RESEARCH ARTICLE

Identifying opportunities for conservation embedded in cropland anthromes

John E. Quinn · Ron J. Johnson · James R. Brandle

Abstract Anthromes characterize terrestrial ecological patterns in terms of human populations and how these populations use the land. However, data are needed to assess the conservation value of habitats embedded in anthromes, particularly when possible conservation opportunities do not reflect the traditional focus of conservation in a region. One such region is the central Great Plains of North America where the grassland biome has been replaced by a cropland anthrome with a landscape mosaic dominated by arable crops with small patches of grass and woody cover embedded within. Grassland birds have been the primary focus of avian conservation research and practice, a reflection of the biome classification. Yet conservation of other bird species may be a missed conservation opportunity better identified via anthromes. In this project we evaluated the variation in abundance of shrubland and open forest birds in response to heterogeneity and availability of woody and grass cover at local (100 m) and landscape (5,000 m) scales. We found that local heterogeneity, a trait of croplands not grasslands, was the best predictor of abundance, with five species of conservation concern more abundant in heterogeneous sites. There was limited response to woody cover and a mixed response across scale to grassland cover with local response positive and landscape negative. These data suggest that increasing heterogeneity in the Great Plains cropland anthrome may provide a unique conservation opportunity. In particular, farm systems have the capacity to complement regional species conservation efforts by increasing heterogeneity. Importantly these conservation efforts may not come at the expense of grassland bird conservation or crop production. The limited response to extensive grassland cover at the larger scale suggests that in Great Plains agroecosystems, a diverse mix of crops, pasture, and linear habitats would allow farmers to continue to produce food while contributing to the conservation of species of concern.

Keywords Agroecosystems · Avian · Farmland birds · Heterogeneity · Land sharing and land sparing · Landscape · Novel ecosystem

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Introduction

The need for conservation action beyond protected areas is apparent (Scott et al. 2001). Many landscapes outside protected areas, however, do not mimic natural land cover predicated on potential vegetation (Ellis et al. 2010: Kareiva and Marvier 2012) and thus present a challenge in setting conservation goals and management objectives. Anthromes characterize the diversity of global ecological land cover patterns created and sustained by human populations and land use while also incorporating their relationships with biotic communities (Ellis and Ramankutty 2008). Such landscapes are often a mix of novel (Hobbs et al. 2006) and managed ecosystems such as patches or linear strips of grassland and woody cover embedded within agricultural landscapes. Indeed, twenty-five percent of woodlands are found embedded within cropland anthromes (Ellis and Ramankutty 2008; Ellis et al. 2010). Of particular interest is the capacity of the anthrome framework to identify unique conservation opportunities that may currently lack recognition or focus under current landscape classification structures, in particular biomes (Martin et al. 2014).

An anthrome may contain ecosystems that have unique and potentially unrecognized conservation challenges and opportunities. In cropland anthromes, these environments exist because of social constructs (e.g., property boundaries), soil and water conservation practices (e.g., windbreaks), or landscape features that prevented the land from being farmed (e.g., riparian buffers). Today these agricultural features are broadly recognized as ecologically and culturally significant (Johnson et al. 2011; Schoeneberger et al. 2012). Yet, the complexity of local and landscape interactions limits their blanket application for conservation (Batáry et al. 2011). For example, in France specialist and area sensitive species require contiguous habitat while generalists may benefit from heterogeneity (Teillard et al. 2014). Thus, given the prevalence of these land use types, better data are needed to identify how the extent and arrangement of these elements embedded in agroecosystems contribute to local conservation efforts and how this contribution may vary by spatial and historical context.

One example of such an opportunity is the conservation of non-grassland obligate bird populations in the North American cropland anthrome. Populations of these species are declining in much of the eastern and western United States (Askins 1993; Schlossberg et al. 2010) and many are considered to be species of conservation concern (Rich et al. 2004). The observed decline is attributable to reforestation and urbanization across much of the eastern portion of the United States (Drummond and Loveland 2010; King and Schlossberg 2014) and urbanization, energy development, and water usage in the west (Noss et al. 1995; Hoekstra et al. 2005).

While shrubland and open forest habitat is declining or degrading in much of the eastern and western United States, woody cover has become more abundant in much of the eastern Great Plains in the central United States, an ecoregion historically associated with extensive grasslands and currently with extensive croplands. The central Great Plains of North America historically transitioned from tallgrass prairie in the east to mixed and short grass farther west (Samson et al. 1998; Askins et al. 2007). However, land use and land cover of the region has undergone dramatic change in the last 200 years (Ellis et al. 2010). Today, agricultural land uses dominate the study area (Henebry et al. 2005; Ellis et al. 2010). Embedded in this high intensity agroecosystem are grasslands and woodlands of various shapes and extents (Perkins et al. 2003, Supplementary Fig. 1).

