Influence of forestry and conspecific attraction on habitat use and reproductive activity of the Canada warbler (*Cardellina canadensis*) in the western boreal forest: Implications for critical habitat identification

by

Anjolene R. Hunt

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Department of Biological Sciences
University of Alberta

ABSTRACT

Recovery strategies for species at risk are legally mandated in Canada and the Government of Canada must identify which habitat is important for a species and which activities result in its destruction. The Canada Warbler (*Cardellina canadensis*) has been designated as a threatened species in Canada due to large population declines (~3% annually over the last 50 years). Forestry has been identified as a threat, but some studies suggest it can create productive breeding habitat. I quantified multiple orders of habitat use to study the response of the Canada Warbler to forestry, accounted for the effect of conspecific attraction which may affect habitat use patterns, and assessed how use patterns influenced reproductive activity.

Specifically, my first objective was to quantify the relative importance of forestry-related stand metrics versus conspecific proximity on multiple levels of habitat use of Canada Warblers. I used point count surveys and tracked individuals to determine density, 2nd and 3rd order habitat use, and probability of pairing and fledging young for male Canada Warblers in Alberta, Canada. I found fewer territorial males in survey blocks with more harvesting, effects which were not mitigated by retention of unharvested fragments, stand regeneration ≤30 years post-harvest, or abundance of old-growth stands in the surrounding matrix. Male home ranges (2nd order use) in post-harvest were typically near edges of adjacent unharvested stands and near conspecifics. Males also had higher intensity of use in areas within their home ranges (3rd order use) that were further from edges and nearer to conspecifics. This suggests that forest harvesting poses a threat to Canada Warblers in Alberta, and that post-harvest stand use reported in other studies may be influenced more by conspecific attraction than by attributes of post-harvest stands themselves. Hence, large tracts of unharvested stands should be protected in Alberta, with higher

prioritization in areas where territories are already established to support the Canada Warbler's clustered distribution, and only post-harvest stands near conspecifics and near unharvested stands should be considered usable.

My second objective was to test whether males using post-harvest stands suffered consequences to pairing success and/or probability of fledging young and whether density reflected these metrics of reproductive success. I found that use of post-harvest stands did not affect probability of pairing or fledging young, but that pairing success was lower when male densities were high.

My final objective was to discuss potential reasons for discrepancies between conclusions about the effects of forestry on Canada Warblers across their breeding range, and provide specific recommendations to aid designation of critical habitat for this species. These include using information from breeding-range-wide point counts to determine important parts of the range to protect (i.e. areas with large breeding populations) and population recovery targets, in conjunction with studies specific to each Bird Conservation Region within the breeding range that address habitat quality, land-use effects, and clustered habitat use. At a minimum, incorporating proximity to undisturbed habitat and to conspecifics in regional models could provide valuable information when prioritizing areas for conservation.

PREFACE

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CHAPTER 1: INTRODUCTION

Declines in population size of many bird species in North America are leading to a growing number of studies working to identify their habitat needs, threats, and strategies for recovery required by governmental agencies (e.g. Species at Risk Act [hereafter: "SARA"], Government of Canada 2011; Endangered Species Act, Fish and Wildlife Service 1973). However, the "best available data" for these assessments are rarely consistent in methodology (e.g. type of habitat association metric employed, spatial and temporal scale), inclusion of non-vegetation attributes (e.g. social cues, predators), demographic data, and ecological context (e.g. geographic area). Thus, managers have to work with a wide variety of contradictory and incomplete information when making decisions about species at risk and how they should be protected. Many authors have suggested that studies at multiple spatial scales are necessary to understand the context of an animal's association with an area or habitat type (Hutto 1985, Boyce 2006, Meyer and Thuiller 2006), demographic data is necessary to define habitat quality (Van Horne 1983, Johnson 2007), and assessing how non-vegetation attributes affect use patterns is essential to understand which areas will be used by a species versus which areas are suitable for use (Campomizzi et al. 2008).

1.1 Legislation to protect species at risk

Preserving rare or at-risk species is an objective of sustainable forest management in Canada (Natural Resources Canada 2016). Furthermore, SARA legally requires recovery plans for threatened species to be released within two years of listing (Government of Canada 2011), which should identify critical habitat i.e. "the habitat necessary for the survival or recovery of a listed endangered, threatened or extirpated species in Schedule 1 of SARA", and the activities which threaten that habitat. This process of habitat and threat identification can be extremely difficult when adequate information on habitat associations is unavailable, or contradictory. As a result, a large proportion of species (>50%) with finalized recovery strategies do not have critical habitat defined, and many other listed species still do not have recovery strategies released (Mooers et al. 2010, McCune et al. 2013).

1.2 Threats and conservation issues of boreal songbirds

Canada's boreal forest is one of the largest and least-disturbed forests remaining on earth (Andrew et al. 2012). It is comprised of a mosaic of wetlands (e.g. bogs and fens) and forested areas (coniferous and deciduous) of different ages and composition which were historically regulated mainly by natural processes (e.g. forest fires and insect outbreaks; Rowe and Scotter 1973). The natural disturbance regimes of the boreal forest make for a patchy landscape that supports a wide diversity of species including over 300 breeding bird species, 35 of which have over 80% of their breeding population exclusively in the boreal forest (Wells et al. 2011). Since the turn of the century, there have been extensive anthropogenic changes to the boreal system that pose high risk threats to bird species such as expansion of: "agriculture, linear features, biological resource use, human intrusions and disturbance, natural system modifications, invasive and other problematic species, and pollution" (Environment Canada 2013, Langor et al. 2014, Bayne et al. 2016, Loss 2016, Mahon et al. 2016).

Whereas permanent conversion of forested to non-forested areas results in definitive habitat loss, non-permanent disturbances such as forestry involve relatively short-term habitat loss and alteration of stand structure. Following a disturbance, forests regenerate through a successional process, transforming from early seral stages dominated by shrubs with little vertical structure to in late seral stages with complex vertical diversity and high densities of large, old trees (Huettmann 2003). Forestry companies are attempting to mimic effects of natural disturbances on forest ecosystems (Huettmann 2003), which should result in structural heterogeneity that provides suitable habitat for a wide range of species with differing habitat/seral requirements. Reviews of forestry effects on birds showed positive, neutral, and negative effects on abundance and species richness, and responses depended on forest type, harvest method, and species life-history (Wedeles and Donnelly 2004, LaManna and Martin 2016). Generally, as a result of forestry practices, the boreal forest is becoming more homogeneous (i.e. lower proportion of mixed-wood stands and coniferous stands; Hobson and Bayne 2000a, Venier et al. 2014) , stand structure is becoming less complex (Venier et al. 2014), and old-growth stands are becoming less common (Huettmann 2003, Venier et al. 2014), which could pose issues to species that rely on old-growth, mixed-wood, or structurally complex conditions.

Certain species have life history traits and habitat needs that make them particularly vulnerable to forestry-related change (Schieck et al. 1995, Bayard and Elphick 2010, Lee and Jetz 2011). Habitat specialists, particularly those that require vegetation structure associated with old-growth forests, are limited in their ability to respond to rapid changes in vegetation via disturbance (Schieck et al. 1995, Huettmann 2003, LaManna and Martin 2016). Dispersal movements of individuals following forest disturbance can result in crowding into remaining undisturbed areas (Schmiegelow et al. 1997, Harrison et al. 2005). Likewise, area-sensitive species will only occupy or reach high abundance in large habitat fragments (reviewed by Bayard and Elphick 2010), and will be more affected than area-insensitive species by fragmentation of suitable habitat. For forest species that rely on old-growth stands, the benefits and drawbacks of single large or several small (SLOSS) fragments of undisturbed forest have been highly discussed in the literature (Simberloff and Abele 1982, Bayard and Elphick 2010, Smith et al. 2011), but habitat loss is generally considered more important than habitat alteration or fragmentation in boreal ecosystems (Schmiegelow and Mönkkönen 2002, Smith et al. 2011, Fahrig 2013). Neotropical migrants also may be particularly susceptible to habitat alteration from forest management on the breeding grounds (Hutto 1985, Lee and Jetz 2011). Because of the short time long-distance migrants spend in the boreal breeding grounds, these species may have less time than resident and short-distance migrants to find breeding locations after disturbances resulting in habitat loss and fragmentation (Schmiegelow et al. 1997, Ahlering et al. 2010). Furthermore, migratory species must deal with threats on both the breeding and wintering grounds, and along their migratory routes which can affect timing of breeding events, survival and productivity on the breeding grounds (Saino et al. 2004, González-Prieto and Hobson 2013, Drake et al. 2014), and act cumulatively with effects on the breeding grounds.

1.3 Knowledge gaps about effects of forestry on birds

Ecological processes that affect habitat use occur at different spatial scales (Addicott et al. 1987, Boyce 2006, Holland and Yang 2016), so studies that measure processes at different spatial scales or orders of habitat use may arrive at different conclusions about habitat associations and threats. Patterns of habitat use can also vary across a species' geographic range, particularly for species with large breeding ranges, as the available vegetation types and the extent and type of disturbance can vary regionally (Welsh and Fillman 1980, LaManna and Martin 2016). Furthermore, habitat-specific density estimates have often been used as a proxy for habitat quality (Johnson 2007), and although there is strong evidence supporting this claim (Bock and Jones 2004), there are instances of non-ideal habitat use where probability of fledging young is lower in habitat types supporting higher densities (Van Horne 1983, Pärt et al. 2007). Hence, densities in harvested areas may not be a good proxy for breeding success. Lastly, habitat structure is not the only factor affecting species' use patterns, and inclusion of factors such as prey availability, predator abundance, conspecific attraction, interspecific competition can all improve our understanding of habitat associations and threats (Hutto 1985, Jones 2001, Rodriguez et al. 2001, Ahlering et al. 2010).

1.4 Study species and research objectives

The Canada Warbler (*Cardellina canadensis*) is a small neotropical migratory bird which breeds primarily in Canada's boreal forest (>75% of breeding population; Partners in Flight 2013). Population declines of ~3% annually over the last ~50 years have resulted in this species being listed as threatened in Canada, and a recovery strategy was recently released (Environment Canada 2016a). This strategy is based on the best available information, but includes contradictory information about habitat requirements and threats across the breeding range, which make the identification of critical habitat and threats difficult. It also acknowledges the paucity of demographic data across most of the breeding range (but see Hallworth et al. 2008a, Goodnow and Reitsma 2011a, Becker et al. 2012) and uncertainty about how these processes relate to density, making it difficult to assess habitat quality. The Canada Warbler has a large extent of occurrence, but is patchily distributed across its breeding range in diverse landscapes across the boreal region of Canada, through the northeastern U.S. and south along the Appalachians (Reitsma et al. 2010). Canada Warblers are associated with forested areas with shrubby understories, but their associations with certain forest types and ages and the effects of forestry activities are less clear (reviewed by Reitsma et al. 2010, Environment Canada 2016a). They have been reported to use old-growth aspen in the western boreal (Schieck et al. 1995, Schieck and Song 2006, Ball et al. 2016), younger mixed-wood stands in eastern Canada (Drapeau et al. 2000, Lambert and Faccio 2005), swamps and second-growth forests in the eastern U.S. (Hallworth et al. 2008b), and rhododendron thickets in the southern U.S. (Becker et al. 2012). While forest harvesting seems to have a negative effect on abundance of Canada Warblers in the western breeding range (Schieck and Hobson 2000, Schieck and Song 2006, Ball et al. 2016), neutral or positive effects have been reported in the eastern breeding range (King and DeGraaf 2000, Hallworth et al. 2008b, Becker et al. 2012).

Canada Warblers have a short breeding season relative to other migratory songbirds (Flockhart 2010). Within days of arriving on the breeding grounds, they pair with a mate if they did not arrive together, and begin nesting within a few days (Reitsma et al. 2010), leaving limited time for individuals to assess habitat quality and search for mates. This aspect of the species' breeding phenology and its clustered distribution (Reitsma et al. 2010) suggests that Canada Warblers are likely to exhibit conspecific attraction, a behavioral phenomenon where animals settle in areas near conspecifics. Birds arriving on the breeding grounds earlier are likely older and more experienced individuals (Flockhart 2007), and are expected to secure high-quality habitat (Nocera et al. 2009, McKellar et al. 2014). Later arriving birds or inexperienced birds might benefit from using presence of conspecifics as a habitat selection cue (Stamps 1988, Beauchamp et al. 1997, Nocera et al. 2009).

Few studies have documented breeding success of Canada Warbler (but see Hallworth et al. 2008a, Goodnow and Reitsma 2011a, Becker et al. 2012). Nests are well concealed on the ground near logs or hummocks and females are not prone to flush from the nest easily, which makes nests difficult to find without behavioral observations (Reitsma et al. 2010). Hence, most studies on this species have employed coarse measure of breeding success using evidence of pairing or provisioning of young (≥1 fledging) from behavioural observations (Flockhart et al. 2016, Hallworth et al. 2008a, Reitsma et al. 2008a). There is no current evidence that forest harvest affects breeding success of Canada Warblers (see Hallworth et al. 2008a, Becker et al. 2012), but some research suggests that density is not necessarily a good proxy for breeding success for this species (Flockhart et al. 2016).

1.5 THESIS OUTLINE

The main objectives of this thesis were to: 1) assess the relative importance of effects of forestry and conspecific attraction on Canada Warbler habitat use and reproductive activity in northern Alberta (Chapter 2); and 2) discuss potential reasons for discrepancies between conclusions about the effects of forestry on Canada Warblers across their breeding range, and provide specific recommendations to aid designation of critical habitat for this species (Chapter 3).

In Chapter 2, I demonstrated how multiple spatial scales of habitat use and behavioural phenomena can be used to understand responses to forestry, and assessed whether density and use patterns affect individual reproductive activity. Specifically, I assessed how forestry-related stand metrics and conspecific cues affect 2nd order use (location of home ranges), 3rd order use (intensity of use within the home range), and density within ~17 ha survey blocks. Then, I tested for effects of forestry-related vegetation cues and density-dependent processes on pairing and probability of fledging young. In chapter 3, I compared and contrasted results and recommendations from this thesis with those from regional and local studies across the breeding range (reviewed by Reitsma et al. 2010, Environment Canada 2016a) and a breeding-range-wide study (Hache et al. 2014) to assess the data requirements to understand habitat needs and threats for this species-at-risk.

CHAPTER 2: INFLUENCE OF FORESTRY AND CONSPECIFICS ON CANADA WARBLER (*CARDELLINA CANADENSIS*) HABITAT USE AND REPRODUCTIVE ACTIVITY

2.0 SUMMARY

Recovery planning for species-at-risk requires identifying important habitat, the threats to that habitat, and the effects of habitat use on fitness. Scale-dependent differences in habitat use and behavioural phenomena such as conspecific attraction can lead to habitat use patterns that can be difficult to explain by vegetation structure or composition alone. Differences in the order of habitat use considered among studies and relative importance of conspecific attraction across the species range could explain variation in the effects of forest harvesting that have been reported for species of conservation concern such as the Canada Warbler (*Cardellina canadensis*). Our objective was to quantify the relative importance of forestry-related stand metrics versus conspecific proximity on multiple levels of habitat use and reproductive activity of Canada Warblers. We used point count surveys and tracked individuals to determine density, 2^{nd} and 3^{rd} order habitat use, and probability of pairing and fledging young for male Canada Warblers in Alberta, Canada. Forest harvesting had negative effects on density and 2^{nd} order use. There was limited evidence that local vegetation structure, forest age within post-harvest stands, or retention of unharvested fragments influenced use of harvested areas. However, males were more likely to use post-harvest stands in areas close to adjacent unharvested stands, and areas near conspecifics (2^{nd} order). Within the home range (3^{rd} order), intensity of use was highest in unharvested stands, closer to conspecifics, and further from post-harvest-unharvested edges but was not influenced by local vegetation structure. Lastly, there was no evidence that forestry affected pairing or probability of fledging young. However, pairing success was lower in areas

with a higher density of Canada Warblers. Overall, this suggests that to accommodate the clustered distribution of Canada Warblers, the retention of large tracts of unharvested forest, particularly in areas where occurrence is known, is warranted.

2.1 INTRODUCTION

Conservation of species-at-risk requires the identification of their habitat requirements (i.e. habitat required for survival and recovery) and the human activities likely to result in the destruction of that habitat (Fish and Wildlife Service 1973, Government of Canada 2011). In legally designating the habitat requirements of a species, there is considerable uncertainty about how to integrate data from different studies collected at varying spatial scales, as different ecological processes and cues affect habitat associations at various scales (Addicott et al. 1987, Meyer and Thuiller 2006, Lele et al. 2013). Thus, multi-scale approaches are needed to understand habitat associations and threats to species of conservation concern (Hutto 1985, Meyer and Thuiller 2006). The hierarchical orders-of-selection concept, proposed by Johnson (1980), provides a useful framework to assess habitat use (i.e. the way a species or individuals utilize habitat to meet their life requirements; Jones 2001). Studying habitat use at lower orders provides information about local populations, while studying use at higher orders (hierarchically nested in lower orders) provides specific information on resources supporting individual life requirements, (e.g. nesting, foraging; Meyer and Thuiller 2006). Unlike habitat selection (i.e. a behavioural process resulting in disproportionate use of a certain habitat type relative to the availability of that type; Hutto 1985), habitat use does not require assumptions about the habitat type and amount available to an individual (Jones 2001, Kertson and Marzluff 2011). For example, to determine that an animal "selected" one resource unit relative to another resource unit (tangible items distributed over space and time; Lele et al. 2013), we would have to assume that each resource unit was encountered by the animal. Furthermore, differences in practitioners' definitions of extent and number of available resource units can result in different probabilities of selection (Kertson and Marzluff 2011, Lele et al. 2013). Hence, assessing habitat use (e.g. used vs. unused or intensity of use) provides important data on habitat needs within or across habitat types without arbitrarily defining availability (Marzluff et al. 2004, Kertson and Marzluff 2011).

Presence/absence from avian point count surveys is often used to determine where forest songbirds will place their territories (2^{nd} order use; Rosenstock et al. 2002, Bart 2005, Simons et al. 2007). Density estimates (i.e. the number of individuals/unit area) or relative abundance (i.e. the number of individuals/sample) can also be generated from such data (Hache et al. 2014, Bayne et al. 2016). Forest type, amount, stand age, edge, and configuration are often important predictors of 2^{nd} order use and density for most forest songbirds (MacArthur and MacArthur 1961, Smith et al. 2011), and have been widely used to characterize habitat requirements (reviewed by Jones 2001). Where birds spend the most time within their home range (i.e. 3^{rd} order use) remains unknown for many species (but see Marzluff et al. 2004). Because 3^{rd} order use is nested within2^{nd} order use, it can only vary within the resource units included in a home range (Meyer and Thuiller 2006), and so it should be more strongly influenced by local vegetation features correlated with food availability, concealment from predators, and nesting sites (Meyer and Thuiller 2006).

Although vegetation characteristics are a strong predictor of habitat use in forest songbirds, there is growing evidence that social cues are important to assess habitat quality (reviewed by Ahlering et al. 2010). Use of such cues can result in conspecific attraction, where individuals are more likely to use areas near conspecifics despite more or equally suitable habitat structure existing elsewhere (Stamps 1988, Ahlering et al. 2010). Conspecific attraction can be quantified by measuring spatial autocorrelation of individuals after accounting for the effects of vegetation conditions (Campomizzi et al. 2008, Cunningham et al. 2016). Settling in areas near conspecifics can reduce search time when deciding where to place territories (Fletcher 2006), and increase mating opportunities (Stamps 1988, Wagner 1998, McKellar et al. 2014) and hence can be particularly important in fragmented landscapes where suitable vegetation is patchily distributed or mates are difficult to locate (Fletcher 2006). Species with short breeding seasons have less time to assess resources and, as a result, seem to rely on conspecific attraction to a greater degree than other species (Stamps 1988, Fletcher 2006). Thus, we need to understand the relative importance of vegetation cues and conspecific attraction on habitat use to inform conservation strategies, as resource availability alone may not be sufficient to determine which areas will be used (Campomizzi et al. 2008).

While conspecific attraction is presumably adaptive (i.e. increases fitness), it could also result in use of lower quality habitat if areas near conspecifics do not maximize fitness (Beauchamp et al. 1997, Pärt et al. 2007). For example, individuals settling in the periphery of patchily distributed habitat due to conspecific attraction may experience lower breeding success (Nocera et al. 2009). Hence, per capita productivity may not always be correlated with density of breeding individuals (Brown 1969, Van Horne 1983, Skagen and Yackel Adams 2011, Flockhart et al. 2016). We might expect that older individuals would secure high quality territories as they typically arrive on the breeding grounds earlier and have previous experience, while younger individuals will use lower quality habitat near conspecifics, resulting in lower fitness (Fretwell and Lucas 1970). Alternatively, individuals using lower quality habitat to be near conspecifics may be able to compensate by adjusting home range size (i.e. the area used by an individual for foraging, mating, and raising young; Burt 1943) under an ideal free distribution (IFD; Fretwell and Lucas 1970, Haché et al. 2013). Conspecific attraction could result in either of these outcomes, but the resulting distribution would be clustered, rather than regularly distributed within patches, as ideal distributions typically predict (Nocera et al. 2009). Furthermore, conspecific attraction could result in negative density-dependent effects on breeding success due to increased resource competition and higher predation/parasitism rates for individuals in clusters compared to individuals using areas with fewer conspecifics (Brown 1969, Gilroy and Sutherland 2007). With rare and endangered species, all occupied sites are usually considered important because of small population sizes, but protection of demographic sources (i.e. where excess individuals are produced) should generally be prioritized over demographic sinks (i.e. where productivity does not compensate for adult mortality; Pulliam 1988, Dias 1996, Bonnot et al. 2013). Hence, information about how habitat use influences bird behavior and subsequent breeding success is also needed to identify habitat requirements and prioritize areas for conservation.

The Canada Warbler (*Cardellina canadensis*) is a forest songbird considered threatened in Canada (Environment Canada 2016a). Habitat loss is thought to be the main driver of population declines and degradation of breeding habitat quality by forestry activities is considered a possible threat (Environment Canada 2016a). The Recovery Strategy for the Canada Warbler identified the need to determine the amount and characteristics of forest harvesting that can maintain suitable conditions for the species (Environment Canada 2016a). Current information on the effects of forestry across the species breeding range is inconclusive (reviewed by Reitsma et al. 2010; Environment Canada 2016a). Furthermore, conspecific attraction may play an important role for this species' habitat use patterns given its clumped distribution (Reitsma et al. 2010) and short breeding season (Flockhart 2007).

