Seasonal changes in acoustic detection of forest birds

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Abstract

Autonomous recording is commonly used to examine the structure of avian communities in a variety of landscapes. Many birds return to the breeding grounds in May yet acoustic surveys typically begin in June. In many species, singing activity declines through the breeding season and so detections may be lower later in the season. The aim of our study was to compare the species richness and the community composition measured early (mid-late May) and later (mid-late June) in the breeding season. We recorded the community of singing birds at 13 locations in York Region, Ontario, Canada woodlots over two days using autonomous recorders. We used spectrographic analysis to scan recordings and identify all vocalizing species. We found that species richness was significantly higher in early recordings compared to later recordings with detections of both migrants and residents displaying this trend. Most food and foraging guilds were also detected significantly less often later in the season. Despite changes in species richness, the proportion of the community represented by each foraging guild did not vary between early and late recordings. Our results suggest that acoustic recordings could be collected earlier in the breeding season, extending the survey period into May. If the primary goal of monitoring is to document species presence/absence then earlier recordings may be advantageous.

Introduction

Birds are used as indicators of ecological changes in systems experiencing disturbance (Hutto, 1998; Furness et al., 2013; Ogden et al., 2014). Surveying bird communities has traditionally been accomplished using three- to ten-minute point counts where all individuals seen or heard are counted by a single observer (Fuller and Langslow, 1984; Koenig and Liebhold, 2017; Matsuoka et al., 2014). Because many species of birds vocalize at high rates during the breeding season, counts are largely auditory in nature (Alldredge et al., 2007; Brewster and Simons, 2009). Studies suggest that variation in observer accuracy or ability to detect sounds within different

frequency ranges can influence count outcomes (Emlen and DeJong, 1992; Nichols et al., 2000; Alldredge et al., 2007). Recent advances in acoustic recording techniques have made it possible to survey the community using various hand-held and autonomous recording units (reviewed in (Shonfield and Bayne, 2017). Comparisons between standard point counts and analysis of acoustic recordings show that the methods are comparable or that analysis of recordings results in a larger range of species detected (Haselmayer and Quinn, 2000; Hutto and Stutzman, 2009; Venier et al., 2012; Rempel et al., 2013; Alquezar and Machado, 2015; Leach et al., 2016). One benefit of acoustic recording is it creates a permanent record of the count (Haselmayer and Quinn, 2000). One drawback of many acoustic recording techniques is that often only presence/absence data can be collected, whereas point counts can include information on local abundance (Hedley et al., 2017).

Because of long battery life and the capacity to store large files, acoustic monitoring can extend beyond the shorter traditional point count period. As a result, more species or individuals may be detected in longer counts (La and Nudds, 2016; Foote et al., 2017). Examination of species detection curves over time reveal that longer acoustic recordings result in more species detected, with a trade-off against analysis time (Wimmer et al., 2013; La and Nudds, 2016).

In addition to the length of sampling, there may also be an optimum time to survey bird communities. In many species of birds, the rate of vocalization decreases after pairing occurs, or as the breeding season progresses (Merilä and Sorjonen, 1994). As such, the best time to survey would be the time when song rates are highest and probability of detection is higher. A problem with early sampling, however, is that migrant species may still be present and not all breeding migrants may have arrived (Ralph et al., 1995; Howe et al., 1997). Thus the best sampling time for a site will balance migrant arrival and breeding season progression (Venier et al., 2012). Detection of species can vary with season and may increase, decrease or remain constant over the late spring/early summer period when many temperate songbirds breed (Best and Petersen, 1985; Wilson and Bart, 1985; Gibbs and Wenny, 1993; Demko, 2012; Foote et al., 2017).

Selection of the appropriate time of day can also be important when setting up acoustic surveys if sampling is limited to a particular part of the day. Many species vocalize prolifically before the sun rises in a display called the dawn chorus (Staicer et al., 1996), making this a good time of day to sample, but a challenging time to disentangle various recorded songs due to considerable overlap in vocalizations of different species. Additionally, many species sing as the sun sets in a dusk chorus that is typically shorter and less species rich than the dawn chorus but may include species that do not sing at dawn (Staicer et al., 1996; La and Nudds, 2016). this period, diurnal birds have variable song rates with many singing more earlier than later in the day (Foote et al., 2017). As such, researchers often employ time-of-day corrections when using point counts to adjust for a decreased rate of vocalization as the morning progresses (Rosenberg and Blancher, 2005). For acoustic recordings, sampling periodically throughout the day can help mitigate any daily variation in detectability (La and Nudds, 2016).

Monitoring bird populations in response to environmental change is a critical activity both for avian conservation and for using birds as bio-indicators of ecosystem integrity. Deforestation is a major threat to forest dwelling birds (Brooks et al., 2002; Galetti and Dirzo, 2013; Ochoa-Quintero et al., 2015) that, together with climate change, forest disturbance, and non-native invasive species, threatens forest stands on which birds depend (Hessburg et al., 1994; Haack, 2006; Millar et al., 2007; Barlow et al., 2016). An intact forest canopy is essential for many species of nesting birds providing both foraging and nesting habitat or promoting a rich understory for species occupying the lower canopy or ground (Robbins et al., 1989; Mills et al., 1991; Minor and Urban, 2010; Reidy et al., 2017). Insect damage to forests can change the habitat available for birds such that avian community membership shifts in response to changes in canopy cover, understory characteristics, forest structure (*e.g.*, snag availability), and food availability (Showalter and Whitmore, 2002; Tingley et al., 2002; Perkins and Wood, 2014; Buchanan et al., 2016). Monitoring of bird biodiversity before, during and after disturbance and invasions can reveal changes in species composition in forest stands. Changes in canopy structure can result in positive, negative, or no change in occupancy by particular species (Showalter and Whitmore, 2002; Tingley et al., 2002; Chan-McLeod, 2006; Flower et al., 2014; Perkins and Wood, 2014).

