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Influence of crop type, heterogeneity and woody structure on avian biodiversity in agricultural landscapes

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A B S T R A C T

Agriculture is a primary factor underlying world-wide declines in biodiversity. However, different agricultural systems vary in their effects depending on their resemblance to the natural ecosystem, coverage across the landscape, and operational intensity. We combined data from the North American Breeding Bird Survey with remotely sensed measures of crop type and linear woody feature (LWF) density to study how agricultural type, woody structure and crop heterogeneity influenced the avian community at landscape scales across a broad agricultural region of eastern Canada. Specifically, we examined whether 1) avian diversity and abundance differed between arable crop agriculture (e.g., corn, soy) and forage (e.g., hay) and pastoral agriculture, 2) whether increasing the density of LWF enhances avian diversity and abundance, and 3) whether increasing the heterogeneity of arable crop types can reduce negative effects of arable crop amount. Avian diversity was lower in landscapes dominated by arable crop compared to forage agriculture likely due to a stronger negative correlation between arable cropping and the amount of natural land cover. In contrast, total avian abundance did not decline with either agricultural type, suggesting that species tolerant to agriculture are compensating numerically for the loss of non-tolerant species. This indicates that bird diversity may be a more sensitive response than bird abundance to crop cover type in agricultural landscapes. Higher LWF densities had positive effects on the diversity of forest and shrub bird communities as predicted. Higher crop heterogeneity did not reduce the negative effects of high crop amount as expected except for wetland bird abundance. In contrast, greater crop heterogeneity actually strengthened the negative effects of high crop amount on forest bird abundance, shrub-forest edge bird diversity and total bird diversity. We speculate that this was due to negative correlations between crop heterogeneity and the amount of shrub and forest habitat patches in crop-dominated landscapes in our study region. The variable response to crop heterogeneity across guilds suggests that policies aimed at crop diversification may not enhance avian diversity on their own and that management efforts aimed at the retention of natural forest and shrub patches, riparian corridors, and hedge-rows would be more directly beneficial.

1. Introduction

Agricultural expansion and intensification has been a principal driver of biodiversity loss in temperate and tropical regions (Donald et al., 2001; Kremen et al., 2002; Tscharntke et al., 2005; Mahood et al., 2012). As the human population approaches an expected 9 billion mid-century, a critical conservation question is: how can we maintain biodiversity amidst the need for increased agricultural yields (Godfray et al., 2010)? The designation of protected areas free of agriculture is important, as some species are intolerant to any form of agricultural conversion (Maas et al., 2009; Mahood et al., 2012), but there is a limit to how much land can be set aside because of the resulting loss in yield. Therefore, we also need to understand how to maximize biodiversity to the extent possible within a working agricultural landscape (Tscharntke et al., 2005; Bátary et al., 2010a). Knowledge of how and why different agricultural production systems influence biodiversity is a key step in this process.

Agricultural systems are defined by decisions such as the extent of

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pastoral versus crop lands, the varieties of crops grown, the configuration of different crop and natural land covers, and the intensity of techniques used to grow crops. The degree to which an agricultural system negatively impacts biodiversity depends in part on how it transforms the landscape. This influence can vary along two axes related to the extent to which the system occupies the landscape and how strongly the system contrasts with the natural cover types that agriculture replaced (Cunningham et al., 2013). Agricultural systems can vary widely in their contrast to the natural ecosystem, from expansive crop monocultures with typically low biodiversity to wildlife-friendly systems that retain large proportions of the native faunal and floral communities (Donald, 2004; Tscharntke et al., 2012; Liu et al., 2013).

Positive relationships are typically observed between biodiversity and total landscape heterogeneity, including both natural and agricultural cover types (e.g., Jonsen and Fahrig, 1997; Benton et al., 2003; Wiebull et al., 2008). However, it is also important to understand whether biodiversity benefits specifically from a greater diversification of the agricultural components of the landscape as these may be easier to manage than the natural components. Crop heterogeneity might be beneficial for biodiversity if multiple crop types support different species or allow single species to meet different resource requirements (Dunning et al., 1992; Fahrig et al., 2011). Crop heterogeneity might also be beneficial if the separation of different crops leads to a greater retention of semi-natural habitats such as hedge rows, riparian corridors and grassy strips at field edge boundaries (Benton et al., 2003; Duelli and Obrist, 2003; Weibull et al., 2008; Evans et al., 2014). Evidence supports the benefits of crop heterogeneity for biodiversity at spatial scales within and between farm fields (Vandermeer et al., 1998; Henderson et al., 2009; Malézieux et al., 2009). However, results are mixed at landscape scales with positive relationships in some studies (Siriwardena et al., 2000; Billeter et al., 2008; Lindsay et al., 2013) but not others (Fahrig et al., 2015; Hiron et al., 2015). Variation in the benefits of crop heterogeneity for biodiversity across regions and taxa may be related to factors such as the extent and scale at which taxonomic groups use agricultural cover types and the role of semi-natural habitat for those groups (Piha et al., 2007; Gabriel et al., 2010; Fahrig et al., 2015).

