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Habitat associations and conservation opportunities for priority birds on small, diversified farms in the northeastern USA

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Abstract

Although the impacts of intensive agriculture on biodiversity and strategies for mitigating these effects have been widely described, small-scale, diversified farms and the opportunities they present for bird conservation have been less thoroughly examined. This omission is potentially significant, because this form of agriculture represents a growing sector of the industry in the populous northeastern USA, and the diverse habitats on these farms contrast with larger, structurally homogeneous intensive agriculture. To evaluate bird-habitat associations and conservation opportunities for supporting species of conservation concern on these small, diversified farms, we conducted avian point count and vegetation surveys across 23 farms in western Massachusetts during the summers of 2017 and 2018. We used Poisson-binomial mixture models and canonical correspondence analysis to assess the effects of a suite of microhabitat-, field- and landscape-scale (1 km buffer around the field) variables on the abundance of bird species. Our results confirmed that shrubland birds, a group of species of elevated conservation concern, accounted for 52% of the total observations, including song sparrow (*Melospiza melodia*), gray catbird (*Dumatella carolinensis*), common yellowthroat (*Geothlypis trichas*) and American goldfinch (*Spinus tristis*). Species–habitat relationships were diverse; however, smaller field sizes, and increased cover of tall, dense, woody or non-productive vegetation types were associated with higher abundance of shrubland species as well as lower abundance of crop pests such as European starling (*Sturnus vulgaris*) and house sparrow (*Passer domesticus*). These findings support the hypothesis that small, diversified farms are supporting birds of high conservation concern, and we provide species-specific guidelines for farmers interested in conserving birds on their land.

Introduction

Avian communities in the northeastern region of the USA have been dramatically transformed and shaped by human activity and impacts on the landscape. From 1966 to 2013 across the USA and Canada, shrubland birds dropped 16.5%, while grassland species and aerial insectivores experienced even steeper declines of 20.5 and 39.5%, respectively (Stanton *et al*., 2018). These losses coincide with changes in agricultural production, toward more intensified practices such as higher-yield crops; larger farm sizes; increased use of chemicals such as pesticides, herbicides and fertilizers; and landscape homogenization resulting from specialization in a single product, and removal of natural or non-productive habitats like field margins and hedgerows (Matson *et al*., 1997; Jeliazkov *et al*., 2016; Stanton *et al*., 2018). Because agricultural intensification reduces native vegetation and thus decreases potential habitat value, it has been identified as a key challenge to bird populations throughout the developed and developing world (Green *et al*., 2005). In the Northeast, where hayfields and pastures provide critical breeding habitat for obligate grassland songbirds such as bobolinks (*Dolichonyx oryzivorus*) and savannah sparrows (*Passerculus sandwichensis*), agricultural intensification in the form of earlier initiation and increased frequency of haying have been identified as drivers of severe population declines through degradation of habitat and directly impacting nesting success (Perlut *et al*., 2006; Askins *et al*., 2007).

Increasingly, farms in the northeast USA are adopting practices that increase habitat heterogeneity and retain uncultivated vegetation amongst productive areas. These include crop diversification, rotation and cover cropping; integrated pest management; and the retention of natural habitats such as hedgerows, buffer strips, riparian corridors, meadows, shrublands and woodlands adjacent to productive areas (Kremen and Bacon, 2012; Kremen and Merenlender, 2018; Sutter *et al*., 2018). Many of these farms are also certified organic or follow organic production practices without the certification. United States Department of Agriculture (USDA) Census of Agriculture data show that the number of certified organic farms in New England states (CT, MA, ME, NH, RI and VT) has risen from 869 farms in

2011 to 1407 farms in 2019, a 38% increase. While the percentage of organic farms out of all farms in New England may appear low at 5.2%, it is significantly higher than the percentage of organic farms out of total farms in the USA, at only 0.9% (USDA, 2017). By 2014, nearly 45% of all New England organic farms maintained buffer strips, and close to 20% maintained habitat for beneficial insects and vertebrates (USDA, 2017). These changes are bolstered by a resurgence of public demand and support for local, sustainable food production, evidenced by the success of community supported agriculture, farmer's markets, roadside stands and other direct marketing practices. According to the 2020 USDA Local Food Marketing Practices Survey, the northeastern region accounted for 28% of all direct farm sales in the USA, a higher percentage than any other region in the country and a 5% increase since 2015 (USDA, 2020).

As working lands that already utilize a variety of ecologically oriented practices, small, diversified farms have high conservation value potential; however, due to the inherently different vegetation structure and composition present on these farms, the bird communities present will likely be considerably different from larger, more grassland-type farms. We predict that shrubland birds may represent a significant component of the small, diversified, farmland bird community because they generally prefer a heterogeneous mix of grasses, forbs, and shrubs, and they tend to be less area-sensitive than grassland obligates (Schlossberg *et al.*, 2010). As the recent significant population declines experienced by New England shrubland species have largely been attributed to loss or fragmentation of breeding and foraging habitat, conservation is a high priority for managers. Government agencies and non-governmental conservation organizations have concentrated considerable funds and effort into the creation and management of shrubland habitats to mitigate declines of the many species that rely on them (Schlossberg and King, 2007, 2015). Currently, 78% of shrubland bird habitat in New England is created by forestry activities, and while many species have responded positively, no single habitat type is sufficient to support the broad range of habitat preferences that shrubland birds exhibit (Schlossberg and King, 2007, 2015).

Although these small, diversified farms appear to have potential for supporting shrubland and other species of conservation concern, they are largely unstudied in this region. Due to their small size, we anticipate that the environmental conditions present outside the boundaries of these farms and outside the influence of the farmer may have an outsized effect on bird-habitat use. Previous studies have found that the impact of farm diversification on biodiversity is heavily influenced by the surrounding matrix. For instance, low intensity farms in simplified agricultural landscapes with higher proportions of cropland have been found to show increased benefits to birds than those in more diverse landscapes with highly available natural non-crop habitat (Tscharntke *et al.*, 2005; Batáry *et al.*, 2010; Smith *et al.*, 2020). In shrubland systems, landscape composition, such as the proportion of shrubland habitat in the landscape, has been shown to impact the suitability of smaller patches of habitat such as small, forest openings for shrubland bird species (Roberts and King, 2017). Small, diversified farms in New England can be seated in landscapes dominated by a range of habitat types, from forested settings to more developed suburban interfaces. The impact that these different matrices may have on bird communities and abundance has direct implications for understanding the best way to manage the habitat present on these farms for the benefit of avian species.

To address the gaps in our understanding of this unique agricultural system and regional context, we undertook this study with the aim to (1) characterize the breeding bird communities of small, diversified, New England farms, and (2) quantify bird-habitat associations at the microhabitat-, patch- and landscape scale. Establishing a better understanding of how shrubland and other priority species utilize small, diversified farms in this region will help inform managers and farmers alike to better understand current availability of potential habitat for these species and to identify and realize conservation opportunities within these operations.