Consequently, the presence of non-grassland bird species has increased the richness of bird communities in the Great Plains with 75 % of bird species and 83 % of individuals detected on USGS Breeding Bird Survey routes being forest edge or generalist species (Pierce et al. 2001). Thus to better understand the response of species to land use and land cover in cropland anthromes and identify possible opportunities for conservation in agroecosystems, we consider here the variation in abundance of twelve avian species of conservation concern (Rich et al. 2004) and five species not considered species of concern. Specifically we investigated the response of these bird species to land cover gradients dictated by farm management beyond the crop field (percent woody cover, percent grassland cover, and land cover heterogeneity) in agroecosystems at two spatial scales (100 m and 5,000 m).

We selected six model parameters (Table 1) by reviewing published literature from both avian and agroecosystem conservation (e.g., Perkins et al. 2003; Benton et al. 2003; Murphy 2003; Bengtsson et al. 2005; Wilson et al. 2009; Schlossberg et al. 2010).

Table 1 Description and summary statistics for local (within 100 m from the center of each point) and landscape (within 5,000 m from the center of sampled farms) variables

Scale/Parameter	Mean	SD
Local		
Woodland	2.9	8.2
Grassland	25.1	38.0
Shannon diversity index (SHDI)	0.8	0.4
Landscape		
Woodland	5.1	5.2
Grassland	28.0	16.4
Shannon diversity index (SHDI)	1.7	0.2

Woody cover, including windbreaks, riparian buffers, hedgerows, and volunteer trees and shrubs provide the core habitat of these species (Perkins et al. 2003) and other farmland species (Green et al. 1994). Grassland cover was once the predominant land cover in the region and grassland environments provide a greater abundance of prey then comparable crop fields (Robertson et al. 2012). Lastly land cover heterogeneity has been shown to be positively related to increased diversity (Batáry et al. 2010; Fahrig et al. 2011: Pickett and Siriwardena 2011). We considered each of these parameters at local (i.e., farm scale) and landscape scales (Burel et al. 1998).

Methods

We sampled 285 points embedded within 19 farms in the central Great Plains of Nebraska, USA. Points were assigned randomly within the farm boundary; as such, they fell across cropland, field margins, pasture, set-aside grasslands, windbreaks, riparian strips, and shrub rows. All farms had organic row crops (e.g., corn or soybean) as part of their operation and many included livestock. Farm size ranged between 65.8 ha (160 acres) and 2,472.9 ha (1,017 ac). Farms were distributed across the eastern third of the state and were at least 1,609 m apart. We located survey points on each farm by digitizing the farm perimeter and randomly selecting up to 16 points > 250 m apart within each farm using HawthsTools extension (Beyer 2004) for ArcMap (ESRI Redlands, CA).

Trained field ornithologists visited each point four times between 14 May and 10 July during 2007, 2008,

and 2009. We applied unbounded point counts to maximize detections. While not as accurate for density estimates as other methods (e.g., fixed radius counts), in addition to maximizing detections, unbounded counts reduce bias with regard to bird-distance estimation, over-estimation at the perimeter of a count circle, and birds dispersing in response to the observer (Bani et al. 2006). In addition, while past analysis techniques were more limited by variations in detectability, we applied process-observation models (Royle and Dorazio 2008) to more accurately account for variation in detectability caused by weather and observer bias (Quinn et al. 2011). Thus, by employing process-observation models, we take advantage of the increased number of observations in the data set, a valuable outcome when sampling populations with low probability of detection.

All counts were 5 min in duration and conducted within 4 hours of sunrise. We recorded the species and number of all birds heard or seen. We recorded average wind speed for ten seconds prior to each count using a Kestrel® 1000 Pocket Wind Meter (Boothwyn, PA). We did not conduct counts during times of high winds or heavy rain that limited visibility and we varied order and time of counts to limit bias.

We measured percent woody cover, percent grass cover, and heterogeneity as the Shannon Diversity Index within 100 m from the center of each point, reflecting local scale variability, and within 5,000 m from the center of each farm, reflecting landscape variability (Table 1, Supplementary Fig. 1). All measures at both scales were obtained using ArcGIS, v9.3 (ESRI Redlands, CA) and Fragstats v3.3 (McGarigal et al. 2002) from land cover data compiled and validated based on Hierarchical All Bird System's habitat associations and local conditions (Rainwater Basin Joint Venture Rainwater Basin Joint Venture 2012).

