et al. 2014). Murray and Best (2003) suggest that bioenergy grasslands, such as switchgrass fields grown for biomass, are most valuable to habitat generalists and of lesser value for habitat specialists. We found that SGCNs, many of which are grassland specialists, could benefit strongly from

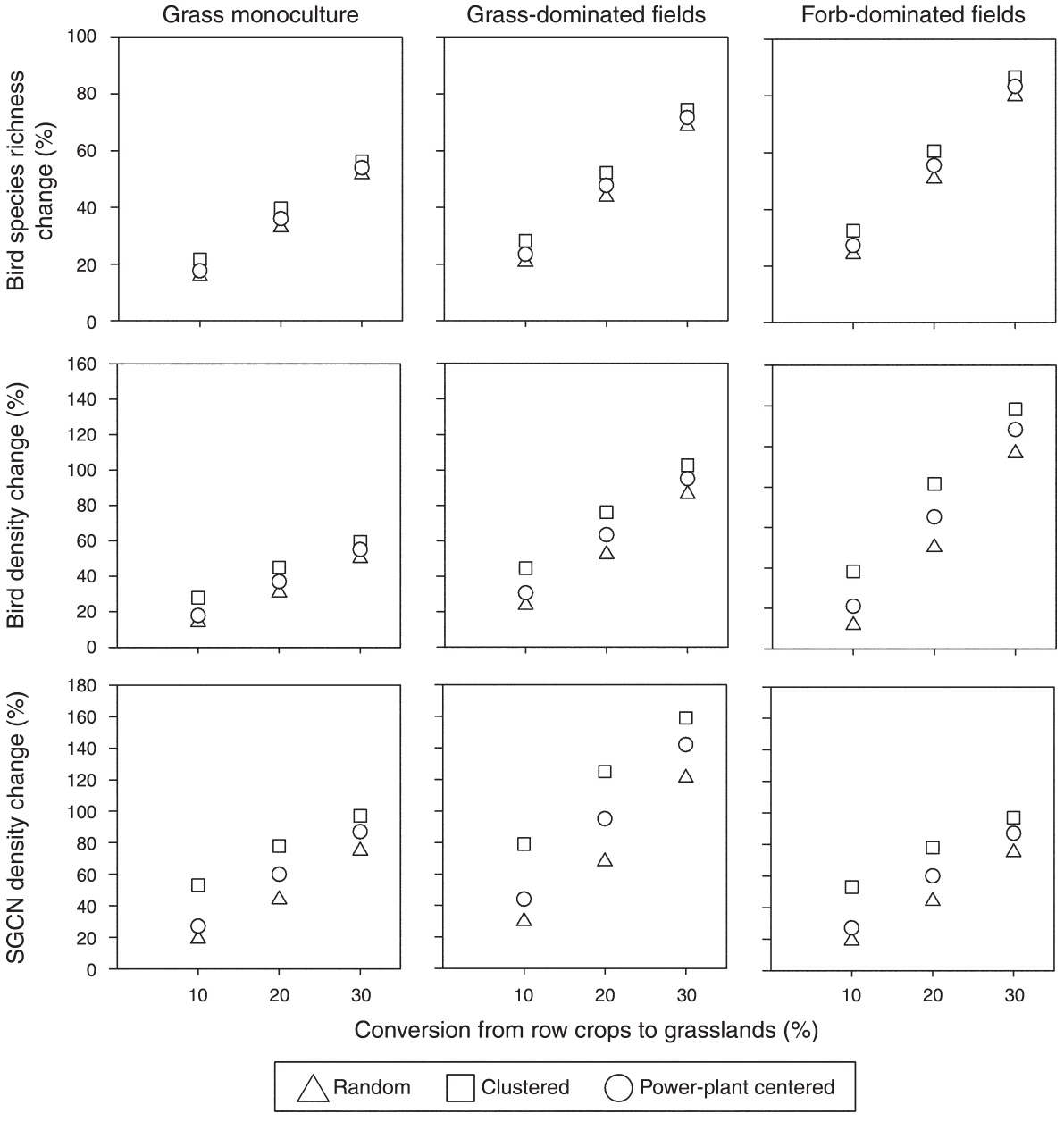

FIG. 4. Percent change in bird species richness (number of species per hectare; top row), total bird density (number of birds per hectare; middle row), and species of greatest conservation need (SGCN) density (number of birds per hectare; bottom row) from the current landscape under the increasing grassland scenarios.