In the future, monitoring bird populations in response to changes in habitat will become increasingly important. Thus, we tested whether acoustic monitoring would be effective earlier into the breeding season. We characterized species richness and community composition in 13 plots in York Region, Ontario in both early (mid-late May) and late (mid-late June) field recordings. We hypothesized that earlier recordings would result in greater species richness because song rates are typically higher early in the breeding season, which should increase detectability. We hypothesized that the community composition of the avian foraging guilds could also shift between early and late recordings if members of these guilds differed in their seasonal patterns of vocalization.

Methods

Study area

York Region is a municipality in Southern Ontario beginning north of Toronto and stretching north towards Lake Simcoe, with a human population of just over one million. Established in 1924, York Regional forest encompasses 2,300 ha of protected and managed landscapes (York Region, 2014). There are 18 forest tracts within York Region municipality, twelve of which include ash species including white ash (*Fraxinus americana*), black ash (*Fraxinus nigra*), or green ash (*Fraxinus pennsylvanica*). These ash species often occupy different forest types of upland hardwood, bottomland hardwood, and mixedwood respectively. White ash is an upland hardwood species, preferring well drained soils usually mixed with other deciduous species like maples (*Acer* spp.) and poplar (*Populus* spp.) (Schlesinger, 1990). Black ash, a species tolerant of saturated soils and seasonal flooding, occurs in mixedwood swamps with coniferous species such as white cedar (*Thuja occidentalis* L.) or deciduous components such as red maple (*Acer rubrum* L.); however, it can also occur in pure stands (Wright et al., 1990). Green ash occurs across a wide range of soil conditions, but is most prevalent as a flood tolerant bottomland species, often found near areas of standing water together with red maple, willow (*Salix* ssp.) and poplars (Kennedy, 1990).

Sampling design

Thirteen plots were identified using satellite images (Google Earth, Google, Mountain View, CA, USA) in the 12 York Region forest tracts with ash composition of >10% canopy cover based on maps provided by York Region Municipality (pers. comm.). One plot was selected in each of the tracts, with the exception of the largest tract, where two plots were positioned. Plots were circular, at least 100 m in radius, and at least 100 m away from forest edges. For an additional project the maximum number of independent (minimum of 200 m between plot centres) circular plots that could be arrayed in each tract were created and one of those plots was randomly selected for this study. Plots were then established in the field based on the coordinates for selected points obtained from Google Earth™ and uploaded to a handheld GPS (Global Positioning System) unit (eTrex 10, Garmin Olathe, KS, USA). The nearest ash tree to the selected coordinates for each plot was identified and was deemed to be the plot center. We then used the GPS unit to record the coordinates of the new plot center.

Field recordings

At the plot center, we affixed an autonomous recording unit to the tree (Song Meter, model SM2, Wildlife Acoustics, Maynard MA) and left the recording unit in place for 48 hours. The song meter was programmed to record five of every fifteen minutes throughout the day flanked by two longer two-hour recordings centered at dawn and dusk. The first longer recording began two hours before sunrise and recorded for two hours capturing the dawn chorus. The second longer recording began at 19:05 EST, through at least evening nautical twilight thus capturing the dusk chorus, which begins at sunset. Recording beyond early morning captures species that sing irregularly or do not vocalize at dawn (La and Nudds, 2016). The longer dawn and dusk recordings were written as 59 minute files with a one-minute pause to allow files to write. We selected to record five-minute samples every fifteen

minutes between dawn and dusk recordings to record 1/3 of the daytime song balancing analysis time and sampling time. Recorders were programmed to record in stereo at a 22,050 Hz sampling rate with 16-bit precision in WAV format. Song Meters were deployed in each location during peak songbird migration (18–29 May) and again later in the season within the normal standards of auditory bird monitoring (18–29 June) (Howe et al., 1997).

Spectrogram analysis

We scanned recordings in Syrinx PC (John Burt, Seattle WA) using spectrograms generated with a Blackman window with a transform size of 512 fast Fourier transform and a 10ms/line viewing window. Each species was identified the first time we detected a song or call for that species. We compared songs to known song exemplars (McAuley Library, 2014) to confirm species identifications. Because the York Region forest tracts are diverse, adjacent to farmland, and include swampy green ash stands, the song exemplars we used included species not typical of forest interiors. We did not attempt to infer abundance of species because we did not know the direction of each song and thus determined presence/absence (Celis-Murillo et al., 2009; Blumstein et al., 2011). There were three species that we were not able to reliably identify to the species level, pine warbler (*Setophaga pinus*), chipping sparrow (*Spizella passerina*), and dark-eyed junco (*Junco hymalis*). All three species have songs that are simple "trills" (Middleton, 1998; Rodewald et al., 1999; Nolan et al., 2002). These trills were most likely chipping sparrows or pine warblers based on habitat and breeding range (Middleton, 1998; Rodewald et al., 1999; Nolan et al., 2002). However, because the chipping sparrow is an omnivorous ground forager and the pine warbler is an insectivorous bark gleaner they belong to different guilds and could not be lumped together. These species were excluded from our list due to the uncertainty in identification.

