INFLUENCE OF WILDFIRE-INDUCED RESIDUAL STAND STRUCTURE ON BIRD DIVERSITY PATTERNS IN JACK PINE ECOSYSTEMS OF NORTHERN LOWER MICHIGAN

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This is dedicated to my husband Riaan.
Your support, sacrifice, and love made
the completion of this project possible.

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ABSTRACT

INFLUENCE OF WILDFIRE-INDUCED RESIDUAL STAND STRUCTURE ON BIRD DIVERSITY PATTERNS IN JACK PINE ECOSYSTEMS OF NORTHERN LOWER MICHIGAN

by Bridget L. Cullinane Anthony

Prior to European settlement, stand replacing fires were part of the historic natural disturbance regime that maintained 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 most jack pine habitat is managed plantation style to create breeding habitat for the Endangered Kirtland's warbler (*Setophaga kirtlandii Baird*). Jack pine plantation management has had the inadvertent consequence of creating a stand structure significantly different than that created naturally by wildfire, partly because biological legacies are not maintained. Stringers, or patches of biological legacies, are a unique feature left behind after wildfires and are not accounted for in plantation management. In this study, we examined the biodiversity value of stringers from an avian perspective by comparing bird assemblages found within stringers and the surrounding non-stringers. Our objective was to answer two research questions: 1) do stringers have unique bird communities relative to the surrounding habitat? ; and 2) how much of the variation in bird communities can be explained by variation in vegetation structure and composition and time since disturbance?

We conducted breeding season point counts across seven sample sites and non-breeding season point counts across two sites in northern Lower Michigan. We also used acoustic recorders at two sites to determine the effectiveness of point counts and recorders in developing species lists. We used abundance data to run multi-response permutation procedures and non-metric multidimensional scaling to compare bird species found within stringers and non-stringers. We documented 57 bird species across 50 point count stations during the breeding season and 22 species across 16 point count station during the non-breeding season. Differences in bird assemblages between stringers and non-stringers during the breeding season were found in recently disturbed sites (T=-10.11, A=0.07, $p=<0.0001$) but not in the intermediate (T=-0.5, A=0.006, $p=0.29$) or mature (T=-0.7, A=0.01, $p=0.23$) sites. Non-breeding season results showed a difference between stringers and non-stringers at Muskrat Trail (T=-2.15, A=0.09, $p=0.024$) but not at Leota (T=0.10, A= -0.005, $p=0.48$). Differences in vegetation structure between stringers and non-stringers at the recently disturbed sites appear to be driving the differences in bird assemblages found within stringers and non-stringers. In the intermediate and mature sites, both the vegetation structure and the bird communities were similar in the stringer and non-stringer habitats suggesting that the convergence in structure over time drives similar responses in bird communities. Acoustic recorders detected more species than point counts during both the breeding and non-breeding seasons, but only at Muskrat Trail. We believe our results provide support for the importance of stringers for bird communities, especially in recently disturbed areas. Patches of biological legacies should be included in jack pine management silviculture plans to promote emulation of natural process and avian biodiversity.

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INFLUENCE OF WILDFIRE-INDUCED RESIDUAL STAND STRUCTURE ON BIRD DIVERSITY PATTERNS IN JACK PINE ECOSYSTEMS OF NORTHERN LOWER MICHIGAN

INTRODUCTION

Across the xeric, outwash plains of northern Lower Michigan (NLM) jack pine (*Pinus banksiana* Lamb.) ecosystems predominate (Whitney 1986, Whitney 1987). Prior to European settlement, stand replacing crown fires maintained these ecosystems (Whitney 1986, 1987, Frelich 2002). Currently, the occurrence and extent of wildfire is much reduced relative to the past and most jack pine regeneration across the landscapes of NLM is through planting seedlings and other artificial regeneration techniques.

Many jack pine-dominated ecosystems of NLM are managed as breeding habitat for the Endangered Kirtland's warbler (KW, *Setophaga kirtlandii* Baird). Although this songbird evolved to utilize young (5-20 year) stands of fire-regenerated jack pine, mid-20th century fire suppression reduced the availability of KW habitat until 201 males were counted in the 1971 census 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 KW breeding habitat, state and federal land managers currently harvest mature jack pine and regenerate these sites by planting jack pine seedlings in an opposing wave pattern. The result is a uniform arrangement of densely planted jack pines separated by small openings in which KW forage (Probst 1986, Kepler et al. 1996). This management and the occurrence of two large wildfires (the Bald Hill Fire in 1975 and the Mack Lake Fire in 1980), produced an increase in the amount of young jack pine habitat and the number of singing male KWs increased substantially in the later part of the

20th century (Probst et al. 2003). By 2001, the population was at or above the established recovery objectives of 1,000 singing males and breeding was documented in places other than NLM (Probst et al. 2003). Nearly 95% of the KW breeding population is now found in plantations (Probst et al. 2003).

Natural disturbances, like wildfire, leave behind organisms, structures, and other patterns of the previous ecosystem. These “biological legacies” add structural, compositional, and functional heterogeneity within the disturbance perimeter and may act as refugia for many species by providing critical habitat and food sources not available in disturbed areas (Franklin et al. 2000). In NLM, jack pine plantation management for KW (although instrumental in the population increase of the species) has had the inadvertent consequence of creating a stand structure significantly different than that created naturally by wildfire (Spaulding and Rothstein 2009). This is partly because biological legacies (e.g., snags, live standing trees from the previous stand, and coarse woody debris) are usually not maintained in these artificial systems, or are not found at the density that would be found in more natural systems (Spaulding and Rothstein 2009, Corace and Goebel 2010). Specifically, stringers (Kashian et al. 2012) or patches of biological legacies, 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). While the value of stringers has not been studied in the broader context of biodiversity maintenance in jack pine forests 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 may provide important structural diversity in an otherwise homogeneous area of jack pine plantations 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 biological legacies are important for bird communities in forested landscapes, including aspen clearcuts in Minnesota (Merrill et al. 1998), the Cascades region of the Pacific Northwest (Hansen et al. 1995), red pine (*Pinus resinosa*) forests in Minnesota (Atwell et al. 2008), jack pine forests in Ontario, Canada (Venier and Pearce 2005), and the boreal forest of western North America (Schieck and Song 2006). These studies provide support for the idea that stringers play an important role in the overall jack pine landscape by providing increased vertical structure and additional habitat possibilities for birds in an area that has undergone disturbance.

While it is understood that jack pine plantations are necessary for the conservation of the KW population, efforts are underway to manage jack pine ecosystems within the limits of the natural disturbance patterns and processes (Corace et al. 2009, 2010; Corace and Goebel 2010). Such an approach is in step with the general concepts of ecological forestry as proposed by Seymour and Hunter (1999) and Franklin et al. (2007). With the KW 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, including the multi-taxa value. 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 KW (Corace et al. 2010).

The overall goal 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 plantation habitat in NLM. Specifically, we investigated the following research questions: 1) Do stringers have unique bird communities relative to the surrounding habitat and is there seasonal variation?; and 2) How much of the variation in bird communities can be explained by variation in vegetation structure and composition and time since disturbance? We hypothesize that stringers will increase overall avian species diversity in these habitats, especially in recently disturbed sites.

METHODS

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 (Albert 1995).

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 by in 2008 and replanted with jack pine seedlings in 2009. The Leota site was burned by a wildfire in 1977 and left stringers from a mature jack pine-red pine stand. Field work was also conducted during the breeding season at five additional wildfire sites. These sites formed part of the sample 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, represented independent sampling sites, and because they vary in time since the areas burned. At each of the seven sites we sampled birds and vegetation 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), Leota and Mack Lake as "intermediate age" sites (>30 years post disturbance), and No Pablo, Hughes Lake, and Muskrat Trail as "recently disturbed" sites (4-12 years post disturbance). These labels did not refer to the actual age of the canopy in the stringer, but the time since last major disturbance in the area (fire or timber harvest). Corace et al. (2010) examined bird communities associated with different age classes of jack pine plantations managed for the KW. Their results show that recent clear cuts, 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, Kashian et al. (2012) noted the high amount of variability in the vegetation structure and composition between stringers of different sites, lending further support to our categorization of sites. The stringers at Damon and St. Helen are primarily composed of jack pine with some red pine at Damon. Mack Lake and Leota stringers have a high amount of red pine, jack pine and deciduous species. Hughes Lake, No Pablo, and Muskrat Trail stringers are largely composed of jack pine with a small amount of red pine and deciduous species