We used hierarchical Poisson-binomial N-mixture models (Royle 2004; Clark 2005; Royle and Dorazio 2008) to predict the relationship between estimated bird abundance and the six selected habitat variables. N-mixture models use spatial and temporal replication to estimate abundance and to account for the varied and imperfect detection probability of a species. By accounting for varied detection probability, model estimated abundances are more accurate than using a maximum or average across multiple counts. Model parameters were checked for multicolinearity. We

Table 2 Mean abundance estimates (log scale) and standard deviation from posterior distribution of N-mixture models for shrubland birds of conservation concern

Species	Wood100		Grass100		SHDI100		Wood5000		Grass5000		SHDI5000	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Baltimore Oriole (*Icterus galbula*)	0.03	0.05	0.06	0.06	0.07	0.06	0.08	0.13	−0.03	0.11	0.17	0.12
Bell's Vireo (*Vireo bellii*)	**−0.38**	**0.19**	0.02	0.23	**0.55**	**0.21**	0.17	0.30	**0.84**	**0.28**	0.51	0.33
Brown Thrasher (*Toxostoma rufum*)	**−0.12**	**0.06**	−0.02	0.07	0.06	0.06	0.18	0.18	−0.06	0.16	−0.03	0.17
Eastern Kingbird (*Tyrannus tyrannus*)	−0.10	0.06	**0.18**	**0.06**	**0.15**	**0.05**	**−0.25**	**0.10**	0.05	0.09	0.15	0.09
Eastern Wood-Pewee (*Contopus virens*)	−0.32	0.24	0.33	0.30	0.50	0.26	−0.15	0.50	0.62	0.48	0.74	0.45
Eastern Towhee (*Pipilo erythrophthalmus*)	0.16	0.19	0.21	0.36	0.56	0.30	**1.36**	**0.45**	0.39	0.52	0.57	0.55
Field Sparrow (*Spizella pusilla*)	**−0.32**	**0.13**	**−0.28**	**0.07**	−0.12	0.06	−0.71	0.40	**−0.70**	**0.31**	0.25	0.35
Great-Crested Flycatcher (*Myiarchus crinitus*)	−0.04	0.28	0.39	0.45	**0.85**	**0.33**	0.59	0.47	0.62	0.37	**−0.89**	**0.44**
Lark Sparrow (*Chondestes grammacus*)	0.04	0.08	0.09	0.13	−0.01	0.11	0.48	0.40	−0.09	0.36	−0.19	0.38
Northern Flicker (*Colaptes auratus*)	−0.04	0.08	0.10	0.09	0.18	0.09	−0.17	0.32	0.40	0.28	0.61	0.35
Orchard Oriole (*Icterus spurius*)	0.08	0.17	**0.41**	**0.09**	**0.28**	**0.08**	0.03	0.09	**−0.19**	**0.08**	0.10	0.08
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	−0.01	0.07	−0.01	0.09	0.02	0.08	0.12	0.33	0.15	0.29	0.27	0.32

Credible intervals not overlapping zero are highlighted in bold

Wood100, percent woody cover at 100 meters; Grass100, percent grass cover at 100 meters; SHDI100, habitat heterogeneity at 100 meters. Other estimates for percent cover at 5000 meters

applied hierarchical modeling to control for effects of spatial-autocorrelation and pseudoreplication that may result from analysis of multiple points within multiple sites. Observer and wind speed were included as detection covariates.

We assigned non-informative priors with normal distributions (Mean = 0, SD = 1,000) to parameters and intercepts (McCarthy 2007; Kéry 2010). Bayesian analysis was run with WinBugs (Lunn et al. 2000) through the R2WinBugs package (Sturtz et al. 2005) for program R v. 2.12.0 (R Development Core Team 2010) using three Markov Chain Monte Carlo (MCMC) simulation chains with 250,000 iterations, discarding the first 100,000 iterations as a burn-in and thinning chains by 50:1. We checked results for autocorrelation and for convergence with Gelman and Rubin's convergence diagnostic (Gelman and Rubin 1992; Brooks and Gelman 1998). Given the limitations of the deviance information criterion (DIC) as a model selection criterion for hierarchical models (Celeux et al. 2006), we present here the result of full models, accepting the loss of precision (Bolker et al.

2009), with inference based on 95 % Bayesian credible intervals.

