Ornithological Methods

Springtime bird use of agricultural landscapes examined by using autonomous recording units

La utilización de paisajes agrícolas por aves en primavera evaluado mediante unidades de grabación autónomas

Joseph M. McGovern [1] , Jordan C. Giese [1] and Lisa A. Schulte [1]

ABSTRACT. Autonomous recording units (ARUs) emerged as a novel technology for avian acoustic monitoring in the 2000s. They have since been primarily used as a substitute for human observers during the breeding season. Autonomous recording units have potential uses in springtime soundscapes, such as to study spring departure or arrival of migratory birds and territory establishment of resident breeding birds. We described springtime bird communities of agricultural landscapes based on data collected between 1 April and 15 May 2015–2019, from ARUs deployed at 32 locations across 13 counties in Iowa, USA. We compared bird communities across site types, analyzed trends in migrant arrival dates and detection rates, and examined springtime occupancy of five species that commonly use grassland cover: Common Yellowthroat (*Geothlypis trichas*), Field Sparrow (*Spizella pusilla*), Grasshopper Sparrow (*Ammodramus savannarum*), Savannah Sparrow (*Passerculus sandwichensis*), and Vesper Sparrow (*Pooecetes gramineus*). We made 4029 detections of 86 bird species. The most frequent detections were of common farmland species, including Red-winged Blackbird (*Agelaius phoeniceus*), American Robin (*Turdus migratorius*), Brown-headed Cowbird (*Molothrus ater*), Ring-necked Pheasant (*Phasianus colchicus*), and Eastern Meadowlark (*Sturnella magna*); however, detections also included 18 species of greatest conservation need. Sites with reconstructed prairie vegetation, conventionally grown corn (*Zea mays*) and soybean crops (*Glycine max*), crops with prairie strips, and crops with terraces had similar species richness. We found that, in addition to documenting species richness and departure/arrival times of migratory species, ARUs generated species-level detection probabilities similar to or higher than existing studies on breeding season occupancy. Detection probabilities of five focal species ranged from 0.36–0.89. Occupancy models revealed significant springtime land cover associations for Common Yellowthroats, Field Sparrows, Savannah Sparrows, and Vesper Sparrows. We conclude that springtime deployment of ARUs can provide valuable information on phenological patterns and springtime habitat use of birds.

RESUMEN. Las unidades de grabación autónomas (ARUs, por sus siglas en inglés) surgieron como una tecnología novedosa para el monitoreo acústico de aves en la década de 2000. Desde entonces, se han utilizado principalmente como un sustituto de observadores humanos durante la temporada de reproducción. No obstante, las unidades de grabación autónomas tienen aplicaciones potenciales en paisajes sonoros de primavera, como el estudio de la salida o llegada de aves migratorias y el establecimiento de territorios de aves residentes. Este estudio se centra en las comunidades de aves en paisajes agrícolas durante la primavera, basándose en datos recopilados entre el 1 de abril y el 15 de mayo de 2015-2019, a partir de ARUs desplegadas en 32 ubicaciones en 13 condados de Iowa, EE. UU. La comparación de comunidades de aves entre tipos de sitios, el análisis de tendencias en las fechas de llegada y tasas de detección de aves migratorias y la evaluación de la ocupación de cinco especies que comúnmente utilizan cobertura de pastizales (*Geothlypis trichas*, *Spizella pusilla*, *Ammodramus savannarum*, *Passerculus sandwichensis* y *Pooecetes gramineus*) fueron los focos de estudio. Se registraron 4029 detecciones de 86 especies de aves, incluyendo especies comunes en tierras de cultivo (*Agelaius phoeniceus*, *Turdus migratorius*, *Molothrus ater*, *Phasianus colchicus* y *Sturnella magna*) y 18 especies con mayores necesidades de conservación. Los resultados mostraron que los sitios con diferente tipo de vegetación, como pradera reconstruida, cultivos de maíz (*Zea mays*) y soja (*Glycine max*) cultivados de manera convencional, cultivos con franjas de pradera y cultivos con terrazas, tenían una riqueza de especies similar. Además de documentar la riqueza de especies y los tiempos de salida/llegada de especies migratorias, se encontró que las ARUs, generaron probabilidades de detección a nivel de especie similares o mayores que los estudios existentes sobre ocupación durante la temporada de reproducción. Las probabilidades de detección de las cinco especies focales oscilaron entre 0.36–0.89. Los modelos de ocupación revelaron asociaciones significativas de cobertura terrestre durante la primavera para *Geothlypis trichas*, *Spizella pusilla*, *Passerculus sandwichensis* y *Pooecetes gramineus*. En conclusión, el despliegue de ARUs en primavera puede proporcionar información valiosa sobre patrones fenológicos y el uso de hábitats por parte de las aves.

Key Words: *acoustic monitoring; detection probability; habitat associations; occupancy; phenology; soundscape ecology*

INTRODUCTION

Autonomous recording units (ARUs) emerged as a novel technology for avian acoustic monitoring in the 2000s (Shonfield and Bayne 2017). Programmable recording schedules, affordability, and recent advances in battery life and file storage capacity of ARUs provide several advantages to researchers including broader spatial and temporal sampling, reductions in observer bias, and data quality control (Sugai et al. 2019). Autonomous recording units have been employed in studies examining settlement patterns of migratory birds (e.g., Johnson and Bayne 2022, Swicegood et al. 2023), soundscape dynamics (e.g., Suer and Farina 2015, Bennocci et al. 2020, Stowell and Seur 2020), and

[1]Department of Natural Resource Ecology and Management, Iowa State University

diel patterns (e.g., Jahn et al. 2017, Pérez-Granados and Schuchmann 2020, Schroeder and McRae 2020). Although they can be deployed long-term, ARUs have been primarily used during the breeding season because birds are more vocally active while breeding and are therefore more identifiable in audio recordings (e.g., Alquezar and Machado 2015, Furnas and Callas 2015, Pérez-Granados et al. 2018). The application of ARUs for studying birds during other periods of the annual cycle, such as arrival to and departure from breeding grounds, remains underdeveloped.

There is potential for use of ARUs in springtime soundscapes, such as during spring departure or arrival of migratory birds, and territory establishment of resident and spring arriving birds. Buxton et al. (2016) used ARUs to examine shifts in arrival of migratory songbirds in Alaska and found bioacoustic indices to be useful for tracking arrival of songbirds. Swicegood et al. (2023) deployed ARUs in agricultural landscapes to investigate settlement patterns of Thick-billed Longspurs (*Rhynchophanes mccownii*). Other springtime studies include Sanders and Mennill (2014) and Colbert et al. (2015), which used ARUs to examine spring migratory movements and spring gobbling activity of Wild Turkey (*Meleagris gallopavo*), respectively. Autonomous recording units have also proven effective for studying Ruffed Grouse (*Bonasa umbellus*) drumming behavior using April recordings in Minnesota (Déaux et al. 2020, Grinde et al. 2021). The use of ARUs to study spring migration and territory establishment, however, is still relatively underexplored. Autonomous recording unit studies could form a "middle ground," augmenting broad-scale taxon-wide data collected through radar surveys with species-level information and individual-scale data tracked through global positioning systems with community information. With climate change, land use change, and other potential disruptors affecting temporal and spatial patterns in biological activity, networks of ARUs could potentially be deployed to track species-level shifts in migration timing or spatial concentration or dispersion. Climate change is already thought to be the primary driver of shifts in spring arrival of birds, which respond to increases in local and regional temperatures during wintering and spring migration (Bradley et al. 1999, Brown et al. 1999, Sparks et al. 2007, Swanson and Palmer 2009, Van Buskirk et al. 2009).

Data from ARU recordings are often analyzed though occupancy modeling (e.g., Furnas and Callas 2015, Stiffler et al. 2018). Similarly, nearly all habitat-association studies that use occupancy modeling take place during the breeding season, with little attention given to non-breeding patterns. A major reason for this is the closure assumption of occupancy modeling, i.e., that there are no changes in availability between survey periods (MacKenzie et al. 2002, Rota et al. 2009). However, Kendall et al. (2013) demonstrated that the closure assumption can be met by staggering arrival and departure times to avoid biasing occupancy estimates. Higher vocal activity near the beginning of the breeding season may also lead to higher detection rates. A study of Canadian forest birds found higher detection rates and higher species richness earlier in the breeding season (Ehnes et al. 2018). Springtime detection rates are largely unexplored in most systems, but vocal activity may be high enough for some species to develop accurate occupancy estimates.

We evaluated the utility of ARUs for studying spring bird communities as part of a larger study seeking to understand grassland bird use of agricultural landscapes of the U.S. Corn Belt. Grassland species are more susceptible to local extinctions due to increasing temperatures compared to forest birds; species occupying fragmented grasslands are at even higher risk (Jarzyna et al. 2016). Since 1970, grassland birds in North America have experienced a 53% overall decline, the steepest reduction of any bird community, primarily due to grassland habitat loss (Rosenberg et al. 2019). In North America, 80% of all grasslands have been lost through conversion to agriculture and only 1% of the original tallgrass prairie remains in most states and provinces (Knopf 1994, Samson and Knopf 1994). Corn Belt agriculture has intensified during the last several decades, creating vegetative monocultures that support fewer native wildlife species (Matson et al. 1997, Brown and Schulte 2011). Increasing agricultural efficiency has removed natural field edges and expanded artificial drainage, use of pesticides, and livestock stocking rates in pastures (Newton 1998, Brown and Schulte 2011). Many grassland-breeding species now rely on small, semi-natural grassy features embedded within agricultural landscapes. Some features have been found to increase bird use of crop fields including grass terraces (Hultquist and Best 2001), grass waterways (Bryan and Best 1991), field borders (Conover et al. 2009, Burger et al. 2010), and riparian buffers (Berges et al. 2010). These grassy features, usually dominated by exotic cool-season grasses, are unlikely to provide high quality breeding habitat to species that once relied on extensive tracts of tallgrass prairies. Grassy areas with established non-native grasses are structurally different from prairies, with substantially higher grass height and cover. They have been associated with temporal and spatial shifts in breeding patterns of grassland birds (Andersen and Steidl 2020).