We quantified the relative importance of forestry and conspecific attraction on density, hierarchical habitat use, and reproductive activity of Canada Warblers within extensively harvested landscapes in boreal Alberta, Canada. Specifically, we estimated density, use at the point count level (2^{nd} order) and within home ranges (3^{rd} order), and pairing success/probability of fledging young for male Canada Warblers. We tested the effects of forestry-related stand-level metrics and local vegetation characteristics on habitat use, density, and reproductive activity. We also tested for effects of proximity of conspecifics on these response variables. Lastly, we tested effects of density and habitat use on individual pairing success and probability of fledging young. Based on the "vegetation cue" hypothesis, we predicted that forestry-related variables would have negative effects on Canada Warbler density and habitat use. Based on the orders-of-selection hypothesis, we predicted stand-level vegetation metrics would be more important at the 2^{nd} order, while local vegetation metrics would be more important at the 3^{rd} order. According to an IDD model, lower pairing/probability of fledging young for individuals using post-harvest areas might be expected relative to birds using unharvested areas, and lower pairing/probability of fledging young should be observed for younger over older males. Alternatively, based on an IFD, we predicted that males would adjust home range size to compensate for habitat quality differences, in which case we would not see differences in pairing/probability of fledging young between post-harvest and unharvested stands or between age groups. Lastly, based on the "conspecific attraction" hypothesis, we predicted that male Canada Warblers would use areas closer to conspecifics, independent of vegetation cues, and that conspecific proximity would explain more of the variation in density and 2^{nd} order use than in 3^{rd} order use.

2.2 MATERIALS AND METHODS

2.2.1 Study Area

We conducted this study in three areas near Lesser Slave Lake (55.4313° N, 115.6039°W; LSL), Calling Lake (55.2103° N, 113.1933° W; CL), and Lac La Biche (54.7696° N, 111.9725° W; LLB; Fig. 1) in the boreal central mixedwood natural sub-region of northern Alberta, Canada. This sub-region is dominated by aspen (*Populus tremuloides*) and aspen-white spruce (*Picea glauca)* mixedwood stands. We selected these study areas based on known presence of Canada Warblers (Ball et al. 2016) in extensively harvested landscapes. The primary land use in our study area was logging for pulp and lumber production, but conventional oil and gas extraction also occurred. Seismic lines and gravel roads were common across the three study areas.

2.2.2 Sampling Design

2.2.2.1 Density and 2nd order use

Using Geographic Information Systems, we pre-selected 132 square survey blocks (17.3 ha each; n=53, 35, and 44 for LSL, CL, and LLB, respectively; Fig. 2) within aspen-dominated stands (i.e. dominant tree species, Alberta Vegetation Inventory 2008). Blocks represented a gradient of harvest amount (0-100% of survey block harvested) and years since harvesting (0-30 years post-harvest; ABMI 2014, Appendix 11). A subset of survey blocks included riparian buffers (n=44) or isolated forest fragments (n=31), control blocks without harvesting (n= 21) while the remaining blocks included a portion of one or more contiguous unharvested stands (n=36) expanding into the survey block (Appendix 12). Survey blocks along riparian areas ran parallel to the water body (~60 m). All other survey blocks had south-north transects.

From May 27 to June 15, 2014, in the LSL and CL areas, and from June 1 to July 6, 2015, in the LLB area, we determined the number of territorial males at point count stations and estimated the total number of males in each survey block (hereafter "density"). We achieved this by conducting playback point count surveys between 0500 and 1400 in each survey block. For each survey block, we conducted a single point count at four equally spaced sampling stations (100 m apart) along four 300 m transects (Fig. 2), resulting in 16 point counts per survey block with a total of 2,112 point counts across the three study areas. We recorded the total number of territorial males detected by sight or sound at each station using the following protocol: 1) 1 minute silence; 2) 30 seconds with songs of conspecifics; and 3) 1 minute silence. We considered a point count station used if ≥1 male was detected (2nd order use). We recorded the exact locations of each male using a handheld GPS to ensure we did not double count individuals.

2.2.2.2 3rd order use

We tracked a total of 62 males using burst sampling to delineate home ranges. We were specifically interested in use patterns in and near post-harvest stands. Hence, to determine how much post-harvest forest was used, we targeted and tracked 55 males that had been detected <200m from post-harvest stands on block surveys (n=23, 14, and 18 for LSL, CL, and LLB, respectively). We also tracked seven birds that had been detected >200m from post-harvest stands to compare home range sizes and age structure of males using unharvested stands vs. those using post-harvest and unharvested stands. We used songs of conspecifics and mist-nets to capture territorial males (n=42), but some could not be captured (hereafter "unbanded"; n=20). We aged each captured male as second-year or after-second-year using molt limits (Pyle 1997) and fitted them with a unique colour band combination to identify individuals on subsequent visits. We also tracked unbanded males, but we relied on spatial location from the previous visit and/or song characteristics to identify these individuals.

We began tracking males 24 hours after capture and conducted weekly 30-60 minute tracking bouts between 0500 and 1900 (95% occurred between 0500 and 1400) per individual for approximately 6 weeks. We designed daily sampling rotations among males and among observers to avoid introducing a temporal or observer bias. We tracked 41 birds from May 25 to July 14, 2014 in LSL (n=25) and CL (n=16), and 21 birds from June 3 to July 18, 2015, in LLB. During each tracking bout, we located the male and recorded a GPS location at 5 minute intervals (to ensure independence among sampling locations; Otis and White 1999), and obtained a total of 30 location points per male over the season. If males were not located after three attempted tracking bouts (i.e. 1 hour of searching per weekly visit), no further bouts were conducted for those males. Due to small sample size of use locations, we were unable to use kernel density estimators (Seaman et al. 1999), so we used 95% minimum convex polygons (MCP) to delineate home range boundaries of each male (ArcGIS 10.2 [ESRI 2012]) based on 30 location points per individual. We overlaid a 10m × 10m grid on those home ranges that overlapped post-harvest stands (>0% area harvested; n=24; total of 3,147 cells) to calculate 3rd order use, which was modelled as the number of use points within each cell (Fig. 2).

2.2.2.3 Reproductive activity

Finding and monitoring individuals' nests to assess breeding success is a difficult and time consuming endeavor (Vickery et al. 1992, Diemer and Nocera 2016). Due to logistical constraints (i.e. large distances between tracked males), and our objective to track and assess reproductive activity of as many males in or near post-harvest stands as possible, we opted to use a reproductive index ranking rather than assessing total reproductive output and success. During each tracking bout, we recorded observations of reproductive activity, and ranked each male in three categories according to a modified version of Vickery et al. (1992) reproductive index ranking. Males observed nest building, with nests with eggs/nestlings, and/or seen with a female were considered paired (rank of 1), while those observed carrying food to multiple spots within the territory (Flockhart et al. 2016) and/or observed with ≥1 fledgling (Howlett et al. 2003, Reitsma et al. 2008b, Haché et al. 2013) were considered to have successfully fledged ≥1 young (rank of 2). Territorial males without any evidence of reproductive activity were considered unpaired (rank of 0).

2.2.3 Vegetation and Conspecific Cues

Forestry variables were obtained from the Alberta Biodiversity Monitoring Institute (ABMI) Cutblock layer (2014) and were selected to represent forestry-related stand metrics such as: presence, amount, and age of post-harvest stands, and presence, size, and edge of unharvested fragments (Appendix 13). We used area-based measurements for density models where the survey block was the sampling unit, whereas presence and distance-based measurements were used for use models where point count stations (2^{nd} order) and grid cells (3^{rd} order) were the sampling units. We controlled for several confounding environmental variables that have been shown to be important predictors of Canada Warbler occurrence in Alberta (Ball et al. 2016) including: 1) Hydrography variables, obtained from AltaLis (http://www.altalis.com/products/base/20k_base_features.html) which included rivers (i.e. a natural hydrographic feature with banks that are an average of ≥20 metres wide), streams (i.e. natural linear hydrographic feature with shorelines that are an average of <20 metres wide), and lakes (i.e. a body of water situated in a depression of the earth's surface, usually having a well-defined open water area and shoreline); and 2) Compound topographical index (CTI), a measure of wetness as a function of slope, solar insolation, and terrain wetness, was developed for northern Alberta using the approach of (Gessler et al. 1995). Low CTI values indicated areas with small catchments and steep hills, while high values indicated large catchments and gentle slopes.

For each survey block, we extracted: 1) percentage of area harvested (0-100%); 2) area-weighted age of post-harvest stands (i.e. [sum of area[m^2] of each post-harvest stand within survey block × years since harvested]/survey block area [m^2]); 3) contrast-weighted edge density (CWED, i.e. length of post-harvest-unharvested stand edge × year of harvest); 4) presence of isolated unharvested fragment (0=absent, 1=present); 5) amount (m^2) of old-growth (>125 years) aspen-dominated forest within a 1 km buffer around each survey block; 6) distance (m) to the nearest block occupied by ≥1 Canada Warbler; 7) distance (m) to nearest stream, river, and lake; and 9) average CTI.

For each point count station (2nd order use), we extracted the same hydrography and CTI variables as well as: 1) presence/absence of post-harvest (post-harvest=1, unharvested=0); 2) origin year of stand; 3) distance (m) to post-harvest-unharvested edge; 4) size (m^2) of unharvested fragment (if point is in unharvested stand); and 5) distance (m) to nearest point count station occupied by a male Canada Warbler.

To determine what influenced within-home range use (3rd order), the same variables as described for 2nd order use were extracted at the centroid of each 10 x 10m cell within home ranges, in addition to age of tracked male (SY=second year, ASY=after-second-year). These variables were also used to explain variation in reproductive activity in addition to: 1) percent of home range overlapping post-harvest stands; 2) number of use locations within post-harvest stands; 3) density of post-harvest-unharvested edge within home range; and 4) density of males in the survey block.

We conducted ground-based local vegetation surveys at a subset of point count stations (n=89) within a subset of survey blocks (n=49). For control blocks with no harvesting, we randomly selected one point count station to conduct vegetation surveys, whereas for blocks with both unharvested and post-harvest stands we randomly selected one point count station in each of these treatment types. Vegetation surveys were also conducted in a subset of grid cells within all home ranges (3-4 per home range, n=84), one at the center of the home range and at 3 randomly selected cells within the home range (2 for small home ranges where vegetation plots would have overlapped). Plots consisted of: 1) number of trees (>8cm diameter at breast height); 2) average tree size (cm); 3) percent canopy cover; 4) canopy height (m) within a 11.3 m radius; 5) percent green cover; 6) percent shrub cover; 7) percent downed log cover; 8) number of small shrubs (<2.5cm in diameter); 9) number of large shrubs (>2.5-8cm in diameter); and 10) organic litter depth (mm) within a nested 5m radius (BBIRD protocol: Martin et al. 1997, also see Hallworth et al. 2008b, Flockhart et al. 2016). Vegetation surveys were conducted from mid-July to mid-August.

2.2.4 Statistical analysis

We used negative binomial regression to explain variation in density. We started by building a baseline model using nuisance variables (i.e. day of survey, time of day, study area [1 = LSL, 2 = CL, 3=LLB], and observer [n=8]), CTI, and distance to lake, river, and stream. We used a backwards step selection process to select variables that resulted in the best model fit based on Akaike's Information Criterion ranking for small sample sizes (AICc). Other variables were added to the baseline model using a two-stage approach. First, we tested for effects of forest harvesting and ranked these models using AICc to determine which combination of forestry and nuisance variables resulted in the best model fit. Second, we tested whether adding a covariate for conspecific proximity improved the “baseline-forestry model” using the same model selection approach. We also tested for non-linear effects (squared, quadratic, and cubed). When variables with a quadratic term were included in the top-ranked model, we tested whether a threshold response provided a better fit using package ‘segmented’ in R (Muggeo 2008).

We used mixed effect logistic regressions to explain variation in 2nd order use, where survey block ID was added as a random effect, and mixed effect negative binomial regressions with bird ID as a random effect to assess 3rd order use. The same model building process was used as for density, with the addition of a third stage. Using the subset of stations (2nd order) or cells (3rd order) with detailed ground-based vegetation data, we tested if adding ground-based local vegetation covariate(s) to the best model from stage 2 improved model fit. In addition, for the subset of males where age was known, we tested for age x presence/absence of post-harvest stand interactions (3rd order) at stage 1.

We used logistic regressions to analyze reproductive activity. We analyzed probability of pairing (paired vs. unpaired) separately from probability of fledging young (fledged young vs. paired only), as pairing (i.e. attracting a mate) and fledging (i.e. successfully raising young to fledgling stage) may be driven by different mechanisms (Reitsma et al. 2008a). First, we evaluated if probability of pairing (i.e. paired vs. unpaired males) was influenced by: 1) 2nd order variables; or 2) 3rd order variables, using the same 3 stage modelling approach previously described, with the addition of male age as a baseline variable, and density of conspecifics as a variable in stage 2. We then used the same modeling approach to test for effects of 2nd and 3rd

order variables on the probability of males fledging ≥1 young (i.e. fledging young vs. paired only).

Wilcoxon signed rank tests were used to test for differences in home range sizes between males who only used unharvested stands versus those individuals who used post-harvest and unharvested stands.

We analyzed use and density models using the package glmmADMB (Skaug et al. 2011) in R3.1.2 (Team 2014), and reproductive activity models using the ologit command in STATA 13 (Hamilton 2012). We reported standardized regression coefficients (β) ± SE, test statistic (z), and p-value (p) for each independent variable for the top regression models and test statistic (W) and p-values for the Wilcoxon signed rank test. Lastly, for each top model, we calculated pseudo r^2 values as a measure of goodness-of-fit using the package MuMIn in R (Barton 2013).

2.3 RESULTS

2.3.1 Density

We detected a total of 96 males on block surveys: 51, 10, and 35, in LSL, CL, and LLB, respectively. Density per block ranged from 0-9 territorial males (mean = 0.75 ± 1.67), but males were only detected on 29% of the survey blocks (38/132). The best ranked forestry model included a negative cubic effect of percent post-harvest (β = -0.81 ± 0.27; Fig. 3A; Appendix 1,3). This model was improved by adding distance to the nearest occupied block (AICc wt=0.8; Table 1; Appendix 1). Relative to LSL, the other two study areas had significantly lower male density (CL: β = -1.98 ± 0.54; LLB: β = -1.93 ± 0.57; Table 1) and density was higher in areas with low CTI values (i.e. areas with small catchments and steep hills; β = -0.67 ± 0.19; Table 1).

2.3.2 2nd order use

We detected ≥1 territorial male at 91 point count stations (48, 10, and 33 at LSL, CL, and LLB, respectively; 4% of point count stations). The top-ranked forestry model included a presence of post-harvest stands × distance to the nearest edge interaction (β = -3.52 ± 1.13; Table 1; Appendix 1,4) suggesting that in post-harvest stands males used areas closer to unharvested-post-harvest edge rather than the core harvested area (Fig. 3B). A non-linear negative effect of distance to the nearest occupied station (β = -1.45 ± 0.37) improved the model further (Table 1; Appendix 1) indicating that 2nd order use decreased with increasing distance to the nearest occupied point count station up to approximately 600m (±125), after which proximity to conspecifics had no effect (Fig. 3C). No local (ground-based) vegetation variables were significant in predicting 2nd order use (Appendix: Table 5), and did not improve stage 2 models (Appendix: Table 1). Point count stations in CL and LLB had lower 2nd order use than in LSL (CL: β = -1.72 ±0.49; LLB: β = -1.10 ± 0.47, Table 1).

2.3.3 3rd order use

Average home range size was 0.94 ha (± 0.86). Post-harvest stands were included in the home range of 44% (24/55) of the males that were captured <200m from a post-harvest stand (i.e. the other 31/55 males used exclusively unharvested stands). Most of these males (15/24) had low amount of overlap (<20%) of post-harvest stands in the home range. Mean size of home ranges that included post-harvest stands was larger than those of home ranges that did not include post-harvest stands ($W=305$, $p<0.05$).

The best model included a positive effect of distance to nearest post-harvest-unharvested edge, suggesting intensity of use increased with distance from edges (β = 0.61 ± 0.19; Table 1). The model was improved by adding proximity to conspecifics (AICc wt=0.70; Appendix 1,6).

Males had higher intensity of use in unharvested than post-harvest stands, and intensity of use in unharvested stands was higher near conspecifics (post-harvest stands × distance to nearest conspecific interaction; $\beta = 0.33 \pm 0.17$; Table 1; Fig. 3D; Appendix 1). No ground-based vegetation variables were significant, nor did they improve upon model stage 2 (Appendix 1, 7). Relative to LSL, the other two study areas had significantly higher intensity of use within grid cells (CL: $\beta = 0.58 \pm 0.27$; LLB: $\beta = 0.83 \pm 0.43$; Table 1) indicating that the home ranges in the latter were more compact (i.e. smaller with higher intensity of use per cell) than the former. Intensity of use was also higher further from streams ($\beta = 0.28 \pm 0.12$; Table 1). We did not find significant differences in intensity of use of post-harvest stands between male age classes (Appendix 6).

2.3.4 Reproductive activity

We tracked a total of 18 after-second-years (ASY), 24 second-years (SY), and 20 unbanded males of unknown age. Pairing and evidence of fledgling ≥1 young was confirmed for 84% and 69% of males, respectively. For pairing success, the top model only included a negative non-linear (squared) effect density of conspecifics ($\beta = -0.82 \pm 0.30$; Table 1, Appendix 2), indicating that pairing success was higher for males at low and mid-densities (i.e. 1-3 males per block), but decreased at higher densities (Fig. 4). Stand-level forestry variables and ground-based vegetation variables did not improve models.

For probability of fledging ≥1 young, the best model included 3rd order variables (AICc wt = 0.66; Appendix 2). There was a significant positive effect of distance to river ($\beta = 1.48 \pm 0.60$; Table 1), suggesting that probability of fledging young was higher for paired males with home ranges further from rivers. The model was not improved by adding stand-level forestry variables, or proximity to conspecifics, but was improved by adding average shrub cover (Table 1; Appendix 2).

2.4 DISCUSSION

2.4.1 Density

Male densities decreased with increasing amounts of harvesting. This is consistent with studies across the boreal breeding range (Schieck et al. 1995, Cooper et al. 1997, Schieck and Song 2006, Ball et al. 2016) where Canada Warblers were most abundant in old-growth deciduous stands, and post-harvest stands were not deemed suitable habitat (Ball et al. 2016). A breeding-range wide report also found that Canada Warbler abundance increased with increasing canopy height and canopy cover (Hache et al. 2014), attributes which are typically associated with older forests. Unharvested stands (particularly older stands) differ substantially in vegetation structure from younger stands, and the combination of vertical stratification, structural diversity and high densities of old, large trees associated with old-growth stands (>125 years post-harvest; Huettmann 2003) could be important for Canada Warblers. Although some studies suggest that residual retention in harvested areas or in regenerating stands 11-30 years post-harvest may support some Canada Warblers (Schieck and Hobson 2000, Schieck and Song 2006), we did not find evidence that retention of unharvested fragments (≤ 5 ha), or regeneration of harvested stands (≤ 30 years post-harvest) mitigated effects of forest harvest on density. Other studies also reported that the use of unharvested fragments was relatively uncommon (Schieck and Hobson 2000, Schieck and Song 2006), and that the only occupied fragments were relatively large (Ball et al. 2016).

Density of males was also higher in areas with low CTI values indicating small catchments and steep slopes and wetter soils. This is consistent with results in the western boreal range of Canada Warblers (Enns and Siddle 1996, Ball et al. 2016) and elsewhere in the species breeding range (Peck and James 1987, Smith 1996, Hallworth et al. 2008b, Palmer-Ball Jr 2015, Westwood 2016). Slopes and wet forests could create the underlying conditions for more complex understory and higher shrub density that Canada Warblers have been associated with in other studies. Sloped areas could provide important concealment as nests can be built with an overhang (Goodnow and Reitsma 2011a). Of the relatively few nests that we located in this study 4/9 were located on "slopes" (A. Hunt, pers obs). Goodnow and Reitsma (2011b) rarely found Canada Warbler nests on flat ground in New Hampshire, and Peck and James (1987) suggested that nests in Ontario, Canada were associated with slopes.

Our forestry model was improved by adding proximity to other occupied survey blocks (Table 1). It has been suggested that Canada Warblers might have a clustered breeding distribution (Reitsma et al. 2010), but to our knowledge our study is the first to quantify this spatial distribution. Other studies have found that conspecific attraction in songbirds resulted in a clustered distributions (reviewed by Ahlering et al. 2010). According to the hidden lek hypothesis (Wagner 1998), females will preferentially select areas with high male densities because it provides more possibilities for extra-pair copulations. Sex ratios for some species tend to be more male biased in areas of low abundance, suggesting that females are more likely to recruit into larger populations (Morrison et al. 2016). Hence, in addition to males using areas near conspecifics to locate suitable habitat, unpaired males may cluster around males in high-quality habitat to obtain extra-pair copulations from females (Wagner 1998, 1998, Nocera et al. 2009, McKellar et al. 2014). Canada Warblers have a broad distribution which is locally concentrated (Ball et al. 2016), so clustering of males could be important to attract females and increase mating opportunities.

2.4.2 2nd order use

Territorial males were less likely to use post-harvest than unharvested stands. Previous studies on Canada Warblers have also documented lower use of post-harvest stands in western boreal regions (Schieck and Hobson 2000, Ball et al. 2016). Our results also suggest that males are using portions of post-harvest stands that are near the edges of unharvested stands. This is consistent with Becker et al. (2012), who noted that Canada Warblers seemed to use clearcuts in areas closer to edges, whereas this was not the case in areas with heavy partial harvests (i.e. clear-cuts with residual trees plus deferment and shelterwood cuts), or light partial harvests (i.e. single-tree selection and diameter limit cuts). Furthermore, we found that males were more likely to settle in a stand close to conspecifics irrespective of vegetation cues. Hallworth et al. (2008b) also suggested that the proximity of their two study areas in undisturbed and second-growth stands may have influenced the use of harvested stands by Canada Warblers. These results are consistent with other studies on conspecific attraction. For example, Nocera et al. (2009) found higher densities of smaller Bobolink (*Dolichonyx oryzivorus*) territories clustered in “core” high-quality habitat and lower densities of larger territories were in the periphery. Clustering near conspecifics could explain why some studies have detected Canada Warblers in post-harvest stands (Schieck and Hobson 2000, Schieck and Song 2006), as males could be using post-harvest stands that are near conspecifics in adjacent stands. This suggests that when generating estimates of how many individuals post-harvest stands can support (see Ball et al. 2016) researchers should account for the fact that only post-harvest stands at edges of unharvested stands and near conspecifics tend to be used.