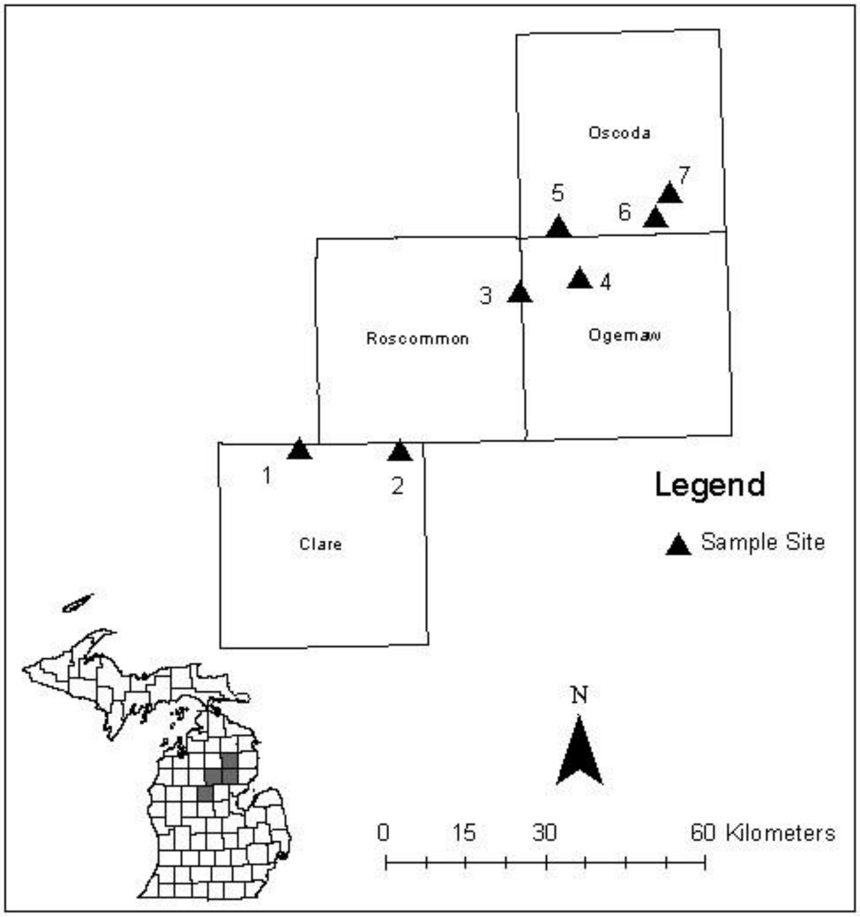

Figure 1: The highlighted areas in the map show the location of the counties of northern Lower Michigan on the right. Sample locations are marked with triangles: 1=Muskrat Trail, 2=Leota, 3=St. Helen, 4=Damon, 5=Hughes Lake, 6=No Pablo, 7=Mack Lake. Bird communities at Muskrat Trail and Leota were sampled during the non-breeding and breeding seasons of 2012 and 2013. Bird communities at St. Helen, Damon, Hughes Lake, No Pablo, and Mack Lake were sampled during the breeding seasons of 2012 and 2013.

Table 1: Locations, disturbance size, event year, and type of disturbance for the seven sampling locations in northern Lower Michigan. Size was determined by Kashian et al. (2012) and through a review of air photos and management documents.

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

BIRD SAMPLING WITH POINT COUNTS

To determine whether stringers have unique bird communities relative to the surrounding jack pine forest or plantation and to examine whether seasonal variation exists in bird communities between these broad habitat types, 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. Fixed-radius (50m) point counts were conducted during both the non-breeding (December-March) and breeding seasons (May-August) of each year at Muskrat Trail and Leota, and during the breeding season only at Damon, St. Helen, Mack Lake, No Pablo, and Hughes Lake 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 meters 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 habitats and to better ascertain bird species affinity for stringer and non-stringer habitats. While monitoring guidelines for most passerines suggest 250 m as the minimum distance between sampling sites, our points were placed a minimum of 200 meters apart, due to the size of stringers and sample locations (Ralph et al 1993). The Muskrat Trail, Leota, No Pablo, and Hughes Lake sites each had eight points, four within the stringer and four points in the surrounding habitat. Damon, St. Helen, and Mack Lake sites each had six points, three within the stringer and three within the surrounding habitat. Point counts started no more than 10 minutes before sunrise and continued for no longer than four hours; counts occurred for five minutes 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. A minimum of one week was observed between visits. We did not conduct point counts during precipitation, when winds exceeded 17 kph, or when temperatures were below -6.7 degrees Celsius. A new route was followed for consecutive count dates to minimize bias caused by the time of day point counts were conducted. 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 habitat 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. Approximately three weeks were observed between each 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 assumed to be the same due to the same habitats being sampled. Also, the high number of visits to each site allowed us to detect the full range of species that use the sample sites.

VEGETATION SAMPLING

To examine whether the variation in bird communities was influenced by vegetation structure, we evaluated vegetation structure and composition at all seven sites. Methods were a simplified version of protocols established by the U.S. Forest Service's Forest Inventory and Analysis Program. Vegetation sampling was conducted once during the 2012 breeding season and because no treatments occurred on any sites we assumed few, if any, vegetation changes occurred thereafter. A fixed-radius, 0.01-ha circular plot was established with the bird point count station as the center of the plot (radius 5.5 m). Because of the typical uniformity produced in the development of even-aged jack pine forests or plantations, this plot size was deemed large enough to characterize the vegetation for the associated 50 m bird point count area. Within the plot, the average percent canopy coverage was estimated using four readings (one from each cardinal direction) from a spherical densiometer. The number and diameter of all trees > 10 cm and snags > 10 cm at breast height (dbh) was recorded by species, and the number and species of all other stems (< 10 cm) were all measured. From the center of the plot, three sub-plot transects (set at 0 degrees, 135 degrees, and 225 degrees) 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).

Table 2: Vegetation variables used to assess vegetation structure within each 0.01 ha plot in seven study sites of northern Lower Michigan.

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 dead 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 <10cm and >0.76 m tall

DATA ANALYSIS

STUDY SITES

Data from the non-breeding season was analyzed with data points pooled as stringer or non-stringer at Muskrat Trail and Leota. Each site was also analyzed separately to look at the influence the age of the developing forest found in non-stringers may have on bird species. Breeding season data was 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 habitat selection by birds. Pooled sites included Damon and St Helen (both burned 45 years ago), Leota and Mack Lake (burned 32 and 35 years ago, respectively), and No Pablo, Hughes Lake, and Muskrat Trail (disturbed within the last 4-12 years). Muskrat Trail, having the only anthropogenically produced stringer was also compared to Hughes Lake, which is similar in age since disturbance and natural, to determine if bird assemblages are different between anthropogenically produced stringers and naturally created stringers.

POINT COUNT

Observations from multiple point count surveys were pooled by point count station by selecting the census visit with the highest maximum abundance for each individual species. The sample of points within a stringer within a site, or group of sites, were pooled together and compared to the pooled non-stringer sample points, making the assumption that variation in vegetation between the individual stringers within a site was negligible. Abundance, species richness, and Shannon Diversity (H’) were used to characterize the bird communities for each of the seven sample sites for stringers and non-stringers. We tested if bird composition between stringers and non-stringers differed using the abundance data and Multi-response Permutation Procedures (MRPP). MRPP does not require distributional assumptions (multivariate normality and homogeneity of variances) making it a powerful test for ecological community data (McCune and Grace 2002). Blossom statistical software (Cade et al. 2001) was used to run the MRPP using a natural weighting factor and Euclidean distances. MRPP results are negatively influenced by rare species, so species seen at ≤ 2 points within pooled data points were removed from the analysis. To determine the importance of habitat 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). This package computes the indicator value for each species using the methods of Dufrene and Legendre (1997). Randomization tests were used to determine statistical significance of the indicator value using 1000 permutations.

VEGETATION

To characterize potential habitat differences we compared vegetation composition and structure of stringers and non-stringers, with sites pooled as described above. 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. The Mann-Whitney rank sum test is a non-parametric test that is suitable for data that is not normally distributed, while a Student’s t-test is best for normal data. Data transformations were not conducted due to the large number of zeros in our data.

BIRD COMMUNITIES AND VEGETATION

Non-metric Multidimensional Scaling (NMDS) was used to evaluate the relationship of bird community composition with vegetation structure. The complete set of bird abundance data, including rare species, was used for this analysis. NMDS 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). Bray-Curtis is considered the best measure for community data (McCune and Grace 2002). Due to our 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.

RESULTS

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 census visits, a mean abundance (±1SD) of 74.4 (±18.4) individual birds were documented in stringers while a mean abundance of 99 (±37.7) individual birds were documented in non-stringers (Table 3). Conversely, species richness and Shannon's Diversity Indices were greater in the stringers compared to the non-stringers. 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. There were fewer species specific to 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 both had 9 species found only in the stringers (Appendix A).

Breeding season MRPP results indicate no difference in bird composition found in stringers and non-stringers for the mature sites (T=-0.7, A=0.01, p=0.23) and the intermediate aged sites (T=-0.5, A=0.006, p=0.29). The results for the recently disturbed sites show there is a difference in bird composition between stringers and non-stringers (T=-10.11, A=0.07, p=<0.0001). When the stringers of Muskrat Trail were compared to the stringers of Hughes Lake, there was no difference seen in bird composition (T=1.4, A=-0.03, p=0.94). The differences in bird composition between non-stringers of the two sites were significant (T=-1.6, A=0.052, p=0.07).

Table 3: Mean (± 1SD) values describing breeding season (May – August) bird community measures of stringers and non-stringers at all seven study sites in northern Lower Michigan.

