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Research Paper

Canada Warbler response to vegetation structure on regenerating seismic lines

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ABSTRACT. Seismic lines have an extensive footprint in Canada's western boreal forest that alter habitat conditions for many species. Seismic lines exist within a range of seral states due to changing practices and regulations related to operational needs. Forest regeneration is often hindered on seismic lines as they are frequently repurposed for recreational or alternative industrial uses. The Canada Warbler (*Cardellina canadensis*) is a Neotropical migrant songbird that relies on Canada's boreal region for breeding habitat. As a species at risk both federally (Threatened) and provincially within Alberta (Sensitive), their response to seismic lines has been a significant gap in our understanding of human impacts on the boreal breeding grounds. We used playback surveys along seismic lines within Canada Warbler habitat to identify individual territories. Arrays of autonomous recording units (ARU) were deployed to conduct acoustic source localization (ASL) and map the locations of territorial singing events. Canada Warblers avoided seismic lines with little to no woody vegetation but were more likely to be observed near seismic lines when shrub cover on the line increased. Canada Warblers used the seismic line and the edge environment but did not select for the line when compared to its availability. Use was more evenly distributed across the seismic line as shrub density on the line increased. However, even the most overgrown seismic lines were still perceived as a feature and influenced Canada Warbler space use and behavior. For Canada Warblers, ensuring that seismic lines in old-growth deciduous forests are allowed to recover by reducing reuse of lines should mitigate population level impacts, but more work is needed to assess how population dynamics are influenced by seismic lines and other energy sector disturbances.

Réponse de la paruline du Canada à la structure de la végétation sur les lignes sismiques en cours de régénération

RÉSUMÉ. Les lignes sismiques occupent une place très importante dans la forêt boréale de l'ouest du Canada, ce qui modifie les conditions d'habitat de nombreuses espèces. Les lignes sismiques sont présentes à différents états biotiques en raison des changements des pratiques et des réglementations liées aux besoins opérationnels. La régénération de la forêt est souvent entravée sur les lignes sismiques, car ces zones sont fréquemment réaffectées à des usages de loisirs ou industriels alternatifs. La paruline du Canada (*Cardellina canadensis*) est un passereau migrateur néo-tropical qui vient se reproduire dans la région boréale du Canada. En tant qu'espèce en danger à la fois au niveau fédéral (menacée) et provincial dans l'Alberta (sensible), sa réponse aux lignes sismiques a beaucoup nui à notre compréhension de l'impact humain sur les territoires de reproduction des régions boréales. Nous avons utilisé des relevés d'enregistrement de cris le long des lignes sismiques dans l'habitat de la paruline du Canada afin d'identifier les territoires individuels. Des séries d'unités d'enregistrement autonomes (ARU) ont été déployées pour procéder à la localisation acoustique de la source (ASL) et cartographier les emplacements d'où provenaient les cris sur le territoire. Les parulines du Canada évitaient les lignes sismiques présentant peu ou pas de végétation boisée, mais étaient plus fréquemment observées à proximité des lignes sismiques où les buissons étaient nombreux. Les parulines du Canada utilisaient la ligne sismique et l'environnement limitrophe, mais lorsqu'elles avaient le choix, elles se tenaient à l'écart de la ligne sismique. Leur présence était plus également répartie sur l'ensemble de la ligne sismique à mesure que la densité des buissons augmentait. Toutefois, même les lignes sismiques les plus végétalisées restaient perçues comme des cicatrices et influençaient l'utilisation de l'espace et le comportement des parulines du Canada. Pour les parulines du Canada, si l'on s'assure que les lignes sismiques présentes dans des forêts de feuillus de croissance ancienne peuvent repousser en réduisant la réutilisation de ces zones, il devrait être possible d'atténuer l'impact sur le niveau de la population. Toutefois, des travaux supplémentaires seront nécessaires pour évaluer dans quelle mesure la dynamique de la population est influencée par les lignes sismiques et les autres perturbations liées au secteur de l'énergie.

Key Words: *acoustic source localization; boreal; Canada Warbler; Cardellina canadensis; regeneration; seismic line*

INTRODUCTION

Studies into the effects of forest fragmentation on birds first appeared in the early 1970s. This research focused on fragmentation in agricultural and urban landscapes, in which forest patches existed within a matrix of anthropogenic land uses typically in eastern North America (Bibby 1973, Lynch and

Whigham 1984, Yahner and Scott 1988, Robbins et al. 1989). In this setting, forest patches are isolated by large tracts of unsuitable habitat with an abrupt and distinct edge between land use types. How fragmentation influences birds in relatively intact ecosystems like the boreal forest (Wells et al. 2014) are less clear. Understanding how fragmentation affects the billions of birds in

the boreal forest is an important conservation question. Within Canada, over 32% of the boreal forest has been accessed for natural resource extraction in the last few decades, and this percentage is growing rapidly (CBI 2005, Lee 2006). Some evidence has shown impacts of human access on songbirds through changes in forest patch size (Askins 1994, Schmiegelow et al. 1997, Ries et al. 2004, Bayne et al. 2005a, Lankau et al. 2013), isolation (Schmiegelow et al. 1997, Bayne et al. 2001), and edge effects (Ball et al. 2009, Lankau et al. 2013).

The energy sector has contributed to the fragmentation of the boreal forest through a growing network of linear features like access roads (dirt trails, gravel roads, highways), transmission lines, and features associated with hydrocarbon discovery and extraction (seismic lines and pipelines). Individually, the area of linear features is small and combined, resulting in only about 5–10% loss of trees in some of the most intensively explored areas (Bayne et al. 2016, Sólmos et al. 2020, Riva and Nielsen 2021). Therefore, while loss of forest due to such features is relatively small, the extent and pattern of linear features may create novel and extensive fragmentation effects. Seismic lines are the narrowest but most pervasive linear disturbances created by the energy sector. The cumulative footprint of seismic lines has become a focus of industry and conservation groups; with research directed at understanding changes in species composition (Finnegan et al. 2018, Riva et al. 2018b), animal movement (Tigner et al. 2015, Finnegan et al. 2018b, Riva et al. 2018a), predator–prey relationships (James and Stuart-Smith 2000), large mammal population dynamics (Dyer et al. 2001), and changes to songbird communities (Bayne et al. 2016).

Traditionally, the ecological impacts of seismic lines were viewed by industry and government as neutral due to their small footprint and the expectation that they would disappear quickly with natural regeneration (Jordaan et al. 2012). However, historical seismic exploration activities were sometimes conducted in the summer months with heavy equipment that disturbed soil and vegetation. Growing evidence shows such practices impede natural regeneration with many lines still being open 50 years after creation (Lee and Boutin 2006, Dabros et al. 2018, Finnegan et al. 2018). The technology and methods used to create seismic lines have improved considerably over the past few decades. Companies have reduced the width of seismic lines from an average of 8 meters to <3 meters, and far greater care is taken to construct lines during periods of the year that reduce disturbance to the forest floor. Despite these advancements, research has found correlations between wildlife behavior /abundance and seismic line density (Bayne et al. 2005a, Machtans 2006, Lankau et al. 2013). While less well understood, there is evidence that changes in food availability, competition, and predation may be the mechanisms underlying these patterns (James and Stuart-Smith 2000, Machtans 2006, Lankau et al. 2013, Riva et al. 2018a).

Across Alberta's oilsands region, the estimated density of conventional seismic lines is 1.61 km/km² (ABMI 2020). However, within the northeastern part of the region, conventional seismic line densities range between 1 and 5 km/km², and low-impact seismic lines (LIS) exist at local densities up to 40 km/km² (Riva et al. 2018a, Stern et al. 2018). The percentage of these lines that are recovered, and what recovered means from a wildlife perspective, is thus an important question for managing

fragmentation effects. For territorial songbirds with small home ranges, or those associated with interior forest and late successional habitat, there are concerns that seismic lines dissect forest habitat into small patches because the seismic line is not used and seismic line edges are avoided because of altered resource availability. If this is the case, then seismic lines could drastically reduce the number of songbird territories that fit within the remaining forest (Ries et al. 2004, Bayne et al. 2005b). However, the idea that seismic lines create significant avoidance of edges, is not well understood for most species nor is how edge effects change as seismic lines recover.

The Ovenbird (*Seiurus aurocapilla*) is the only migratory songbird, breeding in Canada's boreal forest, which has been extensively studied for its response to seismic lines and seismic line edges. Our broad knowledge of this species and its known sensitivity to seismic lines provide valuable context for species with comparable niche characteristics (Lankau et al. 2013). This includes the Canada Warbler (*Cardellina canadensis*) which has a similar breeding habitat and nest placement (AESRD and ACA 2014). Bayne et al. (2005b) showed that Ovenbirds do not include open conventional (8 m wide) seismic lines within their home ranges, and often define territorial boundaries based on the location of seismic line edges. Narrower low-impact seismic lines, or seismic lines with greater vegetation, were more likely to be included within an Ovenbird territory (Bayne et al. 2005a, Lankau et al. 2013). However, Machtans (2006) and Bayne et al. (2005b) found that ground and shrub nesting species (including the Ovenbird) showed an increase in territory size when their territory included a seismic line regardless of seismic line width. This increase in territory size was larger than the corresponding area disturbed by the seismic line, suggesting a disproportionate increase in area may be required to compensate for diminished resources on the seismic line per se. Increases in territory size to compensate for reduced resources on seismic lines, could in theory, result in lower bird density.

The Canada Warbler is a federally threatened neotropical migrant songbird that breeds in Canada's boreal forest, including northern Alberta (AESRD and ACA 2014). In Alberta, they are predominantly associated with deciduous or mixed-wood stands that have a dense shrubby understory (AESRD and ACA 2014). Nest placement is typically on or near the ground in a well concealed location (AESRD and ACA 2014). Canada Warblers do occur in early seral deciduous stands that have dense woody vegetation with some residual canopy trees but are typically at much lower densities in young versus old forests in the western boreal (Schieck and Song 2006, AESRD and ACA 2014, Ball et al. 2016). Whether regenerating seismic lines create the shrubby environment needed by the Canada Warbler is unknown.

The goal of this study was to understand how Canada Warbler relative abundance and space use were influenced by conventional seismic lines and whether this was influenced by the vegetation structure on and around the seismic line. We hypothesized that Canada Warblers will use regenerated seismic lines provided that they have reached a sufficient state of recovery that results in a dense woody understory. We also predicted an increase in Canada Warbler relative abundance near seismic lines with an increase in regeneration. We further predicted that the density of woody stems on the seismic line would lead to increased use of the seismic

line and the edge. Point counts were conducted along seismic lines to locate individual Canada Warbler territories. Presence–absence data and site photos from these surveys were then used to classify vegetation regeneration and determine its influence on the presence of Canada Warbler territories. We then used arrays of autonomous recording units (ARUs) to conduct acoustic source localization (ASL) to evaluate the behavior of Canada Warblers in terms of where they sang relative to seismic lines. This allowed us to achieve accurate locations of each Canada Warbler throughout the day without human interference. These locations were used to identify whether Canada Warblers were selecting for or against the seismic line, edges, and whether vegetation on and near the line influenced these behaviors.

