Songbird community response to vegetation regeneration on reclaimed oil and gas well sites in the boreal forest of Alberta

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Introduction

Modern restoration ecology uses multiple indicators of ecosystem function and state in comparison to a reference condition to evaluate recovery success (Ruiz-Jaen and Aide 2005, Shackelford 2013). Previous emphasis has been placed on recovery of soil and vegetation attributes under the premise that animals will begin to use recovered areas if suitable habitat has been created (Cristescu et al. 2012, Jones and Davidson 2016). However, ecosystem components such as birds do not always recolonize reclaimed features in a predictable relationship to soil and vegetation parameters (Jones and Davidson 2016). It is beneficial to assess how birds recover following reclamation, as their presence can facilitate recovery through stimulation of ecological processes such as seed dispersal and insect management (Latja et al. 2016).

The boreal forest of Northern Alberta is important breeding habitat for North American songbird species. The relationship between songbird communities 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). Bird communities are good indicators of ecological recovery, as they require variation in woody plant structure for foraging and nesting, and are dependent on presence of other taxa for nutrition (Schieck and Song 2006, Brady and Noske 2010). Community composition and individual species abundance often change with regeneration state based on available vegetation (Hobson and Bayne 2000).

Populations of many songbird species in the western boreal are declining, and concerns have been raised that extensive oil and gas development may be partially responsible (Van Wilgenburg 2013). Among the disturbances created by the energy sector, are hundreds of thousands of one hectare, oil and gas well sites. Well sites differ in size and magnitude of impact relative to natural disturbances such as fire. Well sites no longer in production have been actively reclaimed in Alberta, Canada since 1963 using various criteria to characterize recovery. Current criteria measures similarity of soil, vegetation, and hydrology to a reference condition with the goal of returning to 'equivalent land capability' (Bott et al. 2016). Studies examining the impact of well site disturbances on birds have focused primarily on the effects at the landscape scale (Bogard and Davis 2014, Thomas et al. 2014). Limited information exists on the relationship between vegetation recovery on oil and gas disturbances, and bird community recovery, with no data on well sites available (Lankau et al. 2013, Foster et al. 2016). Failure of these sites to regenerate over time will influence the amount of habitat available, potentially resulting in detrimental effects on boreal songbirds if restoration is not effective (Venier and Pearce 2005).

Reclamation and subsequent monitoring must balance effectiveness of ecological recovery with cost and time effectiveness (Richardson and Lefroy 2016). Point counts have been used extensively in bird monitoring programs, as they are time and cost effective (Hutto et al. 1986, Matsuoka et al. 2014). Point counts provide information on species occurrence, abundance, and community composition. A challenge with point counts is the ability to accurately estimate distance from the observer to a singing bird, and determine the area over which birds are sampled (Alldredge et al. 2007). This becomes a larger issue with new approaches to monitoring that rely on audio recording technology (Blumstein et al. 2011, Shonfield and Bayne 2017). This may be less important when monitoring recovery of larger disturbances, as the birds detected tend to be within the recovering area. However, the area that is accurately sampled by human point counts, and commonly used recording technology exceeds the size of the footprint of the reclaimed well sites in this study. The consequence is that point counts detect species living in the adjacent forest, and do not have the resolution to accurately determine how birds respond to well sites per se, resulting in high variance for estimating recovery success (Bayne et al. 2016, Yip et al. 2017).

An alternative method to measure bird response to regenerating well sites is to use arrays of microphones to collect spatial data on birds by estimation of singing locations based on their time of arrival difference to time synchronized microphones, termed localization (Blumstein et al. 2012). This method has been used extensively to study marine mammals (Watkins and Schevill 1972, Hayes et al. 2000) and communication in songbirds (Mennill et al. 2006, Fitzsimmons et al. 2008). Localization has been used less frequently to study habitat use, or response to disturbance in birds. Benefits of localization include accurate spatial locations, and assessment of bird behaviour in the absence of a human observer (Blumstein et al. 2012, Wilson et al. 2013). Critics of localization suggest that equipment requirements, and requirement of detection of vocalizations on multiple microphones make the method impractical (Dawson and Efford 2009). However, when precise measures of location are required, as may occur with small disturbances such as well sites, such a method may be crucial. Few studies have examined community composition, or abundance of birds using localization relative to other methods such as point counts (Campbell et al. 2012).