	Stringers	**Non-stringers**
Species Abundance (# of individuals)		
Damon Fire	54	47
St Helen	59	62
Leota	100	76
Mack Lake	58	45
No Pablo	79	116
Hughes Lake	76	104
Muskrat Trail	95	131
Mean	74.4 (±18.4)	99 (±37.7)
Species Richness		
Damon Fire	19	18
St Helen	22	26
Leota	26	20
Mack Lake	25	19
No Pablo	27	23
Hughes Lake	24	24
Muskrat Trail	30	24
Mean	24.7 (3.5)	22 (3)

Shannon Diversity (H')		
Damon Fire	2.7	2.7
St Helen	2.8	2.9
Leota	3	2.8
Mack Lake	3.1	2.7
No Pablo	3	2.9
Hughes Lake	3	2.9
Muskrat Trail	3.1	2.9
Mean	3 (0.2)	2.8 (0.1)

We documented 22 bird species across 16 point count stations during the non-breeding season at Muskrat Trail and Leota (Appendix B). When individuals of all species were pooled across plots in stringer and non-stringer habitat across all non-breeding season census visits, a mean abundance (±1SD) of 29.5 (±0.7) birds were documented in stringers, while 18 (±5.7) birds were documented in non-stringers (Table 4). Species richness and Shannon's Diversity Index (H') were also greater in the stringers than in the non-stingers (Table 4). Non-breeding season MRPP results for Muskrat Trail and Leota combined show there is a difference in bird assemblages between stringers and non-stringers (T=-2.12, A=0.03, *p*=0.03). The two sites were then run independently to determine if time since disturbance had an influence on bird assemblages during the non-breeding season. The results for Muskrat Trail show there is a difference between stingers and non-stringers (T=-2.15, A=0.09, *p*=0.024), while the results for Leota show there is no significant difference between the two habitat types (T=0.10, A= -0.005, *p*=0.48). At Muskrat Trail, eight bird species were found in the stringer that were not found in the non-stringer while seven species were found within the stringer that were not found in the non-stringer at Leota (Appendix B).

Table 4: Non-breeding season (December-March) bird community measures of stringers and non-stringers at Muskrat Trail and Leota.

	Stringer	Non-stringer
Species Abundance (# of individuals)		
Muskrat Trail	29	14
Leota	30	22
Mean (+/- 1SD)	29.5 (±0.7)	18 (±5.7)
Species Richness		
Muskrat Trail	13	7
Leota	16	11
Mean (+/- 1SD)	14.5 (±2.1)	9 (±2.8)
Shannon Diversity (H')		
Muskrat Trail	2.4	1.8
Leota	2.5	2.2
Mean (+/- 1SD)	2.5 (±0.1)	2 (±0.3)

VEGETATION

Mature sites had similar vegetation characteristics in the stringers and non-stringers (Table 5). There was a difference is in the size (dbh) of canopy trees with larger trees in the stringers (p=0.006), the number (mean ±1SD) of red pine (100 (±200) in stringer compared to 0 in non-stringer) and deciduous species (16.7 (±40.8) compared to 0) in the canopy, and the number of red pine in the understory (66.7 (±103.3) compared to 0). For intermediate aged sites differences between stringers and non-stringers were primarily related to the species composition of the canopy and understory. Non-stringers had more jack pine in the canopy (p=0.02) and understory (p=0.005), and stringers had red pine (p=0.04) in the canopy (285.7 (±401.8) compared to 0) and understory (p=0.04) and deciduous species (p=0.004) in the understory. The primary difference between stringers and non-stringers at the recently disturbed sites were found in the canopy, since non-stringers lack a canopy and associated vertical structure. Non-stringers also have more coarse woody debris (p=0.007) and jack pine in the understory (p=0.07). The number of jack pine, red pine, deciduous species, snags in the canopy, canopy dbh, and snag dbh at the recently disturbed sites have a value of zero for the non-stringer subset. While these data cannot be tested for statistical significance, we can assume there is a difference between stringer and non-stringers for these variables.

Table 5: Mean vegetation values (±1SD) for all seven sites for comparing bird patterns seen during the breeding season (May-August). Significant (P≤0.10) differences are in bold (Mann-Whitney test or Student's t-test).

	Recently Disturbed Sites		Intermediate Aged Sites		Mature Sites	
	Stringer	Non-stringer	Stringer	Non-stringer	Stringer	Non-stringer
Percent Closed Canopy (%)	**0.7 (0.1)**	**0 (0)**	0.7 (0.2)	0.7 (0.1)	0.7 (0.1)	0.5 (0.3)
# Canopy Jack Pine (trees/ha)	**475 (411.5)**	**0 (0)**	**228.6 (403)**	**985.7 (343.6)**	566.7 (432.0)	700 (438.2)
# Canopy Red Pine (trees/ha)	**50 (90.5)**	**0 (0)**	**285.7 (401.8)**	**0 (0)**	**100 (200)**	**0 (0)**
# Canopy Deciduous (trees/ha)	**58.3 (173)**	**0 (0)**	71.4 (95.1)	57.1 (78.7)	**16.7 (40.8)**	**0 (0)**
# Canopy Snags (snags/ha)	**50 (100)**	**0 (0)**	100 (115.5)	71.4 (149.6)	150 (122.5)	100 (89.4)
Canopy dbh (cm)	**16.1 (7.5)**	**0 (0)**	**23.8 (7.5)**	**12.7 (2.1)**	**19.2 (7.7)**	**14.6 (3.1)**
Snag dbh (cm)	**14.7 (4.5)**	**0 (0)**	**16.8 (4.8)**	**12.5 (1.8)**	18.8 (7.1)	13.2 (3.7)
# Jack pine Understory (trees/ha)	**753.3 (1022.9)**	**1550 (1399)**	**171.4 (314.7)**	**1300 (852.4)**	400 (328.6)	416.7 (487.5)
# Red Pine Understory (trees/ha)	50 (173.2)	0 (0)	**214.3 (267.3)**	**14.3 (37.8)**	**66.7 (103.3)**	**0 (0)**
# Deciduous Understory (trees/ha)	1216.7 (1506.2)	916.7 (1166.1)	**2214.3 (1002.4)**	**600 (522.8)**	533.3 (784)	183.3 (231.7)
Number CWD pieces (logs/ha)	**133.3 (137.1)**	**558.3 (594.6)**	314.3 (106.9)	214.3 (167.6)	150 (137.8)	66.7 (81.6)

We compared the vegetation characteristics of Muskrat Trail and Leota separately for the non-breeding season. There is a high amount of variation when stringers and non-stringers of Muskrat Trail are compared. Stringers at Muskrat Trail have a high amount of jack pine, red pine, and deciduous species in the canopy and understory, while non-stringers have more jack pine in the understory (p=0.03) and lack a canopy and associated vegetation structure and composition (Table 6). At Leota, there is a difference in the dbh of canopy trees (p=0.0) and deciduous species in the understory (p=0.006), with larger trees and more deciduous species being found in the stringer. There is also a difference in the amount of jack pine in the understory, with more being found in the non-stringer (p=0.04).

Table 6: Mean vegetation values (±1SD) for Leota and Muskrat Trail for comparing bird patterns seen during the non-breeding season (December-March). Significant differences are in bold.

	Muskrat Trail		Leota	
	Stringer	Non-stringer	Stringer	Non-stringer
Percent Closed Canopy (%)	**0.6 (0.1)**	**0 (0)**	0.6 (0.1)	0.6 (0.1)
# Canopy Jack Pine (trees/ha)	**400 (294.4)**	**0 (0)**	400 (483)	1050 (465.5)
# Canopy Red Pine (trees/ha)	**50 (100)**	**0 (0)**	**200 (400)**	**0 (0)**
# Canopy Deciduous (trees/ha)	**25 (50)**	**0 (0)**	25 (50)	75 (95.7)
# Canopy Snags (snags/ha)	**25 (50)**	**0 (0)**	**75 (95.7)**	**0 (0)**
Canopy dbh (cm)	**18.5 (7.3)**	**0 (0)**	**21.9 (6.7)**	**12.7 (1.9)**
Snag dbh (cm)	**21.1 (0)**	**0 (0)**	**1.6 (4.7)**	**0 (0)**
# Jack Pine Understory (trees/ha)	**100 (200)**	**2725 (788.9)**	**100 (200)**	**1125 (670.2)**
# Red Pine Understory (trees/ha)	**150 (300)**	**0 (0)**	325 (320.2)	25 (50)
# Deciduous Understory (trees/ha)	1225 (1374.5)	475 (250)	**2500 (496.7)**	**675 (623.8)**
Number CWD pieces (logs/ha)	250 (173.2)	225 (95.7)	325 (125.8)	325 (95.7)

BIRD COMMUNITIES AND VEGETATION

We observed an overlap in the bird species seen in the stringers and non-stringers at the mature sites during the breeding season, adding further support to the MRPP (Figure 2; convergent solutions found, 2 dimensions, stress= 14%). There were two significant indicators of stringer habitat, white-breasted nuthatch (*Sitta carolinensis* Latham) and ovenbird (*Seiurus aurocapilla* L.). The white-breasted nuthatch had an indicator value of 100 (p=0), indicating it was exclusive to stringers and was documented at every stringer point of these two sites. The indicator value of the ovenbird was 81.8 (p=0.03).