METHODS

Study Area

The study area was located in upland deciduous and mixed-wood forests between Lesser Slave Lake and Lac La Biche, Alberta. The forest canopy was composed of trembling aspen (*Populus tremuloides*) and/or balsam poplar (*P. balsamifera*); white spruce (*Picea glauca*) was the dominant conifer in mixed-wood stands. Understory vegetation consisted of beaked hazelnut (*Corylus cornuta*), wild red raspberry (*Rubus idaeus*), and wild rose (*Rosa acicularis*) (Hunt et al. 2017). Locations for playback surveys and ASL arrays were selected in areas containing seismic lines and where Canada Warblers were expected to breed based on maps in Ball et al. (2016). The specific sampling locations were identified by selecting the most suitable forest types using human footprint and land-cover layers from the Alberta Biodiversity Monitoring Institute (ABMI 2016). Seismic lines within the study ranged from 3.07 to 18.0 m wide ($n = 26$, mean = 8.64, SD = 3.15). All seismic lines were digitized with in-field measurements recorded using a highly accurate Hemisphere S320 GNSS RTK base and rover system (Hemisphere, Scottsdale, Arizona, USA).

Sampling Design

Playback Surveys & Line Conditions

Unlimited distance point counts were done in the summer of 2017 to locate Canada Warbler territories; point counts were conducted from May 26 to June 29 from 04:00 to 10:00 AM. At each location, an observer would listen silently for 3 minutes; if no individuals were detected, the observer would broadcast a recording of songs for 5 minutes, alternating every 30 seconds between broadcast and silent listening. Altogether, 76 surveys were done on 30 unique seismic lines. Stations were a minimum of 200 m apart. When sampling on the same seismic line, we surveyed areas that differed in vegetation structure (i.e., height and stem density of woody plants) on that seismic line relative to the previously surveyed point. This meant we often traveled more than 200 m between survey points. Point counts were used to calculate the response variable Mean count (#) (Table 1a).

To create an explanatory variable describing seismic line condition, we took pictures of the vegetation on the seismic line in both directions at each location. These images were then classified by the 1st author into four ordinal recovery states for each location (Fig. 1a–d for visual examples). A mostly disturbed (rank 1) seismic line had a clearly defined linear feature path for the entire extent. There was little to no in-growth of shrubs or

trees from the adjacent forest and the line, if it had vegetation, was dominated by forbs. A partially disturbed (rank 2) line had a clearly visible linear feature path. However, trees and shrubs were present on the edges of the seismic line. In addition, the center of the line had an area actively used by off-highway vehicles at least 2 meters wide. A partially regenerated (rank 3) line could still be perceived as a line from the ground, but the pathway used by people or animals was less than a meter wide. Tall shrub and/or sapling growth was observed over most of the line. A mostly regenerated (rank 4) line could only be perceived by looking for gaps in the canopy. There was no consistent human use pathway observed and tall shrubs and/or saplings occurred across the entire seismic line.

Sampling within our study area was focused on areas known to be suitable for Canada Warblers, therefore, the range of forest and shrub conditions sampled was relatively narrow (Ball et al. 2016). Forest type within a 100 m buffer of each location was derived from a land-cover layer created by the Alberta Biodiversity Monitoring Institute (2016). We computed the proportion of broadleaf forest cover (0.00–1.00), proportion of grass (0.00–0.91), proportion of shrub (0.00–0.26), and proportion of mixed-wood (0.00–0.96) for each location. The proportion of grass was high, as some previously deciduous forests that have been harvested had not regrown at the time of survey. Conifer stands and lowland forests were not sampled.

Acoustic Source Localization

Acoustic source localization (ASL) was conducted at 46 locations by deploying an array of autonomous recording units (ARU) across the seismic line (Fig. 2; Wilson et al. 2014, Cobos et al. 2017). The recording equipment included GPS enabled SM3 recorders and external SMM-A1 microphones (Wildlife Acoustics, Inc., Maynard, Massachusetts, USA). In 2016, square arrays of 25 stations with 35 m spacing were deployed using the SM3 recorders and external microphones placed 1.5 m above the ground; a SM3 recorder and its external microphone were placed at adjacent stations within the array, resulting in monaural recordings. These arrays were placed with no *a priori* knowledge of whether Canada Warblers were present. In 2017, the array size was reduced to increase the number of sites we could sample. This modified design included a 3 x 5 array with the same spacing and height. In 2017, the playback surveys were used as a preliminary assessment of whether Canada Warblers would likely occur on the array prior to ASL placement. The arrays were oriented lengthwise along the seismic line and each station included an SM3 recorder with the microphones oriented perpendicular to the disturbance (stereo recordings). In both years, ARUs recorded at a sample rate of 48000 Hz and a gain of 19.5 dB; recordings were collected in Wildlife Acoustics's compressed WAC format. The recording schedule included 29-minute intervals every half hour from 5:00 to 9:00 am. This was done to ensure manageable recording intervals for post-processing while maintaining near-continuous recording. Each ASL array was offset toward one side of the seismic line, so the central row of ARUs could be attached to a stable tree along the edge of the line. ARUs were deployed from between 1 and 5 days. However, audio data was processed for only one day of data collection during optimal weather conditions (i.e., same duration of time) on each array. To standardize effort, we only used detections within 35 m of the seismic line to make results between years directly comparable.

Table 1. Summary statistics for each analysis. All values are in reference to adult male Canada Warblers (*Cardellina canadensis*; CAWA). A) Presence and Relative Abundance: the number of individuals detected during playback surveys, probability of presence among acoustic source localization (ASL) arrays, and ln-count of singing events detected given presence among ASL arrays; B) Use of Space: the average distance of detections from the seismic line for each ASL array, skewness of detections in relation to the seismic line (“+” is towards, “-” is away), proportion of detections on the dominant side of the seismic line, and proportion of detections on the seismic line; C) Selection: selection for the dominant side of the seismic line, selection for the seismic line, and selection for relative distance to the seismic line. The conclusion describes what effect was observed for a given response variable and whether it could be attributed to vegetation attributes along the seismic line.

Response variables	n	Mean	Lower 95 CI	Upper 95 CI	Conclusion
A) Presence and Relative Abundance					
Mean # - Playback	76	0.34	0.22	0.50	Number of CAWA observed using playback was dependent on vegetation on the seismic line.
Prob. Present - ASL	46	0.57	0.41	0.71	Probability of observing CAWA on ASL array was dependent on vegetation on the seismic line.
Ln-Song Count - ASL	26	5.00	4.38	5.62	Conditional on presence, CAWA song count on ASL arrays increased with more shrubs on the seismic line.
B) Use of Space (ASL)					
Average Distance (m)	21	19.9	17.0	22.8	Avg. distance of CAWA locations from line is not strongly influenced by vegetation on the seismic line.
Skewness	21	-0.39	-0.78	0	Locations skewed towards forest interior but not strongly influenced by vegetation on the seismic line.
Proportion (1 Side)	21	0.86	0.79	0.94	Prop. of points on 1 side of line not 50/50. CAWA more likely on both sides with more shrubs on the seismic line.
Proportion (Line)	21	0.02	0.006	0.037	CAWA sang from seismic lines on some ASL arrays but was not dependent on vegetation on the seismic line.
C) Selection (ASL)					
Select (1 Side)	21	-2.46	-3.85	-1.07	Significant selection by CAWA to use 1 side of line but not strongly dependent on vegetation on the seismic line.
Select (Line)	21	-2.65	-3.35	-1.95	Significant avoidance by CAWA of seismic lines but not strongly dependent on vegetation on the seismic line.
Select (Distance [m])	21	0.05	0.01	0.09	CAWA further from line than available but avoidance not strongly dependent on vegetation on the seismic line.

To maximize localization accuracy, each SM3 recorder was time-synchronized to 1µs using a Garmin GPS 16x (Garmin International, Inc., Olathe, Kansas, USA). The location of each station was recorded using a Hemisphere S320 GNSS RTK base and rover system (Hemisphere, Scottsdale, Arizona, USA) accurate to less than 20 centimeters. Localization accuracy was assessed using data from a playback experiment that was conducted separately from fieldwork. This experiment compared known speaker locations to the estimated position calculated using the methods described in ASL Audio Data Processing.

ASL Vegetation Surveys

Vegetation surveys were modified from the Boreal Ecosystem Recovery and Assessment (BERA) Protocol, as described in Hird et al. (2016). A point intercept method was used in a 150 m transect [hereafter, long transect] along the center of the seismic line and three cross transects that ran perpendicular to the main seismic line axis at 60 m, 75 m, and 90 m. Measurements were recorded at 10 m intervals along the long transect and at 0.5 m intervals along the cross transects to record ground cover and the maximum height of each herbaceous and woody species. From 60 to 90 m along the long transect, tree and shrub stem density of plants taller than 1m was assessed in 2 x 30 m and 1 x 30 m plots,

respectively. To compare the seismic line against conditions in the forest, one side of the seismic line was randomly selected, and a parallel 30 m transect was set up 25 m into the adjacent forest. Point intercept (hereafter, vegetation point intercept or VPI) and tree/shrub density plots were also done along this forest transect to account the structure of the forest.

Data Processing

ASL Audio Data

Data from the ASL amounted to over 200 hours of recordings. To process this data, a series of tools were developed which automated the detection and localization processes. For the identification of Canada Warbler vocalizations, a species-specific recognizer was designed using the acoustic analysis software Song Scope (Wildlife Acoustics, Maynard, MA, USA). The recognizer was intentionally designed to be inclusive of Canada Warbler song variations and partial songs in order to capture any evidence of occurrence among the ASL arrays. Output from this recognizer includes the start and end time of each detection, the recording from which they were identified, and attributes pertaining to the quality of the detections (Knight et al. 2017). Recognizer outputs were validated in two stages, including (1) a preliminary review

Fig. 1. Description of ordinal regeneration categories for seismic lines on which playback surveys were conducted. The categories summarize the overall regeneration, incorporating the delineation of the line, the presence and pattern of sapling tree and shrub encroachment, and the severity of disturbance from off-highway vehicles (OHV) traffic. The four categories include: (a) mostly disturbed - clearly defined linear feature, little to no woody ingrowth, forb or low shrub dominated; (b) partially disturbed - linear feature is visible, fabricated pathway is clearly defined, tall shrub or sapling ingrowth; (c) partially regenerated - linear feature is visible, fabricated pathway is narrow (< 1 m) or undefined, and tall shrub or sapling ingrowth; (d) mostly regenerated - linear feature is visible only by canopy or not at all, fabricated pathway is variable or non-existent, tall shrub or sapling regrowth is across the entire feature.

