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192

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Canada

December 2011

Correct Citation for this report is:

Bayne, Dr. E., H. Lankau and J. Tigner. 2011
Ecologically-based criteria to assess the impact and recovery of seismic lines: The importance of width, regeneration, and seismic density. Report No. 192. Edmonton, AB. 98 p.

The Environmental Studies Research Funds are financed from special levies on the oil and gas industry and administered by Natural Resources Canada for the Minister of Natural Resources Canada and the Minister of Aboriginal Affairs and Northern Development Canada.

Published under the auspices of the
Environmental Studies Research Funds
NE22-4/192E-PDF

Ecologically-based criteria to assess the impact and recovery of seismic lines: The importance of width, regeneration, and seismic line density

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EXECUTIVE SUMMARY

- Energy sector development in the western boreal forest has generated concerns about the environmental impacts of linear features. These concerns have led to proposals that linear feature density thresholds should be implemented to minimize impacts on wildlife.
- A key uncertainty is which types of linear features should be counted when estimating if a threshold has been surpassed. Major questions are whether narrow seismic lines and seismic lines with vegetation regrowth should be included when estimating thresholds.
- We conducted a series of surveys to evaluate wildlife responses to different types of seismic lines in bogs, conifer-dominated, mixedwood and deciduous forests in the western boreal forest. Research was focused on passerine birds and medium-to-large size mammals.
- The Ovenbird was used as a model species to evaluate how passerine birds react to linear feature width. Ovenbirds include narrow (3m or less) seismic lines within their territories in mature deciduous forest. Conventional 6-to-10m wide lines that have little vegetation growth are not included within Ovenbird territories in the same forest type.
- Over time, canopy closure over conventional seismic lines tends to increase, height of trees on lines increases and the amount of bare ground on the line decreases. With these changes in vegetation structure, Ovenbirds increasingly include seismic lines within their territories. However, the likelihood of an Ovenbird including a seismic line in its territory is also a function of Ovenbird density. In areas with lots of Ovenbirds, conventional seismic lines delimit where birds place their territories regardless of vegetation recovery. Effectively, in high-quality Ovenbird habitat, seismic lines last for 30 to 40 years while in low-quality Ovenbird habitat, seismic lines have a limited effect on territorial behaviour.
- Using 50-m radius point counts, the use of conventional seismic lines by 34 bird species was evaluated. Point counts provide a rough index of bird behaviour around seismic lines. 16 species showed significant differences in the use of seismic line edges relative to forest interiors. 13 species showed positive behavioural responses to seismic line edges.
- Point counts done on seismic lines showed that some bird species were more likely to use open lines and others more likely to use revegetated lines. Eight species were correlated with vegetation conditions describing more open seismic lines, while ten species were more likely to be detected on or near a seismic line when vegetation had recovered. Canopy openness on the line was the best predictor of use, followed by shrub density and

horizontal cover scores. Tree density and height were not good predictors of bird use of areas around regenerating seismic lines.

- We clumped nine unlimited distance point counts together to get a relative index of bird population size as a function of seismic line density at an 80-hectare scale. The American Robin, Yellow Warbler and Warbling Vireo showed small increases in abundance, with increased linear feature density, but the models had low predictive power.

- Using camera trapping, we evaluated seismic line use by mammals. While pictures were taken of 17 species, there was only sufficient data to model marten and black bear.

- Marten show strong behavioural avoidance of seismic lines at a local scale. Marten use low-impact (2m or less) seismic lines with the same frequency as the forest interior. Wider lines were avoided, however. Wide lines that had recovered and had high shrub densities were used as much as, or more than forest interiors.

- Black bears show strong selection of seismic lines. As lines narrow and vegetation increases, use becomes more similar to forest interiors but remained slightly higher than the forest interior. Seismic lines seem to act as movement routes for black bears.

- Clumping six camera stations together at a 5,000-hectare scale, marten were less likely to occur in areas with high seismic line density. For every 1 km per km^2 increase in seismic line density, marten occupancy decreased 0.91 times. Black bears did not respond to seismic line density.

- Vegetation recovery on lines can be predicted by the age of the seismic line but the models are not very accurate. Density and height of trees on seismic lines are the factors that are best predicted by line age. Shrub density, horizontal structure, canopy openness and downed woody material are better predicted by the conditions occurring in the forest adjacent to the line rather than line age *per se*.

- Invasive plant species are present on seismic lines close to roads but decrease away from roads. Virtually no species of non-native plants were located in the forest interior and penetration into the edge seems to be confined mainly to areas at the junction of roads and seismic lines.

- At local scales, the behaviour of many animals is influenced by seismic lines. Whether such behaviours translate into population consequences at larger scales is less clear. Marten are the clear exception, as they show a strong negative effect of linear features at all scales, suggesting their populations may be negatively affected by seismic line development.

- Measuring vegetation data on the ground to evaluate recovery is extremely time-consuming but is needed to determine if thresholds have been surpassed. Alternatively, remote sensing might be a cost-efficient way of measuring seismic line recovery. We tested the use of LiDAR as an alternative to ground-based vegetation surveys. Automation of seismic line recovery rates using LiDAR was not possible with standard tools. We developed a semi-automated approach to describe the state of line recovery using LiDAR. More work is required to set criteria for recovery based on LiDAR, but there is evidence that such a tool would be cost-effective for measuring seismic line recovery in the boreal forest.

- As with almost all human land-use, there are species that are winners and there are species that are losers as seismic development occurs. The issue of seismic line management using thresholds should not be viewed as a question of "is there an effect?" as t here is for many valued ecosystem components. Effort needs to be focused on quantifying the magnitude of these effects and determining how much the "losers can afford to lose" when setting seismic line thresholds.