The first objective of this study was to determine the relationship between community similarity of songbirds, based on singing locations on reclaimed well sites and the adjacent forest, across a gradient of well site vegetation recovery. We argue localization provides exact singing locations and reflects territorial behaviour in birds (Kroodsma and Byers 1991). Singing locations within a regenerating well site footprint, indicating inclusion of well sites in a territory, and should be the best measure of a bird's perception of the quality of a well site as habitat (Whitaker and Warkentin 2010). We hypothesized that as woody vegetation recovers on the well site, similarity of bird use of the reclaimed well site to the adjacent forest should increase, as the well site is more likely to meet habitat requirements for a greater proportion of the bird community (Schieck and Song 2006, Brady and Noske 2010).

The second objective was to determine if the same inferences about vegetation recovery on bird community composition could be determined using the acoustic location system (providing a measure of well site use), versus an unlimited radius point count (providing presence-absence of species) using a microphone placed in the centre of the well site. There is growing evidence that data that provide functional measures are required to understand how wildlife respond to restoration treatments which can be more intensive to collect (Jones and Davidson 2016). It is challenging to monitor multiple aspects of ecological recovery, therefore the feasibility of lower cost, coarser methods, should be investigated. We hypothesized that point count data would be too coarse to determine the impact of vegetation regeneration on the bird community, due to the detection radius of the microphone exceeding the footprint of the well site, and detecting individuals whose entire territories are in the adjacent stand. Point counts constrained to the well site footprint (50m radius) were previously more effective at determining the impact of disturbance on bird communities than larger radius point counts (Bayne et al. 2016). However, if the impact of a well sites on the bird community is large, and bird response regeneration is robust it may be possible to detect recovery in bird communities from point counts, rather than using the more intensive localization approach.