We did not find evidence that local vegetation features influenced 2nd order use. Other studies have shown that shrub density is an important vegetation feature across the Canada Warbler breeding range (Hallworth et al. 2008b, Chace et al. 2009, Palmer-Ball Jr 2015, Flockhart et al. 2016). One possible explanation is that some males settle on certain vegetation types, whereas conspecific attraction drives settling behaviour of other males, who settle on the vegetation near conspecifics. Hence, local vegetation use patterns could be confounded by the effects of conspecific attraction. For example, Nocera et al. (2009) found that males in “core” habitat with small territories had significantly different vegetation structure and composition inside vs. outside of territories, whereas this was not the case for males with larger territories in the periphery.

2.4.3 3rd order use

The majority of males that we tracked did not include more than 20% of post-harvest stands in their home range, and home ranges which overlapped both post-harvest and unharvested stands were larger than those solely in unharvested stands. Larger home range size may suggest that resource availability is lower and males must traverse larger distances to obtain necessary resources (Smith and Shugart 1987, Newmark and Stanley 2016). Machtans et al. (1996) found that Ovenbird (*Seiurus aurocapilla*) home ranges that overlapped linear features were larger than home ranges that did not include linear features, and that the linear features themselves were unused. Canada Warblers using post-harvest stands in New Hampshire, U.S. also had larger home ranges than those using unharvested stands (Hallworth et al. 2008a). In portions of the home range in unharvested stands, we found that males spent more time near conspecifics than they did in portions of their home range in post-harvest stands. This use pattern likely reflects the need for greater territorial defense in the unharvested portion of the home range where birds tended to have more neighbours (Lankau et al. 2013). As there are lower densities of males associated with post-harvest stands, males likely do not have to spend as much time defending the part of the home range closer to the core of the harvested area because few conspecifics are present to defend against. We also found that males spent less time near the post-harvest – unharvested edges within the home range. This suggests that edge habitat is included in the home range as a function of males using areas near conspecifics in adjacent unharvested stands, and being forced to live on both sides of the edge in areas with high densities of males.

We did not find strong evidence that local vegetation influenced 3rd order use. To our knowledge there are no other studies on Canada Warbler 3rd order use for comparison. Again, our sample size for ground-based vegetation surveys is small, which may limit our ability to detect variation. The majority of our use locations were singing locations, when the birds are most detectable during tracking, which may present a bias as our results may not be representative of vegetation needs for other life requirements.

We found 3rd order use was higher further from streams. This may indicate that streams are used as natural territory boundaries (i.e. the boundaries of the portion of the home range that is actively defended; Burt 1943), so males may spend less time defending these parts of the home range and more time defending areas without natural territory boundaries (Mesterton-Gibbons and Adams 2003, Bayne et al. 2005). At first glance, this result seems contradictory to our findings for density, where small catchments and steep slopes supported higher density. However, higher use further from streams may indicate that although riparian areas are important for broader use by the population or as territory boundaries, the areas immediately adjacent to streams may not be highly used by individuals. This result could have implications for regulating riparian buffer widths in forest management plans. If more individuals cluster near riparian areas, but individuals do not use areas nearest to streams, small buffers may not be used as they may not extend far enough from the stream to accommodate clusters of Canada Warblers. Current guidelines require only 30-60m buffers for small and large permanent streams (ASRD 2008).

Lastly, we did not find a significant difference in the intensity of use of post-harvest stands used by ASY vs. SY males. Hallworth et al. (2008a) also did not find a significant difference in proportion of ASY vs. SY males in undisturbed vs. second-growth stands. This is contrary to results from Nocera et al. (2009) who found that younger male Bobolinks were more likely to use lower quality habitat near conspecifics and have larger territory sizes than older males. Our result is more consistent with an IFD where adjustments in home range size can compensate for differences in individuals' ability to obtain high-quality home ranges (Fretwell and Lucas 1970).

Overall, our results show that Canada Warblers require at least some unharvested stands to support a home range, again suggesting that only those portions of post-harvest stands adjacent to unharvested stands should be considered as usable. Hence, predicted values for Canada Warbler habitat suitability should take into account that typically only ~20% of an individual home range can be supported by post-harvest habitat, so these areas are less valuable than unharvested areas. For example, when mapping suitable habitat (see Ball et al. 2016), suitability of each area/pixel in post-harvest stands could be weighted based on the proportion of a home range that can be supported (i.e. 0.2), and by its proximity to unharvested stands.

2.4.4 Reproductive activity

There were no effects of forest harvesting on individual males probability of pairing or fledging young. However, larger home range sizes were observed for males whose home ranges overlapped both post-harvest and unharvested stands, suggesting that males may adjust home range size to compensate for lower resource availability, resulting in similar per capita productivity (Fretwell and Lucas 1970). Flockhart et al. (2016) also suggested that Canada Warbler home range size may be a function of habitat quality, where home ranges in high quality habitat are smaller due to pressures from competition and territory defense (Ridley et al. 2004).

We found evidence of a negative relationship between density and pairing success. However, probability of paired males fledging young was not influenced by local density effects. This pattern could be explained by the hidden lek hypothesis (Wagner 1998), in which unpaired males cluster in areas near paired males to obtain extra-pair copulations (EPC) from females, so unpaired males drive higher densities rather than vice versa. McKellar et al. (2014) found that areas with high local densities of American Redstarts (*Setophaga ruticilla*) had high proportions of unpaired males, and higher rates of EPC. Reitsma et al. (2010) have suggested that EPCs are likely common in Canada Warblers, although empirical studies have not been conducted. While Flockhart et al. (2016) found evidence that density affected breeding success of Canada Warblers in Lesser Slave Lake Provincial Park, they did not distinguish between pairing and probability of fledging young, so whether this was caused by a large number of unpaired males or other density-dependent effects is unknown.

We also did not find effects of male age on pairing or probability of fledging young, which is consistent with McKellar et al. (2014) findings, and again is consistent with an IFD. Conversely, other studies on species known to exhibit conspecific attraction found that ASY males had higher pairing success than SY males (Nocera et al. 2009), and other Canada Warbler studies in the eastern breeding range have found this as well (Reitsma et al. 2008b). Pairing success of males is often linked to traits that should be positively correlated with male age such as: suitable site selection (Nocera et al. 2009), access to recurring mates from previous years (McKellar et al. 2014), and females' selection of males with brighter colours and bolder plumage patterns (Rappole 1983, Reitsma et al. 2008b). However, if sites from previous years are no longer suitable due to disturbance, or if female mates do not return, these age-related patterns may not be apparent. Our sample size of males with known ages was fairly small (n=42), which may have limited our ability to detect effects. The lack of age effect on probability of paired males fledging young is consistent with McKellar et al. (2014) and with studies of Canada Warblers from the eastern breeding range (Reitsma et al. 2008b), and suggests that even if younger birds use lower quality habitat, they can adjust home range size to obtain the resources to successfully fledge young.

We found that the probability of paired males fledging ≥1 young was higher for those males with home ranges further from rivers. This may suggest that male territories are more compressed in small riparian buffer strips, and may be subject to higher competition for a limited space or edge effects (Ridley et al. 2004). Average shrub cover (<50cm in height) also improved our model assessing probability of fledging young, but the effect of this variable was not significant (Table 1; Appendix: 2). Reitsma et al. (2008b) suggested that although shrub density >1m in height is an important cue for nest selection, that high shrub cover at lower horizons may prevent the growth of other ground cover features that are important to nesting Canada Warblers such as moss. Hence, low shrub cover may have weak indirect effects on probability of fledging young through limiting development of important nesting substrate. Flockhart et al. (2016) found that shrub cover was higher in smaller territories, and that smaller territories tended to have lower breeding success, also suggesting an indirect relationship between shrub cover and breeding success. If shrubs are an important local vegetation feature for Canada Warblers, and if males cluster in these high-quality areas, breeding success could be affected by density-dependent effects like increased competition.

2.4.5 Conclusions

These results have several implications for prioritizing areas for conservation and for forest management with the aim to recover Canada Warbler populations in Alberta. In general, forest harvesting seems to constitute a threat to breeding habitat, as it is resulting in lower use and lower densities of Canada Warblers than unharvested stands. Post-harvest stand age, local vegetation, presence/size of unharvested fragments, and landscape availability of unharvested stands do not appear to mitigate these effects. Only post-harvest stands near unharvested stands are used, meaning that the core of harvested areas does not constitute usable habitat. The use of post-harvest stands by Canada Warblers in Alberta seems to be more strongly influenced by social factors than attributes of post-harvest stands themselves. Conspecific attraction might also explain why seemingly "suitable" areas of unharvested stands are not inhabited, while similar areas can support very high densities. Hence, leaving large tracts of contiguous unharvested stands (particularly where Canada Warbler occur) will be important to provide enough suitable habitat to accommodate a clustered distribution. There is also the potential to use experimental manipulations to attract birds to areas that are less likely to be harvested in the future and thus aid with long-term conservation planning. Overall, although density and pairing success seem to be inversely related, this result is likely due to a hidden lek, unpaired males clustering around paired males, resulting in high densities, rather than effects of the high density itself on pairing success. Hence, it is likely that high density of Canada Warblers in unharvested stands is reflective of high quality habitat.

Future studies should model size of Canada Warbler clusters to determine necessary size of protected areas, examine interactions between distance to river × distance to nearest edge and buffer widths required to support home ranges to determine appropriate buffer regulations, and investigate differential habitat use for singing and non-singing behaviours to assess within home range local vegetation requirements.

More generally, understanding factors influencing different orders of use, the relative importance of behavioural processes and vegetation cues, and the consequences of use patterns on reproductive activity can improve the information used for recovery strategies. Studies based on single spatial scales or orders of habitat use have been shown to provide contradictory recommendations that hinder the efficiency of conservation actions (Addicott et al. 1987, Girard et al. 2004), which is consistent with our results. We showed that edges are not an important predictor of density of males, but that male home ranges in post-harvest stands are typically near unharvested stand edges, and that within the home range, edges are generally avoided. Conspecific proximity was important for 2nd and 3rd order use and density, but density of conspecifics, rather than conspecific proximity was more predictive of pairing success. This study demonstrates that prioritization of conservation areas for species-at-risk is best informed by a hierarchical multi-level approach. Prioritizing areas based on presence or density alone could result in overestimating the amount of suitable habitat available as areas may remain vacant if social cues or adjacent habitat is not present. In scenarios where intensive behavioural observations are not possible, incorporating proximity to undisturbed habitat and to conspecifics could provide valuable information when prioritizing areas for conservation.

2.5 TABLES

Table 1. Variables and coefficients for top ranked models predicting: A) Density of males (17.3 ha survey blocks; n=132); B) 2nd order use (used/unused; n=2,112); C) 3rd order use (in 24 male home ranges; n=3,147); and D) pairing success (n=62); and E) probability of fledging young (n=51) for territorial male Canada Warblers in managed forests in northern Alberta. N is the sample size of the model, β is the standardized coefficient, SE is the standard error, z is the test statistic, and p is the p value. "*" represents interactions between terms.

Variables in top models	N	β	SE	z	P
DENSITY					
CUT3	132	0.81	0.27	-3.06	<0.005
NEAROCC	132	-0.32	0.18	1.66	< 0.1
STUDYAREA	132				
CL:		-1.98	0.54	-3.65	< 0.0005
LLB:		1.93	0.57	-3.42	< 0.0005
CTI	132	-0.67	0.19	-3.62	<0.0001
DISTRIVER	132	-0.32	0.23	-1.39	<0.1
2ND ORDER USE					
IFCUT*DISTEDGE	2112	-3.52	1.13	-3.11	< 0.005
NEAROCC	2112	-1.45	0.37	-4.31	< 0.0005
STUDY AREA	2112				
CL		-1.72	0.49	-3.50	<0.0005
LLB		1.10	0.47	-2.40	<0.05
DISTRIVER	2112	-0.35	0.19	-1.82	<0.1
3RD ORDER USE					
IFCUT*NEAROCC	3147	0.33	0.17	1.93	0.05
DISTEDGE	3147	0.61	0.19	3.13	<0.001
DISTSTREAM	3147	0.28	0.12	2.37	<0.05

PAIRING SUCCESS					
CONSDENSITY2	62	-0.82	0.30	-2.70	<0.001
PROBABILITY OF FLEDGING YOUNG					
SHRUBCOV	51	-0.99	0.54	-1.83	<0.1
STUDY AREA	51				
CL		2.14	1.34	1.6	0.1
LLB		1.67	1.24	1.34	0.2
DISTRIVER	51	1.48	0.60	2.47	<0.05

* CUT3 is a cubed term representing the percent of a survey block comprised of post-harvest stands, NEAROCC is the distance to the nearest conspecific, DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), IFCUT is the presence/absence(1/0) of post-harvest stands at a point count station, DISTEDGE is the distance (m) to the nearest post-harvest/unharvested edge, DISTSTREAM is the distance (m) to nearest stream, CTI is the average compound topographic index, CONSDENSITY2 is a squared term representing the number of conspecifics (males) on the survey block. SHRUB is the density of shrubs (<2.5cm diameter), GREENCOV is the % green cover <50cm height. CTI is the average compound topographical index.

2.6 FIGURES

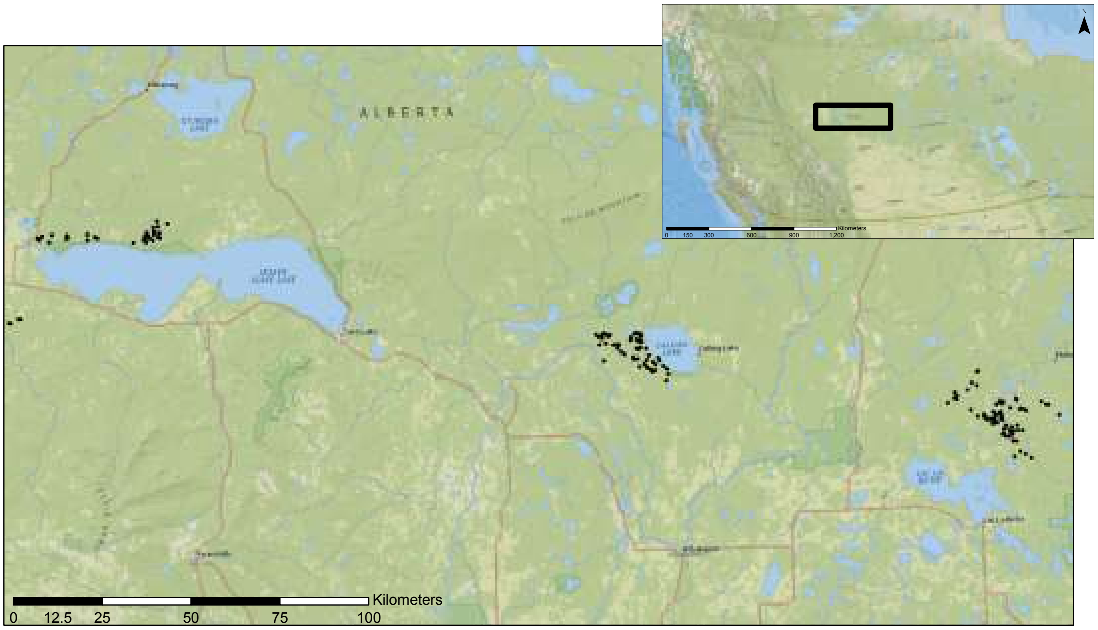

Figure 1. Survey block locations (n=132) in the 3 study areas: Lesser Slave Lake (left), Calling Lake (centre), and Lac La Biche (right). Inset map of Canada (National Geographic basemap).

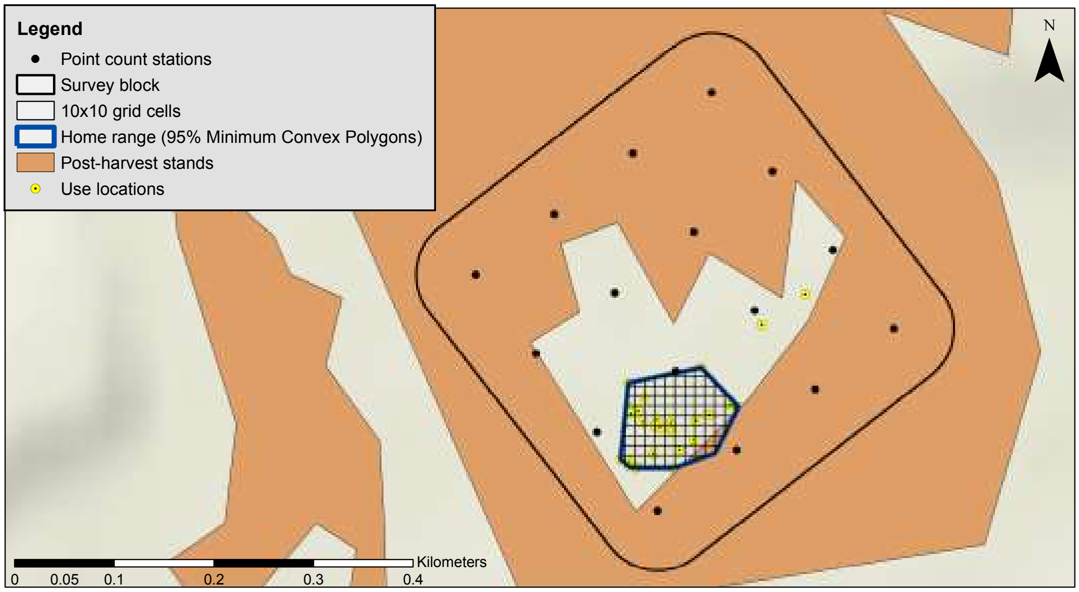

Figure 2. Example of a territorial male Canada Warbler home range with corresponding 10 × 10 m cells.

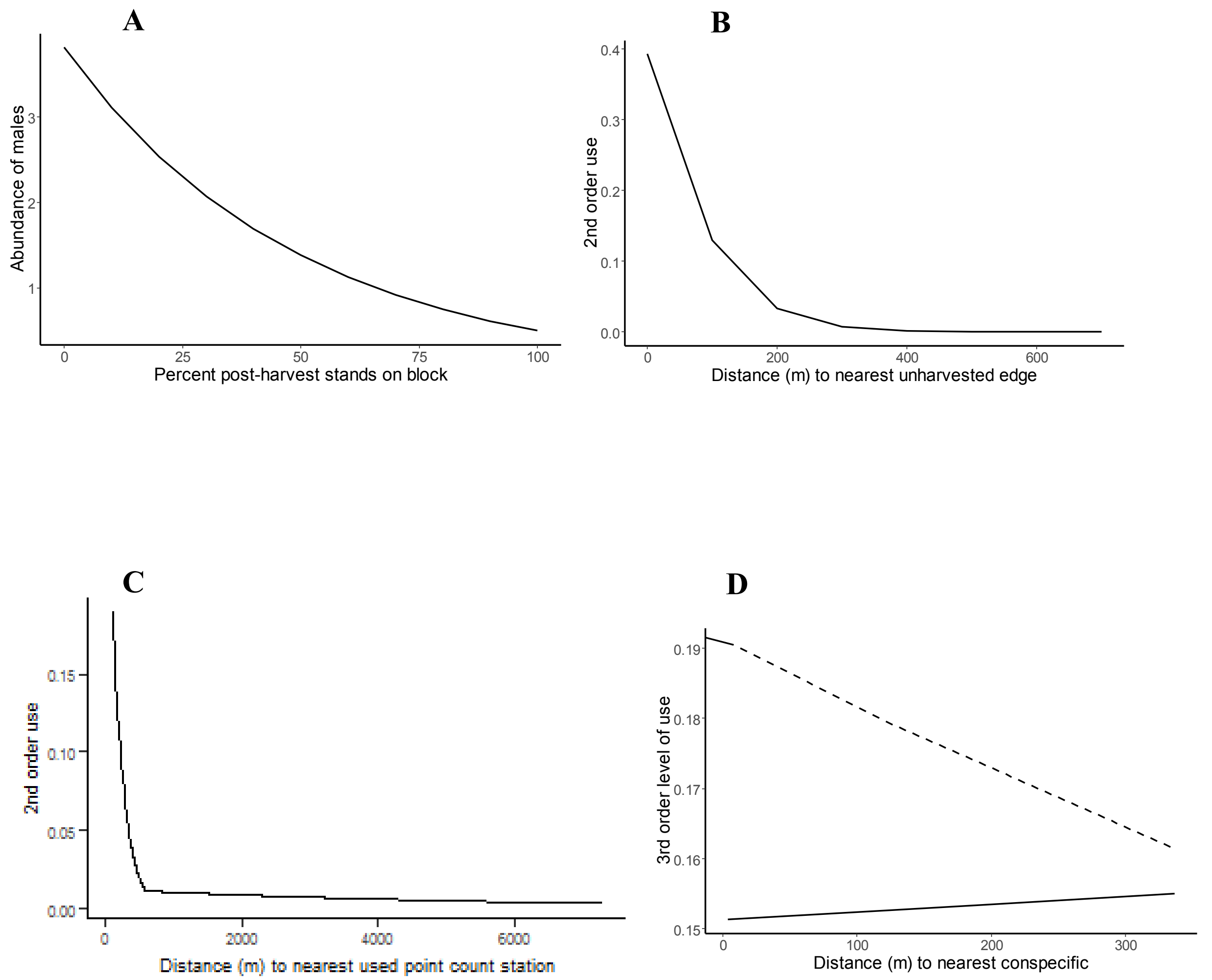

Figure 3. Predicted density of territorial male Canada Warblers in survey blocks as a function of increasing amount of post-harvest stands (A); 2nd order use of post-harvest stands in response to distance to nearest unharvested edge (B); 2nd order use of post-harvest stands as a function of increasing distance (m) to the nearest point count station used by a conspecific (C); and 3rd order use in harvested areas (solid line) and unharvested areas (dashed line) in response to distance to the nearest conspecific (D).

