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Influence of residual forest patches on post-fire bird diversity patterns in jack pine-dominated ecosystems of northern Lower Michigan

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ABSTRACT

Stand-replacing fires are part of the natural disturbance regime that maintain jack pine (*Pinus banksiana* Lamb.) forests of northern Lower Michigan. Currently, the occurrence and extent of wildfire is much reduced relative to the past and young jack pine plantations specifically managed for Kirtland's warbler (*Setophaga kirtlandii* Baird) are a prominent feature on the landscape. Stringers, or patches of residual pre-fire forest, are a unique feature left behind after wildfires which are not often accounted for in plantation management. In this study, we examined the ecological value of stringers from an avian biodiversity perspective by comparing bird assemblages found within stringers to those in the surrounding forest (non-stringers). Our objective was to answer two research questions: (1) do stringers have unique bird communities relative to the surrounding vegetation (forest or plantation)?; and (2) how much of the variation in bird communities can be explained by differences in vegetation structure and composition between stringers and non-stringers? We conducted breeding and non-breeding season point counts and used abundance data to compare bird species found within stringers and non-stringers at seven sites grouped by time since disturbance. Species richness was significantly higher ($P = 0.01$) in the stringers when the non-stringers were 30–40 years old, with 32 species discovered in the stringers and 29 species in the non-stringers. During the breeding season, bird assemblages differed between stringers and non-stringers when the non-stringers were <12 years old (multi-response permutation procedures; $T = -10.11$, $A = 0.07$, $P = <0.00$), but no differences were observed when non-stringers were 30–40 years old or >40 years old. Non-breeding bird communities differed between stringers and non-stringers only when the non-stringer was a recently planted (<5 years old) plantation ($T = -2.15$, $A = 0.09$, $P = 0.02$). Differences in bird assemblages appear to be driven by the vegetation structure of stringers and non-stringers where fires were recent, but increasing similarity in vegetation structure occurs with time since fire; over time the importance of stringers for avian biodiversity is reduced. Our results suggest that stringers are important for bird communities, especially in recently disturbed areas, and that these biological legacies should be considered where jack pine management attempts to emulate natural patterns and processes.

1. Introduction

Across the xeric, sandy outwash plains of northern Lower Michigan (NLM) jack pine (*Pinus banksiana* Lamb.)-dominated ecosystems predominate (Whitney, 1986, 1987). Stand-replacing crown fires are part of the historic natural disturbance regime that maintains these ecosystems (Whitney, 1986, 1987; Frelich, 2002). Currently, the occurrence and extent of wildfire is much reduced relative to the past and young jack pine plantations are a prominent feature on the landscape.

Natural disturbances, like wildfire, leave behind organisms, structures, and other remnants of the previous vegetation. These "biological legacies" add structural, compositional, and functional heterogeneity within the disturbance perimeter and may act as refugia for many species by providing critical cover and food sources not available in disturbed areas (Franklin et al., 2000).

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Wildfire behavior in jack pine systems often produces long, narrow, unburned strips of the pre-fire vegetation arranged parallel to the direction of fire spread (Kashian et al., 2012). These unburned strings of trees (hereafter termed "stringers") provide heterogeneity on a landscape historically shaped by stand-replacing wildfires (Kashian et al., 2012). While the value of stringers has not been studied in the broader context of biodiversity maintenance in jack pine-dominated ecosystems of NLM, they have been shown to comprise nearly 10% of the post-fire area and have relatively long-term persistence on the landscape (Kashian et al., 2012). As suggested by Kashian et al. (2012), stringers provide important structural diversity in an otherwise even-aged, relatively homogeneous area of regenerating jack pine and thus may offer refugia for birds, insects, and small mammals that otherwise do not use the adjacent disturbed area. Several studies have shown that patches of remnant, pre-disturbance forests are important for bird communities in forested landscapes, including aspen (*Populus* spp.) clearcuts in Minnesota (Merrill et al., 1998), the Cascades region of the Pacific Northwest (Hansen et al., 1995), red pine (*Pinus resinosa* Ait) forests in Minnesota (Atwell et al., 2008), jack pine forests in Ontario, Canada (Venier and Pearce, 2005), the boreal forest of western North America (Schieck and Song, 2006), and the mixed eucalypt (*Eucalyptus* spp.) forests of south-east Australia (Robinson et al., 2014).

Many jack pine-dominated ecosystems of NLM are managed as breeding habitat for the Federally Endangered Kirtland's warbler (*Setophaga kirtlandii* Baird), which breeds in young (5–20 years old) jack pine. Jack pine requires fires for regeneration, and mid-20th century fire suppression therefore greatly reduced the availability of Kirtland's warbler habitat and the species was listed pursuant to the *Endangered Species Act* (Probst, 1986). In an effort to increase the amount of young jack pine coverage necessary for Kirtland's warbler breeding habitat, state and federal land managers currently harvest mature jack pine and regenerate these sites by planting 2-yr old jack pine seedlings in an "opposing wave pattern" (Probst, 1986, 1988). Trees are typically planted at 1.2 m intervals in rows of alternating "waves" that are 1.8 m apart to create elliptical openings (Houseman and Anderson, 2002). The result is a uniform arrangement of densely planted jack pines separated by small (<1 ha) openings in which Kirtland's warbler forage (Probst, 1986; Kepler et al., 1996) and a stand structure significantly different than that created naturally by wildfire (Spaulding and Rothstein, 2009). Specifically, stringers are often unaccounted for in management, even though they are a unique and common feature left behind after stand-replacing wildfires in this region (Kashian et al., 2012).

In step with the general concepts of ecological forestry (Seymour and Hunter, 1999; Franklin et al., 2007), efforts are underway in the Great Lakes Region to manage jack pine ecosystems within the limits of the natural disturbance patterns and processes so that better outcomes of biodiversity conservation can be achieved (Corace et al., 2009, 2010; Corace and Goebel, 2010). This can be accomplished through silvicultural plans that emulate the patterns of natural disturbances of the region, including the return interval, severity, the spatial patterns of the disturbance, and the biological legacies left behind (Seymour and Hunter, 1999). Stringers are common features of naturally disturbed jack pine-dominated ecosystems and are naturally persistent throughout the fire return interval (Kashian et al., 2012). However, the role of stringers in overall stand and landscape-level biodiversity is unknown as few multi-taxa studies have been conducted in jack pine plantations produced for Kirtland's warbler.

The overall objective of this research was to examine the biodiversity value of stringers from an avian perspective by examining the interactions between stringers and surrounding jack pine forests or plantations in NLM. Specifically, we investigated the following research questions: (1) Do stringers have unique bird communities relative to the surrounding vegetation (forest or plantation) and is there seasonal variation?; and (2) how much of the variation in bird communities can be explained by differences in vegetation structure and composition between stringers and non-stringers? Bird communities were analyzed in sites with wildfire-generated stringers to determine the natural range of variability in bird diversity patterns in jack pine-dominated forests of NLM. Bird communities within an anthropogenically created stringer surrounded by a plantation were analyzed to determine if unharvested forest within plantations contribute to avian diversity. Understanding bird diversity patterns in naturally disturbed jack pine-dominated forests of NLM will provide some general principles to guide mangers in better mimicking natural patterns within plantations managed for Kirtland's warbler habitat. We hypothesize that stringers will increase overall avian species diversity within jack pine-dominated forests of NLM, especially in recently disturbed sites.