Methods

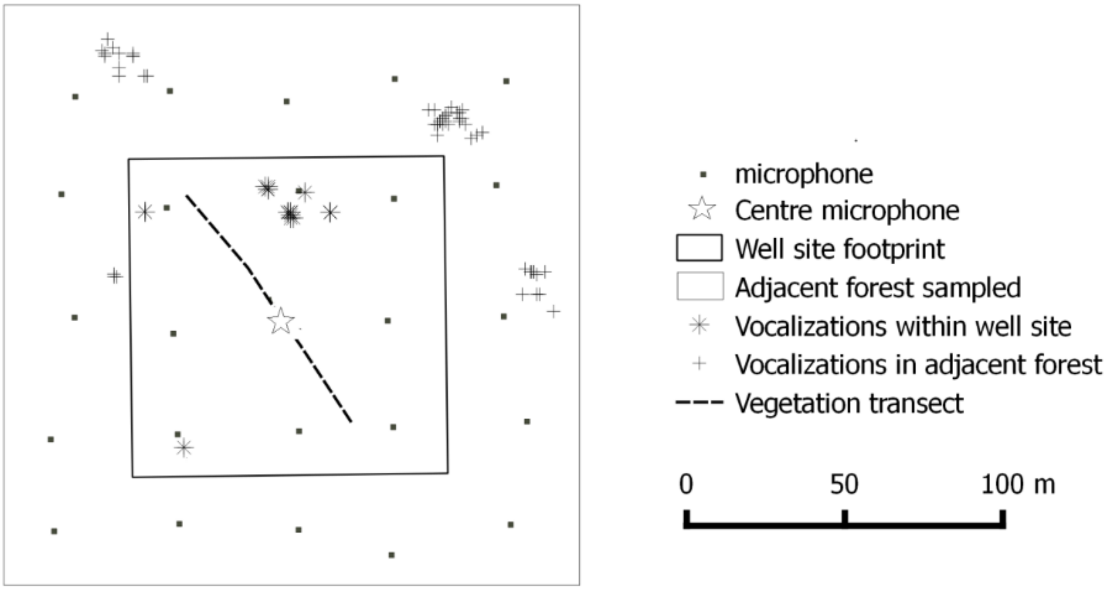

Figure 1. Schematic of study design. Bird locations were determined within an area equivalent to the well site footprint in the adjacent stand. The microphone in the centre of the well site was listened to by trained observers as an unlimited radius point count.

Site Selection

Certified reclaimed well sites (n=19) were selected within the central mixedwood sub region of the boreal forest natural region, within 50km of the communities of Lac La Biche, and Slave Lake, Alberta (Natural Regions Committee 2006). Sites were located in mesic upland ecosites where the main soil type was grey luvisols (Beckingham and Archibald 1996, Natural Regions Committee 2006). Well sites were in forests dominated by aspen poplar (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*). Common understory shrubs included alder (*Alnus spp.*), willow (*Salix spp*.), and beaked hazelnut (*Corylus cornuta*).

Well sites ranged from 11 to 66 years since development, and 3 to 48 years since a reclamation certificate was issued. Reclamation treatments in forested lands have been updated multiple times since their initial implementation (Bott et al. 2016). For these reasons, sites were selected to sample a gradient of woody vegetation recovery, ranging from sites dominated by grass and forb cover, to sites with woody vegetation greater than five metres in height. Sites were required to be accessible by a linear feature, and had no significant additional human disturbance within the area sampled. Well site footprints covered an average of 1.01 ± 0.09 ha, determined through digitization of survey diagrams and ground truthing (Abadata 2016).

Acoustic Data Collection

The acoustic location system used GPS enabled Wildlife Acoustic SM3 units equipped with external SMM-A1 microphones. A total of 475 microphones were deployed over the 19 sites during the bird breeding season (May-June) in 2015 and 2016. At each site, microphones (n=25) were deployed to a height of 1.5m, and spaced an average of 33.9m ± 0.52m apart in a 5x5 grid. Arrays varied slightly in their design, covering an average area of 2.30 ± 0.25 ha. Positions were determined using a Hemisphere S320 survey GPS, set to a horizontal accuracy of ±3.0cm. When not possible to obtain locations using the survey GPS due to dense canopy, positions were determined from the mounted Garmin 16x GPS attached to the recording unit (accuracy 3.28 ± 0.25m). Recordings were collected at each site from 5:30AM to 8:30AM on one day. Recordings were time synchronized to ±1 ms through the GPS clock of the Garmin 16x. A 48000 Hz sample rate was used, and recordings were collected in a compressed wac format.

It is necessary to quantify error in positional estimates using acoustic localization, as error will vary based on habitat type and species (Wilson et al. 2013). Playback experiments were performed at one of the study sites to quantify error in localization associated with the different spacing of microphones and GPS accuracy. The average baseline error in spatial locations was determined as 3.05± 0.39m, from 576 singing events across 14 passerine species. Error increased with inter-microphone distance, and accuracy of GPS, resulting in a maximum average error of 11.5 ± 0.91m.

Vegetation Data Collection

Vegetation data were collected by observers experienced with identification of woody plants of Northern Alberta. The point intercept method was used along a 90m diagonal transect from randomly selected corner of the well site to the opposite corner (Figure 1). Ground cover, coarse woody debris (>7cm diameter), and the maximum height of each species which intercepted the pole was recorded at each distance along the transect. Rectangular shrub stem (30m^2) and tree density plots (60m^2) were set up adjacent to the transect.

Data from the point intercept method was summarized into percent cover estimates from all woody plants <2m, 2-5m, and >5m (canopy) in height, as well as coarse woody debris per hectare. The same measures were calculated separately for coniferous shrubs and trees. Percent litter, and grass ground cover were calculated. Shrub stems and trees per hectare were calculated from rectangular plots. Sites ranged from 0 to 100% canopy cover, 0 to 98% litter cover, and 0 to 15667 shrub stems/ha.