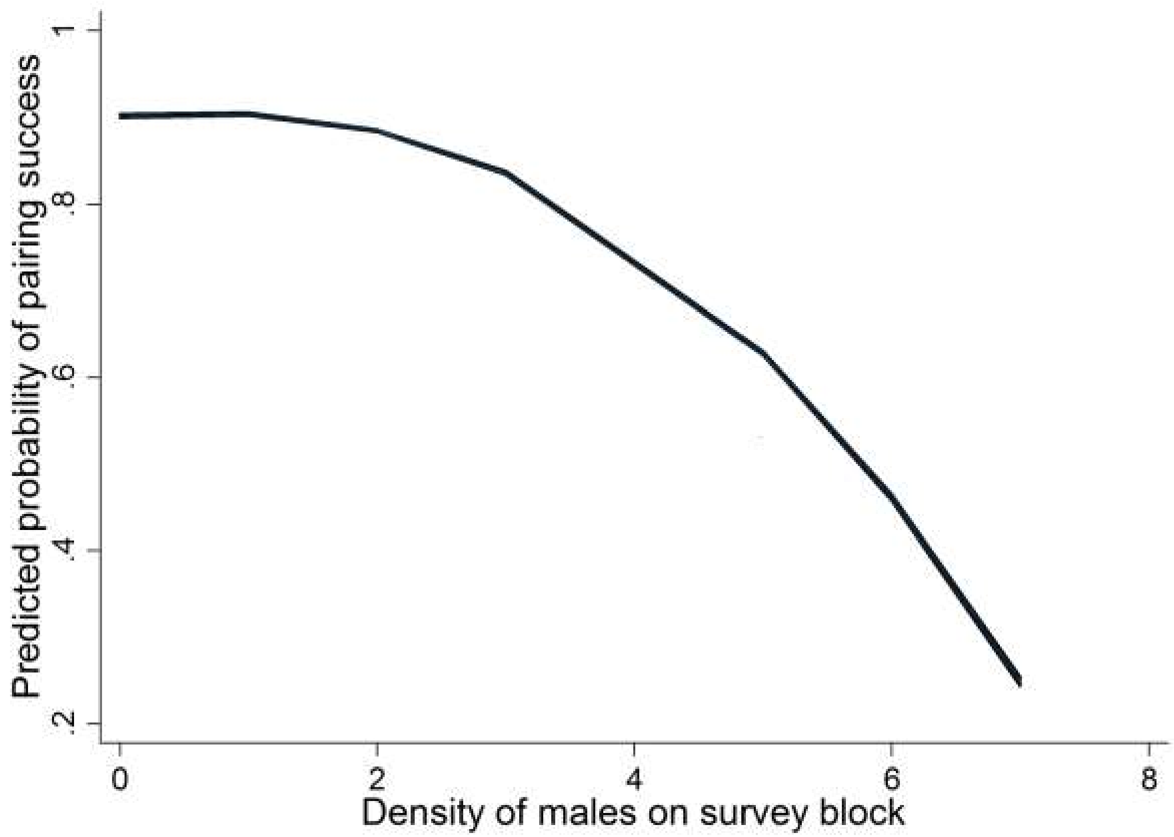

Figure 4. Predicted probability of pairing success in male Canada Warblers in response to density of conspecifics

CHAPTER 3: CONCLUSION

The main objective of my thesis was to determine the relative importance of forest harvesting and conspecific attraction on Canada Warblers in boreal Alberta. I surveyed over 2,000 ha of boreal forest over two field seasons, and collected data on density of territorial males, home ranges, within home range use, proximity to conspecifics, age structure and reproductive activity (see Chapter 2). Throughout this project, I not only learned about effects of forestry on Canada Warblers specifically, but also gained insights into the types and extent of data required to understand habitat needs and threats to avian species-at-risk. In Chapter 3, I compare my results from Chapter 2 to those of other local and regional studies across the breeding range and a national modeling initiative (Hache et al. 2014) to identify potential drivers of discrepancies between studies and provide specific recommendations for recovery action planning for Canada Warblers.

Under the Species at Risk Act, recovery plans must be released within two years of listing the species as threatened and should "identify the species' critical habitat unless it is not possible to do so; and where critical habitat is identified, provide examples of activities that are likely to result in its destruction" (Government of Canada 2011). If critical habitat is fully identified, the area defined is sufficient to meet population and distribution objectives. When critical habitat is partially identified, a schedule of studies must be drafted to identify information gaps and research needs to fully identify critical habitat (Environment and Climate Change Canada 2016). Many recovery strategies acknowledge gaps in the knowledge of species needs, threats, and critical habitat. For example, Mooers et al. (2010) reported that only 5% (23/447) of all listed species-at-risk in Canada had critical habitat identified, and in 2013 (McCune et al. 2013) reported that <50% of species with completed recovery strategies have critical habitat identified. Hence, the recovery process is slowed by the need for further research before any meaningful recommendations for action can take place.

There is a tendency for managers and conservationists to prefer broad-scale information about a species as data collection is more efficient (i.e. usually based on presence/absence; Guillera-Arroita et al. 2015), financially feasible (Guisan and Zimmermann 2000, Kearney and Porter 2009), and a similar management plan can be implemented across the species range. However, large-scale species distribution models (e.g. based on point counts alone) are relatively imprecise (Guisan and Zimmermann 2000) and alone may not be the best method to assess habitat requirements and threats for species-at-risk for several reasons. First, identifying which vegetation type and structure are actually used or avoided by individuals requires knowledge of their spatial location, whereas point counts provide only a rough assessment of the conditions the species is using (Marzluff et al. 2004). Second, identifying important habitat for species at risk requires an understanding of habitat-specific reproductive success and/or survival (Johnson 2007). Third, habitat requirements and threats can vary regionally (Whittingham et al. 2007, Bamford et al. 2009, Boves et al. 2013, LaManna and Martin 2016), particularly when species have large ranges. Guidelines for critical habitat identification suggest that identification can be made at the site-level (small/localized geographic range, narrow habitat specificity), area-level (intermediate geographic range, wide or narrow habitat specificity), or landscape-level (large geographic range, wide habitat specificity; Environment and Climate Change Canada 2016). However, these categorizations do not account for species that exhibit habitat specificity that varies over the geographic range.

The recovery strategy for the Canada Warbler, a threatened species, was recently released (Environment Canada 2016a). This strategy, like those for many other species, identified numerous knowledge gaps and inconsistencies in knowledge about habitat requirements and threats across the breeding range. Data are available from regional multiple-species studies, and several directed studies, but there is no consensus on breeding habitat requirements and threats for this species (reviewed by Reitsma et al. 2010). As such, the Government of Canada is unable to fully identify critical habitat at a landscape scale without further research. Regional and local scale studies across the breeding range have found different habitat requirements and responses to forestry by Canada Warblers (reviewed by Reitsma et al. 2010). They have been reported to use old-growth aspen in the western boreal (Schieck et al. 1995, Schieck and Song 2006, Ball et al. 2016), younger mixed-wood stands in eastern Canada (Drapeau et al. 2000, Lambert and Faccio 2005), swamps and second-growth forests in the eastern U.S. (Hallworth et al. 2008b), and rhododendron thickets in the southern U.S. (Becker et al. 2012). Furthermore, forest harvesting has been identified as a threat by some (Zlonis and Niemi 2014, Ball et al. 2016), while others have suggested it can create productive breeding habitat (Hallworth et al. 2008b, Becker et al. 2012). The Boreal Avian Modeling project (BAM) recently released a report with the objective to generate species distribution models using point count datasets across the species breeding range to help critical habitat identification for the Canada Warbler (Hache et al. 2014). However, they found no effects of forestry (positive or negative), and no differential habitat selection across the breeding range. As discussed in Chapter 2, differences in study methodology (i.e. which order of use is studied, whether ecological constraints and reproductive activity are measured) may account for apparent differences in habitat associations and responses to forestry, but there are also inherent differences between ecoregions creating unique conservation scenarios in each. In the following essay, I discuss potential reasons for discrepancies among regional and national studies, and suggest how these conflicting results can be best applied to Canada Warbler conservation.

3.1 Spatial accuracy and intensity of use

Point counts are the most common method to estimate relative abundance of birds (i.e. the number of individuals/sample), population trends, habitat associations, and the proportion of the population that will be affected by different management activities (Rosenstock et al. 2002, Bart 2005, Johnson 2007, Cumming et al. 2010). Point counts consist of observations of presence and number of birds detected by sight/sound within pre-determined or unlimited radii and a given time period (e.g. 10 minutes). This method is efficient because it allows researchers to cover large areas with minimal effort, and data are collected for many species simultaneously (Rosenstock et al. 2002). Large-scale point-count datasets provide an opportunity to model and create habitat suitability maps based on derived density estimates (Hache et al. 2014, Bayne et al. 2016). However, information on the spatial location of individuals, and intensity of use in different habitat types is important to understand the effects of human disturbance (Marzluff et al. 2004, Kertson and Marzluff 2011). Point counts conducted in disturbed areas may count birds that are using the disturbed area, the adjacent undisturbed area, or the edge interface, distinctions that have different implications for the importance of disturbances. In addition, point counts only provide a snapshot of the habitat that is being used, as they do not provide information on the time spent in different habitat types (i.e. intensity of use) or for non-territorial activities like nesting and foraging (Meyer and Thuiller 2006).

In Chapter 2, I showed that territorial males using post-harvest stands were near edges of unharvested stands and near conspecifics. Most males that used post-harvest stands had home ranges that were comprised of $\geq 80\%$ unharvested stands. In most other studies of Canada Warblers across the breeding range, there have been no measures of the spatial location of used post-harvest stands in relation to unharvested stands or to conspecifics (review by Reitsma et al. 2010), meaning that point count stations located in post-harvest stands may be detecting birds in the post-harvest stand itself, or in adjacent unharvested stands. In areas with high densities of Canada Warblers and high amounts of harvesting, more individuals may be detected in post-harvest stands as they may use these areas to be closer to conspecifics. Hence, in highly harvested landscapes, the proportion of individuals in post-harvest will likely be higher. Although they did not empirically test use patterns relative to edge or conspecifics, Becker et al. (2012) also suggested that clearcuts were used more in areas closer to edges, and Hallworth et al. (2008b) suggested that the proximity of unharvested and harvested study plots may have influenced the reported use of harvested stands by Canada Warblers.

To my knowledge, no other Canada Warbler study has provided information on intensity of use within the home range. Thus, these studies had to assume that when individuals were detected in a given land use type, they used this exclusively throughout the breeding season. However, results from chapter 2 suggest that individuals detected in post-harvest stands spend the majority of their time in the unharvested parts of their home range near conspecifics, and away from stand edges.

3.2 Assumptions about habitat quality

Since Van Horne's (1983) seminal paper "*Density as a misleading indicator of habitat quality*", it is widely accepted that demographic information is required to assess habitat quality

(Johnson 2007). A meta-analysis by Bock and Jones (2004) showed that in most cases, density of birds was positively related to breeding success, but the relationship was less consistent in human-disturbed landscapes. For example, negative relationships between breeding success and density can arise when birds disproportionately use habitat types where they experience lower breeding success than in other habitat types (i.e. ecological traps; Gates and Gysel 1978, Battin 2004), or where crowding of individuals may result in lower per capita productivity for individuals through competition for resources and mates (Brown 1969, McKellar et al. 2014).

Hache et al. (2014) suggested that density of Canada Warblers was a good indicator of habitat quality and that high density areas should be used to inform critical habitat identification. Other studies have expressed concerns about whether density is a good proxy for per unit area or capita productivity of Canada Warblers (Hagan et al. 1997, Ball et al. 2013, Palmer-Ball Jr 2015), but most studies did not empirically test for discrepancies. In Chapter 2, I showed that pairing success and probability of fledging young were not affected by forest harvest. Density affected pairing success (i.e. pairing success was lower in high density areas), but did not affect probability of already paired males fledging young. This suggests that unpaired males are attracted to areas where they can obtain extra-pair copulations with females, rather than suggesting density-dependent effects on reproductive activity per se. In Lesser Slave Lake Provincial Park, Flockhart et al. (2016) found negative density-dependent effects on breeding success of Canada Warblers, but they did not separate the effects on paired and unpaired males. In our study area, males only used small portions of post-harvest stands in their home range, so potential effects on reproductive activity may be less evident than if the entire home range was composed of post-harvest. This effect could be different in other regions if birds are exclusively using post-harvest stands. Although effects of density on breeding success were not explicitly tested, Hallworth et al. (2008a) found no difference in proportion of successful breeders in areas supporting different densities (i.e. second-growth forest vs. undisturbed maple swamp). Local demographic studies on Canada Warbler populations in each Bird Conservation Region across the breeding range are required to quantify potential geographic variation in the relevance of using density as a proxy for habitat quality. Such an initiative to assess breeding success in several areas across the breeding range is currently underway using a standardized rapid assessment approach developed by Len Reitsma and the Canada Warbler International Conservation Initiative (CWICI; pers. comm).

3.3 Differences in ecological context

Regional variation in habitat use and response to disturbance has been reported in many species (Whittingham et al. 2007, Bayard and Elphick 2010, Boves et al. 2013, Cunningham and Johnson 2016). There are several potential reasons for this variation. Firstly, the availability of certain cover types or features may affect the use patterns that we observe. For example, Cunningham and Johnson (2016) found that several forest bird species responded positively to percent tree cover in landscapes that were open, whereas in wooded landscapes, birds showed neutral or negative responses. Secondly, differences exist in underlying regional characteristics which might alter regeneration rates and overall system productivity of forests (e.g. climate, vegetation, soils; Simard et al. 2011) and ultimately, regional differences in bird responses to disturbances. For example, LaManna and Martin (2016) showed that forest harvest in less productive higher-latitude temperate forests resulted in greater changes in species composition than in lower-latitude temperate forests. LaManna and Martin (2016) also found that the effects of forest harvest on bird species richness were more severe in deciduous or coniferous stands than in mixedwood stands. Thirdly, extrinsic variables other than vegetation structure may be more relevant to a species. For example, food abundance and quality are important drivers of habitat selection and use by birds (Lack et al 1954, Newmark and Stanley 2016). While food abundance/quality is generally correlated with habitat structure, different relationships may exist regionally (Holmes and Schultz 1988, Boves et al. 2013). For example, Sleep et al. (2009) suggested that the high variance in timing of spruce budworm outbreaks across regions could make it difficult to draw general conclusions about the effects of this prey base on Canada Warblers at the national level. Hence, birds might occupy different vegetation types in different geographic areas, depending which vegetation attributes are associated with high food availability in that area. Lastly, responses will often differ with disturbance intensity, which alters vegetation structure and food availability to varying extents (Wedeles and Donnelly 2004). Harvest methods can range from removing a relatively small percentage of trees (e.g. 30-40% in selective harvest; Angers et al. 2005), which generally has minimal effects on forest species loss (Hache et al. 2013), to all or most trees (e.g. clearcut harvest) which can result in drastic changes in species composition (LaManna and Martin 2016). Furthermore, for species with large ranges, range-wide studies may mask variation in regional patterns, or potentially detect only the strongest effects (i.e. those that affect the areas with high population densities).

The Canada Warbler has a large breeding range, extending from the boreal forest at high northern latitudes in the west (~60°N), to temperature forests at low latitudes in the eastern U.S. (~35°N) (Reitsma et al. 2010). This breeding range includes six Bird Conservation Regions (BCR) which are "conservation planning units designated based on ecoregion features such as: climate, human activity, vegetation, soils, geological and physiographic features, and associated biodiversity" (Environment Canada 2016b).

There are more reports of negative forestry effects on breeding populations of Canada Warblers at higher latitudes (e.g. BCR 6; Hobson and Bayne 2000b, Ball et al. 2013) than populations breeding at lower latitudes (e.g. BCR 12, 14, 28; Hagan et al. 1997, King and DeGraaf 2000, Becker et al. 2012, Grinde and Niemi 2016). This latitudinal variation in responses to forestry suggests that inherent differences in regional conditions like climate may result in variation in the availability of certain environmental conditions, vegetation and disturbance types.

Regional differences in responses to forestry can also result from differences in harvest treatments and intensity across the breeding range. Quebec, Ontario, and British Columbia have the highest forest harvest rates (ha/yr) in Canada (Masek et al. 2011), suggesting that unharvested stands might be less available in these provinces and Canada Warblers might be forced to use higher proportion of harvested areas. Furthermore, clearcut harvest and higher volume of trees/ha is more common in boreal regions of Canada (Masek et al. 2011) while selection harvesting is the most common harvest method in the hemiboreal regions and northeastern U.S. (Masek et al. 2011). Hence, neutral or positive responses to forest harvesting documented in the eastern breeding range might be partly due to the prevalence of selective harvesting, whereas negative responses in the western breeding range might be due to the prevalence of clearcuts. This is consistent with Becker et al. (2012) who found that Canada Warblers had higher relative abundance in forests that were managed using selection harvest vs. clearcut harvest. Despite the prevalence of selection harvest in the eastern portion of the species range, several studies have also tested effects of clearcut harvest on Canada Warblers in this region (Hagan et al. 1997, King and DeGraaf 2000, Becker et al. 2012, Grinde and Niemi 2016), suggesting that factors other than harvest intensity also need to be considered.

The national species distribution model generated by Hache et al. (2014) showed habitat associations that were consistent with studies in the central portion of the Canada Warbler breeding range (i.e. mixedwood and deciduous stands; Drapeau et al. 2000), but again, found no effects of forest harvest. Because the highest densities of Canada Warblers are found in the central breeding range, habitat associations and forestry responses of these populations may have a disproportionate effect on the predictions from the national model. Moreover, pooling results from across BCRs could mask regional variability (Woolmer et al. 2008). However, there was no effect of an East-West divide (at -98° longitude) or BCR on habitat-specific density estimates for territorial males (Hache et al. 2014). They did find that densities were higher in areas with a longer growing season (generally lower latitudes) and with tall trees. Hence, climate effects could explain variability in density across the breeding range at larger spatial scales better than vegetation alone, as the availability of certain vegetation types and structures in an area could be regulated by climate (Hogg and Bernier 2005, Simard et al. 2011). Higher productivity and regeneration rates at lower latitudes might also allow Canada Warblers to exploit a wider range of habitats and mitigate some of the effects of forest harvest. Although canopy height can be used as a proxy for stand age, trees are known to grow faster and taller at lower latitudes (Simard et al. 2011). Lastly, Hache et al. (2014) did not test for regional variation in responses to forestry and only considered stands harvested within the last 10 years. In Chapter 2, we showed that effects of forest harvest remained for up to 30 years and considering post-harvest stands >10 years as unharvested stands could be misleading.

3.4 Recommendations for understanding and addressing needs of Canada Warbler

It is clear that both regional studies and range-wide studies have pros and cons for assessing habitat quality and threats for species-at-risk. In this essay, I have discussed potential reasons for discrepancies in habitat associations and threats among regions, and why these discrepancies may not be captured at the national scale. Species distribution models like Hache et al. (2014) provide valuable information on Canada Warbler population trends, where the highest proportion of the breeding population resides, and broad-scale climatic variables used to estimate distribution and population size across jurisdictions. However, this scale of study does not appear to capture the regional variation in habitat use patterns and forestry that will be important for defining critical habitat and determining whether forest harvesting can maintain suitable conditions for Canada Warblers. Recommendations from Hache et al. (2014) include the protection of mixedwood stands with high canopy height and dense cover across the breeding range, although they did not necessarily consider forest management as an important component of conserving populations. Their results would also suggest that conservation efforts should be focused in Ontario and Quebec as these areas support most of the Canadian breeding population. Results from this thesis suggest that post-harvest stands in western boreal regions support fewer males than unharvested stands and that unharvested stands are necessary components of most male home ranges. Furthermore, we showed evidence for a hidden lek system in Canada Warblers, resulting in a clustered distribution of males, suggesting that some suitable areas may remain unused if there are no males already established in neighboring stands. Overall, this suggests that recovery strategies for species-at-risk should include: 1) range-wide modeling initiatives to prioritize areas where the highest proportion of the estimated breeding population occurs; and 2) designations of critical habitat based on BCR-specific habitat needs and threats, which account for habitat quality, and behavioural processes when possible. Work of this nature is currently being undertaken (see Will et al. 2005, Mahon et al. 2014). Identifying critical habitat and threats are key components of developing plans to recover threatened species, and addressing knowledge gaps and contradictory data is necessary to develop comprehensive recovery action plans.

In this thesis, I have presented a case where abundance, habitat use, reproductive activity, and behavioral processes were successfully linked to understand effects of forestry on the Canada Warbler on their breeding grounds in Alberta. However, this is only one piece of a complex story needed to understand and protect this declining species. Cumulative effects of other threats on the breeding grounds (e.g. habitat conversion, collision with structures, etc; Environment Canada 2016a), as well as threats along migratory routes and wintering grounds must also be taken into consideration. Canada Warblers are neotropical migrants, so habitat use and threats on the wintering grounds and stopover areas along migratory routes likely have important implications for population trends and may contribute to the patterns we see on the breeding grounds. For example, on the primary wintering grounds of Canada Warblers in the Andean forests of northern South America, over 90% of forested area has been cleared (González-Prieto et al. 2016). Furthermore, eastern and western breeding populations are geographically segregated on their wintering grounds in Columbia into areas that experience different environmental conditions and disturbance intensity (González-Prieto et al. 2016). Finally, climate is a known driver of broad-scale distributions and use patterns of birds, and Hache et al. (2014) found that the number of growing days was an important predictor of Canada Warbler abundance. In the boreal, although climate change may initially result in increased forest productivity, it is also expected to increase the frequency and severity of fire (Flannigan et al. 2009), drought (Hogg and Bernier 2005), and insect outbreaks (Volney and Fleming 2000), and impact the timing of biological events, leading to mismatches in phenology of arrival on the breeding or wintering grounds vs. vegetation and prey which could result in reduced survival or breeding success (Bowers et al. 2016). This may affect the availability of suitable habitat for Canada Warblers by changing vegetation structure, food availability, and other environmental conditions. These climatic changes will likely be different across the geographic range of the species, and will have different magnitudes of impact on different breeding populations. For example, González-Prieto et al. (2016) suggest that climate effects will be more severe for the eastern wintering populations than the western populations, as climatic conditions are already drier in the former.

