

Songbird community response to regeneration of reclaimed wellsites in the boreal forest of Alberta

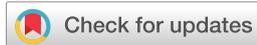
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Abstract

The boreal forest of Alberta, Canada is important breeding habitat for North American songbirds. Thousands of oil and gas wellsites exist in this region that have been actively reclaimed since the 1960s. Limited information exists on how songbirds respond to regeneration of wellsites following reclamation. Methods that provide spatially accurate data are required to determine impacts of these small disturbances characteristic of energy sector on songbirds. Acoustic localization can be used to determine singing locations, based on time of arrival differences of songs to an array of microphones. We used acoustic localization to determine the assemblage of songbirds on 12 reclaimed wellsites ranging from 7 to 49 years since reclamation, and how the similarity of this assemblage to 12 control mature forest sites (greater than 80 years old) changed with increasing canopy cover on the wellsite. Songbird community composition became more similar to mature forest as canopy cover increased on reclaimed wellsites. Results from this study suggest that wellsite reclamation practices are allowing for initial suitable vegetation recovery, however more research on the effectiveness of different strategies at promoting regeneration of wellsites and subsequent impact on songbird communities is required.

Introduction

The boreal forest of Alberta, Canada is important breeding habitat for North American songbirds. The relationship between songbird community composition and vegetation recovery following fire and forest harvesting has been well documented in this region (Hobson and Bayne, 2000; Venier and Pearce, 2005; Schieck and Song, 2006). Forest songbirds respond to variation in woody plant structure and composition, making changes in community composition of songbirds a good indicator of ecosystem deterioration and recovery (Hobson and Bayne, 2000; Schieck and Song, 2006; Brady and Noske, 2010; Versluijs et al., 2017). Human disturbance (i.e. forestry, oil and gas development) has been linked to shifts in community composition and declines of some songbird species in the western boreal forest (van Wilgenburg et al., 2013; Mahon et al., 2016; van Wilgenburg et al., 2018). Among the disturbances created are hundreds of thousands of one-hectare wellsites used for exploration and extraction of oil and gas.

Wellsites no longer in production are actively reclaimed in Alberta, but the reclamation strategies and criteria used to characterize recovery have varied over time (Powter et al., 2012). Construction and reclamation strategies have differed in their treatment of soil and protection of the native seed bank, as well as the type of revegetation (Bott et al., 2016; Frerichs et al., 2017). Current reclamation assessments determine

if plant composition and soil properties are representative of a reference condition, and if density of woody plants meet expected targets (Bott et al., 2016). Limited information exists on the long-term recovery of reclaimed well-sites, the proportion of well-sites at different stages of vegetation recovery, and whether reclamation criteria are successful at creating habitat for wildlife. Monitoring the success of wellsite reclamation is increasingly important, given the large number of existing well-sites, rapid development, and critical habitat thresholds for species at risk that reclamation and restoration efforts are expected to play a large role in meeting (Dabros et al., 2018).

Various methods have been used to study how forest songbirds are impacted by energy sector disturbances (Bayne et al., 2005, 2016; Lankau et al., 2013; Foster et al., 2016). The resolution of data provided by different methods influences how much of an effect these disturbances are estimated to have on songbirds (Newell et al., 2013; Bayne et al., 2016). For example, Bayne et al. (2016) found that using unlimited distance point counts, well-sites had no effect on songbird abundance relative to the adjacent forest. However, when 50 m radius point counts were used, a large impact of well-sites on songbird abundance relative to the adjacent forest was observed. This difference was caused by the fact that unlimited radius point counts, count birds both on the well-site and in the adjacent forest. In contrast, 50 m radius point counts are more likely to count birds on the one-hectare well-site, because most of the area sampled is the well-site itself. However, error in human distance estimation during limited-distance point counts could make conclusions about how birds are using well-sites at different stages of vegetation recovery imprecise (Alldredge et al. 2007; Nadeau and Conway, 2012). This suggests that approaches that precisely locate where birds are singing relative to well-sites are needed to accurately detect how the impact of well-sites changes with regeneration. Acoustic localization is a method that estimates the location of a signal using time of arrival differences of the signal to different channels in a microphone array (McGregor et al., 1997; Mennill et al., 2006). Acoustic localization provides precise singing locations, that can be used to determine the assemblage of songbirds using reclaimed well-sites relative to the adjacent forest (Wilson and Bayne, 2018).

