University of Alberta

Songbird Responses to Regenerating Seismic Lines in the Boreal Forest

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

in

Ecology

Department of Biological Sciences

Spring 2014
Edmonton, Alberta

ABSTRACT

I investigated how songbirds respond to seismic lines as the vegetation cover on lines regenerates and how long seismic line effects on songbirds persist. I found that line age was poorly correlated with natural vegetation recovery and that after an initial increase in recovery after 20 years the mean recovery state of lines did not change. Few bird species showed strong negative responses to young, open seismic lines and changes in relative abundance were generally greater on seismic lines with dense shrubby regrowth. Species richness of birds tended to increase on lines in the early stages of recovery and return toward levels seen in the forest as seismic lines recovered. Ovenbirds responded to seismic lines for multiple reasons. Bare lines were excluded by Ovenbirds because they lacked leaf litter and protective cover. Lines were also excluded as they regenerated because Ovenbirds used them as landmarks between neighbouring territories.

Für meine lieben Eltern, meine Großeltern, mein Bruder and meine Schwestern
und meine ganze Familie. Auch für meine Freunde jetzt und von Kindheit an,
beide Mensch und Tier.
Und meistens für meinen lieben Martin.

Alle Vögel sind schon da, alle Vögel, alle!
Welch ein Singen, Musiziern, Pfeifen, Zwitschern, Tiriliern!
Frühling will nun einmarschiern, kommt mit Sang und Schalle.

Was sie uns verkünden nun, nehmen wir zu Herzen:
Wir auch vollen lustig sein, lustig wie die Vogelein,
Hier und dort, feldaus, feldein, singen, springen, scherzen.

Deutsches Volkslied

ACKNOWLEDGEMENTS

Thank you to my supervisor, Erin Bayne, for providing me the opportunity to complete this research project. As an undergraduate at the University of Alberta, I became very interested in how human impacts were affecting the boreal forest, in which I grew up, and I wanted to do research in the Northwest Territories. This research project allowed me to realize that dream. I am grateful for all your understanding, patience and support, and all that you taught me.

Thank you to the many technicians who, over the course of three summers, spent many hours in often challenging field conditions to gather data with me. These excellent people are Simon Valdez, James Campbell, Bryce Hoye, Alex MacPhail, Kaela Perry, Logan McLeod, Emily Hamblen, Calvin Chueng, Jenny Atamanik, Joshua See, Trey McCuen, Keil Knish and Jodanna Samuels. Thank you, Cris Gray, for doing point counts and helping with field preparation the first years. Thanks especially to James Campbell for working that last hard shift in the field: because this, Chapter 3 is based on a complete dataset. Thank you also for putting in many tedious hours of data entry and proofing.

Thank you, Jesse Tigner, for your contribution to this work as my fellow graduate student and collaborator. Thank you for assistance on creating the vegetation protocol and the arduous task of collecting vegetation data. Thank you also for taking on the challenging task of sifting through varied and sometimes cryptic records to get line age information for our study area.

Thank you to my committee members, Scott Nielsen, Stan Boutin and M Derek MacKenzie for suggestions and for challenging me to think critically. Thank you also to my fellow lab members in the Bayne and Boutin labs for your company and support, especially Samuel Hache and Jeff Ball.

I owe special thanks to my family: My parents, my brother and sisters, for your encouragement and support. Thank you to my grandparents for support throughout my life and my university education: You will always be with me even if you are not here.

Most of all, thank you to my husband, Martin, who has done more than anyone else over the course of this research endeavour to support me each and every day. Thank you for spending two weeks in 2009 helping me collect vegetation data: Chapter 3 is complete because of this. Thank you for encouraging me when things were more difficult and took longer than expected.

I acknowledge both in-kind and financial support from the following sources: The Acho Dene Koe First Nation granted permission to access their traditional lands and provided in-kind support at our field site. Research funding and support was provided by Environmental Studies Research Fund, Environment Canada, Paramount Resources, Alberta Upstream Petroleum Research Fund, Canadian Circumpolar Institute, Alberta Sports Recreation Parks and Wilderness Foundation, Association of Field Ornithologists, and Aboriginal Affairs and Northern Development Canada. In-kind support came from the NWT Department of Environment and Natural Resources. I am also very grateful for all the ideas and insight of Craig Machtans, Karen Halwas, Ray Case, Chandra Venables, Karin Clark, Tom Lakusta, David Kerr, and Nicole McCutchen. I received personal funding from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Alberta Advanced Education.

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CHAPTER 1. INTRODUCTION

BOREAL FOREST FRAGMENTATION

There are almost no forested areas in the world that have not been affected by human development either because forest cover is completely removed and the land converted to other uses or because the remaining intact forest is fragmented by smaller disturbances (Hunter 1999). The fragmentation of continuous forest cover can affect the entire ecosystem leading to changes in abundance and species composition of flora and fauna (Blancher 2003, Kirby et al. 2008, Nitschke 2008). Even when the sources of fragmentation are temporary, such as clear cuts from forestry, they increase the amount of forest edge and percentage of younger forest on the landscape (King and Byers 2002, Nitschke 2008, Robinson and Robinson 1999). Such changes are of concern, especially where they result in negative outcomes such as the spread of non-native species or the reduction in rare or threatened species (Dyer et al. 2001, McFarlane 2003).

The boreal forest, which covers 1.4 billion acres (approximately 55 percent) of Canada's land base, is one of the largest forested areas in the world (Boreal Songbird Initiative 2009). It is normally renewed by large disturbances such as fire and insect outbreaks or by smaller events such as wind-throw or single tree deaths that create canopy gaps (Chen and Popadiouk 2002, Greene et al. 1999). Topography, soil and climate vary across the boreal landscape and affect which tree species grow in an area and how fast stands regenerate after disturbances (Greene et al. 1999, Miyamoto et al. 2010). As a result, the boreal forest is a patchwork of stands of different ages and tree species composition with stands ranging from pure deciduous to pure conifer and from dry uplands to wet lowlands.

Large stand replacing events have been considered the major driver of boreal forest structure in western Canada. However, recent research has found that gap dynamics are also important in some boreal forest stands. Canopy gaps can start to form in boreal aspen stands as young as 40 years and the percent area of a forest that is in gap phase increases with forest age across a variety of forest types and reaches up to 40% in some stands (Cumming et al. 2000, Kneeshaw and Bergeron 1998, McCarthy 2001). Thus, the effects of small scale disturbances on forest structure cannot be ignored.

In the last century, the structure of boreal forest stands has been altered extensively by human activities such as agriculture and forestry leading to a reduction in total forest area and old growth forest, and an increase in younger forest (Nitschke 2008, Schneider 2002). For the last 60 years, oil and gas development has created a network of temporary and permanent, and mainly linear, disturbances including well pads, pipelines, seismic lines, access roads and, more recently, oil sands developments (Aumann 2007, Schneider 2002). Seismic lines, long clearings created during exploration for new oil and gas reserves, are the single most common oil and gas disturbance in the boreal forest. Seismic lines are a small scale disturbance (most lines are only 5 m to 9 m wide) that exists at varying densities across the boreal forest. They are left to regrow once they are cut and are, in theory, temporary; but seismic lines are frequently used by all-terrain vehicles, are reopened when seismic surveys are redone, and are often converted to roads and pipelines (Lee and Boutin 2006, Revel 1984).

Dissection of the boreal forest by linear features is of great concern because this area is home to over 300 bird species and is considered the bird nursery of North America (Blancher 2003). Many of these species are Neotropical migrants that breed only in the boreal forest and their populations are declining (Blancher 2003, Kirby et al. 2008). Habitat loss and degradation on the boreal breeding grounds is one suspected cause of these declines (Kirby et al. 2008). An additional concern is that seismic lines affect songbird habitat by reducing forest cover and that the extensive quantities of forest edge created by lines further degrade the remaining forest (Bayne et al. 2005b). Neither vegetation recovery on seismic lines nor the effect of lines on birds in the boreal forest has been studied extensively and there is little information on the long term effects because seismic lines have been around for a relatively short period of time. It is only now, after 50 years, that it is possible to look at the effects over time and find out how long vegetation recovery takes and how long any changes in the bird community may last.

POTENTIAL FACTORS AFFECTING BOREAL FOREST VEGETATION RECOVERY

Time to recovery for vegetation on seismic lines depends on how resilient boreal forest vegetation is to seismic line disturbances (Halpern 1988, Westman 1978). Which species regenerate in a disturbed area depends on the original forest plant community and the disturbance type, intensity and return time (Haeussler et al. 2004; Malanson and Trabaud 1987, Rydgren et al 2004, Westman 1978,). Burns and clear cuts in boreal mixedwood areas tend to have a regeneration patterns that result in the disturbances returning to the same type of forest plant community as before (Chen and Popadiouk 2002). However, the type of initial disturbance can alter the pattern of vegetation recovery (Haeussler and Bergeron 2004, Rydgren et al. 2004). Forest fires tend to remove competing vegetation, giving the tree seedlings a good head start while some forestry methods lead to dense shrub and grass cover which impedes tree growth (Haeussler and Bergeron 2004, Halpern 1988). Similar variation between disturbance and regeneration outcomes have been measured on seismic lines in tundra and taiga habitats where lower impact seismic methods resulted in maintenance of the original plant cover while the use of heavy tracked vehicles leads to severe ground disturbance and the establishment of a different plant community (Felix and Raynolds 1989, Hernandez 1973, Riewe 1979).

Reducing ground disturbance, which has been incorporated into line cutting practices since the 1980's (Riewe 1979, Schmidt 2004), seems to be the best practice in the tundra and taiga regions because of the type of vegetation and the underlying permafrost (Felix and Raynolds 1989, Riewe 1979); but, in the boreal mixedwood, reduced ground disturbance does not always lead to faster and more complete recovery of vegetation because some species require specific and sometimes severe types of disturbance to regenerate (Chen and Popdiouk 2002). Black spruce in the lowland areas germinates best on intact moss (Chen and Wang 2006), but most trees of the boreal mixedwood depend on some level of ground disturbance for seedling germination and survival (Greene et al. 1999). With the exception of aspen (*Populous tremuloides*), boreal forest tree species mainly propagate through seed and having proper seedling microsites is essential to successful tree regeneration (Greene et al. 1999). Seed propagated tree species germinate best on exposed mineral soil, humus or rotten logs (Carlton and Bazzaz 1998, DeLong et al. 1997, Densmore and Page 1992). Germination and seedling survival decreases with increasing leaf litter depth and cover and, even on bare ground, enough leaf litter can accumulate in a few years so that it impedes seedling growth and germination (Greene et al. 1999). Rapid regeneration of forbs, grasses and shrubs can also reduce tree seedling growth and survival (Haeussler and Bergeron 2004, Sims and Mueller-Sombois 1968). The first year post disturbance can be a critical window for tree seedling establishment (Greene et al. 1999).

Disturbances that do not remove leaf litter may promote rapid regeneration of shrubs and understory plants (Haeussler and Bergeron 2004). This will initially result in more rapid recovery of woody vegetation, but, such areas may be very slow to fill in with trees because germination is poor due to a lack of proper seedling microsites and because understory vegetation may out-compete slow growing tree seedlings (Greene et al. 1999, Halpern 1988). Thus, research on seismic line management from tundra and taiga environments may not provide the best information for what to expect in boreal deciduous and mixedwood forest communities. This is supported by research from Lee and Boutin (2006) showing that line regeneration seems to be much poorer in lowland forest types than in deciduous and mixedwood uplands. This suggests that forest resilience to seismic lines may vary between forest types in the boreal.

How closely seismic lines resemble natural or human disturbances is not clear. Lines could be most similar to clear cuts because the trees and shrubs are mechanically removed. However, the size of forest clearings does affect vegetation recovery. Small forest clearings receive less sunlight and are cooler and moister than large ones (McCarthy 2001). Tree species that require more light may grow more slowly and at lower densities in small clearing than shade tolerant species (Kneeshaw and Bergeron 1998, McCarthy 2001). Because of this, seismic lines may more closely resemble forest gaps. However, there are no natural forest clearings that are as long and linear as seismic lines, meaning that seismic lines may have a unique disturbance footprint. The limited published research on seismic lines suggests that tree recovery is highly variable (Revel 1984). A study of natural recovery on lines is one way to gather information about what types of vegetation regrow on seismic lines and at what rate this happens.

SONGBIRD COMMUNITY RESPONSES TO SMALL SCALE FOREST DISTURBANCES

Extensive research on how songbirds respond to forest fragmentation has focussed on habitat loss and edge effects and has shown that responses to forest edge vary depending on the type of edge and the species studied (Ball 2013, Flaspohler et al. 2001). Negative edge effects are thought to be more common for ground foraging birds because microclimate changes at the forest edge can reduce food availability (Laurance 2004, Ortega and Capen 1999, Zannette et al. 2000). Such negative edge effects have been observed when forest fragments are measured next to large clearings and along linear disturbances such as roads and power-line easements (Kroodsma 1982, Laurance 2004, Ortega and Capen 2002). However, seismic lines are much narrower than most roads. Thus, they remove less forest cover than clear-cuts, agricultural fields or roads. They do create a large amount of edge relative to their area, but, because they are so narrow, the clearing adjacent to the forest edge is not large enough to cause measurable microclimate induced vegetation changes far from the forest edge (MacFarlane 2003). Although seismic lines and forest gaps or patch cuts have a different shape, their effects on songbirds may be comparable because they are narrow, have minimal edge microclimate changes and are filled in by early successional vegetation.

Because the boreal forest is structurally diverse and disturbances are frequent (Greene et al. 1999), the bird community may be resistant to change from small clearings that involve low amounts of forest cover loss at a local scale (Forsman et al. 2010, Schmeigelow et al. 1997). Research on the effects of forest gaps and selective logging on forest bird communities indicates that birds may be resilient to up to 30 percent reduction in trees and that small clearings should not result in major changes in bird community composition (Becker et al. 2000, Guenette and Villard 2005,Leupin et al. 2004). A meta-analysis of 11 studies on forest gaps, patch cuts and selective harvesting concluded that, in general, small forest clearings tend to increase species richness and bird abundance in at least the first decade after the forest is removed and that most effects disappear in about 10 to 15 years (Forsman et al. 2010). All of these studies also showed that, with forest removal of less than 30 percent, the bird community did not change significantly, but some individual species showed strong positive or negative responses to lower levels of tree removal (Leupin et al. 2004). The size of the clearing influenced how birds responded (Forsman et al. 2010, Moorman and Guynn 2001) and changes in community composition were related more to changes in abundance than in species richness (Saitersdal and Birks 1993, Schenske and Brokaw 1981). One shortcoming of existing gap studies is that few of them look at effects beyond ten years post disturbance (Forsman et al. 2010). Seismic lines have existed in the boreal forest for over 50 years and provide a good opportunity to look at how the songbird community responds to a small scale disturbance over a longer time.

While community level assessments can give a general measure of disturbance effects, they do not answer questions about individual species which may show more subtle differences (Leupin et al. 2004). Most bird community assessments use point counts, which frequently are 200 m to 300 m in diameter and, thus, overlap the territories of a number of individual birds, including individuals that do not hold territories adjacent to the disturbance and may not be affected by it. Additionally, point counts only show responses based on the singing behaviour of territorial males and provide little information on the possible mechanism driving any change in relative abundance in individual species. Such information can only be gathered by looking at the behaviour of individual birds directly affected by the small scale disturbance.

In the boreal forest, the Ovenbird is the only species that has been shown to react to seismic lines which Ovenbirds exclude from their breeding territories. Because of this known edge sensitivity and negative reaction to seismic lines (Bayne 2005, 2005b, Machtans 2006), I used them as a test species to look at their reaction to lines of different ages so I could see whether increased vegetation on the lines would mitigate their exlusion behaviour and how long this would take. Ovenbirds are a neotropical migrant warbler, are found across the boreal forest and are fairly common in many habitats (Porneluzi et al. 2001). They prefer deciduous dominated forest with deep leaf litter and sing just below the canopy for territorial defence, but nest and forage on the ground (Porneluzi et al. 2011). Ovenbirds have been extensively researched in conjunction with forest edge and forest fragmentation because, like other ground foraging species, they seem to be more sensitive to edge and fragmentation effects (Burke and Nol 1998, Ortega and Capen 1999). However, research on Ovenbird sensitivity to forest edge and fragment size has had mixed results. Some researchers have found that Ovenbird density is lower near forest edges and in small fragments (Burke and Nol 1998, Ortega and Capen 1999), while other research has suggested that this could simply be due to sampling bias from using primarily male singing locations which do not give a good measure of actual home range size because they are not related to foraging behaviour (Mazerolle and Hobson 2003). Ovenbirds do better in areas with deeper leaf litter and a greater abundance of ground arthropods (Smith and Shugart 1987, Stenger 1958). The negative effects of forest edges are likely due to a reduction in food supply because arthropod abundance is lower in the drier leaf litter near the edges (Ortega and Capen 1999, Zanette et al. 2000), which leads males to holding larger territories to compensate. Although seismic lines are much smaller in area and width than the clearing next to the forest edges in other studies, Ovenbirds do react negatively by excluding open 8 m wide lines from their territories (Bayne et al. 2005, 2005b). This exclusion behaviour can result in lower population densities in areas of very high seismic line density (Bayne 2005b). The lines surveyed in Bayne et al. (2005,2005b) were all open with 1 m or less of shrub cover (Bayne pers. com). Thus, I do not know if the avoidance behaviour is due to lack of resources on the lines, or other behavioural reasons. Seeing how Ovenbirds respond to increasing vegetation levels on regenerating lines will provide information on the causes of line exclusion.

STUDY AREA

My study area encompassed part of northeastern British Columbia, the southern Northwest Territories and a small part of northwesten Alberta. Forest types included white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*) and mixedwood stands, and black spruce (*Picea marianna*) and tamarack (*Larix laricina*) bog-fen complexes. There are few roads in the area. Due to the large area covered by bog-fen complexes, off-road vehicle travel in the summer was limited. The primary use in the Northwest Territories was hunting and trapping (DLUPC 2006). In northeastern British Columbia and northwestern Alberta there is extensive oil and gas exploration and some forestry (Nitschke 2008, Schneider 2002).

Seismic exploration within the study area

Seismic exploration has been ongoing in the study area for over 50 years. Exploration has happened in pulses, resulting in an uneven distribution of line ages. There are currently no producing wells in the Northwest Territories portion of the study area. Exploration in northeastern British Columbia and northwestern Alberta is on-going and there are wells, both under construction and producing. In areas with producing wells, there are also roads to facilitate construction of wells and pipelines to transport of petroleum to market. Human use of seismic lines in the Northwest Territories is low and, as a result, many lines have started to regenerate naturally, unlike seismic lines in other areas of western Canada like Alberta (Lee and Boutin 2006, pers. observ.). In general, bog-fen complexes reduce human use of seismic lines because summer traffic is not possible (pers. observ.) and winter traffic from snowmobiles causes less damage to vegetation (Hernandez 1973).

Line cutting methods have changed over time. The oldest lines are 7 to 9 m wide and the ground was frequently heavily disturbed by cat blades during construction. Overtime, lower impact construction methods were implemented but there is little information on when this happened in different regions (J. Tigner, pers. com.). The first mitigation measure was to use mushroom shoes on cat blades so that ground cover was disturbed less (Schmidt 2004). Lines were mostly cut in the winter when ground was frozen and heavy equipment could be moved over creeks, rivers and wetlands to reduce ground disturbance. Eventually, low impact seismic (LIS) techniques were used in some areas. These LIS techniques focussed on narrowing lines and avoiding large trees. Initially, lines were reduced to ~5 m and cut to navigate around large trees. More recently, lines 3 m to 1.5 m wide lines were cut as well. Cutting narrower lines is more expensive (Schmidt 2004, Schneider 2002) and is not legally required in these regions. Lines 5 m or greater are still cut and old lines are reopened by current oil and gas development. Line density also varies across the study area. Spacing ranges from 50 m to 2 km. Older exploration events tend to have more widely spaced lines. Exploration and seismic line cutting are on-going in the entire study area, particularly in British Columbia and Alberta. There is pressure to expand the scope of exploration and development in the NWT as well.

THESIS OUTLINE

The objective of this thesis is to understand how long seismic line disturbances impact plants and birds and determine how vegetation and bird community changes may be related. In Chapter 2, I measured vegetation recovery on seismic lines over a 50 year time span and analyzed whether line age can be used to predict vegetation recovery. I developed a general index of line recovery based on the relative difference between the forest and the seismic line vegetation. In Chapter 3, I measured boreal forest songbird community response to vegetation characteristics and I tested 3 models to assess whether variation in bird abundance was related to forest vegetation, the presence of a seismic line or the amount of recovery of vegetation on the seismic line. In Chapter 4, I investigate whether Ovenbird response to seismic lines is due to loss of foraging and protective cover at the territory scale or a behavioural response to the vegetation structure and shape of seismic lines. Chapter 4 was published in Avian Conservation and Ecology in 2013 and is formatted according to the requirements for that journal. Finally, in Chapter 5, I synthesize the results from chapters 2 through 4 into a complete view of how seismic lines affect forest vegetation structure and boreal songbirds and how the requirements for vegetation recovery for birds relate to the general discussion of seismic line recovery and line density thresholds.

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CHAPTER 2. PATTERNS OF NATURAL VEGETATION RECOVERY ON SEISMIC LINES IN THE BOREAL FOREST

INTRODUCTION

The boreal forest is being increasingly fragmented by anthropogenic development. One of the main sources of forest dissection (the stage along a fragmentation continuum when initial access into an ecosystem occurs; Hunter 1999) is energy sector exploration. Within the last 50 years, energy companies have explored much of the boreal forest in the western sedimentary basin. Dissection continues as energy companies collect more data to better delineate new and existing oil and gas reserves. Collecting data to map energy reserves requires the clearing of seismic lines, which are long linear clearings 10's to 100's of kilometers long cut to provide access for oil and gas exploration equipment. In the western sedimentary basin, seismic lines are the most common type of linear forest disturbance (Schneider 2002, Nitschke 2008). The extensive nature of seismic line development has led to concerns that the seismic line network is negatively impacting wildlife (DLUPC 2006, Schneider 2002). A limited number of studies have shown that species such as the American marten (*Martes americana:* Tigner 2012, Riewe 1980) and Ovenbird (*Seiurus aurocapilla*: Bayne et al. 2005, 2005b, Machtans 2006) avoid seismic lines. Similarly, increases in seismic line density have been linked to declines of woodland caribou (*Rangifer tarandus*) (Latham et al. 2011) because of changes in predator prey dynamics associated with bears and wolves moving along seismic lines (Latham et al. 2001). In addition, seismic lines facilitate human access to remote areas (Fiori and Zalba 2003, Lee and Boutin 2006).

Because of the negative impacts seismic lines have on some species of wildlife, industry is under increasing pressure from government, conservation organizations and First Nations to mitigate seismic line effects by reducing the initial and long-term impacts of new and existing lines and by adhering to line density thresholds (DLUPC 2006, Kennett 2006). Setting thresholds would effectively stop energy development when the density of seismic lines reaches a certain point and, at this point, no additional development could occur until it was proven that the existing seismic line network was sufficiently recovered so that it does not have negative effects on wildlife. This would further increase the pressure on the energy sector to mitigate seismic line effects quickly (DLUPC 2006, Kennett 2006). Until recently, the energy sector took the approach of reducing ground disturbance and making lines narrower using current best practices in the hope that this would mitigate the effects on wildlife more rapidly (Schneider 2002, Schmidt 2004). However, government, conservation organizations and First Nations are not satisfied with the status quo because they are concerned that best practices are not keeping up with development rates and seismic lines are not regenerating sufficiently quickly to mitigate impacts on wildlife (DLUPC 2006, Nitschke 2008). In response, the energy sector has sought out greater clarity in which lines should be counted in threshold calculations, in particular, if very old seismic lines should be included or not.

It is hoped that seismic lines will regrow vegetation naturally similar to forest disturbances such as burns or gaps. While some studies show that vegetation does regrow on lines, they also report that plant community changes are great (Felix and Raynolds 1989a), line cutting method and time of year affect the severity of the disturbance (Hernandez 1973, Riewe et al 1979), the vegetation communities vary in sensitivity (Hernandez 1973, Raynolds and Felix 1989) and regeneration along lines of the same age can be highly variable (Revel et al. 1984). This information is from lines less than 15 years old and little is known about older ages of seismic lines that have had more time to recover. Using aerial photography, Lee and Boutin (2006) found that seismic lines in wetter forest types showed very little regeneration of woody vegetation after 35 years while lines in upland forest were more often not visible suggesting complete recovery.

Understanding the generality of Lee and Boutin's (2006) pattern and exactly why upland versus lowland recovery is so different will influence how the energy sector might plan future restoration efforts and the determination of when seismic line thresholds have been surpassed. Knowing if age is a sufficiently good predictor of recovery is essential for proper implementation of threshold density estimation. If age is not a good predictor of seismic line recovery, research is needed to find out which factors influence seismic line recovery because this information is key to prioritizing where restoration efforts are most needed, most likely to be effective, and which line cutting practices result in the most rapid recovery. When deciding where to invest seismic line dollars, the energy sector has to place priorities based on the trade-off between future land-access and desire to minimize costs of cutting new lines and recovering old lines (Gulley 2006, Schmidt 2004). Hence, there is a need to measure recovery rates on existing seismic lines and to determine what factors influence seismic line recovery rates.