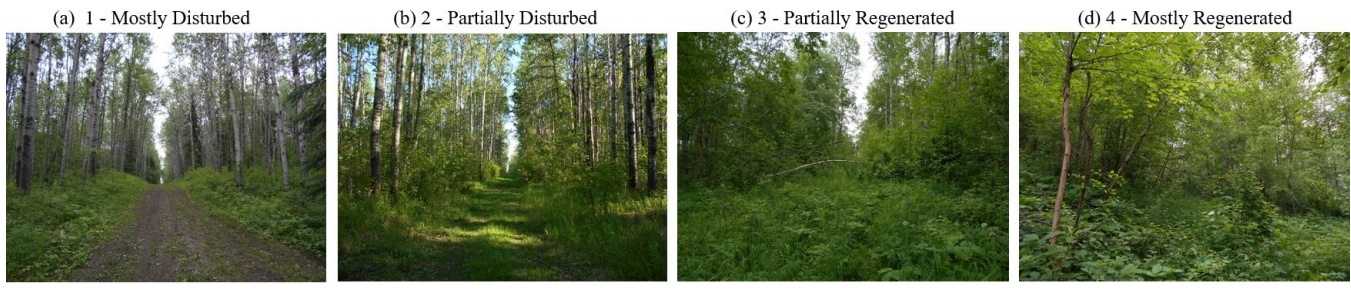
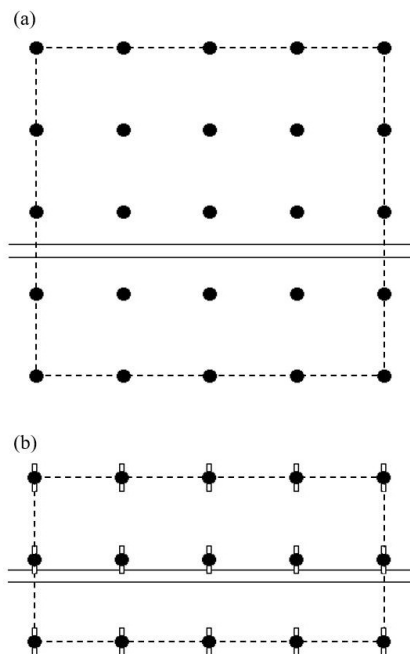


Fig. 2. Layout of acoustic source localization (ASL) arrays for 2016 (a) and 2017 (b). ASL arrays in 2016 included 25 “stations”, each with mono recording from a single microphone (black circle); this was achieved by having an autonomous recording units (ARU) that recorded on the left channel at one station and an external microphone that recorded on the right channel, cabled out to an adjacent station. In 2017, the ASL array was modified to include only 15 stations with stereo recording (black circles with hollow rectangles to either side). The dashed line shows the area in which singing events were localized, and the parallel lines running through each array represent the seismic line.



in which all 46 arrays were validated to a score of 80 or first detection, and (2) a complete validation of the 26 arrays that were confirmed to have Canada Warblers. This validation was done by listening to and visualizing the sound on a spectrogram. We found a broad range in the rate of true positives across sites with Canada Warblers, ranging between 0.29% and 83.04% ($n = 26$, mean = 0.22, SD = 0.23).

To provide a refined search area for localization that reduced the computational requirements of using all ARUs on the array to localize a position, a spectrogram display of each detection as it was perceived by all ARUs within the ASL array was created using the R statistical computing software (Appendix 1; R Core Team 2019). This spectrogram display was used to visually assess song amplitude and select a single channel from the four nearest ARUs within the ASL array which were most likely to contain the vocalization. Using these 4 channels, a custom script that used the mean steered response power (MSRP) algorithm, as described by Cobos et al. (2017), within the Matlab Environment was applied to calculate the location of each detection (Mathworks Inc. 2017). This approach creates a probability surface using an array of 1 m² cells among the selected ARUs by combining information on the location and time difference of arrival to each station to predict the cell most likely to contain the source (Cobos et al. 2017).

Experimental tests on this method of localization showed high accuracy. A test array was set up using four GPS enabled SM3 ARUs, spaced 35 m apart, in a mixed-wood stand outside of Edmonton, Alberta. Songs ($n = 163$) were broadcast at 85 dB from a set of 12 known locations within and around the array; these known broadcast locations were determined using the Hemisphere S320 GNSS RTK base and rover system. The average offset of calculated locations from known broadcast locations within the test array ($n = 70$) was 1.57 ± 1.33 m. Positional accuracy significantly decreased for detections located outside of the ASL array 20.96 ± 17.77 m ($n = 93$). Interference in the time and frequency domains and poor recording quality caused inaccuracies in calculating the time offset for some songs, even within the array. For these reasons, each detection among ASL

arrays was ranked and filtered based on spectrogram quality across all relevant stations (i.e., temporal and frequency interference and strength of signal) and its predicted position within the array (Appendix 2). In summary, only those detections that could be placed within a few meters of the ASL array perimeter were used for analyses that required accurate spatial locations (Fig. 3).

At each ASL array, the recognizer processed data from a single 4-hour period on one day. From this approach, we generated the following 9 response variables, beginning with variables 1 and 2 to capture presence and relative abundance among ASL arrays:

1. Probability present: This was based on validated song detections where we determined if we could hear a Canada Warbler from at least one ARU on a ASL array;
2. Ln-song count: If Canada Warblers were present on an ASL array, we used validated song detections to compute the total number of songs observed.

To assess how Canada Warblers used space around seismic lines we use the recognizer and spatial location data to generate the following response variables:

3. Average distance (m): At sites where Canada Warbler songs could be located with high spatial accuracy and within 35 meters of the seismic line, we calculated average distance to the seismic line from all song locations.
4. Skewness: The distances of each song location were used to compute skewness coefficient. This tested whether the distributions of song locations were uniform in distance or were more likely to be skewed toward or away from the seismic line.
5. Proportion (1 side): To assess if we observed an equal number of points on each side of the seismic line, we computed the proportion of points on the dominant side of the seismic line (i.e., the side on which most song detections were located).
6. Proportion line: We computed what proportion of points were estimated to be on the seismic line per se.

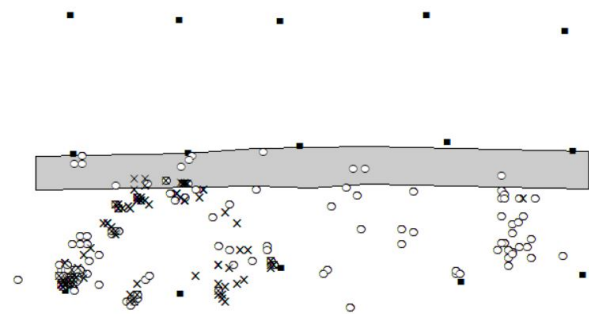
Response variables 3, 5, and 6 were also used to create selection models of used Canada Warbler locations relative to 1000 random points (i.e., available area) within each ASL array. The 1000 random points were generated within a rectangular hull that was 35 m from the seismic line in both directions (Statistical Analysis, for further details).

Selection models:

7. Select (1 side): Allowed us to test if a greater proportion of used locations were on one side of the line than randomly selected points.
8. Select (Line): Allowed us to test if the line was used more or less than expected based on availability.
9. Select (Distance): Allowed us to test if the average location was significantly different than what would be expected if points were random.

A limitation of our ASL approach was the inability to conclusively determine how many individual Canada Warblers had territories on or near each array. As such, a spatial variation variable was

Fig. 3. Example of an acoustic source localization (ASL) array with the location of Canada Warbler (*Cardellina canadensis*) singing events around a seismic line as calculated by our custom script using the mean steered response power algorithm (Cobos et al. 2017). The solid gray rectangle is the boundary of the seismic line and the black squares are autonomous recording units. Canada Warbler locations are denoted by an “X” or a white circle (O); locations shown as “X” represent high quality detections (spectrogram quality < 2) estimated to be within or near the edge of the ASL array (Appendix 2).



created. We treated this as a nuisance variable in all models. We assumed this term was correlated with the number of individuals (i.e., higher values suggest more spatial variation in the locations on the array). Our rationale is that two birds would have higher variation in spatial locations than one territorial individual. To compute the spatial variation variable, we calculated the centroid of accurate Canada Warbler locations on each array. We then measured the distance from each location to the centroid and calculated the standard deviation of Euclidean distances from each array centroid. The standard deviation in Euclidean distances was then ln-transformed and entered as the spatial variation predictor. Conceptually, this is similar to assessing the number of clusters of points in an ARU array without having to select an arbitrary number of clusters.

ASL Vegetation Data

Using the VPI data, we created a shrub height profile and tree height profile for each seismic line and the adjacent forest. The proportion of VPI locations (ranging from 51 to 106 per site) where a shrub species intercepted the pole at 1–50 cm, >50–100 cm, >100–150 cm, >150–200 cm, >200–250 cm, >250–300 cm, and >300 cm were used to describe the height profiles of the shrubs on and off seismic lines. The same approach was used for tree species, but we used profile heights up to 500 cm. Shrub and tree density for those species that reached 1 m in height were measured directly within the quadrats located at the center of each site. Average heights of trees and shrubs were computed for each site based on the maximum height estimated from each VPI for each species of plant observed.

Statistical Analysis

We used a four-stage modeling approach on multiple response variables relating to presence, relative abundance, space use, and selection. At each stage, one variable was added and predictor variables describing the seismic line were added last. We feel this

approach was likely to result in the most parsimonious interpretation of the impacts of seismic lines, as nuisance variables and variation in forest conditions beside the seismic line were entered first. These variables have known effects on bird abundance and song rate and thus should be controlled for prior to assessing human impacts (Sólymos et al. 2015). In the first stage, we computed a null model that did not include any variables. In the second stage, we selected the single nuisance variable that provided the best model improvement based on Akaike's information criteria (AIC). Nuisance variables varied between analyses. In the third stage, we considered how conditions in the forest or surrounding landscape influenced the response variable; this included density of shrubs, average shrub height, and proportion of VPI locations with shrub hits at 50 cm increments up to 300 cm. We did not include VPI profiles for trees in the forest because there were very few intercepts of saplings. Finally, in the fourth stage, we evaluated how birds responded to tree and shrub density on the line, VPI profiles for shrubs and trees on the line, and average heights of shrubs and trees on the line. To reemphasize, at each stage of model construction, one variable from the conceptual set of variables (nuisance, forest conditions, or seismic line conditions) was optimized and the best fitting model from each stage was compared to that of the other model stages via AIC. A decision was made for the overall best supported model based on a combination of AIC, AIC weight, and what was most parsimonious.