The objective of this study was to determine how the similarity of the songbird assemblages on reclaimed well-sites relative to mature forest (greater than 80 years old) changed with increasing canopy cover on the well-site. Specifically, we were interested if the similarity of these assemblages follows a linear trajectory with increasing canopy cover on the well-site and time since reclamation. We hypothesized that songbird community similarity between well-sites and mature forest would increase as canopy cover increased on the well-site. The average similarity among mature forest sites was used as a target of maximum expected similarity of well-sites to mature forest. Exact similarity between well-sites and mature forest was not expected, given that insufficient time has passed for well-site vegetation to regenerate to the equivalent of the mature forest control sites. Immediately following reclamation, we expected well-sites would have limited vegetation structure and be primarily covered with grass and low shrubs. These early successional sites should be more likely to have early successional songbird species, resulting in assemblages that are dissimilar to mature forests. Increasing structural complexity associated with regeneration will likely increase the similarity of songbird assemblages on well-sites to the mature forest, as they will be able to meet habitat requirements for species that rely on later successional stages (Hobson and Bayne, 2000; Schieck and Song, 2006; Brady and Noske, 2010). Results from this study can provide an initial assessment of whether well-site reclamation is likely to result in songbird community composition similar to mature deciduous boreal forests in Northern Alberta.

Methods

Site Selection

Reclaimed well-sites ($n = 12$) were selected within 50 km of Lac La Biche, Alberta in the Central Mixedwood Natural Subregion of the Boreal Forest Natural Region (Downing and Pettapiece, 2006). Well-sites were within mature deciduous forests dominated by trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*), with a shrub layer made up of alder (*Alnus spp.*), willow (*Salix spp.*), and beaked hazelnut (*Corylus cornuta*). We selected well-sites to sample both a gradient of vegetation recovery stages (i.e. well-sites dominated by grass and low shrubs, well-sites dominated by shrubs 2–5 m tall, and well-sites with trees taller than 5 m), as well as a range of time since reclamation. Well-site footprints covered an average of 0.97 ± 0.05 ha (mean \pm SE). The sites ranged in age from 13 to 49 years since development, and 7 to 49 years since a provincial reclamation certificate was issued. Limited information existed on the initial construction practices used at well-sites. Each site typically had an adjacent linear feature (i.e. well-site access road) that was previously used during the resource extraction process. Well-sites had no recent additional human disturbance (e.g. forestry harvest) within a 150 m radius from the centre of the well-site. The mature forest control sites were greater than 80 years old and selected

in the same forest type as wellsites within 50 km of Lac La Biche, Alberta. Sampling locations were on average 20.86 ± 1.46 km from the nearest wellsite, and greater than 150 m from anthropogenic edge (i.e. roads, forestry harvest).

Acoustic Data

Two different methods of acoustic data collection were used to measure songbird assemblages on reclaimed wellsites (acoustic localization) and at the mature forest control sites (a single recording unit). At the mature forest control sites, a single recording unit should only sample songbirds within mature forest, as these sites were greater than 150 m from human disturbance. Based on previous estimates of songbird detection distances using the same recording technology, 150 m between the sampling location and human disturbance should ensure that most of the area sampled will be mature forest for the songbird species of interest (van Wilgenburg et al., 2017). However, use of acoustic localization is necessary to accurately determine the songbird species that are present on reclaimed wellsites as the detection radius of a single recording unit will exceed the footprint of the one-hectare wellsite and detect species in the adjacent forest. The area sampled by the two methods will differ, however we believe this is acceptable as we were interested in comparing the relative change in songbird species composition, rather than songbird abundance or density.

Acoustic localization was used to determine the songbird assemblage that sang from reclaimed wellsites. The 5×5 grid of microphones used to perform acoustic localization was comprised of GPS enabled Wildlife Acoustics SM3 units equipped with external SMM-A1 microphones (Wildlife Acoustics, Inc., Maynard, Massachusetts, USA). Across sites, microphones were spaced an average of 33.9 ± 0.38 m apart (Figure 1). The grid was rotated across 12 sites during the songbird breeding season in 2015 (May 25–June 20; 5 sites) and 2016 (May 28–June 15; 7 sites). Recordings were collected from 05:30AM to 08:30AM on 1–5 subsequent days at each wellsite. Microphone positions were determined using a Hemisphere S320 survey GPS (Hemisphere GNSS, Scottsdale, Arizona, USA). When not possible to obtain locations using the survey GPS due to dense canopy ($n = 125$ stations), positions were determined from the mounted Garmin 16x GPS attached to the recording unit. Speed of sound was estimated using hourly temperature data from the nearest Environment and Climate Change Canada weather station (Wilson et al., 2013; Environment and Climate Change Canada, 2017).