Acoustic Data Processing

Three recording periods that were 3-minutes long were selected within the dawn chorus on one day at each site for processing (i.e. 5:00-5:03AM, 6:00-6:03AM, and 7:00-7:03AM). Recording files were converted to wav format and spectrograms were visualized using a 512 FFT hamming window in the program Audacity 2.1.3 (Audacity 2016). All files were grouped into four channel tracks based on spatial proximity, and scanned visually to locate passerine songbirds performing territorial vocalizations within the microphone grid. Corvids (American crow (*Corvus brachyrhynchos*), common raven (*Corvus corax*) and gray jay (*Perisoreus canadensis*) were not included in analyses. Vocalizations were included in further analyses if the entire song was detected clearly on four microphones, and did not coincide with other songs of greater amplitude, or overlap with any fainter singing events for 25% of the duration of the target vocalization on any channel (Spiesberger 2001). Species identifications were confirmed by multiple trained observers through visual and acoustic cues. The multichannel track which contained the strongest signal for each identified bird was used in subsequent analyses.

Hourly Environment Canada data were summarized from the weather station closest to each research site, and used for estimation of speed of sound (Wilson et al. 2013, E&CCC 2017). The multichannel tracks, microphone positions, and speed of sound, were imported into the MATLAB based program XBAT for analysis (Figueroa 2007, Math Works Inc. 2014). Each vocalization that met these criteria was annotated. The CSE location algorithm (version 2.3) was used for acoustic localization (Cortopassi 2006). This algorithm uses cross correlation of a selected signal between channels to determine the time of arrival difference of the signal to the microphone position associated with each channel of the recording (Cortopassi 2006**,** Campbell and Francis 2012). The time of arrival differences between channels are used to calculate the location of individuals based on the distance and bearing of the signal from the array under a known speed of sound (Cortopassi 2006). Each annotated vocalization was localized using a minimum of four channels using a search criteria of 100m (Campbell and Francis 2012).

Spatial locations were validated to determine if they were closer to the channel with the greatest amplitude than to other channels used in localization. Observations were discarded if not closest to the channel with the greatest amplitude, however this occurred for few events, and mainly when obstructed by another vocalization. If singing locations did not occur within the multichannel track (resulting in positions outside the set of four microphones) but were still within the microphone grid, they were rerun in the correct multichannel track based on the estimated locations. This was to achieve the most accurate positions, as accuracy of localization degrades with distance from the centre of the array (Mcgregor et al. 1997, Campbell and Francis 2012, Wilson et al. 2013).

Singing locations were exported from and visualized in QGIS 2.12.3 (Quantum GIS Development Team 2016). A buffer the equivalent size of the well site polygon was created around each site in the adjacent forest. Vocalizations occurring beyond this buffer were excluded from subsequent analyses. Error in localization was accounted for by buffering well site footprints by error estimates based on GPS accuracy, and microphone spacing at different sites. If singing locations occurred within the buffer they were excluded from analyses as their position could not be confirmed as on, or off of the well site. Remaining singing locations were then classified as occurring within the well site footprint, or within the adjacent forest.

The microphone on the centre of each well site was used for the equivalent of an unlimited radius point count at times concurrent to when localization data was processed. Three trained observers identified all territorial passerine vocalizations based on auditory and acoustic cues, according to the protocol of the Bioacoustic Unit (hereafter 'listening', Lankau et al. 2015). Recordings were visualized using a 2048 FFT Blackmann-Harris window in the program Audacity 2.1.3, and listened to at a standard volume.

