Bird communities in future bioenergy landscapes of the Upper Midwest

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Mandates for biofuel and renewable electricity are creating incentives for biomass production in agricultural landscapes of the Upper Midwest. Different bioenergy crops are expected to vary in their effects on biodiversity and ecosystem services. Here, we use data from the North American Breeding Bird Survey to forecast the impact of potential bioenergy crops on avian species richness and the number of bird species of conservation concern in Midwestern landscapes. Our analysis suggests that expanded production of annual bioenergy crops (e.g., corn and soybeans) on marginal land will lead to declines in avian richness between 7% and 65% across 20% of the region, and will make managing at-risk species more challenging. In contrast, replacement of annual with diverse perennial bioenergy crops (e.g., mixed grasses and forbs) is expected to bring increases in avian richness between 12% and 207% across 20% of the region, and possibly aid the recovery of several species of conservation concern.

agriculture | biofuel | diversity

A variety of bioenergy crops are being considered for fuel, heat, and electricity production in the Upper Midwest. Candidate crops vary along gradients of plant diversity and perenniality. At one end of the spectrum are crops such as corn and soybeans, which are planted annually, enhanced with fertilizers and pesticides, and managed for minimum plant diversity [high-input low-diversity (HILD) crops] (1). At the other end of the spectrum are stands of native perennial grasses and forbs that, once established, are not replanted or treated with fertilizers and pesticides, and have relatively high plant diversity [low-input high-diversity (LIHD) crops] (1). The large volume of biomass needed to meet ethanol and renewable electricity mandates (2, 3) virtually guarantees that bioenergy crop choices will have far-reaching impacts, and requires that crops are chosen wisely.

A number of studies have been conducted to compare the potential performance of candidate bioenergy crops. For example, quantitative analyses have been conducted to gauge the economic and energetic viability (4, 5) of these crops and their impacts on ecosystem processes such as carbon sequestration and nutrient loss (6, 7). However, there are few studies that consider how bioenergy crops will affect biodiversity (8, 9), and none that explicitly model biodiversity impacts under different bioenergy cropping scenarios. The lack of quantitative information regarding the biodiversity impacts of Midwestern bioenergy crops is cause for concern, given the extensive land-cover change that has occurred and the tenuous state of biodiversity in the region (10).

How might different bioenergy crops influence biodiversity? Previous work suggests that animal diversity is driven, in part, by plant diversity and concomitant variation in plant chemistry, structure, and phenology (11–14). Thus, we might hypothesize that landscapes dominated by HILD crops will host fewer animal species than those dominated by LIHD crops (8, 9). Indeed, several studies in agricultural systems have shown that intensive annual agriculture has negative impacts on insect and bird diversity (15–18). Complementary studies have shown that insect and bird diversity rebounds as annual crops are converted to, or planted alongside, less intensively managed grasslands (19, 20). Given these findings, it appears that biomass production for bioenergy could have negative or positive effects on biodiversity, depending on the types of crops that are adopted and on local land-use history.

In this study, we explored the potential effects of bioenergy crops on Midwestern birds, a group in which many species have experienced substantial population declines in the past half-century (21). Specifically, we modeled landscape-scale bird species richness as a function of land cover, and used the resulting empirical model to forecast the effects of different bioenergy cropping scenarios on bird communities across the Upper Midwest. Bird data came from 265 landscapes sampled during the 2008 North American Breeding Bird Survey (BBS) (22). Land cover information was derived for 25-km^2 buffers surrounding BBS routes using the 2008 US Department of Agriculture (USDA) National Agriculture Statistics Service Cropland Data Layer (CDL) (23). Land cover variables included the amount of HILD crops (corn and soybeans), LIHD habitat (open perennial habitats such as hayfields, alfalfa fields, pastures, and unmanaged grasslands), forest, wetland, and urban areas (groundcover $\geq$50% impervious surface). Bioenergy scenarios used in this study represented the extremes of what might occur if bioenergy production emphasized HILD or LIHD cropping systems on marginal land. Scenarios were focused on marginal land because many believe that restricting bioenergy crops to marginal land is necessary to alleviate conflicts between food and energy production, and to avoid carbon emissions and biodiversity losses associated with conversion of natural lands to food production in other parts of the world (24).