My goal was to assess recovery patterns of seismic lines after 50 years of plant growth in the boreal forest of British Columbia, Alberta and the Northwest Territories and to determine which factors had the greatest effect on whether the seismic line was similar to the surrounding forest. To do this I evaluated 1) whether line age predicts the level of vegetation recovery, 2) how line orientation influences vegetation recovery and 3) if vegetation recovery differs between forest types using a standardized recovery metric. I predicted that line age should correlate with vegetation recovery on seismic lines if they follow similar successional paths as other forest disturbances where plant species composition and height eventually return to pre-disturbance conditions (Chen and Popadiouk 2002, Haeussler et al. 2004). In the boreal forest, I expected that trees and shrubs would establish on the lines and that shrubby vegetation would initially be dense and would later thin out as trees become larger and shade out the shrub layer (Chen and Popadiouk 2002).

Line orientation may affect tree and shrub regeneration because of differences in the intensity and duration of sunlight (Greene et al. 1999, McCarthy 2001). I predicted that east/west running lines will have taller woody vegetation because they will have more sunlight than north/south running lines but that north-south oriented lines may have denser tree seedling germination (McCarthy 2001). At a smaller scale, I expected that that the sunnier side on the lines would have denser shrub growth and lower moss cover than the shade side due to an increase in light and temperature. The shadier side of a line should have denser regeneration of seed propagated trees species because the increase in moisture promotes seedling survival (McCarthy 2001).

I also expected resilience (the rate and degree of recovery after disturbance; Westman 1978) to vary between upland and lowland forests because this can be determined by original site conditions as much as by disturbance type and severity (Halpern 1988, Hernadez 1973, Rydgren et al. 2004). I predicted longer recovery times for lowland forest types because they seem to be more sensitive to ground disturbance (Lee and Boutin 2006, Reiwe et al. 1979, 1980) and because trees in wet nutrient poor soils grow more slowly (Lieffers and Rothwell 1987, Rossi et al. 2009).

METHODS

Study Area

I measured seismic line regeneration at sites in northwest Alberta (AB), northeast British Columbia (BC), and the southern Northwest Territories (NWT) of Canada. Uplands were dominated by white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*) and mixedwood stands. Lowlands were dominated by black spruce (*Picea marianna*) and tamarack (*Larix* *laricina*) bogs and fens. There are few roads in the study area. Due to the large area covered by bogs and fens, off-road vehicle travel in the summer is more limited than in more southerly regions of the boreal forest. Human use of the area is generally low. For these reasons, human use of lines as travel corridors and recreational access is much lower than on lines in more populated areas. The primary use in the Northwest Territories is hunting and trapping. In northeastern British Columbia and northwestern Alberta there is greater oil and gas activity and some forestry.

Line Age

Oil and gas exploration in my study area began in the 1950's and was done in a number of separate pulses. This has resulted in an uneven distribution of line ages across the region. Seismic line age information was gathered from layers from the National Energy Board (NEB), the British Columbia Ministry of Environment (Terrain Resource Information management Program), the Dehcho First Nation, British Columbia Oil and Gas Commission, and Arcis (Calgary, Alberta). In most instances a specific year was attached to each seismic line in at least one of these data layers. In a small number of cases where no dates were attached to lines, line age was estimated based on knowledge of the exploration history of the area and seismic survey layout patterns. Seismic lines in our study area were often used in subsequent seismic surveys. In cases where multiple years were attached to a single line in one or more data records, I assumed those lines were reused and considered cut date as the most recent year the line had been cleared.

Plot Design

Vegetation data was collected in conjunction with bird and mammal surveys to evaluate wildlife response to vegetation conditions on seismic lines (Tigner 2012, Chapter 3 this document) and was conducted over three years (2008, 2009, and

2010). Slightly different protocols where used for the bird and mammal projects. I combined identical data across both data sets. Some variables were only available for a subset of data points, and I indicated the sample size used for each analyses.

Each seismic line sampling location was composed of an online vegetation plot and a corresponding offline vegetation plot. Online plot centers were spaced either 350 m or 750 m apart on seismic lines corresponding to bird point count locations and mammal camera trap locations respectively. There was an average of 5 points per line (2 to 12 points). The offline vegetation plot was circular, 11.3 m radius, and centered 30m from the forest edge to avoid any edge effects (McFarlane 2003). The online vegetation plot was composed of three subplots that were arranged along a 100m section of the seismic line (Figure 2.1). I did this to account for variation both along and across the line.

Line attributes

The seismic lines I surveyed were oriented either north-south or east-west. Subplot location on each line (sun, center, and shade) was selected relative to the line bearing at the time of sampling (Figure 2.2). Line width was measured at the center subplot to the nearest 0.1 meter. Seismic line edge was determined based on the line of sight created by the forest trees over the entire online plot so that we avoided occasional narrower or wider sections. I noted whether the line had evidence of all-terrain vehicle use or if it was used as a winter road. Lines used as winter roads were frequently not used as summer transportation routes because the ground was too saturated to allow for any vehicle use. Winter roads were generally cleared of trees and shrubs across their entire width but had some shorter woody vegetation.

Vegetation

Sites were divided into upland and lowland depending on the wetness of the site, the ground cover, and tree species. Lowland sites were mainly bog or fen habitats dominated by black spruce or tamarack and the ground was covered by moss or sedges. Wet white spruce dominated stands and willow swamps were also included in the lowland category. Upland sites had leaf litter cover on top of mineral soil and were dominated by white spruce, aspen, balsam poplar, birch and rarely jack pine and did not have standing water in them. The upland or lowland classification was made for the general area around each sampling location. The individual vegetation measurements described below were adapted from the B-Bird protocol (Martin et al. 1997) unless otherwise noted. Detailed field protocols are available in Bayne et al. 2011.

Trees Trees were defined as all woody plants that were greater than 3m tall and greater than 8 cm at DBH (diameter at breast height = 1.37 m). Tree density was assessed differently between bird and mammal survey locations. For bird sites, all trees in a 0.04 ha circle were counted and DBH measured (stem count method). For mammal sites, a #2 prism was used to calculate basal area using a method where trees were counted depending on their diameter and distance from the center of the plot (Weaver 2013). Tree density by the prism method tended to underestimate raw stem density. I included tree method variable in my model to account for differences in tree counts resulting from the two measurement methods. Tree plots on seismic lines where always rectangular to fin on the line and were always done using the stem count method.

Canopy Canopy cover was measured with a concave densiometer using methods described in Lemmon (1956). A concave densiometer was used because it has only a 30 degree angle of view and measures mainly overhead cover (Lemmon 1956). I recorded the open points on the densiometer and higher values correspond to more open canopy. I measured canopy height on the line and beside the line to compare the regeneration of the line relative to the forest. I used a clinometer or a graduated 8m pole depending on tree height. Canopy height in the forest was recorded as the mode height of the trees thus avoiding outliers that were particularly tall or short. Canopy height on the line was recorded as the mode height of woody vegetation on the lines also avoiding rare taller or shorter stems.

Shrubs Stems Shrubs were defined as woody plants that were less than 8cm in DBH and greater than 50 cm tall. Shrub stems were counted in the 22.6 m by 1m transect and conifer and deciduous stems were counted separately for all years. For 2008 data, all shrub stems were counted and the three most common species listed in order of abundance and conifers and deciduous stems separated. For 2009 and 2010 data, all shrub stems were counted and identified to species. Saplings (small trees less than 8 cm DBH) were included in the shrub counts.

Ground Cover Ground cover was visually estimated at ground level (bare ground, leaf litter, moss, water, lichens) and vegetation cover between 0 and 50 cm above ground (shrubs less than 50 cm tall, graminoids). Litter depth to mineral or organic soil was measured in 3 places on each forest plot and in 2 places on each of the three line subplots.

Foliage Density Foliage density was measured using a 0.5 m by 1.0 m cover board. Cover-board readings were taken at four increments: 0.0-0.5 m; 0.5 - 1.0 m; 1.0-2.0 m; and 2.0-3.0m. Percent cover was measured in 6 categories: 0 (0% cover); 1 (0-10% cover); 2 (10-25% cover); 3 (25-50% cover); 4 (50-75% cover); and 5 (75-100% cover).

Down Woody Material Down woody material (DWM) counts included all pieces that were over 0.5m long and at least 8cm in diameter at one end. The length was measured in meters and the diameter in centimetres at both ends so that I could estimate volume using this formula.

Formula: $V = L * pi * ((wn + ww) / 2 / 100) ^ 2$

where V is the estimated volume of down woody material, L is the length of the log, wn is the width (cm) of the narrow end of the log, ww is the width (cm) of the wide end of the log, and 100 is used to convert from centimeters to meters to get a volume in cubic meters. Volume was used because it accounted for both length and diameter of logs.

Statistical Analysis

Difference Index To compare regeneration between upland and lowland forests and look at the effects of line bearing and subplot location, I measured the relative difference between the line and forest vegetation. I summarized the difference between the line and forest values at each paired vegetation sample using an index so that I could compare them using the same scaling. I used the following equation, which incorporates both line and forest vegetation values in the denominator, to create an index of the relative difference (RD) between the line and the forest:

Formula: $RD = (-1) * (f - l) / (f + l)$

where f is the forest vegetation value and l is the line vegetation value and -1 is used to change the sign so that the index is scaled from -1 (line vegetation less than forest vegetation) and +1 (line vegetation greater than forest vegetation). The point of reference is 0, which occurs when line and forest values are equal. The index represents a relative difference that accounts for the variability among sampling locations such that a point where a vegetation variable is low in the forest and low on the line would get the same index value as a point where the variable was high in the forest and high on the line.

Shrub Dissimilarity Index Because I had locally ranked shrub diversity data and only the top three shrubs were ranked, available dissimilarity indices for partially ranked data did not apply (Dale 1989). I created my own formula to compare between line and forest subplots and calculated similarity on a scale of 0 to 3 by comparing the three dominant shrubs from the forest plot to the three dominant shrubs in the sun, shade and center line subplots individually. If none of the species matched, the score was zero. If all of them matched, the score was 3. Then I scaled this value between zero and one so that higher numbers represented greater dissimilarity (Table 2.1).

Linear Model I used a mixed effects linear regression to look at which variables most influenced the relative difference between the adjacent forest and the line. I included subplot and line bearing as fixed effects in my model to test for a difference between sun, shade and center plots and between north-south versus east-west running lines. I included line age as a categorical variable. Line segment was treated as a random effect to account for lack of independence among points on the same section of line. STATA 11 (StataCorp 2010) was used to run all models and significance was assessed at alpha = 0.05.

Recovery Index I created a set of recovery indices based on all the RD values to summarize the regeneration state of each seismic line point. To do this I first converted all RD values to an absolute number so that all values had the same sign using the following formula:

Formula: $RD_{abs} = (-1)\ (abs(RD))$

where RD is any relative difference value and (-1) scales the value from -1 to 0 so that more negative numbers indicate a greater difference between line and forest. This conversion was necessary so that I could correctly average the difference between the seismic line value and zero (no difference) for values both above and below zero. For example, an RD value of 0.9 for bare ground and -0.9 for trees both indicate low regeneration states for a point but, if averaged result in a value of zero, falsely indicating no difference between the line and the forest.

I then averaged the RD_{abs} values to calculate four separate recovery indices (RI) using this formula:

$$RI_{(x)} = [\text{sum}\ (RD_{abs(1)} + RD_{abs(2)} + \ldots\ldots + RD_{abs(i)})] / (i)$$

where $RI_{(x)}$ is the recovery index and $RD_{abs(1)}$ to $RD_{abs(i)}$ are the component relative difference values and (i) is the total number of RD_{abs} values included in the index. Using this formula I calculated four separate recovery indices. RI-all included all twelve individual recovery variables. RI-tree included four measures of tree recovery: tree density, sapling density, height and canopy cover. RI-shrub included shrub stem density and percent deciduous shrubs. RI-ground included leaf litter depth, bare ground cover, moss cover, water cover, graminoid cover and down woody material.

RESULTS

Summary I surveyed at total of 434 paired vegetation plots (Table 2.2). 244 points were located in lowland habitats and 190 in upland. This number did not include 89 points that had evidence of summer all-terrain vehicle use on the line, which I excluded from my analysis of natural line regeneration. Line age ranged from 0 to 50 years old. Line width ranged from 5 to 15 m wide (mean 8.5 m).

Line Age

Predicted relative difference between forest and line vegetation did not change consistently with line age and many variables were significantly different from the forest after 41 to 50 years. Many variables showed an initial decrease in RD in the first 10 to 20 years but values do not get closer to zero difference after that. Height increased from an RD of -0.8 on open lines to an RD of -0.5 at 11 to 20 years and stayed at that level up to 50 years for lowland lines (Figure 2.3). The same pattern was evident on upland lines where the RD changed from -0.9 on open lines to -0.6 at 21 to 30 years and then maintained that level to 50 years (Figure 2.3). Similar patterns existed for litter depth, graminoid cover, shrub density and bare ground in both upland and lowland forests (Figure 2.3 and 2.4).

Upland versus lowland forests

Sapling and tree density differed the most between upland and lowland forests (Figure 2.3). Saplings on upland seismic lines never differed significantly from zero but there was high variability (Figure 2.3). Saplings in lowland forests were much lower on the line relative to the forest, but increased consistently over time changing from an RD of -0.8 on open lines to an RD of approximately -0.3 at 41 to 50 years (Figure 2.3). There were no trees on lowland lines until they wer at least 20 years old, while on upland lines there were a few trees (approximately 4 stems/ha) on 11 to 20 year old lines (Figure 2.3). The RD at 41 to 50 years for tree density was -0.9 for lowland lines and -0.7 for upland lines. RD for shrub density was slightly greater in upland forest but percentage of deciduous shrubs was consistently greater in lowland forests (Figure 2.3).

The mean RI values between upland and lowland forest do not differ greatly (Figure 2.10). Both RI-tree and RI-ground also do not differ much between land types. RI-shrub was the only index where lowland lines rank lower than upland lines and also start from more negative values (Figure 2.10).

Line Bearing

Line bearing had no significant effect on any of the variables in lowland forests (Table 2.4). In upland forests, shrub density and percent deciduous shrubs were significantly greater on north-south running lines (Figures 2.5 and 2.6, Table 2.4). Shrub density and percent deciduous shrubs varied more on east-west running lines because the center subplot was consistently lower (Figures 2.5 and 2.6,). In contrast, lowland lines have similar RD values between north-south running lines and the pattern across the width of the line was the same as well (Figures 2.5 and 2.6).

Subplot Location

Subplot location significantly affected a number of variables in both upland and lowland forests. Shrub density was greater on the shade subplot on upland lines (Table 2.4, Figure 2.5). Percent deciduous shrubs and litter depth were significantly greater in the shade and sun side subplots than in the center (Table 2.4, Figure 2.6). In lowland areas, percent deciduous shrubs, bare ground and down woody material were greater on the sun side of the lines (Table 2.3). Consistent but statistically insignificant patterns in subplot variation were evident in other variables. For example, differences in sapling density were consistently less in the center subplot for lowland lines and RD values show a gradient from lower density on the shade side to higher density on the sun side on north-south lines in upland areas (Figure 2.7).

Shrub Dissimilarity Index

Overall, shrub dissimilarity decreased over time. Lowland shrub density decreased from an average of 0.7 for open lines to an average of 0.5 over 50 years and there appeared to be a steady downward trend (Figure 2.8). Upland shrub dissimilarity decreased from 0.7 to 0.6 after 20 years and did not change with age after that (Figure 2.9). In upland lines shrub dissimilarity was on average 0.1 to 0.2 units greater on the center subplot for all age categories (Table 2.5, Figure 2.9). There was a consistent but non-significant increase in shrub dissimilarity on the shade side of the lines (Figure 2.9).

DISCUSSION

My results demonstrate that, as seismic lines age they do get more similar to the surrounding forest for the first 20 years in lowland and 30 years in upland forests. After that, mean regeneration does not change with line age indicating that line age was not a particularly strong predictor of RD with high variation existing even on the same seismic line. Line bearing did influence RD values in upland forests. Perhaps my most important finding was that RD for most of the vegetation variables tended to move toward zero over the first 30 years and thereafter seemed to have reached a plateau. Mean vegetation height was a variable that I predicted would continue to return consistently to zero but did not. By 30 years of age, mean vegetation height on both upland and lowland lines reached relative difference values of -0.6 and -0.5 respectively and maintained that level through to 50 years. The same pattern was found in shrub density but, in this case, shrub density increased and plateaued at an RD close to zero meaning that shrub density had recovered relative to the forest interior. I suspect that the pattern in average vegetation height was driven by differences in how trees and shrubs grow. Average vegetation height increases with increasing shrub density because shrubs, especially tall shrubs like alder and willow, increase in height over time but quite quickly reach their maximum height within the first 30 years. Because tree density was so low, mean vegetation height on the lines was dictated primarily by the maximum height of shrubs and does not continue to increase as it would if trees were dense enough to form a consistent canopy. Another reason for the apparent plateau in height and tree recovery is poor correlation between line age and vegetation recovery. Vegetation recovery on some locations on older lines was much greater and actually follows the expected trend by continuing to increase with age, but the mean was brought down and the variability increased by the sections on older lines that remain in low states of recovery.

Shrub dissimilarity also plateaued after an initial decrease in the first 10 to 20 years. This may be related to the lack of tree recovery. When trees fail to form a consistent canopy over the line, shrubs that grow in open areas may continue to dominate the shrub layer instead of being shaded out by trees and replaced by forest understory shrubs. Shrub dissimilarity was also greater in the center of the line than at the edges in upland areas because the percentage of deciduous shrubs was slightly greater on the sun and shade sublots than the center subplots. The lack of return to predisturbance shrub composition, even after 50 years, suggests that the vegetation community on seismic lines has shifted. Other research looking at time since disturbances has shown that return to predisturbance species composition can take time and suggested that time since disturbance on its own is not enough to predicted regeneration outcomes (Rydgren et al 2004).

The difference in line bearing effects between upland and lowland forests can likely be explained by differences in forest height and canopy cover. The interior of lowland forests had a more open canopy (lowland canopy cover values in the forest were on average 1/3 of upland values) and were typically shorter (mean canopy height in forest plots was 10 m for lowland and 23 m for upland). I suspect lowland forests were simply not tall enough to shade the line and have fewer trees to cast shade. Thus, whether a line was east-west or north-south was irrelevant in lowland forests. In upland areas, east-west running lines receive more direct sun at noon than north-south running lines. This difference in direct sunlight can influence tree germination and growth rates (McCarthy 2001). Our data do show a trend toward increased tree density on north-south running lines. This can occur because tree germination is better in moister areas with smaller changes in temperature (McCarthy 2001). East-west running lines should generally be drier and have greater daily temperature fluctuations, creating a more stressful environment for tree seedlings (McCarthy 2001). Shrub density was also greater on north-south running lines in upland areas indicating that an increase in moisture may be more important than increased warmth. The significant difference among subplots shows that there was with-in line variation in vegetation regrowth. The low variation among subplots in lowland forests was possibly for the same reason there was a lack of difference caused by line orientation. In upland areas, RD values for shrub density, percent deciduous shrubs, and litter depth were consistently lower in the center subplot than the sun or shade subplots which were close to the forest edge. This trend could driven by the pattern on east-west running lines (Figures 2.5 and 2.6). Since east-west running lines have more direct sunlight, the center could be drier than the edges and support a different shrub community. Therefore, line orientation is one variable that increases variation in vegetation recovery on seismic lines.

Upland tree densities were significantly different than the interior at 40 to 50 years, but the RD was not as large as for lowland areas, and sapling density was similar between the seismic lines and the forest. I did not see increases in density over the forest interior as the literature on gaps and clear cuts suggests should happen (Cumming et al. 2000, Mallik et al. 1997). Our results are similar to those of other forest seismic lines studies (Revel et al. 1984, McFarlane 2003) which show a reduction in tree regeneration on seismic lines compared to other forest disturbances. The reason is likely related to tree seedling germination and survival in the first few years after the lines are cut because boreal forest trees may not be adapted to regenerating in this type of disturbance. In general, trees species in upland forests require a certain level of soil disturbance because exposed seedbed microsites in the first few years after disturbance are crucial to tree seed germination and growth (DeLong et al. 1997, Lavertu et al. 1994, Carlton and Bazzaz 1998). The first year post disturbance is a critical window for seedling germination for species such as white spruce and birch because, after 5 to 10 years, leaf litter accumulation may impede seedling germination and heavy leaf falls can smother young seedlings (Carlton and Bazzaz 1998, DeLong et al. 1997, Densmoore and Page 1992, Greene et al 1999). In contrast, seismic lines that have been cleared by bulldozers may have exposed mineral soil but the bare areas would be quite level and can easily be covered again by leaves falling from the adjacent forest. There also are no root wads to provide elevated mineral soil because trees are cut down and not uprooted as would happen in gaps created by wind throw (Carlton and Bazzaz 1998, Delong et al. 1997). Finally, down woody material was much lower on seismic lines even 50 years after lines were cut meaning there were fewer decaying logs that could provide litter-free seedling microsites. The use of mushroom shoes to elevate bulldozer blades above the ground (Schmidt 2004), which was used as the seismic line clearing technique in the 1980-1990's, might have left even less exposed mineral soil and deeper leaf litter. This would encourage shrub rather than tree regeneration. Even asexual aspen regeneration is poorer under deeper leaf litter because the ground does not warm up; and clearing methods on seismic lines may not disturb the ground enough to stimulate suckering (Frey et al. 2003, Lavertu et al. 1994). The comparatively rapid increase in leaf litter depth in the first 10 year post cut observed in our data supports that leaf litter depth may be a limiting factor in successful tree regeneration.

Reduced tree regeneration in lowland areas may happen for a number of reasons such as poor tree seedling germination and growth for black spruce. Black spruce germinates better in less disturbed areas on sphagnum moss but growth is faster on mineral soil (Chen and Wang 2006). Tree growth in black spruce is slower when the water table is higher (Lieffers and Rothwell 1987) and conifers may also be outcompeted by grass (Sims and Mueller-Dombois 1968). Recently cleared seismic lines always had more graminoid cover, more bare ground, and more standing water than the surrounding forest (Figure 2.4) meaning that tree germination and survival may be poor along many sections of such lines. Tamarack seedlings germinate and grow best in areas with moist ground, and some exposed mineral soil (Brown and Zobel 1988). This may explain why tree and sapling regeneration on lowland seismic lines shows a greater proportion of tamarack than in the forest beside the line (H. Lankau, pers. observ.).

The substantially different pattern in relative difference in sapling density between upland and lowland lines supports that tree regeneration was affected by different factors in the two forest types. Saplings on the lowland lines do not seem to be limited by a short window of time immediately after clearing; instead, the relative difference continues to decrease over time. Since black spruce and tamarack can germinate on moss (Chen and Wang 2006) and moss cover also increased over time, new seedlings continued to grow. In addition, shrub density stayed lower than the forest for longer on lowland lines, meaning that the lines were more open and there was less competition for light and resources by shrubs.

Whether lowland forests are less resilient than upland forests depends on which variables are considered. The mean of all values, as presented in recovery index (RI-all, Figure 2.10), shows no substantial difference between upland and lowland forests. The mean of tree structure variables in RI-tree and ground variables in RI-ground also do not show substantial differences between land types. Only RI-shrub shows lower recovery on lowland lines, likely due to the significant increase in deciduous shrubs. However, looking at the individual RD values for tree and sapling densities in the lowland relative to upland indicates that trees were less resilient in lowland forests. Shrub cover also points to lower resilience in lowland forest because RD values close to zero occurred between 11 to 21 years, ten years later than in upland areas. In addition, the deciduous shrubs were on average more common on lowland lines indicating that the shrub community was slower to shift back to forest interior values. My results on shrub recovery for the first 20 years are similar to those of Lee and Boutin (2006) who found that woody cover on lowland lines was much less on than on upland lines after 35 years. But in my study area these differences disappear over time and were minimal after 30 to 50 years. Even though RD values for trees were more negative on lowland lines, the recovery of shrubs indicates that woody cover was not different between upland and lowland lines. The greater degree of similarity between upland and lowland forests that I found, compared to Lee and Boutin (2006), also has to do with the different survey methods: The upland lines that Lee and Boutin (2006) surveyed may well have looked recovered from the air simply because the crowns of deciduous trees grow laterally into the seismic line and obscured the line from above. I surveyed the actual vegetation from the ground up and observed that upland lines that were very open on the ground still had partial to complete crown closure at the canopy level.

Whether an index of average recovery or individual vegetation variables are more important in assessing line recovery will have to be determined by wildlife responses to the lines. Species that react to tree density may be affected by seismic lines much longer than those that only react to changes in shrub density. The decreased rate of regeneration on the center of lines means that travel corridors down lines may stay open longer than expected, especially on east-west running lines in upland areas. Ground traveling mammals such as bears, wolves, marten and caribou are most affected by the density of the shrub layer below 3 m in height (Tigner 2012), and may find lines regenerated once woody cover in the shrub layer again similar to density of stems and foliage in the forest, which happens after 10 to 20 years. However, the continued increase in deciduous shrubs on lowland lines is a concern because it is suggested that this could attract deer and moose to the area along with wolves and bears and, thus, contribute to increased predation risk for woodland caribou (Fisher et al. 2013, Latham et al. 2011).

On the other hand, songbirds, which use all layers of the forest, may be affected for longer periods of time. Effects on ground and shrub dwelling birds should be mitigated in a similar time frame as mammals. However, longer lasting changes in the bird community could exist for canopy dwelling species because the tree layer is the slowest to recover. This would be a concern to birds for two possible reasons: A loss of tree canopy could represent a loss of resources for nesting, foraging and protective cover. The gap in the canopy may affect territorial behaviour if birds use habitat structure as an aid in defining territorial boundaries (St. Louis et al. 2004).