2. Methods

2.1. Study sites

All field work was conducted in the Highplains Subsection (VII.2) of the Northern Lacustrine-Influenced Lower Michigan Section (VII) as described by Albert (1995). The Highplains Subsection has the most severe climate of NLM due to its inland location, high elevation, and northern latitude. Late spring freezes are common in the area and the annual precipitation is between 71 and 81 cm. The subsection consists mainly of broad outwash plains with excessively drained sand or sand mixed with gravel.

Stringer locations were determined following the methods of Kashian et al. (2012). Aerial photographs of each site were analyzed to determine stringer locations and stringer area. We defined stringers from the surrounding forest or plantation by locating contiguous areas of mature trees within a burn perimeter. Boundaries between stringers and non-stringers were drawn where the edge of the stringer meets the burned area. Kashian et al. (2012) describes the natural range of variability of stringers in jack pine-dominated ecosystems of NLM. While stringers are variable in size and shape across our sample sites, for this study we required that all stringers and non-stringers be a minimum of 100 m wide.

The primary research areas were two sites within the U.S. Fish and Wildlife Service's Kirtland's Warbler Wildlife Management Area (KWWMA): Muskrat Trail and Leota. Sampling was conducted during the non-breeding (December–March) and breeding season (May–August). Muskrat Trail includes an anthropogenically produced stringer that represents a remnant of the tract harvested in 2008. The remaining acreage at this site was planted with jack pine seedlings in 2009. The Leota site was burned by a wildfire in 1977 that left stringers from the previous mature jack pine-red pine stand. Field work was also conducted during the breeding season at five additional wildfire sites. These sites included some of those examined by Kashian et al. (2012) and included Damon (burned in 1967), St. Helen (1967), Mack Lake (1980), No Pablo (2000), and Hughes Lake (2006) (Fig. 1, Table 1). These sites were chosen because they were known to have stringers, were geographically isolated from one another, and because they include a range of times since fire or harvesting. At each of the seven sites we sampled birds and vegetation structure at a minimum of three points located in the stringer and three in the surrounding forest/plantation (non-stringer). For the purposes of this work, we categorized Damon and St. Helen as "mature" sites (>40 years post-disturbance that created the stringer), Leota and Mack Lake as "intermediate age" sites (>30 years post-disturbance), and No

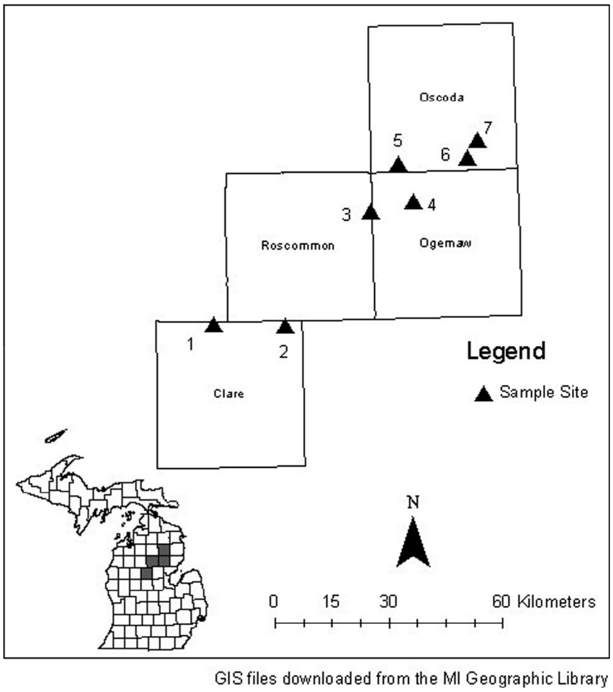

Fig. 1. Locations of study sites across four counties in northern Lower Michigan: 1 = Muskrat Trail, 2 = Leota, 3 = St. Helen, 4 = Damon, 5 = Hughes Lake, 6 = No Pablo, 7 = Mack Lake.

Table 1
Locations, disturbance size, event year, and type of disturbance for the seven sampling locations in northern Lower Michigan.

Site Name	County	Size of disturbance (ha)	Year of disturbance	Type of disturbance
Damon	Ogemaw	481	1967	Wildfire
St. Helen	Roscommon	331	1967	Wildfire
Leota	Clare	965	1977	Wildfire
Mack Lake	Oscoda	9825	1980	Wildfire
No Pablo	Oscoda	2104	2000	Wildfire
Hughes Lake	Oscoda	2345	2006	Wildfire
Muskrat Trail	Clare	65	2008	Mechanical

Pablo, Hughes Lake, and Muskrat Trail as “recently disturbed” sites (4–12 years post-disturbance). Corace et al. (2010) examined bird communities associated with different age classes of jack pine plantations managed for the Kirtland’s warbler. Their results show that recent clearcuts, 5–23 year-old plantations, and mature jack pine stands each have unique bird assemblages that are largely driven by forest structure that develops over time in jack pine ecosystems. These results were used as a guideline for categorizing our sites. Furthermore, the stringers at Damon and St. Helen have a similar relative abundance of jack pine (87% at Damon and 81% at St. Helen) with some red pine at St. Helen (19%). Mack Lake and Leota stringers have a high amount of deciduous species in the understory (85% at Mack Lake, 85% at Leota). Hughes Lake, No Pablo, and Muskrat Trail stringers are largely composed of jack pine (91% at No Pablo, 70% at Hughes Lake, and 84% at Muskrat Trail).

2.2. Bird sampling with point counts

To quantify differences in bird communities, bird sampling began in December 2011 and was completed in August 2013. Counts occurred within a total of 50 point count stations across the seven sites using 50-m fixed radius plots following standard point count methodology (Ralph et al., 1993). Due to the irregular shape and size of stringers, point count stations were selected so that each point was a minimum of 200 m apart and ⩾50 m from the edge of the stringer for stringer points and ⩾50 m from the closest stringer for non-stringer points. This was to minimize counting birds found in surrounding vegetation communities and to better ascertain bird species affinity for stringer and non-stringer vegetation. The Muskrat Trail, Leota, No Pablo, and Hughes Lake sites each had eight points, four within the stringer and four points in the non-stringer. Damon, St. Helen, and Mack Lake sites each had six points, three within the stringer and three within the non-stringer. Point counts started no more than 10 min before sunrise and continued for no longer than 4 h; counts occurred for 5 min at each sample station. Muskrat Trail and Leota were sampled six times during the non-breeding season of both sampling years, once per month in December and March, and twice per month in January and February. We did not conduct point counts during precipitation, when winds exceeded 17 kph, or when temperatures were below −7 °C. A minimum of one week was observed between visits and a new route was followed for consecutive count dates to minimize bias caused by the time of day point counts were conducted. At Muskrat Trail and Leota, we conducted breeding season point counts following the same procedure from May through August, with a single count in May and August and twice in June and July, to document vegetation use during the breeding season. Sampling occurred once a month at Damon, St. Helen, Mack Lake, No Pablo, and Hughes Lake from May to August using the same methods. We waited approximately three weeks between each sampling visit and a new route was followed for consecutive count dates to minimize bias caused by the time of day point counts were conducted. During the breeding season we did not conduct point counts during precipitation or when winds exceeded 17 kph. Detectability was not measured, but we believe our methods were appropriate to compare and contrast bird communities of stringers and non-stringers within a given landscape because each count was conducted by the same individual (BCA) over multiple years. We also assume the high number of visits to each site allowed us to detect the full range of species that use the sample sites.