Results

During 3 years of sampling, we observed 17 non-grassland obligate species listed for regional conservation concern in at least one of ten Bird Conservation Regions that lie within and beyond the central and tall grass prairies (Rich et al. 2004). Of these, twelve species had sufficient data for model convergence, with models for the remaining five species failing to converge. Varied detection probability was evident for five species.

The abundance of three species of conservation concern declined as woody cover became more prevalent within 100 m (Table 2; Fig. 1a). The Eastern Kingbird (all scientific names given in Table 2) and Orchard Oriole were more abundant but the Field Sparrow less abundant at points with greater grass cover within 100 m (Table 2; Fig. 1b). Five species
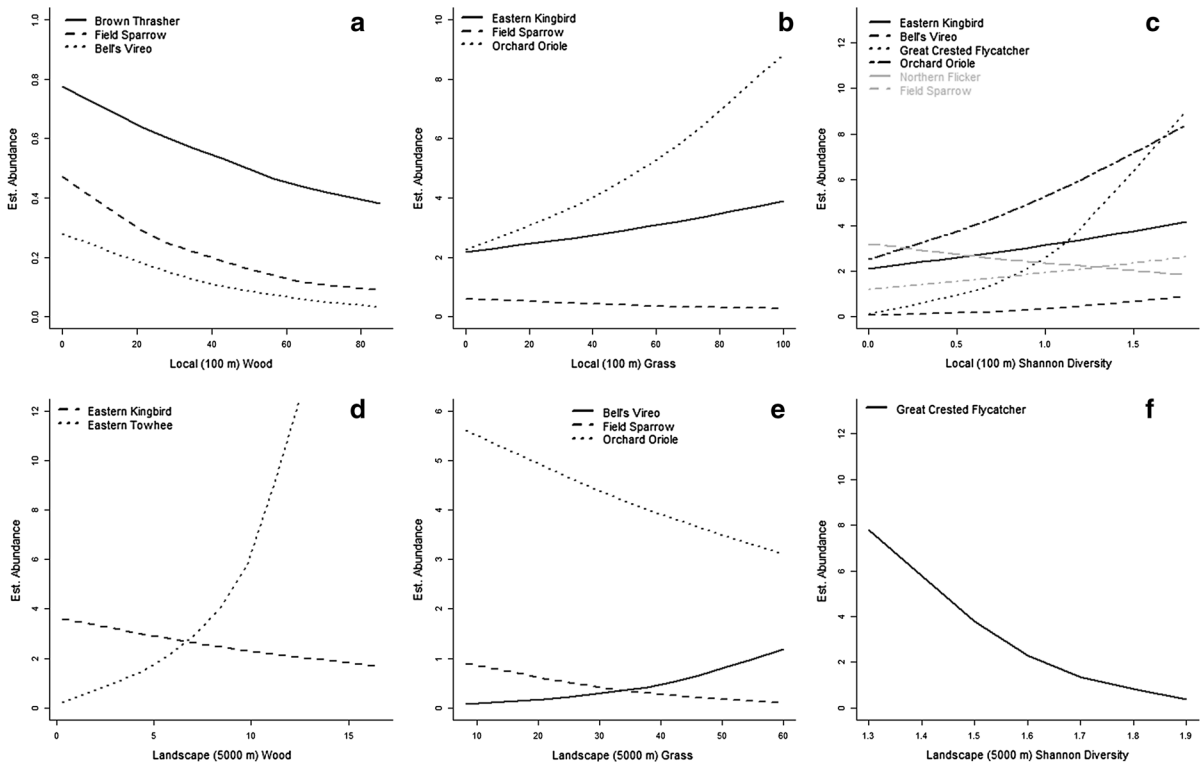
Fig. 1 Predicted relationship from N-mixture models between abundance of species of conservation concern and local (**a,b,c**) and landscape variability (**d,e,f**). Only strongly supported relationships are shown, except for local diversity where weak relationships are shown in *gray*. Credible intervals excluded for clarity, but measures of precision reported in Table 2

Table 3 Mean abundance estimates (log scale) and standard deviation from posterior distribution of N-mixture models for shrubland birds not currently of conservation concern