Fifty year old lines are still on average very different from the forest beside them in tree density, sapling density and canopy height and appear to be similar to the forest in ground cover and shrub structure. Some difference in vegetation structure was expected because seismic lines have been disturbed more recently than the surrounding forest (Chen and Popadiuk 2002). Assessing how different line recovery is from other forest disturbances requires a more detailed comparison to existing literature than I present here; however, the plateau in recovery rate suggests that there may be a shift in plant community structure (Suding 2004). The long term changes in vegetation structure indicate that wildlife response to lines may also be long lasting. My results point to a possible trade-off between rapid shrub recovery, such as has also been shown in seismic line replanting trials (Gulley 2001), that mitigates issues for ground and shrub dwelling species and better tree regeneration which also removes seismic lines impacts for all species including those that live in the forest canopy. Whether the difference in tree and shrub regeneration matters can be assessed only based on known wildlife responses to lines. If reducing the proportion of deciduous shrubs and achieving tree regeneration is necessary for certain species, industry may need to consider different mitigation methods between upland and lowland areas. Decreasing ground disturbance, such as existing guidelines suggest (AANDC 2011, MoE 2011), is best for lowland forests; but, some type of site preparation, such as is used by forestry companies to promote natural regeneration, may be more successful for promoting seismic line regeneration in upland forests.

Table 2.1. Example of shrub dissimilarity index calculations. The forest shrub plot is used as the reference for all three line shrub plots.

Plot Location	Shrub 1	Shrub 2	Shrub 3	Matches (to Forest)	Dissimilarity
Forest	Rose	Dogwood	Green Alder		
Shade	Dogwood	Green Alder	Poplar	2	0.333333
Center	Green Alder	Willow	None	1	0.666667
Sun	Rose	Poplar	Dogwood	2	0.333333

Table 2.2. Number of paired sampling locations in each category of upland, lowland, east-west and north-south lines. Excluded are all lines with quad trails and those wider than 15 m.

		Lowland			Upland		
Age Category	All	E-W	N-S	Sum Up.	E-W	N-S	Sum Low.
0	22	15	3	18	3	1	4
10	57	16	4	20	24	13	37
20	73	29	3	32	23	18	41
30	58	6	16	22	20	16	36
40	136	31	57	88	24	24	48
50	88	13	51	64	14	10	24
All	**434**	**110**	**134**	**244**	**108**	**82**	**190**

Table 2.3. Regression coefficients and standard errors of the mean for lowland RD models. N represents the number of paired sampling locations, each with a shade, center and sun subplot. SH = Shade subplot. SN = Sun subplot. SH*LB = Shade line bearing interaction. SN*LB = Sun line bearing interaction. LW= line width. TM= tree method. MD = ground cover method. Bolded and underlined values are significant at alpha=0.05. Italicized and underlined values are significant at alpha=0.1

Variable	N	SH	SN	LB	SHxLB	SNxLB	1-10	11-20	21-30	31-40	41-50	LW	TM	MD	Cons.
Tree Density	221			-0.022			-0.068	-0.045	0.012	0.124	0.006	0.018	**0.167**	**0.227**	**-1.152**
				0.042			0.094	0.085	0.096	0.077	0.081	0.013	**0.070**	**0.091**	**0.126**
Sapling Density	196	-0.059	-0.062	-0.050	-0.061	-0.080	0.244	**0.353**	**0.315**	**0.413**	**0.559**	-0.004			**-0.765**
		0.074	0.074	0.086	0.094	0.094	0.198	**0.128**	**0.135**	**0.114**	**0.128**	0.018			**0.200**
Height	245			0.041			*0.224*	**0.282**	**0.236**	**0.251**	**0.331**	**-0.023**			**-0.598**
				0.047			*0.132*	**0.085**	**0.094**	**0.083**	**0.101**	**0.012**			**0.142**
Canopy Cover	231	*0.064*	0.038	0.021	-0.047	0.016	-0.128	-0.097	-0.026	0.032	0.144	-0.011			-0.104
		0.035	0.035	0.045	0.046	0.046	0.097	0.069	0.075	0.065	0.078	0.010			0.112
Shrub Density	237	*-0.081*	-0.011	-0.068	0.060	0.048	**0.472**	**0.574**	**0.748**	**0.831**	**0.777**	*0.023*			**-0.875**
		0.047	0.047	0.058	0.062	0.062	**0.117**	**0.089**	**0.097**	**0.083**	**0.096**	*0.012*			**0.140**
%Decd. Shrubs	237	0.037	**0.098**	0.011	0.015	-0.039	**0.348**	**0.335**	**0.351**	**0.378**	**0.271**	**0.030**			**-0.449**
		0.780	**0.037**	0.047	0.049	0.049	**0.096**	**0.071**	**0.078**	**0.067**	**0.078**	**0.010**			**0.113**
Litter depth	194	0.083	0.093	-0.113	0.088	0.076	**0.435**	**0.458**	**0.399**	**0.516**	**0.522**	-0.006			**-0.776**
		0.067	0.066	0.074	0.085	0.085	**0.146**	**0.108**	**0.112**	**0.096**	**0.106**	0.015			**0.170**
Bare Ground	210	-0.015	**0.094**	-0.014	0.010	-0.053	**-0.541**	**-0.767**	**-1.027**	**-0.685**	**-0.685**	-0.021		-0.055	**1.010**
		0.069	**0.069**	0.084	0.092	0.092	**0.155**	**0.120**	**0.137**	**0.112**	**0.132**	0.018		0.090	**0.215**
Moss Cover	210	0.017	-0.039	0.073	-0.051	0.026	0.084	*0.169*	0.142	0.116	0.153	-0.009		**0.161**	**0.677**
		0.052	0.052	0.063	0.070	0.070	0.114	*0.089*	0.102	0.083	0.097	0.013		**0.066**	**0.228**
Water Cover	210	-0.135	-0.325	-0.120	-0.034	0.092	-0.203	-0.118	*0.226*	-0.032	-0.171	0.018		**0.156**	0.167
		0.082	0.083	0.088	0.111	0.111	0.127	0.108	*0.129*	0.098	0.106	0.017		**0.071**	0.194
Gram, Cover	210	*-0.132*	-0.099	-0.013	0.006	-0.030	-0.214	-0.159	*-0.277*	**-0.261**	**-0.455**	-0.004		0.090	**-0.360**
		0.072	0.072	0.089	0.096	0.097	0.166	0.127	*0.144*	**0.119**	**0.141**	0.019		0.096	**0.160**
DWM Count	220	0.076	**0.163**	-0.097	-0.047	-0.037	-0.141	**-0.511**	**-0.368**	-0.125	-0.051	**-0.053**			0.291
		0.077	**0.077**	0.089	0.102	0.102	0.157	**0.129**	**0.138**	0.117	0.132	**0.018**			0.200

Table 2.4. Regression coefficients and standard errors of the mean for upland RD models. N represents the number of paired sampling locations, each with a shade, center and sun subplot. SH = Shade subplot. SHN = Sun subplot. SN*LB = Sun line bearing interaction. LW= line width. TM= tree method. MD = ground cover method. Bolded and underlined values are significant at alpha=0.05. Italicized and underlined values are significant at alpha=0.1

Variable	N	SH	SN	LB	SHxLB	SNxLB	1-10	11-20	21-30	31-40	41-50	LW	TM	MD	Cons.
Tree Density	188			*0.106*			0.083	0.036	**0.796**	**0.403**	**0.321**	0.032	**-0.393**	**0.584**	**-1.363**
				0.059			0.215	0.211	**0.218**	**0.209**	**0.216**	0.019	**0.101**	**0.102**	**0.267**
Sapling Density	94	0.109	0.037	-0.067	-0.171	0.002	0.305	0.035	0.423	0.255	0.297	0.021			**-0.440**
		0.107	0.107	0.151	0.154	0.153	0.373	0.289	0.346	0.315	0.329	0.026			**0.416**
Height	189			0.000			0.188	0.241	0.310	0.315	0.342	0.021			**-1.129**
				0.029			0.085	0.080	0.088	0.083	0.086	0.007			**0.103**
Canopy Cover	176	0.038	0.086	-0.004	-0.107	-0.109	-0.153	0.106	0.078	*0.296*	0.138	**-0.026**			-0.171
		0.053	0.053	0.077	0.078	0.078	0.175	0.163	0.183	*0.172*	0.177	**0.013**			0.214
Shrub Density	178	**0.097**	*0.085*	**0.226**	-0.070	-0.082	**0.456**	*0.283*	**0.504**	**0.509**	**0.490**	0.009			**-0.565**
		0.047	*0.047*	**0.071**	0.070	0.069	**0.162**	*0.150*	**0.170**	**0.159**	**0.164**	0.012			**0.196**
% Decid. Shrubs	178	**0.027**	**0.079**	**0.110**	-0.048	-0.044	0.150	0.037	0.134	0.127	0.157	*0.012*			**-0.257**
		3.260	**0.027**	**0.041**	0.041	0.041	0.094	0.088	0.099	0.093	0.095	*0.007*			**0.114**
Litter Depth	120	**0.233**	**0.200**	0.027	-0.024	0.061	0.228	0.184	0.100	**0.337**	*0.274*	**-0.031**			*-0.377*
		0.053	**0.053**	0.071	0.077	0.077	0.162	0.143	0.161	**0.151**	*0.153*	**0.013**			*0.201*
Bare Ground	156	-0.059	*-0.106*	0.030	-0.099	0.083	**-0.334**	**-0.294**	*-0.309*	**-0.429**	**-0.347**	0.015		-0.034	**0.488**
		0.057	*0.057*	0.076	0.083	0.083	**0.159**	**0.149**	*0.172*	**0.153**	**0.161**	0.014		0.059	**0.203**
Moss Cover	156	*0.152*	0.015	**-0.266**	-0.026	0.109	-0.185	*-0.390*	0.016	-0.100	-0.097	-0.009	-0.083		**0.626**
		0.091	0.091	**0.116**	0.133	0.133	0.233	*0.220*	0.247	0.223	0.237	0.021	0.085		**0.285**
Water Cover	156	0.006	**0.070**	-0.009	0.043	-0.030	-0.068	-0.044	-0.061	-0.024	-0.006	**-0.020**		-0.016	0.198
		0.035	**0.035**	0.049	0.052	0.052	0.106	0.098	0.116	0.102	0.107	**0.009**		0.039	0.134
Gram. Cover	156	*-0.158*	-0.094	-0.139	0.103	-0.022	-0.201	-0.198	-0.272	-0.196	-0.228	0.016		-0.036	0.035
		0.083	0.083	0.108	0.121	0.121	0.222	0.209	0.238	0.213	0.226	0.020		0.081	0.300
DWM Count	156	-0.018	0.060	0.045	0.041	0.073	0.101	0.199	0.211	0.159	0.284	-0.002			-0.647
		0.083	0.083	0.110	0.125	0.126	0.229	0.218	0.231	0.221	0.233	0.019			0.285

Table 2.5. Regression coefficients and standard errors of the mean for shrub dissimilarity. N represents the number of paired sampling locations, each with a shade, center and sun subplot. SH = Shade subplot. SHN = Sun subplot. SN*LB = Sun line bearing interaction. LW= line width. Bolded and underlined values are significant at alpha=0.05. Italicized and underlined values are significant at alpha=0.1.

Forest Type	N	SH	SN	LB	SHxLB	SNxLB	1-10	11-20	21-30	31-40	41-50	LW	Constant
Lowland	243	-0.018	-0.014	0.012	0.017	0.041	-0.073	-0.091	**-0.198**	**-0.177**	**-0.277**	*0.016*	**0.614**
		0.034	0.034	0.041	0.046	0.046	0.078	0.063	**0.067**	**0.058**	**0.065**	*0.009*	**0.097**
Upland	188	**-0.178**	**-0.125**	-0.050	0.068	0.035	-0.142	*-0.196*	-0.178	**-0.227**	-0.112	-0.003	**0.855**
		0.034	**0.034**	0.048	0.051	0.051	0.110	*0.104*	0.113	**0.107**	0.111	0.009	**0.135**

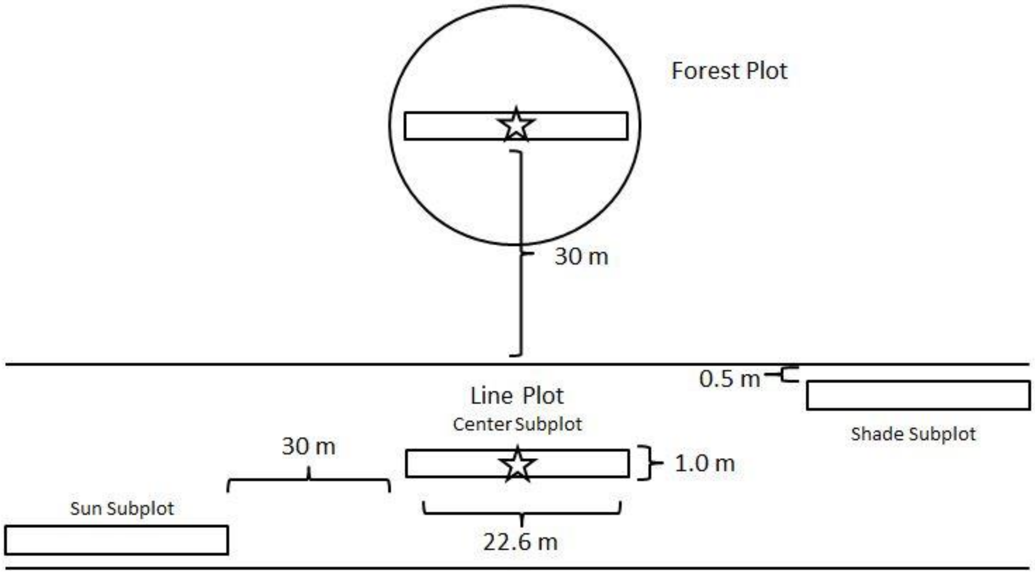

Figure 2.1. Diagram of vegetation sampling locations (not to scale).

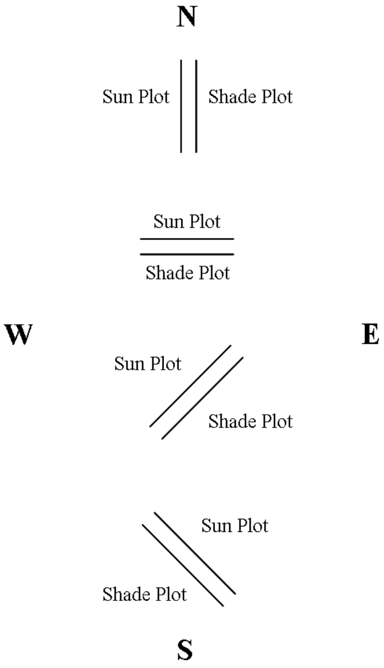

Figure 2.2. Seismic lines are constructed on a grid pattern and may be (from top to bottom) N-S, E-W, or slant lines. Sun and Shad subplots are located relative to line orientation and the track of the sun.

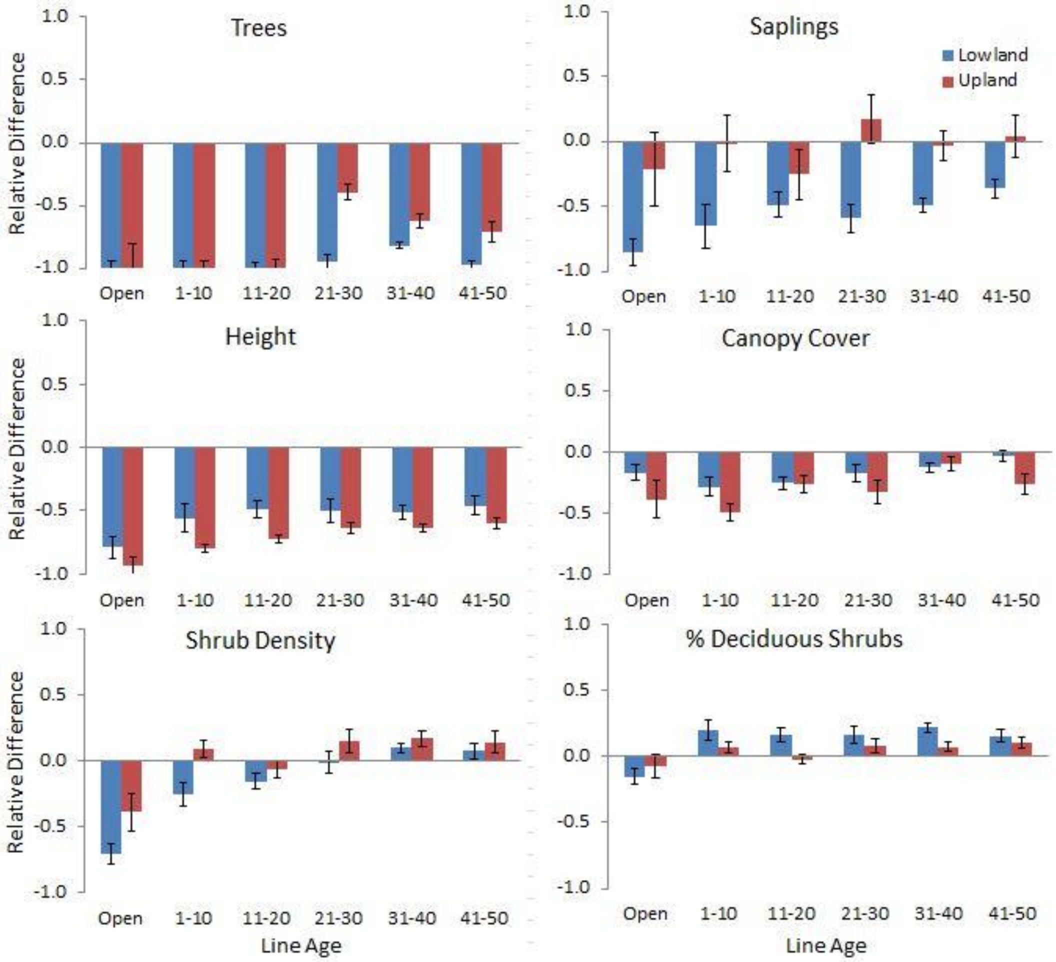

Figure 2.3. Predicted mean relative difference (RD) values for height canopy cover and woody vegetation by age category for upland and lowland forests. Blue bars are lowland values. Brown bars are upland values. Error bars are standard errors of the mean.

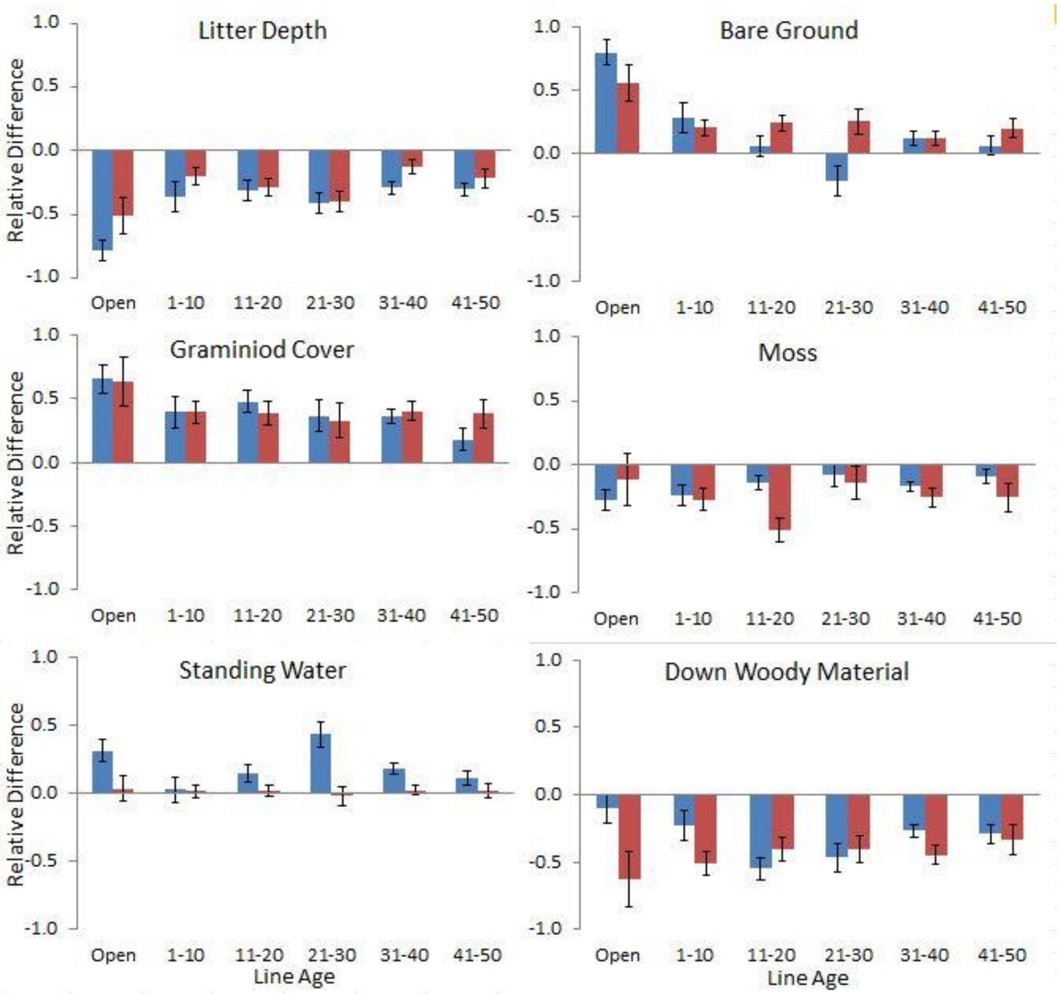

Figure 2.4. Predicted mean relative difference (RD) values for ground vegetation variables by age category for upland and lowland forests. Blue bars are lowland values. Brown bars are upland values. Error bars are standard errors of the mean.

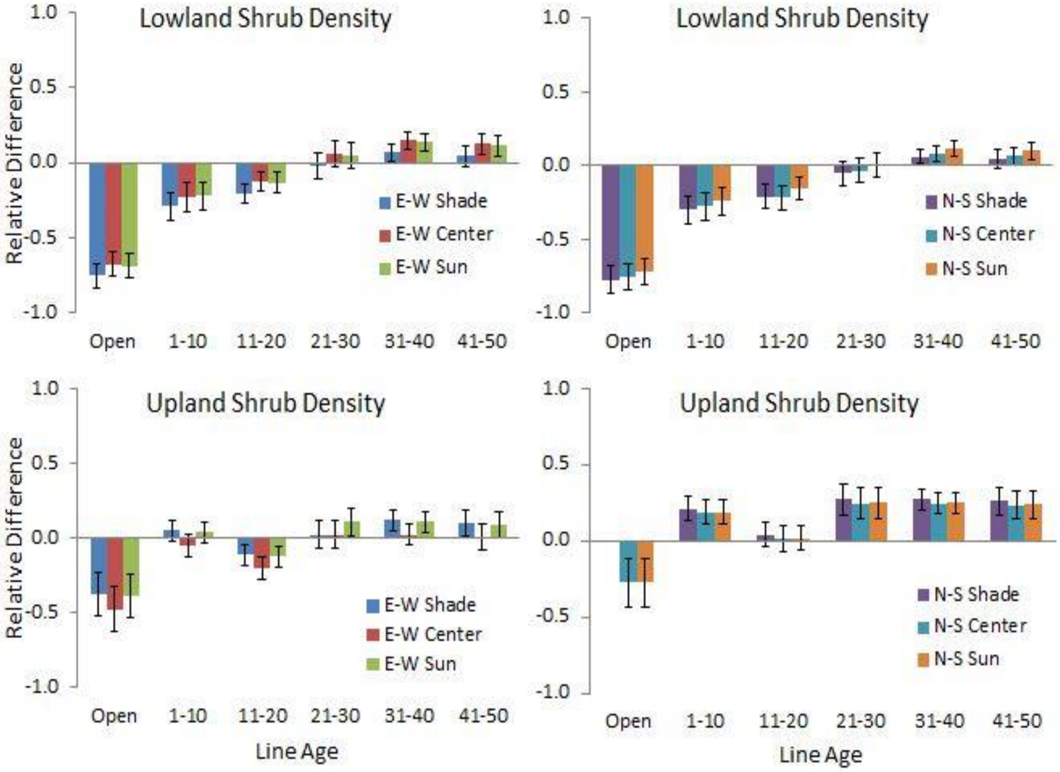

Figure 2.5. Predicted mean relative difference (RD) values for shrub density separated by subplot, line bearing and land type. Error bars are standard errors of the mean.