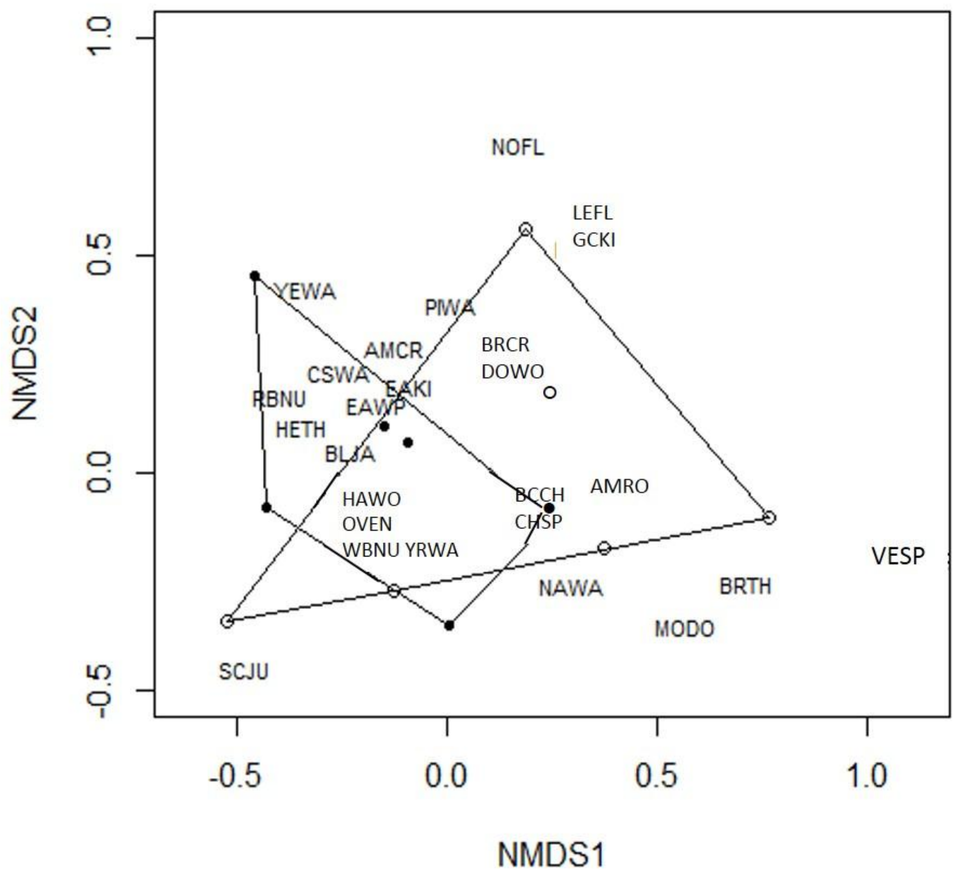

Figure 2: NMDS ordination biplot of breeding season abundance data from the mature sites (e.g., Damon and St. Helen). Bird species are represented as four-letter codes (see Appendix A). Closed circles are stringers. Open circles are non-stringers. There is an overlap in species composition at these sites. The polygon is the convex hull connecting the vertices of the points made by the two habitat types.

For the intermediate aged sites, there is an overlap in the bird species seen in the stringers and non-stringers, adding further support to the MRPP results (Figure 3; convergent solutions found, 2 dimensions, stress= 16%). The white breasted nuthatch was the only significant indictor of stringer habitat with an indicator value of 66 (p=0.07).

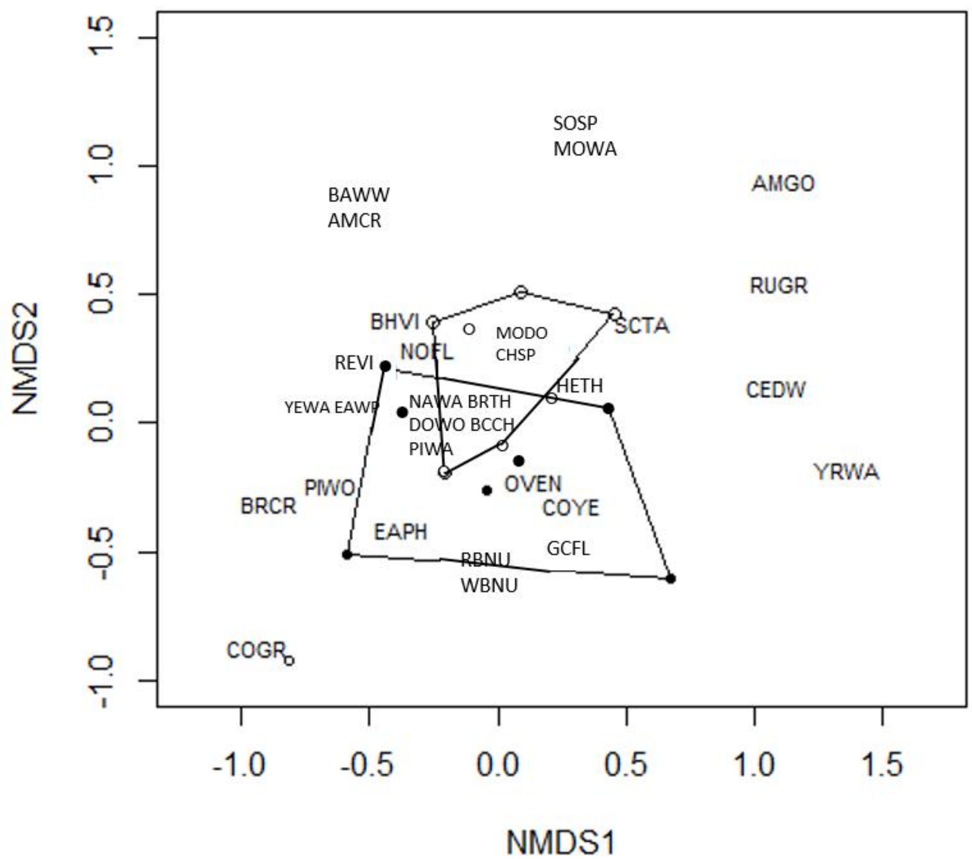

Figure 3: NMDS ordination biplot of breeding season abundance data from the intermediate age sites (e.g., Leota and Mack Lake). Bird species are represented as four-letter codes (See Appendix A). Closed circles are stringers. Open circles are non-stringers. There is an overlap in species composition at these sites. The polygon is the convex hull connecting the vertices of the points made by the two habitat types.

The MRPP results are supported by the NMDS results for the breeding season data from the recently disturbed sites (Figure 4; convergent solutions found, 2 dimensions, stress= 14%). NMDS ordination shows that species assemblages found within stringers are distinctly different than species assemblages in non-stringers. There were seven significant indicators of stringer habitat, black-capped chickadee (69, *p*=0.004; *Poecile atricapillus* L.), downy woodpecker (50, *p*=0.019; *Picoides pubescens* L.), white breasted nuthatch (45.8, *p*=0.031), red breasted nuthatch (42.9, *p*=0.047; *Sitta Canadensis* L.), Eastern wood-pewee (41.7, *p*=0.036; *Contopus virens* L.), hairy woodpecker (33.3, *p*=0.096; *Picoides villosus* L.) and pine warbler (33.3, *p*=0.078; *Dendroica pinus* Wilson).

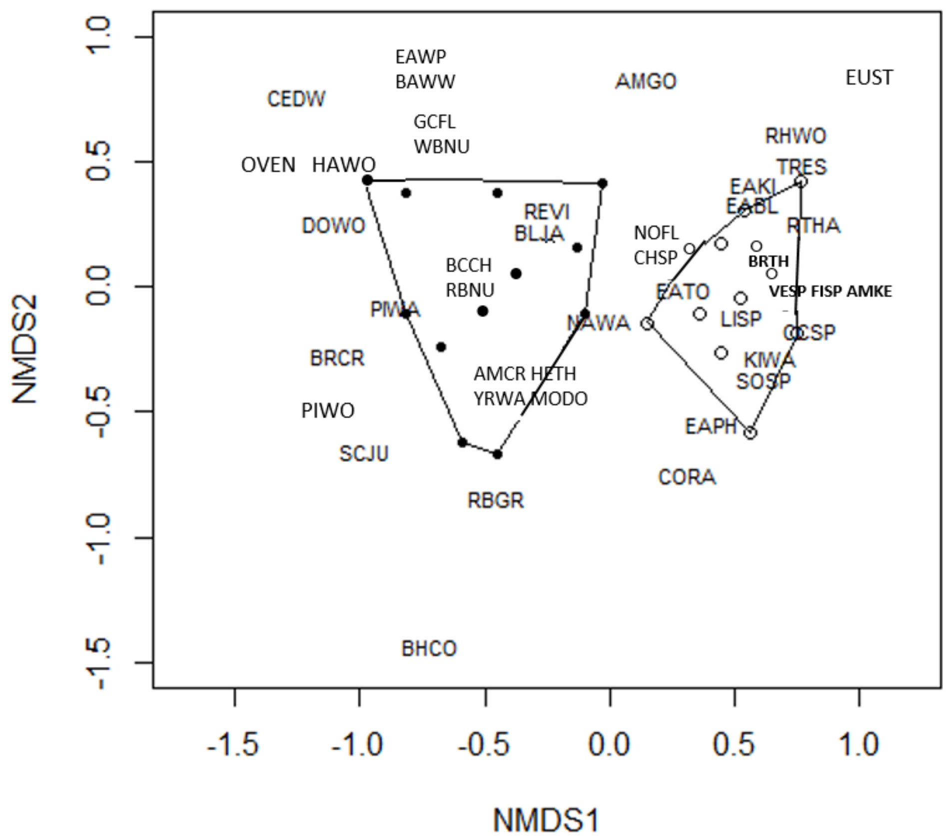

Figure 4: NMDS ordination biplot of breeding season abundance data from the recently disturbed sites (e.g., Hughes Lake, No Pablo, Muskrat Trail). Bird species are represented as four-letter codes (See Appendix A). Closed circles are stringers. Open circles are non-stringers. There is strong separation in species composition at these sites. The polygon is the convex hull connecting the vertices of the points made by the two habitat types.