Migratory grassland birds are thus likely to be heavily affected by both climate change and habitat modification that accompanies land use change. However, little research has been devoted to their springtime habitat use when energetic resources are crucially needed by birds to support breeding effort and food availability may be low. We sought to fill this gap by using ARUs to investigate the springtime bird community across agricultural landscapes in Iowa, a central U.S. Corn Belt state. Our specific objectives were to:

1. Describe springtime bird communities of agricultural landscapes,

2. Examine springtime detectability and occupancy, and

3. Evaluate the utility of ARUs for springtime studies of avian habitat use.

We hypothesized that species richness would increase with the amount of grass cover at study sites given the Corn Belt region was historically, prior to EuroAmerican colonization, dominated by grasslands (Conner et al. 2001). We made predictions regarding species occupancy based on published habitat associations (Brennan et al. 2020, Vickery et al. 2020, Wheelwright et al. 2020.). We also hypothesized that springtime species-level detection probabilities would be lower than those generated during breeding season studies.

METHODS

Study area

The study area was composed of 32 sites located across 13 counties in Iowa (Appendix 1). Iowa is a central state within the U.S. Corn Belt, and its landscapes are dominated by annual row crop agricultural production, primarily for corn (*Zea mays* L.) and soybeans (*Glycine max* [L.] Merr.), which comprised 72.1% of the statewide land cover (Farmland Information Center 2016). Other common land cover types include pasture (9.4%; mostly cool-season exotic grasses such as *Bromus inermis* Leyss), forest (7.9%; USDA Forest Service 2022), and developed (5.4%; Farmland Information Center 2016). The climate is humid continental, with cold winters and warm summers. Average statewide monthly temperature during the period of observations (April–May) was 22.5 degrees Celsius, and average monthly precipitation was 11.1 cm (NOAA 2022, NWS 2022).

Study sites were chosen as a part of a broader investigation of bird use of agricultural landscapes (Stephenson 2022, Giese 2023). Permission to access the land from the land manager was required for study. Sites were composed of one of four types: (1) reconstructed or restored prairie (hereafter, large patch prairies), (2) corn and soybean crops grown using conventional practices for the region and without substantial areas of conservation cover, (3) conventionally managed crops with terraces, and (4) conventionally managed crops with prairie strips. Large patch prairies ranged from 38-102 ha in size, similar to crop fields, which ranged from 17.89 ha to 93.14 ha. Crop fields with terraces included narrow berms installed to minimize soil erosion and were covered in cool-season grasses. Crop fields with prairie strips included linear non-crop areas composed of diverse, reconstructed native prairie vegetation to improve biodiversity and provide multiple ecosystem services (Schulte et al. 2017). Perennial vegetation at sites was mostly dormant during the study period and crops were planted between mid-April and early-May.

Data collection

For each ARU deployment (Songmeter SM3, Wildlife Acoustics, Maynard, Massachusetts, USA), we generated a random point within a farm field and placed the unit in the nearest grassy feature or otherwise unfarmed area. Autonomous recording units were deployed a minimum of 250 m apart. Each unit was mounted ~1.5 m above the ground on a steel fence post. At each site, ARUs were programmed to record for 1 hour beginning 15 minutes before sunrise and ending 45 min after sunrise each day. We analyzed data collected from 1 April–15 May, 2015–2019. We chose this period to coincide with the migratory season for grassland birds, and prior to when in-person observations through bird point counts typically begin in the study region. Data storage cards were collected every 2–3 months and stored for later analysis. Figure 1 summarizes workflow.

We analyzed each 60-min recording of the daily dawn chorus from each deployment location through the period 1 April-15 May for each year, excluding days with excessive wind, rain, or other background noise. Days with background noise deemed excessive showed a steady sound signature above 1 kHz. Of the 2088 total available recordings, 348 were deemed usable with little noise interference. Due to low availability of recordings in some years, 299 of the surveys occurred in 2016 and 2018. We used an intermittent subsampling procedure generated using R statistical

Fig. 1. Summary of workflow for collecting, processing, and analyzing autonomous recording units (ARU) recordings.
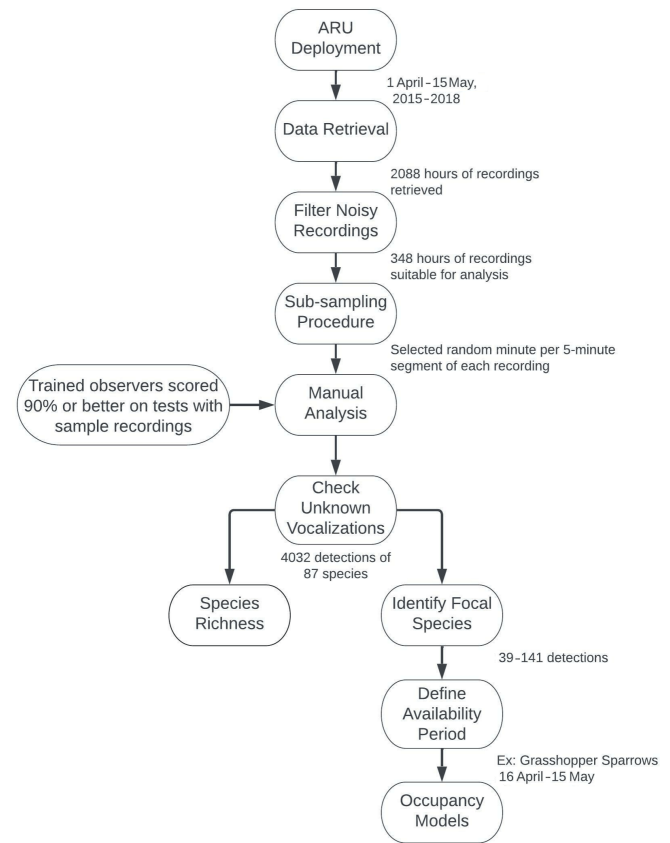
software R 4.1.2 (R Core Team 2021), listening to a random minute out of each 5-min segment per 60-min recording, resulting in 12 1-min samples per 60-min recording. In cases of abrupt disturbances, such as farm equipment and road noise, within recordings, the observer would move to the next available minute without such noise. For each recording, we recorded the common name of each species present with the ordinal number of each minute in which that species was detected (e.g., Savannah Sparrow, *Passerculus sandwichensis*, in minutes 2, 8, 11, and 40). All species that could not be initially identified were checked by a secondary observer. We removed 111 unknown vocalizations, mostly distant calls that could not be identified to the species level, from the analysis. Of the 87 species we detected, we classified 44 species as spring arrivers, 34 as year-round residents, and 9 as winterers, according to the Iowa Ornithologists' Union classifications (IOU 2020; Table 1).

Temperature and wind speed are known to affect bird activity and thus detectability (Robbins 1981). We obtained mean daily temperature data from the nearest regional weather monitoring station (NOAA 2022). We were unable to obtain reliable historical wind speed data but accounted for this factor's impact on observation by excluding days with excessive wind in recordings.

To examine environmental predictors of occupancy, we used aerial images provided by the National Agriculture Imagery Program (USDA NAIP 2020) to digitize land cover within 200 m

Table 1. Eighty-seven bird species detected during springtime autonomous recording unit (ARU) surveys in Iowa, 2015–2019. Migration classes based on IOU (2020) designations. Dashes indicate no detections.