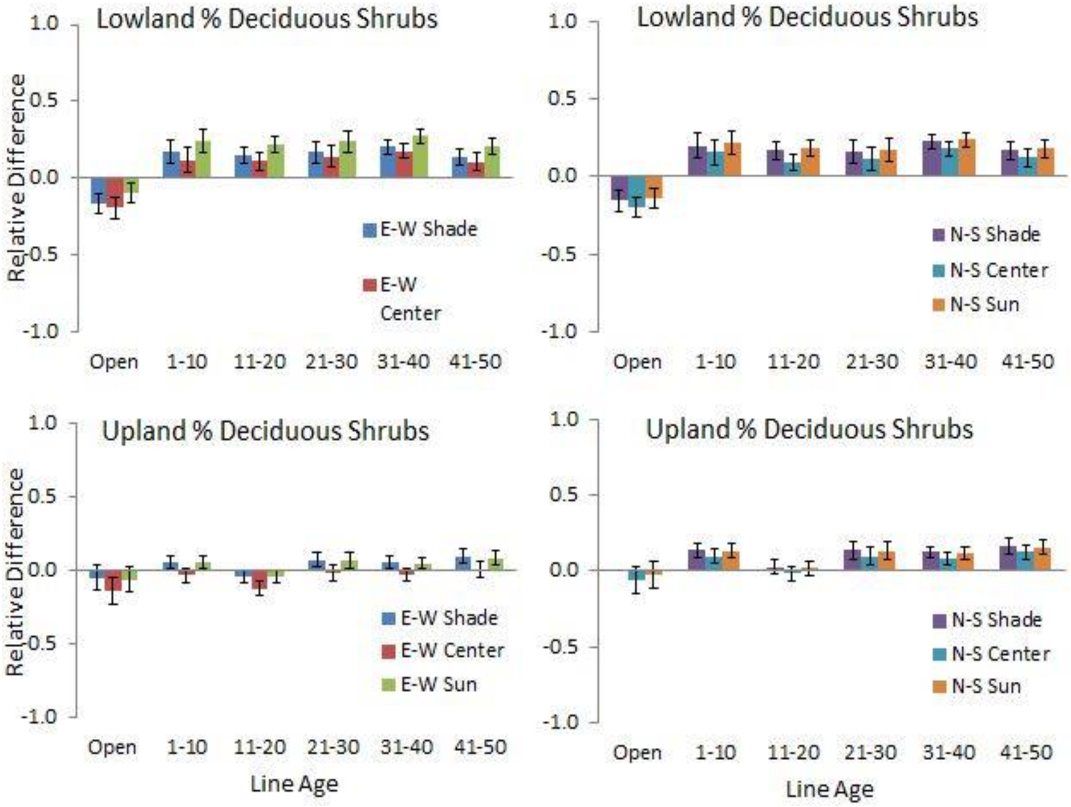

Figure 2.6. Predicted mean relative difference (RD) values for percent deciduous shrubs separated by subplot, line bearing and land type. Error bars are standard errors of the mean.

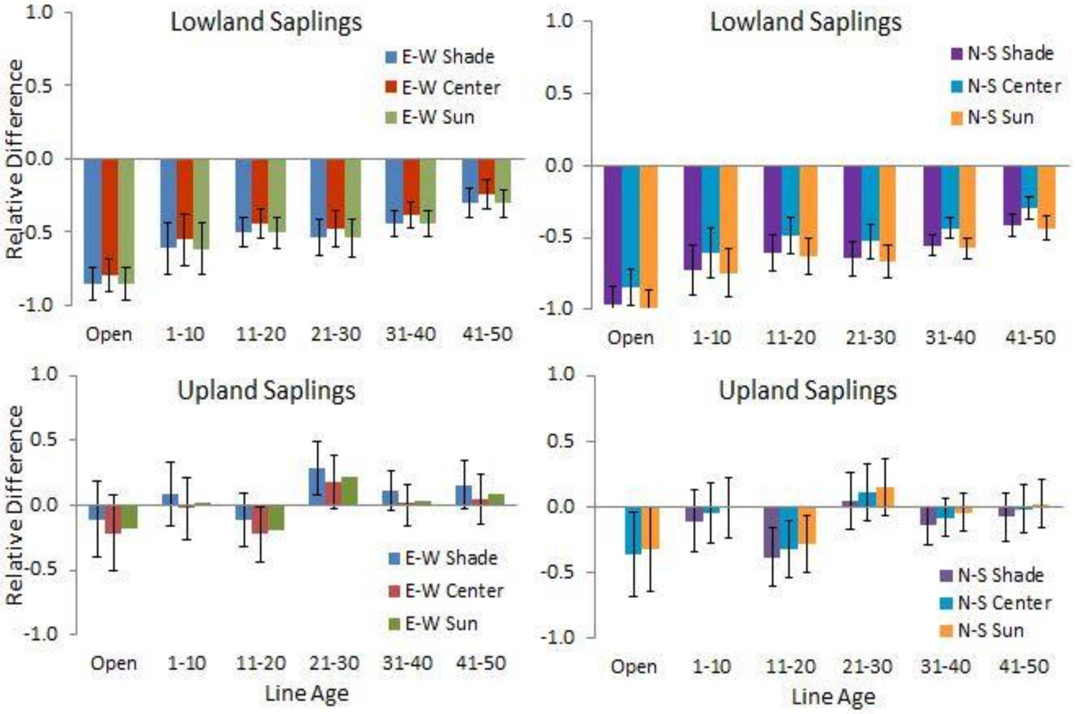

Figure 2.7. Predicted mean RD values for sapling density separated by subplot, line bearing and land type. Error bars are standard errors of the mean.

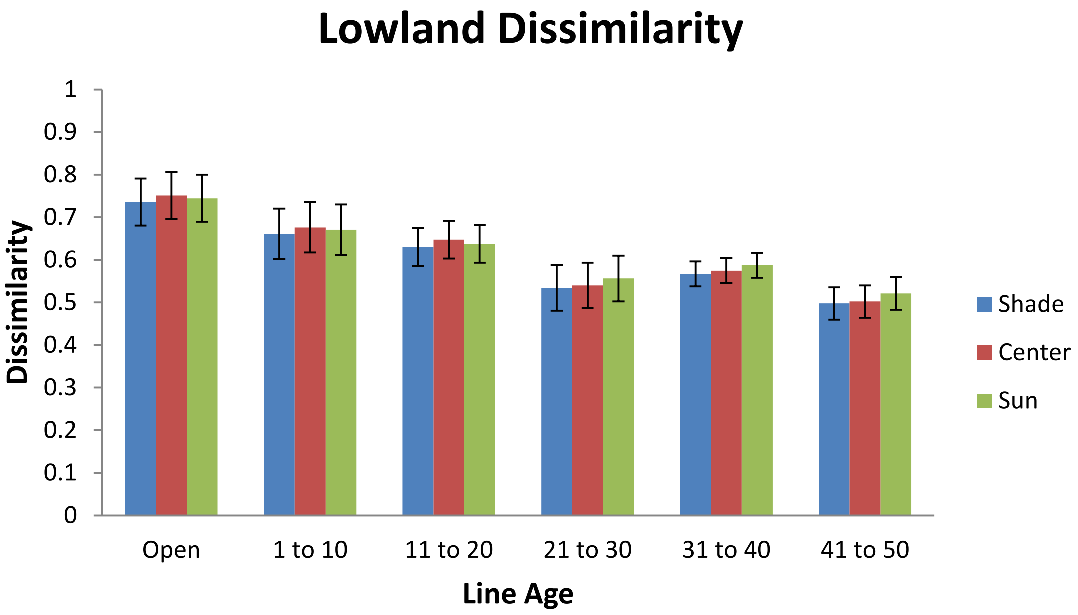

Figure 2.8. Predicted mean values of shrub species dissimilarity for the three most common shrubs at each subplot for lowland forests. Error bars are standard errors of the mean.

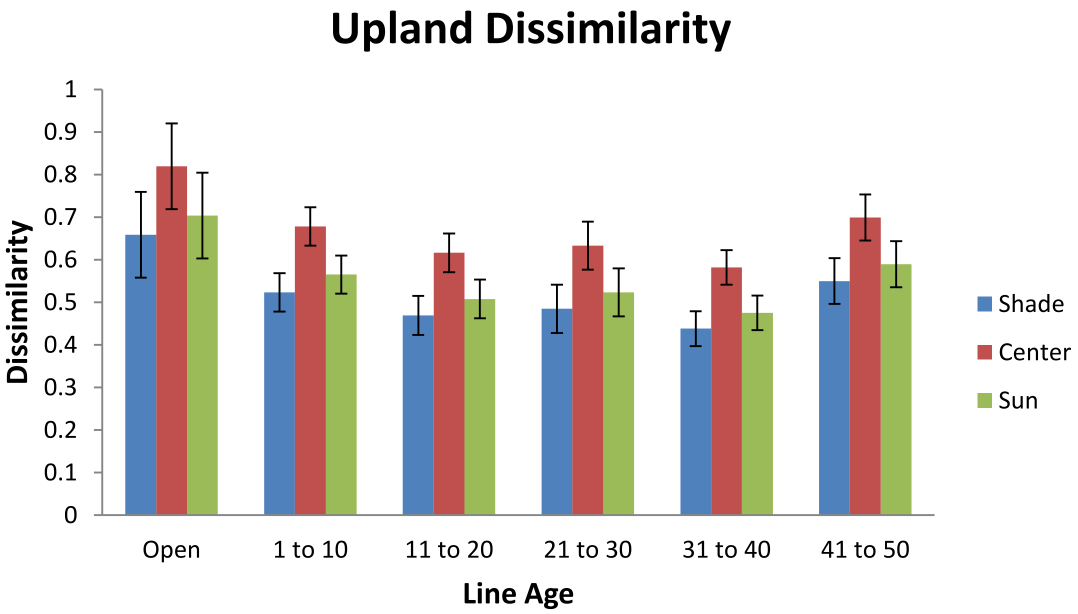

Figure 2.9. Predicted mean values of shrub species dissimilarity for the three most common shrubs at each subplot for upland forests. Error bars are standard errors of the mean.

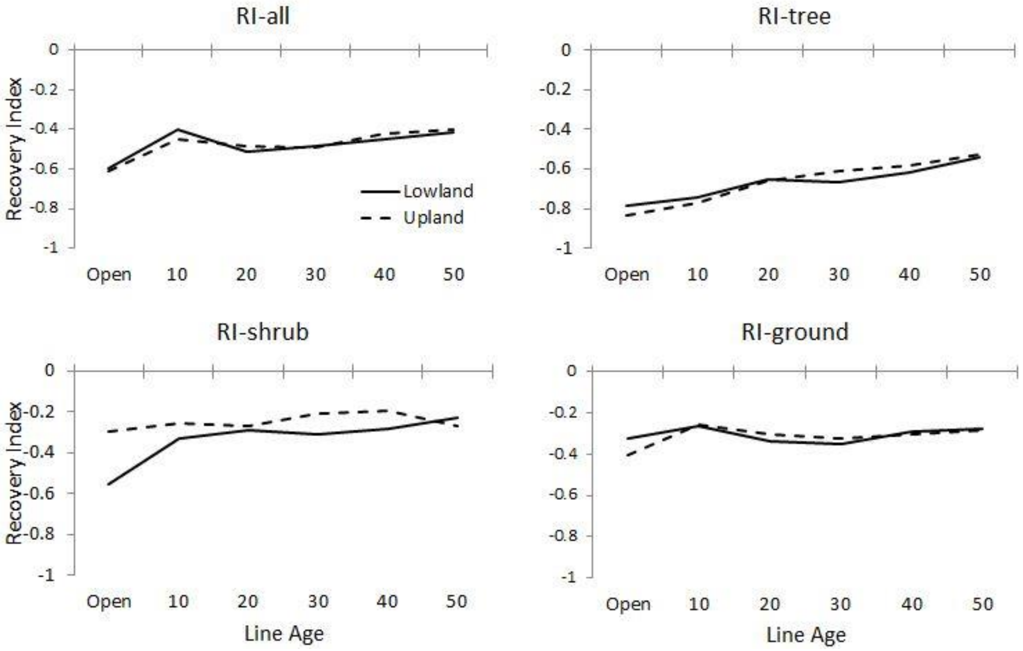

Figure 2.10. Comparison of four recovery indices between upland and lowland areas. RI-all is the average of all 12 vegetation variables. RI-tree includes canopy height, tree density, sapling density and canopy cover. RI-shrub includes shrub density and percent deciduous shrubs. RI-ground includes bare ground, litter depth, graminoid cover, moss cover, water cover and down woody material.

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CHAPTER 3. BOREAL SONGBIRD COMMUNITY RESPONSE TO OPEN AND REGENERATING SEISMIC LINES

INTRODUCTION

Historically, habitat edges were viewed as beneficial for wildlife because of the increased availability of different resources caused by higher vegetative diversity typical of edge environments (Johnston 1947, Leopold 1993, Wang et al. 2002, Willson 1974). However, over the past 30 years, a growing body of research on anthropogenic forest edges has shown that some wildlife species avoid edges because they are less successful in breeding there due to increased predation and/or nest parasitism (Flashpohler et al. 2001, Suarez et al 1997). More recently, changes in the abundance of the insect food supply near edges has also been demonstrated (Burke and Nol 1998, Zannette et al. 2000). This has led some to suggest that declines in forest songbird populations are the result of forest loss caused by human activities and are exacerbated by the associated increase in the proportion of forest near human created edges (Blancher 2003, Flashpohler et al. 2001, Suarez et al 1997). In general, edge-related effects on forest birds seem to be most severe in landscapes where forest is no longer the main vegetation type and the landscape matrix is dominated by agriculture (Parker et al. 2005). However, even very small disturbances that create internal forest edges such as roads and trails have been shown to cause negative effects on some species, although the generality of such patterns is less clear (Miller et al. 1988, Ortega and Capen 1999).

In the boreal forest, which covers 55% of Canada’s land area and is home to hundreds of species of birds (Blancher 2003, Boreal Songbird Initiative 2009), linear disturbances such as roads, pipelines and seismic lines created by energy sector exploration and development are one of the most widespread causes of dissection of intact boreal forest (Hunter 1999, Schneider 2002). The most common of these linear disturbances are seismic lines. Historically, seismic lines were 5 m to 8 m wide strips that extended for 10’s to 100’s of kilometres and were cleared of all forest cover to survey for oil and gas reserves (Lee and Boutin 2006). While causing relatively little forest loss, these seismic lines may have a measurable effect on songbirds if birds move their territories away from lines to avoid the linear clearing (Bayne et al. 2005b, Machtans 2006). The density of lines (which can be as little as 50 m apart) and the area of the boreal forest across which they are found is such that any amount of line avoidance could result in considerable reductions in songbird density.

Such concerns have resulted in calls from government, conservation organizations and First Nations to limit future seismic line development (DLUPC 2006, Kennet 2006, Nitschke 2008). From an energy sector perspective, seismic lines have been left to regenerate naturally with the expectation that they do not create large edge effects and regenerate to forest vegetation sufficiently quickly so that they have little impact on wildlife. While changes in microclimate at seismic line edges seem to be small (MacFarlane 2003), research on vegetation regrowth on seismic lines themselves shows that regeneration is variable (Lee and Boutin 2006, Revel et al. 1984, Chapter 2). There is also considerable uncertainty about the magnitude of impacts of seismic lines on boreal wildlife and how long these impacts last (DLUPC 2006). If lines indeed regenerate and have diminishing impacts on songbirds over time, then additional lines should not result in large impacts on songbirds making threshold approaches unnecessary for avian conservation. However, if old lines have the same or greater effects as newer lines (Aschenhurst 2008), then impacts on songbirds will stay the same or become more widespread as seismic line density increases over time.

Seismic lines share characteristics with other linear features such as roads and trails in that they are long and narrow and create a disproportionate amount of forest edge per area cleared (Bayne et al. 2005) and may be used a travel corridors by species such as wolves and bears (Latham et al. 2011, Tigner 2012). Roads and trails have been shown to have persistent negative edge effects on birds that can reach 50 to 100 metres into the forest (Laurance 2004, Miller et al. 1998, Ortega and Capen 1999). However, unlike roads and trails which are used by humans (i.e. hikers, automobiles) and no vegetation growth occurs, seismic lines are subject to less human use and vegetation does regrow over time (Lee and Boutin 2006, Revel et al. 1984). Additionally, because microclimate changes within the forest edge of a linear feature tend to be small (MacFarlane 2003), the edge-related reduction in ground dwelling arthropods, which is thought to occur because edges are drier (Ortega and Capen 1999, Zannette et al. 2000), may be less of a factor next to seismic lines than other edges. Although, the area cleared by seismic lines in even some of the most developed parts of the boreal forest amounts to 1 % or less at a landscape level (Aumann et al. 2007), the impact on an individual bird territory is much greater because an average 8 m wide line could occupy 10 % of 100 m diameter (0.8 ha) songbird territory if the territory was directly across a linear feature. This represents a substantial area that can influence territory placement relative to the line, either because a bird does not wish to defend lower value habitat (due to reduced food availability or increased predation risk from the loss of mature forest cover), or because the early successional vegetation represents a valuable resource that makes a territory including a line more desirable than the surrounding forest.

Because of this, avian response to seismic lines may be more similar to what has been observed near partial cuts or natural forest gaps. The response by birds to small gaps varies widely and seems to depend on whether the species prefers mature forest and is negatively influenced by removal of trees or prefers early successional vegetation (Robinson and Robinson 1999, Steventon et al. 1998). Research on partial cuts shows that the greatest changes in avian species composition tend to occur in the first 5 to 10 years after clearing (Forsman et al. 2010, Robinson and Robinson 1999). Whether seismic lines cause a similar response is unknown. There is some data on the effects of newly cut lines on boreal forest songbirds (Bayne et al. 2005, Machtans 2006), but there is no information on how long effects on songbirds last nor on how songbird response to vegetation recovery on lines changes over time.

I surveyed boreal songbirds on seismic lines with varying amounts of vegetation recovery relative to forest interiors to understand how seismic lines affected the relative abundance of birds as vegetation regenerated. I tested three hypotheses: 1) Variation in bird abundance is best explained by variation in forest structure through which seismic lines are cut (Forest Structure Hypothesis). I predicted that the abundance of birds that are generalists (can live in a variety of forest structures and ages) will be best predicted by this model because they should not respond to the additional habitat variation introduced by seismic lines. 2) Birds will respond to all lines equally regardless of the amount of vegetation on the line because the vegetation on the line is always younger than in the forest beside (Permanent Edge Hypothesis). Based on this hypothesis I expected a negative response to persist over time for most species because, although the line regrows, the vegetation is younger and continues to represent a loss of mature forest area. I predicted that this model should better explain the behaviour of forest interior birds like the Ovenbird since they prefer to hold territories within mature forest. I predicted that the strongest effects would exist for canopy nesting and foraging species because the reduction in tree and sapling density (Chapter 2) means that the lines are more open above the shrub layer and provide less foraging area, singing perches and protective cover than the neighbouring forest (Norton and Hannon 1997). I also predicted these effects to be more apparent for species associated with mature coniferous forests because there is less chance that the canopy gap could be filled in by lateral branch growth as is possible in deciduous stands. 3) Bird response to lines will vary based on the amount of vegetation recovery on the line (Line Recovery Hypothesis). Ground foraging and nesting birds should show the strongest response to open lines because they nest and forage on the ground, and an open line represents both a change in foraging substrate and a lack of protective cover of nests and for day to day movement (Lima 1985, Rail et al. 1997). As a result, they should also show a linear response to vegetation regeneration, with a decreasing negative effect on relative abundance as foraging microhabitat and protective cover are restored. Species attracted to early successional vegetation and dense shrub growth for nesting and foraging should be most common on moderately regenerated lines. As a result, they should show a non-linear response where relative abundance increase as early successional shrubby vegetation increases and then decreases as lines mature and tree cover is re-established (Forsman et al. 2010, Steventon et al. 1998).

METHODS

Study Area

My study area encompassed a large area of north eastern British Columbia and the southern Northwest Territories. Forests ranged from dry uplands to wet lowlands. Uplands included white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*) and mixedwood stands. Lowlands included black spruce (*Picea marianna*) and tamarack (*Larix laricina*) bog-fen complexes. There are few roads in the area. Due to the large area covered by bog-fen complexes, off-road vehicle travel in the summer is also limited. Human use of the area is generally low. The primary use in the Northwest Territories is hunting and trapping. In northeastern British Columbia and northwestern Alberta there is extensive oil and gas exploration and some forestry.

Seismic line selection and study design

Lines were selected to get a range of variation in vegetation re-growth on the line. Because forest height varied between and within forest types (upland and lowland area as defined above) from a little as 6 m to as much as 30 m, I examined the height of the line relative to the forest to assess how regenerated the lines were.

Vegetation cover on lines ranged from completely open to having low shrubs to having tall shrubs and saplings, and the most regenerated lines had trees that reached close to the canopy height of the surrounding forest. The oldest lines were cut 50 years ago (Chapter 2).

I located point counts on seismic lines in varying stages of regrowth in upland and lowland forest in 2008, 2009 and 2010. Controls were located in forest interior locations at least 350 from a forest edge in the same forest types as the seismic line locations. All point counts were located a minimum of 350 m apart and a minimum of 350 m from any road or other known anthropogenic habitat edge.

Survey Methods

I conducted 10 minute point counts. For each individual bird all observers estimated the distance from the observer in 2 distance categories: 0 tm o 50 m and >50 m. Birds were identified from primary songs used by males for territorial defence. Observers were trained as a group to identify birds and estimate distances before starting surveys. Observers were alternated between line and interior point counts to reduce observer bias. All counts were conducted between the 27 May and the 30 June within 4 hours of sunrise. Counts in the interior and on lines of different stages of regeneration were spread across the entire survey period so that there would be no seasonal or within-day bias between the forest interior and the different line types.

Vegetation Methods

I collected vegetation measures for both forest interior and seismic line point count locations. Each forest interior point count had one vegetation survey location at the center. Each seismic line point count had two vegetation sampling locations, one on the seismic line and one in the forest beside the seismic line. I located one sampling location on the seismic line in the middle section of the line centered on the point count location to measure line vegetation, and I placed a forest vegetation plot with in the forest edge to measure the forest vegetation directly adjacent to the line. Vegetation on lines was highly variable, especially on older lines. To account for this, three subplots were placed along a distance of 100m to capture the variation in line vegetation. The three subplots were averaged to get the mean online value for each vegetation variable. Line plots were shaped to fit on the seismic line. I located a forest vegetation plot 30 m into the forest to avoid any vegetation changes related to the seismic line edge (McFarlane 2003). Forest plots covered a maximum area of 0.04 ha, and the combination of the three line plots covered a similar area. An identical circular plot was located at each interior point count. At each circular forest plot I measured the density of trees and poles, tree height, and canopy cover and identified trees to species. At each seismic line plot I measured density of trees and shrub stems, vegetation height, canopy cover, ground cover and foliage density from 0 m to 3 m.

I measured the density of trees (woody plants greater than 8 cm diameter at breast height, DBH) as stems per hectare and density of shrub stems (defined as woody plants less than 8cm DBH and greater than 50 cm tall) as stems per square meter. Ground covered by leaf litter, moss, grass, forbs, and bare ground was visually estimated. Litter depth was measured to the nearest centimetre. I measured canopy height on the line and beside the line to compare the regeneration of the line relative to the forest using a clinometer or a graduated 8 meter pole depending on tree height. Canopy height in the forest was recorded as the mode height of the trees to avoid outliers that were particularly tall or short. I assessed angular canopy cover using a concave densitometer. Horizontal vegetation density from 0 m to 3 m in height was measured using a 0.5 m wide cover-board: one observer held the board while the second stood 10 m away and estimated the percentage of the board that was obscured by green vegetation in four height increments (0 - 0.5 m; 0.5 - 1.0 m; 1.0 - 2.0 m; and 2.0 - 3.0 m). Further details of the vegetation surveys are available from Bayne et al. (2011) and Chapter 2.

Forest Vegetation

I standardized all vegetation variables to zero mean and variance and then used a principal factor analysis to summarise forest structure into a series of uncorrelated factors that included the following variables: height, canopy cover, tree density, pole density, percent deciduous trees, percent deciduous poles, mean tree DBH and tree species richness. I retained all factors with an eigenvalue equal or greater to 1 and which had factor loadings equal to or greater than 0.5 for at least one vegetation variable (Jackson 1993).

Recovery Index

Seismic line vegetation was summarized as a recovery index (RI). The RI was based on the relative difference (RD) between the vegetation on the forest and the seismic line. Details of the RI and RD calculations are provided in Chapter 2. I used the same method as in Chapter 2 to calculate seismic line RI that included the following components: height, canopy cover, tree density, shrub density, percent deciduous shrubs, bare ground, graminiod cover, moss cover, water cover and down woody material. The index was then used to divide lines into recovery categories ranging from low to high. Lines with less than 0.5 m mean height woody vegetation were categorized as open. All remaining lines where binned into four even sized (based on number of sampling locations) categories (RC-1, RC-2, RC-3 and RC-4) ranging from low to high recovery.

Detection Radius

I calculated the effective detection radius (EDR) to determine whether there was a consistent effect of the point count locations (forest interior or seismic line) on the number of individuals detected. Because there may be less vegetation interfering with sound transmission on seismic lines, there was a possibility that birds were consistently heard farther along line edge, which could lead to a perceived increase in detections near the seismic line simply because birds can be heard farther (Schieck 1997). I used two distance classes of 50 m and unlimited distance to estimate the effective detection radius (Buckland et al. 1987, Matsuoka et al. 2012). I based my decision on the results from the ten most common species in my survey area because they had a large enough sample size to compare EDR between the line and the forest.

Analysis

I assigned each bird species in the study area into upland, lowland or a generalist "guild" depending on how many survey locations they were detected at in each forest type. Species were assigned as upland or lowland specialists if 85 % or more of the survey locations where they were detected were in one forest type. Generalist species were found at less than 85% of locations in any one forest type. I analyzed data for all species that were detected at 30 or more stations across the entire study area or within each forest type for upland and lowland species.

I reviewed species accounts on Birds of North America Online (BNA 2014) to look at recent summaries of general habitat associations, foraging and nesting microhabitats to aid in making species specific predictions of line response for different recovery categories. I also provided nesting and foraging guild groupings because these criteria have previously been used for grouping birds to predict line and gap responses (Machtans 2006, Norton and Hannon 1997).