2.3. Vegetation sampling

Vegetation structure and composition was evaluated at all seven sites in 2012 using a simplified version of protocols established by the U.S. Forest Service’s Forest Inventory and Analysis Program (Corace and Petrillo, 2014). A fixed-radius, 0.01-ha circular plot (radius 5.5 m) was established with the bird point count station as the center of the plot. Within the plot, the average percent canopy coverage was estimated using four readings (one from each cardinal direction while at the center of the plot) from a spherical densiometer. The number and diameter of all trees >10 cm and snags (dead, standing trees) >10 cm at breast height (dbh) was recorded by species, and the number and species of all other stems (<10 cm) were all recorded. From the center of the plot, three sub-plot transects (set at 0°, 135°, and 225°) were established from which coarse woody debris (CWD) was measured if it was >10 cm dbh and >1.2 m length, and intersected one of the transects (Table 2).

3. Data analysis

3.1. Study sites

Breeding season data were analyzed by pooling the sites together based on the time since the area was disturbed to account for varying vegetation structure and composition that may have an influence on vegetation selection by birds. Pooled sites included

Table 2
Variables used to assess vegetation structure within each 0.01 ha plot in seven study sites of northern Lower Michigan. Point counts were conducted from these plot centers.

Variable	Method
Percent canopy coverage	Four readings at each plot, facing N,S,E,W. The four numbers are averaged
Number of trees by species	Count trees >10 cm dbh and >0.76 m tall
Diameter breast height (DBH)	Measure all trees >10 cm dbh
Number of standing snags	Count dead, standing trees >10 cm dbh
Coarse woody debris (CWD)	Measure pieces of CWD that are >10 cm dbh and >1.2 m in length
Number and species of saplings (<10 cm)	Count stems <10 cm and >0.76 m tall

Damon and St. Helen, with six stringer and six non-stringer sample points total (both burned 45 years ago), Leota and Mack Lake, with seven stringer and seven non-stinger points total (burned 32 and 35 years ago, respectively), and No Pablo, Hughes Lake, and Muskrat Trail, with 12 stringer and 12 non-stringer sample points total (disturbed within the last 4–12 years). Muskrat Trail (four stringer and four non-stringer points), having the only anthropogenically produced stringer was also compared to Hughes Lake (four stringer and four non-stringer points), which is similar in time since disturbance, to determine if bird assemblages are different between anthropogenically produced stringers and naturally created stringers. Data from the non-breeding season was analyzed separately for Muskrat Trail and Leota (four stringer and four non-stringer points) with data points pooled as stringer or non-stringer.

3.2. Point counts

Observations from repeated point count surveys were pooled by point count station by selecting the repeat with the highest maximum abundance for each individual species (Nur et al., 1999). The sample of points within a stringer were pooled together and compared to the pooled non-stringer sample points, making the assumption that variation in vegetation between the individual stringers within each of the seven sites was negligible. Abundance, species richness, and Shannon's diversity (H') were used to characterize the bird communities for each of the seven sample sites for stringers and non-stringers and a Mann–Whitney test was used to determine significance. We tested if bird community composition between stringers and non-stringers differed using the abundance data and Multi-response Permutation Procedures (MRPP). A separate MRPP was run for each of the three categories of sites (mature, intermediate, and recently disturbed) using Blossom statistical software (Cade and Richards, 2001) with a natural weighting factor and Euclidean distances. MRPP results are negatively influenced by rare species (McCune and Grace, 2002), so species observed at $\leqslant 2$ points within pooled data points were removed from the analysis. To determine the importance of vegetation types to specific bird species, the MRPP was supplemented with an indicator species analysis using the "indicspecies" package in R version 3.0.2 (De Cáceres, 2013). Randomization tests were used to determine statistical significance of the indicator value using 1000 permutations.

3.3. Vegetation

Vegetation composition and structure of stringers and non-stringers were compared with sites pooled as described above, and all variables were examined for normality. A Mann–Whitney rank sum test was used to compare vegetation characteristics between stringers and non-stringers for data that was not normally distributed and a Student's *t*-test was used for normal data. Data transformations were not conducted due to the large number of zeros in our data.

3.4. Bird community response to vegetation

Non-metric Multidimensional Scaling (NMDS) was used to examine the response of bird community composition, including rare species, to vegetation structure. NMDS is an ordination method that finds the strongest structure and displays the points and species in multi-dimensional space (McCune and Grace, 2002). NMDS is recommended for data that is non-normal because it uses ranked distances and avoids the assumption of linear relationships among variables (McCune and Grace, 2002). Analyses were conducted using the "metaMDS" function in R version 3.0.2 using the vegan package and a Bray-Curtis dissimilarity matrix (Oksanen et al., 2013). NMDS ordinations comparing stringers to non-stringers were calculated for each of the three site categories to determine how the time since disturbance influences bird community response. Preliminary NMDS analyses were run with as many as 4 dimensions, and stress was examined to determine the best choice. Final NMDS analyses were run with two dimensions, a random starting configuration, and 50 iterations. To better understand how the bird communities respond to the vegetation of stringers and non-stringers, convex hull polygons were used to connect the vertices of the points made by the stringers or non-stringers at the site. An overlap in the polygons indicates the bird species share space within the sample sites. Due to our relatively low sample size of 50 point count stations we used $\alpha = 0.10$ for all statistical analyses as the possibility of not seeing important patterns was more of a concern to us than erroneously identifying something as significant.

4. Results

4.1. Point counts

We documented 57 bird species across 50 point count stations during the breeding season at all seven study sites (Appendix A). When individuals of all species were pooled across plots in stringers and non-stringers across all breeding season visits, mean abundance (±1SE) tended to be greater within the non-stringer (83 ± 12.97) when compared to the stringer (74.4 ± 6.94), but the differences were not significant (Table 3). Conversely, species richness and Shannon's diversity index tended to be greater in the stringers when compared to the non-stringers, but only Shannon's diversity was significant ($P = 0.08$; Table 3). The number of bird species found within the stringers and non-stringers varied across the seven sites, but all seven sites had species that were found only in stringers or only in the non-stringers (Appendix A). There were fewer species found only in stringers at the mature sites (six at Damon, two at St. Helen) than at the recently disturbed sites (10 at No Pablo, 10 at Hughes Lake, and 17 at Muskrat Trail). Leota and Mack Lake (intermediate aged sites) both had 9 species found only in the stringers (Appendix A). The intermediate aged sites had fewer species found only in non-stringers (4 at Leota, 3 at Mack Lake) than the mature sites (5 at Damon, 11 at St. Helen) and the recently disturbed sites (5 at No Pablo, 10 at Hughes Lake, 11 at Muskrat Trail). Species richness was significantly higher ($P = 0.01$) in the stringers at intermediate aged sites, with 32 species discovered in the stringer and 29 species in the non-stringer. Species richness was not significantly different between stringer and non-stringers at the mature and recently disturbed sites.