Species	Wood100		Grass100		SHDI100		Wood5000		Grass5000		SHDI5000	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Brown-headed Cowbird (*Molothrus ater*)	**−0.11**	**0.04**	**0.09**	**0.03**	0.00	0.03	−0.06	0.10	−0.04	0.09	−0.13	0.10
Blue Jay (*Cyanocitta cristata*)	−0.02	0.05	−0.07	0.08	−0.01	0.07	**0.59**	**0.26**	−0.05	0.23	0.19	0.26
Common Yellowthroat (*Geothlypis trichas*)	−0.01	0.07	−0.11	0.08	0.08	0.08	−0.41	0.28	−0.40	0.25	0.42	0.26
Gray Catbird (*Dumetella carolinensis*)	−0.04	0.28	0.39	0.45	**0.85**	**0.33**	0.59	0.47	0.62	0.37	**−0.89**	**0.44**
Red-bellied Woodpecker (*Melanerpes carolinus*)	−0.01	0.07	0.12	0.13	0.12	0.09	**0.87**	**0.47**	−0.20	0.40	**0.88**	**0.43**

Credible intervals not overlapping zero are highlighted in bold

Wood100, percent woody cover at 100 meters; Grass100, percent grass cover at 100 meters; SHDI100, habitat heterogeneity at 100 meters. Other estimates for percent cover at 5000 meters

were more abundant at points with greater local (100 m) heterogeneity (Table 2; Fig. 1c), though the effect for Field Sparrow and Northern Flicker is less

certain. The Eastern Kingbird was less and the Eastern Towhee more abundant at points with greater percentage of woodland within the larger landscape

(Table 2; Fig. 1d). The Bell's Vireo was more abundant while the Orchard Oriole and Field Sparrow were less abundant in landscapes with an increased percent of grassland within 5,000 m (Table 2; Fig. 1e). Only the Great-created Flycatcher was more abundant in more heterogeneous landscapes (Table 2; Fig. 1f).

Of the species not of conservation concern (Table 3), the Gray Catbird was more abundant at points with greater heterogeneity locally but, in contrast, less abundant with greater heterogeneity at the larger-scale landscape scale. The Red-bellied Woodpecker was more abundant with greater heterogeneity at the larger landscape scale. Brown-headed Cowbirds were more abundant at points with more grassland locally but less abundant at points with more local woody cover. There was no response to landscape level grass cover. Two species, Blue Jay and Red-bellied Woodpecker were more abundant in landscapes with greater woody cover.

Discussion

Although the central Great Plains of North America were originally dominated by grasslands, agriculture now dominates much of the region, hence it is better described as a cropland anthrome. Novel ecosystems embedded in anthromes provide a space for conservation beyond protected areas and crop fields that are typically the focus of research and practice in applied ecology (Hobbs et al. 2006; Lindenmayer et al. 2008; Quinn 2013). Embedded in an agricultural matrix, they provide nest sites, foraging space, and cover for many species. Remnant woody and grassland habitat support declining bird populations and offer potential conservation opportunities.

The value of local heterogeneity as a conservation target in agroecosystems is highlighted by the evidence that five species of conservation concern, including habitat specialists, were more abundant in heterogeneous areas. Interestingly, of the non-listed species only the Gray Catbird was more abundant in heterogeneous areas, suggesting that species not of current conservation concern may be better adapted to the more homogeneous landscapes associated with intensive agroecosystems or perhaps extensive grasslands. Habitat heterogeneity is a key element of wildlife-friendly farming (Fischer et al. 2008), suggesting that land sharing, where farming and conservation goals are met

on the same lands, may benefit shrubland and open forest birds of conservation concern. The measured heterogeneity in the system may reflect small diverse fields found on participating farms and the presence of field buffers. It may also be a proxy of woody or grassy patches and strips not captured at the grain of imagery used. The lower abundance of Great-crested Flycatchers where there was greater heterogeneity at the larger scale suggests a preference for larger contiguous landscapes, likely forest cover.

The lack of and negative response to woody cover was unexpected, though Shake et al. (2012) also showed that proportion of forest was not important for eight shrubland birds. However, combined with the response to heterogeneity, the lack of importance may demonstrate a patch-matrix interaction (Prevedello and Vieira 2010). We can infer from the mostly neutral or negative response at the local and landscape scales that while these species do require patches of shrub and/or tree cover for nesting, perching, or cover, extensive woody cover is of lower conservation value for these species. Furthermore, the value of individual woody patches have been shown to be moderated by the matrix in which they are embedded (Wilson et al. 2009; Batáry et al. 2010), with availability of linear woody cover (i.e., hedge length) only significant in simple landscapes (Batáry et al. 2010). Thus, one possible explanation is that matrix quality around the woody patches (e.g., crop type or heterogeneity) is overshadowing the influence of patch availability. Further work is needed to explicitly test this pattern in the Great Plains to better connect with the European literature (Batáry et al. 2011). Lastly, it may be that many of the smaller patches of woody cover were not captured at the grains of the land cover images or any of the additional habitat layers added, with woody patches being better represented by heterogeneity.