Results

We modeled relationships between landscape-scale bird species richness and land cover using general linear models, and selected a best model for forecasting the impacts of bioenergy scenarios using the biased-corrected version of Akaike's information criterion (AIC$_c$) (25). The land cover model resulting from this process included parabolic relationships between bird diversity and the area of HILD and forested habitats in the landscape (Table 1 and Fig. S1). The effect of HILD crops was positive at low values, and increasingly negative at values greater than 1,000 ha, or roughly 40% of the landscape. Forest area had a strong positive effect on bird diversity until it reached $\approx$2,300 ha, or roughly 90% of the landscape. Thereafter, forest area had an increasingly negative effect. The AIC$_c$ best model also included a positive relationship between bird richness and LIHD crops. This relationship was linear up to the maximum observed area of

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Table 1. **Parameter estimates and R^2 values for AIC_c best models of landscape-scale avian richness (total richness) and the number of bird species of conservation concern (SCC richness) as a function of land cover**

	Intercept	HILD	HILD^2	LIHD	LIHD^2	Forest	Forest^2	Model R^2
Total richness								0.53
Estimate	36.036	0.016	−0.000008	0.003	—	0.023	−0.000005	
SE	3.912	0.004	0.000001	0.002	—	0.004	0.000001	
SCC richness								0.25
Estimate	0.720	0.004	−0.0000010	0.005	−0.000002	0.005	−0.0000009	
SE	1.140	0.001	0.0000004	0.002	0.000001	0.001	0.0000004	

HILD, high-input low-diversity bioenergy crops such as corn and soybeans; LIHD, low-input, high-diversity habitats such as pastures, hay fields, and grasslands.

1,700 ha, or ≈70% of the landscape. The effects of wetlands and urban areas on richness were positive and negative, respectively. However, these variables were not consistently included in the most-competitive models (Table S1). The low predictive power of these variables is likely related to the limited amounts of wetland and urban areas in study landscapes (the mean cover of these two habitats was <2%).

We used the land cover model to predict bird species richness in 25-km^2 landscape blocks under current landscape conditions in the Upper Midwest. A map of observed and predicted richness showed that the model adequately captured broad spatial patterns (Fig. 1), although there was notable residual variation around predicted values. Some of this residual was likely due to weather-, site-, and observer-related sampling variation that is inherent to the BBS (26). Another share of this residual was likely driven by misclassification of habitats in the CDL (23), which has a classification accuracy of 80–90% for major crops and forested habitats, and less than 80% for open perennial habitats. This variation clearly limits the precision of site-specific predictions, but should not restrict our ability to make generalizations in a region where land cover is highly spatially autocorrelated (Moran's I = 0.88, 0.79, and 0.88 for the amount of HILD, LIHD, and forest habitat, respectively, in neighboring landscape blocks).

Next we used the land cover model to forecast changes in bird communities under two divergent bioenergy scenarios. Under the increased HILD scenario, 9.5 million ha of marginal land, currently containing LIHD habitats, were converted to HILD crops. Under the increased LIHD scenario, 8.3 million ha of marginal land, currently containing HILD crops, were converted to LIHD habitats. Marginal land designation was derived from the Land Capability Classification (LCC) system of the USDA National Resources Conservation Service (27). For this analysis, marginal land included land that was considered unsuitable for crop production, and cropland with "severe" to "very severe" cropping limitations. The area of land converted for the two scenarios, ≈9 million ha, is similar to that estimated by Fargione et al. (8) for the additional land necessary to meet ethanol mandates in the Energy Independence and Security Act of 2007 (2) using corn grain.

The land cover model projected that the HILD scenario would bring ±5% changes in richness for ≈70% of the landscape blocks in the study region (Fig. 2). Minor increases in richness could result from increases in HILD habitats and associated species in areas where they are not currently abundant. Minor decreases