The 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%) are shown in Figure 5 and Figure 6. NMDS results support the MRPP results and show a strong division between stringer and non-stringers at Muskrat Trail and an overlap in species composition at Leota. Black-capped chickadee was a significant indicator of stringers at Muskrat Trail with an indicator value of 80 (*p*=0.05).

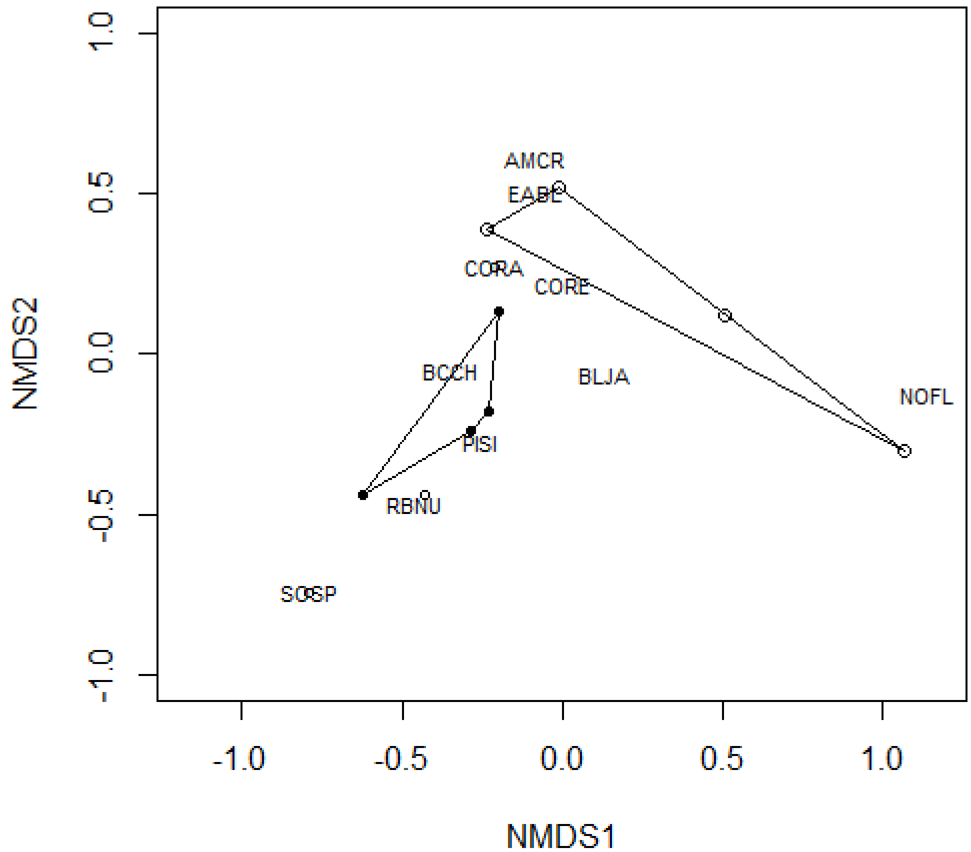

Figure 5: NMDS ordination biplot of Muskrat Trail non-breeding season abundance data. Bird species are represented as four-letter codes (See Appendix B). Closed circles are stringers. Open circles are non-stringers. There is a clear difference between stringers and non-stringers. The polygon is the convex hull connecting the vertices of the points made by the two habitat types.

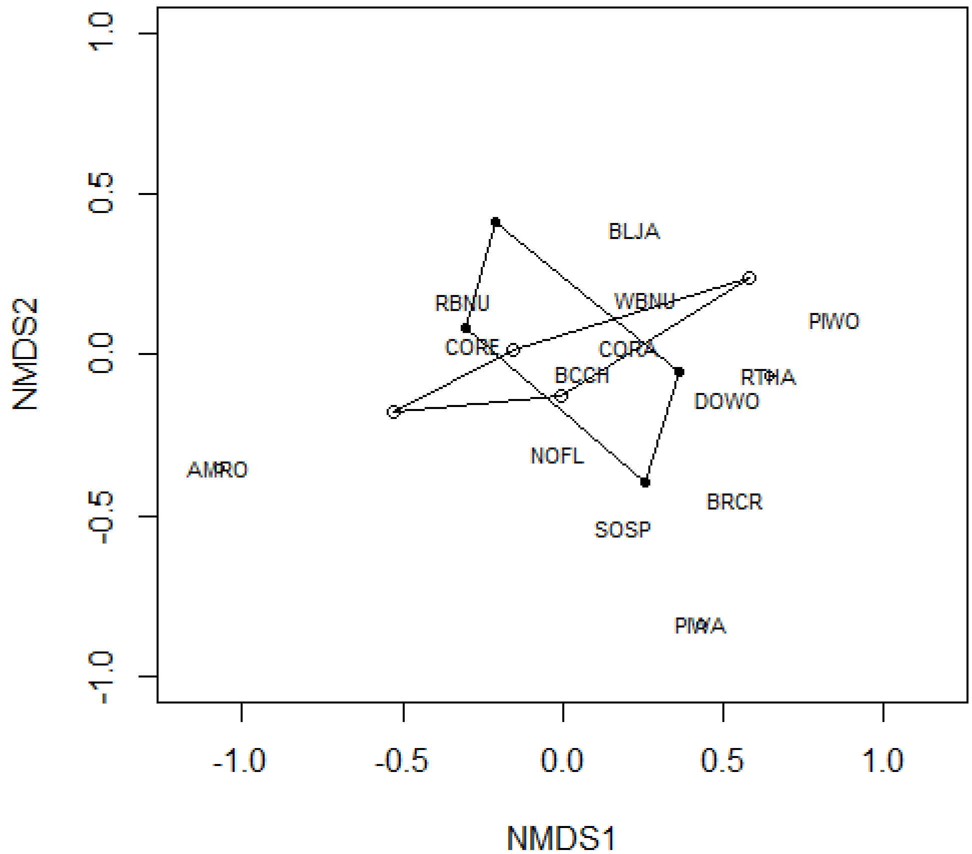

Figure 6: NMDS ordination biplot of Leota non-breeding season abundance data. Bird species are represented as four-letter codes (See Appendix B). Closed circles are stringers. Open circles are non-stringers. There is an overlap in species composition at this site. The polygon is the convex hull connecting the vertices of the points made by the two habitat types.

DISCUSSION

The results show there are differences in bird assemblages in stringers and non-stringers at recently disturbed sites, probably attributable to the lack of canopy and associated vertical structure in the young, developing forests of the non-stringers. The non-stringers at these sites are open stands with high amounts of CWD that favor bird species that forage and nest in open areas, such as field sparrow (*Spizella pusilla* Wilson), Eastern bluebird (*Sialia sialis* L.), and vesper sparrow (*Pooecetes gramineus* Gmelin). In contrast, stringers at the recently disturbed sites provide mature habitat preferred by other bird species. There were seven significant indicator species for stringers at these sites indicating the niche requirements for these seven species are only found in the stringer. In addition, 10 species at No Pablo, 10 at Hughes Lake, and 17 at Muskrat Trail were only found in the stringer habitat. By providing diverse habitat within the same forest perimeter, stringers clearly increase the biodiversity within a burned area.

We detected no differences in bird assemblages found within stringers and non-stringers at the mature and intermediate aged sites for those points sampled during the breeding season, probably because of the convergence of vegetation structure that occurred between the stringers and non-stringers as the recovering forest aged (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. There was not a statistically significant difference in bird assemblages between stringer and non-stringers in these two age classes, nevertheless six species at Damon, two species at St. Helen, and nine species at both Leota and Mack Lake were only found in the stringers. Notably, stringers in both age classes had a more diverse canopy composition, which likely provides more foraging and nesting opportunities than the more compositionally homogeneous non-stringers. This is similar to results of previous studies that found bird species specific to mature age classes (Venier and Pearce 2005, Atwell et al. 2008, Corace et al. 2010). For example, there were two significant indicators of stringer habitat at the mature sites (white-breasted nuthatch and ovenbird) and only one at the intermediate age sites (white-breasted nuthatch). The ovenbird prefers to breed in deciduous or mixed deciduous/coniferous closed canopy forests (Kirk and Hobson 2001), which are lacking in the non-stringers of the mature sites. The white-breasted nuthatch is less specific and will breed in deciduous, mixed deciduous, and coniferous forests but also prefers to be near open areas (Root 1988). The lower density of overstory and understory trees in the stringers at the mature sites more closely resembles open areas compared to the recovering forest around them.