Three recording periods that were three minutes long were selected between 05:00 AM and 08:30 AM on one day at each wellsite for processing using acoustic localization (i.e., 05:00-05:03 AM, 06:00-06:03 AM, and 07:00-07:03 AM). Species identifications were confirmed by multiple trained observers through acoustic cues and visual cues from spectrograms. The multichannel tracks, microphone positions, and speed of sound were

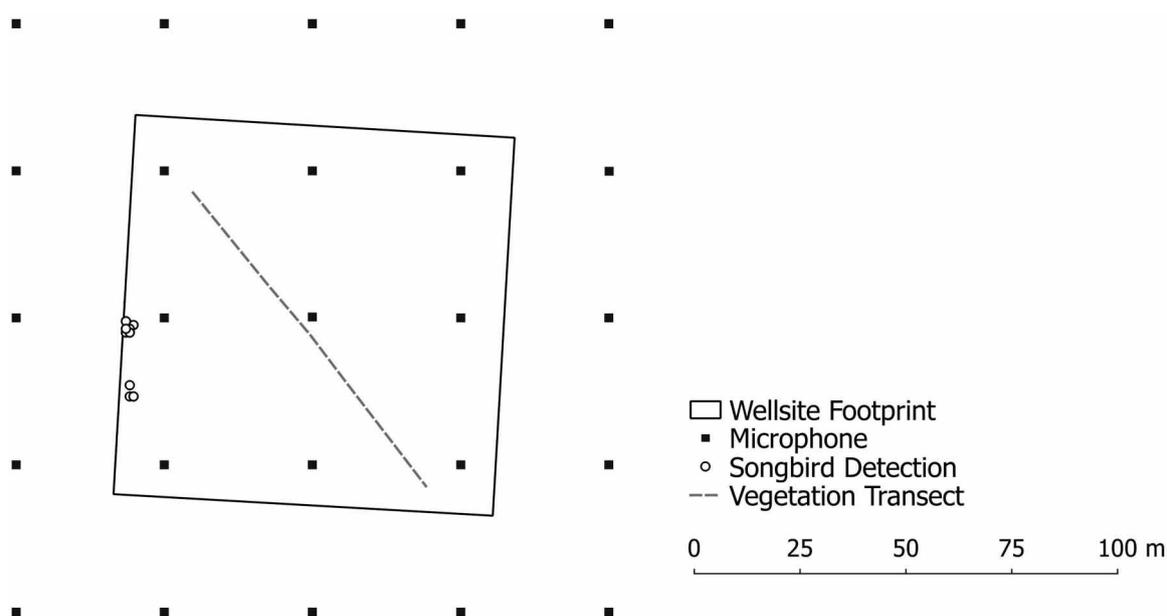


Figure 1. Study design and layout of microphone array around reclaimed wellsites.

Songbird detections within the footprint of each wellsite were included in analysis. At mature forest sites, a single recording unit was placed at the sampling location.

imported into the MATLAB based application XBAT, and the CSE location algorithm (version 2.3) was used for acoustic localization (Cortopassi, 2006; Figueroa and Robbins, 2007; MathWorks Inc., 2014). We only included singing locations occurring on wellsites in further analysis. Further details on collection and processing of data used for acoustic localization are outlined in Wilson and Bayne (2018).

We performed playback experiments at one of the study sites to estimate spatial error in acoustic localization for Alder Flycatcher (*Empidonax alnorum*), Chipping Sparrow (*Spizella passerina*), Hermit Thrush (*Catharus guttatus*), Lincoln's Sparrow (*Melospiza lincolni*), Ovenbird (*Seiurus aurocapilla*), Swainson's Thrush (*Catharus ustulatus*), and White-throated Sparrow (*Zonotrichia albicollis*). These species were selected as they were present within the study region, and vary in their song characteristics. The distance between five known locations of a speaker broadcasting the songbird vocalizations, and the location of the speaker determined using acoustic localization was used to estimate error. At each playback location, a single vocalization of the 7 species was broadcast at 85 dB using the playback apparatus and method for measuring sound power level described in Yip et al. (2017). We performed multiple trials to determine the error in acoustic localization under variation in microphone spacing (approximately 35 m to 50 m) and GPS accuracy (survey grade GPS or mounted the Garmin 16x GPS attached to the recording unit) that occurred across research sites. An average error was estimated for each site, which ranged from 2.40 m (5th percentile: 0.36 m, 95th percentile: 7.11 m) to 10.8 m (5th percentile: 4.83 m, 95th percentile: 17.5 m). Further details on estimation of error in acoustic localization are outlined in Wilson and Bayne (2018). Locations of singing events of the same species that were likely to represent a single singing location were averaged to account for error in acoustic localization. For example, if error in acoustic localization was estimated to be ± 2.40 m at site, and 30 Red-eyed Vireo (*Vireo olivaceus*) songs were produced within a 2.40 m radius, the location of these events would be averaged to represent a single singing location.