RÉSUMÉ

- Le développement du secteur énergétique dans la forêt boréale de l'Ouest a donné naissance à des préoccupations au sujet des impacts environnementaux des caractéristiques linéaires. Ces préoccupations ont entraîné à leur tour des propositions selon lesquelles des seuils de densité devraient être respectés pour ces caractéristiques afin de minimiser les impacts sur les animaux sauvages.
- Une des principales incertitudes concerne les types de caractéristiques linéaires qui devraient être comptées lorsqu'on estime si un seuil a été dépassé. On se demande essentiellement si les profils sismiques étroits et ceux démontrant un rétablissement de la végétation devraient être inclus dans l'estimation des seuils.
- Nous avons mené une série d'études dans la forêt boréale de l'Ouest pour évaluer les réactions d'animaux sauvages à différents types de profils sismiques dans des tourbières ainsi que des forêts à prédominance de conifères, des forêts mixtes et des forêts décidues. Notre recherche s'est concentrée sur les passereaux et les mammifères de moyens à gros.
- La paruline couronnée a été utilisée en tant qu'espèce modèle pour évaluer comment les passereaux réagissent à la largeur des caractéristiques linéaires. Cet oiseau inclut dans son territoire des profils sismiques étroits (3 m ou moins) situés dans la forêt décidue mature. Les profils conventionnels de 6 à 10 m ayant une faible croissance de la végétation et situés dans le même type de forêt ne sont pas inclus dans le territoire de la paruline.
- Au fil du temps, la fermeture du couvert a tendance à s'intensifier dans les profils sismiques conventionnels, les arbres sont de plus en plus hauts et le sol est de moins en moins nu. Étant donné ces changements dans la structure de la végétation, la paruline couronnée inclut de plus en plus les profils sismiques dans son territoire. Cependant, la probabilité d'inclusion varie aussi en fonction de la densité de l'espèce. Dans les zones où règne une abondance de parulines, les profils sismiques conventionnels délimitent l'endroit où l'oiseau installe son territoire, sans égard au rétablissement de la végétation. Effectivement, dans un habitat de haute qualité pour la paruline, les profils sismiques durent entre 30 et 40 ans, alors que dans un habitat de mauvaise qualité, ils ont un effet limité sur le comportement territorial.
- À l'aide du dénombrement ponctuel effectué dans un rayon de 50 m, on a évalué l'utilisation de profils sismiques conventionnels par 34 espèces d'oiseaux. Les

dénombrements ponctuels fournissent un indice général du comportement des oiseaux dans les profils sismiques. Seize espèces ont montré des écarts importants dans l'utilisation des extrémités des profils relativement aux forêts intérieures. Treize espèces ont montré des comportements de réaction positifs relativement aux extrémités des profils.

- Les dénombrements ponctuels effectués dans les profils sismiques ont montré que certaines espèces d'oiseaux étaient plus susceptibles d'utiliser les profils ouverts et d'autres, les profils présentant une végétation rétablie. Huit espèces ont été associées avec des conditions de végétation décrivant des profils sismiques plus ouverts, tandis que dix espèces étaient plus susceptibles d'être aperçues dans un profil ou près d'un profil où la végétation s'était rétablie. L'ouverture du couvert dans le profil était le meilleur facteur de prévision de l'utilisation, suivie par la densité des arbustes et le couvert horizontal. La densité et la hauteur des arbres n'étaient pas de bons facteurs de prévision de l'utilisation dans les zones situées aux abords de profils sismiques en rétablissement.

- Nous avons regroupé neuf dénombrements ponctuels effectués sur une distance illimitée pour obtenir un indice relatif de la taille de la population d'oiseaux en fonction de la densité d'un profil sismique de 80 hectares. Le merle d'Amérique, la paruline jaune et le viréo mélodieux ont montré de légères augmentations de l'abondance associées à une densité accrue des caractéristiques linéaires, mais la capacité de prévision de ce modèle était faible.

- À l'aide de la prise de photos par appareils à déclenchement par télécommande, nous avons évalué l'utilisation des profils sismiques par différents mammifères. Bien qu'on ait pris des photos de dix-sept espèces, les données n'ont été suffisantes que pour modéliser le comportement de la martre et de l'ours noir.

- Chez la martre, on a observé un comportement majeur d'évitement des profils sismiques à l'échelle locale. La martre utilise des profils sismiques à faible impact (2 m ou moins) aussi fréquemment que la forêt intérieure. Cependant, elle évite les profils plus larges. Les profils plus larges où la végétation s'était rétablie et qui présentaient des densités d'arbustes plus élevées étaient autant utilisés que les forêts intérieures, sinon plus.

- Chez l'ours noir, on a observé un comportement de sélection fort probant par rapport aux profils sismiques. Plus les profils rétrécissent et plus la végétation s'intensifie, plus l'utilisation se compare aux forêts intérieures, tout en demeurant légèrement plus importante. Les profils sismiques semblent représenter des trajets de déplacement chez cette espèce.

- En regroupant six stations de prise de photos sur un territoire de 5 000 hectares, on a remarqué que la martre était moins susceptible d'être présente dans les zones de profil sismique à forte densité. Pour chaque augmentation de 1 km par km^2 de la densité du profil sismique, l'occupation diminuait selon un facteur de 0,91. Quant à l'ours noir, il n'a pas réagi à la densité du profil sismique.

- Le rétablissement de la végétation dans les profils peut être prédit par l'âge du profil sismique, mais les modèles ne sont pas très exacts. La densité et la hauteur des arbres dans les profils sismiques sont les meilleurs facteurs de prévision de l'âge d'un profil. La densité des arbustes, la structure horizontale, l'ouverture du couvert et la matière ligneuse abattue sont mieux prédites par les conditions qui caractérisent la forêt adjacente au profil que l'âge du profil *en soi*.

- On trouve des espèces de végétaux envahissants dans les profils sismiques situés près des routes, mais leur présence diminue lorsqu'on s'en éloigne. On n'a trouvé pratiquement aucune espèce de végétaux étrangers dans la forêt intérieure et la pénétration par les extrémités semble être confinée principalement aux zones situées à la jonction de routes et de profils sismiques.