There was a significant difference in bird community composition between stringers and non-stringers for the sites most recently disturbed ($T = -10.11$, $A = 0.07$, $P = <0.00$) but no

Table 3
Breeding season (May–August) bird community measures of stringers and non-stringers at seven study sites in northern Lower Michigan. Significant ($P \leqslant 0.10$) differences are in bold.

	Abundance		Species richness		Shannon's diversity (H′)	
	Stringers	Non-stringers	Stringers	Non-stringers	Stringers	Non-stringers
>40 years old						
Damon Fire	54	47	19	18	2.7	2.7
St. Helen	59	62	22	26	2.8	2.9
30–40 years old						
Leota	100	76	26	20	3	2.8
Mack Lake	58	45	25	19	3.1	2.7
4–12 years old						
No Pablo	79	116	27	23	3	2.9
Hughes Lake	76	104	24	24	3	2.9
Muskrat Trail	95	131	30	24	3.1	2.9
Mean (±1SE)	74.4 (6.9)	83 (13.0)	24.7 (1.3)	22 (1.1)	**2.96 (0.1)**	**2.8 (0.04)**

difference for the intermediate or mature sites. There were seven significant indicators of stringer vegetation in recently disturbed sites: black-capped chickadee (68.8, $P = 0.00$; *Poecile atricapillus* L.), downy woodpecker (50.0, $P = 0.02$; *Picoides pubescens* L.), white-breasted nuthatch (45.8, $P = 0.03$), red-breasted nuthatch (42.9, $P = 0.05$; *Sitta Canadensis* L.), eastern wood-pewee (41.7, $P = 0.04$; *Contopus virens* L.), hairy woodpecker (33.3, $P = 0.10$; *Picoides villosus* L.) and pine warbler (33.3, $P = 0.08$; *Dendroica pinus* Wilson). There were nine significant indicators of non-stringer vegetation: field sparrow (97.3, $P = 0.00$; *Spizella pusilla* Wilson), brown thrasher (85.6, $P = 0.00$; *Toxostoma rufum* L.), vesper sparrow (82.4, $P = 0.00$; *Pooecetes gramineus* Gmelin), Kirtland's warbler (75.0, $P = 0.00$), song sparrow (62.5, $P = 0.01$; *Melospiza melodia* Wilson), eastern bluebird (59.8, $P = 0.01$; *Sialia sialis* L.), Lincoln's sparrow (53.5, $P = 0.02$; *Melospiza lincolnii* Audubon), American kestrel (50.0, $P = 0.022$; *Falco sparverius* L.), and eastern kingbird (43.3, $P = 0.05$; *Tyrannus tyrannus* L.).

No difference in bird community composition was detected when the stringers of Muskrat Trail were compared to the stringers of Hughes Lake, although the differences in bird community composition between non-stringers of the two sites were significant ($T = -1.6$, $A = 0.052$, $P = 0.07$).

We documented 22 bird species across 16 point count stations during the non-breeding season at Muskrat Trail and Leota (Appendix B). Species abundance, richness, and Shannon's diversity all tended to be higher within the stringer, but were not significantly different (Table 4). Bird communities were significantly different between stringers and non-stringers at Muskrat Trail ($T = -2.15$, $A = 0.09$, $P = 0.024$), but not at Leota. Nevertheless, eight bird species were found in the stringer that were not found in the non-stringer at Muskrat Trail; seven species were found within the stringer that were not found in the non-stringer at Leota (Appendix B). Conversely, only two species were found in the non-stringer at Muskrat Trail that were not found in the stringer and there were no species found only in the non-stringer at Leota. The black-capped chickadee (80, $P = 0.05$) was the only significant indicator species of the non-breeding season and was found in stringers at Muskrat Trail.

Table 4
Non-breeding season (December–March) bird community measures of stringers and non-stringers at Muskrat Trail and Leota. No significant differences ($P \leqslant 0.10$) were observed.

	Stringer	Non-stringer
Species Abundance (# of individuals)		
Muskrat Trail	29	14
Leota	30	22
Mean (±1SE)	29.5 (0.5)	18 (4.0)
Species Richness		
Muskrat Trail	13	7
Leota	16	11
Mean (±1SE)	14.5 (1.5)	9 (2.0)
Shannon Diversity (H′)		
Muskrat Trail	2.4	1.8
Leota	2.5	2.2
Mean (±1SE)	2.5 (0.05)	2 (0.2)

4.2. Vegetation

Sites >40 years old had similar vegetation structural characteristics in the stringers and non-stringers (Table 5). The non-stringer vegetation of these sites are mature enough to have canopy trees, but canopy trees found in stringers were significantly larger in dbh ($P = 0.01$). Stringers averaged (±1SE) 100 (±81.65) red pine/ha in the canopy, 16.7 (±16.7) deciduous species/ha in the canopy, and 66.7 (±42.16) red pine/ha in the understory; all of these characteristics were absent in the non-stringers. Differences between stringers and non-stringers at the sites 30–40 years old were primarily related to the species composition of the canopy and understory. Non-stringers had more jack pine/ha in the canopy ($P = 0.02$) and understory ($P = 0.01$), and stringers had more red pine/ha in the canopy (non-stringers had none) and understory ($P = 0.04$), as well as more deciduous species/ha ($P = 0.00$) in the understory. The primary differences between stringers and non-stringers at the 4–12 year old sites were found in the canopy, since non-stringers lacked a canopy and associated vertical structure. Non-stringers also had more coarse woody debris (logs/ha; $P = 0.01$) and jack pine/ha in the understory ($P = 0.07$). The number of jack pine/ha, red pine/ha, deciduous species/ha, snag/ha in the canopy, canopy dbh, and snag dbh at the recently disturbed sites had a value of zero for the non-stringer subset.

We compared the vegetation characteristics of Muskrat Trail and Leota separately for the non-breeding season. Stringers at Muskrat Trail had a mean (±1SE) of 400 (±147.2) jack pines/ha, 50 (±50) red pine/ha, and 25 (±25) deciduous species/ha in the canopy. Non-stringers had more jack pine in the understory ($P = 0.03$) and lacked a canopy and associated vegetation structure and composition (Table 6). At Leota, the size (dbh) of canopy trees and the amount of deciduous species in the canopy differed with larger trees ($P = <0.00$) and more deciduous species being found in the stringer ($P = 0.01$). There is also a difference in the amount of jack pine in the understory, with more being detected in the non-stringer ($P = 0.04$).

Table 5
Mean vegetation values (±1SE) for seven sites in northern Lower Michigan. Significant ($P \leqslant 0.10$) differences are in bold.