A single Wildlife Acoustics SM2+ or SM3 recording unit was deployed at the 12 mature forest control sites to determine the songbird species assemblage in mature forest. Ten of the sites were deployed in both 2015 and 2016, while one site was deployed in 2015, and one only in 2016. The recorders were set up until four recordings could be obtained on separate days, pending weather from May 27 – June 16 in 2015 and May 24 – June 25 in 2016. Sites deployed in both years used at least one visit from each year. Six of the sites used were surveyed using an SM2 in 2015 and SM3 in 2016; the remaining six sites were surveyed with an SM2 or SM3 in both years. To determine the species pool in mature forest control sites within the study region, four three-minute recordings (between 5:00–6:30 AM) on separate days of appropriate weather (i.e. absence of heavy rain or wind) were processed by four trained observers. Recordings were visualized using a 2048 FFT Blackmann-Harris window in the program Audacity 2.1.3. (Audacity Team, 2017). Trained observers identified all territorial passerine vocalizations based on acoustic cues and visual cues from spectrograms. Locations of birds were not estimated.

Vegetation Data

Canopy cover was used as a measure of vegetation recovery on reclaimed wellsites, as it should represent a recovery trajectory towards mature forest. The point intercept method was used to measure canopy cover on reclaimed wellsites using a 90 m transect from a randomly selected corner of the wellsite to the opposite corner. Presence or absence of woody vegetation above 5 m in height was recorded at 3 m increments for the first and last 30 m, and 1 m increments for the center 30 m along the transect (Figure 1; Floyd and Anderson, 1987). These data were used to determine percent canopy cover on each reclaimed wellsite, which ranged from 0 to 100%.

Statistical Analyses

Species detected on reclaimed wellsites using acoustic localization were summarized into a presence-absence site-species matrix. Data from mature forest recordings were also summarized into a presence-absence site-species matrix. The Sorensen index was calculated using the site-species matrices between each wellsite, and each mature forest control site. The average community similarity of each mature forest site to each other mature forest site was determined, and these values were averaged to produce a single value representing the average similarity among mature forest sites. Next, the similarity of each wellsite to each mature forest site was determined, and these values were averaged to present an average similarity of each wellsite to all mature forest sites. Non-metric multidimensional scaling (NMDS) was used to visualize the songbird assemblage in ordination space, using Sorensen dissimilarity as a distance measure (Oksanen et al., 2017; R Core Team, 2017). The mean and 99% standard error confidence ellipse was determined for mature forest sites and reclaimed wellsites. Species detected within microphone arrays at reclaimed wellsites were classified as associated with 'open' or 'closed' habitat and the average distance of singing locations for the two groups to wellsite edge was calculated (Sólymos et al., 2018). Singing locations within the wellsite footprint were assigned a distance of 0. Simple linear regressions were

performed to determine the influence of canopy cover on community similarity between the wellsites and mature forest, how community similarity was influenced by time since reclamation, and how canopy cover was influenced by time since reclamation (R Core Team, 2017).

Results

Of the 35 species detected at mature forest sites and reclaimed wellsites, 16 species were only found at mature forest sites (Table 1). This included Brown Creeper (*Certhia americana*; 6 sites), Canada Warbler (*Cardellina canadensis*; 6 sites), Connecticut Warbler (*Oporornis agilis*; 6 sites), and Hermit Thrush (*Catharus guttatus*; 10 sites) that were found at more than half of mature forest sites. Six species were only detected on wellsites, notably Alder Flycatcher (*Empidonax alnorum*; 4 sites), Clay-colored Sparrow (*Spizella pallida*; 2 sites) and Common Yellowthroat (*Geothlypis trichas*; 1 site), all of which are associated with open habitats. A total of 421 singing events from 19 different songbird species were detected on reclaimed wellsites using acoustic localization (Table 1). These vocalizations were summarized into 101 unique singing locations. On average, species associated with closed habitats sang 13.72 ± 0.36 m from wellsite edge, and species associated with open habitats sang 0.38 ± 0.14 m from wellsite edge.