Much of our knowledge of the impacts of agriculture on biodiversity is at the field and farm scales, but there is a growing recognition of the importance of landscape-scale studies. Most landscape-scale research on agricultural impacts thus far has been conducted in European systems (e.g. Billeter et al., 2008; Gabriel et al., 2010; Fischer et al., 2011). By contrast, there is less known about the extent to which different agricultural systems support biodiversity at landscape scales in North America. Landscape-scale studies are difficult to conduct because of the effort and resources involved but the integration of two data types hold potential for such research. First, recent advances in remote sensing allow us to identify the composition and configuration of agricultural landscapes with greater precision than was previously possible (Fisette et al., 2013; Van der Zanden et al., 2013; Pasher et al., 2016). Second, large, volunteer-based efforts (i.e. citizen science) allow us to expand the spatial scope of analyses far beyond the limits of traditional field studies (Dickinson et al., 2010). Among vertebrate taxa, monitoring data are often the most spatially and temporally extensive for birds (e.g., PECBMS, 2012; Sauer et al., 2014). Combined with the diversity of habitat use and broad geographic coverage across avian taxa, this makes birds excellent and frequently used indicators for the effects of human activity on biodiversity (Gregory and van Strien, 2010; Suarez-Rubio et al., 2013; Herrando et al., 2014; Morelli et al., 2014). In this study, we combined data from the North American Breeding Bird Survey (BBS, Pardieck et al., 2017) with remotely sensed measures of land cover type and linear woody feature (LWF) density (Fisette et al., 2013; Pasher et al., 2016) to examine how the amount, type and heterogeneity of agriculture influenced avian diversity and abundance across a broad agricultural region of eastern Canada.

Our first objective examined, at the landscape scale, whether the effects of agriculture on avian diversity and abundance differed depending on whether the agricultural system was 1) forage (e.g., hay) and pastoral agriculture (hereafter "forage"), or 2) crop agriculture excluding forages (hereafter "arable crop", e.g., oilseeds, cereals, grains and pulse crops). Of these two agricultural systems, forage and pasture typically receive lower agrochemical inputs, lower tillage and have more permanent cover between years compared to arable crops (Boutin and Jobin, 1998). Our second objective tested the hypothesis that a greater density of LWF enhances avian diversity and abundance in agricultural landscapes (Hinsley and Bellamy, 2000; Bátary et al., 2010b). We expected these benefits to occur primarily for forest and shrub bird communities. Our final objective tested the hypothesis that increasing the heterogeneity of arable crop types enhances biodiversity by creating greater compositional diversity and a higher retention of semi-natural habitats in the landscape. Based on this hypothesis, we expected to observe 1) a positive relationship between indices of arable crop heterogeneity and avian diversity and abundance, and 2) that increasing the heterogeneity of arable crop types would lessen negative impacts of the amount of arable cropping.

2. Methods

2.1. Survey region

We measured agricultural effects on avian diversity across regions of eastern Ontario and southwestern Quebec, Canada, covering a latitudinal span of ~590 km and a longitudinal span of ~970 km (Fig. 1). Prior to European settlement, the region was largely a combination of deciduous and mixed forests interspersed with lakes and wetlands. Extensive clearing of forests and draining of wetlands for logging and agriculture occurred during the 18th and 19th centuries. Forest regeneration has occurred since the mid-20th century, particularly in eastern Ontario and southern Quebec, although forest cover is still limited in southern Ontario (Butt et al., 2005).

2.2. Avian surveys

We used data from the North American Breeding Bird Survey (BBS, Pardieck et al., 2017) to create survey transects in 131 replicate 20 km^2 landscapes. The BBS was initiated in 1966 and is conducted by experienced observers each year from late May through early July. The survey comprises thousands of ~40 km roadside routes across North America. Each route is composed of 50, 3 min (400 m radius) point counts spaced ~0.8 km apart that are ordinarily summed to create a single estimate of abundance for each species on that route (Sauer et al., 2014). For the purposes of our analysis, we created two transects from each BBS route located in the study area. The first transect included stops 1 through 11, and the second transect included stops 21 through 31. With ~0.8 km between stops, the total distance for each transect was ~8 km and the two transects on each route were separated by ~8 km. This separation allowed us to avoid any spatial autocorrelation that may have occurred had we used consecutive transects. For 11 of the 71 BBS routes included in the study, we only used one transect because land cover imagery was not available for the other transect. We used a single year of BBS data for each transect. The crop mapping data used in this analysis were from 2012, so we selected BBS data for 2012 when possible (115 of 131 transects). However, some BBS routes were not surveyed in 2012, so we used the next closest year with data (9 transects from 2013, 5 from 2009 and 2 from 2008). It is possible that there were some changes in land cover between the timing of the land cover analysis in 2012 and the BBS survey for these transects. However, given the large size of the replicate landscapes, i.e. 20 km^2 areas, we reasoned that the influence of such land cover changes on our landscape variables (arable crop amount, forage amount and arable crop diversity) was slight and unlikely to influence our results.

All species were identified to one of 6 guilds (forest, shrub-forest