	4–12 years old		30–40 years old		>40 years old	
	Stringer	Non-stringer	Stringer	Non-stringer	Stringer	Non-stringer
Closed Canopy (%)	**0.7 (0.03)**	**0 (0)**	0.7 (0.1)	0.7 (0.03)	0.7 (0.1)	0.5 (0.1)
# Canopy Jack Pine (trees/ha)	**475 (118.8)**	**0 (0)**	**228.6 (152.3)***	**985.7 (129.9)***	566.7 (176.4)	700 (178.9)
# Canopy Red Pine (trees/ha)	**50 (26.1)**	**0 (0)**	**285.7 (151.9)**	**0 (0)**	**100 (81.7)**	**0 (0)**
# Canopy Deciduous (trees/ha)	**58.3 (49.9)**	**0 (0)**	71.4 (36.0)*	57.1 (29.7)*	**16.7 (16.7)**	**0 (0)**
# Canopy Snags (snags/ha)	**50 (28.9)**	**0 (0)**	100 (43.6)*	71.4 (56.5)*	150 (50)	100 (36.5)
Canopy dbh (cm)	**16.1 (2.2)**	**0 (0)**	**23.8 (2.8)***	**12.7 (0.8)***	**19.2 (3.2)***	**14.6 (1.3)***
Snag dbh (cm)	**14.7 (1.3)**	**0 (0)**	**16.8 (1.8)**	**12.5 (0.7)**	18.8 (2.9)*	13.2 (1.5)*
# Jack pine Understory (trees/ha)	**758.3 (295.3)***	**1550 (403.9)***	**171.4 (119.0)***	**1300 (322.2)***	400 (134.2)	416.7 (199.0)
# Red Pine Understory (trees/ha)	50 (50)	0 (0)	**214.3 (101.0)***	**14.3 (14.3)***	**66.7 (42.2)**	**0 (0)**
# Deciduous Understory (trees/ha)	1216.7 (434.3)*	916.7 (336.6)*	**2214.3 (378.9)**	**600 (197.6)**	533.3 (320.1)*	183.3 (94.6)*
Number CWD pieces (logs/ha)	**133.3 (39.6)***	**558.3 (171.7)***	314.3 (40.4)	214.3 (63.4)	150 (56.3)	66.7 (33.3)

[*] Show data that was not normally distributed.

Table 6
Mean vegetation values (±1SE) for Leota and Muskrat Trail. Significant differences are in bold.

	Muskrat Trail		Leota	
	Stringer	Non-stringer	Stringer	Non-stringer
Percent Closed Canopy (%)	**0.6 (0.04)**	**0 (0)**	0.6 (0.06)	0.6 (0.03)
# Canopy Jack Pine (trees/ha)	**400 (147.2)**	**0 (0)**	400 (241.5)	1050 (232.7)
# Canopy Red Pine (trees/ha)	**50 (50)**	**0 (0)**	**200 (200)**	**0 (0)**
# Canopy Deciduous (trees/ha)	**25 (25)**	**0 (0)**	25 (25)	75 (47.9)
# Canopy Snags (snags/ha)	**25 (25)**	**0 (0)**	**75 (47.9)**	**0 (0)**
Canopy dbh (cm)	**18.5 (3.6)**	**0 (0)**	**21.9 (3.4)**	**12.7 (0.93)**
Snag dbh (cm)	**21.1 (0)**	**0 (0)**	**13.6 (2.3)**	**0 (0)**
# Jack Pine Understory (trees/ha)	**100 (100)**	**2725 (394.5)**	**100 (100)**	**1125 (335.1)**
# Red Pine Understory (trees/ha)	**150 (150)**	**0 (0)**	325 (160.1)	25 (25)
# Deciduous Understory (trees/ha)	1225 (687.2)	475 (125)	**2500 (248.3)**	**675 (311.9)**
Number CWD pieces (logs/ha)	250 (86.6)	225 (47.9)	325 (62.9)	325 (47.9)

4.3. Bird community response to vegetation

We observed an overlap in the bird species seen in the stringers and non-stringers at the sites >40 years old during the breeding season (Fig. 2; convergent solutions found, 2 dimensions, stress = 14%). For sites aged 30–40 years, there was also an overlap in the bird species seen in the stringers and non-stringers (Fig. 3; convergent solutions found, 2 dimensions, stress = 16%). In general, bird communities detected within the stringers and non-stringers were similar at the mature and intermediate aged sites.

In contrast to mature and intermediate-aged sites, species assemblages detected within stringers were distinctly different than species assemblages in non-stringers at sites 4–12 years old (Fig. 4; convergent solutions found, 2 dimensions, stress = 14%). There was a strong division in the bird community composition of stringers and non-stringers, adding further support to the MRPP results.

Non-breeding season NMDS results for the Muskrat Trail (convergent solutions found, 2 dimensions, stress = 6%) and Leota (convergent solutions found, 2 dimensions, stress = 4%) showed a strong division between stringer and non-stringers at Muskrat

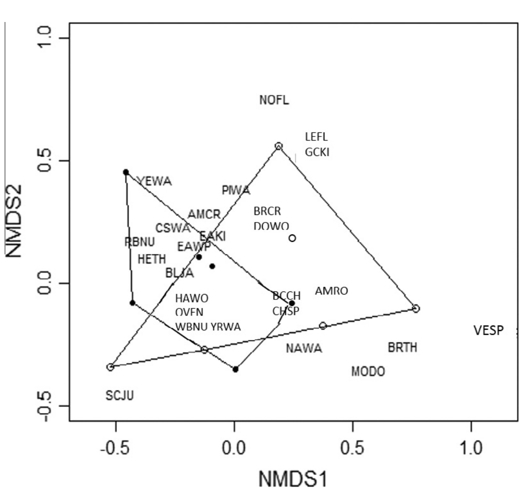

Fig. 2. NMDS ordination biplot of breeding season abundance data for sites >40 years old (e.g., Damon and St. Helen). Closed circles represent stringers, and open circles represent non-stringers. See Appendix A for bird species represented as four-letter codes.

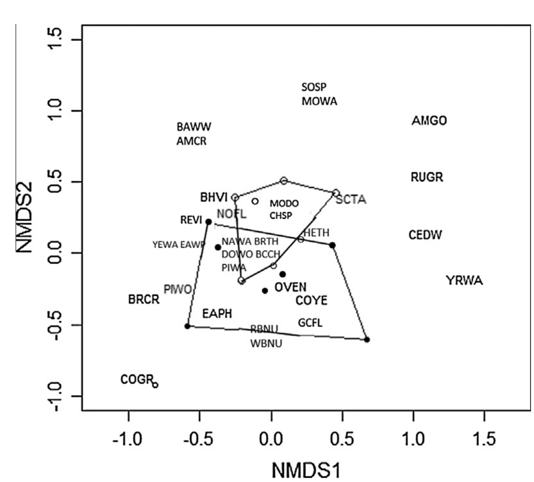

Fig. 3. NMDS ordination biplot of breeding season abundance data for the sites aged 30–40 years (e.g., Leota and Mack Lake). Closed circles represent stringers, and open circles represent non-stringers. See Appendix A for bird species represented as four-letter codes.