For the non-breeding season, abundance, species richness, and Shannon's diversity were all higher in the stringers at both Muskrat Trail and Leota. The recently disturbed non-stringer habitat of Muskrat Trail appears to be less important for winter residents than the stringers while the stringers provide a greater contribution to the overall composition of bird assemblages. There were eight bird species found in the stringer at Muskrat Trail that were not found in the non-stringer, indicating how important the stringers are to winter residents. This is also evident at Leota, but stringer and non-stringer habitats show more similarities to each other. There is also seasonal variation in bird communities at these sites, with higher abundance and richness during the breeding season.

Understanding the influence of stringers in jack pine forests on bird communities is an important part of developing plans to manage jack pine ecosystems within the limits of the natural disturbance patterns and processes. Jack pine plantations have been essential in the recovery of the KW, however they do not emulate the patterns of natural disturbance. Based on the results of this study, we recommend that land managers in jack pine-dominated landscapes of NLM include stringers in their silviculture plans because stringers play an important role in the overall jack pine landscape. Due to political and social constraints, it is unlikely that natural fire events can be implemented on a large scale in NLM but land managers do have options for including stringers in their management plans. When a wildfire moves through an area, mangers should protect the burned area by preserving the biological legacies found in the burn perimeter. This would leave naturally created stringers, snags, and coarse woody debris in the landscape. Secondly, managers can include leave strips or residual patches of trees during a clearcut, mimicking naturally created stringers. There is a high range of variability in the structure, composition, and size of stringers, giving and mangers flexible options for including them in management pans (Kashian et al. 2012).

Additionally, our research shows bird assemblages found in the anthropogenically created stringers of Muskrat Trail are similar to bird assemblages found in the naturally created stringers at Hughes Lake. Regardless of the disturbance type, the stringer provides important habitat for bird species. Land managers do not need wildfire created stringers to increase bird diversity in jack pine forests, anthropogenically created stringers adequately mimic natural stringers. While these results should be interpreted with caution, due to our small sample size and lack of replication, previous research found that residual trees have a positive influence on the abundance and diversity of bird species. When comparing bird assemblages in post-harvest and post-wildfire habitat, studies have shown the greatest differences between the two habitat types are found immediately post-disturbance. Hobson and Schieck (1999) compared post-wildfire and post-harvest bird assemblages in the boreal forests of Canada. In their study, at one year post-disturbance, there was a difference in bird assemblages but by 14 years post-disturbance the differences were diminished. Stuart-Smith and Schieck (2006) found the differences in bird communities $\geq$ 7 years post disturbance are related to abundance and not composition.

CONCLUSION

Stringers do provide important habitat for bird communities in jack pine dominated landscapes, although the importance of stringers within a particular burned area diminish as the recovering forest ages and its similarity to the stringer increases. Stringers provide the structural complexity for bird species that depend on mature habitat for foraging and nesting within a matrix of younger forests that provide habitat for a different set of bird species, thereby increasing overall bird diversity. Our findings support the idea of including stringers as part of jack pine management. As land management practices shift to more ecologically based multi-species management, it is important to include elements of the natural disturbance regime. Stringers have been shown to persist throughout the entire fire return interval and are part of the natural range of variability making them important part of the jack pine landscape (Kashian et al. 2012). This study provides support for the importance of stringers to bird communities and future work should be conducted to determine the importance of stringers to overall biodiversity.

APPENDICES

Appendix A: Breeding season (May – August) bird abundance (percent composition) found 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 found only in the stringers at each site are in bold.

			Damon Fire		**St Helen**		**Leota**		**Mack Lake**		**No Pablo**		**Hughes Lake**		**Muskrat Trail**	
Species	**Binomial**	**Species Code**	**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)
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	*Pipilo*	EATO	0	0	0	0	0	0	0	0	6	5	1	7	3	10

Towhee	*erythrophthalmus* L.										(8)	(4)	(1)	(7)	(3)	(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*	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)

	Wilson															
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
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 composition) found 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 found only in the stringers at each site are in bold.

			Muskrat Trail		**Leota**	
Species	**Binomial**	**Species Code**	**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	*Sialia 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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CHAPTER II

A COMPARISON OF ACOUSTIC RECORDINGS AND POINT COUNTS AS SURVEY METHODS FOR BIRDS IN JACK PINE ECOSYSTEMS OF NORTHERN LOWER MICHIGAN

INTRODUCTION

Point counts are the most commonly used method to survey bird species (Ralph et al. 1993). Point counts allow an individual to survey a large area in a relatively short amount of time with very little equipment required. However, point counts require specialized site specific training and several observations are required to obtain a large sample size (Hobson et al. 2002). Recently, researchers have started using acoustic recorders to document bird populations (Hasselmayer and Quinn 2000, Hobson et al. 2002) because they are useful when trained observers are not available for field work, when a large sample size is needed, and to create a permanent recording (Celis-Murillo et al. 2009). Acoustic recorders are most commonly used in tropical areas, where there is a high number of bird species and visual detection is limited. A study conducted by Hasselmayer and Quinn (2000) in the tropical forests of Peru found that recordings are an appropriate alternative to point counts in certain situations. Recordings were more useful than point counts in areas with high species richness, including the dawn chorus, because recordings could be listened to repeatedly. However, point counts detected more rare species and more species overall. Celis-Murillo et al. (2012) found no difference in the effectiveness of acoustic reorders and point counts in determining species richness and composition the northern Yucatan Peninsula at the community level. Hobson et al. (2002) compared the two methods in boreal mixed-wood forests of Saskatchewan, Canada and found slightly higher species richness (< 5 species) using acoustic recorders. In general, studies show that acoustic recorders and point counts are comparable when used to determine species richness and composition.

The goal of this research was to compare the effectiveness of acoustic recorders and point counts for estimating species richness and composition in jack pine forests. We compared data collected using both methods to answer the following questions: 1) Do acoustic recordings and point counts detect the same number of species? 2) Do recordings and point counts detect the same species? Our ultimate goal is to assess whether acoustic recorders can be used effectively to document bird diversity, especially when the ability to use other methodologies may be limited by safety concerns, remoteness of study location, or other issues.

METHODS

STUDY SITES

The research areas were two sites within the USFWS's Kirtland's Warbler Wildlife Management Area (KWWMA): Muskrat Trail and Leota (Figure 1). Sampling was conducted during the non-breeding (December-March) and breeding season (May-August). We sampled bird species found within stringers and the surrounding non-stringers of each site so we could determine the effect stringers have on bird assemblages. Stringers are patches of biological legacies (e.g., snags, live standing trees from the previous stand, and coarse woody debris) remaining after a wildfire (Kashian et al. 2012). Muskrat Trail includes an anthropogenically produced stringer that represents a remnant of the tract harvested by in 2008 and replanted with jack pine seedlings in 2009. The Leota site was burned by a wildfire in 1977 and left stringers from a mature jack pine-red pine stand.

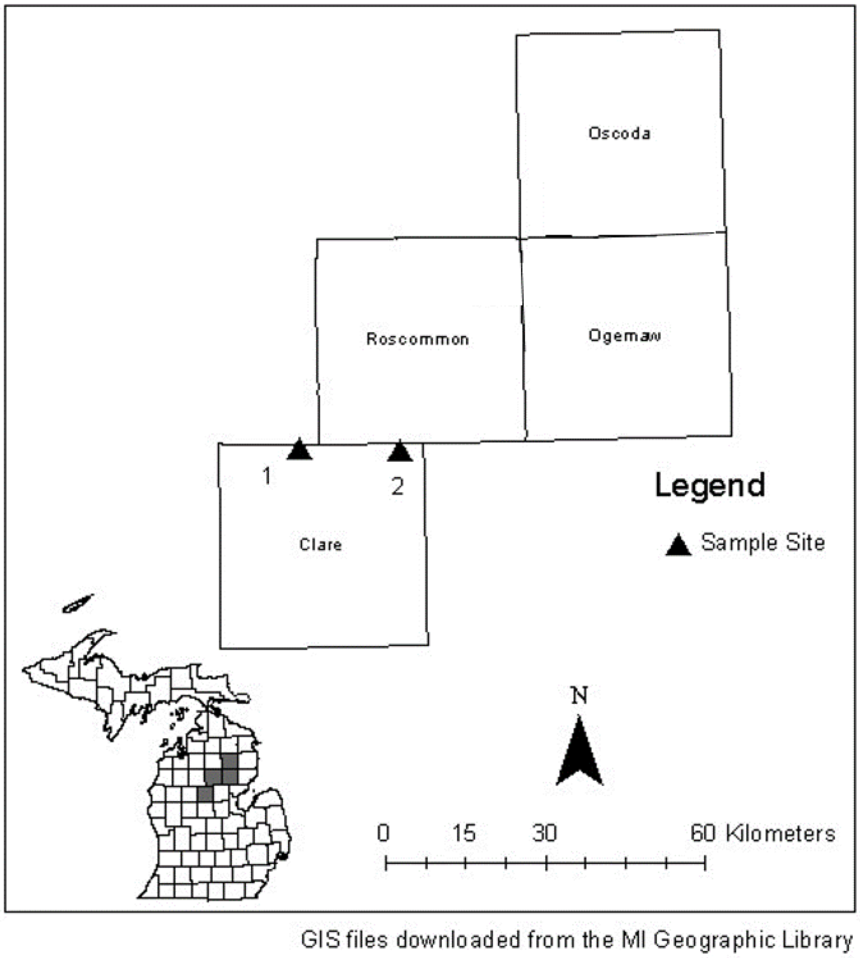

Figure 1: The highlighted areas in the map show the location of the counties of northern Lower Michigan on the right. Sample locations are marked with triangles: 1=Muskrat Trail, 2=Leota. Bird communities at Muskrat Trail and Leota were sampled during the non-breeding and breeding seasons of 2012 and 2013.