Species	Migration class	% Occurrence	Detections by site type				Availability start date[†]	Availability end date[†]
			Large patch prairie	Conventional crops	Crops with terraces	Crops with prairie strips		
American Coot	Arriving	0.3	-	-	1	-	113	113
American Crow	Resident	35.2	14	34	43	31	92	136
American Goldfinch	Resident	18.9	10	29	6	17	95	135
American Robin	Resident	86.3	11	119	69	102	91	136
American Tree Sparrow	Wintering	1.1	-	-	-	4	100	110
Barred Owl	Resident	0.5	1	1	-	-	133	134
Baltimore Oriole	Arriving	3.6	1	3	3	2	125	136
Barn Swallow	Arriving	3.8	1	4	1	6	108	135
Black-capped Chickadee	Resident	1.4	-	2	1	-	97	130
Bell's Vireo[‡]	Arriving	0.3	1	-	-	-	128	130
Blue Jay	Resident	33.1	10	65	8	30	92	135
Bobolink[‡]	Arriving	4.6	6	1	2	4	123	134
Brown-headed Cowbird	Resident	78.1	10	107	59	98	91	136
Brown Thrasher	Arriving	33.1	10	50	15	41	98	136
Canada Goose	Resident	42.3	13	40	36	56	91	136
Cedar Waxwing	Resident	0.5	0	1	-	1	129	133
Chipping Sparrow	Arriving	6	1	14	2	4	98	133
Common Grackle	Resident	33.6	2	50	28	42	92	133
Common Nighthawk[‡]	Arriving	0.5	1	1	-	-	133	134
Common Yellowthroat	Arriving	18	15	11	10	24	117	136
Dark-eyed Junco	Wintering	3.8	-	14	-	-	92	110
Dickcissel[‡]	Arriving	9.8	4	6	10	10	122	136
Eastern Bluebird	Resident	2.2	2	4	1	1	103	132
Eastern Kingbird	Arriving	2.7	-	2	-	7	105	134
Eastern Meadowlark[‡]	Resident	59	14	77	48	61	91	136
Eastern Phoebe	Arriving	0.8	-	2	-	1	108	123
Eastern Towhee	Arriving	4.6	1	13	-	3	97	132
Eastern Wood-peewee	Arriving	0.3	1	-	-	-	125	130
Eurasian Collared-dove	Resident	5.7	3	4	7	5	97	135
European Starling	Resident	20.2	-	47	5	20	92	135
Field Sparrow[‡]	Arriving	17.2	12	20	11	14	100	136
Great Blue Heron	Resident	1.1	2	1	1	-	124	135
Great Crested Flycatcher	Arriving	0.5	-	-	2	-	132	135
Golden-crowned Kinglet	Wintering	0.3	-	1	-	-	111	111
Great Horned Owl	Resident	0.3	-	0	-	1	103	103
Gray Catbird	Arriving	3	3	3	1	2	123	136
Grasshopper Sparrow[‡]	Arriving	11.5	13	9	9	8	106	136
Greater Yellowlegs[‡]	Arriving	2.2	-	3	1	4	98	117
Greater White-fronted Goose	Arriving	0.3	1	-	-	-	126	126
Harris's Sparrow	Wintering	3.6	-	10	-	3	93	133
Henslow's Sparrow[‡]	Arriving	3	7	-	1	-	125	134
House Finch	Resident	3.3	2	9	-	1	92	131
Horned Lark	Resident	29	-	24	33	43	91	134
House Sparrow	Resident	10.1	-	25	-	10	94	130
House Wren	Arriving	4.1	2	4	3	4	114	136
Indigo Bunting	Arriving	2.2	-	4	2	1	125	136
Killdeer	Arriving	52.7	3	68	46	67	91	136
Lapland Longspur	Wintering	10.1	-	17	2	18	95	115
Lark Sparrow	Arriving	0.3	-	-	1	-	132	132
Lesser Yellowlegs[‡]	Arriving	1.6	-	3	1	2	105	129
Mall1ard	Resident	3	-	6	3	1	98	123
Mourning Dove	Resident	39.1	7	59	29	39	91	136
Northern Bobwhite[‡]	Resident	3.8	-	2	3	6	112	136
Northern Cardinal	Resident	50.3	8	90	21	57	91	136
Northern Flicker	Resident	10.4	2	14	9	13	95	129
Northern Parula	Arriving	0.3	-	1	-	-	129	129
Northern Saw-whet Owl	Wintering	0.3	1	-	-	-	126	126

(con'd)

Purple Martin	Arriving	1.1	1	-	3	-	97	126
Rose-breasted Grosbeak	Arriving	1.4	-	1	2	2	121	136
Red-bellied Woodpecker	Resident	7.4	8	2	4	8	117	136
Red-headed Woodpecker[‡]	Resident	2.2	2	-	1	5	108	132
Ring-necked Pheasant	Resident	71.6	16	90	61	81	91	136
Rusty Blackbird[‡]	Wintering	1.6	-	3	-	3	94	117
Red-winged Blackbird	Resident	92.1	15	121	76	108	91	136
Sandhill Crane[‡]	Arriving	0.3	-	-	-	1	99	99
Savannah Sparrow	Arriving	16.1	1	14	11	30	98	133
Sedge Wren[‡]	Arriving	6.8	11	3	4	3	122	135
Sora	Arriving	1.6	2	1	2	-	123	135
Solitary Sandpiper[‡]	Arriving	0.5	-	-	-	2	114	123
Song Sparrow	Resident	54.1	6	77	34	71	91	136
Spotted Sandpiper	Arriving	3	1	2	3	5	95	131
Swamp Sparrow	Resident	0.8	-	-	-	3	107	118
Tennessee Warbler	Arriving	0.3	-	-	-	1	131	131
Tree Swallow	Arriving	6	1	12	5	2	95	135
Trumpeter Swan[‡]	Resident	0.3	-	-	-	1	115	115
Upland Sandpiper[‡]	Arriving	2.2	-	3	-	4	117	133
Vesper Sparrow	Arriving	39.3	5	47	27	62	95	136
Warbling Vireo	Arriving	0.8	-	-	2	1	126	136
White-crowned Sparrow	Wintering	1.1	-	4	-	-	93	126
Western Meadowlark	Resident	56.8	1	65	49	88	91	136
Wilson's Snipe	Arriving	0.8	-	-	3	-	103	109
Wild Turkey	Resident	9.8	6	8	14	5	92	136
Wood Duck	Resident	1.1	-	1	1	2	103	135
White-throated Sparrow	Wintering	3	-	8	1	2	109	129
Yellow Warbler	Arriving	1.1	-	3	-	1	126	135
Yellow-rumped Warbler	Arriving	1.6	-	6	-	-	100	119

[†] Julian date.
[‡] Iowa species of greatest conservation need (IDNR 2015).

of each ARU. We used field verification to resolve ambiguous land cover in aerial imagery. We calculated the land cover percentage of local environmental variables within 200 m of each ARU (Table 2). We chose 200 m based on the maximum detection distance of around 100 m for most grassland bird species, which was determined by in-person breeding bird surveys at our sites (Giese 2023). We used a five-class cover classification system: crop, grass, prairie, woody, and developed. We calculated the distance from each ARU to the nearest road, a variable that is commonly accepted as influencing the detectability of birds (Yip et al. 2017).

Statistical Analysis

All analyses were performed using package "lme4" (Bates et al. 2015) in R statistical software R 4.1.2 (R Core Team 2021). We examined the relationship between site type and species richness using a generalized linear mixed model (glmm) with a Poisson error distribution and log link function. We included deployment location as a random term and accounted for variation in survey effort across deployment locations by including (log-transformed) effort (i.e., number of recordings analyzed) as an offset in the model. Differences in species richness among site types were examined using Tukey post hoc comparisons (Bretz et a. 2016).

Using occupancy models, we evaluated five species with enough variability in occurrence to allow successful model-fitting, including Common Yellowthroat (*Geothlypis trichas*), Field Sparrow (*Spizella pusilla*), Grasshopper Sparrow (*Ammodramus savannarum*), Savannah Sparrow (*Passerculus sandwichensis*), and Vesper Sparrow (*Pooecetes gramineus*); hereafter, we refer to them as focal species. We did not model the occurrence of common species, such as Dickcissel (*Spiza americana*) and Red-winged

Blackbird (*Agelaius phoenicius*), which were present at nearly all sites. Using detection histories of the five focal species, we created single-season occupancy models using the "occu" function in R package "unmarked" (Fiske and Chandler 2011). We considered a site to be each ARU deployment location in each year (hereafter "site-year") and treated each day as a separate site visit. We assumed independence among years. We also assumed independence among sites given that minimum distances between ARUs were greater than the effective detection distances of the focal species. In preparation for occupancy analysis of grassland songbirds, we classified each species as one of the following: year-round resident, winterer, or spring arriving. All focal species were considered spring arrivers. To avoid violating the closure assumption for occupancy modeling (MacKenzie et al. 2002), we did not consider any of these species available for detection until either its first detection at a site or first detection at a nearby site if it was never detected during a specific year (Kendall et al. 2013).

We tested for correlations among spatial variables before constructing models. We used temperature and distance-to-road to model detection of each focal species. Other variables commonly used to model detection, such as observer and time of day, did not vary in our study. After determining the best predictor of detection for each species, we then used spatial covariates to construct occupancy models. Among spatial variables, both prairie cover and developed cover were zero-inflated due to their absence at many ARU deployment sites. To account for this, we converted both variables to a binomial factor based on their presence or absence within 200 m of the ARU. We created interaction models for each species based on known habitat associations and life history traits, predicting that Common

Table 2. Summary of mean land cover composition (standard deviation) surrounding autonomous recording unit (ARU) deployment sites in Iowa, USA, and distance from ARU to nearest road.

Site type	Number sites	% Crop	% Grass	% Prairie	% Woody	% Developed	% Water	Distance to road (m)
Large patch prairie	4	3.0 (4.2)	9.8 (4.9)	70.0 (21.1)	11.5 (9.7)	5.0 (5.8)	0.75 (1.5)	575.8 (311.4)
Crop fields with prairie strips	10	57.7 (15.1)	16.9 (11.9)	15.4 (7.6)	4.8 (8.2)	2.6 (2.3)	2.6 (5.3)	407.4 (184.0)
Crop fields with terraces	7	67.9 (11.5)	27.1 (13.5)	0 (0)	2.6 (4.5)	1.4 (2.6)	1.0 (2.6)	601.9 (420.9)
Conventional crop fields	11	66.8 (13.6)	21.6 (11.2)	0 (0)	7.2 (6.7)	3.2 (2.8)	1.2 (2.3)	299.55 (255.0)

Yellowthroat occupancy would increase with prairie cover and woody cover, Field Sparrow occupancy would increase with woody cover, Grasshopper Sparrow and Savannah Sparrow occupancy would increase with grass cover, and Vesper Sparrow occupancy would increase with crop cover based on habitat associations described in Brennan et al. 2020, Vickery et al. 2020, and Wheelwright et al. 2020. In all occupancy models, we accounted for variation in survey effort by offsetting each model's regression by the number of surveys conducted at each site. We evaluated and ranked candidate models using Akaike's information criterion adjusted for small sample size (AIC$_c$) and the associated Akaike weight, w_i (Burnham and Anderson 2002). We used model averaging and multimodel inference with ΔAIC$_c$ < 2.0 across all candidate models to estimate the effects of covariates on occupancy using package "AICcmodavg" (Mazerolle 2020) in R statistical software 4.1.2 (R Core Team 2021). After constructing model sets, we tested for collinearity among covariates using variance inflation factor (VIF). We reported parameter estimates derived from AIC model selection with 85% confidence intervals as recommended for limited sets of a priori models (Arnold 2010). We reported 95% confidence intervals for all other parameter estimates.