Local grassland may provide foraging opportunities for the Eastern Kingbird and Orchard Oriole, both species that forage away from woody edges (Puckett et al. 2009). However, increased grassland at greater extents provided few benefits to the above species. The exception was the Bell's Vireo, which was more abundant when embedded in extensive grasslands at the larger scale. This presents an interesting conservation and management challenge when combined with the positive response of the Bell's Vireo to local heterogeneity. In general, the limited requirement for extensive grassland suggests that the birds we studied

can benefit in working agroecosystems from small-scale land use change, unlike many area sensitive grassland bird species (Johnson and Igl 2001). The more frequent focus in the Great Plains has been on grassland birds, admittedly a group of high conservation need (Askins et al. 2007). Grassland obligates, however, may not be compatible with extensive agriculture (Quinn et al. 2012). Furthermore, a conservation focus on grassland birds does not reflect the current land cover, perhaps best represented as a cropland anthrome (Ellis et al. 2010) rather than a grassland biome.

The lack of response to extensive grassland cover suggests that in Great Plains agroecosystems, a diverse mix of crops, pasture, and linear habitats would allow farmers to continue to produce food while contributing to the conservation of the above species of conservation concern. While the value of narrow grass margins to grassland obligates varies (Quinn et al. 2012), and woody encroachment is detrimental to many grassland obligate bird species (Askins et al. 2007), management for heterogeneity may provide suitable habitat for birds in areas unsuitable for grassland obligate species. Indeed the high return for conservation with low opportunity costs to farmers (and grassland bird conservation) has potential as a targeted agri-environmental scheme in the Great Plains of North America.

Ultimately, capturing this conservation opportunity could benefit bird populations within cropland anthromes and allow a shift to greater focus on larger scale projects that restore, protect, or spare larger contiguous grasslands necessary for many grassland species. Thus, conservation in agroecosystems can be seen as a strategy complementing grassland bird conservation in protected areas rather than managing for all species in cropland anthromes. This shift could be seen as analogous to the designation of farmland birds in Europe, where many species that are the focus of conservation likely had lower abundance pre-farming or if reforesting occurred across Europe.

Given the low likelihood of converting vast swaths of row-crop agriculture back to prairie and the opportunity costs to farmers of landscape-scale grassland conservation, conservation efforts in local agroecosystems associated with row-crop agriculture and cropland anthromes provides multiple benefits. Shrubland and open forest species fill many ecological habitats created from the conversion of grasslands to croplands and from subsequent extensive tree planting and may provide ecosystem services to the farm (Whelan et al. 2008; Zhang et al. 2007). Furthermore, these habitats provide many ecosystem services to agricultural lands (Schoeneberger et al. 2012) suggesting potential to bundle conservation efforts and ecosystem services.

These data extend our understanding of the value of using anthromes as a conservation framework (Martin et al. 2014), in particular for species that are not historically a conservation target in the region of interest. Given the decline of early successional forest in the eastern United States (King and Schlossberg 2014) and the value prescribed to intact forest conservation beyond the Great Plains, investment in shrubland and open forest bird conservation in the eastern Great Plains may be a unique conservation opportunity well suited for cropland anthromes. Although the conservation opportunity in this anthrome is clear, policy development (e.g., Kleijn et al. 2004; Atwell et al. 2011; Pe'er et al. 2014) and the rapid homogenization and intensification of farmland (Matson et al. 1997; Krebs et al. 1999), including loss of linear woodlands and increased local and landscape homogeneity threatens to eliminate this opportunity.

References

Askins RA (1993) Population trends in grassland, shrubland, and forest birds in eastern North America. Curr Ornithol 11:1–34

Askins RA, Chávez-Ramírez F, Dale BC, Haas CA, Herkert JR, Knopf FL, Vickery PD (2007) Conservation of grassland birds in North America: understanding ecological processes in different regions. Ornithol Monogr 64:1–46

Atwell RC, Schulte LA, Westphal LM (2011) Tweak, adapt, or transform: policy scenarios in response to emerging bioenergy markets in the U.S. Corn Belt. Ecol Soc 16:10. [online] URL: http://www.ecologyandsociety.org/vol16/iss1/art10/

Bani L, Massimino D, Bottoni L, Massa R (2006) A multiscale method for selecting indicator species and priority conservation areas: a case study for broadleaved forests in Lombardy, Italy. Conserv Biol 20:512–526