Methods

We selected study sites on 22 small, diversified farms located in Franklin and Hampshire counties in western Massachusetts, USA (Fig. 1). These two counties comprise over one-fifth of the agricultural production and 28% of the total farmland in the state (USDA, 2012) and reflect recent trends across the New England region toward smaller farm sizes, product diversification, community involvement and sustainable production practices (Hollingsworth *et al.*, 1993; USDA, 2012; Donahue *et al.*, 2016). We selected farms that reflected these trends, focusing on small, diversified operations producing primarily non-grassland-type crops such as vegetables, fruits and berries, were either certified organic or implementing organic practices. We considered farms with less than 50 acres (20.2 ha) to be 'small', based on categories used by the USDA Census of Agriculture, although a few of the farms included exceeded this size limit. Average farm size was 13.7 ha (S.D. 15.6, range 0.4–48.6). Farms were considered diversified if they produced two or more crop types. We initially selected farms that met these criteria for inclusion from the Community Involved in Sustaining Agriculture (CISA) online local farm database for western Massachusetts, then contacted farmers directly to secure participation and land access. The most common vegetable crops present on our farms were *Allium sp.* such as onions, garlic and chives; *Brassica sp.* such as kale, cabbage, broccoli or cauliflower; *Cucurbita sp.* such as summer squash; and *Solanum sp.* such as tomatoes, peppers and eggplant. Berry and orchard crops were predominantly raspberries, strawberries, blueberries, as well as apple and *Prunus sp.* such as peach, plum or cherry. Farms also planted a variety of cover crops including grasses such as cereal rye (*Secale cereale*) and oats (*Avena sativa*), legumes such as clover (*Trifolium sp.*) and hairy vetch (*Vicia villosa*) or non-legume broadleaves such as buckwheat (*Fagopyrum esculentum*).

Bird surveys

Farm boundaries were delineated in ArcMap 10.3.1 (ESRI 2011) using a combination of MassGIS standardized assessors' parcel data, ortho imagery and ground-truthing. Sampling locations were then randomly distributed over the entire area of the farm, with the constraint that they were located ⩾200 m apart to minimize double counting. Standardized point count surveys of breeding birds were conducted from May through July of 2017 and 2018 at 60 sampling locations. On average, points were surveyed every 16 days (standard deviation = 3.7 days). Point count radii included areas of both productive and natural land cover. Birds were detected by sight and sound within a 50 m fixed radius plot over a 10 min period (Ralph *et al.*, 1995). For each observation, we recorded the number of individuals observed, the type of

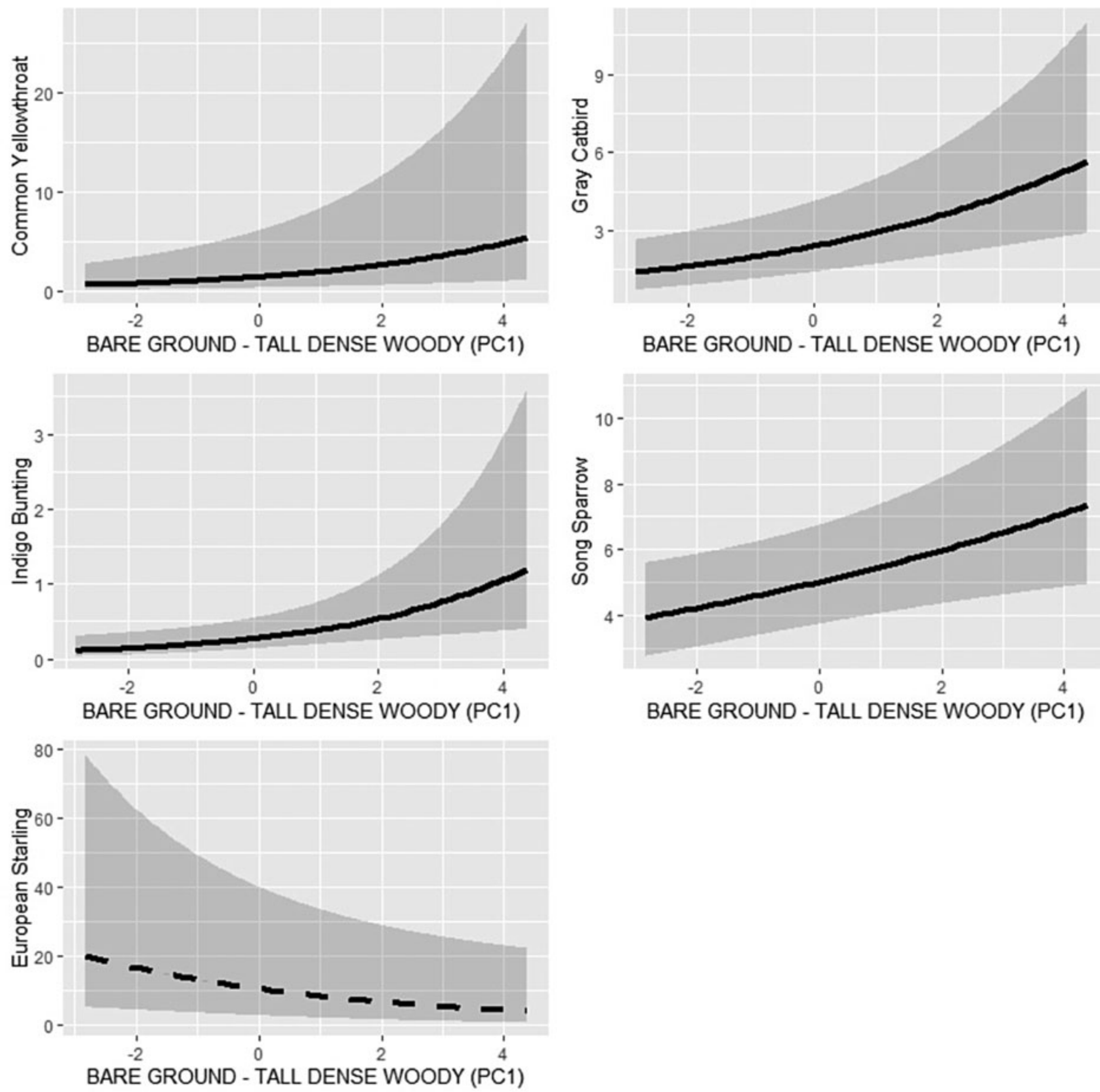

Figure 1. Poisson-binomial mixture model predictions visualizing relationships between species abundance and microhabitat-scale variable PC1 (a gradient from bare ground to tall, dense, woody vegetation cover). Solid lines indicate shrubland species and dashed lines represent crop pests. Data come from 22 small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018.

observation (visual, audio or both) and any breeding or foraging behaviors exhibited by the individual. We also recorded site and visit-specific information including estimated percent visual obstruction at the point, level and type of disturbance or ambient noise experienced during the survey, temperature (°C), cloud cover (%) and wind speed (mph). Counts were conducted from 0.5 h before to 4 h after sunrise on mornings with zero precipitation and wind less than 20 mph. We repeated surveys three times over the course of the season and systematically rotated the order of point visitations during each round of surveys to avoid confounding effects of time of day.

Vegetation surveys

Within each of the 50 m radius point count plots, distinctive habitats were delineated and classified into land cover categories in ArcMap 10.3.1 (ESRI 2011) using orthophotos and subsequent ground-truthing using a handheld Global Positioning System (GPS). Eight land cover types were included in our final analysis (bare ground, cover crop, herbaceous row crop, herbaceous/grassland, hedgerow, woody row crop, woodland and shrub). Percent land cover of each land cover category was calculated as a proportion of the total area within the plot. Vegetation was sampled at five random points within each habitat cover type, resulting in up to 30 sampling locations per plot. At each point, we measured canopy height as the point at which the tallest vegetation intersected with a 3 m density pole, identified vegetation to the highest possible degree of classification and recorded percent visual obstruction (% VO) for every 0.5 m segment of the 3 m density pole that intersected with vegetation (Collins *et al.*, 2009; Reiley and Benson, 2019). Vegetation was surveyed twice, once at the beginning and once at the end of the field season, to account

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for changes in vegetation structure resulting from crop growth or harvest and an average was taken across the two sampling periods to be used in subsequent statistical analyses.