BIRD SAMPLING

From December 2011 through August 2013, eight acoustic recorders were used to document breeding and non-breeding season bird use within the Muskrat Trail and Leota sites. Acoustic recorders facilitate intensive sampling across seasons because daily field monitoring is not required (Haselmayer and Quinn 2000). We used Song Meter SM2 digital recorders and SMX-II Weatherproof Microphones (two on each meter) from Wildlife Acoustics (www.wildlifeacoustics.com). We placed four recorders at each sample site, two inside the stringers and two in the non-stringer. Recorders were placed a minimum of 250 meters apart, approximately 1.5 meters off of the ground, and attached to the northern side of trees with the fewest acoustic obstructions. Recording started 30 minutes prior to sunrise and continued for four hours. These devices were programmable, so changes in sunrise time were taken into account as the seasons changed. Stored data were downloaded at least once a month. These acoustic recorders were used to collect data during both the non-breeding and the breeding season during both study years.

Point counts began in December 2011 and were completed in August 2013. Counts occurred within a total of 16 point count stations across the two sites. Fixed-radius (50m) point counts were conducted during both the non-breeding (December-March) and breeding seasons (May-August) of each year. Due to the irregular shape and size of stringers, point count stations were selected so that each point was a minimum of 200 meters 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 habitats and to better ascertain bird species affinity for stringer and non-stringer habitats. While monitoring guidelines for most passerines suggest 250 m as the minimum distance between sampling sites, our points were placed a minimum of 200 meters apart, due to the size of stringers and sample locations (Ralph et al. 1993). Each site had eight points, four within the stringer and four in the surrounding habitat. Point counts started no more than 10 minutes before sunrise and continued for no longer than four hours; counts occurred for five minutes 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. A minimum of one week was observed between visits. We did not conduct point counts during precipitation, when winds exceeded 17 kph, or when temperatures were below -6.7 °C. A new route was followed for consecutive count dates to minimize bias caused by the time of day point counts were conducted. 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 habitat use during the breeding season. We did not conduct point counts during precipitation or when winds exceeded 17 kph.

DATA ANALYSIS

Vocalizations was analyzed using SongScope® (Wildlife Acoustics) and RavenPro® (Cornell Laboratory of Ornithology – Bioacoustics Research Program) software. One day was selected from each month (December-March and May-August) and all bird species heard on the recording were documented. Days with winds <17 kph and no precipitation were selected for analysis. We determined species richness for each acoustic recorder by counting the total number of species heard on the recorder for each the breeding and non-breeding season. To determine if recordings and point counts detect the same species richness, we compared the species richness found during point counts in stringers and non-stringers to the species richness of stringers and non-stringers on the recordings using a Mann-Whitney test. A Mann-Whitney test was chosen because point count data is non-parametric. Due to our sample size of 8 acoustic recorders and 16 point count stations we used α=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.

Data was analyzed by site with data points pooled as stringer or non-stringer and non-breeding and breeding season data was analyzed separately. Observations from multiple point count surveys were pooled by point count station by selecting the census visit with the highest maximum abundance for each individual species.

RESULTS

We analyzed a total of 64 sound recordings collected during the non-breeding season (2 per month for each of the 8 recorders). A total of 24 bird species were documented on the recorders in the stringers and 19 species were documented on the recorders in the non-stringers at Muskrat Trail. During point counts we documented 13 species in the stringers and 7 in the non-stringers at Muskrat Trail. Thirteen species were heard on the recorders in the stringers and ten in the non-stringers that were not heard during point counts at Muskrat Trail (Table 1). There were three species heard within the stringers during point counts that were not heard on the recorders (common grackle (*Quiscalus quiscula* L.), pine warbler (*Dendroica pinus* Wilson), red-tailed hawk) at Muskrat Trail. During the non-breeding season at Leota, a total of 20 bird species were documented on the recorders in the stringers and 20 in the non-stringers. During point counts, we documented 16 species in the stringers and 11 in the non-stringers. Six species were heard on the recorders in stringers and ten in the non-stringers that were not heard during point counts at Leota (Table 1). There were four species heard within the stringers (Eastern bluebird (*Sialia sialis* L.), pine warbler, red-tailed hawk, song sparrow) and two within the non-stringers (red-tailed hawk, song sparrow) that were only heard during point counts at Leota. Species richness of acoustic recorders was higher than point counts in the stringers (p=0.09) and non-stringers (p=0.10) at Muskrat Trail (Table 4). While richness of recorders and point counts were not significantly different in the stringers (p=0.11) and non-stringers (p=0.11) of Leota (Table 2). The total species richness calculated by combining both methods was similar to the richness found only on the acoustic recorders.

Table 1: Bird species heard on the acoustic recorders that were not heard during point counts within both habitat types during the non-breeding season (December-March) at Muskrat Trail and Leota.

	Binomial	Species Code	Muskrat Trail		Leota	
			Stringer	Non-stringer	Stringer	Non-stringer
American Crow	*Corvus brachyrhynchos* Brehm	AMCR			X	
American Goldfinch	*Carduelis tristis* L.	AMGO	X	X	X	X
American Robin	*Turdus migratorius* L.	AMRO	X	X	X	
Brown Creeper	*Certhia Americana* Bonaparte	BRCR	X			X
Brown-headed Cowbird	*Molothrus ater* Boddaert	BHCO	X		X	X
Canada Goose	*Branta Canadensis* L.	CANG				X
Cedar Waxwing	*Bombycilla cedrorum* Vieillot	CEDW				X
Common Grackle	*Quiscalus quiscula* L.	COGR		X		
Common Nighthawk	*Chordeiles minor* Forster	CONI	X	X		
Common Raven	*Corvus corax* L.	CORA		X		X
Downy Woodpecker	*Picoides pubescens* L.	DOWO			X	X
Eastern Bluebird	*Sialia sialis* L.	EABL	X			
Eastern Meadowlark	*Sturnella magna* L.	EAME		X		
Hairy Woodpecker	*Picoides villosus* L.	HAWO	X			
Mourning Dove	*Zenaida macroura* L.	MODO	X	X	X	X
Northern Flicker	*Colaptes auratus* L.	NOFL	X	X		
Pileated Woodpecker	*Dryocopus pileatus* L.	PIWO	X			X
Pine Siskin	*Carduelis pinus* Wilson	PISI	X			
Red-winged Blackbird	*Agelaius phoeniceus* L.	RWBL	X	X		
Ruffed Grouse	*Bonasa umbellus* L.	RUGR				X
Sharp-shinned Hawk	*Accipiter striatus* Vieillot	SSHA	X			
Slate Colored Junco	*Junco hyemalis* L.	SCJU		X		

Table 2: Non-breeding season (December-March) species richness at Muskrat Trail and Leota for both sampling methods and total species richness using both methods. Species richness found on the acoustic recorders is higher than richness found during point counts.

Site	**Habitat**	**Acoustic**	**Point Count**	**Total Species Richness**
Muskrat Trail	Stringer	24	13	27
	Non-stringer	19	7	19
Leota	Stringer	20	16	24
	Non-stringer	20	11	22

We analyzed a total of 64 sound recordings collected during the breeding season (2 per month for each of the 8 recorders). During the breeding season, a total of 56 bird species were documented on the recorders in the stringers and 46 species were documented on the recorders in the non-stringers at Muskrat Trail. During point counts we documented 30 species in the stringers and 24 in the non-stringers at Muskrat Trail. Twenty-one species were heard on the recorders in the stringers and 29 in the non-stringers that were not heard during point counts (Table 3). There was one species heard during point counts at Muskrat Trail within the stringers (black-and-white warbler (*Mniotilta varia* L.)) and six within the non-stringers (American kestrel (*Falco sparverius* L.), clay-colored sparrow (*Spizella pallida* Swainson), Lincoln's sparrow (*Melospiza lincolnii* Audubon), Nashville warbler (*Vermivora ruficapilla* Wilson), red-tailed hawk (*Buteo jamaicensis* Gmelin), yellow-rumped warbler (*Dendroica coronate* L.)) that were not heard on the recorders. At Leota, a total of 35 bird species were heard in the stringers and 37 in the non-stringers on the recorders during the breeding season. During point counts, we documented 26 species on the stringers and 20 in the non-stringers. Fourteen species were heard on the recorders in stringers and 19 in the non-stringers that were not heard during point counts at Leota (Table 3). There were five species heard during point counts within the stringer (common yellowthroat (*Geothlypis trichas* L.), European starling (*Sturnus vulgaris* L.), golden-crowned kinglet (*Regulus satrapa* Lichtenstein), rose-breasted grosbeak (*Pheucticus* *ludovicianus* L.), white-breasted nuthatch (*Sitta carolinensis* Latham)) and four within the non-stringer (blue-headed vireo (*Vireo solitaries* Wilson), Eastern phoebe (*Sayornis phoebe* Latham), mourning warbler (*Oporornis Philadelphia* Wilson), song sparrow (*Melospiza melodia* Wilson)) that were not heard on the recorders at Leota. Species richness was significantly higher on the acoustic recorders in the stringer (p=0.10) and non-stringer (p=0.10) at Muskrat Trail while richness was not different between the two methods in stringers (p=1.0) and non-stringers (p=0.11) at Leota (Table 4). The total species richness calculated by combining both methods was slightly higher than the richness found only on the acoustic recorders.