For open lines, I used the following criteria to predict line responses: Species were expected to respond negatively if they were known to be edge sensitive based on information from other forest disturbances such as clear-cuts, agricultural lands and roads, and if they were described as preferring dense shrub cover and/or closed canopy forests. Species were predicted to respond positively to open lines if they were noted to be found frequently near habitat edges or used forest edges or small clearings for foraging or nesting. Species were expected to have a neutral response to open lines if they were commonly associated with open forest types that already contained natural clearings or if they did not seem to specialize on any microhabitat.

For shrubby regenerating lines I used the following criteria to predict line response: Species were expected to respond negatively if they were a canopy nesting or foraging species. Species were expected to have a positive response to shrubby lines if they were noted to be associated with habitat edges and if there was any indication that they preferred areas with early successional vegetation. Species were expected to have a neutral response if they did not prefer early successional vegetation, but commonly lived across a variety heterogeneous forest types.

I created three statistical models, one for each hypothesis, and ran them for each species. The first model, FOREST, tested the null hypothesis that the presence of a seismic line had no effect on the number of individuals detected at a survey location. The second model, LINE, tested whether the presence of a seismic line, regardless of regeneration state, had an effect on the number of individuals detected. The third model, RECOVERY, tested whether the number of individuals detected varied with the recovery status of the seismic line.

I used Akaike's Information Criteria (AIC) to select the best model (Anderson 2008). Models were ranked based on AIC weights and evidence ratios. A model was considered the best model if the AIC weight (AICw) was greater than 0.6. If the AIC weight was less than 0.6 and ΔAIC less than 2, I considered both top models to be equally possible. I used evidence ratios to compare all models to the FOREST model. I used the results of the model rankings and the confidence intervals for the recovery categories in the RECOVERY model to determine the actual response to open and shrubby lines.

I ran all models using a mixed effects regression that included time of day and day of year as nuisance variables to account for changes in song rates. Observer was included in all models as a random effect. I used logistic regression on species that were present at less than 100 survey locations and there was rarely more than one individual detected per survey. I used Poisson regression for 5 species where the mean was less than the variance and which would not solve using negative binomial regression. For all other species I used negative binomial regression because this was the best fitting model for the count data. Lastly, I used a mixed effects regression to look at the species richness of all territorial passerines separately for upland and lowland areas. I included the same nuisance variables as for the count models. All models were fit using STATA 11 (Statacorp 2010).

Finally, I predicted the mean number of individuals detected based on the LINE and RECOVERY models. For the LINE model I present the predicted mean counts to show both the difference between forest interior and seismic lines points as well as the relative rate of detection of each species on the surveys in the study area. I calculated the predicted means count of occurrence for each model using average forest vegetation conditions for at 5 AM on June 15th.

RESULTS

I conducted 676 point counts across 3 years. 379 point counts, 238 in lowland area and 141 in upland areas, were located on seismic lines and 297 points, 133 in lowland areas and 164 in upland areas were located in the forest interior. I detected a total of 52 species of passerine birds. 24 of these species had enough data to run all of the models on. Six species were found primarily in upland area, eight primarily in lowland areas and ten across both land types. Species codes and names are summarized in Table 3.1.

Effective Detection Radius

I did not find a consistent line related pattern in EDR for the ten most common species and error bars mostly overlap (Figure 3.1). Error bars for both forest interior and seismic line detections of Hermit Thrushes and Ruby-crowned Kinglets were very large, indicating large observer variation in estimating how far away these species are. Based on the lack of evidence for a different EDR, I used the raw count data in the models and the response variable was the number of individuals detected per count.

Forest Vegetation

I retained two vegetation factors, Factor 1 and Factor 2. Factor 1 was weighted heavily on increasing canopy height, increasing percent deciduous trees, increasing percent deciduous poles and increasing tree DBH and less heavily on increasing tree species richness and increasing canopy cover. Factor 2 was weighted moderately on increasing tree density and increasing canopy cover (Table 3.2).

Recovery Categories

The RI ranged from -0.549 on open lowland lines to -0.296 on the most recovered lines (Table 3.3). For lowland lines, shrub density was greater than the forest on RC-1 and RC-2 lines and percent deciduous shrubs was greater than the forest for all lowland recovery categories, especially on open lines. In upland areas, the RI ranged from -0.626 on open lines to -0.311 on RC-4 lines (Table 3.4). Increases in shrub density and percent deciduous shrubs were greatest on RC-1 lines but returned to close to zero for all of the higher recovery categories.

Species Richness

Species richness in upland areas increased by an average of two species detections per station on lines in early stages of recovery (recovery category = RC-1, Coef. = 2.04, $P<0.001$) and decreased by one species detection per station on highly recovered lines (recovery category = RC-4, Coef. = -1.27, $P = 0.02$; Figure 3.2). Species richness in lowland areas increased by an average of one species per station on open lines (Coef. = 0.85, $P = 0.018$), and all other categories were not different from the forest interior (Figure 3.2).

Model Rankings

The LINE model fit best for 3 species: American Redstart, Dark-eyed Junco and White-throated Sparrow (Table 3.6). American Redstarts were higher across all recovery categories except for open lines. Based on evidence ratios, both LINE and RECOVERY models were many times more likely than the forest model (Table 3.6). White-throated sparrows increased moderately near seismic lines, particularly in the open category. Dark-eyed Juncos were detected less often near lines than in the forest interior (Figure 3.3). They were lowest on open lines and increased with increasing recovery category. All AIC weights and model rankings are summarized in Table 3.6.

For two additional species the LINE model was as probable as the second ranked model. Alder Flycatchers were detected more frequently near seismic lines, particularly on open lines (Figure 3.3, mean count = 0.25 for open line compared to 0.05 for forest interior), but the LINE model explained their response as well as the RECOVERY model (Table 3.6). Hermit Thrushes were lower on lines on average and all recovery categories were negative except RC-2 but the LINE model was not better than the FOREST model in explain individuals detected per count.

The RECOVERY model fit best for two species: Palm Warbler and Swainson's Thrush, and this model was supported by a large ΔAIC, AICw and evidence ratios for both species. Palm Warblers were on average less common near lines and also showed a non-linear response to recovery category. They were least common on open lines, increased in the first two recovery categories and then decreased again as lines were closest to recovered (Figure 3.3). Swainson's Thrushes show a positive response to lines, particularly to shrubbier lines in the RC-1 category (Figure 3.4).

For two species the RECOVERY model was as likely as the second ranked model: American Robin and Yellow-rumped Warbler (Figure 3.4). The number of American Robins detected was explained by the forest structure model equally as well as by recovery category. There was no consistent pattern in response to either more open or more recovered lines and 95 % confidence intervals for all recovery categories were very large. Yellow-rumped Warblers showed a general negative response to seismic lines. For the highest recovery category (RC-4) the 95% CI did not overlap zero and confidence intervals for RC-1 through RC-3 were similar.

The FOREST model fit best for 9 species: Black-and-white Warbler, Bay-breasted Warbler, Canada Warbler, Least Flycatcher, Lincoln's Sparrow, Ruby-crowned Kinglet, Red-eyed Vireo, Western Tanager and Yellow-bellied Flycatcher. Canada Warblers and Bay-breasted Warblers did not show strong relationships with either Factor 1 or Factor 2. Both Red-eyed Vireos and Least Fly-catchers showed positive relationship with forest vegetation Factor 2 (increasing tree density and canopy cover). Western Tanagers and Lincoln's Sparrows showed a negative relationship with Factor 2: they preferred lower tree density and reduced canopy cover. Yellow-bellied Flycatchers showed a negative relationship with Factor 1: they preferred forests with less deciduous cover and lower canopy height. Yellow-bellied Flycatchers did show a negative response to

RC-1 lines. Black-and-white Warblers and Ruby-crowned Kinglets showed a positive response to both Factor 1 and Factor 2 indicating that they preferred taller forests with denser trees, more canopy cover, a higher percentage of deciduous trees and larger trees.

For five species FOREST was as probable as the second ranked model: Chipping Sparrow, Fox Sparrow, Magnolia Warbler, Ovenbird, Rose-breasted Grosbeak, and Tennessee Warbler. Chipping Sparrows showed a consistent negative response to seismic lines and the 95% CI for line presence and for the RC-4 category were small and barely overlapped zero, lending some support to the LINE model. Fox Sparrows showed no consistent negative or positive response to lines based either on line presence or recovery categories and 95% CI completely overlapped zero. Magnolia Warblers showed a positive response to only one recovery category (RC-3): for all other categories as well as line presence, 95% CI were small but overlapped zero. Because of the lack of a consistent recovery category response, the FOREST model probably best explains Magnolia Warbler distribution. For Ovenbirds, the LINE model had similar support as the FOREST model (Table 3.6, Figure 3.3). There was a consistent negative trend in Ovenbird detections near lines and for most recovery categories, but 95% CIs broadly overlap zero in most cases suggesting that presence of a line was not a strong predictor for detecting Ovenbirds. For Rose-breasted Grosbeaks, FOREST and LINE models had equal support and there was a positive effect of line. In addition, 95% CI for RC-4 are positive and do not overlap zero. However, all 95% CIs were wide and the lower counts for RC-3 indicates uncertainty about whether there was actually an effect of line presence or recovery category on this species. For Tennessee Warblers, the LINE model ranked second to the FOREST mode, and there was a small average increase in detections near lines. There was a linear trend with recovery category where open lines have a positive effect (95% CI barely overlaps zero) and 95% CIs are consistently less than 1, and higher recovery categories have less effect. This lends some support to there being a line effect but variability in forest structure still seems to predict Tennessee Warblers best.

DISCUSSION

The lack of strong negative responses to open seismic lines by many species suggests that open lines do not have a large impact. Stronger effect sizes were found as the lines recovered with American Redstarts, Alder Flycatchers, Swainson's Thrushes, Palm Warblers and Yellow-rumped Warblers showing the strongest response. This means that previous surveys of open seismic lines do not capture the full extent of seismic line impacts in the boreal forest. Aschenhurst (2008) found the same result near tundra seismic lines where 35 year old lines had a greater impact than 1.5 year old lines. Boreal songbird response does vary with the amount of vegetation recovery on seismic lines for a number of species, and simply accounting for the presence or absence of a line does not provide information about what features on lines these species respond to.

Ground and shrub nesting and foraging species did not generally have a negative response to open lines. This result is similar to the that of Machtans (2006), and it appears that predictions of a general negative response based on the assumption that a loss of protective cover and changes in ground cover result in large changes in the number of birds detected near lines are unfounded. My result indicate that Ovenbirds did not, as predicted, show a large reduction in rate of detection near seismic lines. Machtans (2006) and Bayne et al. (2005) found that Ovenbirds excluded lines from their territories and moved away slightly from newly cut lines. The difference in results is probably caused by different methods of measuring songbird response. I used point counts which record only primary territorial vocalizations and do not provide any information on territory boundaries, whereas, the other two studies used spot-mapping which shows actual territory locations. If male Ovenbirds sing more at territory boundaries to demarcate their territories against other males, they may sing as frequently near seismic lines as away from them, and point counts will not pick up on the actual behavioural changes. In general, there was not a great difference between open lines with less than 0.5 m of vegetation and shrubby lines with taller vegetation in terms of Ovenbird counts.

Moderately negative responses to open lines by Dark-eyed Juncos, Hermit Thrushes and the strong response by Palm Warblers are unexpected based on my predictions that these species should tolerate lines because all are known to use open forests and sometimes even use forest openings for foraging and/or nesting (BNA 2014). Dark-eyed Juncos have been observed increasing in response to partial harvesting because they prefer open habitats over closed forests (Steventon et al. 1998). It seems that for these species, the seismic lines do represent a loss of forest habitat that does have some effect on where they are detected. Open seismic lines in lowland areas have much more graminiod cover and standing water than the forests beside the lines (Table 3.3) and may be unsuitable foraging and nesting habitat because of this. Dark-eyed Juncos are also associated with downed woody material and less regenerated lines have very little ground structure because it takes time for dead trees and branches to accumulate on lines. In addition, I observed that juncos tend to sing from taller perches out in bogs. Seismic lines do not provide such song posts until they reach the RC-3 and RC-4 categories when trees are large enough to be counted. Thus the reduced number of juncos detected near lines may not indicate any actual reduction in population but rather a change in singing behaviour resulting in fewer bird detections near lines. The response by Palm Warblers to open lines may also be related to territorial behaviour or placement. They are known to align their territories with habitat edges (BNA 2014), especially on the edge between denser forest and open bogs. They also have the same behaviour as Dark-eyed Juncos where they sing from taller perches within open bogs. White-throated sparrows were the only species that had a positive response to open lines as predicted by information on general and microhabitat preferences (BNA 2014).

Chipping sparrows did not show a positive response to open or shrubby lines even though they are listed as a species that prefers edges, are frequently seen using a variety of shrubby, grassy and early successional habitats, forage in open areas, and are recorded as increasing in gaps and partial harvest situations (Steventon et al. 1998). Instead, Chipping Sparrows had a slightly negative response to seismic lines, which was similar to the negative response Miller et al. (1998) found for Chipping Sparrows near recreational trails.

A number of species that are associated with early successional habitat, and/or dense shrub cover did show positive responses to shrubby lines as predicted. The greatest increase was by American Redstarts which were detected much more frequently near lines with heavier shrub cover. The increase was somewhat less on the most recovered lines indicating that lines with increasing height and tree density may not be as preferred by this species. A similar trend was evident for Alder Flycatchers, Least Flycatchers and Swainson's Thrushes which were detected more frequently near shrubby lines but which no longer showed any marked increase over the forest interior on highly recovered lines. These results agree with existing literature on small scale forest disturbances that regenerate to early successional vegetation (Becker et al. 2011, Forsman et al. 2010).

I found no evidence that canopy nesting and foraging birds are generally negatively affected by open lines. The only species that showed a decrease on open lines were Red-eyed Vireos. For Red-eyed Vireos the lack of a significant negative response could be caused by two things. Firstly, Red-eyed Vireos sing and forage in the canopy but nest in shrubs, and recovery of shrubs may mitigate the impact of a lack of nesting substrate. Secondly, Red-eyed Vireos live in deciduous dominated forests where I observed that the gap caused by the line tends to be reduced from the sides at canopy level because branches grow into the open space. Because of this, both foraging area and protective cover at the canopy level may be restored more quickly in deciduous compared to coniferous forests.

This may be particularly important to a species like the Red-eyed Vireo where canopy volume has been associated with territory quality (BNA 2014). Machtans (2006) suggested that canopy nesting and foraging birds in mature forests should not respond to lines because the gap created by the seismic line was not wider than natural canopy gaps already existing in the forests. This seems to be true for Western Tanagers, Bay-breasted Warblers and Ruby-crowned Kinglets, which did not show any response to seismic lines. These species also do not forage or nest in the ground or shrub layer and, therefore, seismic lines do not represent lost nesting or foraging opportunities. The forests that I surveyed have not been burned for at least 100 years and, therefore, have reached the stage where natural gaps become more frequent (McCarthy 2001).

One thing that I have to consider in interpreting these results is the limitation of point counts for determining the mechanism causing changes in the number of individuals detected on the line versus the forest. The general density of a species in a landscape may help understand what caused the changes in the counts I did observe. Individuals of species that are common on the landscape, such as the Swainson's Thrush or the Ovenbird, have fewer options for selecting territories if they want to move near or away from lines (Gill et al. 2001). Simply excluding the line, such as Ovenbirds have been observed doing (Bayne et al.2005) will not result in a large reduction in the number of individuals detected unless seismic line density is high. This is particularly true when using unlimited distance point counts that can, theoretically, detect an individual anywhere in its territory, as long as it is within hearing range of the observer. An Ovenbird could achieve line exclusion simply by reducing territory size, which would not result in an actual reduction in Ovenbird density in areas near lines. This could explain the lack of strong negative responses by common ground nesting and foraging species such as the Ovenbird when using point count surveys.

In contrast, a less common species such as the American Redstart (Figure 3.3) have less pressure from conspecifics and should have more leeway to select territories in the most desirable locations. Because of this, an increase in the number of American Redstarts detected near seismic lines was more likely to indicate a real change in the density of birds near lines. This would explain why American Redstarts were detected up to 3 times more frequently on younger seismic lines with denser shrub cover than the surrounding forest. Because point count surveys are restricted in picking up smaller adjustments in songbird behaviour, any measurable and consistent positive response could indicate a real change in the local abundance of species and should be investigated more closely. One should also be somewhat cautious about accepting the results from species that are less common on the landscape because there was a greater chance that they were located near or far from seismic lines simply due to chance. Bay-breasted Warblers, Black-and-white Warblers, and Canada Warblers are particularly uncommon and lack of response to lines does not mean that they are not affected. I simply may not have had sufficient statistical power to detect such effects. In addition, because of the number of individual species analysed, there is an increasing chance of a Type I error. Where species responses were similar to those found near other types of edges and disturbances (such as American Redstarts and Yellow-rumped Warblers), I am confident that there is actually a response to lines.

Another factor that point counts fail to address entirely is how successful birds are at nesting and reproduction if they hold territories near seismic lines. For example, Yellow-rumped Warblers show a consistent but non-significant response to many different types of forest disturbance where tree cover is reduced but not removed completely (BNA 2014, Machtans 2006). They seem to increase their territories to compensate for a reduction in forest cover (Machtans 2006, BNA 2014). If Yellow-rumped Warblers are as successful at rearing young on territories in disturbed forest as in intact forest, then there should be no long-term population consequences; but, if reproductive success is lower, then there is a cause for concern. Therefore, species that show negative responses to seismic lines should be investigated more closely to understand whether the change in detection rate near lines is simply due to change in singing behaviour or actually in numbers of individuals.

The increase in some species, such as American Redstarts, on regenerating lines is not really a conservation concern. From a conservation point of view, the only reason why it might be necessary to mitigate a positive effect would be if an increase in one species results in a decrease of another species through interspecific territoriality. Based on the information available, I did not see any evidence for such relationships, with one exception. White-throated sparrows are known to be aggressive toward Dark-eyed Juncos in some areas (BNA 2014). If this was true in my study area, then it is possible that the small increase in White-throated Sparrows on lines comes at the expense of the small decrease in Dark-eyed Juncos. However, for both of these species, there is not a significant response to the most highly recovered lines.

The positive effect on species richness on RC-1 lines supports the concept that increases in vegetative diversity are positively correlated with increases in bird diversity (Leopold 1933, Wang et al. 2002, Willson 1974). My results are very similar to those looking at species diversity near gaps and partial harvest studies where small clearings are introduced into continuous mature forest (Forsman et al. 2010, Greenberg and Lanham 2001). None of the species I surveyed were new to the boreal forest or viewed as an invasive species. Unlike wide linear features such as power line easements, seismic lines do not provide enough new habitat for non-forest species to establish (Chasko and Gates 1982, King and Byers 2002). The large increase in Alder Flycatchers on open lines in lowland areas may mean that Alder Flycatchers are moving into areas that they do not normally use due to the increase in deciduous vegetation. They are generally associated with dense deciduous shrub cover, which was not as commonly available in lowland areas but did increase on seismic lines. The return toward forest interior species richness with increasing recovery category provides additional support for the importance of line recovery state in determining bird species response and is one metric that could be used to determine when lines are recovered.

With the exception of Palm Warblers, Yellow-rumped Warblers, Hermit Thrushes and, possibly, Chipping Sparrows, it seems that shrub and moderate tree recovery was sufficient to bring the bird community near seismic lines back to the same state as the forest interior. Because these three species show negative trends, even highly regenerated lines cannot be removed from calculations of seismic line density if one wants to accurately assess line impacts. If these negative trends indicate real changes in population density, then one would have to conclude that shrub layer recovery was insufficient to mitigate seismic line effects on all species of songbirds.

Knowing whether shrub or shrub and tree recovery is necessary is important for trying to create universal recovery criteria across multiple taxa for managers interested in setting line density thresholds. Research on American Marten (*Martes americana*) shows that low shrub recovery of 3 m is sufficient to mitigate the negative effects of seismic lines (Tigner 2012). On the other hand, black bears appear to use seismic lines even with high recovery (Tigner 2012). What level of recovery is required to reduce the use of seismic lines as travel corridors for wolves is not known, but since they travel on the ground, thick shrub regeneration, such as is seen on RC-1 and RC-2 category lines in lowland areas, may be sufficient (Latham et al. 2011). How much and what type of vegetation recovery is enough to call seismic lines recovered from a biodiversity perspective will be challenging given the wide array of species responses. There has recently been a shift in energy sector policy in western Canada that involves planting trees on seismic lines (Gulley 2001). While this effort is generally focused on reducing large carnivore movement, it presumably should benefit birds.

The reduction in mean species richness on highly regenerated upland lines and the persistence of reduced relative abundance for some species even at the most recovered states indicates that large portions of 50 year old lines cannot be considered completely recovered for all songbirds if the desired outcome is to have no difference from the forest interior. The variable response of different species to lines means that recovery may have to be assessed on a species by species basis. Given that age is not a good predictor of seismic line regeneration (Chapter 2) and that birds do respond to the recovery state of lines, vegetation structure, not age, should be used to assess whether seismic lines are recovered for boreal songbirds.

Table 3. 1. English names, scientific name, species codes and forest type associations for the 24 most common species in the study area.

English Name	Code	Latin Name	Land Type	Nesting Guild	Foraging Guild
Alder Flycatcher	ALFL	*Empidonax alnorum*	Lowland	Shrub	Air
American Redstart	AMRE	*Setophaga ruticilla*	Upland	Shrub	Shrub & low canopy
American Robin	AMRO	*Turdus migratorius*	Generalist	Shrub	General
Black-and-white Warbler	BAWW	*Mniotilta varia*	Generalist	Ground	Bark
Bay-breasted Warbler	BBWA	*Setophaga castanea*	Generalist	Lower canopy	Upper canopy
Canada Warbler	CAWA	*Cardellina canadensis*	Upland	Ground	Lower canopy / shrub
Chipping Sparrow	CHSP	*Spizella passerina*	Generalist	Shrub	Ground
Dark-eyed Junco	DEJU	*Junco hyemalis*	Lowland	Ground	Ground
Fox Sparrow	FOSP	*Passerella iliaca*	Lowland	Ground	Ground
Hermit Thrush	HETH	*Catharus guttatus*	Lowland	Ground	Ground
Least Flycatcher	LEFL	*Empidonax minimus*	Upland	Canopy	Upper canopy
Lincoln's Sparrow	LISP	*Melospiza lincolnii*	Lowland	Ground	Ground
Magnolia Warbler	MAWA	*Setophaga magnolia*	Generalist	Shrub	Lower canopy / shrub
Ovenbird	OVEN	*Seiurus aurocapilla*	Upland	Ground	Ground
Palm Warbler	PAWA	*Setophaga palmarum*	Lowland	Ground	Ground
Rose-breasted Grosbeak	RBGR	*Pheucticus ludovicianus*	Generalist	Lower canopy	Upper canopy
Ruby-crowned Kinglet	RCKI	*Regulus calendula*	Lowland	Canopy	Canopy
Red-eyed Vireo	REVI	*Vireo olivaceus*	Upland	Shrub	Upper canopy
Swainson's Thrush	SWTH	*Catharus ustulatus*	Generalist	Shrub	General
Tennessee Warbler	TEWA	*Oreothlypis peregrina*	Generalist	Ground	Upper canopy
Western Tanager	WETA	*Piranga ludoviciana*	Upland	Canopy	Upper canopy
White-throated Sparrow	WTSP	*Zonotrichia albicollis*	Generalist	Ground	Ground
Yellow-bellied Flycatcher	YBFL	*Empidonax flaviventris*	Lowland	Ground	Air
Yellow-rumped Warbler	YRWA	*Setophaga coronata*	Generalist	Lower canopy	Shrub & low canopy

Table 3. 2. Results from principal factor analysis showing unrotated factor loadings, uniqueness, Eigen Values and cumulative variance explained. Factor 1 and Factor 2 were retained for analysis because at least variable had a factor loading greater than +/-0.5 and the Eigen Values was equal to or greater than one.

Variable	Factor1	Factor2	Factor3	Factor4	Uniqueness
Height	0.896	-0.146	0.009	0.070	0.171
Canopy Cover	-0.562	-0.512	-0.155	0.110	0.386
Tree Density	0.093	0.667	-0.225	-0.003	0.496
% Deciduous Trees	0.731	0.034	-0.032	-0.242	0.406
Pole Density	-0.275	0.257	0.401	0.043	0.696
% Deciduous Poles	0.759	-0.212	0.061	-0.136	0.357
Tree DBH	0.821	-0.203	0.035	0.198	0.244
Tree Spp. Richness	0.509	0.303	-0.032	0.252	0.584
Eigenvalue	3.246	0.973	0.243	0.199	
Variance Explained	0.789	1.025	1.084	1.132	1.120

Table 3. 3. Means of relative difference (RD) values for all categories for lowland areas. RD is the relative different between the forest and the seismic lines at each sampling location. Methods and formulas used to calculate RD are explained in detail in Chapter 2. The upper value is the mean and the lower value is the standard error of the mean for all variables and categories.