Statistical analysis

Our original set of microhabitat or point-scale variables included vegetation height (cm), vegetation density (% VO) and percent horizontal cover of bare ground, cover crop, herbaceous row crop, herbaceous/grassland, hedgerow, woody row crop, woodland and shrub. We also included one field-scale variable [field area (ha)], and four landscape-level variables [percent cover of agriculture, development, forest and wetland within a 1 km buffer around the farm (Nilon *et al.*, 2011; Berg *et al.*, 2015)]. Because the number of microhabitat variables measured exceeded levels necessary to successfully achieve model convergence, we sought to reduce the dimensionality of our microhabitat variables using a principal component analysis (PCA). We scaled all variables before running the PCA. We ultimately included two axes, PC1 and PC2, which explained 44% of the total variance (27% explained by PC1, 17% explained by PC2), as response variables in candidate models for bird abundance and habitat (Table 1). The first principal component was characterized by a gradient across points from high percent bare ground cover to increased vegetation height, density and percent cover of woody landcover types. The second principal component described a gradient that ranged from points with high percent cover of productive habitat types such as herbaceous row crop to non-productive cover types such as herbaceous/grassland and hedgerow.

Landscape-scale variables were derived from the MassGIS 2016 Land Cover/Land Use dataset, which features 19 land cover classes which we consolidated into the four landscape-level categories for inclusion in our models. We selected a 1 km buffer as this scale best matches the expected home range sizes of most species observed on site (Henckel *et al.*, 2019). We screened all variables for influence of outliers and collinearity, considering variables highly correlated if they exceeded $r > 0.5$. Landscape-scale forest cover was highly correlated with agriculture, development and wetland, and wetland was also highly correlated with agriculture, so these two variables were removed from inclusion in our analysis. Our final set of predictor variables included both principal components, the single field-scale variable, and the two landscape-level variables (agriculture and development). Proportion of agriculture at the landscape scale ranged from 6.0 to 36.0% cover (mean = 18.4 ± 8.0) and development ranged from 4.8 to 73.8% cover (mean = 24.5 ± 14.0).

We analyzed relationships between habitat variables and bird abundance using Poisson-binomial (*N*-mixture) models (Royle, 2004). We selected species for inclusion in our analysis based on two criteria. First, we only analyzed data for breeding species present on ⩾10% of the plots and with ⩾30 observations (Schlossberg and King, 2007). Second, to focus specifically on species using the farm for nesting and/or foraging habitat, we excluded species with fewer than 20 total breeding or foraging observations based on behavioral observation data collected during the surveys. Fifteen species fit the criteria for inclusion in our *N*-mixture models. This included seven shrubland species: song sparrow (*Melospiza melodia*), gray catbird (*Dumetella carolinensis*), American goldfinch (*Spinus tristis*), common yellowthroat (*Geothlypis trichas*), indigo bunting (*Passerina cyanea*), yellow warbler (*Setophaga petechia*) and willow flycatcher (*Empidonax traillii*). Also included were six species known to depredate crops (Somers and Morris, 2002; Avery *et al.*, 2016): American robin (*Turdus migratorius*), red-winged blackbird (*Agelaius phoeniceus*), house sparrow (*Passer domesticus*), cedar waxwing (*Bombycilla cedrorum*) and European starling (*Sturnus vulgaris*). An additional three species were present in high enough abundance to qualify for inclusion in the analysis: chipping sparrow (*Spizella passerina*), killdeer (*Charadrius vociferus*) and mourning dove (*Zenaida macroura*); however, since they did not fall into the category of either shrubland species or crop pest, we did not include them in our analysis. Species were assigned to different habitat guilds based on their primary breeding habitat and categorizations used in previous studies. Species were categorized as 'shrubland birds' based on Schlossberg and King (2007), forest species and urban generalists were based on the North American Breeding Bird Survey species group summaries (Link and Sauer 1996) and grassland birds were based on Stanton *et al.* (2018).

Modeling was conducted using the unmarked package in R 3.6.1 (Fiske and Chandler, 2011). For each species, using Akaike's information criterion (AIC_c), we began by determining which detection covariates to include in candidate models. While including all habitat variables, we fit all subsets of detection variables (ordinal day, ordinal day as a quadratic term and time of day) using a logit link function (Kéry *et al.*, 2005; Joseph *et al.*, 2009). Detection covariates within $\Delta AIC_c \leqslant 2$ and statistically significant ($P \leqslant 0.1$) were retained (Smetzer *et al.*, 2014; Roberts and King, 2017). Once a top detection model was selected, we held detection variables constant while running all possible combinations of habitat variables. Models were assessed using a goodness-of-fit test and considered top models if they were within ($\Delta AIC_c \leqslant 2$) of the best-performing model, and covariates considered strongly supported if their 95% confidence intervals (CI) did not include zero (Chandler *et al.*, 2009; Roberts and King, 2017). Since several models often fell within $2\Delta AIC_c$ units for each species, we plotted weighted-average model predictions, which allowed us to account for uncertainty in model selection while illustrating observed species–variable relationships. Finally, we selected the model that performed the best for each species and then back-transformed linear combinations of coefficients to derive estimates of bird abundance (per 50 m radius point count plot) and detection probability. Standard errors of estimates

Table 1. Loadings of microhabitat-scale variables on principal component analysis (PCA) axes

Variable		PC1	PC2
Vegetation height	HT	0.532	0.139
Vegetation density	DN	0.502	
Bare ground	BG	−0.392	0.283
Cover crop	CC	−0.209	−0.337
Hedgerow	HD	0.178	−0.213
Herbaceous	HE		−0.438
Herbaceous row crop	HRC	−0.134	0.626
Shrub	S	0.182	−0.216
Woodland	W	0.334	0.331
Woody row crop	WRC	0.502	
Variance explained (%)		26.71	17.68

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were calculated using the delta method (Fiske and Chandler, 2011).

While modeling associations between bird abundance and habitat variables at the point, field and landscape level allowed us to evaluate the importance of spatial scale and matrix habitat composition, we also were interested in more fine-scale patterns that could be described by the two principal components. We used a canonical correspondence analysis (CCA) to examine the multivariate relationships between bird species abundance and our original set of microhabitat variables. We included all species with at least five observations.

Results

Over the 2 years of the study, we recorded 2493 detections and 66 species. As expected, shrubland birds (Schlossberg and King, 2007) were the most frequently detected species, with 21 species accounting for 52% of the total observations. Forest nesting birds (Link and Sauer, 1996) were the most diverse habitat guild, with 29 species, but only accounted for 16% of the total observations. Eight grassland species (Stanton *et al.*, 2018) were recorded, accounting for 12% of the total observations. The remaining 20% of observations (10 species) were urban generalists (Link and Sauer, 1996). Fifteen of the species recorded during point counts are considered Massachusetts Species of Greatest Conservation Need (SGCN) by Massachusetts Department of Fish and Wildlife (MDFW), 12 of which were also considered Regional Species of Greatest Conservation Need (RSGCN) and ranked at a level of high or very high concern (MDFW, 2015). However, none of the RSGCN listed species were encountered frequently enough to include in subsequent analyses.

Detection covariates were included in the top models for ten of the 12 species included in our analysis. Detection of American goldfinch, common yellowthroat and gray catbird all exhibited a quadratic relationship with date. American robin and cedar waxwing detection was positively associated with date, while willow flycatcher and yellow warbler were negatively associated. Detection of red-winged blackbird and song sparrow exhibited a positive relationship with time of day, and finally, house sparrow was negatively associated with both time of day and date.