The main recommendations from my thesis would include the prioritization of protecting large contiguous areas of older unharvested stands, particularly in those areas where Canada Warblers already occur, and to only consider post-harvest stands usable if they are in close proximity to unharvested stands and conspecifics. If hidden leks are occurring in this species, there is a potential to use experimental manipulation to lure Canada Warblers into suitable, but unoccupied habitat (Ahlering et al. 2010). However, we do not currently know the type and timing of conspecific cues to which males are responding (i.e. songs of conspecifics during territory establishment, location and success of males at the end of the previous breeding season), so different cues and timing should be tested. Additionally, pre and post-implementation monitoring should be in place to assess the persistence of Canada Warbler occupancy, reproductive activity and survival in experimentally established territories relative to naturally established territories. Ahlering et al. (2010) provide a useful flowchart and suggestions for best practices when applying conspecific attraction methods to conservation. These results cannot necessarily be extrapolated to other regions given the important regional differences previously discussed. However, accounting for proximity of Canada Warblers to unharvested stands and conspecifics should be considered when assessing use of harvested areas in other regions.

LITERATURE CITED

Addicott, J. F., J. M. Aho, M. F. Antolin, D. K. Padilla, J. S. Richardson, and D. A. Soluk. 1987. Ecological neighborhoods: scaling environmental patterns. Oikos:340–346.

Ahlering, M. A., D. Arlt, M. G. Betts, R. J. Fletcher Jr, J. J. Nocera, and M. P. Ward. 2010. Research needs and recommendations for the use of conspecific-attraction methods in the conservation of migratory songbirds. The Condor 112:252–264.

Alberta Sustainable Resource Development. 2008. Alberta timber harvest planning and operating ground rules framework for renewal.

Alberta Vegetation Inventory Interpretation Standards Version 2.1.1 March 2005 Chapter 3 – Vegetation Inventory Standards and Data Model Documents Resource Information Management Branch, Alberta Sustainable Resource Development.

Andrew, M., M. Wulder, and N. Coops. 2012. De facto protected areas of the Canadian boreal forest. Biological Conservation 146:97–107.

Angers, V. A., C. Messier, M. Beaudet, and A. Leduc. 2005. Comparing composition and structure in old-growth and harvested (selection and diameter-limit cuts) northern hardwood stands in Quebec. Forest ecology and Management 217:275–293.

Ball, J., P. Sólymos, F. Schmiegelow, S. Hache, J. Schieck, and E. Bayne. 2016. Regional habitat needs of a nationally listed species, Canada Warbler (*Cardellina canadensis*), in Alberta, Canada. Avian Conservation & Ecology 11:10.

Bamford, A. J., A. Monadjem, M. D. Anderson, A. Anthony, W. D. Borello, M. Bridgeford, P. Bridgeford, P. Hancock, B. Howells, J. Wakelin, and others. 2009. Trade-offs between specificity and regional generality in habitat association models: a case study of two species of African vulture. Journal of Applied Ecology 46:852–860.

Bart, J. 2005. Monitoring the abundance of bird populations. The Auk 122:15–25.

Barton, K. 2013. MuMIn: multi-model inference. R package version 1.

Battin, J. 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conservation Biology 18:1482–1491.

Bayard, T. S., and C. S. Elphick. 2010. How area sensitivity in birds is studied. Conservation Biology 24:938–947.

Bayne, E., L. Leston, C. L. Mahon, P. Sólymos, C. Machtans, H. Lankau, J. R. Ball, S. L. Van Wilgenburg, S. G. Cumming, T. Fontaine, and others. 2016. Boreal bird abundance estimates within different energy sector disturbances vary with point count radius. The Condor

118:376–390.

Bayne, E. M., S. Boutin, B. Tracz, and K. Charest. 2005. Functional and numerical responses of ovenbirds (*Seiurus aurocapilla*) to changing seismic exploration practices in Alberta's boreal forest. Ecoscience 12:216–222.

Beauchamp, G., M. Belisle, and L.-A. Giraldeau. 1997. Influence of conspecific attraction on the spatial distribution of learning foragers in a patchy habitat. Journal of Animal Ecology 66:671–682.

Becker, D. A., P. B. Wood, and P. D. Keyser. 2012. Canada Warbler use of harvested stands following timber management in the southern portion of their range. Forest ecology and management 276:1–9.

Bock, C. E., and Z. F. Jones. 2004. Avian habitat evaluation: should counting birds count? Frontiers in Ecology and the Environment 2:403–410.

Bonnot, T. W., F. R. Thompson, J. J. Millspaugh, and D. T. Jones-Farrand. 2013. Landscape-based population viability models demonstrate importance of strategic conservation planning for birds. Biological Conservation 165:104–114.

Boves, T. J., D. A. Buehler, J. Sheehan, P. B. Wood, A. D. Rodewald, J. L. Larkin, P. D. Keyser, F. L. Newell, A. Evans, G. A. George, and others. 2013. Spatial variation in breeding habitat selection by Cerulean Warblers (*Setophaga cerulea*) throughout the Appalachian Mountains. The Auk 130:46–59.

Bowers, E. K., J. L. Grindstaff, S. S. Soukup, N. E. Drilling, K. P. Eckerle, S. K. Sakaluk, and C. F. Thompson. 2016. Spring temperatures influence selection on breeding date and the potential for phenological mismatch in a migratory bird. Ecology 97:2880–2891.

Boyce, M. S. 2006. Scale for resource selection functions. Diversity and Distributions 12:269–276.

Brown, J. L. 1969. Territorial behavior and population regulation in birds: a review and re-evaluation. The Wilson Bulletin:293–329.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. Journal of mammalogy 24:346–352.

Campomizzi, A. J., J. A. Butcher, S. L. Farrell, A. G. Snelgrove, B. A. Collier, K. J. Gutzwiller, M. L. Morrison, and R. Wilkins. 2008. Conspecific attraction is a missing component in wildlife habitat modeling. The Journal of Wildlife Management 72:331–336.

Chace, J. F., S. D. Faccio, and A. Chacko. 2009. Canada warbler habitat use of northern hardwoods in Vermont. Northeastern Naturalist 16:491–500.

Cooper, J. M., K. A. Enns, and M. G. Shepard. 1997. Status of the Canada warbler in British Columbia. Wildlife Branch.

Cumming, S. G., K. L. Lefevre, E. Bayne, T. Fontaine, F. K. Schmiegelow, and S. J. Song. 2010. Toward Conservation of Canada's Boreal Forest Avifauna: Design and Application of Ecological Models at Continental Extents Avian Conservation and Ecology 5:8.

Cunningham, J. A., D. C. Kesler, and R. B. Lanctot. 2016. Habitat and social factors influence nest-site selection in Arctic-breeding shorebirds. The Auk 133:364–377.

Cunningham, M. A., and D. Johnson. 2016. What you find depends on where you look: responses to proximate habitat vary with landscape context. Avian Conservation and Ecology 11(2).

Dias, P. C. 1996. Sources and sinks in population biology. Trends in Ecology & Evolution 11:326–330.

Diemer, K. M., and J. J. Nocera. 2016. Bobolink reproductive response to three hayfield management regimens in southern Ontario. Journal for Nature Conservation 29:123–131.

Drake, A., C. A. Rock, S. P. Quinlan, M. Martin, and D. J. Green. 2014. Wind speed during migration influences the survival, timing of breeding, and productivity of a neotropical migrant, *Setophaga petechia.*

Drapeau, P., A. Leduc, J.-F. Giroux, J.-P. L. Savard, Y. Bergeron, and W. L. Vickery. 2000. Landscape-scale disturbances and changes in bird communities of boreal mixed-wood forests. Ecological Monographs 70:423–444.

Enns, K. A., and C. Siddle. 1996. The distribution, abundance, and habitat requirements of selected passerine birds of the Boreal and Taiga plains of British Columbia. Ministry of Environment, Lands, and Parks, Wildlife Branch.

Environment Canada. 2013. Bird Conservation Strategy for Bird Conservation Region 6: Boreal Taiga Plains. Available: http://ec.gc.ca/mbc-com/default.asp?lang=En&n=C2CB4DD5-1 [accessed November 10, 2016].

Environment Canada. 2016a. Recovery Strategy for the Canada Warbler (*Cardellina canadensis*) in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. vii + 56 pp.

Environment Canada. 2016b. Bird Conservation Regions and Conservation Strategies. Available: https://www.ec.gc.ca/mbc-com/default.asp?lang=En&n=1D15657A-1 [accessed November 8, 2016].

Environment and Climate Change Canada. 2016. Species At Risk Act Implementation Guidance for Recovery Practitioners: Critical Habitat Identification Toolbox. Available:

https://www.registrelep-sararegistry.gc.ca/default.asp?lang=En&n=AA794D41-1 [accessed December 23, 2016].

Fahrig, L. 2013. Rethinking patch size and isolation effects: the habitat amount hypothesis. Journal of Biogeography 40:1649–1663.

Fish, U. S., and Wildlife Service. 1973. Endangered Species Act Pages 1531–1544, Department of the Interior.

Flannigan, M., B. Stocks, M. Turetsky, and M. Wotton. 2009. Impacts of climate change on fire activity and fire management in the circumboreal forest. Global Change Biology 15:549–560.

Fletcher, R. J. 2006. Emergent properties of conspecific attraction in fragmented landscapes. The American Naturalist 168:207–219.

Flockhart, D. 2010. Timing of events on the breeding grounds for five species of sympatric warblers. Journal of Field Ornithology 81:373–382.

Flockhart, D., G. Mitchell, R. Krikun, and E. Bayne. 2016. Factors driving territory size and breeding success in a threatened migratory songbird, the Canada Warbler. Avian Conservation and Ecology 11(2).

Flockhart, D. T. T. 2007. Migration Timing Of Canada Warblers Near The Northern Edge Of Their Breeding Range. The Wilson Journal of Ornithology 119:712–716.

Fretwell, S. D., and H. Lucas. 1970. On territorial behavior and other factors influencing habitat distribution in birds. Acta biotheoretica 19:16–36.

Gates, J. E., and L. W. Gysel. 1978. Avian nest dispersion and fledging success in field-forest ecotones. Ecology 59:871–883.

Gessler, P. E., I. Moore, N. McKenzie, and P. Ryan. 1995. Soil-landscape modelling and spatial prediction of soil attributes. International Journal of Geographical Information Systems 9:421–432.

Gilroy, J. J., and W. J. Sutherland. 2007. Beyond ecological traps: perceptual errors and undervalued resources. Trends in ecology & evolution 22:351–6.

Girard, C., M. Darveau, J.-P. L. Savard, and J. Huot. 2004. Are temperate mixedwood forests perceived by birds as a distinct forest type? Canadian Journal of Forest Research 34:1895–1907.

González-Prieto, A. M., N. J. Bayly, G. J. Colorado, and K. A. Hobson. 2016. Topography of the Andes Mountains shapes the wintering distribution of a migratory bird. Diversity and Distributions.

González-Prieto, A. M., and K. A. Hobson. 2013. Environmental conditions on wintering grounds and during migration influence spring nutritional condition and arrival phenology of Neotropical migrants at a northern stopover site. Journal of Ornithology 154:1067–1078.

Goodnow, M. L., and L. R. Reitsma. 2011a. Nest-site selection in the Canada Warbler (Wilsonia canadensis) in central New Hampshire. Canadian Journal of Zoology 89:1172–1177.

Goodnow, M., and L. Reitsma. 2011b. Nest-site selection in the Canada Warbler (Wilsonia canadensis) in central New Hampshire. Canadian Journal of Zoology 89:1172–1177.

Government of Canada. 2011. Species at Risk Act. Available: http://www.sararegistry.gc.ca/default_e.cfm [Accessed October 19, 2016]

Grinde, A. R., and G. J. Niemi. 2016. Influence of landscape, habitat, and species co-occurrence on occupancy dynamics of Canada Warblers. The Condor 118:513–531.

Guillera-Arroita, G., J. J. Lahoz-Monfort, J. Elith, A. Gordon, H. Kujala, P. E. Lentini, M. A. McCarthy, R. Tingley, and B. A. Wintle. 2015. Is my species distribution model fit for purpose? Matching data and models to applications. Global Ecology and Biogeography 24:276–292.

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147–186.

Hache, S., T. Pétry, and M.-A. Villard. 2013. Numerical Response of Breeding Birds Following Experimental Selection Harvesting in Northern Hardwood Forests Avian Conservation and Ecology 8:4.

Hache, S., P. Solymos, T. Fontaine, E. Bayne, S. Cumming, F. Schmiegelow, and D. Stralberg. 2014. Analyses to support critical habitat identification for Canada Warbler, Olive-sided Flycatcher, and Common Nighthawk. Boreal Avian Modelling Project, Technical Report for Environment Canada.

Haché, S., M.-A. Villard, and E. M. Bayne. 2013. Experimental evidence for an ideal free distribution in a breeding population of a territorial songbird. Ecology 94:861–869.

Hagan, J. M., P. S. McKinley, A. L. Meehan, and S. L. Grove. 1997. Diversity and abundance of landbirds in a northeastern industrial forest. The Journal of wildlife management 61:718–735.

Hallworth, M., P. M. Benham, J. D. Lambert, and L. Reitsma. 2008a. Canada warbler (*Wilsonia canadensis*) breeding ecology in young forest stands compared to a red maple (*Acer rubrum*) swamp. Forest ecology and management 255:1353–1358.

Hallworth, M., A. Ueland, E. Anderson, J. D. Lambert, and L. Reitsma. 2008b. Habitat selection and site fidelity of Canada Warblers (Wilsonia canadensis) in central New Hampshire. The

Auk 125:880–888.

Hamilton, L. C. 2012. Statistics with Stata: version 12. Cengage Learning.

Harrison, R. B., F. K. Schmiegelow, and R. Naidoo. 2005. Stand-level response of breeding forest songbirds to multiple levels of partial-cut harvest in four boreal forest types. Canadian Journal of Forest Research 35:1553–1567.

Hobson, K. A., and E. Bayne. 2000a. Breeding bird communities in boreal forest of western Canada: consequences of "unmixing" the mixedwoods. The Condor 102:759–769.

Hobson, K. A., and E. Bayne. 2000b. Effects of forest fragmentation by agriculture on avian communities in the southern boreal mixedwoods of western Canada. The Wilson Bulletin 112:373–387.

Hogg, E., and P. Y. Bernier. 2005. Climate change impacts on drought-prone forests in western Canada. The Forestry Chronicle 81:675–682.

Holland, J. D., and S. Yang. 2016. Multi-scale Studies and the Ecological Neighborhood. Current Landscape Ecology Reports 1:135–145.

Holmes, R. T., and J. C. Schultz. 1988. Food availability for forest birds: effects of prey distribution and abundance on bird foraging. Canadian Journal of Zoology 66:720–728.

Howlett, J. S., B. J. Stutchbury, and M. Murphy. 2003. Determinants of between-season site, territory, and mate fidelity in Hooded Warblers (*Wilsonia citrina*). The Auk 120:457–465.

Hutto, R. 1985. Habitat selection by nonbreeding, migratory land birds. Page 455:473 in: Habitat selection in birds.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, M. D. 2007. Measuring habitat quality: a review. The Condor 109:489–504.

Jones, J. 2001. Habitat Selection Studies in Avian Ecology: A Critical Review. The Auk 118:557.

Kearney, M., and W. Porter. 2009. Mechanistic niche modelling: combining physiological and spatial data to predict species' ranges. Ecology letters 12:334–50.

Kertson, B. N., and J. M. Marzluff. 2011. Improving studies of resource selection by understanding resource use. Environmental Conservation 38:18–27.

King, D. I., and R. M. DeGraaf. 2000. Bird species diversity and nesting success in mature, clearcut and shelterwood forest in northern New Hampshire, USA. Forest Ecology and management 129:227–235.

Lack, D. 1954. The natural regulation of animal numbers. Oxford University Press, Oxford.

LaManna, J. A., and T. E. Martin. 2016. Logging impacts on avian species richness and composition differ across latitudes and foraging and breeding habitat preferences. Biological Reviews.

Lambert, J. D., and S. D. Faccio. 2005. Canada Warbler population status, habitat use, and stewardship guidelines for northeastern forests. VINS Technical Report 05-4. Quechee Vermont.

Langor, D. W., E. K. Cameron, C. J. MacQuarrie, A. McBeath, A. McClay, B. Peter, M. Pybus, T. Ramsfield, K. Ryall, T. Scarr, and others. 2014. Non-native species in Canada's boreal zone: diversity, impacts, and risk 1. Environmental Reviews 22:372–420.

Lankau, H. E., E. M. Bayne, and C. S. Machtans. 2013. Ovenbird (*Seiurus auocapilla*) territory placement near seismic lines is influenced by forest regeneration and conspecific density. Avian Conservation and Ecology 8:5.

Lee, T. M., and W. Jetz. 2011. Unravelling the structure of species extinction risk for predictive conservation science. Proceedings of the Royal Society of London B: Biological Sciences 278:1329–1338.

Lele, S. R., E. H. Merrill, J. Keim, and M. S. Boyce. 2013. Selection, use, choice and occupancy: clarifying concepts in resource selection studies. The Journal of animal ecology 82:1183–91.

Loss, S. R. 2016. Avian interactions with energy infrastructure in the context of other anthropogenic threats. The Condor 118:424–432.

MacArthur, R. H., and J. W. MacArthur. 1961. On Bird Species Diversity. Ecology 42:594–598 .

Machtans, C. S., M.-A. Villard, and S. J. Hannon. 1996. Use of riparian buffer strips as movement corridors by forest birds. Conservation Biology 10:1366–1379.

Mahon, C. L., E. M. Bayne, P. Sólymos, S. M. Matsuoka, M. Carlson, E. Dzus, F. K. Schmiegelow, and S. J. Song. 2014. Does expected future landscape condition support proposed population objectives for boreal birds? Forest Ecology and Management 312:28–39.

Mahon, C. L., G. Holloway, P. Sólymos, S. G. Cumming, E. M. Bayne, F. K. Schmiegelow, and S. J. Song. 2016. Community structure and niche characteristics of upland and lowland western boreal birds at multiple spatial scales. Forest Ecology and Management 361:99–116.

Martin, T., C. Paine, C. Conway, W. Hochachka, P. Allen, and W. Jenkins. 1997. BBIRD field protocol. Montana Cooperative Wildlife Research Unit, University of Montana, Missoula, MT

59812.

Marzluff, J. M., J. J. Millspaugh, P. Hurvitz, and M. S. Handcock. 2004. Relating resources to a probabilistic measure of space use: forest fragments and Steller's jays. Ecology 85:1411–1427.

Masek, J. G., W. B. Cohen, D. Leckie, M. A. Wulder, R. Vargas, B. de Jong, S. Healey, B. Law, R. Birdsey, R. Houghton, and others. 2011. Recent rates of forest harvest and conversion in North America. Journal of Geophysical Research: Biogeosciences 116.

McCune, J. L., W. L. Harrower, S. Avery-Gomm, J. M. Brogan, A.-M. Cserg\Ho, L. N. Davidson, A. Garani, L. R. Halpin, L. P. Lipsen, C. Lee, and others. 2013. Threats to Canadian species at risk: An analysis of finalized recovery strategies. Biological Conservation 166:254–265.

McKellar, A. E., P. P. Marra, P. T. Boag, and L. M. Ratcliffe. 2014. Form, function and consequences of density dependence in a long-distance migratory bird. Oikos 123:356–364.

Mesterton-Gibbons, M., and E. S. Adams. 2003. Landmarks in territory partitioning: a strategically stable convention? The American Naturalist 161:685–697.

Meyer, C. B., and W. Thuiller. 2006. Accuracy of resource selection functions across spatial scales. Diversity and Distributions 12:288–297.

Mooers, A. O., D. F. Doak, C. S. Findlay, D. M. Green, C. Grouios, L. L. Manne, A. Rashvand, M. A. Rudd, and J. Whitton. 2010. Science, policy, and species at risk in Canada. BioScience 60:843–849.

Morrison, C. A., R. A. Robinson, J. A. Clark, and J. A. Gill. 2016. Causes and consequences of spatial variation in sex ratios in a declining bird species. Journal of Animal Ecology 85:1298–1306.

Muggeo, V. M. 2008. Segmented: an R package to fit regression models with broken-line relationships. R news 8:20–25.

Natural Resources Canada. 2016. Sustainable Forest Management in Canada: Key Facts. Report, Government of Canada.

Newmark, W. D., and T. R. Stanley. 2016. The influence of food abundance, food dispersion and habitat structure on territory selection and size of an Afrotropical terrestrial insectivore. Ostrich 87:199–207.

Nocera, J. J., G. J. Forbes, and L.-A. Giraldeau. 2009. Aggregations from using inadvertent social information: a form of ideal habitat selection. Ecography 32:143–152.

Otis, D. L., and G. C. White. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. The Journal of Wildlife Management 63:1039–1044.

Palmer-Ball Jr, B. L. 2015. The Kentucky breeding bird atlas. University Press of Kentucky, Lexington, Kentucky.

Pärt, T., D. Arlt, and M.-A. Villard. 2007. Empirical evidence for ecological traps: a two-step model focusing on individual decisions. Journal of Ornithology 148:327–332.

Partners in Flight Science Committee. 2012. Species Assessment Database. Version 2012. Laurel, MD. Available: http://rmbo.org/pifassessment [accessed: 16 September 2014].

Peck, G. K., and R. D. James. 1987. Breeding birds of Ontario: nidiology and distribution. Royal Ontario Museum Toronto.

Pulliam, H. R. 1988. Sources, Sinks, and Population Regulation. The American Naturalist 132:652–661.

Pyle, P. 1997. Molt limits in North American passerines. North American Bird Bander 22:49–89.

Rappole, J. H. 1983. Analysis of plumage variation in the Canada Warbler. Journal of Field Ornithology 54:152–159.