- À des échelles locales, le comportement de bon nombre d'animaux est influencé par les profils sismiques. À savoir si ces comportements se traduisent par des conséquences démographiques à des échelles plus vastes, on ne peut le dire. La martre est une exception évidente, puisqu'elle démontre que les caractéristiques linéaires provoquent un effet très négatif à toutes les échelles, suggérant que les populations peuvent subir les effets néfastes du développement des profils sismiques.

- Mesurer les données sur la végétation au sol afin d'en évaluer le rétablissement exige beaucoup de temps, mais c'est une tâche pourtant nécessaire pour déterminer si les seuils ont été dépassés. Aussi, la télédétection peut-elle s'avérer un moyen rentable de mesurer le rétablissement de la végétation dans les profils sismiques. Nous avons évalué l'utilisation de LiDAR comme solution de rechange aux études de la végétation au sol. L'automatisation des taux de rétablissement des profils sismiques établis avec LiDAR n'a pas été possible avec les outils standards. Nous avons élaboré une approche semi-automatisée pour décrire l'état du rétablissement des profils à l'aide de LiDAR. Du travail supplémentaire est cependant requis pour définir les critères du rétablissement en fonction de LiDAR, mais il semble évident que ce genre d'outil serait rentable pour mesurer le rétablissement des profils sismiques dans la forêt boréale.

- Lorsqu'on procède au développement de profils sismiques, il existe des espèces gagnantes et des espèces perdantes – comme c'est le cas avec presque toutes les utilisations des terres par les humains. Ainsi, en gérant les profils sismiques à l'aide des seuils, on ne devrait pas se demander « Existe-t-il un effet?, car il y en a pour de nombreuses et importantes composantes d’écosystèmes. Les efforts doivent plutôt focaliser sur la quantification de l’ampleur de ces effets. Il importe aussi de déterminer « ce que les perdants peuvent se permettre de perdre » au moment d’établir les seuils des profils sismiques.

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1 – THE CHALLENGES OF THRESHOLD-BASED MANAGEMENT

The development of energy reserves in Canada's western boreal forest has resulted in considerable economic investment in the region over the last couple of decades (Tertzakian and Bayton 2011). Despite the obvious economic benefits, there have been calls to slow the rate of oil and gas expansion to protect boreal biodiversity (Schneider 2002). To achieve a balance between energy extraction and biodiversity protection, some authors have suggested the use of threshold-based management (Kennett 2006). Threshold-based management limits the total amount of oil and gas development occurring in a region by spatially distributing it in such a way that impacts are minimized and activity capped until a sufficient level of recovery from past activities has been achieved. The actual levels of activity and the recovery state required before further energy development is allowed remains a key uncertainty (Antoniuk *et al.* 2009).

From an ecological perspective, thresholds occur when there is a switch between ecosystem states such that fundamental changes in ecosystem patterns, processes or functions occur (Turner and Gardner 1991). Previous field studies looking for threshold responses of wildlife to energy sector development have tended to look for any "statistically significant" change in organism behaviour and/or population size relative to undisturbed areas as evidence of a threshold. However, ecologists are increasingly recognizing that "small" changes in animal behaviour and population size can occur with low levels of oil and gas development and remain within acceptable limits for some members of society (Antoniuk *et al.* 2009). As such, recent research has focused on finding the point along human disturbance gradients where changes in animal behaviour or population size become extremely rapid and thus socially unacceptable (With *et al.* 1997; Fahrig 2002). For managers charged with implementing threshold-based management, both perspectives are important as they define the boundaries of risk that influence the decision process used in setting thresholds (Antoniuk *et al.* 2009).

Across the northern boreal, thresholds for the energy sector have focused on limiting densities of linear features (Salmo Consulting *et al.* 2004; DCLUPC 2006). The use of linear features as a threshold metric makes intuitive sense for the oil and gas sector as their footprint is dominated by roads, pipelines and seismic lines (Schneider 2002). Roads have been linked to behavioural changes and population declines in many species (Fahrig and Rytwinski 2009). However, roads impact different species in different ways, and the actual impact of any given road depends on its width, surface type, traffic volume and travel speed (Forman and Alexander 1998). While road thresholds have been set and implemented in several areas of the world (National Road Authority 2008), there is concern that the absolute values of thresholds that have been set are not consistent because of the varying ways roads influence wildlife in different regions (Huggett, 2005; Lindenmayer *et al.* 2005; Groffman *et al.* 2006).

Linear feature thresholds currently recommended for the boreal forest of the Northwest Territories are 0.6 km/km^2 for roads and trails and/or 1.5 or 1.8 km/km^2 of roads and all other linear features > 3m in width (Salmo Consulting *et al.* 2004). These thresholds have been set so that relatively few regions in the NWT greater than 60 km^2 in area will have linear feature densities that surpass these values. These thresholds have the stated goal of ensuring caribou (*Rangifer tarandus*) and grizzly bear (*Ursus arctos horribilis*) populations are maintained. Thresholds of road density stem from studies that show grizzly bears and caribou are more likely to be killed by hunters/poachers near roads or in collisions with vehicles (Seip and Cichowski 1996; Nielsen *et al.* 2004). Woodland caribou also show behavioural evidence of avoiding linear features. Caribou seem to avoid linear features (Dyer *et al.* 2002) because these features are used by predators such as grey wolves (*Canis lupus*) to move through the landscape. Greater movement by wolves through the landscape is believed to result in higher caribou mortality because of increased interactions between wolves and caribou (James and Stuart-Smith 2000; Latham *et al.* 2011). Far less is known about how seismic lines and roads influence interactions between other species in the boreal forest. Understanding how the thresholds set for species like caribou and grizzly bears will or will not protect other valued ecosystem components remains a key uncertainty in threshold-based management. The goal of this report is fill some of these gaps by providing detailed information on how various birds and mammals react to seismic lines of different types at various spatial scales.

1.1. – What are seismic lines?