All seven shrubland species contained at least one strongly supported microhabitat variable (PC1 or PC2) in all top models, with the exception of American goldfinch. Relative abundance of common yellowthroat, gray catbird, indigo bunting and song sparrow was positively associated with PC1, which represented a gradient from bare ground to tall, dense, woody vegetation (Table 1; Fig. 1). Common yellowthroat, willow flycatcher and yellow warbler abundance was negatively associated with PC2, a gradient from non-productive habitat such as hedgerow, cover crop and herbaceous vegetation to productive habitat—specifically herbaceous row crops such as vegetables (Table 1; Fig. 2). Two shrubland species, common yellowthroat and willow flycatcher, exhibited a negative relationship with our field-scale variable, field area (Table 1; Fig. 3). Landscape variable interactions were more diverse, with American goldfinch and gray catbird exhibiting a negative relationship with % agricultural landcover in the 1 km buffer surrounding the farm, whereas indigo bunting and willow flycatcher were positively associated with this variable (Table 1; Fig. 4). Two shrubland species, indigo bunting and yellow warbler, featured a negative relationship with development at the landscape scale (Table 1; Fig. 5).

Of the crop pest species, European starling had a negative relationship with PC1 (Table 1; Fig. 1). American robin, cedar waxwing and European starling were positively associated with PC2, while red-winged blackbird was negatively associated with PC2 (Table 1; Fig. 2). House sparrow had a positive, and American robin a negative relationship with field size (Table 1; Fig. 3). As with shrubland species, responses to landscape-scale variables were more diverse. American robin and house sparrow were positively associated with agriculture in the surrounding landscape. House sparrow was negatively associated with urban/suburban development, but American robin and red-winged blackbird exhibited a positive relationship with this variable (Table 1; Figs. 4 and 5).

Our CCA analysis revealed that the species composition of bird communities on small diversified farms was significantly related to microhabitat characteristics [vegetation height (cm), vegetation density (% VO) and percent cover of bare ground, cover crop, herbaceous row crop, herbaceous, hedgerow, woody row crop, woodland and shrub] (global CCA model, $F = 1.57$, $P < 0.001$; Fig. 6). Among the ten variables considered, species composition on farms was significantly associated with vegetation height ($F = 2.42$, $P < 0.001$), herbaceous vegetation cover ($F = 2.36$, $P < 0.01$) and woody row crop cover ($F = 2.07$, $P < 0.01$). Species associated with cover crop, bare ground and herbaceous row crop included more open habitat-associated species, habitat generalists and invasives such as European starling, killdeer and barn swallow (*Hirundo rustica*). Species associated with vegetation height, woody row crop and woodland cover included more forest-associated species such as black-and-white warbler (*Mniotilta varia*), chipping sparrow and American redstart (*Setophaga ruticilla*). By contrast, most shrubland-associated species, including common yellowthroat, field sparrow (*Spizella pusila*) and yellow warbler, were associated with variables such as vegetation density, shrubland, hedgerow and herbaceous cover. It should be noted that the CCA analysis does not account for imperfect detection, as is done in our *N*-mixture modeling effort. However, we observe similar species–habitat relationships with microhabitat gradients for the more abundant species that were included in our *N*-mixture models; therefore, we believe that the relationships observed in the CCA for less common species are likely robust.

Discussion

Previous studies have highlighted the need for locally adapted approaches to farmland bird conservation (Stanton *et al.*, 2018; Esquivel *et al.*, 2021) and our results show that small, diversified farms in New England appear to support a unique and diverse avian community benefitting from a broad array of available habitat types. Our prediction that shrubland species would represent a significant component of the avian community on these farms was supported by our findings. While many of the shrubland species observed on farms were not species of elevated conservation concern, regional Breeding Bird Survey trends show that many of these relatively common species have experienced population declines in recent decades. Song sparrows and common yellowthroat, for example, which have declined by 0.72 and 1.55% annually in the New England/mid-Atlantic coast region between 1966 and 2019, were among the most abundant species reported on these farms. Species such as chestnut-sided warbler and field sparrow, which have declined by 1.85 and 3.66% annually between 1966

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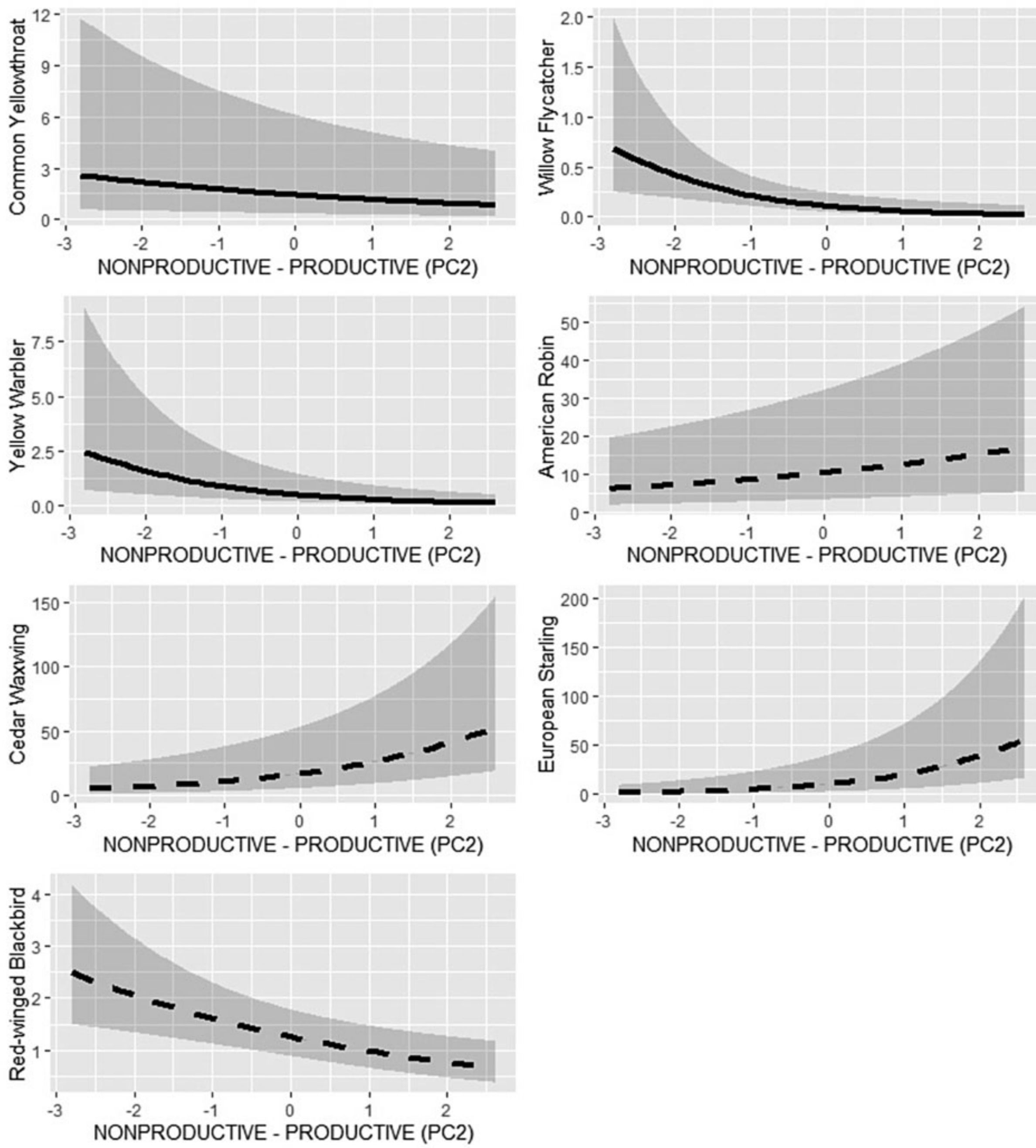