Variable	Open	RC-1	RC-2	RC-3	RC-4
Recovery Index	-0.549	-0.530	-0.445	-0.387	-0.296
	0.015	0.008	0.003	0.002	0.008
Height	-0.964	-0.614	-0.616	-0.602	-0.442
	0.006	0.028	0.029	0.030	0.036
Canopy Cover	-0.244	-0.287	-0.112	-0.087	-0.041
	0.040	0.048	0.035	0.040	0.024
Tree Density	-0.873	-0.984	-0.927	-0.935	-0.683
	0.042	0.008	0.030	0.032	0.063
Shrub Density	-0.421	0.104	0.100	-0.024	0.053
	0.049	0.059	0.045	0.036	0.034
% Deciduous Shrubs	0.083	0.271	0.180	0.124	0.159
	0.056	0.044	0.039	0.031	0.033
Bare Ground	0.399	0.081	0.156	0.053	-0.005
	0.062	0.075	0.075	0.043	0.045
Graminoid Cover	0.700	0.586	0.431	0.255	0.151
	0.045	0.063	0.077	0.072	0.048
Moss Cover	-0.286	-0.286	-0.022	-0.103	-0.029
	0.050	0.047	0.047	0.031	0.037
Water Cover	0.174	0.342	0.093	0.099	0.075
	0.065	0.076	0.093	0.061	0.051
Down Woody Material	-0.346	-0.692	-0.473	-0.247	-0.006
	0.067	0.064	0.094	0.071	0.045

Table 3. 4. Means of relative difference (RD) values for all categories for upland areas. RD is the relative different between the forest and the seismic lines at each sampling location. Methods and formulas used to calculate RD are explained in detail in Chapter 2. The upper value is the mean and the lower value is the standard error of the mean for all variables and categories.

Variable	Open	RC-1	RC-2	RC-3	RC-4
Recovery Index	-0.626	-0.537	-0.448	-0.389	-0.311
	0.030	0.009	0.003	0.003	0.007
Height	-0.987	-0.653	-0.714	-0.559	-0.511
	0.006	0.035	0.034	0.034	0.036
Canopy Cover	-0.551	-0.469	-0.234	-0.128	-0.019
	0.092	0.074	0.062	0.081	0.068
Tree Density	-1.000	-0.960	-0.884	-0.691	-0.494
	0.000	0.020	0.047	0.082	0.087
Shrub Density	-0.243	0.249	0.051	-0.033	-0.035
	0.133	0.060	0.077	0.049	0.050
% Deciduous Shrubs	0.029	0.257	0.005	0.028	-0.002
	0.112	0.060	0.039	0.022	0.012
Bare Ground	0.600	0.149	0.093	0.020	0.027
	0.127	0.073	0.030	0.014	0.021
Graminoid Cover	0.826	0.682	0.337	0.365	0.203
	0.079	0.079	0.071	0.081	0.055
Moss Cover	-0.520	-0.478	-0.297	-0.190	-0.136
	0.141	0.110	0.103	0.108	0.093
Water Cover	0.050	-0.011	0.020	0.010	0.008
	0.050	0.058	0.014	0.010	0.023
Down Woody Material	-0.881	-0.739	-0.472	-0.350	-0.291
	0.064	0.075	0.087	0.086	0.091

Table 3. 5. Predicted and actual responses to open, shrubby lines and RC-4 lines. P, ns = Positive relationship but not significant (95% CI narrowly overlaps zero). N, ns = Negative relationship but not significant (95% CI narrowly overlaps zero). Predicted outcomes are based on information for each species based on general habitat, nesting and foraging microhabitat information gathered from species account in the Birds of North America Online (2014).

Species	Predicted Open	Actual Open	Predicted Shrubby	Actual Shrubby	Actual RC-4
Alder Flycatcher	Neutral	Positive	Positive	P, ns	Neutral
American Redstart	Neutral	Neutral	Positive	Positive	Positive
American Robin	Neutral	Neutral	Neutral	Neutral	Neutral
Bay-breasted Warbler	Negative	Neutral	Negative	Neutral	Neutral
Black-and-white Warbler	Negative	Neutral	Neutral	Neutral	Neutral
Canada Warbler	Negative	Neutral	Neutral	Neutral	Neutral
Chipping Sparrow	Positive	Neutral	Positive	N, ns	N, ns
Dark-eyed Junco	Neutral	N, ns	Neutral	N, ns	Neutral
Fox Sparrow	Negative	Neutral	Positive	Neutral	Neutral
Hermit Thrush	Neutral	N, ns	Neutral	N, ns	N, ns
Least Flycatcher	Neutral	Neutral	Neutral	Positive	Neutral
Lincoln's Sparrow	Negative	Neutral	Neutral	Neutral	Neutral
Magnolia Warbler	Negative	Neutral	Neutral	Neutral	Neutral
Ovenbird	Negative	Neutral	Neutral	Neutral	Neutral
Palm Warbler	Neutral	Negative	Neutral	Neutral	Negative
Red-eyed Vireo	Neutral	N, ns	Neutral	Neutral	Neutral
Rose-breasted Grosbeak	Neutral	Neutral	Neutral	Neutral	Positive
Ruby-crowned Kinglet	Neutral	Neutral	Neutral	Neutral	Neutral
Swainson's Thrush	Negative	Neutral	Neutral	Positive	Neutral
Tennessee Warbler	Neutral	P, ns	Neutral	Neutral	Neutral
Western Tanager	Neutral	Neutral	Neutral	Neutral	Neutral
White-throated Sparrow	Positive	P, ns	Positive	P, ns	P, ns
Yellow-bellied Flycatcher	Neutral	Neutral	Neutral	Negative	Neutral
Yellow-rumped Warbler	Negative	Neutral	Negative	Neutral	Negative

Table 3. 6. AIC results for all species and models. ΔAIC is the difference in AIC value between any model and the top model. ML is the model likelihood. AICw is the AIC weight. ER Forest is the evidence ration relative to the FOREST model. df is the degrees of freedom for each model. N is the number of point count stations (forest and line) used for each model.

Species	MODEL	N	LL	df	AIC	ΔAIC	ML	AICw	ER Forest
ALFL	LINE	371	-146.50	8	308.99	0.00	1.00	0.58	3.94
	Recovery	371	-143.24	12	310.49	1.50	0.47	0.27	1.86
	FOREST	371	-148.87	7	311.73	2.74	0.25	0.15	1.00
AMRE	LINE	305	-162.24	8	340.48	0.00	1.00	0.63	3085.44
	Recovery	305	-158.76	12	341.52	1.04	0.59	0.37	1833.62
	FOREST	305	-171.28	7	356.55	16.07	0.00	0.00	1.00
AMRO	Recovery	676	-146.05	11	314.09	0.00	1.00	0.52	1.61
	FOREST	676	-151.52	6	315.04	0.95	0.62	0.32	1.00
	LINE	676	-151.24	7	316.49	2.40	0.30	0.16	0.48
BAWW	FOREST	676	-134.87	6	281.75	0.00	1.00	0.71	1.00
	LINE	676	-134.81	7	283.62	1.88	0.39	0.28	0.39
	Recovery	676	-133.93	11	289.85	8.11	0.02	0.01	0.02
BBWA	FOREST	676	-241.92	7	497.85	0.00	1.00	0.72	1.00
	LINE	676	-241.92	8	499.85	2.00	0.37	0.27	0.37
	Recovery	676	-241.05	12	506.09	8.25	0.02	0.01	0.02
CAWA	FOREST	305	-99.33	6	210.65	0.00	1.00	0.65	1.00
	LINE	305	-99.01	7	212.01	1.36	0.51	0.33	0.51
	Recovery	305	-98.22	11	218.43	7.78	0.02	0.01	0.02
CHSP	FOREST	676	-724.78	6	1461.56	0.00	1.00	0.49	1.00
	LINE	676	-723.82	7	1461.64	0.08	0.96	0.47	0.96
	Recovery	676	-722.08	11	1466.15	4.60	0.10	0.05	0.10
DEJU	LINE	371	-349.42	8	714.83	0.00	1.00	0.66	2.11
	FOREST	371	-351.16	7	716.33	1.50	0.47	0.31	1.00
	Recovery	371	-348.45	12	720.91	6.08	0.05	0.03	0.10
FOSP	FOREST	371	-140.73	7	295.46	0.00	1.00	0.57	1.00
	LINE	371	-140.64	8	297.29	1.83	0.40	0.23	0.40
	Recovery	371	-136.75	12	297.49	2.04	0.36	0.21	0.36
HETH	LINE	371	-459.23	7	932.46	0.00	1.00	0.55	1.42
	FOREST	371	-460.58	6	933.16	0.70	0.71	0.39	1.00
	Recovery	371	-457.44	11	936.88	4.42	0.11	0.06	0.16
LEFL	FOREST	305	-137.41	7	288.81	0.00	1.00	0.62	1.00
	LINE	305	-137.02	8	290.04	1.23	0.54	0.33	0.54
	Recovery	305	-134.91	12	293.81	5.00	0.08	0.05	0.08
LISP	FOREST	371	-217.93	7	449.85	0.00	1.00	0.70	1.00
	LINE	371	-217.85	8	451.70	1.85	0.40	0.28	0.40
	Recovery	371	-216.58	12	457.15	7.30	0.03	0.02	0.03

Table 3.6. Continued.

Species	MODEL	N	LL	df	AIC	ΔAIC	ML	AIC w	ER Forest
MAWA	FOREST	676	-597.39	7	1208.79	0.00	1.00	0.47	1.00
	Recovery	676	-592.71	12	1209.43	0.64	0.73	0.34	0.73
	LINE	676	-597.28	8	1210.57	1.78	0.41	0.19	0.57
OVEN	FOREST	305	-413.17	7	840.34	0.00	1.00	0.54	1.00
	LINE	305	-412.37	8	840.75	0.41	0.81	0.44	0.81
	Recovery	305	-411.57	12	847.14	6.81	0.03	0.02	0.03
PAWA	Recovery	371	-294.97	12	613.94	0.00	1.00	0.83	986.29
	LINE	371	-300.54	8	617.08	3.14	0.21	0.17	204.90
	FOREST	371	-306.86	7	627.72	13.79	0.00	0.00	1.00
RBGR	FOREST	676	-192.25	6	396.50	0.00	1.00	0.44	1.00
	LINE	676	-191.28	7	396.55	0.05	0.98	0.43	0.98
	Recovery	676	-188.45	11	398.90	2.40	0.30	0.13	0.30
RCKI	FOREST	371	-331.90	6	675.80	0.00	1.00	0.70	1.00
	LINE	371	-331.82	7	677.63	1.83	0.40	0.28	0.40
	Recovery	371	-330.43	11	682.86	7.05	0.03	0.02	0.03
REVI	FOREST	305	-267.48	7	548.95	0.00	1.00	0.61	1.00
	LINE	305	-267.48	8	550.95	2.00	0.37	0.22	0.37
	Recovery	305	-263.74	12	551.48	2.52	0.28	0.17	0.28
SWTH	Recovery	676	-842.68	12	1709.35	0.00	1.00	0.98	102.36
	FOREST	676	-852.31	7	1718.61	9.26	0.01	0.01	1.00
	LINE	676	-851.86	8	1719.72	10.36	0.01	0.01	0.58
TEWA	FOREST	676	-853.22	7	1720.44	0.00	1.00	0.55	1.00
	LINE	676	-852.70	8	1721.40	0.95	0.62	0.34	0.62
	Recovery	676	-849.78	12	1723.56	3.12	0.21	0.11	0.21
WETA	FOREST	305	-147.53	6	307.06	0.00	1.00	0.69	1.00
	LINE	305	-147.41	7	308.83	1.76	0.41	0.29	0.41
	Recovery	305	-146.11	11	314.21	7.15	0.03	0.02	0.03
WTSP	LINE	676	-686.09	7	1386.18	0.00	1.00	0.61	1.68
	FOREST	676	-687.61	6	1387.22	1.04	0.59	0.36	1.00
	Recovery	676	-685.43	11	1392.86	6.67	0.04	0.02	0.06
YBFL	FOREST	371	-187.04	6	386.09	0.00	1.00	0.60	1.00
	LINE	371	-186.89	7	387.78	1.69	0.43	0.23	0.43
	Recovery	371	-183.52	11	389.05	2.96	0.23	0.12	0.23
YRWA	Recovery	676	-641.93	12	1307.86	0.00	1.00	0.50	2.46
	FOREST	676	-647.48	7	1308.95	1.09	0.58	0.29	1.43
	LINE	676	-646.83	8	1309.66	1.80	0.41	0.20	1.00

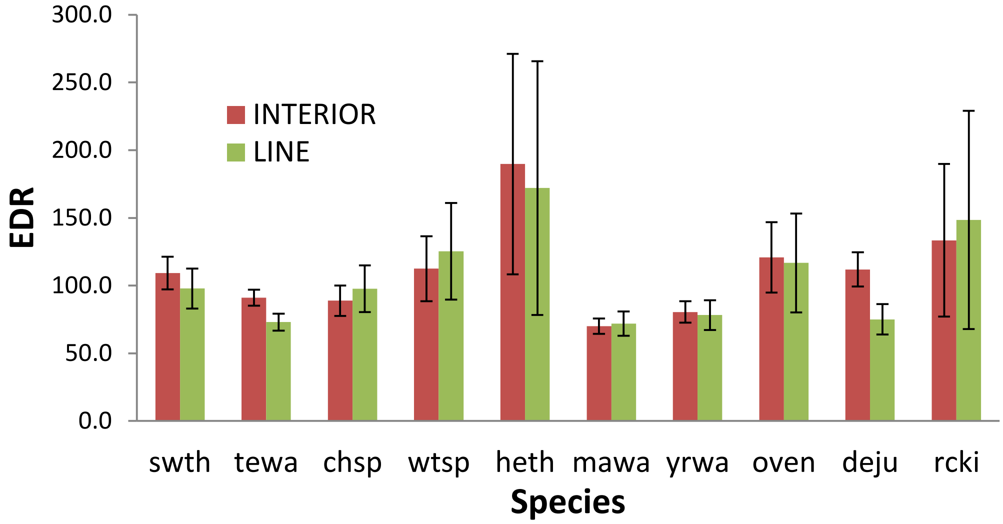


Figure 3. 1. Comparison of actual calculated effective detection radius (EDR) between interior and seismic line point counts. Error bars represent standard error of the mean.

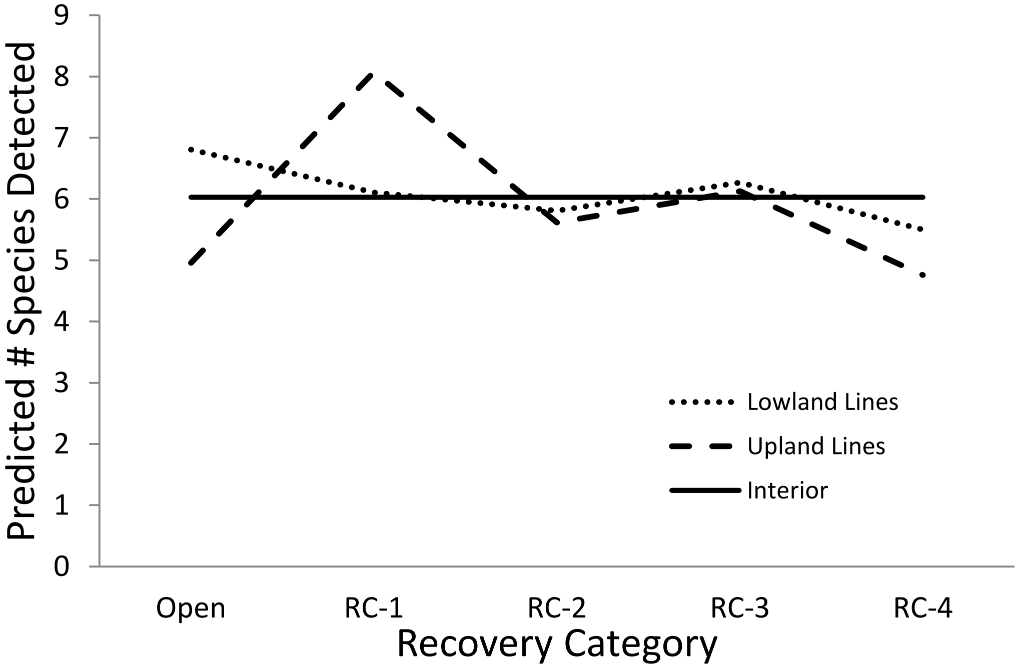


Figure 3. 2. Predicted number of species detected in each recovery category and the forest interior for upland and lowland areas. Predictions made for 5 am on the 15 June for mean forest vegetation values.

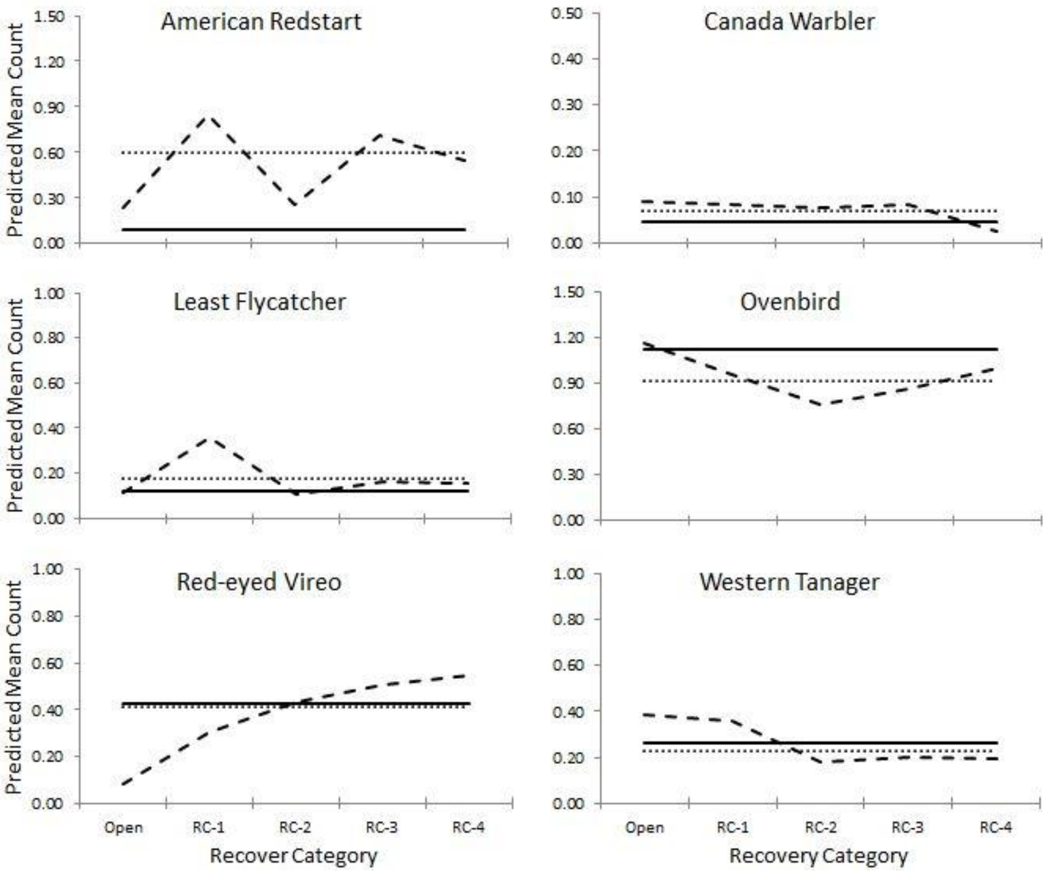


Figure 3. 3. Predicted mean counts for upland species for 5 am on June 15. Solid line = forest interior counts; dotted line = mean seismic line counts; dashed line = mean counts by recovery category.

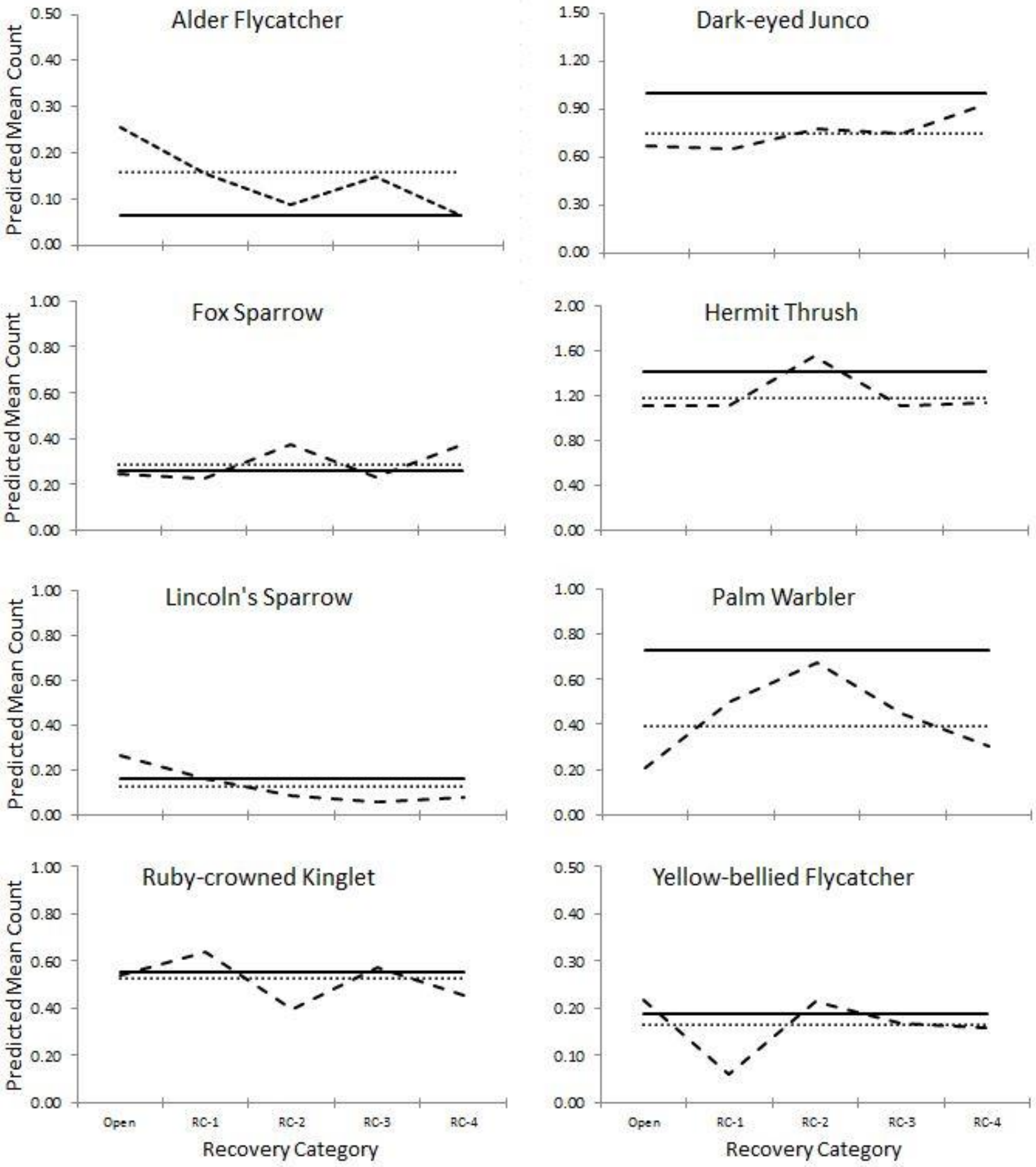
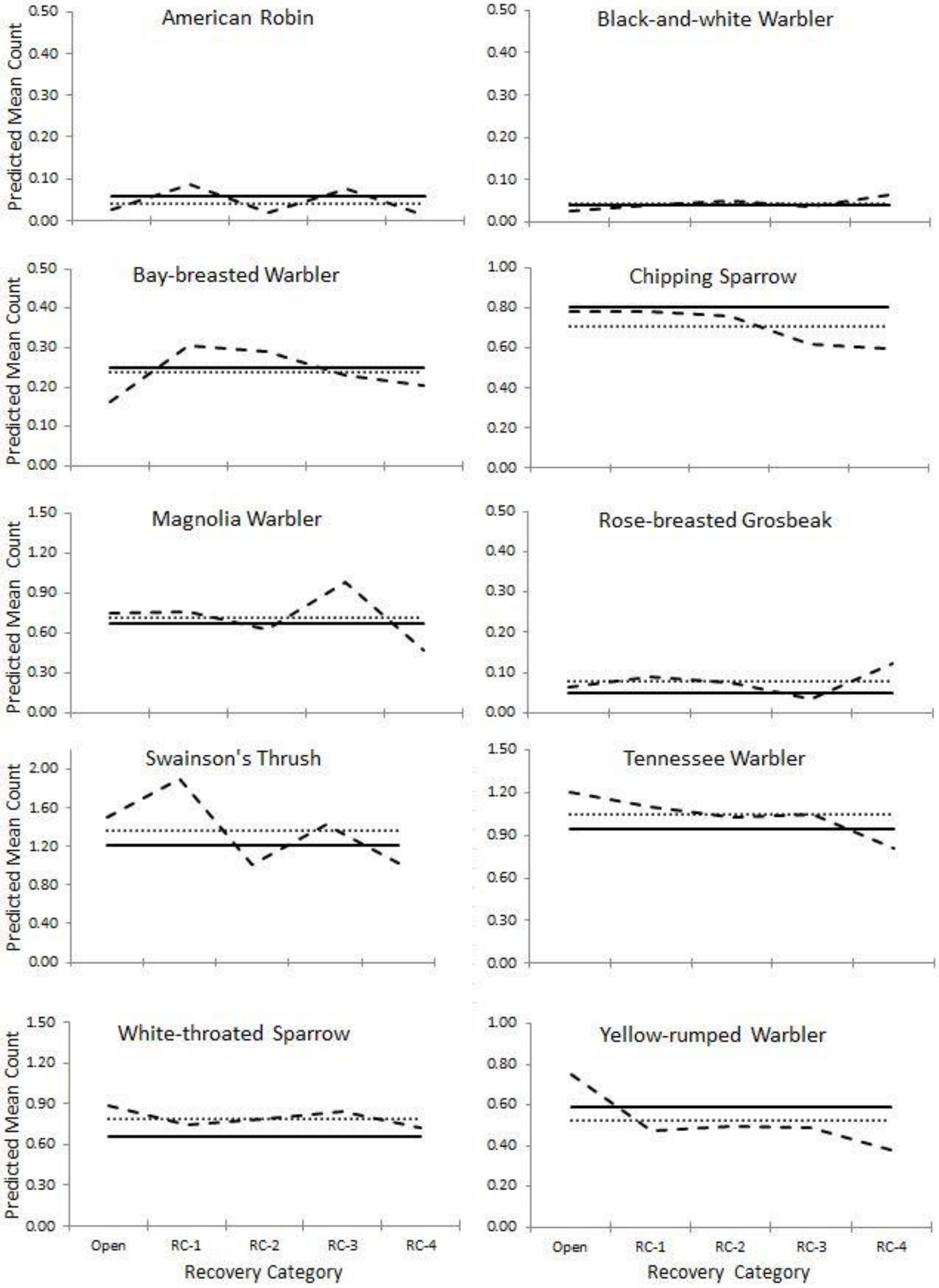


Figure 3. 4. Predicted mean counts for lowland species for 5 am on June 15. Solid line = forest interior counts; dotted line = mean seismic line counts; dashed line = mean counts by recovery category.