Statistical analysis

After determining which species were present at each location, species were classified as either migrants or residents in southern Ontario using The Birds of North America Online (Rodewald, 2017). Species were then separated based on preferred food type (granivore, insectivore, omnivore, and vermivore), substrate type (location of food item *e.g.*, air, bark, ground, lower canopy, upper canopy, and shoreline), and feeding technique (how the food is taken, *e.g.*, gleaner, forager, prober, excavator, and sallier) based on foraging guilds (Table 1; [De Graaf et al., 1985]). We tested for normality using a Shapiro-Wilk Test. We then used paired *t*-tests to compared the number of species detected overall, by migratory status, by food types and by foraging categories between May and June recordings. To control for multiple testing, we used a Benjamini-Hochberg correction factor. We report actual *p*-values but indicate where results are not significant when employing this technique (Benjamini and Hochberg, 1995). Results were considered significant at an alpha level of 0.05. We used JMP v. 13 to carry out all inferential analyses (SAS Institute Inc., Cary, NC, USA). We calculated the proportion of the community represented by each of the food type/foraging guilds in early and late recordings.

To examine patterns of detection at the community level over the two recording periods, we carried out a correspondence analysis on the matrix of species detections (59 species) in the 13 sites during each period (26 cases). Correspondence analysis (CA) is an appropriate ordination technique for summarizing patterns in species abundance or presence/absence data, which typically have non-linear distributions and contain a high proportion of zero values (Kenkel et al., 2002; Kent, 2011; Legendre and Legendre, 2012). Community responses to important environmental gradients are represented on a series of extracted CA axes; however, one issue to consider with CA is that it is possible that the higher axes could represent mathematical distortions of the main gradient summarized on the first axis (McCune and Grace, 2002). Given our specific interest in exploring whether or not the variation in detections was primarily related to the measurement period, CA provided a suitable analysis for identifying the single most important dimension summarizing the pattern in species vocalizations (McCune and Grace, 2002). The CA ordination was conducted using PCORD version 4.2 (MJM Software Co, Gleneden Beach, OR., USA). Correspondence analysis can be influenced by

Table 1. A list of the all avian species (in taxonomic order; *Chesser et al., 2017*) detected in early and late recordings in York Region forest tracts. Food type and foraging location and migratory status classifications are also included for reference.

Species	Food Type	Foraging Location	Migratory Status	Sites (early)	Sites (late)
Wild turkey (*Meleagris gallopavo*)	Omnivore	Ground	Resident	1	1
Mourning dove (*Zenaida macroura*)	Granivore	Ground	Resident	6	4
Killdeer (*Charadrius vociferus*)	Insectivore	Ground	Migrant	5	3
American woodcock (*Scolopax minor*)	Vermivore	Ground	Migrant	2	1
Red-bellied woodpecker (*Melanerpes carolinus*)	Insectivore	Bark	Resident	4	3
Yellow-bellied sapsucker (*Sphyrapicus varius*)	Omnivore	Bark	Migrant	1	5
Downy woodpecker (*Picoides pubescens*)	Insectivore	Bark	Resident	3	4
Hairy woodpecker (*Picoides villosus*)	Insectivore	Bark	Resident	3	12
Northern flicker (*Colaptes auratus*)	Insectivore	Ground	Migrant	6	2
Pileated woodpecker (*Dryocopus pileatus*)	Insectivore	Bark	Resident	13	6
Olive-sided flycatcher (*Contopus cooperi*)	Insectivore	Air sallier	Migrant	1	1
Eastern wood-pewee (*Contopus virens*)	Insectivore	Air sallier	Migrant	12	10
Alder flycatcher (*Empidonax alnorum*)	Insectivore	Air sallier	Migrant	1	0
Willow flycatcher (*Empidonax traillii*)	Insectivore	Air sallier	Migrant	5	0
Red-eyed vireo (*Vireo olivaceus*)	Insectivore	Upper canopy	Migrant	13	11
Blue jay (*Cyanocitta cristata*)	Omnivore	Ground	Resident	13	13
American crow (*Corvus brachyrhynchos*)	Omnivore	Ground	Resident	13	12
Black-capped chickadee (*Poecile atricapillus*)	Insectivore	Lower canopy	Resident	13	13
Red-breasted nuthatch (*Sitta canadensis*)	Insectivore	Bark	Resident	13	8
White-breasted nuthatch (*Sitta carolinensis*)	Insectivore	Bark	Resident	2	13
Brown creeper (*Certhia americana*)	Insectivore	Bark	Resident	11	10