RESULTS

We made 4029 detections of 86 bird species, with an average of 11.6 species per ARU recording per day. The most frequently detected species were Red-winged Blackbird (present in 92% of recordings), American Robin (*Turdus migratorius*; 86%), Brown-headed Cowbird (*Molothrus ater*; 78%), Ring-necked Pheasant (*Phasianus colchicus*; 72%), and Eastern Meadowlark (*Sturnella magna*; 59%). Eighteen of 87 species we detected are listed as Iowa species of greatest conservation need (IDNR 2015). The median last date of detection of wintering species was 26 April (11 April–13 May) and the median first date of detection of arriving species was 5 May (1 April–16 May).

Species richness per site-year was similar among site types and ordered as follows: conventional crops (19.39 ± 12.15 (standard deviation)), crops with prairie strips (19.21 ± 8.97), large patch prairie (18.33 ± 8.15), and crops with terraces (18.25 ± 9.82). Adjusted for survey effort, the relationship between site type and species richness was significant (Table 3), but a Tukey post hoc comparison among site types revealed no statistically significant pairwise differences at the $p = 0.05$ level. Among comparisons with the largest differences in species richness, conventional crops and crops with terraces was insignificant (β = -0.131, 95% CI: -0.634–0.373, $p = 0.98$); and crops with prairie strips and crops with terraces was insignificant (β = -0.431, 95% CI: -0.951–0.083, $p = 0.61$). Most birds were found in multiple site types, but Dark-eyed Junco (*Junco hyemalis*) and White-crowned Sparrow (*Zonotrichia leucophrys*) were only detected at a control site with

Table 3. Generalized linear mixed model analyzing relationship between site type and springtime bird species richness using autonomous recording unit (ARU) surveys in Iowa, USA, 2015–2019. Large patch prairie was used as reference level for site type variable.

Fixed effects	Coefficient	SE	z	P	95% C.I.
Intercept	2.11	0.34	6.19	<0.01	1.61, 2.61
Conventional crops	-0.97	0.40	-2.41	0.12	-1.54, -0.38
Crops with prairie strips	-0.67	0.41	-1.63	0.10	-1.27, -0.07
Crops with terraces	-1.10	0.43	-2.54	0.01	-1.74, -0.47
Random effects	Variance (SD)				
Site	0.44 (0.65)				

nearby woody cover; Greater Yellowlegs (*Tringa melanoleuca*), Horned Lark (*Eremophila alpestris*), and Northern Bobwhite (*Colinus virginianus*) were detected in every site type but large patch prairie; Swamp Sparrows were only detected in a field with prairie strips in 2018; and Wilson's Snipe (*Gallinago delicata*) were only detected at sites with terraces. Several species of greatest conservation need were detected during three or fewer surveys.

The date of first detection of our five focal species varied (Table 4), and the number of occupied sites increased steadily throughout the study period (Fig. 2). All occupancy models met goodness-of-fit criteria and were unadjusted. Naive detection probabilities for our five focal species ranged from 0.36–0.89 (Table 3). The covariates for the top detection probability models for each focal species were temperature for Common Yellowthroat, distance to road for Field Sparrow and Vesper Sparrow, and a constant (i.e., null) for Grasshopper Sparrow and Savannah Sparrow.

Species-level occupancy probabilities varied greatly among land cover types (Table 5). Spatial predictors of occupancy also differed (Table 6, Appendix 2). Common Yellowthroat occupancy was positively related to the presence of prairie cover (β = 2.22, 85% CI: 0.46 ≤ β ≤ 3.97). Field Sparrow occupancy was positively related to woody cover (Fig. 3; β = 2.18, 85% CI: 0.87 ≤ β ≤ 3.50) and the presence of developed cover (β = 2.63, 85% CI: 1.31 ≤ β ≤ 3.94). Savannah Sparrow occupancy was negatively related to woody cover (Fig. 3; β = -1.58, 85% CI: -2.66 ≤ β ≤ -0.50) and positively related to crop cover (β = 1.28, 85% CI: 0.25 ≤ β ≤ 2.30). Vesper Sparrow occupancy was negatively related to woody cover (Fig 3; β = -0.65, 85% CI: -1.27 ≤ β ≤ -0.02). We did not find significant relationships between land cover and the occupancy of Grasshopper Sparrows (Appendix 2). Crop cover was the best predictor of Grasshopper Sparrow occupancy, but confidence intervals of beta estimates overlapped zero (β = -1.57, 85% CI: -3.42 ≤ β ≤ 0.28).

Table 4. Date of first detection based on springtime autonomous recording unit (ARU) surveys in Iowa, USA, 2015–2019 and detection probabilities (and 95% confidence intervals) of five focal bird species.

Species	Mean date of first detection (min - max)	Detection probability (C.I.)
Common Yellowthroat (*Geothlypis trichas*)	2 May (26 April–14 May)	0.89 (0.80, 0.94)
Field Sparrow (*Spizella pusilla*)	25 April (9 April–7 May)	0.45 (0.38, 0.59)
Grasshopper Sparrow (*Ammodramus savannarum*)	1 May (15 April–15 May)	0.39 (0.29, 0.50)
Savannah Sparrow (*Passerculus sandwichensis*)	24 April (7 April–10 May)	0.36 (0.30, 0.43)
Vesper Sparrow (*Pooecetes gramineus*)	25 April (4 April–15 May)	0.55 (0.50, 0.60)

Fig. 2. Mean proportion of sites occupied by five focal species, i.e., Common Yellowthroat (*Geothlypis trichas*), Field Sparrow (*Spizella pusilla*), Grasshopper Sparrow (*Ammodramus savannarum*), Savannah Sparrow (*Passerculus sandwichensis*), and Vesper Sparrow (*Pooecetes gramineus*), across study period (2015–2019) in Iowa, USA. Data were combined across years.
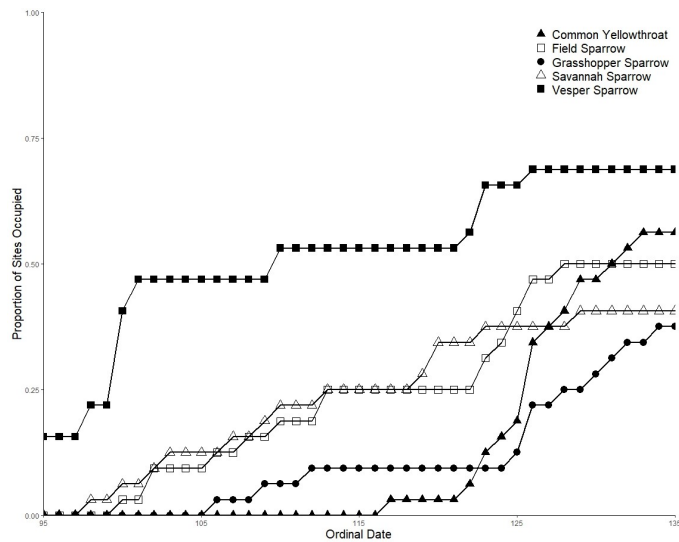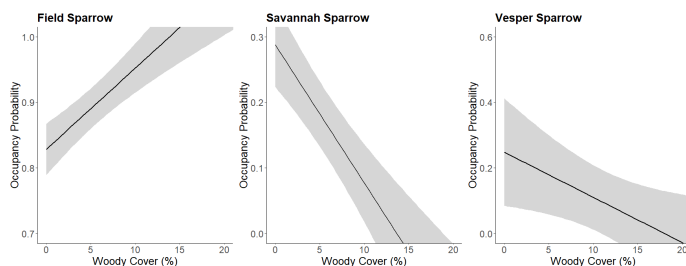

Fig. 3. Model averaged predictions of spring occupancy probabilities of Field Sparrow (*Spizella pusilla*), Savannah Sparrow (*Passerculus sandwichensis*), and Vesper Sparrow (*Pooecetes gramineus*) in relation to woody cover in Iowa, USA. Gray areas represent 85% confidence intervals.

DISCUSSION

We examined the utility of ARUs to study springtime avian habitat use within agricultural landscapes. We found that, in addition to documenting species richness of vocalizing species springtime avian communities, ARUs generated species-level detection probabilities similar to or higher than studies on breeding season occupancy of grassland birds (Sidie-Slettedahl et al. 2015, West et al. 2016, Rigby and Johnson 2019, Vanausdall and Dinsmore 2020), though we conducted more surveys. Several focal migratory species showed significant trends in springtime habitat associations. Our study supports expanded use of ARUs and other acoustic devices in the examination of springtime bird communities.

We detected 87 total species across our study sites, including 44 species as spring arrivers, 34 as year-round residents, and 9 as winterers, corresponding to 28% of species that regularly occur in the state throughout the year (IOU 2022). Among dates of first detections, we documented an Eastern Kingbird (*Tyrannus tyrannus*) on 14 April 2016, which is among the three earliest detections of the species in the state (IOU 2020), and a Brown Thrasher (*Toxostoma rufum*) on 9 April 2016, which is the earliest detection of the species in the state (IOU 2020). These detections occurred during an exceptionally warm period with statewide temperatures 3–5 degrees Celsius above average (NWS 2022).

Our hypothesis of increasing species richness with increasing grassland cover was not statistically supported. Although species richness is a coarse metric of community response, the lack of difference suggests either many bird species did not perceive a difference during the spring season among the site types comprising our study or we were not able to capture differences in their responses based on our methods. Most species of greatest conservation need with more than one detection were documented across all site types with the exception of Greater Yellowlegs and Northern Bobwhite, which were not found in large patch prairie (Table 1). Greater Yellowlegs are migratory during our study period, but Northern Bobwhite breed in Iowa and prefer mosaics of small patches of vegetation including grasslands and early successional vegetation (Brennan et al. 2020). During non-breeding seasons, Janke and Gates (2013) found that Northern Bobwhites selected early successional woody cover over grassland cover. Our large patch prairie sites contained little woody cover and were surrounded primarily by row crops.