Statistical Analyses

We chose to analyze the response of the entire passerine community, as well site reclamation is not directed towards a single species, and bird community response is a standard metric in restoration literature (Munro et al. 2011 Lindenmayer et al. 2012, Latja et al. 2016). The Bray-Curtis Dissimilarity Index was calculated using the number of singing locations on each well site, and in the adjacent forest for each species. A score of 0 indicates complete dissimilarity between the bird assemblage on the well site in comparison to the adjacent forest, and score of 1 indicates complete similarity. Several of the vegetation metrics were highly correlated (Pearson correlation > 0.7), therefore we condensed them using a Principal Components Analysis (PCA) in the R package 'vegan' (Oksanen et al. 2017). Vegetation attributes were standardized to zero mean and unit variance prior to PCA being applied. The first two axes explained 70.26% of variation of vegetation, and were used in subsequent analyses. A positive loading on principal component one indicates increasing litter cover, canopy cover, and medium shrub cover (2-5m). A positive loading on principal component two indicates decreasing low shrub cover, and shrub stem counts.

A beta regression, which allows proportions to be modelled as the response variable, was used to compare the similarity index between the well site and the adjacent forest and how this was influenced by vegetation recovery on the well site, accounting for Julian date of survey (R package 'betareg', Cribari-Neto 2010). Canonical correspondence analysis (CCA) was used to determine if the same trend in the influence of vegetation recovery on bird community composition could be determined from localization and point counts using the R package 'vegan' (Oksanen et al. 2017). CCA was chosen as it allows non-linear relationships between variables, and constrains the ordination to variation explained by the environmental factors (Lindenmayer et al. 2012).

Results

A total of 3995 vocalizations from 31 different songbird species were detected near reclaimed wells using localization. Of these vocalizations, 428 occurred within well site footprints from 16 different species. In the adjacent forest, 2330 vocalizations were detected within an equal sized area as the well site. Alder flycatcher (*Empidonax alnorum*), clay-coloured sparrow (*Spizella pallida*), ovenbird (*Seiurus aurocapilla*), red-eyed vireo (*Vireo olivaceus*), Swainson's thrush (*Catharus ustulatus*), Tennessee warbler *(Leiothlypis peregrine*), and white-throated sparrow (*Zonotrichia albicollis*) sang from three or more well site footprints. Clay-coloured sparrow, ovenbird, Swainson's thrush, mourning warbler (*Geothlypis philadelphia*), Tennessee warbler, and white-throated sparrow sang more than 50% of songs detected on the well site footprint at more than one site. A total of 30 different species were detected near well sites through listening to data from the microphone in the centre of the well site. The species richness of birds detected on the well site alone was 2.05±0.28. The confidence interval for the average number of species detected from listening (7.90±0.54) overlapped with the confidence interval for the average number of species detected on the well site and adjacent forest using localization (7.05±0.64).

Community similarity between the well site and adjacent forest increased with positive loading on principal component two according to the beta regression (Table 1, Figure 2). This indicates that similarity between bird detections on the well site, and the adjacent stand increased with greater litter cover, canopy cover, and medium shrub cover (2-5m), and decreases in low shrub cover and shrub stem counts on well sites. Based on presence-absence species matrices, the effect of vegetation on bird community composition was not detected using localization or listening data using CCA, according to a post hoc ANOVA test for individual terms (Table 2).

Table 1. Results from beta regression, using Bray-Curtis similarity index between well site and adjacent forest as the response variable (pseudo r^2=0.33).

	Estimate	Standard Error	z value	p value
Intercept	4.53	2.89	1.57	0.12
Principal Component One	0.52	0.26	2.02	0.04
Principal Component Two	0.66	0.27	2.50	0.01
Julian Date	-0.04	0.02	-2.39	0.02
Phi	9.40	2.02	4.66	<0.01

Figure 2. Plot of Bray-Curtis similarity in relation to principal component one, and principal component two.