Species	Food Type	Foraging Location	Migratory Status	Sites (early)	Sites (late)
Winter wren (*Troglodytes hiemalis*)	Insectivore	Ground	Migrant	3	5
Golden-crowned kinglet (*Regulus satrapa*)	Insectivore	Lower canopy	Migrant	4	0
Veery (*Catharus fuscescens*)	Omnivore	Ground	Migrant	11	9
Swainson's thrush (*Catharus ustulatus*)	Omnivore	Lower canopy	Migrant	6	0
Hermit thrush (*Catharus guttatus*)	Omnivore	Ground	Migrant	10	11
Wood thrush (*Hylocichla mustelina*)	Omnivore	Ground	Migrant	12	8
American robin (*Turdus migratorius*)	Vermivore	Ground	Migrant	13	13
Gray catbird (*Dumetella carolinensis*)	Omnivore	Ground	Migrant	1	7
European starling (*Sturnus vulgaris*)	Omnivore	Ground	Resident	3	4
Cedar waxwing (*Bombycilla cedrorum*)	Insectivore	Air sallier	Migrant	12	11
Pine grosbeak (*Pinicola enucleator*)	Omnivore	Upper canopy	Resident[a]	4	1
House finch (*Haemorous mexicanus*)	Granivore	Ground	Resident	3	0
Purple finch (*Haemohous purpureus*)	Granviore	Upper canopy	Resident	7	3
American goldfinch (*Spinus tristis*)	Granivore	Lower canopy	Resident	13	13
Eastern towhee (*Pipilo erythophthalmus*)	Omnivore	Ground	Migrant	3	1
American tree sparrow (*Spizella arborea*)	Omnivore	Ground	Migrant	1	0
Field sparrow (*Spizella pusilla*)	Omnivore	Ground	Migrant	0	1
Vesper sparrow (*Pooecetes gramineus*)	Omnivore	Ground	Migrant	1	1
Savannah sparrow (*Passerculus sandwichensis*)	Omnivore	Ground	Migrant	1	0
Grasshopper sparrow (*Ammodramus savannarum*)	Omnivore	Ground	Migrant	1	0
Song sparrow (*Melospiza melodia*)	Omnivore	Ground	Migrant	5	1
White-throated sparrow (*Zonotrichia albicollis*)	Omnivore	Ground	Migrant	5	1
Red-winged blackbird (*Agelaius phoeniceus*)	Omnivore	Ground	Migrant	4	3
Brown-headed cowbird (*Molothrus ater*)	Omnivore	Ground	Migrant	6	2
Ovenbird (*Seiurus aurocapilla*)	Insectivore	Ground	Migrant	13	13

Species	Food Type	Foraging Location	Migratory Status	Sites (early)	Sites (late)
Northern waterthrush (*Parkesia noveboracensis*)	Insectivore	Ground[b]	Migrant	9	7
Black-and-white warbler (*Mniotilta varia*)	Insectivore	Bark	Migrant	4	1
Nashville warbler (*Oreothlypis ruficapilla*)	Insectivore	Lower canopy	Migrant	11	1
Mourning warbler (*Geothlypis philadelphia*)	Insectivore	Ground	Migrant	3	3
Common yellowthroat (*Geothlypis trichas*)	Insectivore	Lower canopy	Migrant	4	3
American redstart (*Setophaga ruticilla*)	Insectivore	Air sallier	Migrant	12	5
Northern parula (*Setophaga americana*)	Insectivore	Upper canopy	Migrant	3	0
Blackburnian warbler (*Setophaga fusca*)	Insectivore	Upper canopy	Migrant	4	1
Yellow warbler (*Setophaga petechial*)	Insectivore	Lower canopy	Migrant	7	2
Chestnut-sided warbler (*Setophaga pensylvanica*)	Insectivore	Lower canopy	Migrant	9	3
Black-throated blue warbler (*Setophaga caerulescens*)	Insectivore	Lower canopy	Migrant	2	1
Black-throated green warbler (*Setophaga virens*)	Insectivore	Upper canopy	Migrant	8	4
Scarlet tanager (*Piranga olivacea*)	Insectivore	Upper canopy	Migrant	7	6
Northern cardinal (*Cardinalis cardinalis*)	Omnivore	Ground	Resident	12	5
Rose-breasted grosbeak (*Pheucticus ludovicianus*)	Insectivore	Bark	Migrant	10	0
Indigo bunting (*Passerina cyanea*)	Omnivore	Lower canopy	Migrant	4	5

a   Pine grosbeak winters in this area and breeds further north; however local breeding has been reported around Lake Simcoe to the north of York Region municipality and this species was present in June (*Raine, 1892*).

b   Northern waterthrush was the sole member of a guild defined by freshwater shoreline; for the purpose of this analysis we combined them with other ground foragers.

rare species and outliers (McCune and Grace, 2002; Legendre and Legendre, 2012); therefore, species that occurred at a frequency of less than 1/5 the maximum frequency in the data set were down-weighted (McCune and Mefford, 1999). In this downweighting, species that meet the low frequency criterion have their abundances (1.00 in the case of presence/absence data) adjusted as follows (Hill, 1979): $Y' = Y \cdot [f/(f_{max}/5)]$, where; Y' = the downweighted value, f = the frequency of the species, and f_{max} = the highest frequency in the data set.
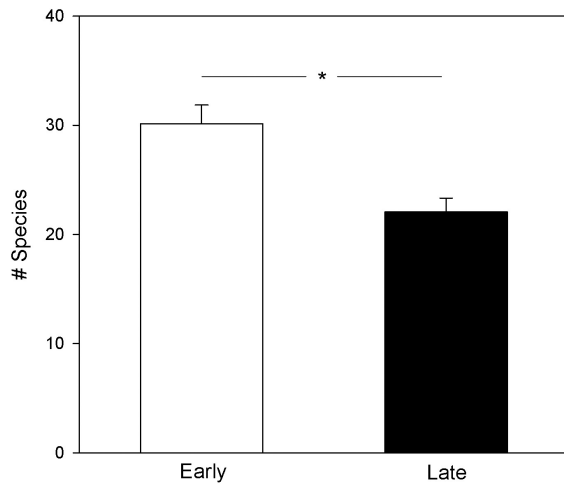
Figure 1. Species richness of birds recorded in York Region, Ontario in early and late recordings (*n* = 13).