Playback Surveys

We used Poisson regression with the playback data to determine the variables that influenced the number of Canada Warblers observed at each survey location. We initially included a random effect to account for sampling on the same seismic line but this explained little variation. Date and time of day were considered nuisance variables. We also assessed whether ordinal rank in line recovery was best modeled as a categorical or continuous variable. A likelihood-ratio test was used to determine whether line recovery categories were significantly different. A negative binomial model was evaluated but did not show improved fit based on a likelihood-ratio test.

ASL Surveys

To assess what influenced whether a Canada Warbler was located at an ASL array, we analyzed the probability of presence, regardless of spatial accuracy or location, using logistic regression. The ln-number song count, conditional on at least one song being detected, was analyzed using ordinary least squares regression. Spatial variation and day of the year were the only nuisance variables considered for these analyses. The use of Poisson regression with song count was considered, however, we found there to be poor fit due to the high variability in song count among arrays, ranging between 14 and 1337 validated songs.

We analyzed average distance from the seismic line at each array using OLS regression with ln-song count, ln-accurate song count, and spatial variation considered as nuisance variables. Ln-accurate song count only used those observations that could be spatially located to within a few meters while ln-song count used any Canada Warbler song detected by the recognizer and validated as true. Our rationale for including song count was to control for the varying degree of accuracy possible in our measure of average distance based on the number of songs detected.

Spatial variation was included to account for the possibility of there being more than one Canada Warbler on an array.

Skewness was analyzed using OLS regression with mean distance, ln-song count, ln-accurate song count, and spatial variation as nuisance variables. When skewness was negative, more of the points were closer to the forest interior. Positive skewness indicated more points were closer to the seismic line. Nuisance variables were considered for the same reasons as average distance. Our goal in these regression analyses was to assess whether patterns of space use were influenced by the presence of a seismic line regardless of vegetation condition. A single-sample t-test was used to test if skewness was significantly different than zero across all arrays to determine where Canada Warblers placed themselves on average.

We used beta regression to assess what influenced the proportion of points on one side of the seismic line or proportion of locations on the seismic line. Nuisance variables considered were ln-song count, ln-accurate song count, and spatial variation. Beta regression is designed to analyze proportions >0 and <1 . For observed proportions of one, we used a value of 0.99. For observed proportions of zero, we used a value of 0.001. A single-sample t-test was used to test if the proportion of points on one side of the line was significantly different than 0.5 as would be expected if Canada Warbler locations were randomly distributed within ASL arrays.

Finally, we evaluated whether each song detection (i.e., "used" location) was on the dominant or non-dominant side of the seismic line, was on the seismic line versus in the forest, and its distance from the seismic line. "Available" locations were randomly generated within the ASL arrays (1000 random locations per array) and had the same three values calculated for each location. Using logistic regression, we computed selection coefficients (beta values) for each array by comparing what was "used" versus "available" against each predictor. The selection coefficients for each array were then used as the response variable ($n = 21$) in a subsequent OLS regression to determine how the average selection value was influenced by nuisance variables (ln-song count, ln-accurate song count, and spatial variation), forest vegetation, and seismic line vegetation. Our rationale for using the array as the unit of measurement when assessing selection is that we did not have measurements of vegetation conditions at each used and available point. Thus, if we had used a mixed effects logistic regression that treated each singing location as an independent point, we would have created a pseudo-replicated design. A single-sample t-test was used to determine if the average selection coefficient was significantly different than zero. An average selection coefficient of 0 indicates used and available points occur in the same proportion.

RESULTS

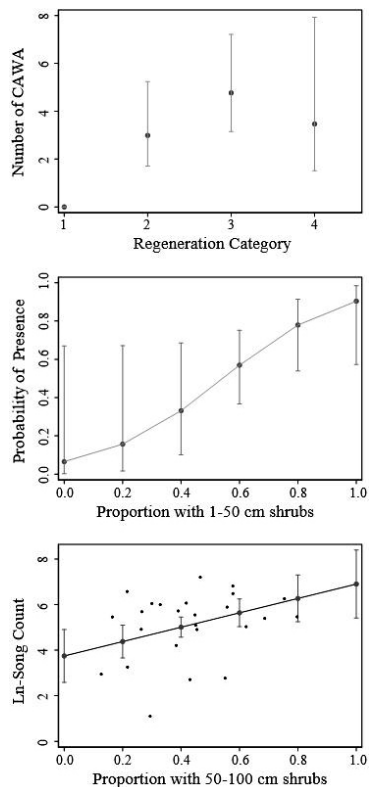
We completed a total of 76 playback surveys with Canada Warbler detected at 26. A total of 46 ASL arrays were established with Canada Warblers at 26. The automated recognizer detected 8046 songs of Canada Warbler across all ASL arrays. Of these songs, 4414 were of sufficient quality to be confident we were locating the position of the singing individual within a few meters. At one ASL array, none of the spatial localizations were of sufficient localization accuracy, and at four arrays fewer than 10

songs were located. Thus, most analyses relied on 21 ASL arrays with sufficient detections and spatial accuracy (Table 1a–b).

Relative abundance

For the playback surveys, the final model (Table 2a) included survey date ($\beta = -0.362$, $SE = 0.137$, $z = -2.64$, $p = 0.008$), proportion of mature deciduous cover ($\beta = 0.23$, $SE = 0.23$, $z = 1.00$, $p = 0.32$), and seismic line vegetation state as a categorical variable ($\chi^2 = 10.5$, $p = 0.015$). After removing the mostly disturbed seismic line category there were no differences in average counts between the other three seismic line categories ($\chi^2 = 1.1$, $p = 0.57$) (Fig. 4 - TOP). However, no Canada Warblers were observed near seismic lines in the mostly disturbed category. The mean Canada Warbler count for the other three categories was 0.4 with a $SE = 0.06$.

Fig. 4. (TOP) – Mean number of Canada Warblers (*Cardellina canadensis*; CAWA) observed at playback locations ($n = 76$) as a function of ordinal ranking of vegetation recovery on the seismic line (1 = mostly disturbed, 2 = partially disturbed, 3 = partially regenerated, 4 = mostly regenerated). The rank was modeled as a categorical predictor in this model. (MIDDLE) – Probability of CAWA being observed on an acoustic source localization (ASL) array ($n = 46$) as a function of the proportion of locations with 1–50 cm high shrub stems on the seismic line. (BOTTOM) – Conditional on CAWA being present, the ln-transformed number of songs found by recognizer per ASL array ($n = 26$) as a function of the proportion of locations with 50–100cm high shrub stems on the seismic line. Error bars are 95% confidence intervals; for continuous variables, they are the confidence intervals of predicted values shown at 5 levels along a continuous gradient for visual clarity. All other variables in the model are set at mean values when making predictions.



The final model of Canada Warbler presence at ASL arrays included the proportion of VPIs in the forest with shrubs 150–200 cm tall ($\beta = 6.02$, $SE = 1.92$, $z = 3.14$, $p = 0.002$) and the proportion of VPIs along the line with shrubs 1–50 cm tall ($\beta = 4.91$, $SE = 2.58$, $z = 1.9$, $p = 0.06$). The probability of Canada Warblers being present showed a weak increase as the proportion of VPI locations with shrubs 1–50 cm in height increased (Fig. 4 - MIDDLE). For ASL arrays where Canada Warbler were present, the final model for average ln-song count was explained by the spatial variation ($\beta = 1.30$, $SE = 0.25$, $z = 5.32$, $p < 0.001$), the proportion of VPIs in the forest with shrubs 1–50 cm tall ($\beta = 2.23$, $SE = 1.82$, $z = 1.22$, $p = 0.22$), and increased with the proportion of VPIs along the line with shrubs 50–100 cm tall ($\beta = 3.28$, $SE = 1.45$, $z = 2.26$, $p = 0.02$; Fig. 4 - BOTTOM).

Space use

Canada Warbler were located at 26 ASL arrays. The number of validated songs detected by the recognizer per ASL site ranged from 4 to 1368. Only 21 arrays had 10 or more accurate locations for space use and habitat selection analyses. On average, Canada Warblers were located 19.9 m from the seismic line (Table 1b). The final model provided only a slightly better fit than the null model ($\Delta AIC = 2.5$). Included in this model was spatial variation ($\beta = -2.40$, $SE = 1.76$, $z = -1.37$, $p = 0.172$), the proportion of VPIs in the forest with shrubs 1-50 cm tall ($\beta = -14.2$, $SE = 8.83$, $z = -1.61$, $p = 0.11$), and the proportion of VPIs along the line > 300 cm tall ($\beta = 49.9$, $SE = 25.7$, $z = 1.94$, $p = 0.052$). Figure 5 - TOP shows that the average distance to the seismic line increased with a greater proportion of VPI locations with shrubs > 300 cm in height.

Fig. 5. (TOP) – Average distance of Canada Warbler (*Cardellina canadensis*; CAWA) from the seismic line on each acoustic source localization (ASL) array ($n = 21$) as a function of the proportion of locations with >300 cm high shrub stems on the seismic line. (BOTTOM) – Controlling for the average location of CAWA on each array, the skewness of locations on each array. Values > 0 indicate more of the points per ASL array ($n = 21$) are closer to the seismic line. Error bars are 95% confidence intervals of predicted values shown at 5 levels along a continuous gradient for visual clarity.

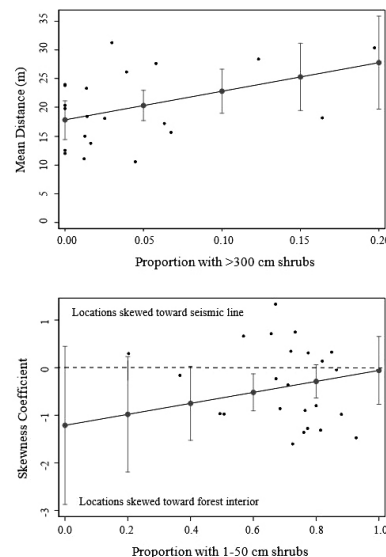


Table 2. Model selection procedure for the effect of habitat and local vegetation attributes on Canada Warblers (*Cardellina canadensis*; CAWA) using 10 different response variables which can be categorized as A) presence and relative abundance, B) use of space, and C) selection. The best model from each stage is reported using Akaike's information criteria and AIC weights; K is the number of parameters estimated. Abbreviations for dependent variables include: the ln-transformed standard deviation of the euclidian distances for each detection to the center of an acoustic source localization (ASL) array (Spatial), the proportion of broadleaf forest within a 100m radius around the survey location (PropBroadleaf), the stem density of shrubs within the 30 m² quadrat in the adjacent forest (ForestShbDensity), the stem density of shrubs within the 30 m² quadrat along the seismic line (LineShbDensity), the proportion of point intercepts in the adjacent forest that have shrub species within a given height category (ForestShb____), the proportion of point intercepts along the seismic line that have shrub species within a given height category (LineShb____), the proportion of point intercepts along the seismic line that have tree species within a given height category (LineTree____), the number of singing events detected by the recognizer for an ASL array regardless of spatial accuracy (Ln-SongCount), and the number of detections which could be accurately localized within an ASL array (Ln-AccurateSongCount).