Seismic lines are the first step in oil & gas development and are used by geophysicists to profile subterranean rock strata in an effort to locate and map energy deposits. Exploration is achieved by the systematic placement of source and receiver points that allow generation and tracking of energy waves created by explosive charges or specialized vehicles (Kearey *et al.* 2002). Systematic placement of exploration points in forested areas is facilitated by seismic lines which are long narrow linear corridors cut into the forest. In any given exploration event, the number of points required to map geological formations results in a variable number of lines being cut. Cumulative activities of multiple companies working an area over time can result in high seismic line densities as multiple passes over the same area can occur. In north-western Alberta (AB) and portions of north-eastern British Columbia (BC), exploration has occurred almost continuously since the 1950s (Nitschke 2008). This has left an irregular lattice of seismic lines of different widths and regeneration across the landscape with some townships (100 km^2 areas) having > 10 km of seismic lines per 1 km^2 of forest (Lee & Boutin 2006).

1.2. - Seismic line width

Changing technologies have altered seismic line practices over the past 50 years. Prior to the mid 1990`s, most seismic lines were created by a single bulldozer pass. Trees were pushed to the side and stacked in long rows along the forest edge. Widths varied, but typically ranged in size from 7 to 10 metres. Over time, technology evolved to allow narrower seismic lines to be cut. With the exception of heli-seismic, where no lines are cut, the narrowest lines currently on the landscape are typically 1-2 metre wide hand-cut lines that only allow ATV or very narrow track vehicle access. More common are 3-6 metre wide lines cut by mulchers or narrower-bladed bulldozers. These lines allow a greater variety of vehicle access. As a best management practice, the reduction of seismic line width has been suggested as a key way for the energy sector to reduce its environmental impact. The assumption is that as lines get narrower, wildlife will no longer perceive them as a gap or barrier. While this may be true for animals that resist crossing linear features or avoid using areas near linear features, there have been few published studies to test the commonality of such behaviours. Also, there is no strong evidence that narrowing lines alters the movement paths of species whose behaviour is facilitated by seismic lines.

1.3. - Vegetation recovery on seismic lines

The energy sector has invested relatively little in actively recovering vegetation on seismic lines that are no longer being used. The rationale for this decision is that these sites will regenerate naturally, as occurs after fire or forest harvesting. Studies evaluating natural recovery of seismic lines have shown mixed results. Revel *et al.* (1984) found that in the foothills of the Rocky Mountains, sapling densities of lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), black spruce (*Picea mariana*) and occasionally balsam fir (*Abies lasiocarpa*) on the majority of seismic lines had tree densities in excess of Alberta's timber regeneration standards. However, the authors found the height of trees was significantly shorter than regenerating trees found in similar-aged cut-blocks. While the density of trees met forestry regeneration standards, achieving these standards took longer to occur than what typically occurs after forest harvesting (10–30 year delay). Conversely, MacFarlane (2003) found no significant differences in the understory vegetation of seismic lines less than 14 years of age relative to seismic lines greater than 23 years in trembling aspen (*Populus tremuloides*) forests of north-eastern Alberta. In both studies, the forbs and herbaceous plant species present on seismic lines of all ages were very different from interior plant communities in part because of the invasion of non-native plants.

Plant regrowth on seismic lines is influenced by many factors, potentially making age a poor predictor of when a line is recovered (see section 6). To set a threshold when a line no longer impedes ecological function requires more information than age of the line alone. Vegetation structure and composition are common metrics proposed to measure recovery. However, recovery of seismic lines based entirely on plant structure and composition requires an appropriate reference state. The most stringent recovery criteria would be when plant structure and composition are the same as the adjacent forest. This is viewed as an unreasonable standard by many as it takes decades to be reached because the time since disturbance is fundamentally different between the adjacent forest and the seismic line. At the other end of the spectrum, some argue that if a seismic line is on a vegetation recovery trajectory somewhat similar to that of early seral forest, then it is recovered (i.e. equivalent land potential). The third approach is to let valued ecosystem components provide the basis for calling things recovered. In such a scenario, recovery might be defined as the point at which no non-native species exist on the seismic line or the point when the seismic line does not alter the behaviour or abundance of boreal animals relative to forest interiors. While no one value is "right" for defining a seismic line as recovered, having information from a variety of valued ecosystem components is crucial for informed threshold setting.

1.4. – How to measure density of seismic lines

Most discussion around seismic line thresholds has focused on limiting seismic line density, with little discussion of which lines should be counted and why. Instead, all lines ever cut are considered when determining whether a threshold has been reached (DCLUPC 2006). Another option for setting linear feature thresholds is to exclude lines with a certain level of revegetation or lines that are sufficiently narrow that wildlife do not react to them. What the threshold vegetation level and/or width of lines should be is not well established for any wildlife species. Answering such questions is critical, because if lines do not recover or cannot be mitigated by industry best practices, then lines remain on the books forever. If true, the ability of the energy sector to operate would be severely restricted in areas using threshold-based management. If not all line widths, configurations or states of vegetative recovery are equal, then estimation of whether a threshold has been reached becomes more flexible and allows for future development once a certain level of recovery has been achieved.

2 – REPORT OBJECTIVES

The objectives of this report are to quantify the response of various bird, mammal, and plant species to seismic lines of different types at different spatial scales. Specifically we provide estimates of the magnitude of effect that seismic lines have on the behaviour and abundance of wildlife relative to forest interiors and how these change as a function of: 1) the width of seismic lines; 2) the level of vegetation recovery on seismic lines; and 3) the density of seismic lines. The primary chapters are split into birds, mammals and plants. Within each taxonomic group, we split our work into the topics of seismic line width, vegetation recovery and seismic line density. Throughout, we emphasize whether our response is based on a behavioural or abundance metric. The implications of a population decline at a stand or landscape scale caused by seismic line development are far more severe than when we see behavioural shifts at local scales. We also evaluate how new remote sensing technologies (LiDAR) could improve our ability to measure the state of the current seismic line footprint, which is crucial in evaluating which seismic lines should be counted when evaluating if thresholds have been reached.