Error bars represent standard error. An asterisk indicates a significant difference between two groups.

Results

In York Region forest tracts, using bioacoustics sampling throughout the breeding season, we collected 448 hours of recording at the height of signalling behaviour for many bird species. We captured two entire dawn and dusk choruses and 112.1 ± 0.89 5-minute recordings in May and 113.2 ± 0.78 5-minute recordings in June. In total, we recorded at each site for a total of 17.2 ± 0.07 hours of recording in May and 17.3 ± 0.06 hours in June. There was no masking of the recordings by either heavy rainfall or high winds during the recording periods.

The 13 plots recorded in May (early) were compared against the same 13 plots recorded again in June (late) for analysis. Overall, significantly more species were detected in May compared to June (t = 5.82, df = 12, p < 0.0001; Figure 1). Significantly fewer resident species (t = 2.03, df = 12, p = 0.033; Figure 2) and migratory species (t = 6.30, df = 12, p < 0.0001; Figure 2) were detected in late compared to early recordings. A total of ten species were detected in May that were not detected in June, however, there were no species detected in June but not in May (Table 1). Three of these ten species with detection differences might not have been detected in the late recordings as a result of their breeding ranges. The American Tree Sparrow (*Spizella passerina*) breeds far north of York Region while Swainson's Thrush (*Catharus ustulatus*) and Northern Parula (*Setophaga americana*) breed just north of York Region. The remaining species with differential detection between the two recording periods breed locally (Cadman et al., 2007; Rodewald, 2017). Excluding the three migrant species with different breeding ranges did not
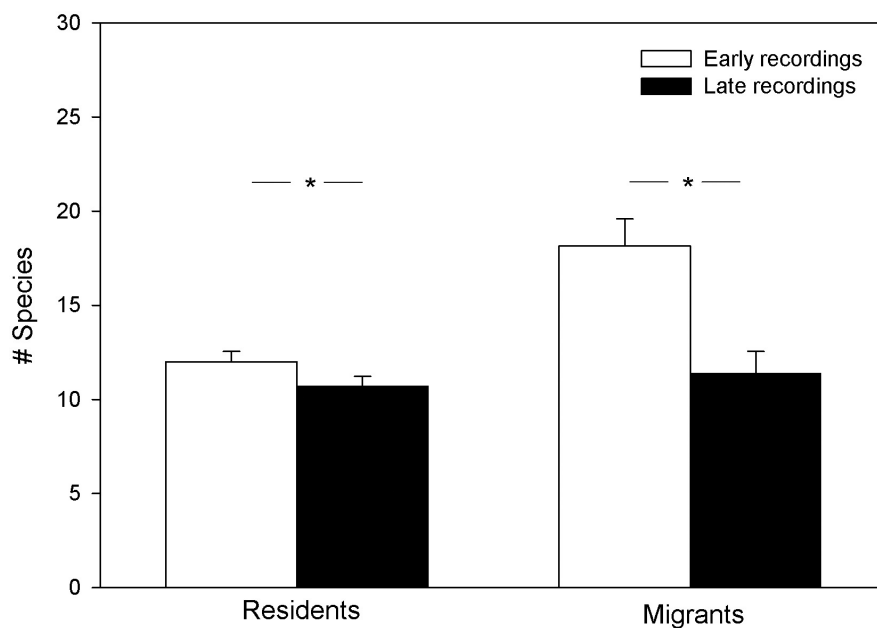

Figure 2. Species richness of migrant and resident birds recorded in York Region, Ontario in early and late recordings (*n* = 13).

Error bars represent standard error. An asterisk indicates a significant difference between two groups.