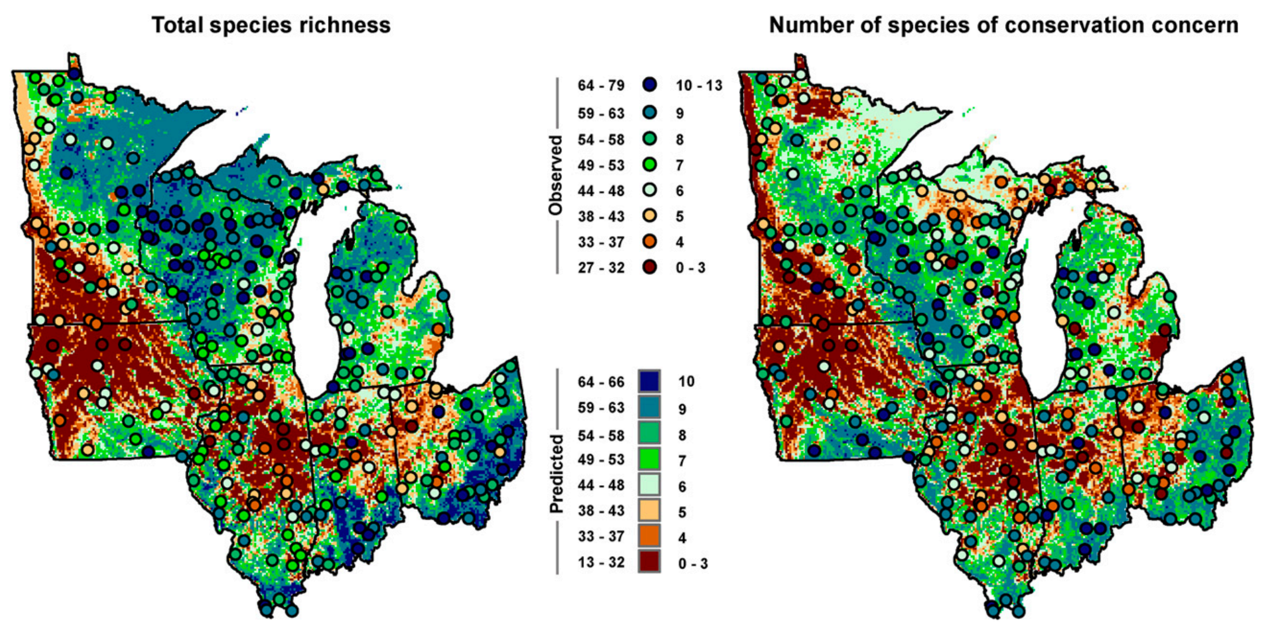

Fig. 1. Maps of observed (circles) and predicted (grids) total bird species richness (*Left*) and number of species of conservation concern (*Right*). Observed values are from 2008 North American BBS routes. Predicted values are for 25-km^2 landscape blocks from the empirical models described in Table 1. Values to the left of the legend symbols refer to total species richness, and those to the right refer to the number of species of conservation concern.