Batáry P, Matthiesen T, Tscharntke T (2010) Landscape-moderated importance of hedges in conserving farmland bird diversity of organic vs. conventional croplands and grasslands. Biol Conserv 143:2020–2027

Batáry P, Báldi A, Kleijn D, Tscharntke T (2011) Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Philos Trans R Soc B 278:1894–1902

Bengtsson J, Ahnström J, Weibull A (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J Appl Ecol 42:261–269

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? TREE 18:182–187

Beyer HL (2004) Hawth's analysis tools for ArcGIS. Available at http://www.spatialecology.com/htools

Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, White JSS (2009) Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol Evol 24:127–135

Brooks SP, Gelman A (1998) General methods for monitoring convergence of iterative simulations. J Comput Graph Stat 7:434–455

Burel F, Baudy J, Butet A, Clergeau P, Delettre Y, Le Coeur D, Lefeuvre JC (1998) Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecol 19:47–60

Celeux G, Forbes F, Robert CP, Titterington DM (2006) Deviance information criteria for missing data models. Bayesian Anal 1:651–673

Clark JS (2005) Why environmental scientists are becoming Bayesians. Ecol Lett 8:2–14

Drummond MA, Loveland TR (2010) Land-use pressure and a transition to forest-cover loss in the eastern United States. Bioscience 60:286–298

Ellis EC, Ramankutty N (2008) Putting people in the map: anthropogenic biomes of the world. Front Ecol Environ 6:439–447

Ellis EC, Klein Goldewijk K, Siebert S, Lightman D, Ramankutty N (2010) Anthropogenic transformation of the biomes, 1700 to 2000. Glob Ecol Biogeogr 19:589–606

Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ, Martin JL (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112

Fischer J, Brosi B, Daily GC, Ehrlich PR, Goldman R, Goldstein J, Tallis H (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming? Front Ecol Environ 6:380–385

Gelman A, Rubin DB (1992) Inference from iterative simulation using multiple sequences. Stat Sci 7:457–472

Green R, Osborne P, Sears E (1994) The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. J Appl Ecol 31:677–692

Henebry G, Putz B, Vaitkus M, Merchant JW (2005) The Nebraska gap analysis project final report. School of Natural Resources, University of Nebraska-Lincoln, Lincoln

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Glob Ecol Biogeogr 15:1–7

Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. Ecol Lett 8:23–29

Johnson DH, Igl LD (2001) Area requirements of grassland birds: a regional perspective. Auk 118:24–34

Johnson RJ, Jedlicka JA, Quinn JE, Brandle JR (2011) Global perspectives on birds in agricultural landscapes. In: Franzluebbers AJ (ed) Integrating Agriculture, Conservation and Ecotourism: examples from the Field. Springer, Netherlands, pp 55–140

Kareiva P, Marvier M (2012) What is conservation science? Bioscience 62:962–969

Kéry M (2010) Introduction to WinBUGS for ecologists: Bayesian approach to regression, ANOVA, mixed models and related analyses. Academic Press

King DI, Schlossberg S (2014) Synthesis of the conservation value of the early-successional stage in forests of eastern North America. For Ecol Manage 324:186–195

Kleijn D, Berendse F, Smit R, Gilissen N, Smit J, Brak B, Groeneveld R (2004) Ecological effectiveness of agri-environment schemes in different agricultural landscapes in the Netherlands. Conserv Biol 18:775–786

Krebs JR, Wilson JD, Bradbury RB, Siriwardena GM (1999) The second silent spring? Nature 400:611–612

Lindenmayer DB, Fischer J, Felton A, Crane M, Michael D, Macgregor C, Hobbs RJ (2008) Novel ecosystems resulting from landscape transformation create dilemmas for modern conservation practice. Conserv Lett 1:129–135

Lunn DJ, Thomas A, Best N, Spiegelhalter D (2000) WinBUGS-a Bayesian modelling framework: concepts, structure, and extensibility. Stat Comput 10:325–337

Martin LJ, Quinn JE, Ellis EC, Shaw MR, Dorning MA, Hallett LM, Wiederholt R (2014) Conservation opportunities across the world's anthromes. Divers Distrib 20:745–755

Matson PA, Parton WJ, Power AG, Swift MJ (1997) Agriculture intensification and ecosystem properties. Science 277:504–509

McCarthy MA (2007) Bayesian methods for ecology. Cambridge University Press

McGarigal K, Cushman SA, Neel MC, Ene E (2002) FRAGSTATS: spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site:www.umass.edu/landeco/research/fragstats/fragstats.html