Springtime occupancy varied among the five focal species we studied and are consistent with previous studies on breeding habitat preferences (Fig. 3). Our hypotheses regarding Common Yellowthroat and Field Sparrow occupancy were supported, but

Table 5. Occupancy probabilities (and 95% confidence intervals) for five focal species during springtime autonomous recording unit (ARU) surveys in Iowa, USA, 2015–2019.

Species	Occupancy (C.I.)			
	Conventional crops	Large patch prairie	Crops with prairie strips	Crops with terraces
Common Yellowthroat (*Geothlypis trichas*)	0.50 (0.31–0.69)	1.00 (NA)	0.87 (0.63–0.96)	0.74 (0.42–0.92)
Field Sparrow (*Spizella pusilla*)	0.83 (0.59–0.94)	1.00 (NA)	0.25 (0.12–0.44)	0.33 (0.15–0.59)
Grasshopper Sparrow (*Ammodramus savannarum*)	0.88 (0.81–0.99)	0.50 (0.19–0.81)	0.61 (0.26–0.87)	0.37 (0.19–0.60)
Savannah Sparrow (*Passerculus sandwichensis*)	0.65 (0.25–0.91)	0.00 (NA)	0.50 (0.29–0.70)	0.59 (0.28–0.84)
Vesper Sparrow (*Pooecetes gramineus*)	0.76 (0.43–0.93)	0.76 (0.43–0.93)	0.64 (0.45–0.79)	1.00 (NA)

the top predictors of Grasshopper Sparrow, Savannah Sparrow, and Vesper Sparrow occupancy were different from our predictions. Our hypothesis that Common Yellowthroat occupancy would show a positive relationship with the presence of prairie cover was supported. Common Yellowthroats prefer dense vegetation during breeding (Guzy and Ritchison 2020), but no study has quantified their springtime habitat preferences.

We predicted that woody cover would be the best predictor of Field Sparrow occupancy. In this analysis, we found woody cover to be the best predictor and have a positive relationship with Field Sparrow occupancy. Developed cover was also an important predictor (Table 6). Field Sparrows prefer fields with a wealth of tree or shrub perches (Carey et al. 2020). During the winter and spring, Field Sparrows used abandoned agricultural fields and forest edges (Allaire and Fisher 1975). The species is more often found in less disturbed edge habitats in the eastern and southeastern U.S. (Marcus et al. 2000, Smith et al. 2005).

Our hypothesis that Grasshopper Sparrow occupancy would show a positive relationship with percent grass cover was not supported due to uninformative models. Grasshopper Sparrows prefer grass-dominated fields and avoid crops (Vickery 2020). During the winter and spring, the species regularly occupies weedy fields in the southeastern U.S. and co-occurs with Savannah Sparrows and Song Sparrows (*Melospiza melodia*; Dunning and Pulliam 1989).

We predicted that grass cover would be the best predictor of Savannah Sparrow occupancy. Conversely, we found woody cover to be the best predictor, having a negative relationship with Savannah Sparrow occupancy. Crop cover was also an important predictor (Table 6). Savannah Sparrows prefer open country including grassy meadows, cultivated fields, and lightly grazed pastures and avoid areas with extensive woody cover (Wheelwright and Rising 2020). During the winter and spring, Savannah Sparrows are found in open fields, coastal marshes, and near surface water (Wheelwright and Rising 2020). The pattern we observed is thus unexpected and may be due to the highly anthropogenic character of our study landscapes, in which there is little natural vegetation (Table 1). Crop cover dominates all but the large patch prairie site types, and grassland land cover is dominated by a few species that tend to form monocultures or near-monocultures, such as the non-native cool-season grass smooth brome (*Bromus inermis*) or reed canary grass (*Phalaris arundinacea*).

We predicted that crop cover would be the best predictor of Vesper Sparrow occupancy, but we found woody cover to be the best predictor, having a negative relationship (Table 6). Vesper

Sparrows breed in dry, open areas with limited woody cover (Jones and Cornely 2020). During winter, Vesper Sparrows are found in grasslands, weedy fields, and savannahs (Howell et al. 1995). In spring, they use pastures and weedy areas near fields and roadsides during migration (Jones and Cornely 2020). Surprisingly, Vesper Sparrow occupancy was lower in conventional crops than Field Sparrow, Grasshopper Sparrow, and Savannah Sparrow occupancy (Table 5). This may be an artifact of our site selection because sites with conventional crops often contained grass waterways.

Due to the precipitous decline of grassland birds, information on their habitat requirements across the entire annual cycle is vital, especially for migratory species which spend periods of time in geographically distinct areas. In addition to springtime habitat use, ARUs have proven useful for tracking arrival times of migratory birds (Johnson and Bayne 2022, Swicegood et al. 2023), which have important consequences for reproduction (Currie et al. 2000, Smith and Moore 2005). Further investigation of non-breeding habitat use of migratory species will provide insight into potential cross-seasonal effects on populations and allow for effective monitoring (Norris and Marra 2007).

Our work was part of a larger project that also employed traditional methods such as bird point counts (Giese 2023) and nest searches (Stephenson 2022) to study bird use of agricultural landscapes. This is the first study of non-breeding bird use of prairie strips, a conservation practice with multiple ecological benefits (Schulte et al. 2017). Combined with bird point counts conducted at the same locations during the breeding season (Giese 2023), our springtime study of bird use of agricultural landscapes provides information on multi-season habitat associations of grassland birds.

Given the limitations of ARUs, we employed several methods to ensure the robustness of our analyses. We did not start survey periods for occupancy analysis until after a site was known to be occupied by a species because we could only be certain of the dates when birds began vocalizing, and not the true arrival dates of migrant birds. Because acoustic recordings are commonly obstructed by ambient noise, particularly wind (Digby et al. 2013), we removed recordings with excess wind and analyzed selected recordings from days with ideal survey conditions. Being able to collect data over a large number of days, but remove surveys conducted under poor observational conditions was an advantage of long-term deployment of ARUs. However, ambient noise still may have reduced our ability to detect some individuals.

Comparisons between acoustic data and those collected by community scientists would reveal how accurate ARUs are for

Table 6. Candidate model sets sorted by Akaike's Information Criterion with small sample adjustment (AICc) for five focal species. Based on data from during springtime autonomous recording unit (ARU) surveys in Iowa, USA, 2015–2019.

Species	Model	K	AIC_c	ΔAIC_c	w_i
Common Yellowthroat (*Geothlypis trichas*)	p(temp) Ψ(prairie)	4	88.06	0	0.46
	p(.) Ψ(.)	2	89.77	1.71	0.19
	p(temp) Ψ(woody+prairie)	5	90.41	2.35	0.14
	p(temp) Ψ(grass)	4	92.04	3.99	0.06
	p(temp) Ψ(crop)	4	92.44	4.39	0.05
	p(temp) Ψ(developed)	4	93.50	5.45	0.03
	p(temp) Ψ(woody)	4	93.87	5.81	0.03
	p(temp) Ψ(crop + grass + woody + prairie)	7	94.18	6.13	0.02
	p(temp) Ψ(global)	8	96.86	8.81	0.01
Field Sparrow (*Spizella pusilla*)	p(distroad) Ψ(woody)	4	197.60	0.00	0.38
	p(distroad) Ψ(developed)	4	198.08	0.49	0.30
	p(distroad) Ψ(woody + prairie + developed)	6	199.12	1.53	0.18
	p(distroad) Ψ(woody * prairie + developed)	7	201.58	3.99	0.14
	p(distroad) Ψ(woody * prairie)	6	202.29	4.69	0.04
	p(distroad) Ψ(global)	8	203.38	5.78	0.02
	p(distroad) Ψ(crop)	4	204.68	7.10	0.01
	p(.) Ψ(.)	2	205.58	7.99	0.02
	p(distroad) Ψ(prairie)	4	207.40	9.80	<0.01
	p(distroad) Ψ(grass)	4	207.97	10.38	<0.01
Grasshopper Sparrow (*Ammodramus savannarum*)	p(.) Ψ(crop)	3	123.84	0.00	0.17
	p(.) Ψ(.)	2	124.03	0.19	0.15
	p(.) Ψ(grass)	3	124.16	0.31	0.15
	p(.) Ψ(distroad * grass)	5	124.83	0.99	0.11
	p(.) Ψ(distroad)	3	124.85	1.01	0.11
	p(.) Ψ(global)	8	125.33	1.49	0.08
	p(.) Ψ(woody)	3	126.25	2.41	0.05
	p(.) Ψ(developed)	3	126.28	2.44	0.05
	p(.) Ψ(prairie)	3	126.33	2.48	0.05
	p(.) Ψ(prairie * grass)	4	126.51	2.67	0.05
	p(.) Ψ(woody * grass)	5	128.06	4.21	0.02
Savannah Sparrow (*Passerculus sandwichensis*)	p(.) Ψ(woody)	3	223.07	0.00	0.48
	p(.) Ψ(crop)	3	224.68	1.60	0.22
	p(.) Ψ(developed)	3	225.25	2.17	0.16
	p(.) Ψ(global)	8	227.77	4.70	0.05
	p(.) Ψ(.)	2	228.14	5.07	0.04
	p(.) Ψ(distroad + crop + woody + prairie)	6	228.46	5.39	0.03
	p(.) Ψ(prairie)	3	230.07	7.00	0.01
	p(.) Ψ(grass)	3	230.26	7.18	0.01
Vesper Sparrow (*Pooecetes gramineus*)	p(distroad) Ψ(woody)	4	350.23	0.00	0.35
	p(distroad) Ψ(crop)	4	352.01	1.78	0.14
	p(distroad) Ψ(prairie)	4	352.06	1.84	0.14
	p(distroad) Ψ(developed)	4	352.49	2.26	0.11
	p(distroad) Ψ(grass)	4	352.49	2.26	0.11
	p distroad Ψ(woody + crop)	5	352.64	2.41	0.10
	p(distroad) Ψ(woody + prairie + crop)	6	354.89	4.66	0.03
	p(distrd) Ψ(global)	8	358.77	8.54	<0.01
	p(.) Ψ(.)	2	383.87	33.64	<0.01

identifying arrival and departure times of migratory birds. Using nocturnal recordings and eBird data, Van Doren et al. (2022) found seasonal timing measured by ARUs to be consistent to that quantified by eBird across multiple taxonomic levels. In our study, such comparisons would be difficult given the low human population densities in rural Iowa. Thus, ARUs could provide an especially important tool for tracking changes in migration phenology due to climate and land use change in areas with low community science coverage.