The NMDS was represented using two axes, with a stress of 0.16 (Figures 2 and 3). Separation exists between the 99% confidence ellipse for mature forest and the 99% confidence ellipse for reclaimed wellsites. Wellsites with greater canopy cover appear closer to the centroid for mature forest sites than those with limited canopy cover (Figure 2). Species associated with open habitats including Alder Flycatcher, Clay-colored Sparrow and Common Yellowthroat diverge from the centroid for mature forest sites. Species associated with mature forest including Black-throated Green Warbler (*Setophaga virens*), Brown Creeper and Connecticut Warbler appear closer to the centroid for mature forest sites (Figure 3). The average similarity among mature forest sites was 0.50 based on the Sorensen similarity index. Similarity of assemblages of songbirds on wellsites to the mature forest sites ranged from 0.06 to 0.39. According to simple linear regression, similarity of wellsite songbird assemblages to mature forest increased with canopy cover on the wellsite ($\beta = 0.18 \pm 0.06$, $p = 0.01$; Figure 4a). Similarity was not predicted by time since reclamation alone ($\beta = 0.004 \pm 0.002$, $p = 0.08$; Figure 4b). Finally, canopy cover increased with time since reclamation ($\beta = 0.02 \pm 0.01$, $p = 0.002$; Figure 4c).

Discussion

Wellsites are abundant in the boreal forest of Northern Alberta, and they have been actively reclaimed for several decades. However, the response of songbird communities to regeneration of wellsites has not been previously examined. We expected that songbird assemblages on reclaimed wellsites would become more similar to mature forest control sites as the wellsites regenerated, as the vegetation will provide a more similar habitat for species found in later successional stages than wellsites with limited recovery of woody vegetation (Hobson and Bayne, 2000; Schieck and Song, 2006; Brady and Noske, 2010). Similarity of wellsite songbird assemblages to mature forest songbird assemblages increased with increasing canopy cover on the wellsite.

It was not expected that songbird assemblages on wellsites would achieve the average similarity seen among mature forest sites, as not enough time has elapsed for wellsites to regenerate to mature forest. However, similarity of some wellsites approached the average similarity seen among mature forest sites. The longest time since reclamation for a wellsite in this study was 49 years, and mature forest sites were in stands greater than 80 years old. Across all reclaimed wellsites, species associated with closed habitats sang farther away from wellsite edges than species associated with open habitats. However, use of wellsites by early-successional species (e.g. Clay-colored Sparrow and Alder Flycatcher) associated with young forest created by fire and forestry harvest suggests that regenerating wellsites are creating an early-successional trajectory for songbirds that is consistent with other forms of disturbance (Hobson and Bayne, 2000; Charchuk and Bayne, 2018). Some species associated with later successional stages (e.g. Brown Creeper and Canada Warbler) were only found at mature forest sites, and never at reclaimed wellsites. This is presumably because wellsites have yet to reach the successional stage where these species would be present. Although we surveyed sites that were developing canopy cover, the majority of wellsites presumably lack the maturity of trees to accommodate cavity nesters, or species that nest in the upper canopy (Hobson and Bayne, 2000; Schieck and Song, 2006). Results from this study suggest that wellsite reclamation practices are allowing for initial suitable vegetation recovery, that translates into use of wellsites by songbird communities typical of upland deciduous boreal forests.

Acoustic localization has been infrequently used to study the impacts of human disturbance on songbirds. Wellsite and mature forest songbird communities would have ideally both been sampled using acoustic

Table 1. Songbird species detected at reclaimed wellsites and mature forest sites and habitat association.

Common Name	Scientific Name	Code	Habitat Association	Wellsites Detected	Mature Forest Sites Detected
Alder Flycatcher	<i>Empidonax alnorum</i>	ALFL	Open	4	0
American Redstart	<i>Setophaga ruticilla</i>	AMRE	Closed	1	4
American Robin	<i>Turdus migratorius</i>	AMRO	Closed	0	2
Black-and-white Warbler	<i>Mniotilta varia</i>	BAWW	Closed	2	1
Bay-breasted Warbler	<i>Setophaga castanea</i>	BBWA	Closed	0	1
Black-capped Chickadee	<i>Poecile atricapillus</i>	BCCH	Closed	0	2
Blue-headed Vireo	<i>Vireo solitarius</i>	BHVI	Closed	0	2
Brown Creeper	<i>Certhia americana</i>	BRCR	Closed	0	6
Black-throated Green Warbler	<i>Setophaga virens</i>	BTNW	Closed	0	2
Canada Warbler	<i>Cardellina canadensis</i>	CAWA	Closed	0	6
Clay-colored Sparrow	<i>Spizella pallida</i>	CCSP	Open	2	0
Cedar Waxwing	<i>Bombycilla cedrorum</i>	CEDW	Closed	1	0
Chipping Sparrow	<i>Spizella passerina</i>	CHSP	Closed	0	2
Connecticut Warbler	<i>Oporornis agilis</i>	CONW	Closed	0	6
Common Yellowthroat	<i>Geothlypis trichas</i>	COYE	Open	1	0
Dark-eyed Junco	<i>Junco hyemalis</i>	DEJU	Closed	1	0
Hermit Thrush	<i>Catharus guttatus</i>	HETH	Closed	0	10
House Wren	<i>Troglodytes aedon</i>	HOWR	Closed	0	1
Least Flycatcher	<i>Empidonax minimus</i>	LEFL	Closed	1	2