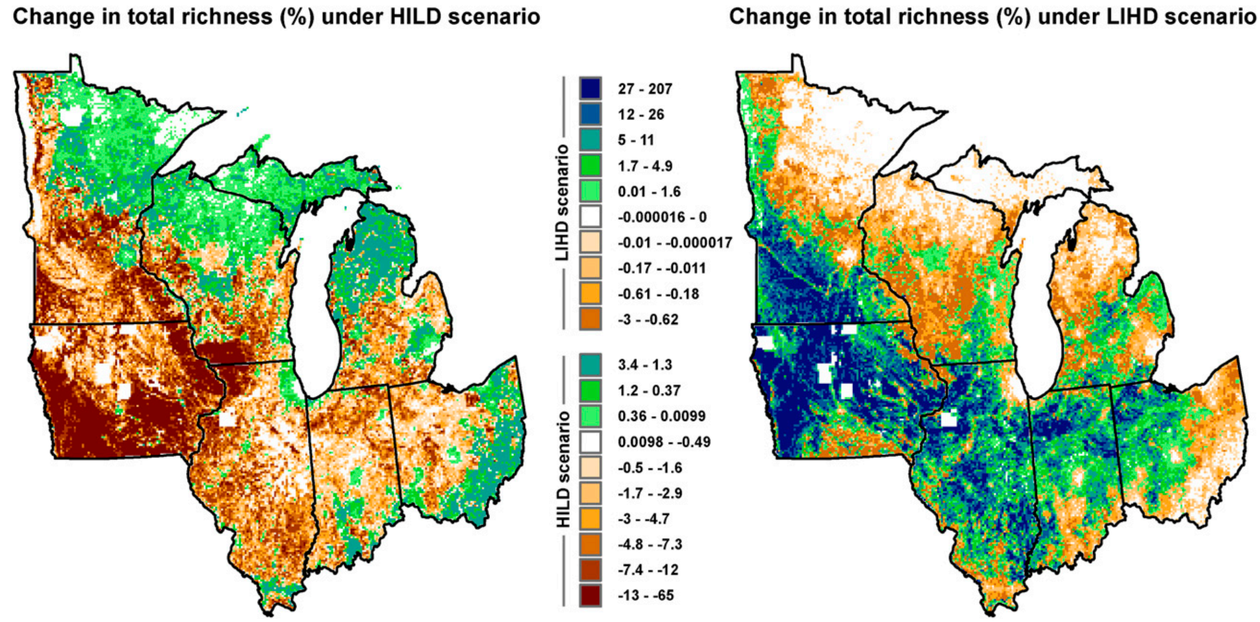

Fig. 2. Percent change in total bird species richness predicted for 25-km^2 landscape blocks by an empirical land cover model (Table 1 and Fig. 1) under divergent bioenergy scenarios. In the HILD scenario (*Left*), 9.5 million ha of marginal land that currently contain LIHD habitats were converted to HILD bioenergy crops. In the LIHD scenario (*Right*), 8.3 million ha of marginal land that currently contain HILD crops were converted to LIHD habitats. Each color shade corresponds with 10% of the distribution of percent change values.

could occur in landscapes that are mostly comprised of HILD habitats on prime agricultural land, and thus subject to relatively little land cover change. Note that changes of ±5% translate to gains or losses of 1–2 species, which is within the error of the predictive model (the average SE for a predicted mean response was 1.1 species), so they should be interpreted with caution. The land cover model predicted that an additional 10% of the landscapes in the region would experience a decline in richness of 5–7% under the HILD scenario. These intermediate declines were distributed broadly across the region. Finally, the model predicted that the HILD scenario would bring declines in richness between 7% and 65% for the remaining 20% of the landscapes in the region. These landscapes were most prevalent in places such as southern and eastern Iowa, southwestern Wisconsin, southeastern Minnesota, and northwestern Illinois, where there are relatively large amounts of hayed, grazed, or set-aside grasslands on marginal soils. Given that these landscapes currently support between 50 and 60 species, a typical 13% percent decrease in richness in these areas translates to a loss of 7–8 species.

Similar to the HILD scenario, the land cover model predicted that the LIHD scenario would bring changes in richness of ±5% for ≈70% of the landscape blocks in the region (Fig. 2). Minor decreases in richness could result from a loss of HILD-associated species due to replacement of HILD crops with LIHD habitat in areas where HILD crops are not currently abundant. Minor increases could occur in landscapes that are dominated by HILD crops on prime agricultural land, and are thus subject to relatively little land cover change. As noted, however, these minor changes are within the error of the forecasting model and should not be overinterpreted. The land cover model predicted that the LIHD scenario would bring an increase in richness of 5–11% for an additional 10% of the landscapes in the region. Finally, the LIHD scenario was projected to increase richness by 12–207% in the remaining 20% of the landscapes in the region. These landscapes occurred throughout the southern half of the study area, and were particularly concentrated in the west, where bird diversity is currently low and landscapes are dominated by HILD crops on marginal land. Given that these landscapes currently host 25–35 species, a typical 26% increase in richness in these areas translates to an additional 7–9 species.

Most environmental policies do not mandate species richness, per se, but rather the persistence of particular rare and endangered species. Thus, we explored the effects of HILD and LIHD scenarios on bird species of conservation concern in the Upper Midwest (28). We did this in two ways. First, we repeated the effort to model landscape-scale species richness as a function of the five land-cover variables. However, this time we used the number of bird species of conservation concern (i.e., SCC richness), instead of the total number of species, as the dependent variable. The AIC_c best model resulting from this analysis was qualitatively similar to the one for total species richness, except that the SCC richness model included a quadratic term for LIHD habitat that caused its positive effect to disappear as LIHD area approached maximum values (Table 1). The fit of the SCC richness model was poorer than that of the total richness model (Fig. 1), but this was not surprising given that SCC richness derives from observations of rare species and encompasses a narrower range of variation than total richness. The model predicted changes in SCC richness under HILD and LIHD scenarios that were qualitatively similar to, if slightly more pronounced than, those for total species richness (Fig. S2). Most notably, the HILD scenario was predicted to decrease SCC richness by 20–90% in 20% of the landscapes, whereas the LIHD scenario was predicted to increase richness between 30% and 1,000% for 20% of the landscape in the region. Second, we used Poisson regression to estimate the effects of HILD and LIHD habitat on the abundances of eight species of conservation concern that are known to nest in open habitats (Fig. 3). We found that increasing LIHD habitat in the landscape had consistent positive effects on the abundances of these species. In contrast, increasing HILD crops in the landscape often had neutral or negative effects on abundance. For species where HILD crops had a positive effect, the magnitude of the effect was generally smaller than that of LIHD habitat (the Dickcissel being an exception), so converting from LIHD to HILD habitat would be expected to have a net-negative impact on abundance.