Reitsma, L., M. Goodnow, H. Michael, and C. J. Conway. 2010. Canada Warbler (Cardellina canadensis), The Birds of North America Online (A. Poole, Ed.). Available: http://bna.birds.cornell.edu/bna/species/421 [accessed: February 9, 2014]

Reitsma, L. R., M. T. Hallworth, and P. M. Benham. 2008a. Does age influence territory size, habitat selection, and reproductive success of male Canada Warblers in central New Hampshire? The Wilson Journal of Ornithology 120:446–454.

Reitsma, L. R., M. T. Hallworth, and P. M. Benham. 2008b. Does age influence territory size, habitat selection, and reproductive success of male Canada Warblers in central New Hampshire? The Wilson Journal of Ornithology 120:446–454.

Ridley, J., Komdeur, W., and J. Sutherland. 2004. Incorporating territory compression into population models. Oikos 105:101–108.

Rodriguez, A., H. Andrén, and G. Jansson. 2001. Habitat-mediated predation risk and decision making of small birds at forest edges. Oikos 95:383–396.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, M. F. Carter, and F. Thompson III. 2002. Landbird counting techniques: current practices and an alternative. The Auk 119:46–53.

Rowe, J., and G. W. Scotter. 1973. Fire in the boreal forest. Quaternary research 3:444–464.

Saino, N., T. Szép, R. Ambrosini, M. Romano, and A. P. Møller. 2004. Ecological conditions during winter affect sexual selection and breeding in a migratory bird. Proceedings. Biological sciences, The Royal Society 271:681–6.

Schieck, J., and K. A. Hobson. 2000. Bird communities associated with live residual tree patches within cut blocks and burned habitat in mixedwood boreal forests. Canadian Journal of Forest Research 30:1281–1295.

Schieck, J., M. Nietfeid, and J. B. Stelfox. 1995. Differences in bird species richness and abundance among three successional stages of aspen-dominated boreal forests. Canadian Journal of Zoology 73:1417–1431.

Schieck, J., and S. J. Song. 2006. Changes in bird communities throughout succession following fire and harvest in boreal forests of western North America: literature review and meta-analyses. Canadian Journal of Forest Research 36:1299–1318.

Schmiegelow, F. K., C. S. Machtans, and S. J. Hannon. 1997. Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. Ecology 78:1914–1932.

Schmiegelow, F. K., and M. Mönkkönen. 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. Ecological Applications 12:375–389.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. The journal of wildlife management:739–747.

Simard, M., N. Pinto, J. B. Fisher, and A. Baccini. 2011. Mapping forest canopy height globally with spaceborne lidar. Journal of Geophysical Research: Biogeosciences 116 (G4).

Simberloff, D., and L. G. Abele. 1982. Refuge design and island biogeographic theory: effects of fragmentation. American Naturalist:41–50.

Skagen, S. K., and A. Yackel Adams. 2011. Potential misuse of avian density as a conservation metric. Conservation Biology 25:48–55.

Skaug, H., D. Fournier, A. Nielsen, A. Magnusson, and B. Bolker. 2011. glmmADMB: generalized linear mixed models using AD model builder. R Package, version 0.7.

Sleep, D. J., M. C. Drever, and K. J. Szuba. 2009. Potential role of spruce budworm in range-wide decline of Canada Warbler. The Journal of Wildlife Management 73:546–555.

Smith, A. C., L. Fahrig, and C. M. Francis. 2011. Landscape size affects the relative importance of habitat amount, habitat fragmentation, and matrix quality on forest birds. Ecography

34:103–113.

Smith, A. R. 1996. Atlas of Saskatchewan birds. Regina: Saskatchewan Natural History Society.

Smith, T., and H. Shugart. 1987. Territory size variation in the ovenbird: the role of habitat structure. Ecology 68:695–704.

Huettmann, F. 2003. " Ecological Basis for Stand Management: A Summary and Synthesis of Ecological Responses to Wildfire and Harvesting in Boreal Forests" edited by SJ Song. 2002.[book review]. The Canadian Field-Naturalist 117(3):500-502.

Stamps, J. 1988. Conspecific attraction and aggregation in territorial species. American Naturalist:329–347.

Team, R. C. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. doi: ISBN 3-900051-07-0.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. The Journal of Wildlife Management 7(4):893–901.

Venier, L., I. Thompson, R. Fleming, J. Malcolm, I. Aubin, J. Trofymow, D. Langor, R. Sturrock, C. Patry, R. Outerbridge, and others. 2014. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests 1. Environmental Reviews 22:457–490.

Vickery, P. D., M. L. Hunter Jr, and J. V. Wells. 1992. Use of a new reproductive index to evaluate relationship between habitat quality and breeding success. The Auk:697–705.

Volney, W. J. A., and R. A. Fleming. 2000. Climate change and impacts of boreal forest insects. Agriculture, Ecosystems & Environment 82:283–294.

Wagner, R. H. 1998. Hidden leks: sexual selection and the clustering of avian territories. Ornithological Monographs:123–145.

Wedeles, C. H. R., and M. Donnelly. 2004. Bird-forestry Relationships in Canada: Literature Review and Synthesis of Management Recommendations. NCASI. Technical Bulletin 892.

Wells, J. V., P. Blancher, and J. Wells. 2011. Global role for sustaining bird populations. In book Boreal Birds of North America: A:7–23.

Welsh, D., and D. Fillman. 1980. The impact of forest cutting on boreal bird populations. Am. Birds 34:84–94.

Westwood, A. 2016. Conservation of three forest landbird species at risk: characterizing and modelling habitat at muliple scales to guide management planning. PhD thesis, Dalhousie

University, N.S., Canada.

Whittingham, M. J., J. R. Krebs, R. D. Swetnam, J. A. Vickery, J. D. Wilson, and R. P. Freckleton. 2007. Should conservation strategies consider spatial generality? Farmland birds show regional not national patterns of habitat association. Ecology Letters 10:25–35.

Will, T., J. Ruth, K. Rosenberg, D. Krueper, D. Hahn, J. Fitzgerald, R. Dettmers, and C. Beardmore. 2005. The five elements process: designing optimal landscapes to meet bird conservation objectives. Partners in Flight.

Woolmer, G., S. C. Trombulak, J. C. Ray, P. J. Doran, M. G. Anderson, R. F. Baldwin, A. Morgan, and E. W. Sanderson. 2008. Rescaling the human footprint: a tool for conservation planning at an ecoregional scale. Landscape and Urban Planning 87:42–53.

Zlonis, E. J., and G. J. Niemi. 2014. Avian communities of managed and wilderness hemiboreal forests. Forest Ecology and Management 328:26–34.

APPENDICES

Appendix 1. Results from a comparison of *a priori* models to generate predictions for three model sets: A) Density of males (17.3 ha survey blocks; n=132); B) 2nd order use (used/unused; n=2,112); C) 3rd order use (in 24 male home ranges; n=3,147) for territorial male Canada Warblers in managed forests in northern Alberta. Model sets include baseline models and up to three stages: 1) forestry effects alone, 2) forestry and conspecific proximity effects, and 3) forestry, conspecific proximity, and ground-based vegetation effects. Model stages within each set are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAICc is the difference in the AICc value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight, N is the sample size of the model. Pseudo r^2 values are reported for top models. "*" represents interactions between terms.

Model description	**N**	**Model Stage**	**ΔAICc**	**Df**	**Weight**	**Pseudo r^2**
DENSITY						
CUT3+NEAROCC+DISTRIVER+CTI +STUDYAREA	132	2	0	9	0.77	0.17
CUT3+DISTRIVER+CTI +STUDYAREA	132	1	2.7	7	0.21	
DISTRIVER+CTI +STUDYAREA	132	0	6.6	6	0.02	
2ND ORDER USE						
IFCUT*DISTEDGE +NEAROCC+DISTRIVER+STUDYAREA	2112	2	0	9	0.99	0.56
IFCUT*DISTEDGE+ DISTRIVER+STUDYAREA	2112	1	13.2	8	0.001	
DISTRIVER+STUDYAREA	2112	0	32.7	5	<0.001	
GROUND-BASED VEGETATION						
IFCUT*DISTEDGE +NEAROCC+ DISTRIVER+STUDYAREA	89	2	0	7	0.72	0.07
IFCUT*DISTEDGE +NEAROCC+	89	3	1.8	8	0.28	

DISTRIVER+STUDYAREA +SHRUB						
3^{RD} ORDER USE						
IFCUT*NEAROCC +DISTEDGE+DISTSTREAM +STUDYAREA	3147	2	0	10	0.70	0.04
IFCUT+DISTEDGE+DISTSTREAM +STUDYAREA	3147	1	1.8	8	0.28	
DISTSTREAM +STUDYAREA	3147	0	7.4	6	0.02	
GROUND-BASED VEGETATION						
IFCUT*NEAROCC +DISTEDGE+DISTSTREAM +STUDYAREA	84	2	0	10	0.77	0.04
IFCUT+DISTEDGE*NEAROCC +DISTSTREAM +STUDYAREA +GREENCOV	84	3	2.4	11	0.23	

** CUT3 is a cubed term representing the percent of a survey block comprised of post-harvest stands, NEAROCC is the distance to the nearest conspecific, DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), IFCUT is the presence/absence(1/0) of post-harvest stands at a point count station, DISTEDGE is the distance (m) to the nearest post-harvest/unharvested edge, DISTSTREAM is the distance (m) to nearest stream, CTI is the average compound topographic index, CONSDENSITY2 is a squared term representing the number of conspecifics (males) on the survey block. SHRUB is the density of shrubs (<2.5cm diameter), GREENCOV is the % green cover <50cm height. CTI is the average compound topographical index.

Appendix 2. Results from *a priori* models used to generate predictions for A) pairing success (paired vs. unpaired; n=62), and B) probability of fledging young (fledged ≥1 young vs. paired only; n=51) of territorial male Canada Warblers using either 1) 2^{nd} order variables or 2) 3^{rd} order variables. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight.

PAIRING SUCCESS:	**ΔAICc**	**Df**	**Weight**	**Pseudo R^2**
2^{ND} ORDER VARIABLES				
CONSDENSITY2	0	2	0.93	0.14

NULL	5.91	1	0.05	
IFCUT*PATCH	7.52	3	0.02	
3RD ORDER VARIABLES				
CONSDENSITY	0	2	0.81	0.10
NULL	3.89	1	0.12	
EDGEINHR	4.01	2	0.11	
GREENCOV	4.85	2	0.7	
PROBABILITY OF FLEDGING YOUNG:				
2ND ORDER VARIABLES				
DISTRIVER+STUDYAREA	0	4	0.82	0.17
IFCUT+DISTRIVER+STUDYAREA	3.42	5	0.15	
CONSDENSITY+DISTRIVER+STUDYAREA	6.42	6	0.03	
3RD ORDER VARIABLES				
SHRUBCOV+DISTRIVER+STUDYAREA	0	5	0.66	0.25
DISTRIVER+STUDYAREA	1.95	4	0.22	
EDGEINHR+DISTRIVER+STUDYAREA	3.94	5	0.09	
CONSDENSITY+ DISTRIVER+STUDYAREA	8.37	5	0.01	

**NULL represents a model with no variables, IFCUT represents whether a station or grid cell is in post-harvest (1) or not (0), PATCH represents the area(m2) of the unharvested patch a station is located in, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), DISTRIVER is the distance(m) to the nearest river, EDGEINHR is the length of post-harvest-unhavested edge in a home range, CONSDENSITY2 is the density of other males on the survey block, SHRUBCOV is the % shrub cover (<50cm), GREENCOV is the % cover of all green material (<50cm).

Appendix 3. Results from 6 *a priori* models (STAGE 1) based on forestry covariates used to generate predictions of density of territorial male Canada Warblers on survey grids (n=132) in managed forests in northern Alberta. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight. All models included BASELINE variables: distance (m) to river from the survey block centroid, average compound topographical index (CTI) on the survey block, and study area (1=Lesser Slave Lake, 2=Calling Lake, 3=Lac La Biche) as fixed effects, all models except BASELINE included CUT3.

Model description	**ΔAIC**	**Df**	**Weight**
CUT3+DISTRIVER+CTI+STUDYAREA	0	7	0.34
CUT3+ CWED+DISTRIVER+CTI+STUDYAREA	0.3	8	0.29
CUT3+YEAR+DISTRIVER+CTI+STUDYAREA	1	9	0.21
CUT3+PATCH+DISTRIVER+CTI+STUDYAREA	1.4	8	0.14
CUT3+LAND+DISTRIVER+CTI+STUDYAREA	2.3	8	0.09
DISTRIVER+CTI+STUDYAREA	3.9	6	0.04

** CUT3 (cubed term) represents the percent of a survey block comprised of post-harvest stands, YEAR represents the area-weighted average year of harvest on the survey block, CWED represents a measure of fragmentation-the contrast weighted edge density (unharvested: harvested edge) on the survey block, PATCH represents whether there is an isolated residual patch in the cutblock (1=patch, 0= no patch), LAND represents landscape effect-the amount of old-growth (>100 years) aspen within a 1 km buffer of the survey block. DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), CTI is the average compound topographic index

Appendix 4. Results from 5 *a priori* models (STAGE 1) used to generate predictions of 2nd order use for point count level surveys (n=2112) for territorial male Canada Warblers in managed forests in northern Alberta. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight. All models included BASELINE variables distance to river and study area (1=Lesser Slave Lake, 2=Calling Lake, 3=Lac La Biche) as fixed effects and survey block number as a random effect, all models except BASELINE included IFCUT.

Model description	**ΔAICc**	**Df**	**Weight**
IFCUT*DISTEDGE+DISTRIVER+STUDYAREA	0	8	0.97
IFCUT*YEAR+DISTRIVER+STUDYAREA	8.1	8	<0.01
IFCUT+DISTRIVER+STUDYAREA	9.5	6	<0.01
IFCUT*PATCH+DISTRIVER+STUDYAREA	13.3	8	<0.001
DISTRIVER+STUDYAREA	19.2	6	<0.001

** IFCUT represents whether a station is in post-harvest (1) or not (0), DISTEDGE represents the distance (m) to the nearest edge (post-harvest to unharvested), YEAR represents the origin year of the stand in which the station is located (harvest year for post-harvest stands and stand origin for unharvested stands), PATCH represents the area(m2) of the unharvested patch a station is located in, DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake).

Appendix 5. Results from 10 *a priori* models (STAGE 3) used to test which ground-based vegetation variables best predict 2nd order use for point count level surveys (n=89) for territorial male Canada Warblers in managed forests in northern Alberta. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight. All models included BASELINE variables distance to river and study area (1=Lesser Slave Lake, 2=Calling Lake, 3=Lac La Biche) as fixed effects and survey block number as a random effect, all models except BASELINE included IFCUT.

Model description	**ΔAICc**	**Df**	**Weight**
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+SHRUB	0	9	0.17
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+SHRUBs	0.1	9	0.15
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+TREESIZE	0.3	9	0.14
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+CANOPYCOV	0.5	9	0.1
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+CANOPYHEIGHT	1	9	0.1
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+SHRUBCOV	1	9	0.09
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+ORGLITTER	1	9	0.08
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+TREECOUNT	1.3	9	0.06

IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+GREENCOV	1.5	9	0.06
IFCUT*DISTEDGE +NEAROCC+STUDYAREA+DISTRIVER+LOGCOV	1.5	9	0.05

* NEAROCC is the distance to the nearest conspecific, DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), IFCUT is the presence/absence(1/0) of post-harvest stands at a point count station, DISTEDGE is the distance (m) to the nearest post-harvest/unharvested edge, SHRUB is the density of shrubs (<2.5cm diameter), SHRUBs is the density of shrubs (2.5-8 cm diameter), GREENCOV is the % green cover <50cm height, SHRUBCOV is the % shrub cover <50cm height, LOGCOV is the % log cover <50cm height,, TREECOUNT is the number of trees (>8cm diameter), ORGLITTER is the average depth (mm) of organic litter, TREESIZE is the average tree size, CANOPYCOVER is the amount of upper canopy cover, CANOPYHEIGHT is the average height of upper canopy trees.

Appendix 6. Results from 6 *a priori* models (STAGE 1) based on forestry variables used to generate predictions of 3rd order use (n=3147) in home ranges of territorial male Canada Warblers that include post-harvest stands (n=24) in managed forests in northern Alberta. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight. All models included BASELINE variables distance to stream and study area (1=Lesser Slave Lake, 2=Calling Lake, 3=Lac La Biche) as a fixed effect and individual bird ID as a random effect, all models except BASELINE included IFCUT.

Model description	**ΔAIC**	**Df**	**Weight**
IFCUT+DISTEDGE+DISTSTREAM+STUDYAREA	0	8	0.76
IFCUT+PATCH+DISTSTREAM+STUDYAREA	3.4	9	0.14
DISTSTREAM+STUDYAREA	5.6	6	0.05
IFCUT+DISTSTREAM+STUDYAREA	6.6	7	0.02
IFCUT*YEAR+DISTSTREAM+STUDYAREA	7.1	9	0.02
SUBSET WITH AGE (N=42)			
IFCUT+DISTEDGE+DISTSTREAM+STUDYAREA	0	10	0.90
IFCUT*MALEAGE+DISTSTREAM+STUDYAREA	4.4	11	0.10

**IFCUT represents whether a grid cell is in post-harvest (1) or not (0), DISTEDGE represents the distance (m) to the nearest post-harvest-unharvested edge, PATCH represents the area(m2) of the unharvested patch a grid cell is located in, YEAR represents the origin year of the stand in which the grid cell is located (harvest year for post-harvest stands and stand origin for unharvested stands) MALEAGE represents the age of the tracked male (1=after second year, 2=second year). DISTSTREAM is the distance (m) to nearest stream, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake).

Appendix 7. Results from 10 *a priori* models (STAGE 3) used to test which ground-based vegetation variables would best predict 3rd order use in home ranges of territorial male Canada Warblers that include post-harvest stands in managed forests in northern Alberta (n=84). Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight.

Model description	**ΔAICc**	**Df**	**Weight**
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+GREENCOV	0	11	0.38
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+CANOPYHEIGHT	2.6	11	0.1
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+NUMTREES	2.8	11	0.09
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+CANOPYCOV	3	11	0.08
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+TREESIZE	3	11	0.05
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+SHRUB	3.9	11	0.05
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+SHRUBs	4.1	11	0.05
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+LOGCOV	4.2	11	0.05
IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+ORGLITTER	4.2	11	0.05

IFCUT*NEAROCC +DISTEDGE+STUDYAREA+DISTSTREAM+SHRUBCOV	4.2	11	0.05

* NEAROCC is the distance to the nearest conspecific, DISTSTREAM is the distance (m) to nearest stream, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), IFCUT is the presence/absence(1/0) of post-harvest stands at a point count station, DISTEDGE is the distance (m) to the nearest post-harvest/unharvested edge, SHRUB is the density of shrubs (<2.5cm diameter), SHRUBs is the density of shrubs (2.5-8 cm diameter), GREENCOV is the % green cover <50cm height, SHRUBCOV is the % shrub cover <50cm height, LOGCOV is the % log cover <50cm height , TREECOUNT is the number of trees (>8cm diameter), ORGLITTER is the average depth (mm) of organic litter, TREESIZE is the average tree size, CANOPYCOVER is the amount of upper canopy cover, CANOPYHEIGHT is the average height of upper canopy trees.

Appendix 8. Results from *a priori* models (STAGE 1) based on forestry covariates used to generate predictions of A) pairing success (paired vs. unpaired; n=62) and B) probability of fledging young (fledged ≥1 young vs. paired only; n=51) of male Canada Warblers. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight.

Model description	**ΔAIC**	**Df**	**Weight**
PAIRING SUCCESS			
2ND ORDER			
NULL	0	1	0.68
IFCUT*PATCH	1.61	3	0.31
IFCUT	2	2	0.25
IFCUT*YEARCUT	3.76	4	0.10
IFCUT*DISTEDGE	4.79	4	0.07
3RD ORDER			
NULL	0	1	0.52
EDGEINHR	0.22	2	0.49
PROPCUT	1.22	2	0.28
NUMPTSCUT	1.86	2	0.20
PROBABILITY OF FLEDGING YOUNG			
2ND ORDER			

DISTRIVER+STUDYAREA	0	0.65	4
IFCUT+DISTRIVER+STUDYAREA	0.99	0.24	5
IFCUT*PATCH+DISTRIVER+STUDYAREA	3.42	0.12	7
IFCUT*DISTEDGE+DISTRIVER+STUDYAREA	3.44	0.12	7
IFCUT*YEAR+DISTRIVER+STUDYAREA	17	0	7
3RD ORDER			
DISTRIVER+STUDYAREA	0	0.51	4
PROPCUT+DISTRIVER+STUDYAREA	1.3	0.26	5
NUMPTSCUT+DISTRIVER+STUDYAREA	1.59	0.23	5
EDGEINHR+DISTRIVER+STUDYAREA	1.99	0.19	5

NULL represents a model with no variables, IFCUT represents whether a station or grid cell is in post-harvest (1) or not (0), DISTEDGE represents the distance (m) to the nearest post-harvest-unharvested edge, PATCH represents the area(m2) of the unharvested patch a station is located in, YEARCUT represents the origin year of the stand in which the station is located, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake),, DISTRIVER is the distance(m) to the nearest river, PROPCUT is the proportion of home range that overlaps post-harvest, NUMPTSCUT is the number of use locations within post-harvest stands in the home range, EDGEINHR is the length of post-harvest-unhavested edge in a home range.

Appendix 9. Results from *a priori* models (STAGE 3) used to test which ground-based vegetation variables would best predict A) pairing success (paired vs. unpaired; n=62) and B) probability of fledging young (fledged ≥1 young vs. paired only; n=51) of male Canada Warblers. in managed forests in northern Alberta. Models are ranked from the lowest to highest corrected Akaike's Information Criterion (AICc) values, ΔAIC is the difference in the AIC value relative to the best fitting model, Df is the degrees of freedom, and weight is the model weight.