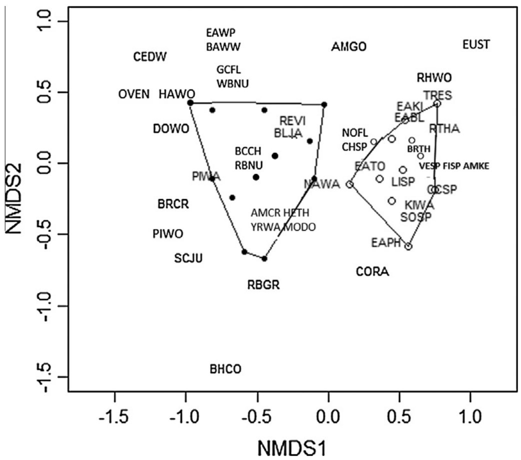

Fig. 4. NMDS ordination biplot of breeding season abundance data from sites 4–12 years old (e.g., Hughes Lake, No Pablo, and Muskrat Trail). Closed circles represent stringers, and open circles represent non-stringers. See Appendix A for bird species represented as four-letter codes.

Trail and an overlap in bird community composition at Leota. Ordination biplots are available in Cullinane-Anthony (2013).

5. Discussion

Bird assemblages differ between stringers and non-stringers at recently disturbed sites, probably attributable to the contrasting vegetation structure between recently disturbed and regenerating forest and remnant patches of the pre-disturbance forest. While most burned areas are bordered by unburned forests, in jack-pine dominated forests of NLM, large wildfires tend to burn unchecked (unless suppressed) until they reach a vegetation type that causes the fire to stop or the fire becomes extinguishable. When this occurs, the surrounding unburned forest is of a different vegetation type than stringers in the center of the burn. Also, the focus of our study is the management unit, which tends to be contained within a burn perimeter. Because biodiversity is assessed at the scale of the management unit, understanding how stringers within that unit affect biodiversity is important.

Non-stringers are open stands that favor bird species that forage and nest in open areas, such as field sparrow, eastern bluebird, and vesper sparrow (Ehrlich et al., 1988). In contrast, stringers at the recently disturbed sites provide mature vegetation, characterized by a closed canopy composed of pine and deciduous species and snags, which is preferred by a different suite of bird species. Stringers clearly increase the biodiversity within a burned area by providing structural heterogeneity within post-disturbance jack pine-dominated ecosystems. Stringers may be beneficial for bird species that require vegetation for perching and nesting such as living legacy trees, snags, or other features that are not available in the surrounding recently burned or planted area.

In contrast to recently disturbed sites, we detected no differences in bird assemblages documented within stringers and non-stringers at sites >30 years old for those points sampled during the breeding season, likely because the non-stringer vegetation structure became more similar to that of the stringer as the non-stringer vegetation aged (Spaulding and Rothstein, 2009; Kashian et al., 2012). Both stringers and non-stringers at these sites had a closed canopy primarily composed of jack pine and a high number of snags. Although bird assemblages did not differ at these sites, six species at Damon, two species at St. Helen, and nine species at both Leota and Mack Lake were only detected in the stringers. The presence of stringer-only bird species is likely attributable to a more diverse canopy composition in the stringers, which likely provides more foraging and nesting opportunities than the more compositionally homogeneous non-stringers. These results are consistent with studies that documented bird species specific to mature age classes of pine-dominated ecosystems in the northern Lake States (Venier and Pearce, 2005; Atwell et al., 2008; Corace et al., 2010).

For the non-breeding season, bird assemblages were only different at the more recently disturbed Muskrat Trail site. There is also seasonal variation in bird communities at these sites, with higher abundance and richness during the breeding season. Vegetation structure and composition are important variables for determining bird diversity patterns (MacArthur and MacArthur, 1961). During the winter season, the stringers provide the structural complexity that birds may need for protective cover and foraging.

Patches of residual trees increase heterogeneity in vegetation found in post-disturbance ecosystems and provide the structural complexity that is important for species diversity (Franklin et al., 2000). Our findings, and those of many other studies, have indicated that the patterns left by a natural disturbance are important for post-disturbance diversity. Robinson et al. (2014) found that unburned patches supported a higher richness and abundance of birds two to three years post-fire than the surrounding burned landscape in south-east Australia. These unburned patches provided the mid to late successional vegetation birds need for foraging, enabling a given bird species to persist on the burned landscape (Robinson et al., 2014). A study conducted by Atwell et al. (2008) in red pine forests of Minnesota found that leaving patches of red pines intact, while disturbing the surrounding area, provided vegetation communities for diverse bird assemblages. A meta-analysis looking at the changes in bird communities following fire and harvest in boreal forests of western North America found that post-fire forests often have a high density of snags and patches of unburned trees that provide resources that would otherwise not be found in the burn perimeter (Schieck and Song, 2006). A study conducted by Venier and Pearce (2005) examined bird community response to succession in jack pine forests of Ontario, Canada and detected more bird species in older age classes. This was attributed to the increase in vertical vegetation structure and the increased availability of foraging and nesting locations.

5.1. Management implications and conclusion

Within the context of bird diversity, stringers in jack pine ecosystems of NLM provide important structure for bird assemblages in the first few decades following fires, although their importance within a particular burned area diminishes as the recovering forest ages and its structural similarity to the stringer increases. As such, stringers provide the structural complexity for bird species that depend on mature vegetation for foraging and nesting within a matrix of younger forests that provide vegetation for a different set of bird species, thereby increasing overall bird diversity. Our results suggest that if managing within the limits of natural disturbance patterns and the maintenance of avian biodiversity is of management interest, silvicultural prescriptions that involve plantations for Kirtland's warbler should include stringers. The high range of variability in the structure, composition, and size of natural stringers provides great flexibility for managers in including them in management plans (Kashian et al., 2012). Despite a lack of replication for stringers specifically created by harvest, our preliminarily research suggests that bird assemblages detected in anthropogenically created stringers are similar to those detected in naturally created stringers. While these results should be interpreted with caution, they suggest that stringers may be a relatively simple and effective way to maintain avian biodiversity even as vegetation structure is highly altered for the purposes of Kirtland's warbler management.

With the Kirtland's warbler population exceeding recovery limits, land managers have the opportunity to focus on the importance of structural features, such as stringers, and consider the broader aspects of jack pine ecosystem management within NLM. This study provides some general principles on bird diversity patterns that land managers can use to manage naturally created stringers and strips of unharvested forest within jack pine-dominated forests of NLM. Future work should continue to examine the importance of stringers to overall biodiversity.

Acknowledgements

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Appendix A

Breeding season (May–August) bird abundance (percent community composition) detected in stringers (S) and non-stringers (NS) at all seven sampling sites in northern Lower Michigan documented in 2012 and 2013. Species are listed alphabetically by common name. Species detected only in the stringers at each site are in bold.