We identified three sources of potential bias in our study. First, we were unable to truly randomize deployment locations of ARUs within fields, as it was necessary to avoid cropped areas to minimize conflict with farming operations. Second, removal of recordings with poor observational conditions may have reduced estimates of species richness or affected occupancy modeling results. Last, we were unable to detect non-vocalizing individuals, which may have biased our estimates of richness, especially of wintering species, which may not increase vocalizations until reaching their breeding grounds.

We manually analyzed recordings in this study. Advances in automated species recognition, now commonly used in simpler soundscapes, will likely increase the efficiency of processing large amounts of acoustic data (Priyadarshani et al. 2018). As of now, software used to generate spectrograms and edit sound are largely unable to parse species-level detections from breeding season recordings, which are often generated in complex soundscapes (Potamitis et al. 2014, Ulloa et al. 2016). Methods for automated detection such as machine learning show promise for tracking arrival times of migratory birds and will make large-scale deployments of ARUs feasible for examining phenological shifts due to climate change and range expansions or contractions with land use change (Oliver et al. 2018).

CONCLUSION

Soundscape ecology is a burgeoning field of research (Gasc et al. 2016) enabled by technological improvements in acoustic recorders (Servick 2014). Autonomous recording units (ARU) allow researchers to easily repeat sampling, reduce observer bias and field time, and maintain a permanent record of surveys (Shonfield and Bayne 2017). We provided ecological information on grassland bird use of agricultural landscapes during spring, a period that remains vastly understudied for most birds (Vickery et al. 1999). We conclude that springtime deployment of ARUs can provide worthwhile investigation into spring bird communities and their dynamics. The technology can provide an important tool in monitoring shifts in avian phenology in response to global climate and land use change, phenomena that are already known to affect the spring dynamics of migrant birds.

LITERATURE CITED

Allaire, P. N., and C. D. Fisher. 1975. Feeding ecology of three resident sympatric sparrows in eastern Texas. Auk 92:260-269. https://doi.org/10.2307/4084555

Alquezar, R. D., and R. B. Machado. 2015. Comparisons between autonomous recordings and avian point counts in open woodland savanna. Wilson Journal of Ornithology 127:712-723. https://doi.org/10.1676/14-104.1

Andersen, E. M., and R. J. Steidl. 2020. Plant invasions alter settlement patterns of breeding grassland birds. Ecosphere 11: e03012. https://doi.org/10.1002/ecs2.3012

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's information criterion. Journal of Wildlife Management 74:1175-1178. https://doi.org/10.2193/2009-367

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67. https://doi.org/10.18637/jss.v067.i01

Berges, S. A., L. A. Schulte Moore, T. M. Isenhart, and R. C. Schultz. 2010. Bird species diversity in riparian buffers, row crop fields, and grazed pastures within agriculturally dominated watersheds. Agroforestry Systems 79:97-110. https://doi.org/10.1007/s10457-009-9270-6

Bradley, N. L., A. C. Leopold, J. Ross, and W. Huffaker. 1999. Phenological changes reflect climate change in Wisconsin. Proceedings of the National Academy of Sciences 96:9701-9704. https://doi.org/10.1073/pnas.96.17.9701

Bennocci, R., G. Brambilia, A. Bisceglie, and G. Zambon. 2020. Eco-acoustic indices to evaluate soundscape degradation due to human intrusion. Sustainability 12:10455. https://doi.org/10.3390/su122410455

Brennan, L. A., F. Hernandez, and D. Williford. 2020. Northern Bobwhite (*Colinus virginianus*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.norbob.01

Bretz, F., T. Hothorn, and P. Westfall. 2016. Multiple comparisons using R. CRC Press, Boca Raton, Florida, USA. https://doi.org/10.1201/9781420010909

Brown, J. L., S.-H. Li, and N. Bhagabati. 1999. Long-term trend toward earlier breeding in an American bird: response to global warming? Proceedings of the National Academy of Sciences 96 5565-5569. https://doi.org/10.1073/pnas.96.10.5565

Brown, P. W., and L. A. Schulte. 2011. Agricultural landscape change (1937-2002) in three townships in Iowa, USA. Landscape and Urban Planning 100:202-212. https://doi.org/10.1016/j.landurbplan.2010.12.007

Bryan, G. G., and L. B. Best. 1991. Bird abundance and species richness in grassed waterways in Iowa rowcrop fields. American Midland Naturalist 126:90-102. https://doi.org/10.2307/2426153

Burger, W. L., P. J. Barbour, and M. D. Smith. 2010. Grassland bird population responses to upland habitat buffer establishment. Wildlife Insight No. 86. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, D.C., USA. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=26890.wba

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Buxton, R. T., E. Brown, L. Sharman, C. M. Gabriele, and M. F. McKenna. 2016. Using bioacoustics to examine shifts in songbird phenology. Ecology and Evolution 6:4697-4710. https://doi.org/10.1002/ece3.2242

Carey, M., D. E. Burhans, and D. A. Nelson. 2020. Field Sparrow (*Spizella pusilla*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.fiespa.01

Colbert, D. S., J. A. Ruttinger, M. Streich, M. Chamberlain, L. M. Conner, and R. J. Warren. 2015. Application of autonomous recording units to monitor gobbling activity by wild turkey. Wildlife Society Bulletin 39:757-763. https://doi.org/10.1002/wsb.577

Conner, R., A. Seidel, L. VanTassell, and N. Wilkins. 2001. United States grasslands and related resources: an economic and biological trends assessment. Institute of Renewable Natural Resources, Texas A&M University, College Station, Texas, USA. https://nri.tamu.edu/media/1101/us_grasslands.pdf

Conover, R. R., L. W. Burger, and E. T. Linder. 2009. Breeding bird response to field border presence and width. Wilson Journal of Ornithology 121:548-555. https://doi.org/10.1676/08-082.1

Currie, D., D. B. A. Thompson, and T. Burke. 2000. Patterns of territory settlement and consequences for breeding success in the Northern Wheatear *Oenanthe oenanthe*. Ibis 142:389-398. https://doi.org/10.1111/j.1474-919X.2000.tb04435.x

Déaux, E. C., N. P. O'Neil, A. M. Jensen, I. Charrier, and A. N. Iwaniuk. 2020. Courtship display speed varies daily and with body size in the Ruffed Grouse (*Bonasa umbellus*). Ethology 126:528-539. https://doi.org/10.1111/eth.13004

Digby, A., M. Towsey, B. D. Bell, and P. D. Teal. 2013. A practical comparison of manual and autonomous methods for acoustic monitoring. Methods in Ecology and Evolution 4:675-683. https://doi.org/10.1111/2041-210X.12060

Dunning, Jr., J. B., and W. M. Pulliam. 1989. Winter habitats and behavior of Grasshopper Sparrows near Athens, Georgia. Oriole 54:51-53.

Ehnes, M., J. P. Dech, and J. R. Foote. 2018. Seasonal changes in acoustic detection of forest birds. Journal of Ecoacoustics 2(1):7. https://doi.org/10.22261/jea.qvdzo7

Farmland Information Center 2016. Iowa data and statistics. Farmland Information Center, Washington, D.C., USA. https://farmlandinfo.org/statistics/iowa-statistics/

Fiske, I., and R. Chandler. 2011. unmarked: an R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43(10). https://doi.org/10.18637/jss.v043.i10

Furnas, B. J., and R. L. Callas. 2015. Using automated recorders and occupancy models to monitor common forest birds across a large geographic region. Journal of Wildlife Management 79:325-337. https://doi.org/10.1002/jwmg.821

Gasc, A., D. Francomano, J. B. Dunning, and B. C. Pijanowski. 2016. Future directions for soundscape ecology: the importance of ornithological contributions. Auk 134:215-228. https://doi.org/10.1642/AUK-16-124.1

Giese, J. C. 2023. An evaluation of conservation efforts in Midwestern agricultural landscapes for birds. Dissertation. Iowa State University, Ames, Iowa, USA. https://www.nrem.iastate.edu/research/STRIPS/files/publication/giese_2023_phddissertation.pdf

Grinde, A., S. Kolbe, and J. D. Bednar. 2021. Chippewa National Forest hunter walking trail project 2021 - pre-harvest results. Technical Report NRRI/TR-2021/37.Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA. https://conservancy.umn.edu/handle/11299/226530

Guzy, M. J., and G. Ritchison 2020. Common Yellowthroat (*Geothlypis trichas*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.comyel.01

Howell, G., N. Steve, and S. Webb. 1995. A guide to the birds of Mexico and northern Central America. Oxford University Press, New York, New York, USA. https://doi.org/10.1093/oso/9780198540137.001.0001

Hultquist, J. M., and L. B. Best. 2001. Bird use of terraces in Iowa rowcrop fields. American Midland Naturalist 145:275-287. https://doi.org/10.1674/0003-0031(2001)145[0275:BUOTII]2.0.CO;2

Iowa Department of Natural Resources (IDNR). 2015. Securing a future for fish and wildlife: a conservation legacy for Iowans. Iowa's wildlife action plan. Iowa Department of Natural Resources, Des Moines, Iowa, USA. https://www.iowadnr.gov/Conservation/Iowas-Wildlife/Iowa-Wildlife-Action-Plan#:~:text=The%20IWAP%20is%20a%20proactive,they%20live%20for%20future%20generations