(Continued)

Table 1. Continued

Common Name	Scientific Name	Code	Habitat Association	Wellsites Detected	Mature Forest Sites Detected
Magnolia Warbler	<i>Setophaga magnolia</i>	MAWA	Closed	1	2
Mourning Warbler	<i>Geothlypis philadelphia</i>	MOWA	Closed	3	4
Orange-crowned Warbler	<i>Oreothlypis celata</i>	OCWA	Closed	0	1
Ovenbird	<i>Seiurus aurocapilla</i>	OVEN	Closed	5	12
Philadelphia Vireo	<i>Vireo philadelphicus</i>	PHVI	Closed	0	3
Pine Siskin	<i>Spinus pinus</i>	PISI	Closed	0	3
Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>	RBGR	Closed	1	6
Red-breasted Nuthatch	<i>Sitta canadensis</i>	RBNU	Closed	0	1
Red-eyed Vireo	<i>Vireo olivaceus</i>	REVI	Closed	4	12
Swainson's Thrush	<i>Catharus ustulatus</i>	SWTH	Closed	2	6
Tennessee Warbler	<i>Oreothlypis peregrina</i>	TEWA	Closed	7	6
Warbling Vireo	<i>Vireo gilvus</i>	WAVI	Closed	1	1
Winter Wren	<i>Troglodytes hiemalis</i>	WIWR	Closed	0	4
White-throated Sparrow	<i>Zonotrichia albicollis</i>	WTSP	Closed	6	9
Yellow Warbler	<i>Setophaga petechia</i>	YEWA	Closed	1	0
Yellow-rumped Warbler	<i>Setophaga coronata</i>	YRWA	Closed	1	3

localization. This approach would allow assemblages to be determined over an equal sized area, allowing more direct comparisons of species richness and community composition. Differences in the length and temporal distribution of recording data used for the two methods likely confound comparisons of community composition between wellsites and mature forest. A longer total length of recordings over multiple days were sampled at mature forest sites, compared to a single day at reclaimed wellsites, creating potential bias of higher species diversity at mature forest sites. However, we argue our current approach was adequate in that we were interested in whether wellsite assemblages were on a trajectory towards mature forest.

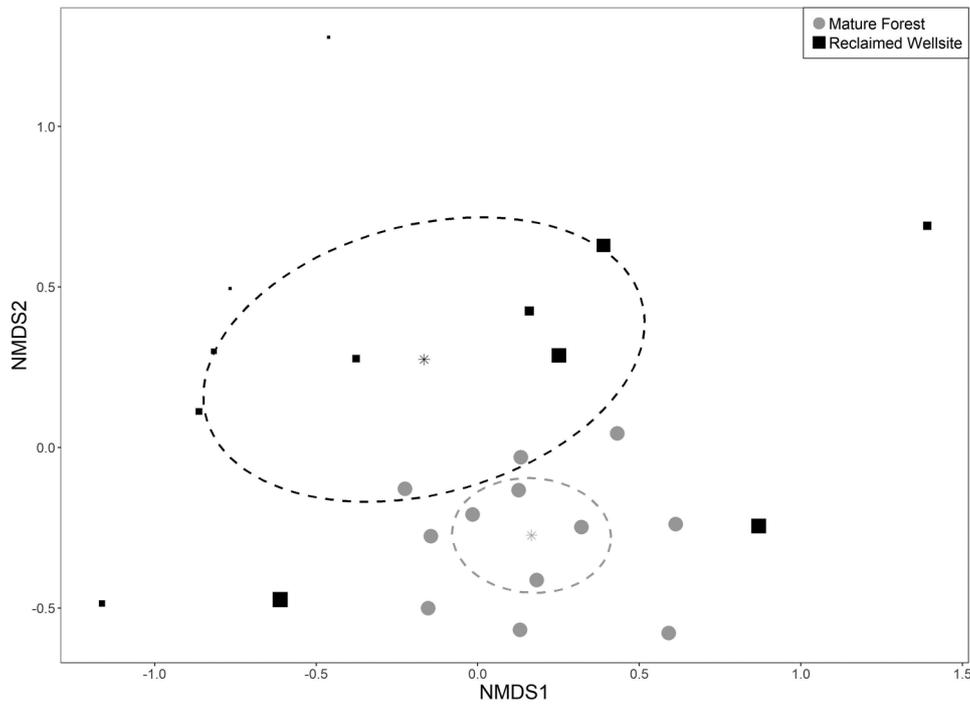


Figure 2. NMDS plot of reclaimed wellsites, and mature forest sites.