Species	Binomial	Species code	> 40 years old				30–40 years old				4–12 years old					
			Damon Fire		St. Helen		Leota		Mack Lake		No Pablo		Hughes Lake		Muskrat Trail	
			S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
American Crow	*Corvus brachyrhynchos* Brehm	AMCR	**1 (2)**	0	2 (3)	2 (3)	0	0	0	1 (2)	2 (3)	2 (2)	0	0	2 (2)	1 (1)
American Goldfinch	*Carduelis tristis* L.	AMGO	0	1 (2)	**2 (3)**	0	0	0	0	1 (2)	0	0	2 (3)	2 (2)	**1 (1)**	0
American Kestrel	*Falco sparverius* L.	AMKE	0	0	0	2 (3)	0	0	0	0	0	5 (4)	0	2 (2)	0	1 (1)
American Robin	*Turdus migratorius* L.	AMRO	3 (6)	3 (6)	1 (2)	3 (5)	6 (6)	3 (4)	3 (5)	4 (9)	2 (3)	1 (1)	**4 (5)**	0	5 (5)	13 (10)
Black -and-white Warbler	*Mniotilta varia* L.	BAWW	0	0	0	0	0	0	0	1 (2)	0	0	0	0	**1 (1)**	0
Black-capped Chickadee	*Poecile atricapillus* L.	BCCH	9 (17)	9 (19)	6 (10)	12 (19)	15 (15)	12 (16)	2 (3)	7 (16)	9 (11)	4 (3)	8 (11)	2 (2)	13 (14)	4 (3)
Blue-headed Vireo	*Vireo solitaries* Wilson	BHVI	0	0	0	0	3 (3)	2 (3)	0	0	0	0	0	0	0	0
Blue Jay	*Cyanocitta cristata* L.	BLJA	5 (9)	5 (11)	8 (14)	5 (8)	7 (7)	7 (9)	6 (10)	6 (13)	4 (5)	4 (3)	9 (12)	5 (5)	8 (8)	2 (2)
Brown Creeper	*Certhia Americana* Bonaparte	BRCR	1 (2)	2 (4)	2 (3)	1 (2)	**3 (3)**	0	**2 (3)**	0	0	0	0	0	**5 (5)**	0
Brown Thrasher	*Toxostoma rufum* L.	BRTH	**1 (2)**	0	0	2 (3)	1 (1)	1 (1)	0	0	1 (1)	4 (3)	0	6 (6)	0	4 (3)
Brown-headed Cowbird	*Molothrus ater* Boddaert	BHCO	0	0	0	0	3 (3)	3 (4)	**1 (2)**	0	**1 (1)**	0	0	0	0	0
Clay-colored Sparrow	*Spizella pallida* Swainson	CCSP	0	0	0	0	0	0	0	0	0	1 (1)	0	0	0	5 (4)
Cedar Waxwing	*Bombycilla cedrorum* Vieillot	CEDW	0	0	0	0	0	0	**1 (2)**	0	0	0	0	0	**2 (2)**	0
Chestnut-sided Warbler	*Dendroica pensylvanica* L.	CSWA	**1 (2)**	0	0	0	0	0	0	0	0	0	0	0	0	0
Chipping Sparrow	*Spizella passerine* Bechstein	CHSP	3 (6)	4 (9)	2 (3)	4 (7)	8 (8)	6 (8)	2 (3)	4 (9)	2 (3)	5 (4)	7 (9)	10 (10)	6 (6)	11 (8)
Common Grackle	*Quiscalus quiscula* L.	COGR	0	0	0	0	0	1 (1)	**2 (3)**	0	0	0	0	3 (3)	0	0
Common Nighthawk	*Chordeiles minor* Forster	CONI	0	0	0	2 (3)	0	0	0	0	**1 (1)**	0	1 (1)	1 (1)	1 (1)	3 (2)
Common Raven	*Corvus corax* L.	CORA	0	0	0	0	0	0	0	0	1 (1)	5 (4)	0	0	0	0
Common Yellow-throat	*Geothlypis trichas* L.	COYE	0	0	0	0	**1 (1)**	0	0	0	0	0	0	0	**1 (1)**	0
Downy Wood-pecker	*Picoides pubescens* L.	DOWO	2 (4)	2 (4)	2 (3)	1 (2)	4 (4)	3 (4)	1 (2)	2 (4)	**1 (1)**	0	**2 (3)**	0	**3 (3)**	0
Eastern Bluebird	*Sialia sialis* L.	EABL	0	0	0	1 (2)	0	0	0	0	0	11 (10)	3 (4)	12 (12)	1 (1)	12 (9)

Appendix A (*continued*)

Species	Binomial	Species code	> 40 years old				30–40 years old				4–12 years old					
			Damon Fire		St. Helen		Leota		Mack Lake		No Pablo		Hughes Lake		Muskrat Trail	
			S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
Eastern Kingbird	*Tyrannus tyrannus* L.	EAKI	0	0	2 (3)	1 (2)	0	0	0	0	0	1 (1)	0	6 (6)	2 (2)	6 (5)
Eastern Phoebe	*Sayornis phoebe* Latham	EAPH	0	0	0	0	0	1 (1)	0	0	**1 (1)**	0	0	0	0	5 (4)
Eastern Towhee	*Pipilo erythrophthalmus* L.	EATO	0	0	0	0	0	0	0	0	6 (8)	5 (4)	1 (1)	7 (7)	3 (3)	10 (8)
Eastern Wood-Pewee	*Contopus virens* L.	EAWP	**1 (2)**	0	0	0	2 (2)	4 (5)	**1 (2)**	0	0	0	**3 (4)**	0	**4 (4)**	0
European Starling	*Sturnus vulgaris* L.	EUST	0	0	0	0	**1 (1)**	0	0	0	0	0	0	3 (3)	0	0
Field Sparrow	*Spizella pusilla* Wilson	FISP	0	0	0	1 (2)	0	0	0	0	1 (1)	10 (9)	0	14 (14)	0	12 (9)
Great Crested Flycatcher	*Myiarchus crinitus* L.	GCFL	0	0	0	1 (2)	**2 (2)**	0	**1 (2)**	0	0	0	0	0	**3 (3)**	0
Golden-crowned Kinglet	*Regulus satrapa* Lichtenstein	GCKI	0	1 (2)	0	0	**1 (1)**	0	0	0	0	0	0	0	0	0
Hairy Wood-pecker	*Picoides villosus* L.	HAWO	2 (4)	1 (2)	3 (5)	1 (2)	0	0	0	0	**1 (1)**	0	**2 (3)**	0	**1 (1)**	0
Hermit Thrush	*Catharus guttatus* Pallas	HETH	3 (6)	2 (4)	4 (7)	2 (3)	2 (2)	5 (7)	2 (3)	3 (7)	6 (8)	4 (3)	**2 (3)**	0	2 (2)	1 (1)
Kirtland's warbler	*Dendroica kirtlandii* Baird	KIWA	0	0	0	0	0	0	0	0	0	9 (8)	0	3 (3)	0	6 (5)
Least Flycatcher	*Epidonax minimus* Baird	LEFL	0	1 (2)	0	0	0	0	0	0	0	0	0	0	0	0
Lincoln's Sparrow	*Melospiza lincolnii* Audubon	LISP	0	0	0	1 (2)	0	0	0	0	0	6 (5)	1 (1)	4 (4)	0	1 (1)
Mourning Dove	*Zenaida macroura* L.	MODO	0	0	0	2 (3)	**2 (2)**	0	2 (3)	1 (2)	6 (8)	2 (2)	2 (3)	1 (1)	**3 (3)**	0
Mourning Warbler	*Oporornis Philadelphia* Wilson	MOWA	0	0	0	0	0	1 (1)	0	0	0	0	0	0	0	0
Nashville Warbler	*Vermivora ruficapilla* Wilson	NAWA	3 (6)	1 (2)	3 (5)	5 (8)	5 (5)	6 (8)	4 (7)	5 (11)	7 (9)	11 (10)	4 (5)	2 (2)	9 (10)	7 (5)
Northern Flicker	*Colaptes auratus* L.	NOFL	1 (2)	3 (6)	0	0	**5 (5)**	0	2 (3)	2 (4)	5 (6)	7 (6)	4 (5)	5 (5)	4 (4)	6 (5)
Ovenbird	*Seiurus aurocapilla* L.	OVEN	**5 (9)**	0	4 (7)	2 (3)	6 (6)	5 (7)	5 (9)	2 (4)	**1 (1)**	0	**2 (3)**	0	**3 (3)**	0
Pileated Wood-pecker	*Dryocopus pileatus* L.	PIWO	0	0	**1 (2)**	0	4 (4)	2 (3)	**2 (3)**	0	0	0	0	0	**1 (1)**	0
Pine Warbler	*Dendroica pinus* Wilson	PIWA	0	5 (11)	2 (3)	1 (2)	7 (7)	6 (8)	3 (5)	1 (2)	**3 (4)**	0	**2 (3)**	0	**1 (1)**	0
Red-breasted Nuthatch	*Sitta Canadensis* L.	RBNU	4 (7)	2 (4)	7 (12)	1 (2)	4 (4)	5 (7)	**3 (5)**	0	**5 (6)**	0	4 (5)	2 (2)	**3 (3)**	0
Red-eyed Vireo	*Vireo olivaceus* L.	REVI	0	0	0	0	**2 (2)**	0	1 (2)	1 (2)	0	0	0	0	**1 (1)**	0
Red-headed Wood-pecker	*Melanerpes erythrocephalus* L.	RHWO	0	0	0	0	0	0	0	0	0	0	0	1 (1)	0	0
Red-tailed Hawk	*Buteo jamaicensis* Gmelin	RTHA	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1)
Red-winged Blackbird	*Agelaius phoeniceus* L.	RWBL	0	0	0	0	0	0	0	0	0	0	1 (1)	1 (1)	**1 (1)**	0
Rose-breasted Grosbeak	*Pheucticus ludovicianus* L.	RBGR	0	0	0	0	**1 (1)**	0	**2 (3)**	0	**2 (3)**	0	0	0	0	0
Ruffed Grouse	*Bonasa umbellus* L.	RUGR	0	0	0	0	0	0	1 (2)	1 (2)	0	0	0	0	0	0
Slate Colored Junco	*Junco hyemalis* L.	SCJU	0	2 (4)	8 (14)	2 (3)	0	0	0	0	**2 (3)**	0	**1 (1)**	0	0	0
Scarlet Tanager	*Piranga olivacea* Gmelin	SCTA	0	0	0	0	0	0	2 (3)	1 (2)	0	0	0	0	0	0