bioenergy grasslands, even from grass monocultures. Although Blank et al. (2014) found few SGCNs in individual grass monocultures, they found more SGCNs in grass monocultures than in row crops. We show here that if enough grass monocultures are planted in large quantities over large landscapes, SGCN populations could benefit substantially. For example, a 10% conversion of row crops to grass monocultures clustered near other grasslands could increase SGCN density by 53%, and a 30% conversion to grass monocultures could increase SGCN density by 97%. SGCN abundance in our study was dominated by Dickcissels, Grasshopper Sparrows, Henslow's Sparrows, and Eastern Meadowlarks. Individual species responses will vary depending on crop type and structural heterogeneity. For example, Sedge Wrens (*Cistothorus platensis*) and Henslow's Sparrows prefer tall and dense grasslands (Murray and Best 2003, Roth et al. 2005) whereas Grasshopper Sparrows prefer grasslands with short to moderate height and low to moderate density (Sample

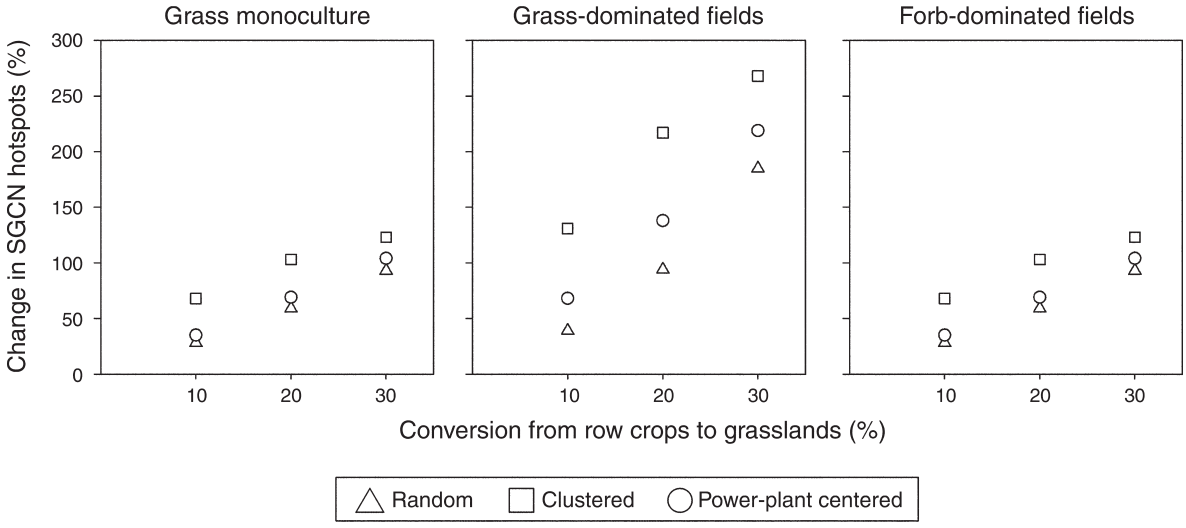

FIG. 5. Percent change in area categorized as SGCN hotspots (≥2 SGCN/ha) from the current landscape under the increasing grasslands scenarios.

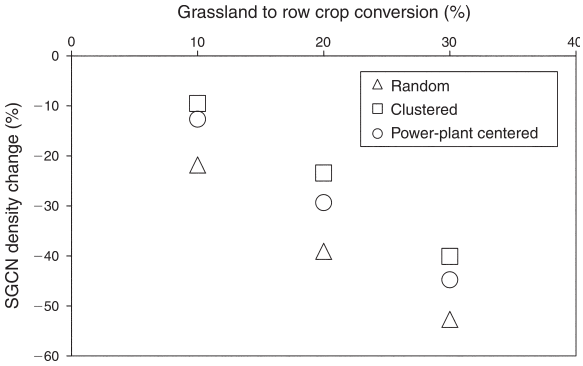

FIG. 6. Percent change in SGCN density from the current land cover under the increasing row crops scenarios.