Iowa Ornithologists' Union (IOU). 2020. Iowa breeding bird atlas II. Iowa Ornithologists' Union, Urbandale, Iowa, USA. https://iowabba2.org/

Iowa Ornithologists' Union (IOU). 2022. Iowa early/late dates. Iowa Ornithologists' Union, Urbandale, Iowa, USA. https://iowabirds.org/Birds/Docs/Early_Late.pdf

Jahn, O., T. D. Ganchev, M. I. Marques, and K.-L. Schuchmann. 2017. Automated sound recognition provides insights into the behavioral ecology of a tropical bird. PLoS ONE 12:e0169041. https://doi.org/10.1371/journal.pone.0169041

Janke, A. K., and R. J. Gates. 2013. Home range and habitat selection of Northern Bobwhite coveys in an agricultural landscape. Journal of Wildlife Management 77:405-413. https://doi.org/10.1002/jwmg.461

Jarzyna, M. A., B. Zuckerberg, A. O. Finley, and W. F. Porter. 2016. Synergistic effects of climate and land cover: grassland birds are more vulnerable to climate change. Landscape Ecology 31:2275-2290. https://doi.org/10.1007/s10980-016-0399-1

Johnson, J. J., and E. Bayne. 2022. Bioacoustically derived migration arrival times in boreal birds: implications for assessing habitat quality. Avian Conservation and Ecology 17(2):13. https://doi.org/10.5751/ACE-02224-170213

Jones, S. L., and J. E. Cornerly. 2020. Vesper Sparrow (*Pooecetes gramineus*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.vesspa.01

Kendall, W. L., J. E. Hines, J. D. Nichols, and E. H. Campbell Grant. 2013. Relaxing the closure assumption in occupancy models: staggered arrival and departure times. Ecology 94:610-617. https://doi.org/10.1890/12-1720.1

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

Marcus, J. F., W. E. Palmer, and P. T. Bromley. 2000. The effects of farm field borders on overwintering sparrow densities. Wilson Bulletin 112:517-523. https://doi.org/10.1676/0043-5643(2000)112[0517:TEOFFB]2.0.CO;2

Matson, P. A., W. J. Parton, A. G. Power, and M. J. Swift. 1997. Agricultural intensification and ecosystem properties. Science 277:504-509. https://doi.org/10.1126/science.277.5325.504

Mazerolle, M. J. 2020. AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 2.3-1. R Foundation for Statistical Computing, Vienna, Austria. https://cran.r-project.org/web/packages/AICcmodavg/AICcmodavg.pdf

National Oceanic and Atmospheric Administration (NOAA). 2022. Climate data online. NOAA, Washington, D.C., USA. https://www.ncei.noaa.gov/cdo-web/

National Weather Service (NWS). 2022. NOWData – NOAA online weather data. National Weather Service, Silver Spring, Maryland, USA. https://www.weather.gov/wrh/climate?wfo=dmx

Newton, I. 1998. Bird conservation problems resulting from agricultural intensification in Europe. Pages 307-322 in J. M. Marzluff and R. Sallabanks, editors. Avian conservation: research and management. Island, Washington, D.C., USA.

Norries, D. R., and P. P. Marra. 2007. Seasonal interactions, habitat quality, and population dynamics in migratory birds. Condor 109:535-547. https://doi.org/10.1093/condor/109.3.535

Oliver, R. Y., D. P. W. Ellis, H. E. Chmura, J. S. Krause, J. H. Pérez, S. K. Sweet, J. C. Wingfield, and N. T. Boelman. 2018. Eavesdropping on the Arctic: automated bioacoustics reveal dynamics in songbird breeding phenology. Science Advances 4:eaaq1084. https://doi.org/10.1126/sciadv.aaq1084

Pérez-Granados, C., D. Bustillo-de la Rosa, J. Gömez-Catasus, A. Barrero, I. Abril-Colön, and J. Traba. 2018. Autonomous recording units as effective tool for monitoring of the rare and patchily distributed Dupont's Lark *Chersophilus duponti*. Ardea 106:139-146. https://doi.org/10.5253/arde.v106i2.a6

Pérez-Granados, C., and K. L. Schuchmann. 2020. Diel and seasonal variations of vocal behavior of neotropical White-tipped Dove (*Leptotila verreauxi*). Diversity 12:402. https://doi.org/10.3390/d12100402

Potamitis, I., S. Ntalampiras, O. Jahn, and K. Riede. 2014. Automatic bird song detection in long real-field recordings: applications and

tools. Applied Acoustics 80:1-9. https://doi.org/10.1016/j.apacoust.2014.01.001

Priyadarshani, N., S. Marsland, and I. Castro. 2018. Automated birdsong recognition in complex acoustic environments: a review. Journal of Avian Biology 49:01447. https://doi.org/10.1111/jav.01447

R Core Team. 2021. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

Rigby, E. A., and D. H. Johnson. 2019. Factors affecting detection probability, effective area surveyed, and species misidentification in grassland bird point counts. Condor 121:duz030. https://doi.org/10.1093/condor/duz030

Robbins, C. S. 1981. Bird activity levels related to weather. Pages 301-310 in C. John Ralph and J. Michael Scott, editors. Studies in avian biology. USGS, Washington, D.C., USA.

Rosenberg, K. V., A. M. Dokter, P. J. Blancher, J. R. Sauer, A. C. Smith, P. A. Smith, J. C. Stanton, A. Panjabi, L. Helft, M. Parr, and P. P. Marra. 2019. Decline of North American avifauna. Science 366:120-124. https://doi.org/10.1126/science.aaw1313

Rota, C. T., R. J. Fletcher, Jr., R. M. Dorazio, and M. G. Betts. 2009. Occupancy estimation and the closure assumption. Journal of Applied Ecology 46:1173–1181. https://doi.org/10.1111/j.1365-2664.2009.01734.x

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44:418-421. https://doi.org/10.2307/1312365

Sanders, C. E., and D. J. Mennill. 2014. Acoustic monitoring of nocturnally migrating birds accurately assesses the timing and magnitude of migration through the Great Lakes. Condor 116:371-383. https://doi.org/10.1650/CONDOR-13-098.1

Schroeder, K. M., and S. B. McRae. 2020. Automated auditory detection of a rare, secretive marsh bird with infrequent and acoustically indistinct vocalizations. Ibis 162:1033-1046. https://doi.org/10.1111/ibi.12805

Schulte, L. A., J. Niemi, M. J. Helmers, M. Liebman, J. G. Arbuckle, D. E. James, R. K. Kolka, M. E. O'Neal, M. D. Tomer, J. C. Tyndall, H. Asbjornsen, P. Drobney, J. Neal, G. Van Ryswyk, and C. Witte. 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn-soybean croplands. Proceedings of the National Academy of Sciences 114:11247-11252. https://doi.org/10.1073/pnas.1620229114

Servick, K. 2014. Eavesdropping on ecosystems. Science 343:834-837. https://doi.org/10.1126/science.343.6173.834

Shonfield, J., and E. M. Bayne. 2017. Autonomous recording units in avian ecological research: current us and future applications. Avian Conservation and Ecology 12(1):14. https://doi.org/10.5751/ACE-00974-120114

Sidie-Slettedahl, A. M., K. C. Jensen, R. R. Johnson, T. W. Arnold, J. E. Austin, and J. D. Stafford. 2015. Evaluation of autonomous recording units for detection three species of secretive marsh birds. Wildlife Society Bulletin 39:626-634. https://doi.org/10.1002/wsb.569

Smith, M. D., P. J. Barbour, L. W. Burger, and S. J. Dinsmore. 2005. Density and diversity of overwintering birds in managed field borders in Mississippi. Wilson Bulletin 117:258-269. https://doi.org/10.1676/04-097.1

Smith, R. J., and F. R. Moore. 2005. Arrival timing and seasonal reproductive performance in a long-distance migratory landbird. Behavioral Ecology and Sociobiology 57:231-239. https://doi.org/10.1007/s00265-004-0855-9

Sparks, T. H., K. Huber, R. L. Bland, H. Q. P. Crick, P. J. Croxton, J. Flood, R. G. Loxton, C. F. Mason, J. A. Newman, and P. Tryjanowksi. 2007. How consistent are trends in arrival (and departure) dates of migrant birds in the UK? Journal of Ornithology 148:503-511. https://doi.org/10.1007/s10336-007-0193-6

Stephenson, M. 2022. The role of habitat area, fragmentation, and vegetation diversity in habitat quality in agricultural landscapes in Iowa, USA. Dissertation. Iowa State University, Ames, USA. https://www.nrem.iastate.edu/research/STRIPS/files/publication/stephensonmatt_2022_dissertation_-_bird_and_snake_habitat_quality_in_ag_landscapes.pdf

Stiffler, L. L., J. T. Anderson, and T. E. Katzner. 2018. Occupancy modeling of autonomously recorded vocalizations to predict distribution of rallids in tidal wetlands. Wetlands 38:605-612. https://doi.org/10.1007/s13157-018-1003-z

Stowell, D., and J. Sueur. 2020. Ecoacoustics: acoustic sensing for biodiversity monitoring at scale. Remote Sensing in Ecology and Conservation 6:217-219. https://doi.org/10.1002/rse2.174

Sueur, J., and A. Farina. 2015. Ecoacoustics: the ecological investigation and interpretation of environmental sound. Biosemiotics 8:493-502. https://doi.org/10.1007/s12304-015-9248-x

Sugai, L. S. M., J. W. Ribeiro, T. S. F. Silva, J. W. Ribeiro, Jr., and D. Lluisia. 2019. Terrestrial passive acoustic monitoring: review and perspectives. Bioscience 69:15-25. https://doi.org/10.1093/biosci/biy147