American Robin

Black-and-white Warbler

Bay-breasted Warbler

Chipping Sparrow

Magnolia Warbler

Rose-breasted Grosbeak

Swainson's Thrush

Tennessee Warbler

White-throated Sparrow

Yellow-rumped Warbler

Figure 3. 5. Predicted mean counts for generalist species for 5 am on June 15. Solid line = forest interior counts; dotted line = mean seismic line counts; dashed line = mean counts by recovery category.

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Note: This chapter was published in Avian Conservation and Ecology 8 (1) : 5. Formatting is according to journal specifications. This chapter has two co-authors so the plural pronoun is used.

CHAPTER 4. OVENBIRD (*SEIURUS AUROCAPILLA*) TERRITORY PLACEMENT NEAR SEISMIC LINES IS INFLUENCED BY FOREST REGENERATION AND CONSPECIFIC DENSITY

INTRODUCTION

The boreal forest that is underlain by the western Canadian sedimentary basin is continuing to be dissected by oil and gas exploration. Dissection is the stage along a fragmentation continuum when initial access into an ecosystem occurs (Hunter 1999) and is mainly caused by linear features. Accumulation of oil and gas features such as roads, pipelines, and seismic lines is leading to concerns that interior habitat is being reduced for forest interior species due to the amount of edge from these disturbances (Schneider 2002). Seismic lines are the dominant source of dissection caused by the energy sector (Schneider 2002, Lee and Boutin 2006). Historically, seismic lines were 5- to 8-m strips that extended for tens to hundreds of kilometers and were cleared of all forest cover to survey for oil and gas reserves. Currently, seismic lines can be <2 m wide in certain circumstances but typically are 3 to 5-m wide (Schneider 2002). After exploration, seismic lines are typically left to regenerate naturally. Regeneration can be poor because of continued human activity on the lines (e.g., all-terrain vehicle access) and poor growing conditions caused by altered light regimes, soil compaction, and/or soil moisture changes (Lee and Boutin 2006). The perception that seismic lines are not recovering and are causing long-term fragmentation effects on a variety of wildlife species has led to calls for limits on seismic line density (Dehcho Land Use Planning Committee 2006, Kennet 2006).

Current thresholds for seismic line density do not distinguish among different types or ages of seismic lines (Environment Canada 2011). Lines are visible on the landscape for long periods of time (Lee and Boutin 2006) but impacts on biodiversity are not necessarily related to visibility. To impose limits on the number of seismic lines deemed acceptable for biodiversity requires an understanding of which types and ages of lines create fragmentation effects and for how long these effects last. We argue that using wildlife as management indicators of seismic line impacts is one tool for deciding whether seismic lines have a functional impact and when that impact has been mitigated.

The Ovenbird (*Seiurus aurocapilla*) is the only boreal songbird whose response to seismic lines has been studied (Bayne et al. 2005*a*, 2005*b*; Machtans 2006), and its known sensitivity to lines makes it a potential management indicator for determining when a seismic line has recovered (Lindenmayer et al. 2000). In high-density populations, Ovenbirds defend territories directly up to the edge of seismic lines (conventional 8-m width) but do not include the lines within their territories (Bayne et al. 2005*b*). In lower-density populations, Ovenbirds place their territories away from seismic lines the year immediately after lines were cut (Machtans 2006). The end result of this behavior is fewer Ovenbirds in areas with high seismic line density (Bayne et al. 2005*b*, Machtans 2006). This behavior does not occur when lines are 3-m wide or less, suggesting industry best practices are an effective mitigation option (Bayne et al. 2005*a*). However, narrowing line width is not an option in all exploration events. An alternative mitigation strategy is to actively restore vegetation on wider seismic lines. No information exists on the composition and structure of vegetation on seismic lines required to reduce dissection effects for birds. Developing mitigation strategies for seismic lines requires an understanding of why species like the Ovenbird do not include wide seismic lines within their territories and/or why they avoid seismic line edges.

We suggest three mechanisms to explain why Ovenbirds exclude seismic lines from their territories. The food abundance hypothesis suggests Ovenbirds exclude lines from their territories because the lines are poor foraging habitat. Reduction in leaf-litter quality due to forest edge microclimate is a suggested cause for Ovenbird sensitivity to road edges and forest patch size (Burke and Nol 1998, Ortega and Capen 1999). Leaf-litter depth and vegetation structure are shown to be correlated with abundance of invertebrate prey (Smith and Shugart 1987, Burke and Nol 1998, Haskell 2000, VanWilgenburg 2001), and recently cut lines with reduced leaf-litter depth and cover may have lower food resources. Similarly, seismic lines may have lower litter depth (and lower food abundance) because leaf litter is disturbed or removed during line clearing. If food abundance is the main factor influencing line exclusion, recovery of leaf-litter depth to that of forest interior values should cause line exclusion behavior to disappear.

The protective cover hypothesis suggests that seismic lines are not included within territories because they represent a risky environment with insufficient shrub cover to conceal nests or to protect foraging adults and juveniles (Rodriguez et al. 2001, Walther and Gosler 2001, Eggers et al. 2008). Many species of mammals and raptors use linear features for movement and hunting (Latham et al. 2011, Tigner 2012), and Ovenbirds may be exposed to higher predation risk on recently cut lines as they cross from one side to the other or attempt to forage on the line. If lines are avoided because they are perceived as having greater risk, then regeneration of overhead cover should cause seismic line exclusion to disappear.

Finally Ovenbirds may live up to the edge of but not include seismic lines in their territories because lines act as landmarks (Bayne et al. 2005*a*). Landmarks are habitat features that reduce conflict between territory holders by providing a visible marker that is used to define territory boundaries (Mesterton-Gibbons and Adams 2003). Anecdotal evidence suggests that birds in open habitats use landscape features such as ridges and streams as boundaries (Errington 1930, Reid and Weatherhead 1988) and that forest birds may use vegetation features (St. Louis et al. 2004). Seismic lines create a visible break in continuous forest canopy similar to streams or ridges. According to the landmark hypothesis, if Ovenbirds use seismic lines as landmarks, individuals would be more likely to exclude seismic lines from their territories in areas where there are greater numbers of conspecifics because such individuals are more likely to have a neighbor on the other side of the line. In addition, individuals should spend less time defending the portion of their territory adjacent to seismic lines than the areas surrounded by uniform forest because of reduced defense costs (Eason et al. 1999). Our objective was to examine how Ovenbirds behave near seismic lines with different levels of vegetation recovery and to test which aspect of vegetation structure best explains their behavior. By understanding the mechanisms causing Ovenbirds to exclude seismic lines, the energy sector will be better able to mitigate their effects and have a better understanding of how long seismic lines last based on their effects on bird territory behavior.

METHODS

Study site

Our study area was near Fort Liard, Northwest Territories, Canada. Mean annual precipitation is 350 to 500 mm and mean seasonal temperatures range from −20°C in the winter to 14°C in the summer. Forest types include black spruce (*Picea marianna*) bogs, white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and mixedwood stands. There is one primary road in the area. Oil and gas exploration has happened in periodic bursts over time and there are currently no producing wells. The low amount of human use of seismic lines in this region means that many lines have started to regenerate naturally, unlike seismic lines in other areas of western Canada (Lee and Boutin 2006).

Seismic line selection

We selected 25 seismic lines that ran through deciduous habitat suitable for Ovenbirds (trembling aspen (*Populus tremuloides*) or paper birch (*Betula papyrifera*) dominated forests). Lines were selected to get a range of variation in vegetation regrowth on the line. Vegetation cover on lines ranged from bare ground to tall shrubs and saplings that reached close to the canopy height of the surrounding forest. The oldest lines were cut 40 years ago. The bare lines were generally used as winter roads or local all-terrain vehicle (for example, snowmobile) access routes. Four of the more revegetated lines had active human trails that were 2 to 3-m wide down the center of much taller online vegetation. All lines had some gap in the canopy, giving them a functional width of 5 to 12 m at forest canopy height. We classified line segments adjacent to Ovenbird territories based on vegetation height as: bare (no woody regrowth), open (woody shrub regrowth up to 2 m), medium (shrubs and saplings up to 6 m), or closed (tall shrubs, saplings, and trees >6 m in height).

Territory mapping

We color banded (by means of Environment Canada Permit No. 10277 U) and mapped the territories of male Ovenbirds using methods similar to Barg et al. (2004). Birds were tracked between 4:00 AM to 12:00PM when they were actively defending territories. Each individual was tracked two to three times for ~3 h/day from its arrival on territory (last week of May) to the end of June. Individual singing locations of male birds were marked with flagging tape and then mapped using a handheld Trimble Nomad GPS data recorder. At each singing location we recorded the amount of time a male spent there and whether he was countersinging with a neighbor. We took a compass bearing and estimated the distance to each neighbor that the focal bird countersang with. The number of Ovenbird territories directly adjacent to the focal territory was also estimated to get a measure of local density of birds (the number of immediate neighbors for each focal bird). Birds were counted as neighbors if they countersang with the individual we were tracking and if their territory edge was within 100 m (approximate diameter of an Ovenbird territory) of the bird we tracked. Territories were located in patches of deciduous forest (within a matrix of other forest types) that were bisected by one or two seismic lines. Each patch of forest sampled was at least 1 km apart. We mapped 1 to 3 focal territories per patch depending on the size of the patch. We ensured that we distinguished these individuals consistently by using color bands (when visible in dense foliage), noting unique song types, and mapping territories simultaneously with multiple observers. We compared singing locations and countersinging events between tracking sessions to ensure that we had the same bird. We did not map the territories of birds that were directly adjacent to each other across the seismic line because their responses to the line would not be independent. We also eliminated any individuals whose territory boundary was found to be more than 50 m from a line and/or where we detected another bird singing between the focal territory and the seismic line at some point during the breeding season. The singing locations of each male Ovenbird were used to derive 100% minimum convex polygons.

Simulation

We created a simulation model in a GIS to determine the rate at which randomly generated territories would include a seismic line simply by chance. This gave us an estimate of the reference condition (how territories would be arranged in a patch of forest without lines). We created a 4x4-km landscape and filled it with either a low density (~0.1 males/ha) or a high density (~0.5 males/ha) of territories. The high density landscape represented the density we observed in the field in areas where males had four neighbors. Low density was chosen to represent a situation with one-quarter of this density and was typical of what we observed in areas where males had a single neighbor. Territory size was simulated as the mean area of the 100% minimum convex polygons in our study area. Territory centers where based on random points generated using Hawth's Tools Extension in ArcMap 9.3 (esri 2009). We bisected the landscape with five random seismic lines and repeated the randomization 20 times for each density for a total of 100 line and point combinations. We used the same criteria as for the real territories to decide whether to count territories as 0 (excluding the line) or 1 (including the line), and we counted only those territories that were within the same distance from the line (50 m) as the actual territories in our study area. Territories that were within the minimum distance from the line but had part of another territory between them and the line were excluded from analysis. We used the resulting random rate of line inclusion as the predicted probability of inclusion if birds do not adjust territory placement due to lines. Seismic lines should be deemed regenerated when the random and observed rates of line inclusion are no longer statistically different.

Arthropods

We sampled arthropods in 2009 to test if the assumption that insect abundance was correlated with leaf-litter depth held true for our study area and if there were differences in the relationship between lines and the forest. We used transects that started on one side of the seismic line perpendicular to the edge, crossed the line, and continued into the forest for 100 m on the other side. At each transect, three samples were collected across the seismic line (one in the center and one on each side 1 m from the forest edge). Forest samples were collected at the following distances from the edge: 1, 5, 10, 20, 30, 40, 50, 60, 80, and 100 m. At each sampling location we used a 15-cm diameter steel pipe to remove a leaf-litter core down to the mineral soil. We put the leaf litter into a white dishpan and hand-picked the sample for 1.5 min (J. Ball and H. Lankau, *personal communication*; VanWilgenburg et al. 2001). We collected and measured all arthropods (to the nearest millimeter) and classified them by order and/or shape. At each sampling location we measured litter depth to the nearest centimeter and recorded ground cover of the core as leaf-litter, moss, or bare dirt. Transects were located in Ovenbird territories so that we were measuring food resources relevant to our study species. We located transects on 15 lines and 27 territories in order to sample a range of forest and line regeneration conditions.

Defense effort

We evaluated the distribution of singing locations, countersinging locations and time spent singing in each bird's territory to assess whether potential landmarks influenced territory defense effort. We located the center of each 100% minimum convex polygon and, assuming the territory to be a rough circle centered on this point, divided the area into quarters. One quadrant (side) faced the seismic line adjacent to the territory and the opposite quadrant faced the forest interior. The other two quadrants were parallel to the seismic line. For each quadrant we recorded presence/absence of landmarks (seismic lines and distinct breaks in the canopy located between territories and at least 8-m wide), and presence/absence of a neighbor (Fig. 1).

Vegetation

We compared species composition, density, and height of vegetation between seismic lines and territory interiors to determine if the level of vegetation recovery correlated with the probability an Ovenbird lived across a seismic line. We located one sampling location (online) on the seismic line in the middle section of the line adjacent to the Ovenbird territory. Online vegetation was highly variable, especially on older lines. To account for this, three subplots were placed along a distance of 100 m to capture the variation in online vegetation. The three subplots were averaged to get the mean online value for each vegetation variable. Online plots were shaped to fit on the seismic line. We located an offline vegetation plot 30 m into the forest to avoid any vegetation changes related to the seismic line edge (McFarlane 2003). The forest plot was located on the side the Ovenbird used the most. Offline plots covered a maximum area of 0.04 ha, and the combination of the three online plots covered a similar area. We measured the density of trees (woody plants > 8 cm diameter at breast height, DBH) as number of stems/ha and density of shrub stems (defined as woody plants <8 cm DBH and >50 cm tall) as number of stems/m^3. Ground covered by leaf litter, moss, grass, forbs, and bare ground was visually estimated. Litter depth was measured to the nearest centimeter. We used a clinometer or a graduated 8-m pole (depending on tree height) to measure canopy height on the line and beside the line to compare the regeneration of the line relative to the forest. Canopy height in the forest was recorded as the mode height of the trees to avoid outliers that were particularly tall or short. We assessed angular canopy cover using a concave densiometer (Nuttle 1997). Finally, horizontal vegetation density from 0 to 3 m in height was measured using a 0.5-m-wide coverboard: one observer held the board while the second stood 10 m away and estimated the percentage of the board that was obscured by green vegetation in four height increments (0 to 0.5 m; 0.5 to 1.0 m; 1.0 to 2.0 m; and 2.0 to 3.0 m). Further details of our vegetation surveys are available in Bayne et al. (2011).

Statistical analysis

To test our three hypotheses, we created logistic regression models to evaluate whether the probability of an Ovenbird holding a territory across a seismic line (hereafter probability of inclusion) was one of the following:

> (1) A function of food availability as measured by leaf-litter depth and percent cover of bare ground (food hypothesis). Leaf-litter depth was used to represent food availability because arthropod abundance was measured only in 2009 but leaf litter was measured in both 2009 and 2009.

(2) A function of vegetation cover (shrub stem density, online tree density, online canopy height, online canopy cover, and line width (protective cover hypothesis)). We also looked at how birds responded to our initial categorization of lines (bare, open, medium, and closed) as assessed in the field.

(3) A function of the number of neighbors (landmark hypothesis). Neighbors was treated as a continuous variable with four values (1,2,3,4) corresponding to the number of neighbors/bird.

(4) A function of a combination of these models.

Our response variable for all models was line inclusion, and we categorized territories as 1 if a male Ovenbird included the line within his territory and 0 if it did not include the line. The model that had the greatest support was determined using Akaike's Information Criteria for small sample size, AIC_c (Anderson 2008). We discussed only those models that were within 10 AIC_c of the top model (Anderson 2008). AIC_c weights and evidence ratios were also shown. We argue that the food and protective cover hypotheses are not confounded even though both litter depth and protective cover increase with vegetation recovery because the correlation between these variables was $r = 0.43$. Some seismic lines had deeper leaf litter but little-to-no canopy cover while others had tall shrubs and trees and relatively shallow leaf litter.

All other analyses did not use AIC because we did not compare alternate models for food–leaf litter relationships, defense effort, or vegetation differences. We analyzed arthropod abundance using a mixed-effects logistic regression model because of the high number of zeros in the data (cores where no arthropod was detected). The response variable was presence/absence of arthropods and the explanatory variables were litter depth and location (line versus forest). Ovenbird territory was included as a random effect to account for repeated samples taken within each bird's territory. A mixed-effects regression model with a Gaussian error distribution was used to analyze whether defense effort differed between quadrants. The presence/absence of a seismic line or neighbor and their interaction for each quadrant were the categorical predictors. We tested for the interaction because seismic lines should reduce defense cost only if there is a neighbor directly adjacent. We used a one-way ANOVA to test whether individual vegetation variables were different among line categories and territory interiors. A Tukey–HSD post hoc test was used to determine which groups were different from each other. All models were fit in Stata Version 11.1 (StataCorp 2010).

RESULTS

Field data were collected in 2008 and 2009, and the data were analyzed in 2010. We mapped the territories of 52 color-marked male Ovenbirds, 19 in 2008 and 33 in 2009. Eight were located beside bare lines, 12 near open lines, 17 near medium lines, and 15 near closed lines (Table 4.1). Seven birds had 1 neighbor, 14 birds had 2 neighbors, 23 birds had 3 neighbors, and 8 birds had 4 neighbors (Table 4.1). The mean number of singing locations collected for each Ovenbird was 37 (SD = 16.7, *n* = 52, min. = 13, max. = 86). Mean territory size was 1.07 ha (SD = 0.69, *n* = 52). The mean distance between focal individuals within the same forest patch was 83 m (SD = 69 m, *n* = 50). This did not include patches with single individuals. We did not use data from birds with <10 points and/or <30 min of observation of singing behavior. We discarded data from 5 individuals where we could not verify that the points from different tracking sessions belonged to the same bird.

The three top-ranking models (<10 $\mathrm{AIC_c}$ different) all included the number of neighbors. The best model for predicting rate of line inclusion by Ovenbirds included the number of neighbors, percent bare ground cover, leaf-litter depth and canopy cover (Table 4.2). This model was 80% more likely to be the top model than any other model (Akaike weight = 0.80, Table 4.2). An increase in the percent cover of bare ground made line inclusion 0.86 times less likely, while an increase in canopy cover made line inclusion 1.1 times more likely (Table 4.3). An increase in the number of neighbors reduced the probability that the line would be included in the territory 0.13 times for every additional neighbor (Table 4.3).

An increase in line type, as categorized in the field, increased the probability that Ovenbirds would include lines (Fig. 4.2). The greatest difference in line regeneration effects was between bare lines and all other lines. Birds next to bare lines consistently included the line 15 to 28% less than any other category regardless of the number of neighbors (Fig. 4.2). Open and medium lines were almost identical in their effect on line inclusion. Birds living next to closed lines had the highest rates of line inclusion regardless of the number of neighbors (Fig. 4.2).

Simulation

For the simulated high and low density landscapes, 65% of the territories were predicted to include the hypothetical line by chance. In comparison, birds in our dataset with four neighbors near bare, open, and medium lines included them 8, 26, and 23% of the time, which was significantly different than what would have been expected due to chance (Fig. 4.2). Of the birds with four neighbors, 42% included the closed line but 95% confidence intervals included the possibility this result was no different from what the simulation predicted (65%) (Fig. 4.2). When Ovenbird density was low (one neighbor), lines in the open, medium, and closed categories were included more frequently than expected (91, 90, and 96%, respectively).

Arthropods

The probability of detecting arthropods in seismic line leaf-litter samples increased as litter depth increased (*b* = 0.066, SE = 0.016, *p* < 0.001), and the likelihood of detecting an arthropod in a sample increased 1.07 times for every additional centimeter of litter depth. The probability of arthropod detection increased at a greater rate with litter depth on seismic lines (*b* = 0.165, se = 0.41, *p* < 0.001) than in the forest (*b* = 1.231, SE = 0.331, *p* < 0.001) because of a significant interaction (*p* = 0.003) (Fig. 4.3).

Defense effort

There was no marked reduction in the proportion of singing locations, countersinging locations, or time spent relative to seismic lines (Table 4.4). There was also no significant interaction between the location of neighbors and the location of seismic lines. The proportion of countersinging locations was greater on sides that had a neighbor (*b* = 0.16, SE = 0.043; *p* < 0.001).

Vegetation comparisons

Once lines reach the closed category, vegetation characteristics were similar to those in the forest interior except for tree density (237 stems/ha on the lines and 1237 stems/ha in the forest) and canopy height (10 m on lines and 24 m in the forest; Table 4.5). Closed lines differed significantly from territory interiors in tree density and canopy height (Table 4.5).

DISCUSSION

Our top-ranked model provides evidence that all three hypothesized mechanisms—the use of lines as landmarks, the amount of potential protective cover, and correlates of food abundance—affect the probability of an Ovenbird including a line within their territory. The food abundance hypothesis is supported by the greater difference in line inclusion between bare lines and all other line types. Litter depth is lowest and percentage of bare ground greatest for bare lines, which means that these lines likely had less food for Ovenbirds. Food resources and leaf-litter depth were correlated; and thicker leaf-litter cores were more likely to contain arthropods. This agrees with existing literature showing that leaf-litter depth is important in determining food abundance for Ovenbirds (Burke and Nol 1998). The differential change in arthropod abundance with increasing leaf-litter depth on the lines suggests low leaf-litter depth values on seismic lines might result in less food relative to similar litter depths in the forest (Fig. 4.3). This could be caused by microclimate conditions on bare and open lines making leaf litter drier and less productive (Remmert 1981, Ferguson 2004) until taller vegetation establishes better cover. The nonsignificant difference in litter depth between closed, medium, and open lines and the forest suggests that food resources have likely recovered on these seismic lines. Although leaf-litter depth and canopy cover were weakly correlated, the model containing leaf litter, canopy cover, and bare ground ranked higher than models with either variable alone.

The role of canopy cover in predicting line inclusion supports the hypothesis that lines with less vegetation may also be perceived as riskier habitat because they lack protective cover. Canopy cover values increase with both vegetation density and height above 1 m. Ovenbirds commonly forage on the ground below shrubs and trees (Porneluzi et al. 2011), and we regularly saw females foraging on the ground below singing males. Bare and open lines have little protective cover from aerial predators, such as hawks and falcons, which are known to hunt along forest edges (Smallwood and Bird 2002, Preston and Beane 2009). As lines regrew and reached our medium category, protective cover at ground level was restored, which seems to allow birds to move across and along lines while foraging without being exposed to visual predators. We observed birds singing on closed lines but never on bare, open, or medium lines. Closed lines had trees with a mean height of 10 m (which is also the mean height at which we recorded Ovenbirds singing) and canopy cover equal to that of the forest interior, suggesting closed lines meet Ovenbird requirements for protective cover.

The importance of local Ovenbird density (number of neighbors) in determining the probability of inclusion partially supports the landmark hypothesis. If a bird has few neighbors, there is less need for birds to agree on territory boundaries, and individuals may roam more widely simply because they can. Alternatively, if a bird has neighbors on more sides, it will have an increased need to defend its territory on more sides and more incentive to reduce defense costs by any means available. Seismic lines are more likely to be the boundary of one side of the territory for most individuals in areas with a high density of conspecifics. On bare, open, and medium lines, lack of food and cover (i.e., quality of the line area) may also contribute to line exclusion because the amount of energy required to defend the area is not compensated by the resources available. We found no support for landmarks reducing defense effort. The greater proportion of countersinging locations on the side of the territory with a neighbor indicates that individuals do focus more effort on the sides of the territory where there is the most threat. One reason we may not have detected a benefit from the presence of landmarks might be that this benefit is most noticeable during territorial establishment when more aggressive interactions occur (Lamanna and Eason 2003). Additionally, singing rate and time spent are not exclusively used for territorial defense (Lein 1981). However, the fact that Ovenbirds on opposite sides of the line will both live up to the edge of but not include the line—even on closed lines where the quality of the line area is no longer lower than the forest—does support the landmark hypothesis. We have observed a number of instances where males were countersinging and having altercations from perches on opposite sides of a seismic line. We observed the same behavior at territory edges within the forest interior. Our results suggest that seismic lines act as landmarks, thus adding to the existing literature showing differences in topography and vegetation characteristics at bird territory boundaries (Errington 1930, Reid and Weatherhead 1988, St. Louis et al. 2004).