Model description	**ΔAICc**	**Df**	**Weight**
PAIRING SUCCESS			
CONSDENSITY2	0	2	0.25
CONSDENSITY2+GREENCOV	0.62	3	0.18
CONSDENSITY2+ORGLITTER	1.03	3	0.15

CONSDENSITY2+CANOPYHEIGHT	1.15	3	0.14
CONSDENSITY2+CANOPYCOVER	2.3	3	0.08
CONSDENSITY2+SHRUBs	2.56	3	0.07
CONSDENSITY2+TREECOUNT	3.56	3	0.04
CONSDENSITY2+SHRUBCOV	3.99	3	0.03
CONSDENSITY2+TREESIZE	4.1	3	0.03
CONSDENSITY2+LOGCOV	4.2	3	0.01
PROBABILITY OF FLEDGING YOUNG			
DISTRIVER+STUDYAREA+SHRUBCOV	0	5	0.27
DISTRIVER+STUDYAREA+SHRUBs	0.8	5	0.18
DISTRIVER+STUDYAREA+CANOPYCOV	0.96	5	0.17
DISTRIVER+STUDYAREA	1.96	4	0.10
DISTRIVER+STUDYAREA+ORGLITTER	2.73	5	0.07
DISTRIVER+STUDYAREA+SHRUB	3.39	5	0.05
DISTRIVER+STUDYAREA+TREECOUNT	3.62	5	0.04
DISTRIVER+STUDYAREA+CANOPYHEIGHT	3.80	5	0.04
DISTRIVER+STUDYAREA+GREENCOV	3.91	5	0.04
DISTRIVER+STUDYAREA+TREESIZE	3.95	5	0.04
DISTRIVER+STUDYAREA+LOGCOV	4.00	5	0.03

* NEAROCC is the distance to the nearest conspecific, DISTRIVER is the distance (m) to nearest river, STUDYAREA is the study areas CL (Calling Lake) and LLB (Lac La Biche) in reference to LSL (Lesser Slave Lake), SHRUB is the density of shrubs (<2.5cm diameter), SHRUBs is the density of shrubs (2.5-8 cm diameter), GREENCOV is the % green cover <50cm height, SHRUBCOV is the % shrub cover <50cm height, LOGCOV is the % log cover <50cm height , TREECOUNT is the number of trees (>8cm diameter), ORGLITTER is the average depth (mm) of organic litter, TREESIZE is the average tree size, CANOPYCOVER is the amount of upper canopy cover, CANOPYHEIGHT is the average height of upper canopy trees, CONSDENSITY2 is a squared term representing density of other males on the survey block.

Appendix 10. Locations (lat/long) of points surveyed (n=2,112) within survey blocks (n=132, 17.3 ha) for male Canada Warblers using playback point counts where males were detected (1) or were not detected (0).

LAT	LONG	Bird_YN	LAT	LONG	Bird_YN	LAT	LONG	Bird_YN
55.514876	-116.075225	0	55.05319	-111.903	0	55.06866	-111.672	0
55.515567	-116.074216	0	55.05233	-111.903	0	55.06839	-111.671	0

55.516258	-116.073207	0	55.05092	-111.876	0	55.06811	-111.669	0
55.516949	-116.072199	0	55.05071	-111.877	0	55.06784	-111.668	0
55.515448	-116.076443	0	55.05051	-111.879	0	54.95182	-111.795	0
55.516139	-116.075434	0	55.0503	-111.88	0	54.95092	-111.795	0
55.51683	-116.074426	0	55.05005	-111.875	0	54.95003	-111.795	0
55.517522	-116.073417	0	55.04984	-111.877	0	54.94913	-111.795	0
55.51602	-116.077661	0	55.04963	-111.878	0	54.95189	-111.793	0
55.516711	-116.076653	0	55.04943	-111.88	0	54.95099	-111.793	0
55.517403	-116.075644	0	55.04917	-111.875	0	54.9501	-111.793	0
55.518094	-116.074635	0	55.04896	-111.876	0	54.9492	-111.793	0
55.516592	-116.07888	0	55.04876	-111.878	0	54.95196	-111.792	0
55.517284	-116.077871	0	55.04855	-111.879	0	54.95106	-111.792	0
55.517975	-116.076862	0	55.0483	-111.874	0	54.95017	-111.792	0
55.518666	-116.075854	0	55.04809	-111.876	0	54.94927	-111.791	0
55.213432	-113.369876	0	55.04788	-111.877	0	54.95203	-111.79	0
55.212565	-113.369464	0	55.04768	-111.879	0	54.95114	-111.79	0
55.211698	-113.369052	0	55.05064	-111.943	0	54.95024	-111.79	0
55.210831	-113.368639	0	55.05048	-111.944	0	54.94934	-111.79	0
55.213668	-113.36836	0	55.05031	-111.946	0	54.94419	-111.772	0
55.212801	-113.367948	0	55.05015	-111.948	0	54.94331	-111.772	0
55.211934	-113.367535	0	55.04976	-111.943	0	54.94243	-111.772	0
55.211067	-113.367123	0	55.0496	-111.944	0	54.94154	-111.771	0
55.213903	-113.366844	0	55.04943	-111.946	0	54.94436	-111.771	0
55.213037	-113.366432	0	55.04927	-111.947	0	54.94348	-111.771	0
55.21217	-113.366019	0	55.04888	-111.942	0	54.9426	-111.77	0
55.211303	-113.365607	0	55.04871	-111.944	0	54.94172	-111.77	0
55.214139	-113.365328	0	55.04855	-111.945	0	54.94453	-111.769	0
55.213272	-113.364916	0	55.04838	-111.947	0	54.94365	-111.769	0
55.212405	-113.364503	0	55.04799	-111.942	0	54.94277	-111.769	0
55.211539	-113.364091	0	55.04783	-111.944	0	54.94189	-111.768	0
55.520734	-116.119303	0	55.04767	-111.945	0	54.9447	-111.768	0
55.52141	-116.118262	0	55.0475	-111.947	0	54.94382	-111.767	0
55.522085	-116.11722	0	54.99583	-111.825	0	54.94294	-111.767	0
55.522761	-116.116179	0	54.99503	-111.825	1	54.94206	-111.767	0
55.521325	-116.120494	0	54.99422	-111.826	0	54.99758	-111.834	0
55.522	-116.119452	0	54.99342	-111.827	0	54.99672	-111.834	0
55.522676	-116.118411	0	54.99543	-111.823	0	54.99586	-111.833	0
55.523352	-116.11737	0	54.99463	-111.824	0	54.995	-111.833	0
55.521915	-116.121685	0	54.99382	-111.825	0	54.99784	-111.832	0
55.522591	-116.120643	0	54.99302	-111.825	1	54.99698	-111.832	0
55.523267	-116.119602	0	54.99504	-111.822	0	54.99612	-111.832	0

55.523942	-116.118561	0	54.99423	-111.823	0	54.99526	-111.831	0
55.522506	-116.122876	0	54.99343	-111.823	0	54.9981	-111.831	0
55.523182	-116.121834	0	54.99262	-111.824	1	54.99725	-111.831	0
55.523857	-116.120793	0	54.99464	-111.821	0	54.99639	-111.83	0
55.524533	-116.119752	0	54.99383	-111.821	0	54.99553	-111.83	0
55.309209	-116.250448	0	54.99303	-111.822	0	54.99837	-111.83	1
55.309215	-116.248875	0	54.99222	-111.823	1	54.99751	-111.829	1
55.30922	-116.247302	0	55.19556	-113.42	0	54.99665	-111.829	0
55.309225	-116.245729	0	55.19492	-113.421	0	54.99579	-111.828	1
55.310106	-116.250458	0	55.19427	-113.422	0	55.25611	-113.634	0
55.310112	-116.248885	0	55.19363	-113.424	0	55.25524	-113.634	0
55.310117	-116.247312	1	55.19494	-113.419	0	55.25437	-113.634	0
55.310123	-116.245738	0	55.19429	-113.42	0	55.2535	-113.633	0
55.311004	-116.250468	0	55.19365	-113.421	0	55.25633	-113.633	0
55.311009	-116.248894	0	55.193	-113.422	0	55.25545	-113.632	0
55.311015	-116.247321	0	55.19431	-113.418	0	55.25458	-113.632	0
55.31102	-116.245748	0	55.19366	-113.419	0	55.25371	-113.632	0
55.311901	-116.250477	0	55.19302	-113.42	0	55.25654	-113.631	0
55.311907	-116.248904	0	55.19238	-113.421	0	55.25566	-113.631	0
55.311912	-116.247331	0	55.19368	-113.417	0	55.25479	-113.63	0
55.311917	-116.245757	0	55.19304	-113.418	0	55.25392	-113.63	1
55.320154	-116.196159	0	55.19239	-113.419	0	55.25675	-113.63	0
55.32071	-116.194924	0	55.19175	-113.42	0	55.25588	-113.629	0
55.321266	-116.193689	0	55.00381	-111.834	0	55.255	-113.629	1
55.321822	-116.192454	1	55.00291	-111.834	0	55.25413	-113.629	0
55.320858	-116.197134	1	55.00202	-111.834	0	55.28474	-113.614	0
55.321414	-116.195899	1	55.00112	-111.834	0	55.28384	-113.614	0
55.32197	-116.194664	0	55.00389	-111.833	0	55.28294	-113.614	0
55.322527	-116.193429	1	55.00299	-111.833	0	55.28204	-113.614	0
55.321562	-116.19811	0	55.0021	-111.832	1	55.28475	-113.612	0
55.322119	-116.196875	0	55.0012	-111.832	0	55.28385	-113.612	0
55.322675	-116.19564	0	55.00396	-111.831	0	55.28295	-113.612	0
55.323231	-116.194405	1	55.00307	-111.831	0	55.28205	-113.612	0
55.322267	-116.199085	0	55.00218	-111.831	0	55.28476	-113.611	0
55.322823	-116.19785	0	55.00128	-111.831	0	55.28386	-113.611	0
55.323379	-116.196615	1	55.00404	-111.83	0	55.28296	-113.611	0
55.323935	-116.19538	1	55.00315	-111.829	0	55.28206	-113.611	0
55.525414	-116.000657	0	55.00225	-111.829	0	55.28476	-113.609	0
55.525573	-115.9991	1	55.00136	-111.829	0	55.28387	-113.609	0
55.525733	-115.997543	0	55.00885	-111.835	0	55.28297	-113.609	0
55.525892	-115.995986	1	55.00892	-111.837	0	55.28207	-113.609	0

55.526297	-116.000938	0	55.009	-111.838	0	55.21874	-113.466	0
55.526456	-115.999381	0	55.00908	-111.84	0	55.21785	-113.466	0
55.526616	-115.997824	0	55.00795	-111.835	0	55.21696	-113.466	0
55.526775	-115.996267	0	55.00803	-111.837	0	55.21607	-113.466	0
55.52718	-116.001219	0	55.00811	-111.838	0	55.21886	-113.465	0
55.52734	-115.999661	1	55.00819	-111.84	0	55.21797	-113.465	0
55.527499	-115.998104	0	55.00706	-111.835	0	55.21708	-113.464	0
55.527658	-115.996547	0	55.00714	-111.837	0	55.21619	-113.464	0
55.528064	-116.001499	0	55.00721	-111.839	0	55.21897	-113.463	0
55.528223	-115.999942	1	55.00729	-111.84	0	55.21808	-113.463	0
55.528382	-115.998385	0	55.00616	-111.836	0	55.21719	-113.463	0
55.528541	-115.996828	0	55.00624	-111.837	0	55.2163	-113.463	0
55.319978	-116.20673	0	55.00632	-111.839	0	55.21909	-113.462	0
55.320535	-116.205495	0	55.0064	-111.84	0	55.2182	-113.461	0
55.321091	-116.20426	0	55.03994	-111.872	0	55.21731	-113.461	0
55.321647	-116.203026	1	55.03949	-111.874	0	55.21642	-113.461	0
55.320683	-116.207706	1	55.03903	-111.875	0	55.22293	-113.485	0
55.321239	-116.206471	0	55.03858	-111.876	0	55.22204	-113.485	0
55.321795	-116.205236	1	55.03917	-111.871	0	55.22115	-113.485	0
55.322352	-116.204001	0	55.03871	-111.873	0	55.22026	-113.485	0
55.321387	-116.208681	1	55.03826	-111.874	0	55.22305	-113.484	0
55.321943	-116.207447	0	55.0378	-111.875	0	55.22216	-113.484	0
55.322499	-116.206212	1	55.03839	-111.871	0	55.22126	-113.483	0
55.323056	-116.204977	1	55.03794	-111.872	0	55.22037	-113.483	0
55.322091	-116.209657	1	55.03748	-111.873	0	55.22316	-113.482	0
55.322647	-116.208422	0	55.03703	-111.875	0	55.22227	-113.482	0
55.323204	-116.207187	0	55.03762	-111.87	0	55.22138	-113.482	0
55.32376	-116.205952	0	55.03716	-111.871	0	55.22049	-113.482	0
55.308407	-116.242215	1	55.03671	-111.872	0	55.22328	-113.481	0
55.308412	-116.240642	1	55.03625	-111.874	0	55.22239	-113.48	0
55.308418	-116.239069	0	55.04157	-111.898	1	55.22149	-113.48	0
55.308423	-116.237495	1	55.04087	-111.899	0	55.2206	-113.48	0
55.309304	-116.242224	0	55.04016	-111.9	0	55.21846	-113.485	0
55.30931	-116.240651	0	55.03946	-111.901	1	55.21757	-113.485	0
55.309315	-116.239078	0	55.04101	-111.896	0	55.21667	-113.484	0
55.30932	-116.237505	0	55.04031	-111.897	0	55.21578	-113.484	0
55.310202	-116.242234	0	55.0396	-111.898	1	55.21857	-113.483	0
55.310207	-116.240661	1	55.0389	-111.899	0	55.21768	-113.483	0
55.310212	-116.239087	0	55.04045	-111.895	0	55.21679	-113.483	0
55.310218	-116.237514	1	55.03975	-111.896	0	55.2159	-113.483	0
55.311099	-116.242243	0	55.03904	-111.897	1	55.21869	-113.482	0

55.311104	-116.24067	0	55.03834	-111.898	1	55.2178	-113.481	0
55.31111	-116.239097	0	55.03989	-111.894	0	55.2169	-113.481	0
55.311115	-116.237523	1	55.03919	-111.895	0	55.21601	-113.481	0
55.219309	-113.374413	0	55.03849	-111.896	0	55.2188	-113.48	0
55.218492	-113.373757	0	55.03778	-111.897	1	55.21791	-113.48	0
55.217676	-113.3731	0	55.02781	-111.899	0	55.21702	-113.48	0
55.21686	-113.372444	0	55.02764	-111.9	0	55.21613	-113.48	0
55.219684	-113.372985	0	55.02748	-111.902	0	55.21538	-113.616	0
55.218868	-113.372329	0	55.02731	-111.903	0	55.2145	-113.615	0
55.218051	-113.371673	0	55.02692	-111.898	0	55.21363	-113.615	0
55.217235	-113.371017	0	55.02676	-111.9	0	55.21276	-113.615	0
55.220059	-113.371557	0	55.02659	-111.901	0	55.21559	-113.614	0
55.219243	-113.370901	0	55.02643	-111.903	0	55.21472	-113.614	0
55.218426	-113.370245	0	55.02604	-111.898	0	55.21384	-113.613	0
55.21761	-113.369589	0	55.02588	-111.9	0	55.21297	-113.613	0
55.220434	-113.370129	0	55.02571	-111.901	0	55.2158	-113.613	0
55.219618	-113.369473	0	55.02555	-111.903	0	55.21493	-113.612	0
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55.533146	-115.869589	0	55.01358	-111.822	0	55.21427	-113.61	0
55.533923	-115.870382	0	55.01444	-111.822	0	55.2134	-113.61	0
55.531143	-115.869374	0	55.01531	-111.823	0	55.25554	-113.572	0
55.53192	-115.870166	0	55.01617	-111.823	0	55.25465	-113.572	0
55.532697	-115.870959	0	55.01333	-111.824	0	55.25375	-113.572	0
55.533474	-115.871751	0	55.0142	-111.824	0	55.25285	-113.572	0
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55.53147	-115.871536	0	55.01593	-111.825	0	55.25462	-113.571	0
55.532247	-115.872329	0	55.01309	-111.825	0	55.25372	-113.571	0
55.533024	-115.873121	0	55.01395	-111.825	0	55.25282	-113.571	0
55.530244	-115.872113	1	55.01482	-111.826	0	55.25548	-113.569	0
55.531021	-115.872906	0	55.01568	-111.826	0	55.25459	-113.569	0
55.531798	-115.873698	0	55.01284	-111.827	0	55.25369	-113.569	0
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55.5251	-116.124727	0	55.01457	-111.827	0	55.25545	-113.567	0
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55.526852	-116.124051	0	55.19864	-113.458	0	55.25366	-113.567	0
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55.528113	-116.126801	1	55.19766	-113.455	0	55.27737	-113.597	0
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55.528195	-115.856304	0	55.19673	-113.454	0	55.28001	-113.594	0
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55.528522	-115.858466	0	55.02717	-111.911	0	55.27495	-113.593	0
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55.527623	-115.861205	0	55.02574	-111.913	0	55.27564	-113.591	0
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55.520208	-115.697671	0	55.07351	-111.888	0	55.27516	-113.588	0
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55.517647	-115.699832	0	55.07098	-111.892	0	55.27128	-113.619	0
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55.527852	-115.991869	1	55.0704	-111.89	0	55.27218	-113.617	0
55.528504	-115.990782	0	55.07012	-111.891	0	55.27128	-113.617	0
55.529157	-115.989696	1	55.083	-111.797	0	55.27038	-113.617	0
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55.528468	-115.993019	0	55.0829	-111.8	0	55.27346	-113.492	0
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55.530389	-115.991997	0	55.08121	-111.796	0	55.27158	-113.491	0
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55.5297	-115.99532	0	55.08111	-111.8	0	55.27327	-113.489	0
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55.533238	-115.993878	0	55.08021	-111.799	0	55.27318	-113.487	0
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55.537334	-115.902257	0	55.07539	-111.876	0	55.26008	-113.602	0
55.538231	-115.902294	0	55.08323	-111.872	0	55.25943	-113.601	0
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55.54811	-115.610567	0	55.05842	-111.78	0	55.27903	-113.644	0
55.209293	-113.399637	0	55.05815	-111.782	0	55.28173	-113.643	0

55.208617	-113.398602	0	55.05787	-111.783	0	55.28083	-113.643	0
55.207941	-113.397567	0	55.07991	-111.859	0	55.27993	-113.643	0
55.207265	-113.396532	0	55.0791	-111.859	0	55.27903	-113.643	0
55.209885	-113.398455	0	55.07829	-111.86	0	55.25136	-113.551	0
55.209209	-113.39742	0	55.07748	-111.861	0	55.25048	-113.552	0
55.208533	-113.396385	0	55.07953	-111.857	0	55.2496	-113.552	0
55.207857	-113.39535	0	55.07872	-111.858	0	55.24872	-113.552	0
55.210476	-113.397273	0	55.0779	-111.858	0	55.25118	-113.55	0
55.2098	-113.396238	0	55.07709	-111.859	0	55.2503	-113.55	0
55.209124	-113.395203	0	55.07914	-111.856	0	55.24942	-113.551	0
55.208449	-113.394168	0	55.07833	-111.856	0	55.24854	-113.551	0
55.211068	-113.396091	0	55.07752	-111.857	0	55.25101	-113.548	0
55.210392	-113.395056	0	55.07671	-111.858	0	55.25012	-113.549	0
55.209716	-113.394021	0	55.07876	-111.854	0	55.24924	-113.549	0
55.20904	-113.392986	0	55.07795	-111.855	0	55.24836	-113.549	0
55.524699	-115.901106	0	55.07714	-111.856	0	55.25083	-113.547	0
55.525212	-115.902405	0	55.07632	-111.856	0	55.24995	-113.547	0
55.525724	-115.903705	0	55.03532	-111.915	0	55.24907	-113.547	0
55.526236	-115.905004	0	55.03622	-111.915	0	55.24819	-113.548	0
55.523962	-115.902009	0	55.03711	-111.915	1	55.246	-113.554	0
55.524475	-115.903308	0	55.03801	-111.915	0	55.24512	-113.554	0
55.524987	-115.904607	0	55.03525	-111.916	1	55.24423	-113.553	0
55.525499	-115.905907	0	55.03614	-111.917	0	55.24335	-113.553	0
55.523225	-115.902912	0	55.03704	-111.917	0	55.24617	-113.552	0
55.523738	-115.904211	0	55.03793	-111.917	1	55.24529	-113.552	0
55.52425	-115.90551	0	55.03517	-111.918	0	55.24441	-113.552	0
55.524762	-115.906809	0	55.03607	-111.918	0	55.24353	-113.552	0
55.522488	-115.903814	0	55.03696	-111.918	0	55.24635	-113.551	0
55.523	-115.905114	0	55.03786	-111.918	0	55.24547	-113.551	0
55.523513	-115.906413	0	55.0351	-111.92	1	55.24458	-113.55	0
55.524025	-115.907712	0	55.03599	-111.92	0	55.2437	-113.55	0
55.555341	-115.608161	1	55.03689	-111.92	0	55.24652	-113.549	0
55.556237	-115.608238	0	55.03778	-111.92	0	55.24564	-113.549	0
55.557134	-115.608315	1	55.04182	-111.947	0	55.24476	-113.549	0
55.558031	-115.608391	0	55.04253	-111.946	0	55.24388	-113.548	0
55.555297	-115.609743	0	55.04324	-111.945	0	55.26231	-113.447	0
55.556194	-115.60982	0	55.04395	-111.944	0	55.26141	-113.447	0
55.55709	-115.609896	0	55.04237	-111.949	0	55.26051	-113.447	0
55.557987	-115.609973	0	55.04308	-111.948	0	55.25961	-113.447	0
55.555254	-115.611324	0	55.04379	-111.947	0	55.26229	-113.445	0
55.55615	-115.611401	0	55.0445	-111.946	0	55.2614	-113.445	0