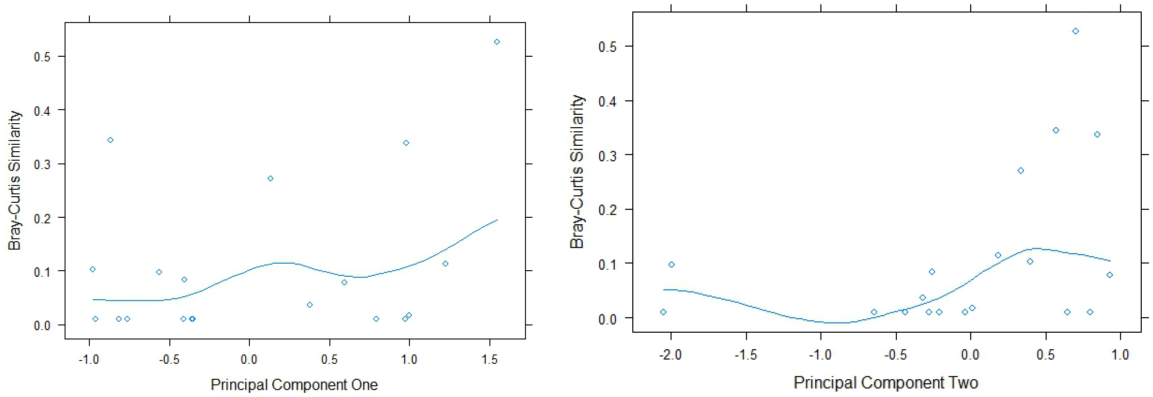

Table 2. Results from Canonical Correspondence Analysis comparing influence of vegetation recovery on the bird community composition detected using listening, and localization.

Model		Df	Chi-Square	F	p
Listening	PC1	1	0.21	1.47	0.06
	PC2	1	0.09	0.64	0.93
	Residual	16	2.29		
Localization	PC1	1	0.43	1.40	0.08
	PC2	1	0.38	1.25	0.25
	Residual	16	4.89		

Discussion

As woody plants regenerated on well sites, we expected that the assemblage of birds on the well site would become more similar to the adjacent stand. We hypothesized that structural complexity of vegetation would meet habitat requirements for a greater number of species, leading to increased singing locations within the well site footprint (Brady and Noske 2010). Use of well sites became more frequent with increasing canopy cover, and replacement of low shrubs with tall shrubs. Species with known associations to regenerating and edge habitat, such as mourning warbler, clay-coloured sparrow, and alder flycatcher placed a majority of their singing locations at some sites. Use of well sites by early successional species associated with young forest created by fire and forest harvesting suggests that the plants growing on well sites are creating a desirable successional trajectory for birds that is consistent with other forms of disturbance and recovery. Well sites are not attracting non-native, pest, or other bird species associated with more intensive human disturbance further suggest that recovery of well sites is occurring.

For most other species, when individuals sang from a reclaimed well, a limited number of events would be on the footprint, with the majority of song posts located in the adjacent forest. Overall, communities remained distinct between the well site and adjacent stand, even at highly regenerated well sites. This was expected due to insufficient time since reclamation treatments, resulting in younger forest in comparison to the adjacent forest. The longest time since reclamation for a well site in this study was 48 years, and sites were in stands generally >80 years old. Given differences between vegetation on the well site, and the adjacent forest, birds perceived well sites as lower quality habitat than the adjacent stand, with greater predation risk, and decreased prey availability, contributing to overall lower probability of defending territories within the well site (Lankau et al. 2013). Birds may have also viewed well sites as boundaries for territories, promoting avoidance of these features over extended periods, demonstrated by some species (Lankau et al. 2013).

Listening data detected the same number of species overall as localization, supporting our expectation that the approximate detection radius of the microphone in the centre of the well site sampled a similar area as the localization grid (Yip et al. 2017). However, the unlimited radius point count gave a more imprecise assessment of the direct impact of regeneration of well sites on birds, as it was not possible to differentiate birds singing from the well site, and birds singing from the adjacent forest (Bayne et al. 2016). Using presence-absence data alone, vegetation regeneration on the well site explained limited variation in the community compositions of birds. This was true for community data collected using a single recording unit in the centre of the well site, and species composition detected on the well site footprint using localization. Detecting the impact of well site regeneration required comprehensive data on differences in use of the well site, and adjacent forest provided by acoustic localization. This finding supports growing literature on the requirement of functional measurements to assess restoration, rather than presence of species alone (Jones and Davidson 2016).