3 - STUDY REGION

This report brings together studies on seismic lines done in whole or in part with the support of the Environmental Studies Research Fund (ESRF) by the Integrated Landscape Management group at the University of Alberta. Most of the field work done during the tenure of the grant was conducted in the Northwest Territories between Fort Simpson, Fort Liard and Kakisa (Figure 1), and in north-eastern British Columbia (Fort Nelson area) and north-western Alberta (Zama City area). Additional projects were done in NE Alberta during the tenure of the award. Data from long-term projects on forest songbirds done in conjunction with Craig Machtans from Environment Canada in the Fort Liard region of the NWT are also reported.

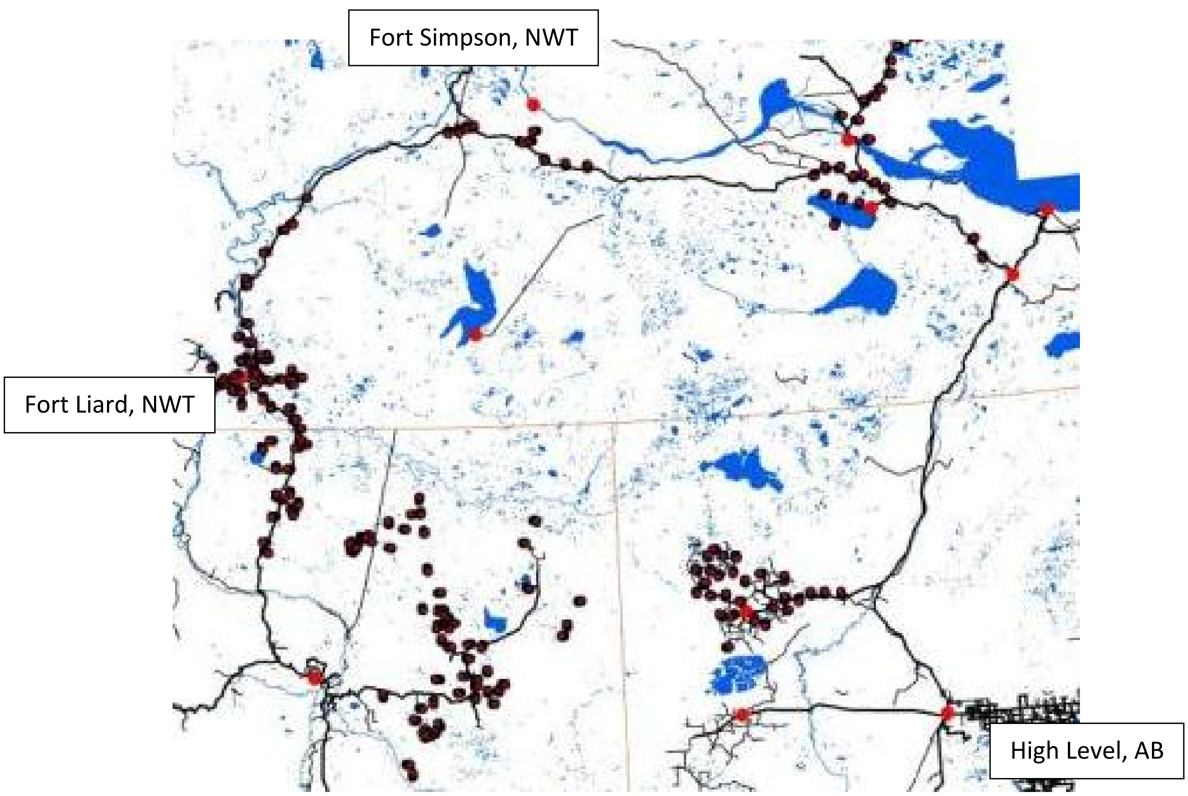


Figure 1 - General locations (burgundy dots) where we surveyed bird and mammal response to seismic lines with support from ESRF funding. Red dots indicate towns in the area.

4 – PASSERINE BIRDS AND SEISMIC LINES

Passerine birds (hereafter songbirds) are useful indicators of ecological health because they are relatively easy to monitor (Bradford *et al.* 1999; O'Connell *et al.* 2000). Research on forestry and agricultural practices has shown that songbirds react quickly to local changes in vegetation composition, structure and landscape patterns caused by human land use, potentially making them good indicators of seismic line impacts.

4.1 Linear feature width

4.1.1 Behaviour of Ovenbirds near seismic lines of different width

The Ovenbird *(Seiurus aurocapilla)* is a neotropical migrant songbird that nests and forages on the ground in mature deciduous and mixedwood forests. The Ovenbird is relatively common in the boreal forest of western Canada within these forest types. Because of its perceived sensitivity to edges in other parts of North America (Bayne *et al.* 2005a), we chose to study this bird in detail. We radio-tracked 24 Ovenbirds near Lac La Biche, Alberta (54°46' N–111°58' W) where two Ovenbirds were tracked in areas with one or two conventional seismic lines (8 metres wide). Seismic lines were ~8-10 years old but only had forbs and grasses because of repeated ATV and truck use (no trees or shrubs > 1 metre in height). There was a distinct gap in the canopy on all lines. Near Engstrom Lake, AB (56°11' N–110°54' W), we repeated this experiment on a seismic grid with 50 metre spacing between lines that were ~3 metres wide. Lines were 3-5 years of age. There was complete canopy closure over these seismic lines as the mulcher that cut the lines did not disturb canopy trees. The forest in each plot was 80-to-110 year old aspen (*Populus tremuloides*) with less than 5% conifer.