Figure 2. Poisson-binomial mixture model predictions visualizing relationships between species abundance and microhabitat-scale variables PC2 (a gradient from herbaceous rowcrop cover to non-productive habitats including hedgerow, cover crop and herbaceous cover). Solid lines indicate shrubland species and dashed lines represent crop pests. Data come from 22 small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018.

and 2019 (Sauer *et al*., 2020), were less frequently observed, but our CCA analysis revealed that they associated with taller, high-density vegetation and habitats such as berries, orchards and woodlands—habitats widely available on small, diversified, non-grassland-type farms. Recent studies have highlighted the importance of recognizing declines in still-common species and highlighted habitat loss, pesticide use and agricultural intensification as some of the foremost culprits for these trends (Stanton *et al*., 2018; Rosenberg *et al*., 2019). Small, diversified farms in this region appear to be supporting many of these common, yet declining shrubland species.

At the microhabitat scale, shrubland bird abundance on small, diversified farms was negatively associated with productive cover such as herbaceous row crop, and positively associated with greater vegetation height, high vegetation density and an increased proportion of woody habitat features such as shrubland, woodland and hedgerows. The importance of structurally complex, natural habitats for birds in the context of agriculture is well established in the scientific literature (Fuller *et al*., 2001; Jobin *et al*., 2001; Deschênes *et al*., 2003; Batáry *et al*., 2010). Higher proportions of woodland, shrubland, hedgerows and other natural habitats correlate with increased bird species

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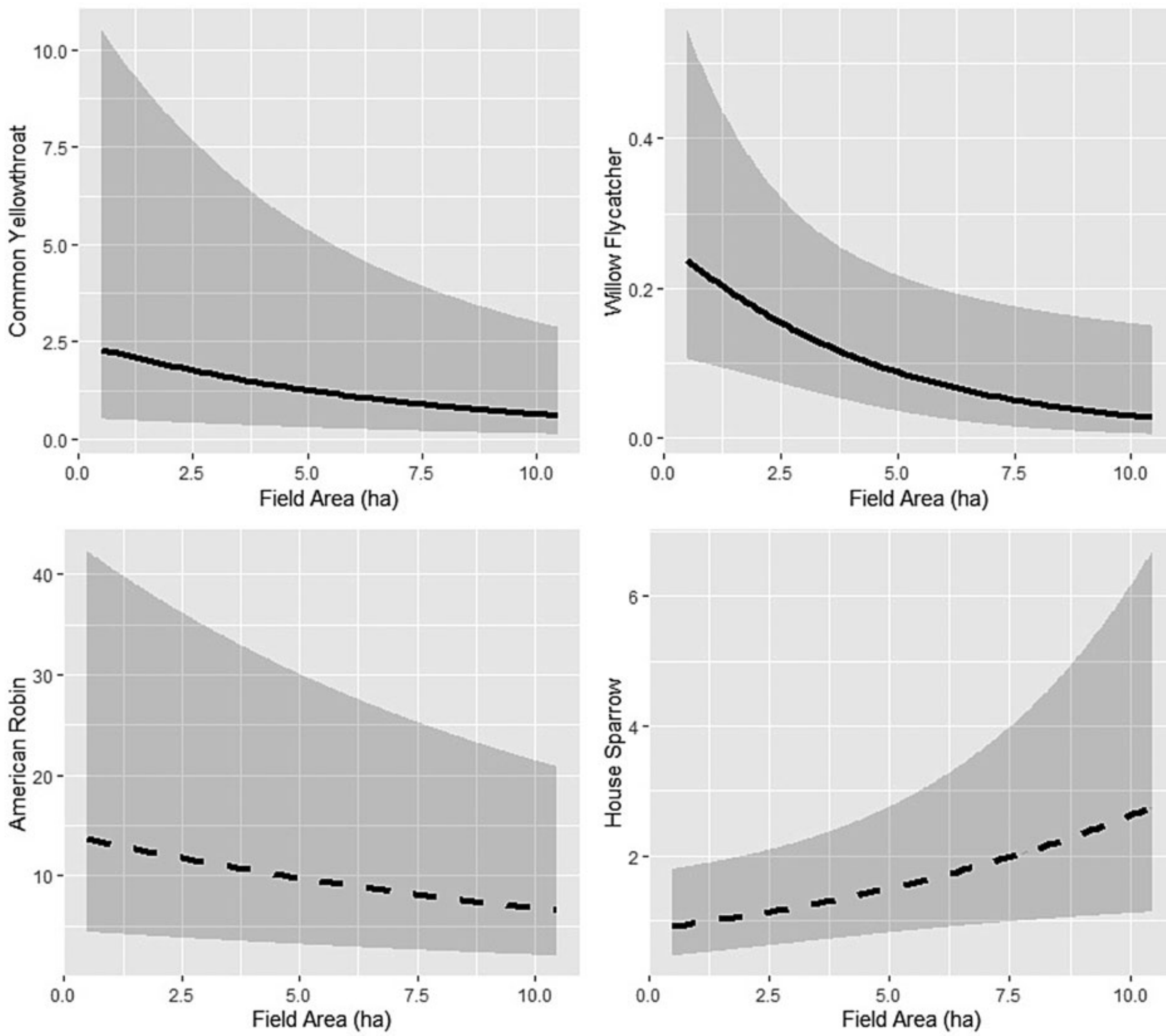

Figure 3. Poisson-binomial mixture model predictions visualizing relationships between species abundance and field-scale variable field area (hectares). Solid lines indicate shrubland species and dashed lines represent crop pests. Data come from 22 small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018.

richness and abundance (Freemark and Kirk, 2001; Heath *et al.*, 2017; Wilson *et al.*, 2017; Goded *et al.*, 2018), provide nesting habitat (Whittingham *et al.*, 2001; Girard *et al.*, 2012) and promote ecosystem services such as insect pest control (Jones *et al.*, 2005; Kross *et al.*, 2016). While our analysis found that for most species of concern, larger patches of woody non-productive landcover had the greatest positive impact on abundance, previous studies have demonstrated that even relatively small patches of complex edge habitat can provide benefits for both birds and farmers (Batary *et al.*, 2010; Ekroos *et al.*, 2019). For instance, one study from intensively managed alfalfa farms in California found that the presence of even two trees >1.5 m at field edges resulted in higher avian abundance, diversity and fewer insect pests in nearby cropped fields (Kross *et al.*, 2016). This suggests that even small changes to increase the proportion of tall, dense, woody, non-productive vegetation in and around productive areas can have a significant positive impact on the abundance of shrubland birds, which require these areas for nesting.