The size of marker for reclaimed wellsites is scaled by canopy cover on the wellsite. The centroid for reclaimed wellsites and mature forest sites are represented by an asterisk.

Error in acoustic localization was greater in this study than seen in other acoustic localization studies but is comparable to human observers estimating distances during simulated point counts (Mennill et al., 2006; Alldredge et al., 2007; Collier et al., 2010; Wilson et al., 2013). This error may have erroneously detected some

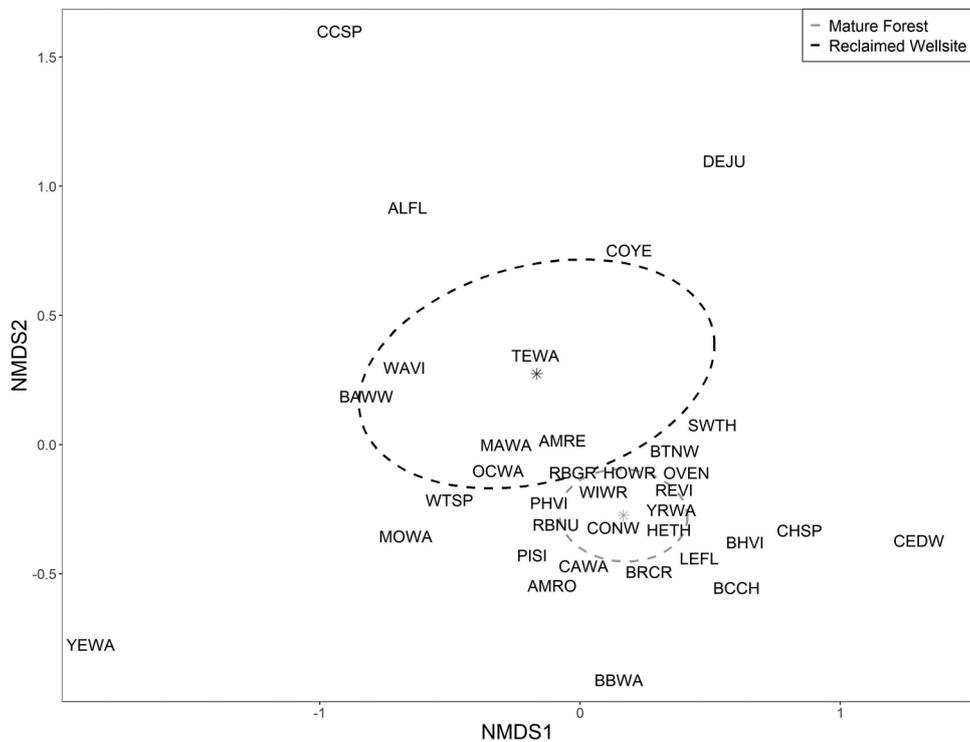


Figure 3. NMDS plot of songbird assemblages detected at reclaimed wellsites, and mature forest sites.

The four-letter bird species codes are presented in Table 1. The centroid for reclaimed wellsites and mature forest sites are represented by an asterisk.