Of the 12 birds near open 8m wide seismic lines, 11 held territories that were exclusively on one side of the line (> 95% of the singing locations were on one side of the seismic line). We concluded open conventional seismic lines act as territory boundaries for Ovenbirds. In other words, one bird lives on one side while a conspecific lives on the other side, with the seismic line acting as the territory boundary. This does not mean that Ovenbirds will not cross conventional seismic lines. All individuals crossed seismic lines at some point during the month of June. Thus, it is unlikely that seismic lines negatively impact dispersal and post-breeding movement of adult male Ovenbirds.

We also tracked 12 Ovenbirds near low-impact (3m wide) seismic lines. All of the birds included these lines within their territories and sang on both sides of the line (Figure 2). Ovenbirds do not perceive 3m wide lines as territory boundaries and in mature forest there is little effect of narrow seismic lines on Ovenbird behaviour (Bayne *et al.* 2005 a & b). Whether the same patterns would be seen in younger forests where lines are more obvious and a canopy gap is created remains a key unknown for the Ovenbird and all other passerine species. Given the push in cumulative effects management to harvest trees prior to cutting seismic lines, understanding how seismic lines influence wildlife in regenerating forests should be a high priority for future research.

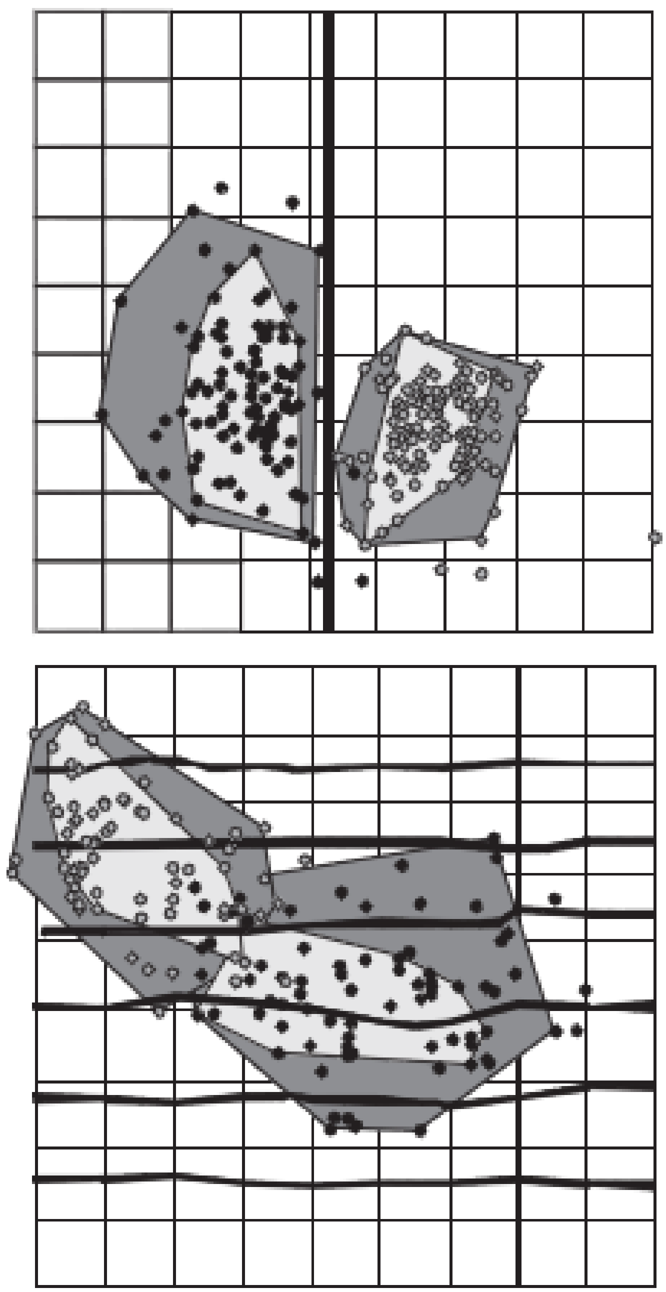


Figure 2 - Example of Ovenbird territories (light grey is a 95% minimum convex polygon based on singing locations) and home range (dark grey is a 95% minimum convex polygon based on all telemetry locations). Results are representative of individuals living near a conventional 8m wide open seismic line (top panel) and individuals in a low-impact 3-D seismic grid with multiple low-impact lines (bottom panel). The point locations used to derive the minimum convex polygons for each individual are also shown. The grid in the background represents a series of 50m x 50m areas mapped out in the forest using flagging tape.

4.1.2 - Songbird behaviour near seismic lines edges relative to forest interiors

While detailed studies such as those on the Ovenbird would be desirable for all species, it is impractical to conduct such work on the 100+ species of songbirds in the boreal. To evaluate which species might show altered patterns of behaviour near conventional seismic lines (4-8 metres), we conducted 4,557 point counts across northern AB, BC, and the NWT. Point counts were 10-minutes in length and recorded birds within 50 metres of the observer. Point counts were either on (n = 1,149) a seismic line or greater than 100 metres away from any linear feature (n = 3,408). Point counts are intended to be a rapid assessment tool for measuring habitat use by birds and as such require a larger effect size to detect statistically significant use or avoidance of seismic lines than more detailed methods like radio-telemetry.

We evaluated whether use of seismic lines and seismic line edges by birds differed from the forest interior using mixed effects logistic regression. Statistically, we controlled for vegetation composition in the adjacent forest, as well as nuisance factors such as time of day and Julian day. The observer was included as a random effect. Vegetation composition of the adjacent forest was extracted from the Earth Observation for Sustainable Development dataset (EOSD; Wulder *et al.*, 2008). EOSD is a raster-based data layer interpreted from Landsat TM 7 EMT+ imagery that provides 23 distinct land cover types at 25m resolution. We reclassified these 23 categories into upland deciduous and lowland coniferous forests, naturally open habitats, anthropogenic disturbances and water.