Table 3: Bird species heard on the acoustic recorders that were not heard during point counts within both habitat types during the breeding season (May-August) at Muskrat Trail and Leota.

	Binomial	Species Code	Muskrat Trail		Leota	
Species			Stringer	Non-stringer	Stringer	Non-stringer
American Crow	*Corvus brachyrhynchos* Brehm	AMCR			X	X
American Goldfinch	*Carduelis tristis* L.	AMGO		X		
American Redstart	*Setophaga ruticilla* L.	AMRE	X	X	X	X
American Woodcock	*Scolopax minor* Gmelin	AMWO		X		
Baltimore Oriole	*Icterus galbula* L.	BOAR	X			
Barred Owl	*Strix varia* Barton	BADO	X	X	X	X
Belted Kingfisher	*Megaceryle alcyon* L.	BEKI				X
Black-throated Green Warbler	*Dendroica virens* Gmelin	BTNW	X			
Brown Creeper	*Certhia Americana* Bonaparte	BRCR		X		X
Brown-headed Cowbird	*Molothrus ater* Boddaert	BHCO		X		
Canada Goose	*Branta Canadensis* L.	CANG	X	X		
Chestnut-sided Warbler	*Dendroica pensylvanica* L.	CSWA	X			X
Common Grackle	*Quiscalus quiscula* L.	COGR		X	X	
Common Loon	*Gavia immer* Brünnich	COLO	X	X	X	X
Common Nighthawk	*Chordeiles minor* Forster	CONI			X	X
Common Raven	*Corvus corax* L.	CORA		X	X	X
Common Redpoll	*Carduelis flammea* L.	CORE				
Common Yellowthroat	*Geothlypis trichas* L.	COYE		X		
Downy Woodpecker	*Picoides pubescens* L.	DOWO		X		
Eastern Kingbird	*Tyrannus tyrannus* L.	EAKI			X	
Eastern Meadowlark	*Sturnella magna* L.	EAME		X		
Eastern Phoebe	*Sayornis phoebe* Latham	EAPH	X			
Eastern Wood-Pewee	*Contopus virens* L.	EAWP		X		
Field Sparrow	*Spizella pusilla* Wilson	FISP			X	
Fox Sparrow	*Passerella iliaca* Merrem	FOSP	X			

Gray Catbird	*Dumetella carolinensis*	GRCA		X		
Gray Flycatcher	*Empidonax wrightii* Baird	GRFL	X			
Great Crested Flycatcher	*Myiarchus crinitus* L.	GCFL		X		X
Hairy Woodpecker	*Picoides villosus* L.	HAWO			X	X
Indigo Bunting	*Passerina cyanea* L.	INBU		X		
Mourning Dove	*Zenaida macroura* L.	MODO		X		X
Northern Flicker	*Colaptes auratus* L.	NOFL				X
Ovenbird	*Seiurus aurocapilla* L.	OVEN		X		
Pileated Woodpecker	*Dryocopus pileatus* L.	PIWO		X		
Pine Siskin	*Carduelis pinus* Wilson	PISI	X	X	X	X
Pine Warbler	*Dendroica pinus* Wilson	PIWA		X		
Red-bellied Woodpecker	*Melanerpes carolinus* L.	RBWO	X			
Red-breasted Nuthatch	*Sitta Canadensis* L.	RBNU		X		
Red-eyed Vireo	*Vireo olivaceus* L.	REVI				X
Red-shouldered Hawk	*Buteo lineatus* Gmelin	RSHA	X			
Red-winged Blackbird	*Agelaius phoeniceus* L.	RWBL		X		
Ring-billed Gull	*Larus delawarensis* Ord	RBGU	X			
Rose-breasted Grosbeak	*Pheucticus ludovicianus* L.	RBGR	X			X
Ruby-crowned Kinglet	*Regulus calendula* L.	RCKI			X	
Ruffed Grouse	*Bonasa umbellus* L.	RUGR				X
Slate Colored Junco	*Junco hyemalis* L.	SCJU	X	X		
Song Sparrow	*Melospiza melodia* Wilson	SOSP	X			
Vesper Sparrow	*Pooecetes gramineus* Gmelin	VESP	X			
White-throated Sparrow	*Zonotrichia albicollis* Gmelin	WTSP	X	X		
White-breasted Nuthatch	*Sitta carolinensis* Latham	WBNU		X		
Yellow Warbler	*Dendroica petechial* L.	YEWA	X	X		X
Yellow-bellied Sapsucker	*Sphyrapicus varius* L.	YBSA		X		
Yellow-billed Cuckoo	*Coccyzus americanus* L.	YBCU			X	
Yellow-rumped Warbler	*Dendroica coronate* L.	YRWA			X	X
Yellow-throated Vireo	*Vireo flavifrons* Vieillot	YTVI	X			

Table 4: Breeding season (May-August) **s**pecies richness at Muskrat Trail and Leota for both sampling methods and total species richness using both methods. Species richness found on the acoustic recorders is higher than richness found during point counts.

Site	**Habitat**	**Acoustic**	**Point Count**	**Total Species Richness**
Muskrat Trail	Stringer	56	30	57
	Non-stringer	46	24	52
Leota	Stringer	35	26	40
	Non-stringer	37	20	41

DISCUSSION

In our study, acoustic recorders detected more species than point counts during both the breeding and non-breeding seasons, but only at Muskrat Trail. As far as we know, this is the first study to look at the effectiveness of acoustic recorders in jack pine habitat, making it difficult to compare our results to previous studies. However, a study conducted by Haselmayer and Quinn (2000) found high species richness on recorders when the location had an overall higher species richness, but when averaged out over the sampling period, the data showed no significant differences between the sampling methods. Conversely, Acevedo and Villanueva-Rivera (2006) found higher estimates of species richness using recorders than they did with point counts. The previous studies were conducted in tropical forests which are quite different from jack pine habitat. Acoustic recording is a relatively new technique for sampling bird communities, and there are several reasons why our results could show such high species richness on the recorders. Recorded samples used by Haselmayer and Quinn (2000) were collected simultaneously with the point counts at all sample locations. They analyzed 10 minutes of recordings from 136 point counts for a total of approximately 22.7 hours of recordings. Acevedo and Villanueva-Rivera (2006) sampled 10 sites and recorded 24 samples, 7 minutes in length, over a 24 hour period, for a total of 28 hours of recorded time. For our study, we analyzed 64 four hour recordings for each season, resulting in 256 hours of analyzed data for each season. When comparing 5 minute point counts to 4 hour recordings, it is not a surprise to see higher species richness on the recordings. Another aspect of recording that would have a significant impact on species richness is the effective recording distance (the maximum distance the recorder will detect a bird). In this study, the recorder was placed in the center of a habitat (such as a stringer) and was, at minimum, 50m from the surrounding habitat; however, the effective recording distance for the recorders was unknown. Hobson et al. (2002) determined detection distance in southern boreal mixed-wood forests of Canada was related to the species. Loud species, like the Northern flicker (*Colaptes auratus* L.), were recorded up to 250 meters away from the source and quiet species, like the golden-crowned kinglet, were recorded at less than 100 meters. It is likely that we recorded bird species from neighboring habitats. This is especially likely at Muskrat Trail where the non-stringers are open, allowing sound to travel unobstructed. Species like the Common loon (*Gavia immer* Brünnich) and Canada goose (*Branta Canadensis* L.) were likely heard while flying over or while on a stop-over at a marshy area adjacent to the Muskrat Trail study site.

There are some disadvantages to using acoustic recorders as the primary sampling method. Acoustic recorders are useful in developing a list of species found within a habitat, but cannot be used to estimate species density (Haselmayer and Quinn 2000). Additionally, while the time spent in the field for acoustic recorders is minimal, the time required to analyze hours of recordings in the lab is very time consuming. Spending 5-10 minutes per point count station may be more time efficient than acoustic recorders. If the goal is to save money by replacing observers with recorders, the cost to purchase an adequate number of recorders must also be taken into consideration. However, there are several advantages to using acoustic recorders. Recorders create a permanent record of bird species found at a particular point, allowing individuals to review the data multiple times. This may be especially beneficial to determine species present in areas of high species richness (Hobson et al. 2002). Recorders are also useful when trained observers are not immediately available, when a large area needs to be sampled, and when sampling areas are difficult to access (Hobson et al. 2002).

CONCLUSION

Overall, it appears that acoustic recorders are an effective tool for sampling bird communities in jack pine forests. When acoustic recorders are used, researchers can develop a reliable list of species present in an area, however, the effective recording distance must be approximated before sampling can begin in order to limit sampling outside of the sample area. Acoustic records may prove effective especially when studies may be limited by the availability of qualified personnel, safety concerns, remoteness or other restrictions.

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