Model	AIC	K	AIC weight
A) Presence and Relative Abundance			
Probability CAWA Present During Playback Surveys			
Null	109.8	1	0.04
Date	109.1	2	0.05
Date + PropBroadLeaf	108.4	3	0.07
Date + PropBroadLeaf + Line Recovery Rank	106.8	4	0.17
Date + PropBroadLeaf + Line Recovery Category [†]	104.0	6	0.67
Probability CAWA Present on or near ASL array			
Null	65.0	1	0
ForestShb150_200	51.6	2	0.24
ForestShb150_200 + LineShb1_50 [†]	49.3	3	0.76
Ln-Song Count on or near ASL array, if CAWA present			
Null	97.2	1	0
Spatial	87.2	2	0.04
Spatial + ForestShb1_50	86.5	3	0.06
Spatial + ForestShb1_50 + LineShb50_100 [†]	81.2	4	0.89
B) Use of Space			
Average distance of CAWA from seismic line (m), including line			
Null	138.7	1	0.16
Spatial	138.9	2	0.15
Spatial + ForestShb1_50	139.3	3	0.12
Spatial + ForestShb1_50 + LineShb>300 [†]	136.2	4	0.57
Skewness of distance from seismic line (m), including line			
Null	54.1	1	0
Mean distance	47.0	2	0.06
Mean distance + ForestShb100_150 [†]	42.9	3	0.47
Mean distance + ForestShb100_150 + LineShb1_50	42.9	4	0.47
Proportion of points on one side of the seismic line, if CAWA present			
Null	-42.5	1	0
Spatial	-44.2	2	0.01
Spatial + ForestShbDensity	-47.3	3	0.06
Spatial + ForestShbDensity + LineShbDensity [†]	-52.8	4	0.92
Proportion of points on seismic line, if CAWA present			
Null [†]	-124.7	1	0.39
Spatial	-124.0	2	0.28
Spatial + ForestShb100_150	-123.1	3	0.18
Spatial + ForestShb100_150 + LineTree150_200	-122.8	4	0.15
C) Selection			
Selection for one side of the seismic line			
Null	107.4	1	0.12
Ln-AccurateSongCount [†]	106.5	2	0.19
Ln-Song Count + ForestShbDensity	105.4	3	0.33
Spatial + ForestShbDensity + LineShb1_50	105.2	4	0.36

(con'd)

Selection for seismic line			
Null [†]	78.6	1	0.26
Spatial	78.1	2	0.33
Spatial + ForestShb100_150	79.2	3	0.19
Spatial + ForestShb50_100 + LineShb1_50	78.9	4	0.22
Selection for distance to seismic line, including line			
Null	-43.2	1	0.07
Ln-Accurate Song Count	-42.9	2	0.06
Ln-Song Count + ForestShb>300	-43.7	3	0.08
Ln-Song Count + ForestShb>300 + LineShb250_300 [†]	-48.2	4	0.80

[†] Top-ranked model for a given response variable

The skewness of distance to the seismic line was significantly negative (Table 1b) ($t = 2.1$, $df = 20$, $p = 0.052$). This suggests a greater proportion of points per array were closer to the forest interior. The final model to predict skewness included mean distance to the seismic line ($\beta = -0.085$, $SE = 0.022$, $z = -3.8$, $p < 0.001$), average height of shrubs in the forest ($\beta = 0.005$, $SE = 0.002$, $z = 2.64$, $p = 0.02$), and the proportion of VPIs along the line with shrubs 1–50 cm tall ($\beta = 1.154$, $SE = 1.086$, $z = 1.06$, $p = 0.303$). There was no compelling evidence that vegetation on the seismic line influenced skewness (Fig. 5 - BOTTOM, Fig. 6).

The proportion of points on one side of the seismic line (Table 1b) was significantly different than 50% ($t = 9.88$, $df = 20$, $p < 0.001$). The final model included spatial variation ($\beta = -0.584$, $SE = 0.326$, $z = -1.8$, $p = 0.07$), shrub stem density in the forest ($\beta = 0.011$, $SE = 0.004$, $z = 3.1$, $p = 0.003$), and shrub stem density along the line ($\beta = -0.014$, $SE = 0.006$, $z = -2.5$, $p = 0.012$). As shown in Figure 7 - TOP, the proportion of points on one side of the line became closer to 50/50 as the number of shrub stems on the seismic line increased.

About 2% of Canada Warbler locations were estimated to be on the seismic line. Canada Warbler were found on 11 out of 21 seismic lines at arrays where Canada Warblers were detected. The final model included spatial variation ($\beta = 0.319$, $SE = 0.264$, $z = 1.21$, $p = 0.227$), the proportion of VPIs in the forest with shrubs 100–150 cm tall ($\beta = -0.940$, $SE = 0.739$, $z = -1.27$, $p = 0.204$), and the proportion of VPIs along the line with shrubs 1–50 cm tall ($\beta = -1.317$, $SE = 1.417$, $z = -0.93$, $p = 0.353$; Fig. 7 - BOTTOM). However, none of the models provided much better fit than the null.

Selection

Canada Warblers sang from one side of the seismic line significantly more than what would be expected due to random chance ($t = -3.63$, $df = 20$, $p = 0.002$). The final model included ln-accurate song count ($\beta = 0.984$, $SE = 0.545$, $z = 1.81$, $p = 0.09$), shrub stem density in the forest ($\beta = -0.010$, $SE = 0.010$, $z = -0.97$, $p = 0.348$), and the proportion of VPIs along the line with shrubs 1–50 cm tall ($\beta = -5.716$, $SE = 3.911$, $z = -1.46$, $p = 0.162$). There was no compelling evidence that vegetation on the seismic line influenced selection for one side of the seismic line (Fig. 8 - TOP).

While Canada Warblers were observed singing from seismic lines, they sang from seismic lines less than expected based on their availability ($t = -2.27$, $df = 20$, $p = 0.002$). The final model included spatial variation ($\beta = 0.698$, $SE = 0.452$, $z = 1.54$, $p = 0.141$), the proportion of VPIs in the forest with shrubs 100–150 cm tall (β

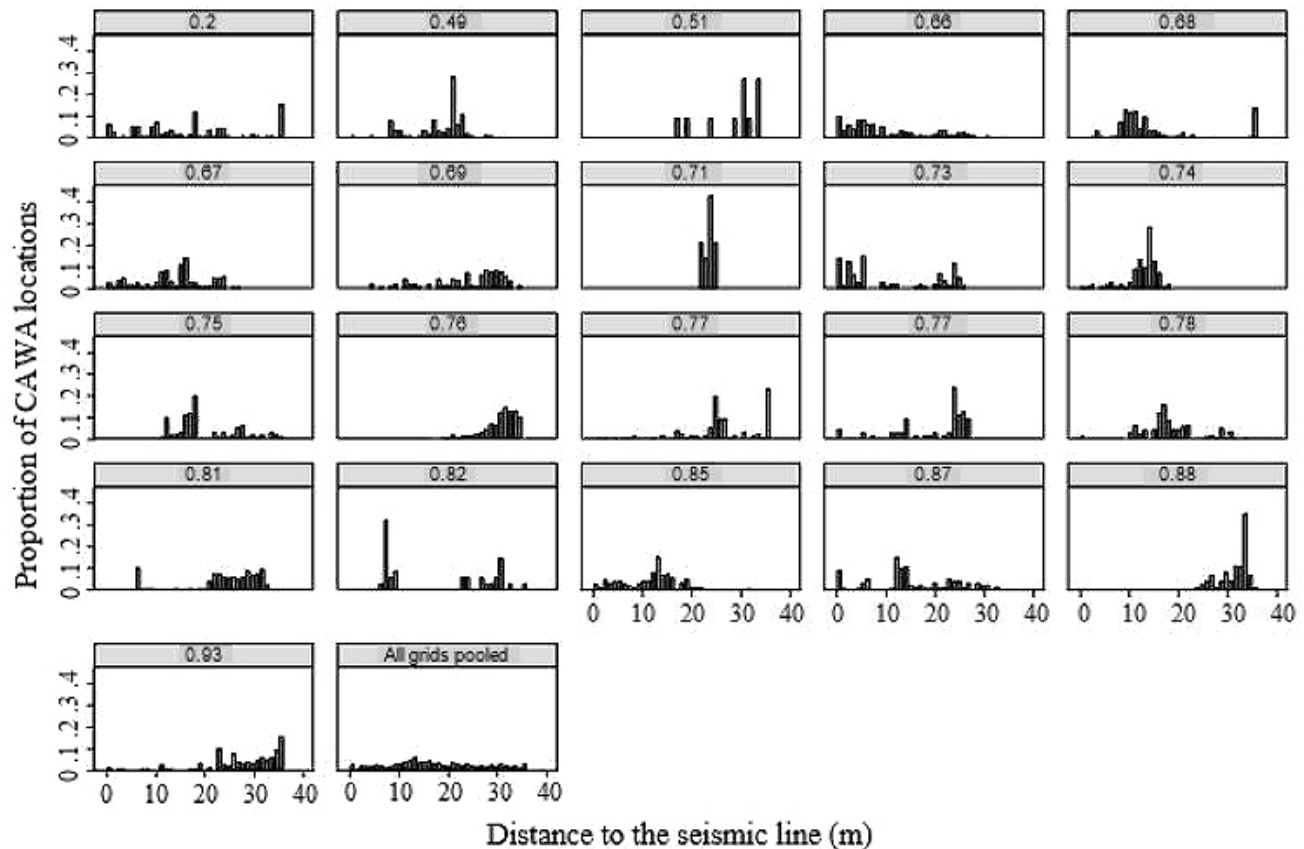
$= -1.576$, $SE = 1.224$, $z = -1.29$, $p = 0.215$), and the proportion of VPIs along the line with shrubs 1–50 cm tall ($\beta = -3.063$, $SE = 2.156$, $z = -1.42$, $p = 0.174$). Overall, there was no compelling evidence that vegetation on the seismic line influenced selection of the line in areas where Canada Warblers are present (Fig. 8 - MIDDLE).