change the results substantially, as significant differences in richness remained for all species (t = 5.31, df = 12, p < 0.0001) as well as migrants (t = 5.85, df = 12, p < 0.0001). We excluded these three species in all further analyses.
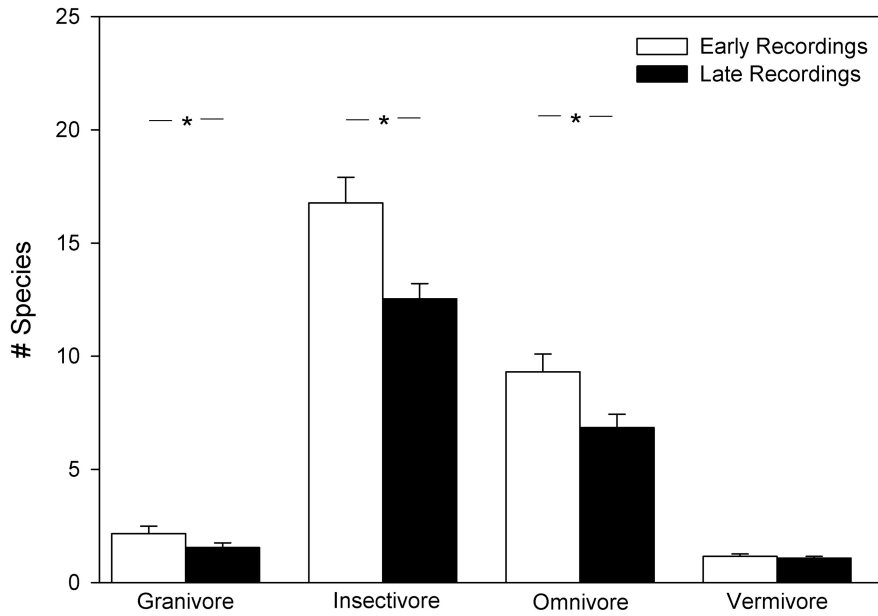
Figure 3. Species richness of birds belonging to different food guilds recorded in York Region, Ontario in early and late recordings (n = 13).
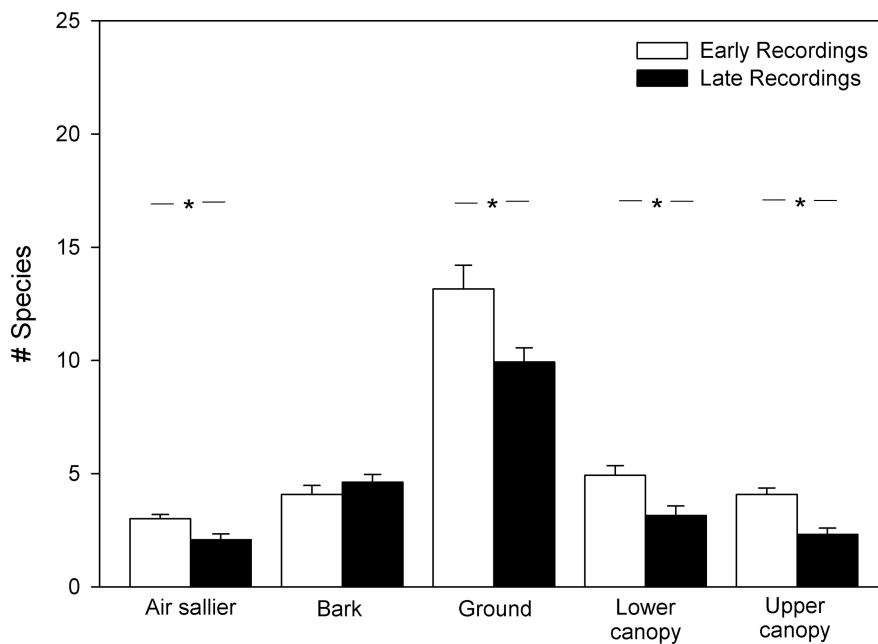
Figure 4. Species richness of birds belonging to different foraging guilds recorded in York Region, Ontario in early and late recordings (n = 13).

Error bars represent standard error. An asterisk indicates a significant difference between two groups.

Classification of species into food guilds showed that there were significantly fewer insectivores (t = 4.37, df = 12, p = 0.0009; Figure 3) and omnivores (t = 3.18, df = 12, p = 0.0079; Figure 3) detected in June recordings compared to May. However, there was no significant change in the number of granivores (t = 1.85, df = 12, p = 0.088; Figure 3) or vermivores detected (t = 1.0, df = 12, p = 0.34; Figure 3).

A similar trend was found when comparing early to late recordings based on foraging guilds (Figure 4). There were significantly fewer species belonging to the air, (t = 3.86, df = 12, p = 0.0023), ground (t = 3.80, df = 12, p = 0.0025), lower canopy (t = 3.89, df = 12, p = 0.0022), and upper canopy (t = 4.90, df = 12, p = 0.0002) foraging guilds in late compared to early recordings. However, there was no significant difference in the number of species detected for bark foraging guilds (t = −1.20, df = 12, p = 0.25).