(*continued on next page*)

Appendix A (*continued*)

Species	Binomial	Species code	> 40 years old				30–40 years old				4–12 years old					
			Damon Fire		St. Helen		Leota		Mack Lake		No Pablo		Hughes Lake		Muskrat Trail	
			S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
Song Sparrow	*Melospiza melodia* Wilson	SOSP	0	0	0	3 (5)	0	1 (1)	0	0	1 (1)	6 (5)	0	1 (1)	0	8 (6)
Tree Swallow	*Tachycineta bicolor* Vieillot	TRES	0	0	0	0	0	0	0	0	0	0	0	2 (2)	0	1 (1)
Vesper Sparrow	*Pooecetes gramineus* Gmelin	VESP	0	0	0	3 (5)	0	0	0	0	3 (4)	9 (8)	3 (4)	9 (9)	0	10 (8)
White-breasted Nuthatch	*Sitta carolinensis* Latham	WBNU	**4 (7)**	0	0	0	4 (4)	2 (23)	6 (10)	1 (2)	1 (1)	1 (1)	**6 (8)**	0	**4 (4)**	0
Wild Turkey	*Meleagris gallopavo* L.	WITU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow Warbler	*Dendroica petechial* L.	YEWA	1 (2)	2 (4)	0	0	**1 (1)**	0	0	0	0	0	0	0	0	0
Yellow-rumped Warbler	*Dendroica coronate* L.	YRWA	4 (7)	1 (2)	0	1 (2)	0	0	1 (2)	1 (2)	4 (5)	3 (3)	**2 (3)**	0	1 (1)	1 (1)
Total			54	47	59	62	100	76	58	45	79	116	76	104	95	131

Appendix B

Non-breeding season (May–August) bird abundance (percent community composition) detected in stringers (S) and non-stringers (NS) at all seven sampling sites in northern Lower Michigan documented in 2012 and 2013. Species are listed alphabetically by common name. Species detected only in the stringers at each site are in bold.

Species	Binomial	Species code	Muskrat Trail		Leota	
			Stringer	Non-stringer	Stringer	Non-stringer
American Crow	*Corvus brachyrhynchos* Brehm	AMCR	1 (3)	1 (7)	0	1 (5)
American Robin	*Turdus migratorius* L.	AMRO	0	0	0	1 (5)
Black-capped Chickadee	*Poecile atricapillus* L.	BCCH	6 (21)	3 (21)	6 (20)	6 (27)
Blue Jay	*Cyanocitta cristata* L.	BLJA	4 (14)	2 (14)	1 (3)	1 (5)
Brown Creeper	*Certhia Americana* Bonaparte	BRCR	0	0	**1 (3)**	0
Brown-headed Cowbird	*Molothrus ater* Boddaert	BHCO	0	1 (7)	0	0
Common Grackle	*Quiscalus quiscula* L.	COGR	**2 (7)**	0	0	0
Common Raven	*Corvus corax* L.	CORA	**1 (3)**	0	**1 (3)**	0
Common Redpoll	*Carduelis flammea* L.	CORE	4 (14)	4 (29)	3 (10)	3 (14)
Downy Woodpecker	*Picoides pubescens* L.	DOWO	0	0	1 (3)	1 (5)
Eastern Bluebird	*ialia sialis* L.	EABL	1 (3)	2 (14)	0	0
Hairy Woodpecker	*Picoides villosus* L.	HAWO	0	0	**1 (3)**	0
Northern Flicker	*Colaptes auratus* L.	NOFL	0	1 (7)	1 (3)	2 (9)
Pine Siskin	*Carduelis pinus* Wilson	PISI	**2 (7)**	0	**1 (3)**	0
Pine Warbler	*Dendroica pinus* Wilson	PIWA	0	0	**1 (3)**	0
Pileated Woodpecker	*Dryocopus pileatus* L.	PIWO	**1 (3)**	0	1 (3)	2 (9)
Red-breasted Nuthatch	*Sitta Canadensis* L.	RBNU	**2 (7)**	0	3 (10)	2 (9)
Red-tailed Hawk	*Buteo jamaicensis* Gmelin	RTHA	0	0	**1 (3)**	0
Ruffed Grouse	*Bonasa umbellus* L.	RUGR	**1 (3)**	0	0	0
Slate Colored Junco	*Junco hyemalis* L.	SCJU	0	0	**3 (10)**	0
Song Sparrow	*Melospiza melodia* Wilson	SOSP	**1 (3)**	0	1 (3)	1 (5)
White-breasted Nuthatch	*Sitta carolinensis* Latham	WBNU	**3 (10)**	0	4 (13)	2 (9)
Total			29	14	30	22

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