The distance from each Canada Warbler location to the seismic line relative to random locations suggests Canada Warblers used areas closer to the seismic line less than they were available ($t = 2.54$, $df = 20$, $p = 0.020$). The final model included ln-accurate song count ($\beta = -0.014$, $SE = 0.015$, $z = -0.95$, $p = 0.355$), the proportion of VPIs in the forest with shrubs > 300 cm tall ($\beta = 0.148$, $SE = 0.084$, $z = -1.77$, $p = 0.094$), and the proportion of VPIs along the line with shrubs 250–300 cm tall ($\beta = 0.490$, $SE = 0.198$, $z = 2.48$, $p = 0.024$). While this is suggestive of an effect of seismic line vegetation on selection, one array had particularly high leverage (Fig. 8 - BOTTOM) and when removed the proportion of VPIs along the line with shrubs 250–300 cm tall was no longer significant ($\beta = 0.132$, $SE = 0.272$, $z = 0.49$, $p = 0.632$).

DISCUSSION

Among our playback surveys, Canada Warbler abundance was related to the level of vegetation regeneration along the seismic line. Most importantly, the decrease in Canada Warbler abundance near seismic lines was driven by their absence from areas with mostly disturbed lines that have no vegetation recovery (i.e., lines that are forb and low shrub dominated with little or no tall shrub encroachment). This suggests that a Canada Warbler's tolerance for disturbance on seismic lines, at this scale, is relatively high. Consequently, the negative effects of seismic lines on home range placement (2nd order selection) among Canada Warblers in Alberta's Oilsands Region is likely restricted to areas with new, heavily used, or legacy seismic lines that are still in the early seral stages of recovery. Once a seismic line reaches a level of regeneration such that woody shrub and sapling encroachment is present, it is more likely to be an area where Canada Warblers will place their home range in the vicinity of a seismic line. Thus, seismic lines are not likely to cause large edge effects across the region, as it pertains to home range placement, if most lines have at least some woody regeneration. However, what proportion of seismic lines in Alberta meet this criterion is unknown at this time. A broader and more detailed survey effort would be required to establish a specific threshold beyond our line regeneration categories. This includes point counts with distance estimates and an on-site rapid vegetation assessment (i.e., dominant vegetation

Fig. 6. Distance of each Canada Warbler (*Cardellina canadensis*; CAWA) location from the seismic line on each acoustic source localization (ASL) array (n = 21). Arrays are ordered from lowest to highest “proportion of 1 to 50 cm high shrubs on the seismic line”. The site with 0.88 shrub cover has a skewness of -0.98 indicating more of the locations at that array are towards the forest interior. The site with 0.66 shrub cover has a skewness of 0.71 indicating more of the locations at that array are closer to the seismic line. All arrays pooled have a skewness of 0.14.



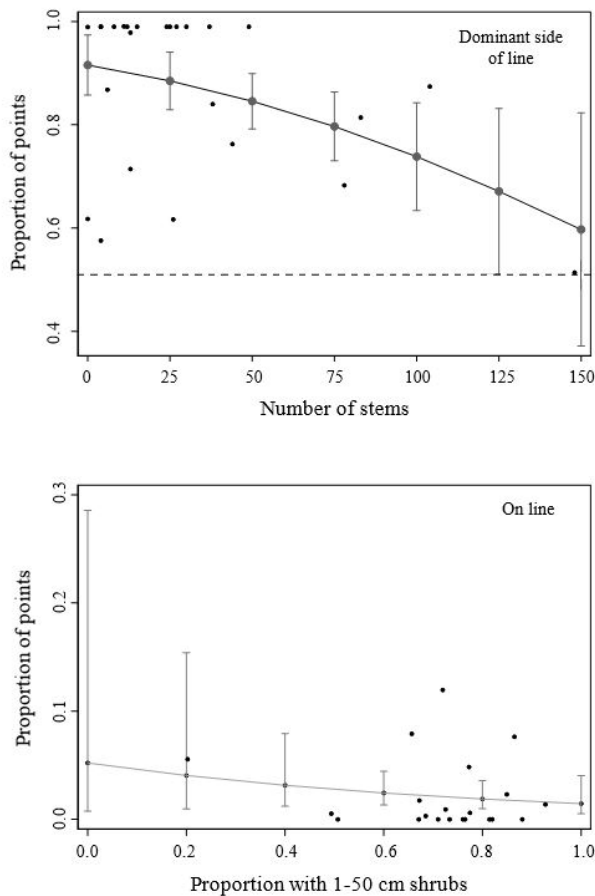
species, density estimates, disturbance characteristics, canopy openness, etc.; Bayne et al. 2011, 2016).

Point counts indicated that Canada Warblers avoided newly created seismic lines or seismic lines that were regularly used by recreational or industrial off-highway vehicles (OHVs). Regular use of OHVs in the boreal forest can impede regeneration on the disturbance and often leads to seismic lines becoming wider over time as operators avoid wet areas, causing damage to the adjacent forest vegetation (Thurston and Reader 2001, van Vierssen Trip and Wiersma 2015). This also means that Canada Warbler avoidance of mostly disturbed lines may not be driven solely by the lack of vegetation on the line. The pattern we observed could reflect the avoidance of areas where OHVs are creating noise or some other form of sensory disturbance (Brumm 2004, Habib et al. 2007, Bayne et al. 2008). Intensity of use and aggregation of human disturbances has a known impact on the behavior and habitat selection of other songbirds (Rich et al. 1994, Miller and Hobbs 2000, Barton and Holmes 2007, Sóllymos et al. 2020). We suggest future studies on seismic lines measure intensity of OHV use to understand why some lines have or have not recovered and

to help separate the relative importance of human use from vegetation recovery.

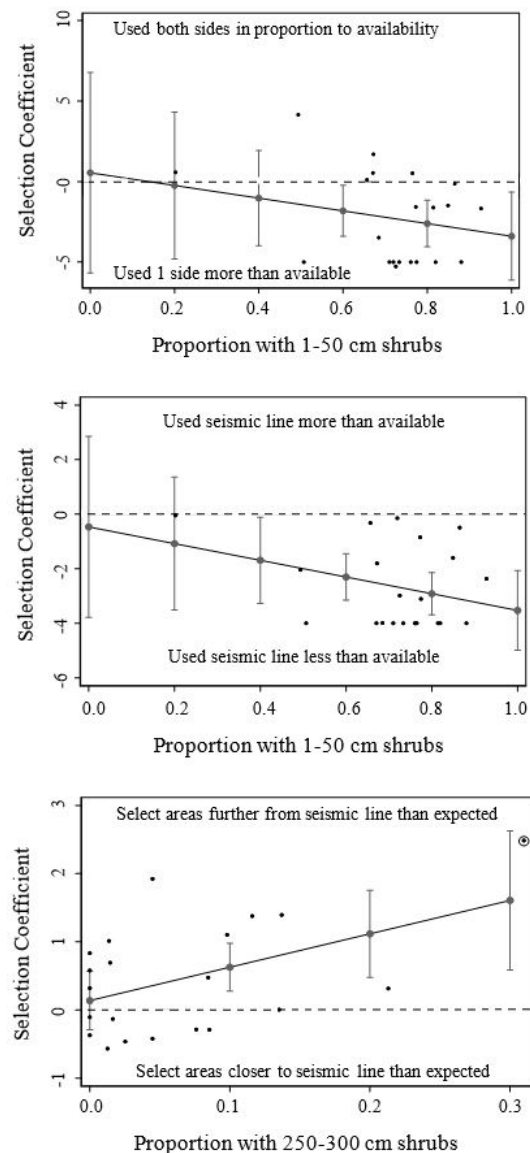
At the ASL arrays, Canada Warbler presence was most influenced by a combination of shrubs both on the seismic line and in the adjacent forest. However, the measure of shrubs on the seismic line that explained the most variation was the number of vegetation point intercepts occurring within the 1–50 cm height category. This suggests that in areas with abundant seismic lines, the presence of shrubs on the line, as opposed to their structure (i.e., height and density), is most influential on territory placement. For a discrete disturbance, the added structure provided through height may not be as important as it would be for a larger disturbance (i.e., a cut block) due to the proximity of cover in the adjacent forest. Given this pattern, we suggest that our use of photographs to assess recovery state may be quite time efficient because it is quite easy to estimate horizontal cover of shrubs from photographs. However, for future studies, we suggest placing a known size object at a set distance from the camera as this would further aid in assessing shrub height.

Fig. 7. (TOP) – Proportion of Canada Warbler (*Cardellina canadensis*; CAWA) locations on the dominant side of the seismic line as a function of the number of shrub stems per 30 m² quadrat (n = 21). The dashed line indicates what would be expected if CAWA locations were randomly distributed across the seismic line. (BOTTOM) - Proportion of CAWA points on the seismic line as a function of the proportion of locations with 1–50 cm high shrub stems on seismic line (n = 21). Error bars are 95% confidence intervals of predicted values shown at 5 levels along a continuous gradient for visual clarity.



Among those ASL arrays where Canada Warblers were present (n = 26), they were found to be more actively engaged in territorial behavior (i.e., more singing events detected) when there were more shrubs within the 50–100 cm height class along the seismic line. We argue that this may be an underestimate of the actual shrub height required due to the point intercept method used in vegetation surveys; with this technique the younger, and therefore shorter, lateral branches near the top of a shrub are less likely to ‘intercept’ the pole. Regardless, Canada Warblers are more likely to place their territories near a line when the shrubs are more established. Canada Warblers also appeared to sing directly from the seismic line more often when taller vertical structures were present, but we did not have sufficient data to confirm such an effect.

Fig. 8. Average selection coefficient for proportion of points used vs. available for all acoustic source localization (ASL) arrays (n = 21): (TOP) on one side of the seismic line as a function of number of shrubs stems per 30m²; (MIDDLE) on versus off the seismic line as a function of the proportion of locations with 1–50 cm high shrub stems on seismic line; (BOTTOM) for distance from the seismic line as function of the proportion of locations with 250–300 cm high shrub stems on seismic line. Error bars are 95% confidence intervals of predicted values shown at 5 levels along a continuous gradient for visual clarity. The solid line indicates use proportional to available. The point circled had high leverage, and when removed resulted in a non-significant and flatter relationship between the selection coefficient and vegetation variables.