and Mossman 1997, Murray and Best 2003, Roth et al. 2005, Gill et al. 2006). Although several of the SGCNs we studied have been positively related to forb cover in other studies (e.g., Fletcher and Koford 2002, Robertson et al. 2012), SGCN density in our study may have been lower in forb-dominated fields than in grass monocultures and grass-dominated fields because the forb-dominated fields used to inform the study may have been too tall and dense for most SGCNs (Blank et al. 2014).

Our methods required several assumptions that should be acknowledged. We assumed that the three grassland crop types were equally likely to be grown. The composition of actual bioenergy grassland crops will depend on many factors, including market forces and technological advancements. Compared to monocultures, diverse grassland feedstocks have greater variation in chemical content and physical properties that lower bioenergy conversion efficiency and add cost to the conversion process (Adler et al. 2009, Garlock et al. 2012). However, although grass monocultures may be more likely to be grown in the short term, many studies have suggested that mixed-species feedstocks could be utilized (e.g., Tilman et al. 2006, Fargione et al. 2009, Anderson-Teixeira et al. 2012). We also assumed that only one biomass crop would be grown in each scenario, although realistically multiple biomass crop types may be grown concurrently. It is likely that because of this assumption the results of our scenarios differ more widely than if we had run scenarios that included a mix of different crop types. Thus, our results represent the extremes of what we might expect in bird response to the effect of bioenergy crop type. We recognize that other biomass feedstocks (e.g., Miscanthus, hybrid poplar) may be used, conversion percentages to bioenergy crops will vary depending on demand, and the spatial arrangement of biomass crops could take many forms. However, we believe our scenarios are plausible and informative representations of bioenergy development trajectories around biomass processing plants.

We also acknowledge that most of the grassland fields used to inform our study were not harvested annually, as would likely be the case in actual bioenergy cropping systems. An annual autumn harvest would impact vegetation structure the following growing season (e.g., reducing litter depth) and could influence the ways that breeding birds use bioenergy grassland fields. However, the five grass monocultures in our

field study (Blank et al. 2014) were harvested annually in the fall, and some of the grass- and forb-dominated fields in our field study were burned in the spring; thus removing biomass before the following breeding season. Actual impacts of bioenergy development on grassland bird communities will depend on the frequency, timing, and amount of grassland biomass harvests (Murray and Best 2003, Roth et al. 2005, Fargione et al. 2009), and nest losses could be minimized if sustainable harvesting practices are followed (Hull et al. 2011).

Our conclusions are predicated on the idea that bioenergy crop production will increase. But is that likely in the near future? Willingness to grow biomass crops will depend on many factors, including the availability of biomass markets, start-up costs, the price of biomass crops, attitudes towards bioenergy and environmental stewardship, and technological breakthroughs (Swinton et al. 2011, Mooney et al. 2013). Ultimately, decisions about producing biomass crops and constructing biomass-processing facilities may largely be based on economic conditions and prevailing policies. For example, abundant natural gas supply has resulted in historically low natural gas prices; reducing current demand for cellulosic bioenergy feedstocks. Farming grasslands will need to be at least as profitable as farming corn before many farm owners will be willing to produce grassland biomass. Given the lack of grass biomass markets and the current price of corn, corn is currently a more attractive option financially for most farmer owners (James et al. 2010, Swinton et al. 2011, Williams et al. 2013). Contracting with third-party growers that own the required planting, harvesting, and baling equipment may be a more viable option for some grass biomass producers than purchasing new specialized equipment. Farm owners could be encouraged to produce perennial grass feedstocks with appropriate financial incentives, such as payments for ecosystem services or conservation, or though changes in regulations (Fargione et al. 2009, Dale et al. 2010a, Jordan and Warner 2010, Robertson et al. 2012, Werling et al. 2014). Incorporating ecological concerns into bioenergy policy will be an important step towards ensuring the sustainability of bioenergy development in agricultural landscapes.

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