Murphy M (2003) Avian population trends within the evolving agricultural landscape of eastern and central United States. Auk 120:20–34

Noss RF, LaRoe III ET, Scott JM (1995) Endangered ecosystems of the United States: a preliminary assessment of loss and degradation, vol 28. USDI National Biological Service Biological Report 28, Washington

Perkins MW, Johnson RJ, Blankenship EE (2003) Response of riparian avifauna to percentage and pattern of woody cover in an agricultural landscape. Wildl Soc Bull 31:642–660

Pickett SR, Siriwardena GM (2011) The relationship between multi-scale habitat heterogeneity and farmland bird abundance. Ecography 34:955–969

Pierce R, Farrand D, Kurtz W (2001) Projecting the bird community response resulting from the adoption of shelterbelt agroforestry practices in Eastern Nebraska. Agrofor Syst 53:333–350

Prevedello JA, Vieira MV (2010) Does the type of matrix matter? A quantitative review of the evidence. Biodivers Conserv 19:1205–1223

Puckett HL, Brandle JR, Johnson RJ, Blankenship EE (2009) Avian foraging patterns in crop field edges adjacent to woody habitat. Agric Ecosyst Environ 131:9–15

Quinn JE (2013) Sharing a vision for biodiversity conservation and agriculture. Renew Agr Food Syst 28:93–96

Quinn JE, Brandle JR, Johnson RJ (2011) Application of detectability in the use of indicator species: a case study with birds. Ecol Indic 11:1413–1418

Quinn JE, Brandle JR, Johnson RJ (2012) The effects of land sparing and wildlife-friendly practices on grassland bird abundance within organic farmlands. Agric Ecosyst Environ 161:10–16

Rainwater Basin Joint Venture (2012) Rainwater Basin Joint Venture landcover accuracy assessment report. Rainwater Basin Joint Venture, Grand Island

Rich TD, Beardmore CJ, Berlanga H, Blancher PJ, Bradstreet MSW, Butcher GS, Demarest DW, Dunn EH, Hunter WC, Iñigo-Elias EE, Kennedy JA, Martell AM, Panjabi AO, Pashley DN, Rosenberg KV, Rustay CM, Wendt JS, Will TC (2004) Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology. Ithaca, NY. Partners in Flight website. http://www.partnersinflight.org/cont_plan/ (VERSION: March 2005)

Robertson BA, Porter C, Landis DA, Schemske DW (2012) Agroenergy crops influence the diversity, biomass, and guild structure of terrestrial arthropod communities. BioEnergy Res 5:179–188

Royle JA (2004) N-Mixture models for estimating population size from spatially replicated counts. Biometrics 60:108–115

Royle JA, Dorazio RM (2008) Hierarchical modeling and inference in ecology: the analysis of data from populations, metapopulations, and communities. Academic Press, New York

Samson FB, Knopf FL, Ostlie W (1998) Grasslands. In: Status and trends of the nation's biological resources. Washington, D.C.: U.S. Geological Survey. 437-4

Schlossberg S, King D, Chandler R, Mazzei B (2010) Regional synthesis of habitat relationships in shrubland birds. J Wildlife Manag 74:1513–1522

Schoeneberger M, Bentrup G, de Gooijer H, Soolanayakanahally R, Sauer T, Brandle J, Current D (2012) Branching out: Agroforestry as a climate change mitigation and adaptation tool for agriculture. J Soil Water Conserv 67:128A–136A

Scott JM, Davis FW, McGhie RG, Wright RG, Groves C, Estes J (2001) Nature reserves: do they capture the full range of America's biological diversity? Ecol Appl 11:999–1007

Shake CS, Moorman CE, Riddle JD (2012) Influence of patch size and shape on occupancy by shrubland birds. Condor 114:268–278

Sturtz S, Ligges U, Gelman AE (2005) R2WinBUGS: a package for running WinBUGS from R. J Stat Softw 12:1–16

Teillard F, Antoniucci D, Jiguet F, Tichit M (2014) Contrasting distributions of grassland and arable birds in heterogeneous farmlands: implications for conservation. Biol Conserv 176:243–251

Wilson JD, Evans AD, Grice PV (2009) Bird conservation and agriculture. Cambridge University Press, Cambridge, UK

Whelan CJ, Wenny DG, Marquis RJ (2008) Ecosystem services provided by birds. Ann N Y Acad Sci 1134:25–60

Zhang W, Ricketts T, Kremen C, Carney K, Swinton SM (2007) Ecosystem services and dis-services to agriculture. Ecol Econ 64:253–260