When the entire suite of microhabitat variables was examined in the CCA, we found that shrubland species on small, diversified farms exhibited diverse preferences for specific land cover types and vegetation structure. Species diverged along a gradient of habitat from taller, denser vegetation, larger patches of contiguous woodland and woody crop cover such as berries and orchards, to more open conditions featuring higher proportions of herbaceous cover, cover crop and linear woody features such as hedgerows. Gray catbird, common yellowthroat, house wren and field sparrow fell into the first category, showing similar habitat preferences to some forest-associated species such as black-and-white warbler and American redstart, while song sparrow, willow flycatcher and yellow warbler appeared to fall into the latter category, in closer proximity to open-habitat species such as red-winged blackbird and brown-headed cowbird. This divergence of habitat preferences among shrubland birds is consistent with findings from previous studies of shrubland bird-habitat associations in non-agricultural habitats in the northeast (Schlossberg *et al.*, 2010). Similarly, in intensive agricultural settings, species such as gray catbirds and indigo buntings were primarily reported in tree-dominant field margins, hedgerows and riparian strips (Jobin *et al.*, 2001; Deschênes *et al.*, 2003).

Song sparrows were more strongly associated with open-structured habitats such as natural herbaceous fields and cover

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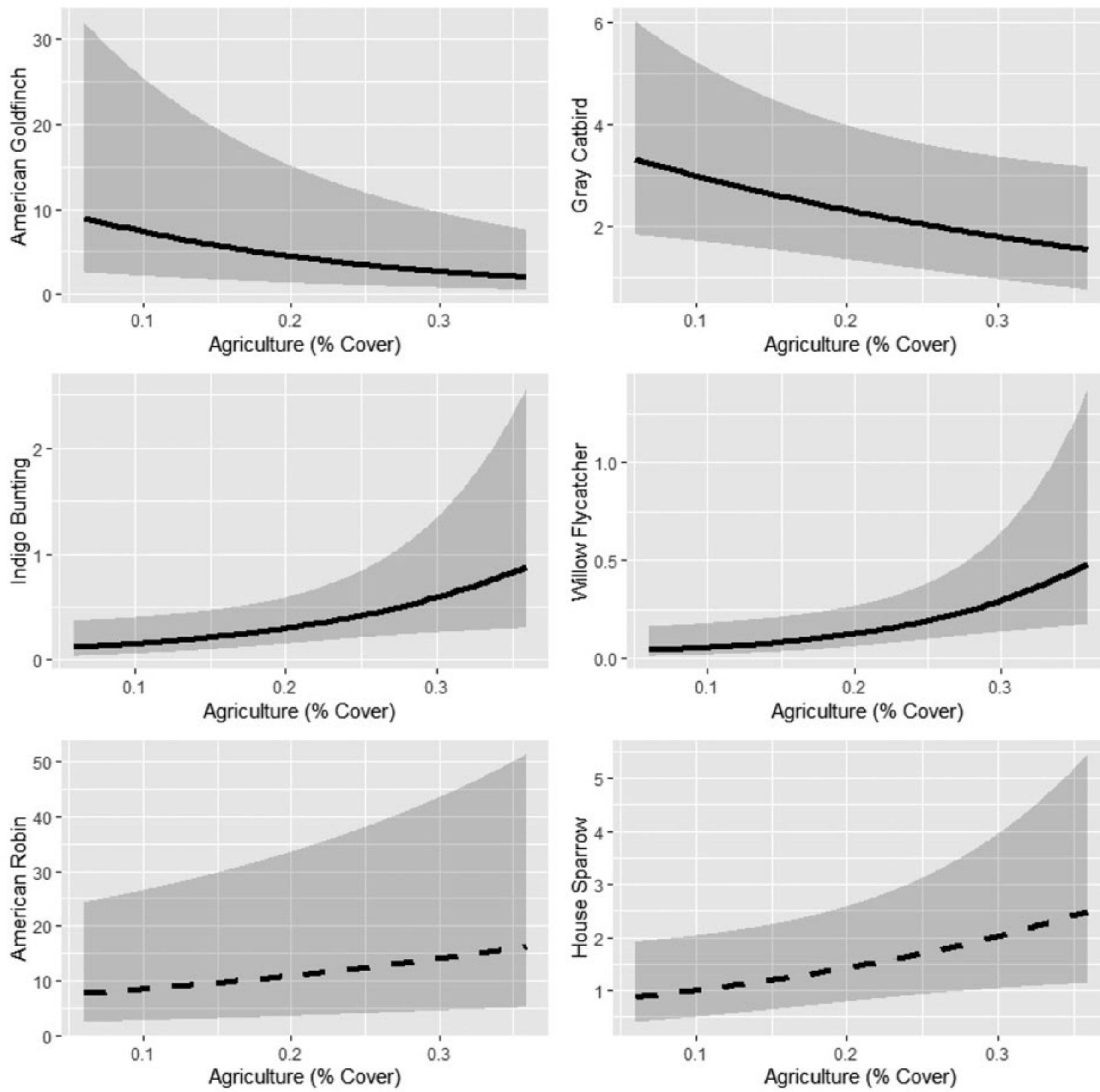

Figure 4. Poisson-binomial mixture model predictions visualizing relationships between species abundance landscape-scale variable agriculture (percent agricultural landcover within 1 km of the farm). Solid lines indicate shrubland species and dashed lines represent crop pests. Data come from 22 small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018.

crops than most other shrubland species included in our CCA analysis. They were also by far the most abundant species observed during surveys, suggesting that cover crops may represent an important habitat feature for them on small, diversified farms. Cover cropping, a practice common in organic or sustainable farming systems, typically involves the sowing of legumes, grasses or brassicas for the purpose of erosion prevention, nitrogen fixation, weed suppression or controlling for insects and disease (Syswerda *et al.*, 2012; Wilcoxen *et al.*, 2018). The cover crops planted on the farms that we surveyed were mixes of grasses such as cereal rye and oats, legumes such as clover and hairy vetch or non-legume broadleaves such as buckwheat. Depending on the species planted, cover crops ranged in height from 0.1 to 1.67 m and visual obstruction from 4 to 68% (Table 2), averaging taller and providing more cover than herbaceous row crops, but shorter and lower density than natural herbaceous habitats. Few studies have examined the effects of cover crops on birds; however, one conducted on intensive maize and soybean farms in the Midwestern USA found higher relative abundance of song sparrows and gray catbirds in fields where crops were planted adjacent to cover crops (Wilcoxen *et al.*, 2018). The utility of cover cropping to farmers and the positive association with the abundance of certain shrubland species is promising; however, more research is needed to understand more specifically which factors or characteristics, such as structure, type and landscape context, impact the usage of these habitats by birds.

Perhaps unsurprisingly, many of the other species that were positively associated with row crop cover, including cedar waxwing, house sparrow, American robin and European starling, are all notorious crop pests. Cedar waxwing in particular is well known throughout the New England region for depredating berry crops such as strawberries (*Fragaria sp.*) (Avery *et al.*,