Correspondence analysis of the species detections over the span of sites and recording periods identified three axes that extracted approximately 35% of the total inertia in the data. The primary axis accounted for 15% of this inertia, and was clearly a representation of the differences in species composition associated with the two measurement periods (Figure 5). The position of the cases on axis one differentiated the May recordings at the high end of the axis from the June recordings at the low end of the axis. This pattern was apparent in all but one of the sites, with only the recordings for site 3 during June (J3) occupying a position on the ordination axis that was more typical of the May recordings. The position of J3 was largely affected by the presence of field sparrow, which was only recorded at that one particular location and time over the entire study. Species with patterns of detection that were different among the two recording periods were strongly correlated to axis one, further suggesting that there was a clear community-level response of the vocalizations in these sites to the progression of the season (Supplementary Material S.1).
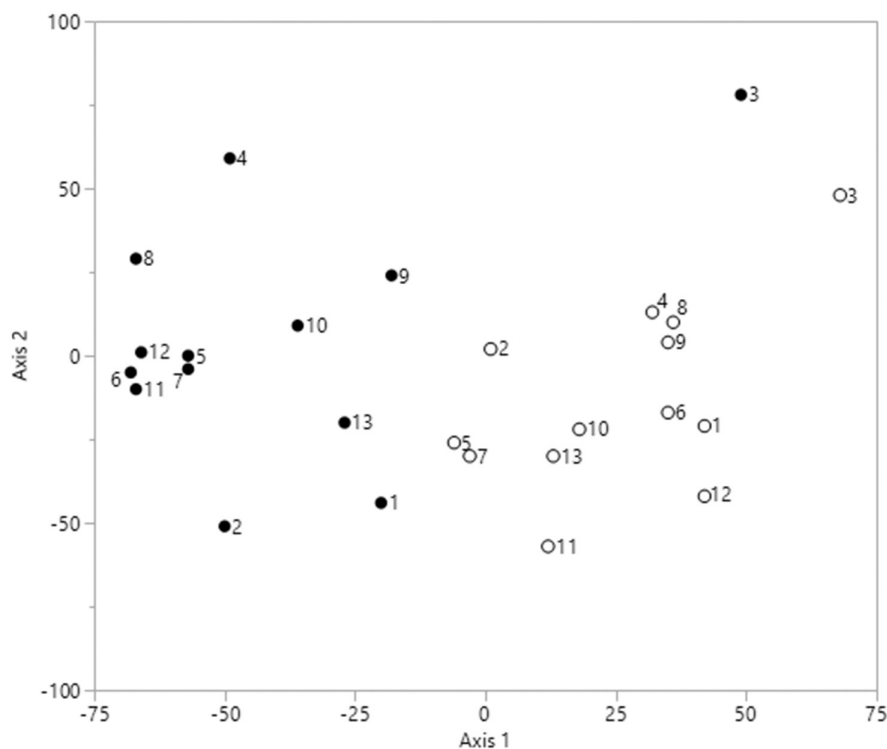

Figure 5. Ordination plot of the site/recording period scores on the first and second axes extracted from a correspondence analysis of a matrix of species detection by location/season data (n = 26).

Each case on the ordination plot represents a specific combination of location (1–13) and recording period (May - open circles or June - closed circles).
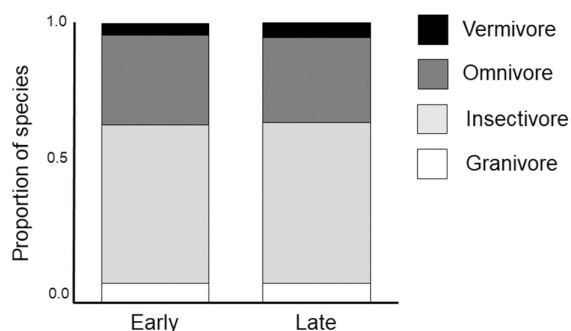
Figure 6. Community composition of birds belong to food guilds recorded in York Region, Ontario in early and late recordings (*n* = 13).
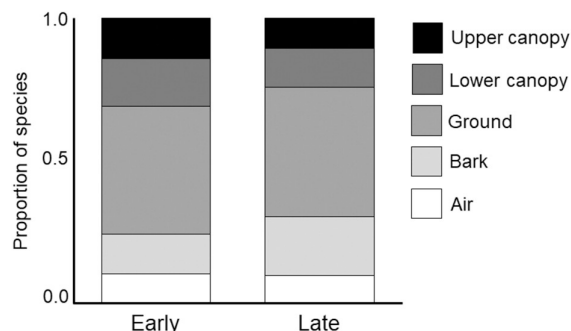

Figure 7. Community composition of birds belong to foraging guilds recorded in York Region, Ontario in early and late recordings (*n* = 13).

Early and late recordings displayed similar trends in community composition across food (Figure 6) and foraging guilds (Figure 7). In all cases the guilds constituted similar proportions of the community represented in each time period.

Discussion

We detected more species from automated recording in May compared to June. This held true when examining species based on migratory status, and for most food types and foraging guilds. We found that insectivores represented the largest food guild in York Region forest tracts in both early and late recordings; this coincides with the seasonal changes that drive the ecosystem processes in the temperate forests of North America (Rappole and McDonald, 1994; Thiollay, 1997). However, our results show no difference in the community composition with respect to food types or foraging guilds between early and late recordings. Our data suggest that an early census is preferable for detecting more species of forest birds and for monitoring overall avian population changes. Additionally, our results suggest that survey season could be extended into May. When possible, recording in both early and late time periods may be valuable given that correspondence analysis revealed differences in community composition between early and late recordings.

As predicted, species richness was significantly higher in May recordings compared to June recordings, with an average of eight more species detected in early recordings. Furthermore, ordination showed a clear separation between early and late recordings, further demonstrating the difference in songbird detections. Earlier visits during the breeding season have previously been shown to detect more vocalizing males in other sites (Pärt, 1991; Ralph et al., 1995; Venier et al., 2012). Most missed detections in June were likely due to variation in male songbirds' singing activity during the breeding season. In many species, males will reduce signalling when a mate is secured (Pärt, 1991; Bruni and Foote, 2014). Thus, paired males are detected less often, particularly after dawn (*e.g.*, Foote et al., 2017). Previous work shows that song rate of many species varies among stages of the breeding season and the pattern differs among species as does the timing of breeding (Moller, 1991; Gil et al., 1999; Foote and Barber, 2009). Our early recordings were taken at a similar time to those of Ralph et al. (1995) and earlier than suggested by Howe et al. (1997); however, all species detected in June were already present and singing in our May recordings suggesting that all species had at least begun to arrive at our site by mid-May. In some bird communities, arrival times have advanced in recent decades and so birds could be arriving earlier that they were 20 years ago (Butler, 2003; Usui et al., 2017; Zaifman et al., 2017). Our results suggest that surveys for breeding birds could extend into May and that earlier censuses are more effective at detecting most species groups.