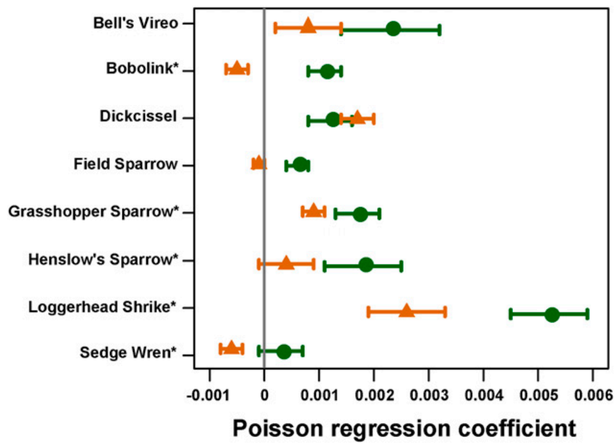

Fig. 3. Slope coefficients and SEs from Poisson regression of abundance vs. area (hectares) of HILD (orange) and LIHD (green) habitat in the landscape. Each of the eight species listed nests in open habitats, and all are currently considered Species of Conservation Concern by the US Fish and Wildlife Service. Asterisks denote species slated for focal species campaigns.

Discussion

Choices between HILD and LIHD crops will have important impacts on avian species richness in Midwestern landscapes. The forecasting model developed here projected that replacing LIHD habitats, such as mixed-species grasslands, with HILD bioenergy crops, such as corn and soybean, could lead to declines in richness between 7% and 65% in 20% of the region. The areas predicted to be most affected include southern and eastern Iowa, southwestern Wisconsin, southeastern Minnesota, and northwestern Illinois. Conversely, if HILD bioenergy crops on marginal land were replaced with LIHD crops, the model suggests that 20% of the Midwest could see an increase in richness between 12% and 207%. The largest impacts of this conversion are expected to occur in northern and western Iowa, southwestern Minnesota, northwestern Ohio, northern Indiana, and much of Illinois.

In addition to influencing overall bird richness, our analysis suggests that choices between HILD and LIHD crops will have a substantial impact on rare and declining species of concern to wildlife managers. Specifically, the number and abundance of these species is expected to decrease in many areas given a proliferation of HILD bioenergy crops, and increase with a transition to LIHD bioenergy crops. The US Fish and Wildlife Service recently implemented a focal species strategy, which involves campaigns to develop and implement management activities for high-priority bird species (29). Several species in our analysis are slated for these focused efforts (Fig. 3), and most of these species showed positive responses to LIHD habitats. Thus, it might be beneficial if focal species efforts proceed with bioenergy development in mind. Carefully designed policies could serve multiple objectives if they encourage both the production of low-carbon energy and the conservation of imperiled species (8).

Conclusions from this study are derived from empirical observations at a large number of study sites distributed throughout the study region. However, it is important to note that they also depend on several important assumptions. First, model coefficients are derived from variation in HILD and LIHD crops in space, and conclusions assume that variation in space will have similar effects as variation in time (i.e., a space-for-time substitution) (30). This assumption is supported by the fact that much of the region was recently covered by open perennial habitat (10) and by observations that conversion from perennial to annual habitats (21, 31), and back again (19, 32), is associated with changes in bird community structure. Second, conclusions are based on the assumption that future management of HILD crops will resemble current management, and that future management of LIHD crops will have similar effects as the combined management of open perennial habitats in this analysis, which contain an unspecified fraction of grazed, mowed, burned, and unmanaged grasslands and prairie. The effects of bioenergy crop management on biodiversity have not been widely studied, and the few available reports (e.g., ref. 33) indicate that this is an important topic for future research. A third assumption relates to the spatial arrangement of habitats within and across landscapes. In their current form, the models for total richness and SCC richness remove or add species as a simple function of the area of HILD and LIHD habitats in a landscape. It is possible that including additional information on the spatial configuration of that area would improve the precision of future models. Note, however, that extensive literature reviews have concluded that habitat amounts are the strongest and most-consistent predictors of landscape-scale diversity, whereas the effects of spatial configuration are less clear (34). Finally, it is important to recognize that the reductions in species richness described in this analysis are not necessarily synonymous with local species extinctions, and certainly do not imply global species extinctions. It is possible that species could remain in landscapes at very small population sizes, such that they are not easily detected through efforts such as the BBS, or that species could persist in other parts of their geographic range, beyond the borders of our analysis.