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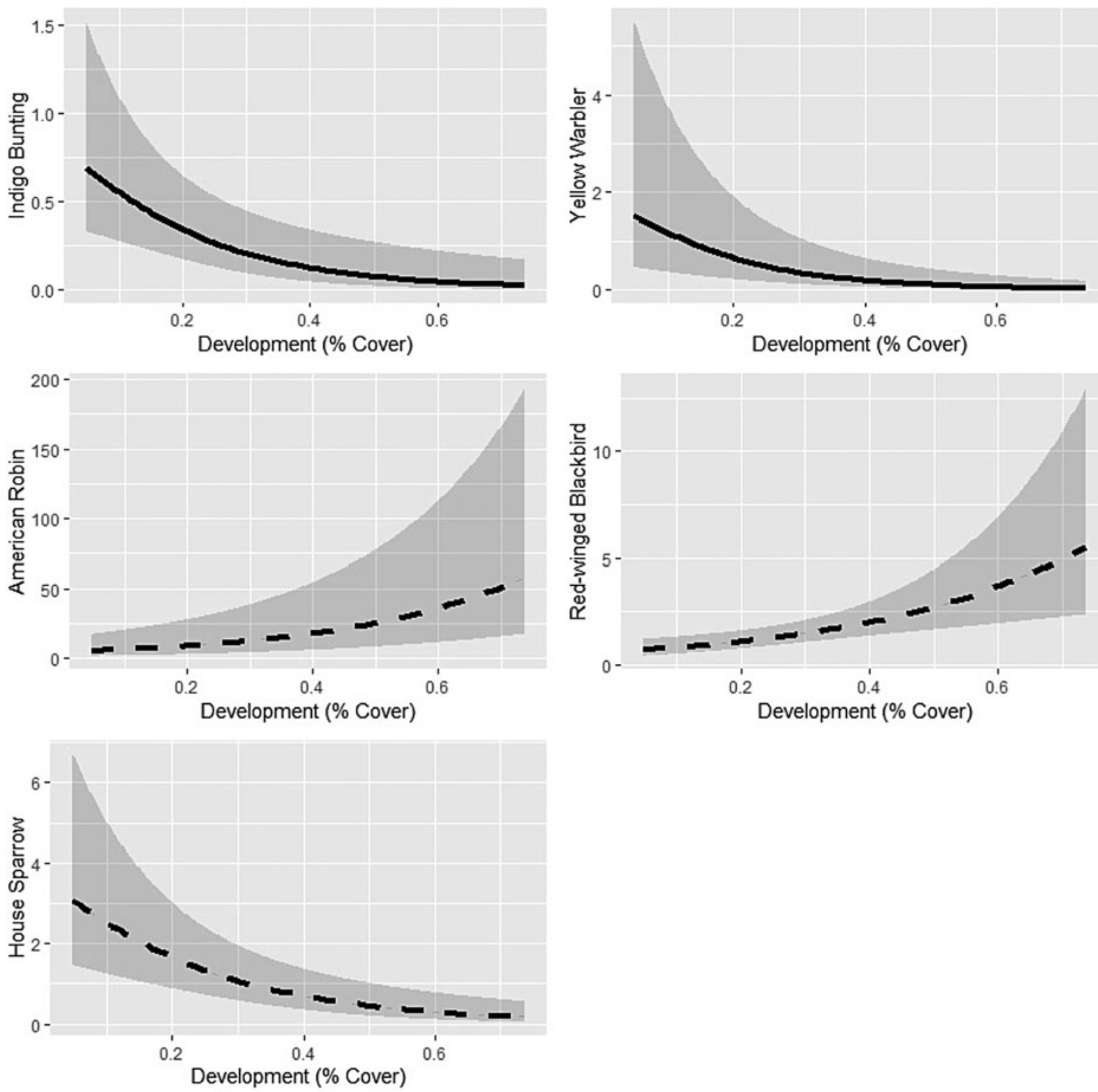

Figure 5. Poisson-binomial mixture model predictions visualizing relationships between species abundance landscape-scale variable development (percent developed landcover within 200 m of the farm). Solid lines indicate shrubland species and dashed lines represent crop pests. Data come from 22 small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018.

2016). However, we did find that the microhabitat-scale associations for most crop-depredating species all exhibited similar negative associations with tall, dense, woody vegetation in our Poisson-binomial mixture models. This relationship between increased cover of tall, woody features such as hedgerows and decreased abundance of crop pests is corroborated by previous studies conducted in more intensified agricultural settings (Jobin *et al.*, 2001; Deschênes *et al.*, 2003). On small, diversified farms, where crop damage inflicted by avian pests can be a critical concern, increasing coverage of tall, woody non-productive habitats may not only benefit farmers by reducing pest abundance, but also increase abundance of priority shrubland birds.

Reducing farm field sizes on small, diversified farms compatible with production goals may also increase abundance of several shrubland species. Common yellowthroat and willow flycatcher were negatively associated with field area, a relationship that has been reported in several other studies and is likely driven by the increased proportion of natural or semi-natural habitats in landscapes with smaller field sizes (Fahrig *et al.*, 2015; Šálek *et al.*, 2018; Martin *et al.*, 2020). Patch- and/or landscape-level effects on bird communities and abundance have been well studied in the context of intensified agriculture, especially in Europe (Devictor and Jiguet, 2007; Winqvist *et al.*, 2012; Chiron *et al.*, 2014; 2010; Hass *et al.*, 2018), but less is known about these associations in low-intensity farming systems or for North American species (Smith *et al.*, 2020). On small, diversified farms, broad-scale variables such as field size and landscape composition appear to be important factors driving bird abundance; all of the species in our analysis responded to variables from at least one of these two spatial scales. For shrubland birds, this was a somewhat surprising result, as previous studies from other habitats such as beaver meadows have reported that microhabitat-scale

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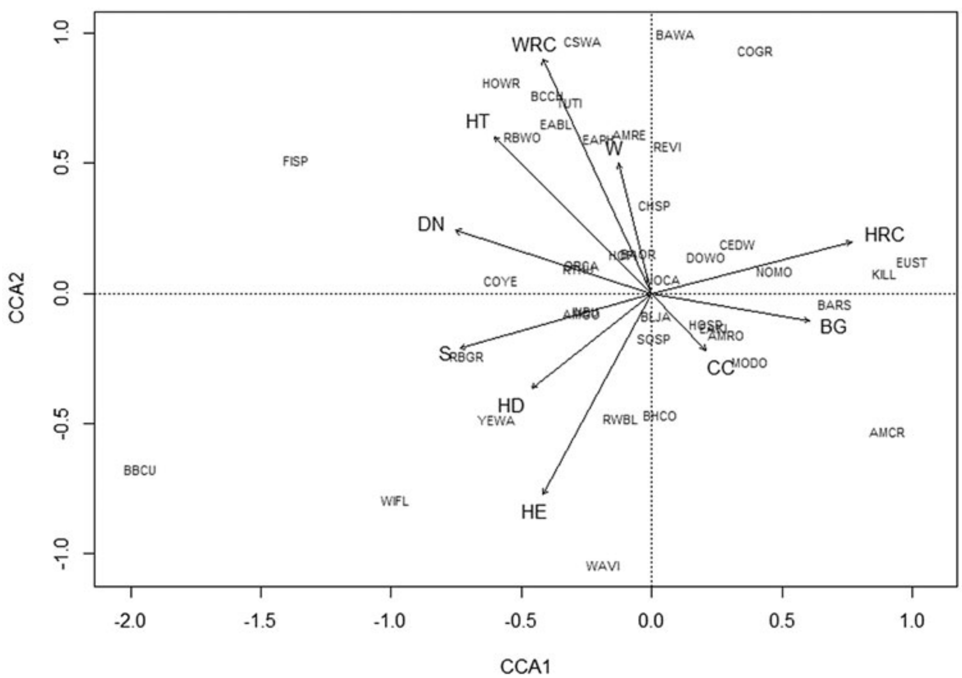

Figure 6. Canonical correspondence analysis (CCA) biplot of associations between microhabitat-scale variables (BG, bare ground; CC, cover crop; DN, vegetation density; HD, hedgerow; HE, herbaceous; HRC, herbaceous row crop; HT, vegetation height; S, shrubland; W, woodland; WRC, woody row crop) and a subset of 41 bird species on small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018. Species abbreviations in Table 2.

characteristics were better at predicting shrubland bird abundance than patch- or landscape-scale factors (MacFaden and Capen, 2002; Chandler *et al*., 2009). This may be due to the fact that the farm fields that we surveyed were, on average, smaller in size than many shrubland habitat patches resulting from silvicultural activities, powerline cuts or beaver meadows and thus more susceptible to the influences of the surrounding landscape (Confer and Pascoe, 2003; Chandler *et al*., 2009; King *et al*., 2009a, 2009b).