Forest interior or areas with no human disturbance was our reference category and was set to a value of 1. We report our results as odds-ratios where species with a value greater than 1 for the seismic line treatment are that many more times likely to be detected at or near seismic line edges than the forest interior. A value less than 1 indicates how many times less likely a species was to be found singing near a seismic line relative to the forest interior. Table 1 highlights species with 95% confidence intervals that did not include 1 indicating they were significantly more or less likely to use areas near seismic lines than forest interiors. We found the American Redstart, Black & White Warbler, Dark-eyed Junco, Fox Sparrow, Least Flycatcher, Lincoln’s Sparrow, Pine Siskin, Rose-breasted Grosbeak, Ruby-crowned Kinglet, Swainson’s Thrush, Tennessee Warbler and Yellow-bellied Flycatcher were more likely to use areas near seismic lines. Latin names for these species are shown in Appendix 1. Seismic lines are too narrow to be the only habitat used by birds (i.e. they may use the seismic line but also have to defend territorial space in the surrounding forest). Thus, the open habitat elements, like grass or forbs found on seismic lines and/or the increased shrub growth occurring in the forest edge because of increased light seem to be creating a positive edge effect for several species. Birds presumably are using resources from the seismic line as well, but with these data we cannot determine whether they feed or nest on the seismic line itself.

Fewer species avoided the edges of seismic lines. The Bay-breasted Warbler, Western Tanager and Red-breasted Nuthatch avoided seismic line edges.

Table 1 - Results from point count surveys (50m radius) measuring use of areas on or near seismic lines by boreal forest songbirds relative to forest interiors. Data are expressed as odds-ratios and 95% confidence intervals where the forest interior is the reference state with a value of 1. Odds-ratios > 1 indicate birds were *X* times more likely to be detected near the seismic line edge than the forest interior while odds-ratios < 1 indicate use was X times less likely. Latin names of species are in Appendix 1.

Species	Seismic Line	L95	U95
Alder Flycatcher	0.67	0.29	1.54
American Redstart	2.87	1.82	4.51
American Robin	1.15	0.64	2.07
Black & white Warbler	2.93	2.00	4.29
Bay-breasted Warbler	0.62	0.42	0.92
Boreal Chickadee	1.44	0.95	2.19
Clay-coloured Sparrow	35.63	0.44	2912.91
Cedar Waxwing	1.67	0.31	8.94
Chipping Sparrow	0.98	0.77	1.25
Dark-eyed Junco	2.72	1.86	3.97
Fox Sparrow	4.52	1.41	14.53
Golden-crowned Kinglet	0.24	0.03	2.09
Grey Jay	1.17	0.79	1.72
Hermit Thrush	1.22	0.66	2.27
Least Flycatcher	2.53	1.27	5.05
Lincoln’s Sparrow	3.20	1.45	7.08
Magnolia Warbler	0.95	0.71	1.26
Ovenbird	0.73	0.53	1.02
Palm Warbler	1.83	0.92	3.65
Pine Siskin	2.94	1.58	5.48
Rose-breasted Grosbeak	1.93	1.02	3.64
Red-breasted Nuthatch	0.39	0.19	0.78
Ruby-crowned Kinglet	2.87	1.42	5.79
Red-eyed Vireo	0.96	0.64	1.43
Swainson’s Thrush	1.42	1.13	1.79
Tennessee Warbler	2.97	2.33	3.78
Warbling Vireo	1.79	1.02	3.16
Western Tanager	0.41	0.23	0.72
Winter Wren	0.44	0.16	1.24
White-throated Sparrow	1.26	0.87	1.83
White-winged Crossbill	1.05	0.58	1.90
Yellow-bellied Flycatcher	2.98	1.23	7.26
Yellow-rumped Warbler	1.06	0.84	1.33

4.2. - Vegetation recovery on seismic lines

4.2.1. - Behaviour of Ovenbirds in response to vegetation recovery on seismic lines

In section 4.1.1, we demonstrated that Ovenbirds do not defend territories across open conventional seismic lines (8 metres wide) in high-density Ovenbird populations. In the Northwest Territories, the same behaviour was observed by Machtans (2006). Importantly, Ovenbirds do not show this behaviour when lines were narrower (3 metres wide). However, narrowing line width is not an option in all exploration events. An alternative approach to mitigation is to ensure that regeneration on lines is following a natural trajectory resulting in reduced effects over an acceptable period of time. The objective of this section was to determine the level of vegetation recovery on seismic lines required to mitigate conventional seismic line impacts on the Ovenbird.

This project was done near Fort Liard, NWT (60°14' N - 123°28' W). We selected 25 seismic lines that ran through deciduous (trembling aspen - *Populus tremuloides* or paper birch - *Betula papyrifera*) habitat suitable for Ovenbirds. Lines were selected based on vegetation height and age to get a range of variation in vegetation regrowth on seismic lines. When choosing birds to sample, we classified each bird as being nearest to bare, open, moderately-closed and closed seismic lines (see Table 2 for vegetation conditions on seismic lines in each category and Figures 4 & 5 for visual examples). We tracked approximately equal number of birds in each category with a total of 53 birds tracked. Lines ranged from having virtually no vegetation to shrubs and saplings that reached the bottom of the canopy of adjacent forest. The oldest seismic lines were 40 years old.

The singing locations of each male Ovenbird were used to derive 100% and 95% Minimum Convex Polygons (MCPs). The 95% MCP was more conservative in estimating the area of the each territory because it excludes points that are potential outliers; however, it is biased towards categorizing territories as not including the seismic line. The 100% MCP is the most rigorous assessment of line response for Ovenbirds because it includes all possible points where the bird defended. For analysis, we categorized territories as a 1 if they included the line and 0 if they did not include the line and analyzed the results using logistic regression.