Despite the many assumptions, we believe that findings from this analysis are useful for understanding how different bioenergy crops, and the policies that promote them, will impact bird diversity across the Upper Midwest. They also highlight that some locations in the Upper Midwest could encounter relatively great conservation opportunities or management challenges, depending on bioenergy crop choices, the prevalence of marginal land, and current land cover. This spatially explicit information could be useful to stakeholders in different parts of the region as they gather to consider the costs and benefits of different forms of bioenergy production in their area.

Materials and Methods

Bird Data. We attained landscape-scale data on total bird species richness and SCC richness for 265 BBS routes for the year 2008 from the US Geological Survey (22). The BBS follows a standard protocol, where one observer drives along a 40-km transect once during early to mid-June and stops every 800 m to count birds within a 400-m radius of the sampling site for 3 min. The total area sampled per route is $\pi(400\text{ m})^2 \times 50$ sites = 25.1 km^2.

There were 161 species of land birds included in our analysis of total bird species richness. Total richness for each landscape was computed as the sum of all species observed at all stops along a route. Given the limited duration of the survey, it is likely that richness measures are underestimates. To deal with this issue, methods have been developed to estimate extrapolated richness based on the species-abundance distribution at a site (35). We computed Chao2 and ACE extrapolated richness estimates (36) for the landscapes in this study and found that these estimates were not substantially different (1–3 species larger) than observed values. Given the inherent assumptions of extrapolation methods and the small difference between observed and extrapolated estimates, we used observed values in our analysis.

For the purposes of this study, species of conservation concern included 31 landbird species that are detected by the BBS and are included on the 2008 Species of Conservation Concern list of the US Fish and Wildlife Service (28) for the biomes in our study area. Eight of these 31 species nest in open habitats, and are often found in HILD and LIHD bioenergy crops: Bell's Vireo (*Vireo bellii*), Bobolink (*Dolichonyx oryzivorus*), Dickcissel (*Spiza americana*), Field Sparrow (*Spizella pusilla*), Grasshopper Sparrow (*Ammodramus savannarum*), Henslow's Sparrow (*Ammodramus henslowii*), Loggerhead Shrike (*Lanius ludovicianus*), and Sedge Wren (*Cistothorus platensis*).

Land Cover Data. The area of HILD, LIHD, woodland, wetland, and urban habitat within the sampling area of each BBS route was determined using the CDL, a remotely sensed dataset with 56-m resolution from the USDA National Agricultural Statistics Service (23). The native CDL classification system was modified for the analysis as follows. Corn, soybeans, sweet corn, and popcorn pixels were reclassified as HILD pixels. LIHD pixels were a mix of hay fields, alfalfa fields, pastures, and unmanaged grasslands. Woodland included deciduous, coniferous, and mixed forests and wooded wetlands. Wetland included all herbaceous wetlands. Urban land included moderately and highly urbanized areas, where impervious surface within a pixel was ≥50%. Other land cover types were ignored in the analysis because they were not particularly abundant (the sum of all other land cover types averaged 15%) and to minimize collinearity among independent variables. We extracted the area for each of the five land-use types from buffers around digitized survey routes (37). Buffers extended 400 m from the route to reflect the distance that birds were sampled during the BBS. The area within this buffer was, ideally, 0.8 km × 40 km = 32 km^2. To scale habitat area derived from the rectangular buffer (total = 32 km^2) to the sum of circular buffers sampled by the BBS (total = 25.1 km^2, see above), we assumed that the proportions of habitats were similar across scales and multiplied land cover areas by the factor 25.1 km^2/32 km^2 = 0.78.