Species detected in May but not June are more often species that sing rarely later in the breeding season and are less likely to be picked up singing close to a recorder. Twenty-three of the 32 species

with lower rates of detection in June and for which data on phenology of song was available sing less as the breeding season progresses while nine do not vary in singing rate (Rodewald, 2017). The breeding season of most species we detected extends well into July and thus these species are still likely present (Cadman et al., 2007; Rodewald, 2017). After excluding species that may have been still migrating in May that were not detected in June, we still detected significantly higher species richness in early compared to late recordings. One reason why survey recommendations suggest recording later in the breeding season is that some species may sing during migration (Howe et al., 1997). The species we recorded either do not sing on migration or sing occasionally during migration (Rodewald, 2017). As such, it is unlikely that we would detect songs of migrants often within our recording plots.

One example of where acoustic monitoring may be useful in the future for monitoring communities is the forests of York Region. These forest tracts range in ash composition from 10 to greater than 30% and are close to municipalities in the midst of emerald ash borer (*Agrillus planipennis*) infestation. Emerald ash borer is an invasive wood-boring beetle, that is spreading across North America causing nearly 100% ash mortality in invaded regions and threatening billions of trees in areas yet to be invaded (Poland and McCullough, 2006). Presently, York Region's forest tracts appear untouched by emerald ash borer; they have low numbers of adult detections at traps and no visible canopy damage (Ehnes, 2017). However, their proximity to municipal trees puts them at risk of death within the next decade (Smitley et al., 2008). Most forest management activities associated with insect damage due to emerald ash borer occur in late June through August when damage can be more easily detected and when adults emerge (Hausman et al., 2010; Polgar and Primack, 2011; Herms and McCullough, 2014; BioForest Technologies Inc, 2017). Our results suggest that acoustic recording is better timed before emerald-ash borer forestry work to more effectively capture avian diversity. Baseline research on communities pre/post invasion is valuable to appreciate ecosystem functions prior to introduction and spread of an invasive species (Blossey, 1999; Lockwood et al., 2013). The possible shifts in species richness following emerald-ash borer related damage warrants long-term landbird monitoring on both local and landscape scales (Koenig and Liebhold, 2017).

We found that early recording schedules in comparison with late, had fewer species of residents and migrants. We also found significantly fewer species belonging to insectivore and omnivore food guilds and air, ground, lower canopy and upper canopy foraging guilds in late recordings. Because most foraging guilds were affected, the proportion of species found among the food and foraging guilds was similar in May and June. Therefore, both early and late recordings may be useful to examine shifts in overall proportions of communities belonging to food and foraging guilds. Ordination revealed that species assemblages detected in early and late recordings were differentiated by several species that were recorded exclusively in May or June, despite the fact that many species were common to both periods. Furthermore, some of the species that differentiate the early and late assemblages were rare, which could be particularly important. Our results suggest that perhaps sampling over a longer time period may be of value depending on the project goal. Recording bird communities could be used to study changes in bird foraging guilds in emerald ash borer damaged forests. Results of other forest disturbance studies suggest the comparison may be worthwhile to understand how the community responds. Fire damage to forests has been shown to influence community composition in birds (Apfelbaum and Haney, 1981; Lowe et al., 2012). Because bird community composition in forests is likely driven by vegetation structure and insect abundance (Holmes et al., 1979; Lee and Rotenberry, 2005; Buchanan et al., 2016), multiple foraging guilds could be affected by emerald ash borer including members of air foraging, lower canopy and upper canopy guilds that are dominated by insectivores that may decrease following canopy loss. Some guilds such as bark-focused species can increase in response to emerald ash borer larvae, which are a food source (Flower et al., 2014). Woodpeckers and other bark-focused birds also use tree mortality as a visual cue indicating abundant food, and will populate these areas, increasing in abundance at least temporarily (Chan-McLeod, 2006; Flower et al., 2014). We found no significant difference in the number of species detected belonging to bark-focused guilds between early and late recordings. As such, if the primary interest is a shift in bark focused species that may increase in response to emerald ash-borer relative to other species then late recordings timed with forestry work well.

In summary, our results show that you can sample forest bird communities effectively in May. The number of species detected using acoustic sampling is significantly lower in June than in May. However, our ordination analysis shows that you may detect some rare species more often than others in either period and so depending on the monitoring goal, sampling multiple times per season may be worthwhile. Annual or bi-annual monitoring of York Region forest tracts as the emerald ash borer invasion progresses can give important insights into potential shifts in bird communities from early invasion to late invasion and finally post invasion.

Supporting material

S1. Nonparametric correlation coefficients (Kendall's Tau) for the association between species detections and site/recording period scores on the first axis extracted from a correspondence analysis ordination of a matrix of species detection by location/season data (n=26). (DOCX)

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Competing interests

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