Given that a Canada Warbler has placed its territory near a seismic line, our results show that they will use the seismic line and the forest edge, but they still perceive the line as being present based on use and selection, even when the vegetation on the seismic line is dense. Only 2% of all singing events were identified on the seismic line. If the territory of a Canada Warbler fits within the bounds of an ASL array (0.98 ha), centered on a 6 m wide seismic line, and birds sang in random locations within their territory, then approximately 8.6% of all singing locations should be on the line. The average distance of all detections from the disturbance was 19.9 m with a significantly negative skew indicating the birds did not randomly place their territories relative to seismic lines. These results did not vary significantly in relation to vegetation conditions on the seismic line but do suggest a localized edge response exists. Changes in understory plant species in upland deciduous and mixed-wood forests typically occur within 10–20 m of the edge depending on disturbance width (Harper and Macdonald 2002, Dabros et al. 2017, Stern et al. 2018). In particular, Dabros et al. (2017) found that changes to woody-species composition and abundance were largely contained within the disturbance footprint, whereas effects on herbaceous plant composition and cover were found up to 15 m away from the seismic line. As such, shrubby species would maintain the vertical understory structure up to the seismic line edge, providing singing perches for territorial defense. Alternatively, the described changes to herbaceous plants may reduce protective cover on the ground and alter microclimate conditions, potentially affecting food resource availability and nest placement (Goodnow and Reitsma 2011, Lankau et al. 2013, Dabros et al. 2018, Stern et al. 2018, Franklin et al. 2021). Regardless, we observed negative skewness of singing locations suggesting that changes to edge vegetation are not attracting Canada Warblers toward seismic lines.

Within our study, Canada Warblers sang from both sides of the seismic line and were observed crossing the line. Alternatively, we found evidence of selection for one side over the other on most ASL arrays. Selection for the dominant side of the seismic line could not be attributed to vegetation on the line, but the proportion of singing events detected on either side was closer to 50/50 with higher shrub density on the disturbance and in the forest. Due to a naturally occurring understory complexity within Canada Warbler habitats, seismic lines with fewer shrubs may be more distinguishable and represent a landmark feature where individuals place their territorial boundaries (Lankau et al. 2013). If this is the case, then the Canada Warblers we observed on each array may have been two individuals each holding a territory on either side. Alternatively, this could reflect less resistance to crossing seismic lines and a greater propensity for a single individual to include the seismic line within their territory. Unfortunately, we could not determine which scenario is most likely using sound localization. The sampling area of the ASL arrays was approximately 1 hectare so it is probable these results show the behavior of a single individual, however, average territory size for Canada Warblers has been shown to range anywhere from < 0.18 to 3.3 ha depending on conspecific density (Machtans 2006, COSEWIC 2008, Hallworth et al. 2008a, Hallworth et al. 2008b, Flockhart et al. 2016).

While our study does show evidence of altered behavior around seismic lines, it is important to consider several limitations. First,

the use of playback recordings can influence the movement of birds and skew the effect sizes of our results (Zuberogoitia et al. 2011). We mitigated this, to the extent possible, in our survey methods by including 3 minutes of silent listening prior to broadcasting Canada Warbler songs. Second, the area and layout of an ASL array means in some cases we may have captured the entire territory of an individual and in other cases only a small portion. Therefore, we could not establish their entire range of movements around the seismic line. As well, the ASL arrays were laid out around a seismic line and offset toward one side. At most, the arrays extended approximately 35 m into the adjacent forest on the side toward which the array was offset. As such, our capacity to capture the full range of movement is limited for Canada Warblers that have a territory centered away from the seismic line. Given a larger array size, it is likely we would see an increase in average distance and a stronger negative or neutral skew of detections away from the seismic line. Third, we were unable to conclusively identify the number of individual territories that occurred on our ASL arrays. The spatial variation nuisance variable is assumed to have partially accounted for multiple individuals on each ASL array. Our original intent with this research was to use song characteristics to identify individuals and track their movements across ASL arrays. However, our results were not accurate enough to draw firm conclusions (Wilson and Bayne 2018 present a situation where this approach did work). Further research which focuses on individual Canada Warbler movements and incorporates detailed vegetation surveys both on and off the seismic line would be valuable to verify the preference for one side of the seismic line and avoidance of crossing seismic lines with limited woody vegetation regeneration.

As a species with high conspecific attraction, the presence of other Canada Warblers is likely to significantly influence an individual's territorial behavior. In a study area close to ours where forest harvesting was the dominant land use, Hunt et al. (2017) found that Canada Warblers were more likely to be found near conspecifics regardless of stand quality. This suggests the presence of different numbers of individuals may change how Canada Warblers behave around seismic lines. Detailed spot-mapping and telemetry of Ovenbirds has shown they place their territories further away from seismic lines when density of conspecifics is low but are more willing to cross seismic lines (Machtans 2006, Lankau et al. 2013). Conversely, in areas with high conspecific density, Ovenbirds are more likely to defend territories right up to the edge of conventional seismic lines but use them as territorial landmarks resulting in fewer instances of crossing the seismic line. Future work on how the state of regeneration affects Canada Warblers' perception of seismic lines should include more information on conspecific density.

Combined, our results show that there is a behavioral response among Canada Warblers to vegetation regeneration on seismic lines. However, whether this has effects on Canada Warbler populations requires further investigation. Sólmos et al. (2020) used a pooled dataset of more than 60,000 point counts from across Alberta to assess whether seismic lines and other energy sector footprints influenced Canada Warblers at two spatial scales (150 m radius around a survey location and in the 1 km² section area that the point count was located in). In their analysis, all seismic lines were treated the same in terms of vegetation recovery.

Locally, they found a negative but insignificant effect of seismic lines on Canada Warbler abundance (Ball et al. 2016, Sólymos et al. 2020). However, when the proportion of seismic lines was beyond 3% of the total area in the surrounding square kilometer they found lower Canada Warbler densities. Ultimately, there is an indication that seismic lines have a negative impact on Canada Warbler numbers, however, it does not translate to large or statistically significant regional changes in population. Research into remote sensing techniques that can more efficiently capture vegetation information along seismic lines is ongoing (Chen et al. 2017, Wilson et al. 2020) and has potential to clarify these results when estimating population level impacts.

Our results have implications for the future research and conservation of Canada Warblers. Conservatively, approximately 35% of the oil sands region within Alberta contains potential Canada Warbler habitats (Ball et al. 2016). In the western Boreal Plains, only 8.2% of conventional seismic lines have regenerated at least 50% woody vegetation cover by aerial photo estimates (Lee and Boutin 2006). The effects on population may not yet be apparent at a regional scale, whereas, the presence and density of woody vegetation on the seismic line have been shown to influence the behavior of Canada Warblers. Woody revegetation of seismic lines will reduce their function as landmark features and minimize fragmentation effects. This highlights the importance of understory vegetation to functional restoration and can inform strategies for seismic line recovery that are directed toward upland forests. Based on the results of this study, successful functional restoration of seismic lines for Canada Warblers and similar ground or shrub nesting species would include woody revegetation to a minimum average height of 1 m at a density equivalent to that of the adjacent forest. Techniques such as the incorporation of shrub species that align with the adjacent habitat into planting operations and restrictions on OHV traffic would promote and maintain overall regeneration. As such, given recent and evolving techniques in seismic exploration, which limit initial disturbance and an approach to restoration that is conscientious of the pre-existing habitat, we believe it is feasible to achieve a functionally restored seismic line in upland habitat from the Canada Warblers' perspective.

Responses to this article can be read online at:
<https://www.ace-eco.org/issues/responses.php/2262>

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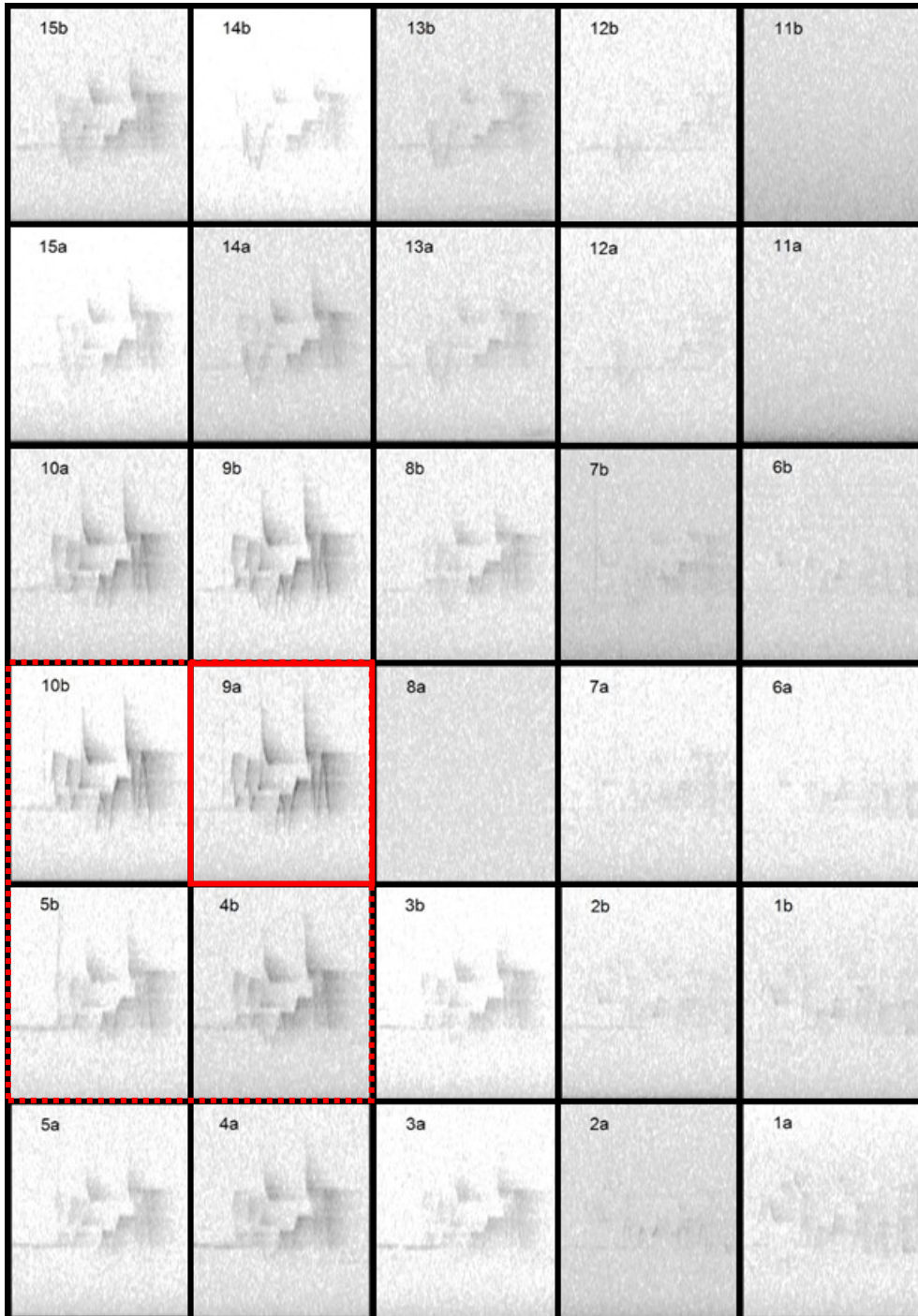


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Appendix 1. The spectrogram display of a single singing event as it was detected across all stations in an ASL array. The visualization was created using R statistical computing software and the panels have been re-arranged to reflect the layout of the ASL grid and orientation of each channel. The numeric values represent the station; a or b indicate the channel (left and right microphone, respectively). The red dashed line shows the 4 channels selected for localization; the solid red line indicates the channel (microphone) that the singing event was closest to. Proximity can be determined by the intensity and definition of the spectrogram within panel 9a.