Model Fitting. Modeling of total species richness and SCC richness was conducted using an information-theoretic approach (25). We began the process by entering all five land-cover variables, along with their quadratic terms (to allow for the possibility of nonlinear relationships), into a single, full model. Next, we estimated model coefficients and bias-corrected AIC_c values for the full and all-possible reduced models. Models with the lowest AIC_c values were selected to make predictions about changes in bird diversity given different bioenergy scenarios (Table 1). Residuals from the AIC_c best models were checked for spatial autocorrelation by computing Moran's I, a measure of global spatial autocorrelation (up to a distance threshold of 120 km, in this case) that ranges from −1.00 to 1.00. These analyses did detect spatial autocorrelation in the model residuals. However, the magnitude of this autocorrelation was small ($0.04 \leq I \leq 0.06$ across response variables), and accounting for it in the modeling process had a negligible effect on parameter estimates and model R^2 values. Thus we used and report results from simpler general linear models.

Mapping Avian Richness. We used the parameter estimates from the AIC_c best models (Table 1) to predict total bird species richness and SCC richness from area (hectares) of HILD, LIHD, and forested habitats within 25.4-km^2 landscape blocks (5,040 × 5,040 m) across the Upper Midwest. Observed richness values for each BBS route were mapped at route centroids and colored using the same scale as the prediction maps to facilitate a visual analysis of model residuals (Fig. 1).

Mapping Changes in Avian Richness. Forecasts for changes in total bird species richness and SCC richness, depicted in Fig. 2 and Fig. S2, were based on two distinct bioenergy scenarios focused on marginal land. Marginal land was defined using the LCC system of the USDA National Resources Conservation Service (27, 38). In the LCC system, land in capability classes 1 and 2 is considered prime cropland with relatively few cropping restrictions. Land in classes 3 and 4 is considered marginal cropland with "severe" to "very severe" cropping limitations, due to soil characteristics, flooding, or erosion potential. Land in classes 5–8 is considered poorly suited for crops, although there are many cases where crops are being grown on this land. For the purpose of this study, marginal land was considered land in classes 3–8. The LCC is based on soil survey data, which is mapped at, approximately, the 1:16,000 scale. For this study, LCC polygons were rasterized to 56-m resolution to overlay LCC and CDL information.

In the increased HILD scenario, all 9.5 million ha of marginal land in the region that contained LIHD habitats (7.3 million ha in capability classes 3 and 4, and 2.2 million ha in capability classes 5–8) were converted to HILD crops. Then we used coefficients from the empirical models for current richness (Table 1) to compute new grids of richness values for the HILD scenario. In the increased LIHD scenario, all 8.3 million ha of marginal land in the region that contained HILD crops (7.7 million ha in capability classes 3 and 4 and 0.6 million ha in capability classes 5–8) were converted to LIHD habitat. Then we used the empirical models for current richness to compute richness values for the LIHD scenario. After calculating new richness grids, we computed the percent change per landscape block ($[(y_2 - y_1)/y_1] \times 100$) for each of the HILD and LIHD scenarios using the current predicted richness values (y_1) and those predicted under a given scenario (y_2).

The reliability of forecasts from prediction models depends on the degree to which they are derived from interpolation vs. extrapolation. Some 98.4% of the predictions for the HILD scenario were based on HILD values that were below the maximum observed area for BBS landscapes, which was 2,306 ha. The remaining 1.6% of the predictions came from HILD values between 2,306 and 2,446 ha. Thus, our conclusions about changes under the HILD scenario are largely based on interpolation and not extrapolation. Even in cases where there was extrapolation, HILD scenario values were, at most, 6% higher than observed ones. Similarly, 97.1% of the predictions for the LIHD scenario were derived from LIHD values that were below the maximum observed area of 1,712 ha, whereas 2.9% of the predictions came from LIHD values between 1,712 and 2,414 ha. Thus, conclusions about changes under the HILD scenario are mostly based on interpolation and not extrapolation. In cases where there was extrapolation, LIHD scenario values were, at most, 41% higher than observed ones.

Abundance of Species of Concern. We used Poisson regression, adjusted for overdispersion (39), to assess relationships between the area of HILD and LIHD habitats and abundance for each of eight species of conservation concern that nest in open habitats (described previously). Regression coefficients and SEs from these analyses are illustrated in Fig. 3.

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