Although use of landmarks may make delineation of territorial boundaries easier, the overall effect on Ovenbird populations may be negative. Machtans (2006) found that total Ovenbird density declined after seismic lines were cut. Geometric relationships demonstrate that bird density at the local scale is reduced with forest dissection because fewer territories fit into patches of forest bisected by seismic lines in a landscape saturated with birds (Bayne et al. 2005*b*). Territorial birds tend to have round- to hexagonal-shaped territories because this shape results in the smallest edge to area ratio and potentially minimizes defense costs (Barlow 1974). The wedge- and triangle-shaped pieces of forest created by overlapping seismic lines mean that a bird needs to live over a line or defend an odd-shaped territory with potentially higher defense costs (Barlow 1974) to exist in areas with high seismic line dissection. Because an increase in the number of neighbors increases the rate of line exclusion, the effect of seismic lines is greatest where Ovenbirds are most abundant.

We suggest that any perceived risk to Ovenbirds of using seismic lines for foraging may disappear once woody vegetation regrows to a threshold value of about 2 m (which can occur in good conditions within <5 years after line clearing), and risk for territorial defense activities can be mitigated once line vegetation reaches an average height of 10 m (which occurs 30 to 40 years after clearing in our study area). Food value is likely restored once leaf-litter depth reaches a mean of 7 to 8 cm. The vegetation characteristics that determine whether lines are suitable as landmarks are most likely tree density and height. These variables are still significantly different between closed lines and territory interiors, suggesting that landmark behavior may persist for a long time. The rate of line inclusion on closed lines is 23% lower than the predicted value; however, our sample size of birds with four neighbors is small (8), and there is uncertainty, due to the wide confidence intervals, about whether the pattern we observed is different than predicted by our simulations. We conclude that 30-to-40-year old lines are close to being functionally regenerated for Ovenbirds.

The amount of habitat directly lost to seismic lines at the landscape level is relatively low (about 1 to 2% in highly developed areas of Alberta, Auman et al. 2007). Thus, the impact of seismic lines alone is not likely to endanger Ovenbird populations in the boreal forest. However, seismic lines do need to be considered in calculations of the cumulative effects of all of the other industrial activities occurring in the boreal forest, including agriculture, forestry, roads, and intensive oil and gas development (Schneider 2002). We currently do not know how Ovenbirds and other boreal songbirds will be affected when they lose habitat and the remaining forest is also degraded by linear features. Therefore, it is important to consider what mitigation techniques might reduce the impact of seismic lines. Regeneration of forest cover on seismic lines can likely be improved by reducing human use (Lee and Boutin 2006) and using line-clearing techniques that provide good tree seedling microhabitat and reduce soil compaction (Greene et al. 1999). Based on our results and the work of Bayne et al. (2005b), the best management practices for the energy sector to use to mitigate their impacts on species like the Ovenbird seem to be a reduction in line width to 3 m and the use of line-clearing practices that increase line canopy cover through rapid regeneration of trees to a minimum of half the height of the surrounding forest.

Table 4. 1. Conspecific density and line category combinations: summary.

Seismic Line Category	Number of Neighbours				
	1	2	3	4	Total
Bare	2	2	2	2	8
Open	0	6	6	1	13
Medium	3	5	7	1	16
Closed	2	1	8	4	15
Total	7	14	23	8	52

Table 4. 2. Ranked logistic regression models predicting probability of line inclusion ranked by AICc score. The full sample size of 52 birds was used in all models. Models are identified by hypothesis: N = neighbors hypothesis; F = food hypothesis; P = predation hypothesis. Both hypotheses and models are presented because there are multiple models for each hypothesis as well as combined models. The evidence ratio (ER) shows the support for the top model relative to all other models, while the Akaike weights (*w*) indicate the probability that a model ranks higher than the lower ranked models.

Hypothesis	Model	Log Likelihood	k	AIC_c	Δ AIC_c	Model Likelihood	*w*	Evidence Ratio
NFP	Neighbours + bare ground + canopy cover + litter depth	-21.98	5	55.26	0.00	1.00	0.80	1.00
NF	Neighbours + bare ground + litter depth	-24.67	4	58.20	2.94	0.23	0.18	4.35
NP	Neighbours + canopy cover	-28.63	3	63.76	8.50	0.01	0.01	70.19
N	neighbours	-31.65	2	67.55	12.29	0.00	0.00	465.81
F	Litter depth + bare ground	-30.71	3	67.91	12.65	0.00	0.00	558.84
FP	Bare ground + litter depth + canopy cover	-29.56	4	67.97	12.71	0.00	0.00	574.77
F	Bare ground	-32.39	2	69.03	13.77	0.00	0.00	977.70
P	Canopy cover	-32.98	2	70.21	14.95	0.00	0.00	1766.32
NP	Neighbours + line category	-29.69	5	70.69	15.43	0.00	0.00	2245.72
	Base	-35.08	1	72.23	16.97	0.00	0.00	4850.83

Table 4. 3. Parameter estimates and odds ratios for variables in the top-ranked logistic regression model (according to AICc score) in Table 2. The probability of line inclusion decreases with increasing amount of bare ground, more neighbors, and reduced canopy cover. Asterisks indicate significant trends ($\alpha = 0.05$). The direction of the response was the same for each explanatory variable in all lower ranked models. Because of the high Akaike weight (0.80), we present only the top model.

Explanatory Variable	Odds Ratio	Coefficient	SE	Lower 95% CI	Upper 95% CI
Neighbours	0.130	-2.039*	0.612	-3.238	-0.84
Bare ground	0.862	-0.149*	0.062	-0.271	-0.028
Litter depth	0.643	-0.441*	0.177	-0.789	-0.093
Canopy cover	0.902	-0.103*	0.042	-0.186	-0.02
Constant		11.581	3.225	5.26	17.902

Table 4. 4. Mean proportion of singing locations, countersinging locations, and time spent, for all quadrants with and without landmarks and with and without neighbors. Italicized numbers represent standard errors on the mean. Asterisks indicate a significant difference in the means ($\alpha = 0.05$).

Response Variable	Landmark	Neighbour			
		No		Yes	
Singing Locations	No	0.237	*0.015*	0.255	*0.018*
	Yes	0.233	*0.044*	0.263	*0.023*
Counter Singing Locations	No	0.145	*0.026*	0.318*	*0.038*
	Yes	0.201	*0.059*	0.299*	*0.051*
Time	No	0.229	*0.018*	0.261	*0.023*
	Yes	0.214	*0.055*	0.256	*0.031*

Table 4. 5. Description (means and standard errors of the means (SE) of selected vegetation variables by line type. Means of vegetation in the neighboring forest and landmark areas are included for reference. Asterisks indicate values that are significantly different from the forest interior (α = 0.05).

Vegetation Variable	Line Category				Forest
	Bare	Open	Medium	Closed	
	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE
Bare ground (%)	24.76* *3.91*	8.20* *2.84*	1.57 *1.13*	1.05 *1.02*	0.00 *0.00*
Leaf litter cover (%)	49.78 *8.03*	53.78 *7.74*	60.78 *7.92*	78.79 *6.98*	77.62 *2.919*
Litter depth (cm)	2.04* *0.25*	6.3 *0.76*	7.21 *0.55*	7.26 *0.40*	8.77 *0.329*
Shrub stem density (m2)	0.19* *0.05*	1.07 *0.21*	1.91 *0.31*	1.35 *0.22*	2.03 *0.175*
Tree density (stem/ha)	0.00* *0.00*	4.36* *3.03*	20.76* *14.38*	237.05* *54.58*	1215 *75.6*
Canopy height (m)	0.00* *0.00*	1.31* *0.12*	3.70* *0.29*	10.34* *0.94*	23.854 *0.738*
Canopy cover *	33.84* *4.52*	26.73* *2.40*	20.02 *2.15*	12.77 *2.44*	10.437 *1.616*
Vegetation density 0-0.5m**	2.89* *0.18*	3.99* *0.19*	4.29 *0.13*	4.19 *0.16*	4.17 *0.12*
Vegetation density 0.5-1.0m**	1.58* *0.18*	3.16* *0.22*	3.40 *0.16*	3.18 *0.19*	3.62 *0.14*
Vegetation density 1.0-2.0m**	0.79* *0.23*	1.57* *0.16*	2.62 *0.25*	2.62 *0.18*	2.84 *0.12*
Vegetation density 2.0-3.0m**	0.85* *0.26*	1.45* *0.15*	2.28 *0.21*	2.58 *0.24*	2.72 *0.12*

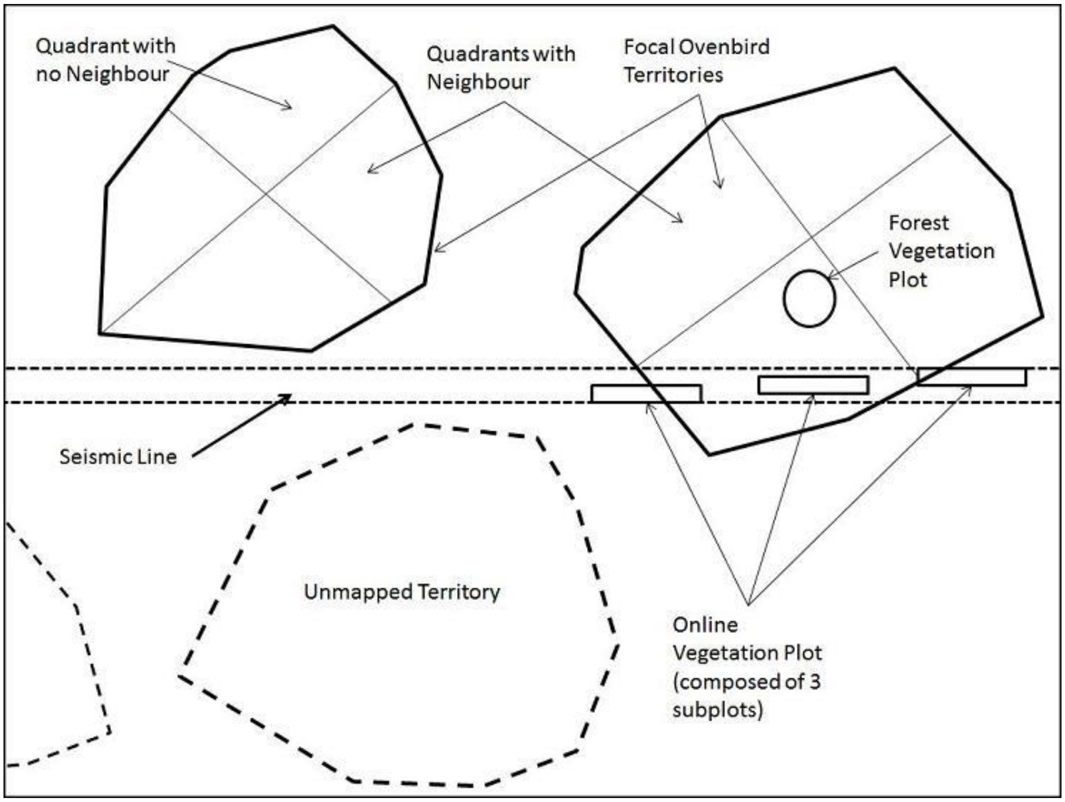

Figure 4. 1. Diagram of territories showing location of vegetation plots, how quadrants are labelled, and a typical territory arrangement. Each quadrant corresponds to one side of the territory. Territories were divided into quadrants using the seismic line as a reference, so that they were all oriented the same relative to the line. Seismic lines ranged from 5 to 10 m in width. Territories were 100 to 150 m in diameter, although shape varied from circular to elliptical.

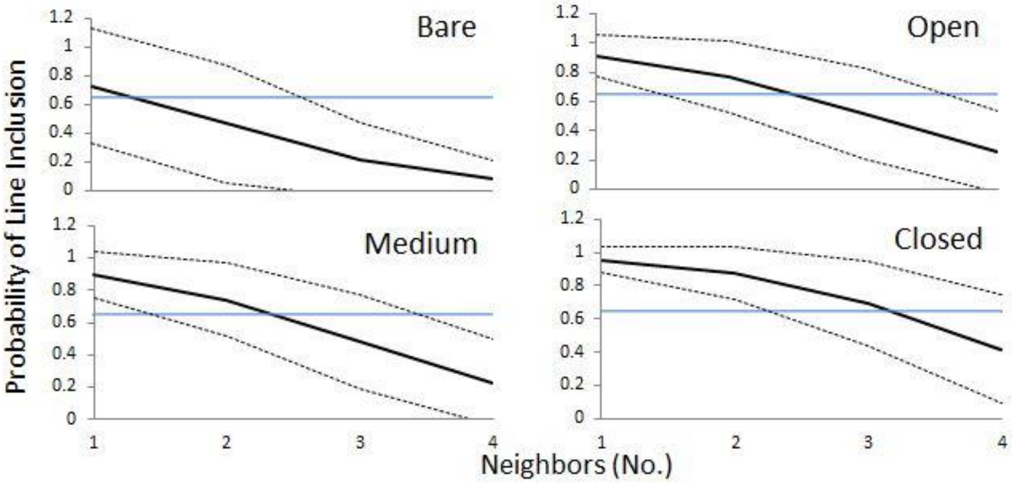

Figure 4. 2. Probability that territories include lines as a function of the number of neighbors and line category. 95% confidence intervals (dotted lines) indicate whether the measured value is different from the expected value (straight line). without regard for seismic line location. Based on 100 runs, the expected rate of line inclusion simply due to chance is 65% (95% CI = +/- 1.2%; SD = +/- 6.1 %).

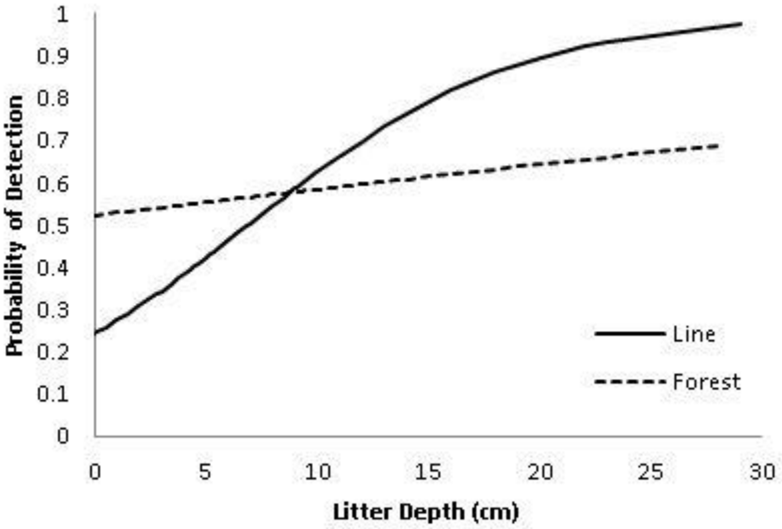

Figure 4. 3.Probability of detecting arthropods in a 15-cm diameter litter core as a function of litter depth on seismic lines and in the forest.

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CHAPTER 5. GENERAL CONCLUSIONS

THESIS SUMMARY

The purpose of this thesis was to investigate how songbirds respond to seismic lines as the vegetation cover on the lines regenerates and how long seismic line effects on vegetation structure and songbirds last. I found that line age is poorly correlated with natural vegetation recovery and that, after an initial increase in recovery index for 20 years, the variability in recovery state of lines did not change. I suggest that this pattern exists because tree density is very low and shrubs are the dominant woody vegetation. Ground vegetation variables such as bare ground and graminoid cover decreased rapidly. The shrub layer also reached densities not much lower than the forest beside the line after 10 to 20 years. However, tree density and vegetation height plateau after 20 years post cut. I suggested that seismic lines do not provide conditions suitable for good tree regeneration and that rapid return of shrub cover may prevent further tree recovery on older lines. I calculated the change in vegetation structure between line and the forest as a relative difference (RD) because I hypothesized that the change in vegetation structure between the seismic lines and the forest at a given point is what songbirds would respond to.

I used the average of all RD values to create a recovery index (RI) to summarize how recovered a line was and included this in models to test whether territorial passerines respond to a seismic line differently based on line recovery values. Few species showed strong negative responses to open seismic lines, and change in relative abundance were generally greater on seismic lines with dense shrubby regrowth. Species richness tended to increase on lines in the early stages of recovery and return toward forest level as seismic lines became more. My results suggest that seismic line impacts on some species are long lasting ranging from 20 to at least 50 year post cut. For birds whose responses track vegetation recovery, it can be expected that both positive and negative responses will continue to exist as long as line vegetation structure is measurably different from the forest surrounding the lines. Forest species that respond negatively, unrecovered lines continue to have an impact and cannot be taken out of calculations of seismic line density for those species.

To understand the mechanisms causing line response, I mapped Ovenbird territories next to seismic lines. I used the Ovenbird as a test species because of their history of negative response to forest edges and their known avoidance of open seismic lines (Bayne et al. 2005, 2005b, Machtans 2006). My results showed that Ovenbirds responded to seismic lines for multiple reasons and that the recovery state of the lines influences the magnitude of the response. Bare lines were excluded because they lacked leaf litter cover to provide habitat for ground dwelling arthropods (Burke and Nol 1998) and protective cover to provide safety for Ovenbirds while foraging or crossing the line at any level (Lima 1985). Lines were also excluded because Ovenbirds use them as landmarks between neighbouring territories. This effect was strongest on open lines and disappeared as tall shrubs and tree regenerated. Ovenbird landmark response was greater in areas with greater conspecific density meaning that seismic lines have the greatest impact in better habitat.

COMMUNITY AND SPECIES SPECIFIC IMPACTS ON BOREAL FOREST SONGBIRDS

Ovenbird territorial behaviour showed that point counts alone do not measure all effects of linear features and that moderate changes in relative abundance as measured by point counts may be indicative of large changes in bird behaviour near lines. Point count surveys will be more likely to pick up larger changes in relative bird abundance that indicate strong selection for or against seismic lines. The moderate negative responses from species such as Dark-eyed Juncos and Hermit Thrushes may mean that other species also use seismic lines as landmarks between neighbors or simply exclude them because they consider them lower quality habitat. On the other hand, the large increase in abundance on shrubby lines seen for American Redstarts indicates strong attraction to seismic lines. American Redstarts were not as common in upland forests as Ovenbirds were and should not be as constrained by conspecific behaviour in terms of where to place their territories. Therefore, the five-fold increase in American Redstarts likely indicates that males were choosing to set up territories with the line itself as a core part of the territory.

The differential response for Ovenbirds based on local conspecific density can possibly provide an explanation of why of avian response to seismic lines may differ between common and uncommon species (Gill et al. 2001). Where Ovenbirds are less dense, they are not influenced by the territorial decisions of other Ovenbirds and do not exclude lines as readily. Similarly, uncommon species like Black-and-white Warblers or Bay-breasted Warblers may not show a significant response to lines or line recovery simply because there is little cost associated with defending less than optimal habitat. This is one possible explanation for the lack of negative effects of open lines on many species. At the same time, the fact that the strongest responses to seismic lines on Ovenbirds are seen in area with high local density in larger habitat patches could also be used to understand potential impacts on more common species. In general I found more negative responses on other more common species such as Dark-eyed Juncos, Hermit Thrushes and Palm Warblers.

The results from Ovenbird territorial placement suggest that where a bird nests and forages may not be a reliable way to predict response to linear disturbances where there is no measurable negative effect within the forest edge. Preferred nesting and foraging structure is frequently used to divide birds into groups and make predictions about their response to disturbances (Machtans 2006, Norton and Hannon 1997). In the case of the Ovenbird, it is the territorial behaviour and the forest strata that Ovenbirds use for territorial demarcation through singing that determines the longest lasting response to seismic lines. This result is not entirely surprising given that bird surveys based on territorial songs of the males most accurately measure territorial behaviour rather than nesting or foraging behaviour. Because of this, auditory surveys on birds near seismic lines will not pick up impacts on foraging or nesting behaviour.

Further research on boreal songbirds and seismic lines should focus on two areas: 1) investigating the mechanism causing the negative responses to seismic lines by Dark-eyed Juncos, Palm Warblers, Yellow-rumped Warblers, Yellow-bellied Flycatchers, Chipping Sparrows and Hermit Thrushes to gain a better understanding of what characteristics of lines they are responding to, and, consequently how these might be mitigated. This could include mapping territorial boundaries to test for landmark behaviour in other species and measuring age distribution of territorial males near and away from seismic lines to test if lines are selected for or against. 2) Assessing seismic line impacts within different forest age classes, especially in upland forests. The upland forests in our study area did not have large stands with even species composition, and all forests had not burned for at least 100 years and, therefore, ranged from mature to old growth forest (Green et al. 1999). Especially the upland forests are naturally more heterogeneous in structure due to the formation of gaps, filled with younger vegetation. The bird community of a heterogeneous forest might be less sensitive to incremental changes in structure such as those caused by low densities of seismic lines. Seismic lines cut through even aged younger stands may have a greater impact on the songbird community. A number of species such as White-throated Sparrows (BNA 2014) are noted as being more abundant in either young or old forests because of the presence of early successional vegetation in both ages groups. The addition of early successional vegetation from seismic lines to even-aged mature but not older growth forest may attract such species to those areas. This has implications for the interaction between forestry and oil and gas development on the landscape.

RECOVERY INDEX

Looking at the mechanisms causing Ovenbird lines avoidance in Chapter 4 as well as the varied responses across the 24 species analyzed in Chapter 3 shows that songbird seismic line responses, both negative and positive, can have multiple causes and that a single mitigation strategy will not address all species or causes of line response. Results from the point counts surveys seem to indicate that shrub layer regeneration is sufficient for most species to deem it recovered. However, the long lasting effects on territorial behaviour on Ovenbirds and the continued negative impacts on some species such as Yellow-rumped Warblers suggest that regeneration of both shrub and canopy vegetation is ideal.

The generalized recovery index includes variables from all vegetation strata from ground level to the canopy. Using the existing information to run a set of species specific models can be used to test how well the recovery index explains bird response to different levels of vegetation recovery on lines. Looking at which specific variables are important to individual species could provide information for improving the recovery index. If some variables are unimportant to all species of songbirds, they could be removed from the index or if a variable is highly important to many species, it could be given a higher weight within the index. This is supported in part by the differential outcomes for Ovenbirds between Chapter 3 and 4. In Chapter 3, I only looked at the presence or absence of a line and the general recovery index that summarized 10 vegetation variables on lines. The top model explaining Ovenbird response to lines in Chapter 4 includes only three vegetation variables: canopy cover, bare ground and leaf litter depth. The RECOVERY model may have ranked lower than line and forest models in explained Ovenbird response simply because it was not specific enough.

Such an approach could also be used to find out if detailed vegetation information or a generalized recovery index is useful for explaining the response of species such as marten, wolves and black bears. Knowing which recovery variables are important for each species can aid in creating more generally applicable recovery criteria (Nitschke 2008). For example, marten only require shrub layer recovery to mitigate seismic lines impacts (Tigner 2012). This is the same level of recovery that seems sufficient for some bird species. On the other hand, black bears show increased use of seismic lines even in higher states of recovery, either because there are travel corridors in the recovered vegetation or better forage (Tigner 2012). Species across many taxa can be grouped into those that require low recovery versus those that require high recovery to assess the overall state of recovery from a biodiversity perspective. Knowing these relationships would aid in calculating the total impact of current seismic lines on the landscape and predicting what the future impact might be for different development scenarios (DLUPC 2006, Kennet 2006).

Additional research on seismic line vegetation should focus on a number of areas. Firstly, what proportion of existing seismic lines are in each recovery category is unknown. The fact that a recovery index based on vegetation structure seems to be an effective way to predict species response to lines is useful because vegetation structure can be mapped via remote sensing techniques such as aerial photographs and LiDAR (Bayne et al. 2011, Lee and Boutin 2006). Integrating remote sensing into seismic lines assessments would make line assessments more economical to do because collecting vegetation data on the ground is time consuming and expensive for the number of lines that can be surveyed. The results from remote sensing could be used to calculate the proportion of lines in low and high recovery states. I caution however, that vegetation height alone, which is most easily measured by LiDAR, is probably insufficient. Based on this, land managers could calculate the actual linear feature density after deciding how many lines (or portions of lines) can be removed from density calculations. This information could also be used to calculate the total impact of seismic lines on boreal songbirds and other species across the boreal forest.

Secondly, how line vegetation will continue to develop over time is also unknown: Will trees never recover or will they eventually fill in the canopy layer on the lines? If continued increases in sapling density on lowland lines occur, then tree density on these lines should increase over time. On the other hand, the consistent low sapling density on upland lines suggests that tree density will be slow to recover. Taking more detailed measurements of the age and height of existing trees will allow calculations to determine how fast a tree or sapling is growing and also when it started growing relative to when the line was cut. This information could help in projecting how long tree regeneration on seismic lines will take.

Thirdly, new lines continue to be cut every year, and will potentially cause impacts on boreal songbirds for at least 50 years. Understanding how to manage newly cut lines so that they recover a minimum amount of woody vegetation (both shrubs and trees) as rapidly and consistently as possible will reduce the length of the impact of future lines. This information can be gained partly by looking closely at the biology of both shrub and tree species across the boreal forest to understand how they normally regenerate in smaller forest disturbances. In addition, extensive research on tree species regeneration and different management is ongoing in the forest industry and can probably be extended to improving woody vegetation recovery on seismic lines.

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