Appendix 2. Categories to filter MSRP detections using a visual scan of the ASL array spectrogram display.

To ensure the most accurate locations were used for further statistical analysis, detections were categorized based on the quality of recording and our best estimate of its position relative to the ASL array. Tables A2.1 through A2.3 provide a visual description of these categories. Figure A2.1 below shows the layout of the site used in these examples. This is provided because the alignment of stations in the output of the array visualization script is transposed. The station channels are also shown left to right which may not be consistent with the site layout.

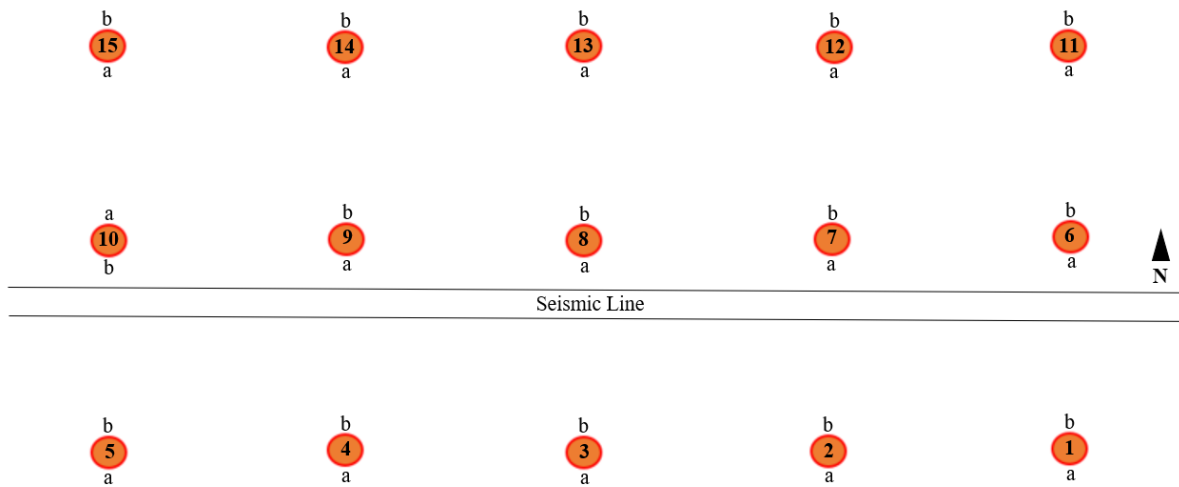
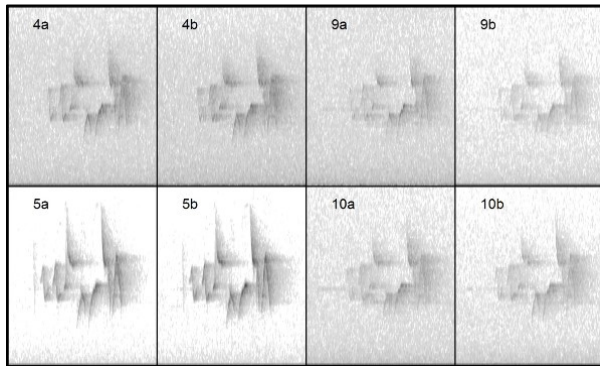


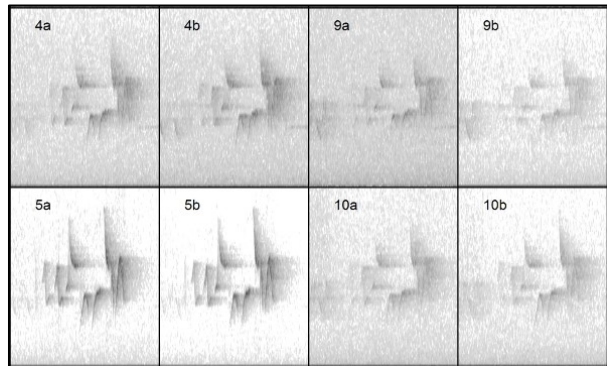
Figure A2.1. The array format of the recordings used in the examples provided for filtering MSRP detections based on the array visualization script. “a” represents channel 1 or the left microphone if you are facing the unit; “b” represents channel 2 or the right microphone. ARUs were not able to consistently face in the same direction based on impeding vegetation or unevenness of the tree trunk itself.

Table A2.1. Spectrogram quality: this describes the quality of a detection as it appears on the four stations selected for localization. Quality of detection considers interference within the time and frequency domain of the clip which would otherwise influence the accuracy of the MSRP localization method. Each example below includes a clip of the same four stations (4,5,9 and 10) from the array visualization script output which was used to determine the categories. The categories are labeled as 0 (no interference, ideal for localization), 1 (no or minimal interference within the frequency range, low intensity interference within time range), 2 (interference within the time and frequency range, either being abundant low to moderate intensity interference or a single high intensity source of interference), and 3 (interference within the time and frequency domain such that it masks the target song and localization would not be reliable).

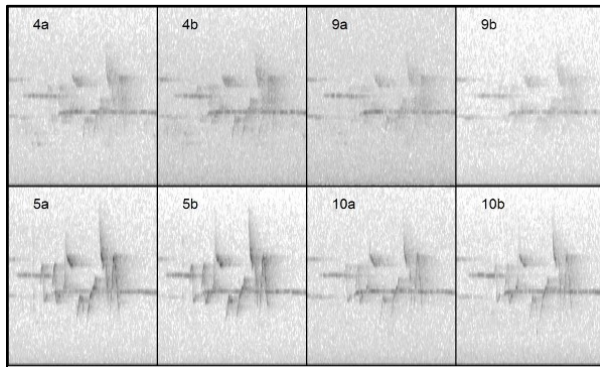
(a) Quality: 0



(b) Quality: 1



(c) Quality: 2



(d) Quality: 3

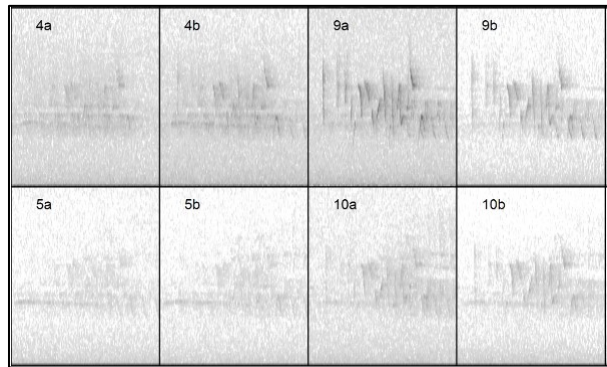
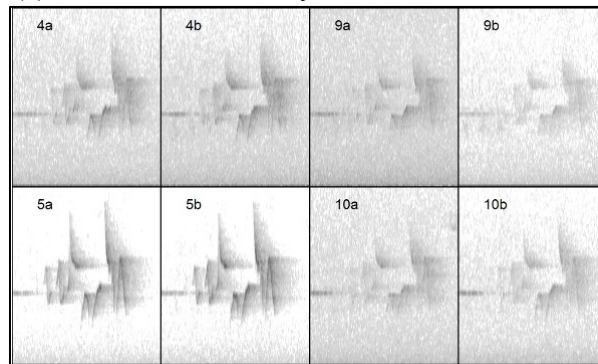


Table A2.2. Contained by the array: this category describes whether a singing event was likely to be within or outside of an ASL array. The approximate location of a singing event could be determined by the relative intensity of the spectrogram amongst ARU stations at a site. The direction it was originating from could then be distinguished by comparing its relative intensity amongst channels at a given station and the orientation of the respective microphones. In (a), the song is close to station 5, however appears most defined among channels 4a and 5a which are oriented towards the outside of the array; in (b), the song is closest to station 9 which is on the interior of the array, as well as most intense among channels 9a and 4b which are oriented towards each other.

(a) Outside of the array



(b) Inside the array

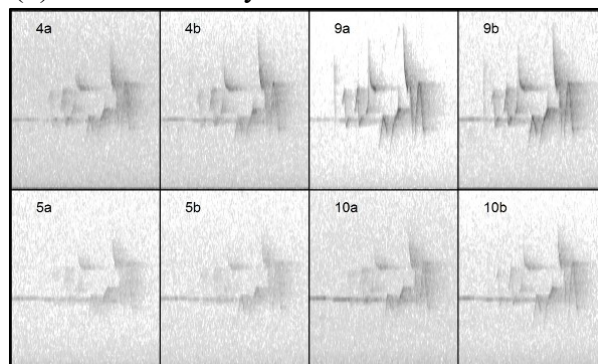
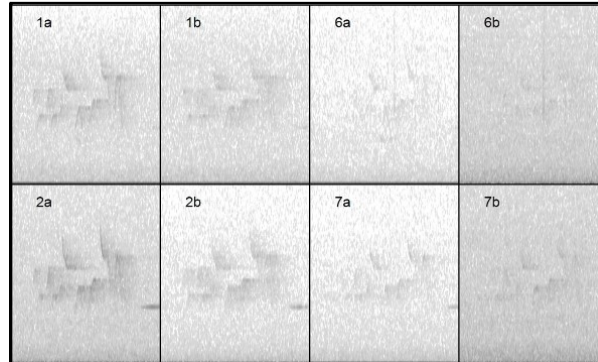


Table A2.3. Proximity to the edge: if singing events were close to the edge of an ASL array, it could be difficult to determine whether it was inside or outside of the array perimeter. This category was included to prevent these locations from being pre-emptively eliminated from the analysis if their approximate location could not be easily distinguished from the visual scan. In (a), the song is closest to station 2 which is located on the edge of the array but has a very low intensity, suggesting that it is far away; in (b), the song appears with a high intensity on station 5, indicating that it is very close to this station, which is on the edge of the array.

(a) Away from the edge



(b) Close to the edge