Swanson, D. L., and J. S. Palmer. 2009. Spring migration phenology of birds in the Northern Prairie region is correlated with local climate change. Journal of Field Ornithology 80:351-363. https://doi.org/10.1111/j.1557-9263.2009.00241.x

Swicegood, A. E., K. S. Ellison, M. Sather, S. G. Somershoe, and L. B. McNew. 2023. Detecting ecological traps in human-altered landscapes: a case study of Thick-billed Longspur nesting in croplands. Ecology and Evolution 13:e9993. https://doi.org/10.1002/ece3.9993

Ulloa, J. S., A. Gasc, P. Gaucher, T. Aubin, M. Réjou-Mechain, and J. Sueur. 2016. Screening large audio datasets to determine the time and space distribution of Screaming Piha birds in a tropical forest. Ecological Informatics 31:91-99. https://doi.org/10.1016/j.ecoinf.2015.11.012

USDA Forest Service. 2022. Forests of Iowa, 2021. U.S. Department of Agriculture, Forest Service, Madison, Wisconsin, USA. https://doi.org/10.2737/FS-RU-363

U.S. Department of Agriculture National Agriculture Imagery Program (USDA NAIP). 2020. U.S. Department of Agriculture

Farm Service Agency: NAIP imager. U.S. Department of Agriculture National Agriculture Imagery Program, Salt Lake City, Utah, USA. https://datagateway.nrcs.usda.gov/

Vanausdall, R. A., and S. J. Dinsmore. 2020. Detection and density of breeding marsh birds in Iowa wetlands. PLoS ONE 15: e0227825. https://doi.org/10.1371/journal.pone.0227825

Van Buskirk, J., R. S. Mulvihill, and R. C. Leberman. 2009. Variable shifts in spring and autumn migration phenology in North American songbirds associated with climate change. Global Change Biology 15:760-771. https://doi.org/10.1111/j.1365-2486.2008.01751.x

Van Doren, B. M., V. Lonstanlen, A. Cramer, J. Salamon, A. Dokter, S. Kelling, J. P. Bello, and A. Farnsworth. 2022. Automated acoustic monitoring captures timing and intensity of bird migration. Journal of Applied Ecology 60:433-444. https://doi.org/10.1111/1365-2664.14342

Vickery, P. D., P. L. Tubaro, J. M. Cardosa da Silva, B. G. Peterjohn, J. R. Herkert, and R. B. Cavalcanti. 1999. Conservation of grassland birds in the western hemisphere. Studies in Avian Biology 19:2-26.

Vickery, P. D. 2020. Grasshopper Sparrow (*Ammodramus savannarum*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.graspa.01

West, A. S., P. D. Keyser, C. M. Lituma, D. A. Buehler, R. D. Applegate, and J. Morgan. 2016. Grassland bird occupancy of native warm-season grass. Journal of Wildlife Management 80:1081-1090. https://doi.org/10.1002/jwmg.21103

Wheelwright, N. T., and J. D. Rising. 2020. Savannah Sparrow (*Passerculus sandwichensis*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.savspa.01

Yip, D. A., E. M. Bayne, P. Sölymos, J. Campbell, and D. Proppe. 2017. Sound attenuation in forest and roadside environments: implications for avian-point count surveys. Condor 119:73-84. https://doi.org/10.1650/CONDOR-16-93.1

Appendix 1. Study site locations and land cover characteristics. Sites with terraces generally lacked flowering plants and were dominated by a few grass species such as smooth brome (*Bromus inermis*) or reed canary grass (*Phalaris arundinacea*). Areas with prairie land cover were intentionally restored to native grasses and forbs, and had consistent presence of flowering plants.

Farm	County	Site Type	% Crop	% Grass	% Prairie	% Woody	% Developed	Distance to Road (m)
ARM	Pottawattamie	Crops with prairie strips	75	8	13	0	4	173
ARM	Pottawattamie	Crops with terraces	74	26	0	0	0	429
ARM	Pottawattamie	Conventional crops	60	22	0	13	5	274
DMW	Dallas	Crops with prairie strips	74	7	11	4	4	610
EIA	Linn	Crops with prairie strips	40	28	21	6	5	236
EIA	Linn	Crops with terraces	82	11	0	0	7	279
EIA	Linn	Conventional crops	88	12	0	0	0	97
GUT	Story	Crops with prairie strips	73	9	18	0	0	616
GUT	Story	Conventional crops	82	18	0	0	0	540
JUD	Carroll	Crops with terraces	59	41	0	0	0	418
JUD	Carroll	Conventional crops	44	50	0	2	0	736
JUD	Carroll	Large patch prairie	0	6	84	7	0	738
JUD	Carroll	Large patch prairie	0	5	87	8	0	817
KAL	Jasper	Conventional crops	61	14	0	21	4	135
KAL	Jasper	Crops with prairie strips	51	32	12	0	5	208
MCN	Lucas	Crops with prairie strips	62	12	8	2	0	421
MCN	Lucas	Conventional crops	51	31	0	5	6	144
SLO	Buchanan	Crops with prairie strips	72	6	22	0	0	506
SLO	Buchanan	Crops with terraces	71	29	0	0	0	1427
SLO	Buchanan	Conventional crops	59	21	0	12	8	47
SME	Webster	Conventional crops	74	14	0	7	3	267
SME	Webster	Crops with terraces	58	21	0	11	3	924

SMI	Wright	Crops with prairie strips	49	22	19	2	0	395
SMI	Wright	Conventional crops	77	23	0	26	0	748
WAT	Page	Large patch prairie	9	13	41	5	11	124
WAT	Page	Crops with terraces	79	14	0	7	0	388
WHI	Guthrie	Crops with terraces	52	48	0	0	0	348
WHI	Guthrie	Large patch prairie	3	15	68	5	9	624
WHI	Guthrie	Conventional crops	76	10	0	10	4	141
WHI	Guthrie	Crops with prairie strips	43	19	26	7	5	147
WOR	Story	Crops with prairie strips	38	14	16	27	3	563
WOR	Story	Conventional crops	63	23	0	9	5	166
	Mean		**56.2**	**19.5**	**13.9**	**6.1**	**2.8**	**427.7**

Appendix 2. Parameter estimates and 85% lower (LCI) and upper (UC) confidence intervals for all competitive models (ΔAICc < 2.0) for predicting occupancy of five focal species. Based on data collected during springtime autonomous recording unit (ARU) surveys in Iowa, USA, 2015-2019.

Species	Parameter	β	LCI	UCI
Common Yellowthroat	Model #1			
	p(int)	1.94	1.25	2.63
	p(temp)	0.34	-0.33	1.00
	Ψ(int)	0.24	-0.41	0.89
	Ψ(prairie)*	2.22	0.46	3.97
	Model #2			
	p(int)	2.05	1.36	2.74
	Ψ(int)	0.92	0.37	1.47
Field Sparrow	Model #1			
	p(int)	-0.35	-0.71	0.00
	p(distance to road)	-0.34	-0.79	0.14
	Ψ(int)	0.94	0.04	1.83
	Ψ(woody)*	2.18	0.87	3.50
	Model #2			
	p(int)	-0.29	-0.64	0.07
	p(distance to road)	-0.25	-0.72	-0.23
	Ψ(int)	-0.93	-1.75	-0.11
	Ψ(developed)*	2.63	1.31	3.94
	Model #3			
	p(int)	-0.30	-0.66	0.05
	p(distance to road)	-0.26	-0.73	0.21
	Ψ(int)	0.19	-1.29	1.67
	Ψ(woody)	1.16	-0.59	2.90
	Ψ(prairie)	-1.33	-3.08	0.42
	Ψ(developed)*	2.31	0.27	4.63
Grasshopper Sparrow	Model #1			
	p(int)	-0.47	-0.88	-0.07
	Ψ(int)	1.00	-0.40	2.41
	Ψ(crop)	-1.57	-3.42	0.28
	Model #2			
	p(int)	-0.43	-0.87	0.01
	Ψ(int)	0.51	-0.36	1.38
	Model #3			
	p(int)	-0.44	-0.92	0.03
	Ψ(int)	0.69	-0.76	2.14
	Ψ(grass)	0.96	-0.76	2.68
	Model #4			
	p(int)	-0.52	-0.91	-0.14
	Ψ(int)	3.53	-0.78	7.83
	Ψ(distance to road)	-3.43	-8.29	1.43
	Ψ(grass)	4.81	-0.12	9.74

	Ψ(distance to road*grass)	-4.16	-9.58	1.26
	Model #5			
	p(int)	-0.46	-0.93	0.00
	Ψ(int)	0.61	-0.49	1.72
	Ψ(distance to road)	-0.77	-1.90	0.32
Savannah Sparrow	**Model #1**			
	p(int)	-0.51	-0.79	-0.24
	Ψ(int)	-0.09	-0.91	0.73
	Ψ(woody)*	-1.58	-2.66	-0.50
	Model #2			
	p(int)	-0.55	-0.84	-0.27
	Ψ(int)	0.24	-0.62	1.10
	Ψ(crop)*	1.28	0.25	2.30
Vesper Sparrow	**Model #1**			
	p(int)	0.47	0.24	0.70
	p(distance to road)	1.02	0.72	1.32
	Ψ(int)	0.79	0.22	1.36
	Ψ(woody)*	-0.65	-1.27	-0.02
	Model #2			
	p(int)	0.48	0.24	0.71
	p(distance to road)	1.05	0.75	1.35
	Ψ(int)	0.86	0.29	1.92
	Ψ(crop)	0.24	-0.25	0.72
	Model #3			
	p(int)	0.48	0.25	0.71
	p(distance to road)	1.06	0.76	1.36
	Ψ(int)	1.11	0.29	1.92
	Ψ(prairie)	-0.49	-1.59	0.60

*Indicates an informative predictor of occupancy