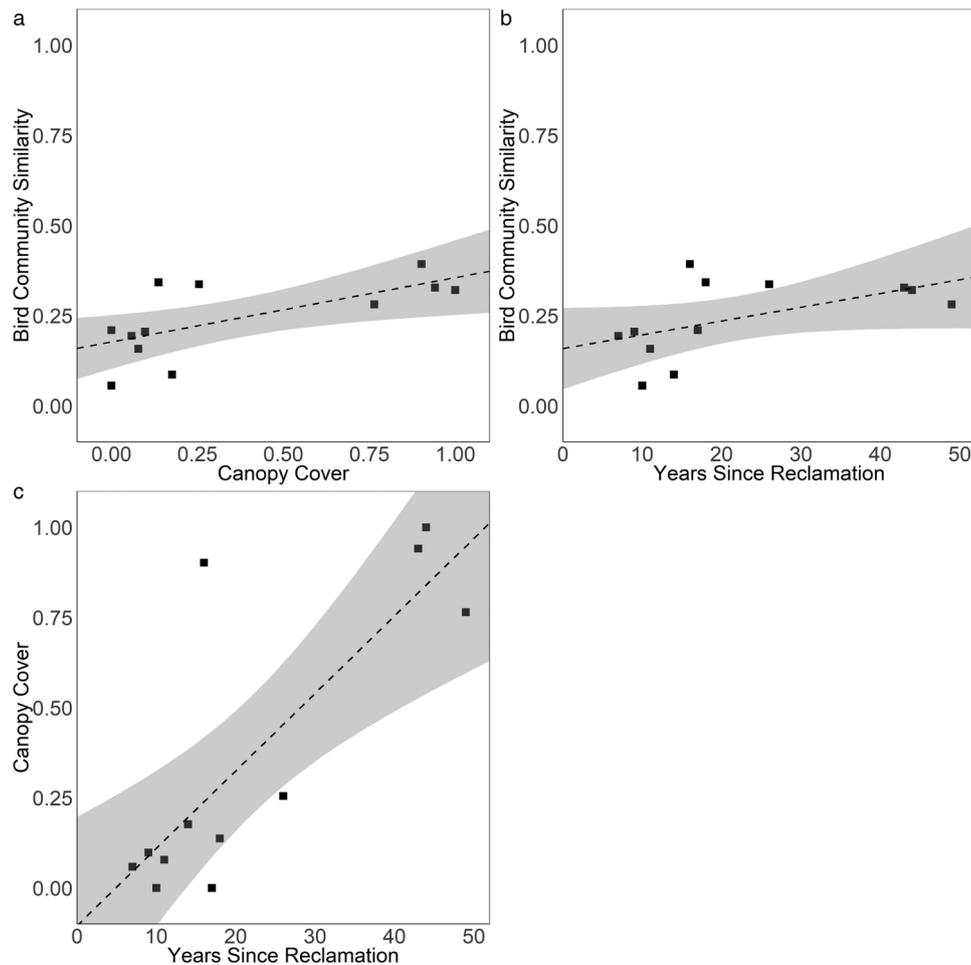


Figure 4. (a) Scatter plot of the Sorenson similarity index of songbird communities on reclaimed wellsites to mature forest sites, as a function of canopy cover on the wellsite. (b) Scatter plot of the Sorenson similarity index of songbird communities on reclaimed wellsites to mature forest sites, as a function of years since the wellsite was reclaimed. (c) Scatter plot of canopy cover on the wellsite as a function of years since the wellsite was reclaimed.

species singing from wellsites that were singing from the adjacent forest. Optimal data require calibration of array layout based on individual species vocalizations, song perch heights, habitat type, and potential acoustic interference (Wilson et al., 2013). Accurate microphone positions can be challenging to obtain under dense canopies, and this challenge likely resulted in higher error in acoustic localization at some study sites (Mennill et al., 2006). Accuracy could be improved by including humidity in estimation of speed of sound, and accounting for influence of differences in vegetation structure across sites (Cramer 1993; Mennill et al., 2006, 2012). Some studies have also identified issues with masking of vocalizations (Campbell and Francis, 2012; Hedley et al., 2017). Although masking was common in this study, enough vocalizations still met our criteria such that the songbird assemblage on reclaimed wellsites could be determined.

Acoustic localization was ultimately effective for determining how songbirds respond to regeneration of reclaimed wellsites. Analyzing acoustic localization data was time intensive, resulting in a limited length of recording data processed at each site on a single day. Thus, these data do not represent a complete assessment of songbird space use in relation to wellsites (Bibby et al., 1992; Wilson and Bayne, 2018). Based on estimates from this study, acoustic localization took approximately 7 hours to collect and process data from a single day at each wellsite. Comparisons of the effort to use this method to other methods that collect similar types of data, such as spot mapping should occur in the future. We recommend use of acoustic localization to answer behavioural questions, when used in combination of other types of data collection such as observation of foraging and nesting behaviours (Taylor et al., 2016). Future studies could examine more detailed questions on space use and behaviour based on multiple different day visits using acoustic localization.

Limited research exists on the recovery of wellsites over an extended time frame, and the proportion of wellsites at different stages of recovery across the boreal forest of Alberta (Frerichs et al., 2017). Wellsite reclamation

criteria in Alberta do not currently account for songbirds, despite the importance of the boreal forest as habitat for these species. Many songbird species appeared to be resilient to wellsite disturbances at the local scale and utilized sites at various stages of vegetation regeneration. However, information on the age structure, and breeding status of birds that sang from wellsites should be investigated, to determine if use of these early successional habitats affects productivity. In addition, further work is required to understand the relative rate of vegetation recovery on reclaimed wellsites in comparison to other disturbances such as fire and forestry harvest, as well as impacts of wellsite disturbances on songbirds on a broader spatial scale. Given that upland mesic habitats have high potential for vegetation regeneration in the study region, recovery of wellsites in habitats with lower probability of regeneration should also be assessed (van Rensen et al., 2015). Further investigation into the effectiveness of different reclamation strategies at promoting regeneration of wellsites, combined with monitoring to determine if convergence between songbird communities on reclaimed wellsites and mature forest occurs is recommended.

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Competing interests

S.J.W. declares that he has no conflict of interest. E.M.B declares that he has no conflict of interest.

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