Landscape-scale effects on shrubland bird abundance were more species-specific. Observed responses to development on the landscape were negative (indigo bunting and yellow warbler); however, shrubland species were split in their relationships with agricultural cover, with gray catbird and American goldfinch showing a negative association, while indigo bunting and willow flycatcher showing a positive one. In New England, an increase in agriculture or development could represent a more simplified or homogenous landscape configuration, with less seminatural cover, which has been shown to have negative impacts on biodiversity and avian ecosystem services in farmland habitats (Pejchar *et al*., 2018; Tscharntke *et al*., 2021; Olimpi *et al*., 2022). The negative association with agriculture exhibited by gray catbird may reflect this species' habitat preferences at smaller spatial scales. In shrubland habitats such as beaver meadows, gray catbird tends to be associated with a higher composition of woody plant cover (Chandler *et al*., 2009) and in farmland habitats, favored riparian strips with tall shrubby or predominantly tree cover (Jobin *et al*., 2001). The negative relationship with agriculture exhibited by American goldfinch is less expected, given that this species is typically associated with more open habitats and herbaceous cover at the microhabitat scale, but this may be explained by the fact that this species tends to select habitats on the basis of food availability rather than habitat structure (Schlossberg and King, 2007).

As landscape-level habitat associations for most species appear to align with microhabitat preferences, it was unexpected to find a positive relationship between agriculture and abundance of indigo bunting and willow flycatcher—two shrubland specialists. One possible explanation is that these agricultural landscapes provide foraging opportunities. One study of farms in north-central Florida characterized indigo bunting as a 'functional insectivore' due to the frequency in which foraging in cropped fields was observed (Jones *et al*., 2005). Indigo buntings also utilize a variety of shrubland habitat types, from wetlands to clearcuts, but agricultural landscapes may fulfill their preference for more open-structured landcover. Willow flycatchers utilizing Conservation Reserve Program (CRP) fields in Illinois were found to exhibit a negative relationship with forest cover in the surrounding landscape (Reiley and Benson, 2019). Likewise, other flycatchers, such as black phoebe and pacific-slope flycatcher, have been reported as high 'multifunctionality' species, indicating species more likely to provide ecosystem services such as consuming pests (Olimpi *et al*., 2022). Alternatively, another explanation is that the farms that we sampled with more extensive agriculture in the surrounding landscape were acting as islands of suitable habitat within a less ideal matrix, and therefore attracting or concentrating the numbers of these species (Pejchar *et al*., 2018; Tscharntke *et al*., 2021).

Landscape characteristics such as urban or agricultural cover surrounding farms typically are not factors that farmers can control, but they may provide context for how certain species are behaving and guide management decisions at smaller spatial scales. For instance, farms embedded in a matrix with high proportions of development may have higher abundance of crop pests such as American robin or red-winged blackbird, but it may be possible to discourage these species by managing field edges for greater proportions of tall, woody, natural vegetation.

Table 2. List of microhabitat-scale landcover types, abbreviation, descriptions, average height (HT), average density/visual obstruction (VO), average percent cover (PC) and associated standard errors (s.e.) from small, diversified farms in the Pioneer Valley, Massachusetts, 2017–2018

Cover type		Description	HT (m)	VO (%)	PC (%)
Cover crop	CC	Legume, grass or cereal cover crop	0.61 (0.06)	0.31 (0.03)	0.42 (0.05)
Hedgerow	HD	Shrub/tree-dominant linear feature	5.78 (1.03)	0.72 (0.02)	0.09 (0.02)
Herbaceous	HE	Forb/grass-dominated vegetation	0.68 (0.04)	0.38 (0.03)	0.40 (0.04)
Herbaceous rowcrop	HRC	Vegetable or other non-woody crop	0.35 (0.03)	0.22 (0.02)	0.36 (0.04)
Shrub	S	Woody vegetation (<3 m)	2.74 (0.50)	0.73 (0.02)	0.14 (0.04)
Woodland	W	Woody vegetation (>3 m)	14.06 (1.00)	0.77 (0.01)	0.16 (0.03)
Woody rowcrop	WRC	Berries, fruit tree or other woody crop	2.15 (0.38)	0.42 (0.03)	0.30 (0.07)

Previous research suggests that localized allocation of natural or semi-natural habitats had a greater positive impact on bird diversity and abundance in more intensified or simple landscapes, as opposed to lower intensity landscapes with greater habitat heterogeneity (Freemark and Kirk, 2001; Tscharntke *et al.*, 2005). Therefore, small, diversified farms located within highly developed areas may provide refuge for species of concern if sufficient non-productive habitats are available.

One of the primary limitations of this study was the use of abundance estimates derived from *N*-mixture models rather than measures of reproductive success as an indicator of habitat quality. While counts of birds have been used in this way for decades, studies have pointed out that reproduction and abundance are not always positively correlated and therefore higher densities of birds do not automatically indicate that habitat quality is high (Van Horne, 1983; Johnson, 2007; Bock *et al.*, 2017). While this study did not monitor nesting activity, we did observe breeding behaviors being exhibited by the species included in this analysis, so we are confident that these species were at least attempting to use the areas in and around these farms as nesting habitat. Whether or not farm-nesting species are successful on farms relative to other habitats warrants further investigation. Previous studies have reported increased predation or parasitism of nests located in small patches or in edges (Weldon and Haddad, 2005; Roberts and King, 2017), which suggests that farms, which generally supply small or linear patches of natural habitat suitable for nesting, may be highly susceptible to such effects. One study from North Carolina found that predation of shrubland bird nests was higher near agricultural edges than mature forest edges (Shake *et al.*, 2011). However, other studies suggest that for species nesting in natural habitats such as hedgerows, nest predation can be reduced by managing for dense, woody vegetation structure to improve cover and protection for nesting species (Dunn *et al.*, 2016).

Conclusion

Agriculture is making a comeback in the New England region, primarily in the form of smaller, diversified operations implementing sustainable growing practices that promote habitat for wildlife including birds. Our results suggest that opportunities exist for integrating priority bird conservation into this type of agriculture. Small, diversified farms already support high numbers of shrubland species, but smaller field sizes, and management of non-productive areas for a mix of dense shrub and tall wooded habitats could help increase the abundance of species like gray catbird, common yellowthroat, indigo bunting, willow flycatcher and yellow warbler, while also discouraging crop pests such as cedar waxwing, European starling and house sparrow. For other shrubland species, such as song sparrow, willow flycatcher and yellow warbler, increased availability of more open habitats such as cover crops and herbaceous fields is key. The influence of landscape-scale habitat composition should also be taken into consideration when making management decisions, with the understanding that impacts at this scale were diverse and species-specific. Overall, our findings provide support to the idea that small, diversified farms in New England exemplify a system in which agricultural production is compatible with and supportive of conservation goals for priority avian species. Finally, exclosure experiments on a subset of these same farms show birds reduce pest numbers and pest damage to most crops (Mayne *et al.*, 2023a), and that gray catbirds, common yellowthroats and song sparrows consume the most pests (Mayne *et al.*, 2023b). Thus, the habitat associations we present provide guidelines for managers interested in enhancing populations of bird species that are most effective at controlling crop pests.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170523000273

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