55.557047	-115.611478	0	55.04291	-111.95	0	55.2605	-113.445	0
55.557944	-115.611555	1	55.04362	-111.949	0	55.2596	-113.445	0
55.55521	-115.612906	1	55.04434	-111.948	0	55.26228	-113.443	0
55.556107	-115.612983	0	55.04505	-111.947	0	55.26139	-113.444	0
55.557003	-115.61306	0	55.04346	-111.951	0	55.26049	-113.444	0
55.5579	-115.613137	0	55.04417	-111.95	0	55.25959	-113.444	0
55.517941	-115.639801	0	55.04488	-111.949	0	55.26227	-113.442	0
55.518838	-115.639717	0	55.0456	-111.948	0	55.26137	-113.442	0
55.519734	-115.639632	0	55.0348	-111.935	1	55.26048	-113.442	0
55.52063	-115.639548	0	55.03527	-111.934	1	55.25958	-113.442	0
55.517989	-115.641381	0	55.03575	-111.933	0	55.28026	-113.587	0
55.518886	-115.641297	0	55.03623	-111.931	0	55.27936	-113.587	0
55.519782	-115.641212	0	55.03556	-111.936	0	55.27846	-113.587	0
55.520678	-115.641128	0	55.03604	-111.935	1	55.27756	-113.587	0
55.518037	-115.642961	0	55.03651	-111.933	0	55.28025	-113.585	0
55.518934	-115.642877	0	55.03699	-111.932	1	55.27935	-113.585	0
55.51983	-115.642792	0	55.03632	-111.937	0	55.27845	-113.585	0
55.520726	-115.642708	0	55.0368	-111.936	0	55.27755	-113.585	0
55.518085	-115.644541	0	55.03727	-111.934	0	55.28024	-113.583	0
55.518981	-115.644456	0	55.03775	-111.933	0	55.27934	-113.583	0
55.519878	-115.644372	0	55.03708	-111.938	0	55.27844	-113.583	0
55.520774	-115.644288	0	55.03756	-111.936	0	55.27755	-113.584	0
55.538125	-115.605844	0	55.03803	-111.935	0	55.28023	-113.582	0
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55.539915	-115.606076	0	55.03541	-111.927	0	55.27844	-113.582	0
55.54081	-115.606191	0	55.03589	-111.926	0	55.27754	-113.582	0
55.538059	-115.607423	0	55.03636	-111.925	0	55.28087	-113.461	0
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55.53985	-115.607654	0	55.03617	-111.928	0	55.27907	-113.461	0
55.540745	-115.60777	0	55.03665	-111.927	0	55.27817	-113.461	0
55.537993	-115.609002	0	55.03712	-111.925	0	55.28088	-113.459	0
55.538889	-115.609117	0	55.0376	-111.924	0	55.27998	-113.459	0
55.539784	-115.609233	0	55.03693	-111.929	0	55.27908	-113.459	0
55.540679	-115.609349	0	55.03741	-111.927	0	55.27818	-113.459	0
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55.538823	-115.610696	0	55.03836	-111.925	0	55.27999	-113.458	0
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55.540614	-115.610928	0	55.03817	-111.928	0	55.27819	-113.458	0
55.54136	-115.639076	1	55.03865	-111.927	0	55.2809	-113.456	0
55.542113	-115.638214	0	55.03912	-111.926	0	55.28	-113.456	0
55.542866	-115.637352	0	55.02954	-111.905	0	55.2791	-113.456	0

55.543619	-115.63649	0	55.02968	-111.904	0	55.27821	-113.456	0
55.541849	-115.640404	1	55.02983	-111.902	0	55.2465	-113.452	0
55.542602	-115.639542	0	55.02997	-111.901	0	55.2456	-113.452	0
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55.544107	-115.637818	0	55.03057	-111.904	0	55.24381	-113.452	0
55.542337	-115.641732	0	55.03071	-111.903	0	55.24645	-113.451	0
55.54309	-115.64087	0	55.03085	-111.901	0	55.24555	-113.451	0
55.543843	-115.640008	0	55.03132	-111.906	0	55.24465	-113.451	1
55.544596	-115.639146	0	55.03146	-111.904	0	55.24376	-113.451	0
55.542826	-115.64306	0	55.0316	-111.903	0	55.2464	-113.449	0
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55.545085	-115.640474	0	55.03235	-111.905	0	55.24371	-113.449	0
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55.542767	-115.598946	0	55.03263	-111.902	0	55.24545	-113.448	0
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55.544557	-115.599177	0	55.06077	-111.83	0	55.24366	-113.448	0
55.541806	-115.600409	0	55.06061	-111.828	0	55.25524	-113.547	0
55.542701	-115.600525	0	55.06044	-111.827	0	55.25434	-113.547	0
55.543596	-115.60064	0	55.06182	-111.831	0	55.25344	-113.547	0
55.544492	-115.600756	0	55.06165	-111.83	0	55.25254	-113.547	0
55.54174	-115.601988	0	55.06149	-111.828	0	55.25521	-113.545	0
55.542636	-115.602104	0	55.06132	-111.827	0	55.25432	-113.545	0
55.543531	-115.602219	0	55.0627	-111.831	0	55.25342	-113.545	0
55.544426	-115.602335	0	55.06254	-111.829	0	55.25252	-113.545	0
55.541675	-115.603567	0	55.06237	-111.828	0	55.25519	-113.543	0
55.54257	-115.603682	0	55.06221	-111.826	0	55.25429	-113.543	1
55.543465	-115.603798	0	55.06358	-111.831	0	55.25339	-113.544	0
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55.557977	-115.587371	0	55.06325	-111.827	0	55.25516	-113.542	0
55.558874	-115.587447	0	55.06309	-111.826	0	55.25426	-113.542	0
55.559771	-115.587523	0	55.0054	-111.797	0	55.25337	-113.542	0
55.560667	-115.5876	0	55.00614	-111.797	0	55.25247	-113.542	0
55.557934	-115.588953	0	55.00687	-111.798	0	55.24444	-113.47	0
55.558831	-115.589029	0	55.00761	-111.799	0	55.24355	-113.47	0
55.559727	-115.589105	0	55.00489	-111.798	0	55.24266	-113.469	0
55.560624	-115.589182	0	55.00562	-111.799	0	55.24177	-113.469	0
55.557891	-115.590535	0	55.00636	-111.8	0	55.24457	-113.468	0
55.558787	-115.590611	0	55.0071	-111.801	0	55.24368	-113.468	0
55.559684	-115.590687	0	55.00437	-111.799	0	55.24279	-113.468	0
55.560581	-115.590764	0	55.00511	-111.8	0	55.2419	-113.468	0

55.557848	-115.592116	0	55.00585	-111.801	0	55.24469	-113.467	0
55.558744	-115.592193	0	55.00658	-111.802	0	55.2438	-113.467	0
55.559641	-115.592269	0	55.00386	-111.8	0	55.24291	-113.466	0
55.560537	-115.592346	0	55.0046	-111.801	0	55.24202	-113.466	0
55.532588	-115.586686	0	55.00533	-111.802	0	55.24482	-113.465	0
55.533484	-115.586801	0	55.00607	-111.803	0	55.24393	-113.465	0
55.534379	-115.586917	0	55.085	-111.805	1	55.24304	-113.465	0
55.535274	-115.587032	0	55.08467	-111.804	0	55.24215	-113.465	0
55.532523	-115.588265	0	55.08433	-111.802	0	55.26706	-113.454	0
55.533418	-115.58838	0	55.08399	-111.801	0	55.26616	-113.454	0
55.534314	-115.588495	0	55.08584	-111.805	0	55.26527	-113.454	0
55.535209	-115.58861	0	55.0855	-111.803	0	55.26437	-113.454	0
55.532458	-115.589843	0	55.08516	-111.802	0	55.26707	-113.452	0
55.533353	-115.589958	0	55.08482	-111.8	1	55.26618	-113.452	0
55.534248	-115.590074	0	55.08667	-111.804	0	55.26528	-113.452	0
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55.532392	-115.591422	0	55.08599	-111.801	0	55.26709	-113.451	0
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55.54244	-115.579588	0	55.08683	-111.801	0	55.2671	-113.449	0
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55.544233	-115.57974	0	55.05748	-111.791	0	55.2653	-113.449	0
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55.542397	-115.581169	0	55.05588	-111.789	0	55.25677	-113.556	0
55.543293	-115.581245	0	55.05508	-111.789	0	55.25599	-113.555	0
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55.542353	-115.582751	0	55.05629	-111.788	0	55.25722	-113.554	0
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55.544147	-115.582903	0	55.0583	-111.788	0	55.25567	-113.553	0
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55.544103	-115.584484	0	55.05871	-111.787	0	55.25613	-113.551	0
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55.276871	-113.447017	0	55.05711	-111.785	0	55.25813	-113.552	0
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55.275319	-113.448601	0	55.03485	-111.866	0	55.25658	-113.55	0
55.274543	-113.449394	0	55.03407	-111.867	0	55.2558	-113.549	0
55.276419	-113.445657	0	55.03329	-111.867	0	55.23719	-113.538	0

55.275643	-113.446449	0	55.03251	-111.868	0	55.23631	-113.538	0
55.274866	-113.447242	0	55.0344	-111.865	0	55.23543	-113.538	0
55.27409	-113.448034	0	55.03362	-111.865	0	55.23455	-113.539	0
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55.274414	-113.445883	0	55.03395	-111.863	0	55.23525	-113.537	0
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55.573159	-115.596853	0	55.0445	-111.864	0	55.229	-113.52	0
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55.565049	-115.545479	1	55.04271	-111.864	0	55.2309	-113.519	0
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55.565006	-115.547061	0	54.98981	-111.841	0	55.26789	-113.468	0
55.565903	-115.547136	0	54.98926	-111.842	0	55.26715	-113.469	0
55.5668	-115.547212	0	54.99017	-111.838	0	55.2664	-113.469	0
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55.567654	-115.548869	0	54.98891	-111.838	0	55.26515	-113.469	0
55.564921	-115.550225	0	54.98837	-111.839	0	55.2669	-113.465	0
55.565818	-115.550301	0	54.98783	-111.84	0	55.26615	-113.466	0

55.566714	-115.550376	0	54.98874	-111.836	0	55.2654	-113.467	0
55.567611	-115.550452	0	54.9882	-111.837	0	55.26465	-113.468	0
55.205873	-113.43685	0	54.98765	-111.838	0	55.2664	-113.464	0
55.204975	-113.436897	0	54.98711	-111.839	1	55.26565	-113.465	0
55.204078	-113.436944	0	54.99277	-111.857	0	55.2649	-113.466	0
55.20318	-113.436991	0	54.99193	-111.858	0	55.26416	-113.466	0
55.205847	-113.43528	0	54.99109	-111.858	0	55.24174	-113.463	0
55.204949	-113.435327	0	54.99025	-111.859	0	55.24085	-113.463	0
55.204051	-113.435374	0	54.99246	-111.856	0	55.23995	-113.462	0
55.203153	-113.43542	0	54.99161	-111.856	0	55.23906	-113.462	0
55.20582	-113.43371	0	54.99077	-111.857	0	55.24183	-113.461	0
55.204922	-113.433757	0	54.98993	-111.857	0	55.24094	-113.461	0
55.204024	-113.433804	0	54.99214	-111.854	0	55.24004	-113.461	0
55.203126	-113.43385	0	54.9913	-111.855	0	55.23915	-113.461	0
55.205793	-113.43214	0	54.99046	-111.855	0	55.24192	-113.46	0
55.204895	-113.432186	0	54.98962	-111.856	0	55.24102	-113.46	0
55.203997	-113.432233	0	54.99182	-111.853	0	55.24013	-113.459	0
55.203099	-113.43228	0	54.99098	-111.853	0	55.23923	-113.459	0
55.534252	-115.647777	0	54.99014	-111.854	0	55.242	-113.458	0
55.534807	-115.646533	0	54.9893	-111.854	1	55.24111	-113.458	0
55.535362	-115.645289	0	55.21543	-113.427	0	55.24022	-113.458	0
55.535917	-115.644046	0	55.21454	-113.427	0	55.23932	-113.458	0
55.534957	-115.648756	1	55.21364	-113.427	0	55.24369	-113.427	0
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55.536067	-115.646268	0	55.21533	-113.425	0	55.24202	-113.426	0
55.536622	-115.645024	0	55.21444	-113.425	0	55.24118	-113.426	0
55.535662	-115.649735	0	55.21355	-113.425	0	55.24402	-113.426	0
55.536217	-115.648491	0	55.21265	-113.426	0	55.24318	-113.425	0
55.536773	-115.647247	0	55.21524	-113.424	0	55.24235	-113.425	0
55.537328	-115.646003	0	55.21434	-113.424	0	55.24151	-113.424	0
55.536367	-115.650714	0	55.21345	-113.424	0	55.24435	-113.425	0
55.536923	-115.64947	0	55.21256	-113.424	0	55.24352	-113.424	0
55.537478	-115.648226	0	55.21514	-113.422	0	55.24268	-113.423	0
55.538033	-115.646982	0	55.21425	-113.422	0	55.24185	-113.423	0
55.534763	-115.634823	0	55.21335	-113.422	0	55.24468	-113.423	0
55.535318	-115.633579	0	55.21246	-113.422	1	55.24385	-113.423	0
55.535873	-115.632335	1	54.99759	-111.868	0	55.24301	-113.422	0
55.536428	-115.631091	0	54.99716	-111.869	0	55.24218	-113.421	0
55.535469	-115.635802	0	54.99674	-111.87	0	55.26042	-113.455	0
55.536024	-115.634558	0	54.99632	-111.872	0	55.25952	-113.455	0
55.536579	-115.633314	1	54.99679	-111.867	0	55.25862	-113.455	0

55.537134	-115.63207	0	54.99637	-111.868	0	55.25772	-113.455	0
55.536174	-115.63678	0	54.99595	-111.87	0	55.26043	-113.454	0
55.536729	-115.635537	0	54.99553	-111.871	0	55.25953	-113.454	0
55.537284	-115.634293	0	54.996	-111.866	0	55.25863	-113.454	0
55.537839	-115.633049	0	54.99558	-111.868	0	55.25774	-113.454	0
55.536879	-115.637759	1	54.99516	-111.869	0	55.26044	-113.452	0
55.537435	-115.636515	0	54.99473	-111.87	0	55.25955	-113.452	0
55.53799	-115.635271	0	54.99521	-111.865	0	55.25865	-113.452	0
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55.188857	-113.388922	0	54.99436	-111.868	0	55.26046	-113.451	0
55.187959	-113.38894	0	54.99394	-111.87	0	55.25956	-113.451	0
55.187061	-113.388957	0	55.00231	-111.863	0	55.25866	-113.451	0
55.186162	-113.388975	0	55.00154	-111.864	0	55.25776	-113.451	0
55.188847	-113.387352	0	55.00078	-111.865	0	55.28253	-113.477	0
55.187949	-113.387369	0	55.00001	-111.866	0	55.28171	-113.478	0
55.18705	-113.387387	0	55.00184	-111.862	0	55.2809	-113.479	0
55.186152	-113.387405	0	55.00108	-111.863	0	55.28009	-113.479	0
55.188837	-113.385781	0	55.00031	-111.864	0	55.28214	-113.476	0
55.187938	-113.385799	0	54.99954	-111.864	0	55.28133	-113.477	0
55.18704	-113.385817	0	55.00138	-111.861	0	55.28052	-113.477	0
55.186142	-113.385835	0	55.00061	-111.861	0	55.2797	-113.478	0
55.188826	-113.384211	0	54.99984	-111.862	0	55.28176	-113.475	0
55.187928	-113.384229	0	54.99908	-111.863	0	55.28095	-113.475	0
55.18703	-113.384247	0	55.00091	-111.859	0	55.28013	-113.476	0
55.186131	-113.384265	0	55.00014	-111.86	0	55.27932	-113.477	0
55.528846	-115.636571	0	54.99938	-111.861	0	55.28138	-113.473	0
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55.529956	-115.634084	0	55.05212	-111.901	0	55.27975	-113.474	0
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55.529551	-115.63755	0	55.05033	-111.901	0	55.28103	-113.448	0
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55.531216	-115.633819	0	55.05118	-111.899	0	55.27834	-113.448	0
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55.530962	-115.639507	0	55.05024	-111.898	0	55.28105	-113.445	0
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55.532072	-115.63702	0	55.05199	-111.896	0	55.27926	-113.445	0
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55.524753	-115.654517	0	55.05019	-111.896	0	55.28107	-113.444	0
55.525308	-115.653274	0	55.0493	-111.896	1	55.28017	-113.444	0
55.525863	-115.65203	0	55.04815	-111.892	0	55.27927	-113.444	0
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55.525458	-115.655496	0	55.04716	-111.895	0	55.28392	-113.468	0
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55.526568	-115.653009	0	55.0474	-111.891	0	55.28213	-113.468	0
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55.527829	-115.652745	0	55.04616	-111.892	0	55.28124	-113.466	0
55.526868	-115.657453	0	55.04566	-111.893	0	55.28394	-113.465	0
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55.529822	-115.62556	0	55.04442	-111.894	0	55.28306	-113.463	0
55.530377	-115.624317	0	55.05393	-111.761	0	55.28216	-113.463	1
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55.531788	-115.626273	0	55.0543	-111.758	0	55.19018	-113.335	0
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55.531384	-115.62974	0	55.05254	-111.758	0	55.19147	-113.332	0
55.531939	-115.628496	0	55.05166	-111.757	0	55.19065	-113.333	0
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55.52637	-115.609316	0	55.05638	-111.768	0	55.26471	-113.497	0
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55.527076	-115.610294	0	55.0572	-111.767	0	55.2643	-113.496	0
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55.191154	-113.405411	0	55.05172	-111.877	0	55.52966	-116.107	0
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55.188681	-113.407854	0	55.05115	-111.874	0	55.53228	-116.105	0
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55.185002	-113.400326	0	55.07389	-111.69	0	55.17866	-113.33	0
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55.052587	-111.904913	0	55.06753	-111.671	0	55.20201	-113.382	0
55.054912	-111.902073	1	55.06726	-111.67	0	55.20402	-113.386	0
55.054052	-111.90252	0	55.06698	-111.668	0	55.20362	-113.385	0
55.203218	-113.38311	0	55.20482	-113.385	0	55.20402	-113.382	0
55.202817	-113.381704	0	55.20442	-113.384	0	55.20362	-113.381	0

Appendix 11. Distribution of survey blocks (17.3 ha, n=132) by percent post-harvest stands and number of years since harvesting on survey blocks in three study areas (Lesser Slave Lake, Calling Lake, and Lac La Biche).

	Percent post-harvest stands on survey block			
	0-25%	26-50%	51-75%	75-100%
LESSER SLAVE LAKE				
0-10 years	2	3	8	7
11-30 years	1	6	4	2
Unharvested	2	-	-	-
Total	5	9	12	9
CALLING LAKE				
0-10 years	-	1	1	2
11-30 years	2	4	25	13
Unharvested	4	-	-	-
Total	6	5	26	15
LAC LA BICHE				
0-10 years	-	3	4	1
11-30 years	3	11	5	-
Unharvested	18	-	-	-
Total	21	14	9	1
ALL STUDY AREAS				
0-10 years	2	6	13	10
11-30 years	6	21	32	15

Unharvested	24	-	-	-
Total	32	27	45	25

Appendix 12. Distribution of survey blocks (17.3 ha, n=132) by percent post-harvest stands on survey block, study area (Lesser Slave Lake, Calling Lake, and Lac La Biche), and whether survey blocks included riparian buffers, isolated forest fragments, or a portion of one or more contiguous unharvested stands expanding into the survey block.

Percent harvested on survey block				
	0-25%	26-50%	51-75%	76-100%
LESSER SLAVE LAKE				
Fragment	-	1	6	6
Buffer	-	1	2	-
Contiguous stand	3	7	5	3
Total	**5**	**9**	**12**	**9**
CALLING LAKE				
Fragment	-	1	8	9
Buffer	1	2	8	3
Contiguous stand	1	3	8	3
Total	**6**	**5**	**26**	**15**
LAC LA BICHE				
Fragment	-	-	-	-
Buffer	3	14	9	1
Contiguous stand	3	-	-	-
Total	**20**	**14**	**8**	**1**
ALL STUDY AREAS				
Total Fragments	**0**	**2**	**14**	**15**

Total Buffers	**4**	**17**	**19**	**4**
Total Contiguous Stands	**7**	**10**	**13**	**6**
Total Unharvested Stands	**21**	**-**	**-**	**-**
Grand total	**32**	**29**	**46**	**25**

Appendix 13. List of forestry-related stand metrics used to generate predictions for: A) Density of males (17.3 ha survey blocks; n=132); B) 2nd order use (used/unused; n=2,112); C) 3rd order use (in 24 male home ranges; n=3,147) D) Reproductive activity (i.e. pairing success and probability of fledging ≥ 1 young) for territorial male Canada Warblers in managed forests in northern Alberta.

Model set	**Presence/amount post-harvest stands**	**Age of post-harvest stands**	**Edge**	**Presence/size of unharvested fragment**
DENSITY	CUT3: % post-harvest stands on survey block	YEAR: represents the area-weighted average year of harvest on the survey block	CWED: represents a measure of fragmentation-the contrast weighted edge density (unharvested: harvested edge) on the survey block	PATCH represents whether there is an isolated unharvested fragment in the cutblock (1=fragment, 0= no fragment), CWED
2ND ORDER USE	IFCUT represents whether a station is in post-harvest (1) or not (0)	YEAR represents the origin year of the stand in which the station is located (harvest year for post-harvest stands and stand origin for unharvested stands)	DISTEDGE represents the distance (m) to the nearest edge (post-harvest to unharvested)	PATCH represents the area(m2) of the unharvested patch a station is located in
3RD ORDER USE	IFCUT represents whether a grid cell is in post-harvest (1) or not (0),	YEAR represents the origin year of the stand in which the grid cell is located	DISTEDGE represents the distance (m) to the nearest post-harvest-	PATCH represents the area(m2) of the unharvested fragment a

		(harvest year for post-harvest stands and stand origin for unharvested stands)	unharvested edge,	grid cell is located in,
REPRODUCTIVE ACTIVITY	IFCUT represents whether a station or grid cell is in post-harvest (1) or not (0) PROPCUT is the proportion of home range that overlaps post-harvest, NUMPTSCUT is the number of use locations within post-harvest stands in the home range	YEARCUT represents the origin year of the stand in which the station is located	DISTEDGE represents the distance (m) to the nearest post-harvest-unharvested edge EDGEINHR is the length of post-harvest-unhavested edge in a home range	PATCH represents the area(m2) of the unharvested patch a station is located in,