Comparing community composition in the forest directly adjacent to the well site was aligned with local reclamation goals of promoting ‘equivalent land capability’ (Bott et al. 2016). Species composition, was our focus rather than richness, as richness can remain similar across gradients of disturbance due to changes in presence of disturbance tolerant species, exchanged with species associated with intact habitats over time (Thomas et al. 2014, Gould and Mackey 2015). However, a more complete assessment of foraging behaviour and reproductive success would be useful to further document habitat quality of well sites for birds. Previous studies found that although vegetation differed between reclaimed and control sites, birds continued to forage at similar rates in these treatments (Morrison and Lindell 2011).

Time since reclamation was not examined here, as the study design was not appropriate to assess as a chronosequence (Walker et al. 2010). Various strategies have been used to set Alberta reclamation standards over time, which may confound regeneration, making the direct assessment of vegetation recovery necessary (Bott et al. 2016). Well sites regenerate heterogeneously over time in part due to changing standards but also due to variability in successional processes. Thus, modelling recovery simply as a function of time since restoration is not likely to inform how birds are recovering (Bayne et al. 2011, Lankau 2014). Instead, more comprehensive ground based vegetation surveys, or more detailed remote sensing techniques like LiDAR or photogrammetry will be needed to determine how many wells in Alberta can be deemed recovered from a bird’s perspective based on vegetation conditions (van Rensen et al. 2015, Cruzan et al. 2016).

Our acoustic location system provided accurate information on bird territory placement in relation to reclaimed well sites. Localization has been used relatively infrequently to study songbirds, likely due to equipment requirements, and logistical constraints. In this study, microphones were spaced at similar distances to previous literature, but the size of arrays was larger, requiring greater numbers of microphones (Mennill et al. 2012, Campbell and Francis 2012). Studies which examine species composition using localization are uncommon, as 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). Error in localization of birds which sing from the upper canopy is possible; in field playback experiments, playbacks 5m above microphones had a limited increase in error (<1m) compared to playbacks level with the microphones (author, personal observation). Accurate microphone positions are necessary, which can be challenging to obtain under dense canopies (Mennill et al. 2006). Some studies have also identified issues with masking of vocalizations during dawn chorus (Campbell and Francis 2012). Although masking was common during dawn chorus in this study, a sufficient number of vocalizations met our criteria for localization. Collecting, and processing localization data was more time intensive than listening data, but listening data alone was too coarse to understand bird community response to well site reclamation. Using the combination of methods provided the opportunity to validate, and demonstrate inflation of species counts using point counts, and provided insight into strengths and weaknesses of each method.

Reclamation monitoring will become increasingly important in the western boreal, with development projected to increase in coming years (Rosa et al. 2016). The current state of well site recovery for in upland deciduous boreal forest indicates that recovery is occurring, but not to the same state as the adjacent forest. Given that upland mesic habitats have high potential for regeneration in the study region, habitats with lower probability of regeneration should be assessed (van Rensen et al. 2015). Many songbirds appeared to be resilient to small well site disturbances at the local scale, and utilized sites at various stages of vegetation regeneration. Determining this relationship required use data, rather than presence/absence data. This finding should inform the resolution of data required to understand the response of the boreal songbird community to well site recovery. However, the reasons birds utilize reclaimed wells, such as for foraging and nesting behaviour, and resulting breeding success should be assessed further. This information could be collected through a combination of behavioural observations, and acoustic localization. Localization is an exciting technology which should become more accessible with the advent of sensor networks (Taylor et al. 2016). Pairing these data, with high resolution photogrammetry or LiDAR data could be used to answer questions on fine scale habitat use in birds.

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