We found the probability that Ovenbirds lived across seismic lines was a function of vegetation recovery but the effects were strongly influenced by the number of neighbouring Ovenbirds (Table 3 & Figure 3). Bare seismic lines were rarely included in an Ovenbird's territory as past studies have also shown. Lines with revegetation were included but only when the focal bird had few neighbours. As the number of neighbours increased, focal birds were less likely to live across seismic lines even with significant vegetation recovery. Based on these results and other studies, seismic lines immediately after clearing are avoided by Ovenbirds. However, for Ovenbirds in forests where there are relatively few conspecifics, seismic lines only require minor vegetation regrowth to be included within a focal bird's territory. In high-quality habitat with lots of neighbouring Ovenbirds, individuals use seismic lines as territory boundaries and this behaviour does not completely disappear even 40 years after line clearing.

Table 2 - Description (means and 95% CI) of selected vegetation variables by line category. Means of vegetation conditions in the surrounding forest are included for reference.

Vegetation Variable	Line Category				
	Bare	**Open**	**Medium**	**Closed**	**Forest**
% Bare ground	22.7 (14.2-30.8)	9.1 (3.6-14.6)	1.6 (0-3.8)	1.0 (0-3.0)	0.00 0.00
% Leaf litter	50.18 (34.4-66.0)	53.08 38.2-68.0	60.32 (44.6-76.0)	78.60 (64.8-92.4)	75.19 (69.7-80.7)
Litter depth (cm)	2.04 (1.94-2.14)	6.03 (4.42-7.63)	7.21 (6.13-8.28)	7.26 (6.48-8.04)	8.87 (6.95-10.79)
Shrub density (m^2)	0.19 (0.09-0.28)	1.07 (0.65-1.48)	1.91 (1.30-2.52)	1.35 (0.92-1.78)	1.07 (0.83-1.31)
Tree density (per ha)	0	4.36 (0-10.3)	20.76 (0-48.9)	237.05 (130.1-344.1)	1,237.71 (1,097.5-1,377.9)
Tree height (m)	0	1.31 (1.1-1.5)	3.70 (3.1-4.3)	10.34 (8.5-12.2)	23.94 (22.6-25.3)
Canopy openness *	33.8 (25.0-42.7)	26.7 (22.0-31.4)	20.0 (15.8-24.2)	12.8 (8.0-17.6)	9.9 (7.4-12.4)

* higher values indicate a more open canopy

Table 3 - Results from territory mapping of Ovenbirds using areas near seismic lines with different levels of regeneration. Data are expressed as odds-ratios that compare how many times more likely Ovenbirds were to include the seismic line in their territory using the bare lines that had been recently cleared as the reference state. Odds-ratios > 1 indicate birds were *X* times more likely to be detected including the seismic line. Also shown is how many times less likely Ovenbirds were to include a seismic line in their territory caused by having an additional territorial neighbour. The P-value tests for any significant difference between line regeneration categories and number of neighbours as a continuous variable.

Territorial Overlap	Bare	Open	Medium	Closed	P-Value	Neighbours	P-Value
100% MCP	1.00	2.49	2.5	5.9	0.07	0.40	0.011
		(0.4-16.4)	(0.4-17.7)	(0.9-40.3)		(0.21-0.81)	
95% MCP	1.00	13.5	10.3	32.0	0.03	0.41	0.015
		(1.4-130.5)	(1.1-100.8)	(3.3-313.5)		(0.20-0.84)	

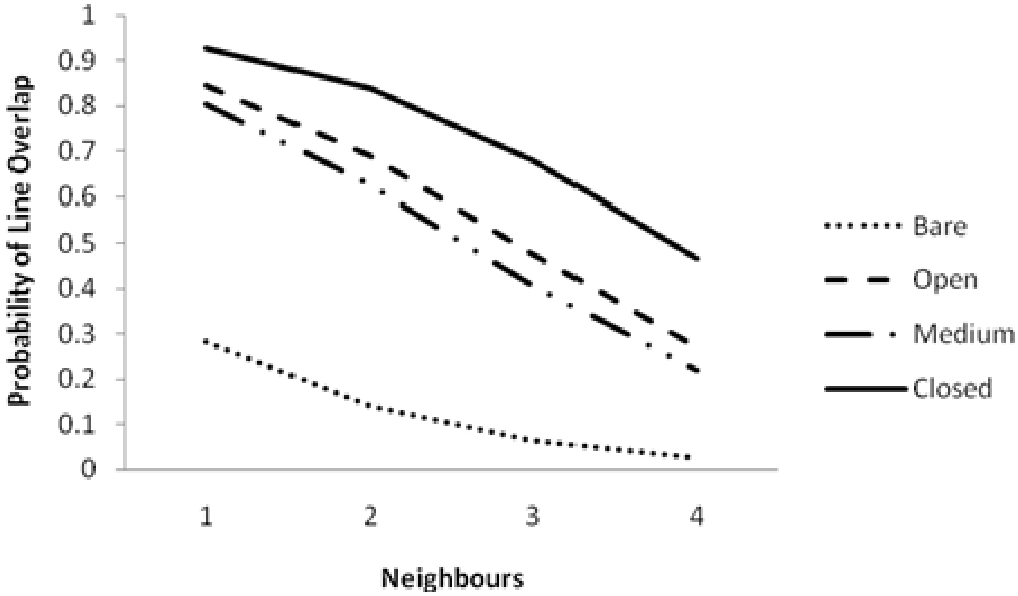


Figure 3 - Probability an Ovenbird's territory overlaps a seismic line as a function of the level of vegetation recovery and the number of neighbours. Results are based on 95% minimum convex polygon.

Figure 4 - Example of bare (top) and open seismic lines in upland (aspen dominated) forest near Fort Liard, NWT.

Figure 5 - Example of moderately closed (top) and closed seismic (bottom) lines in upland (aspen dominated) forest near Fort Liard, NWT.

4.2.2. - Behaviour of songbirds near seismic lines with different levels of regeneration

To address how vegetation recovery influenced species other than the Ovenbird, we used the bird point counts done on seismic lines in the NWT (as described in section 4.1.2). Using the vegetation data described in section 6, we evaluated which vegetation variables predicted use of different seismic lines by each bird species. The variables in all models were: 1) Julian day; 2) hour of day; 3) observer as a random effect; and 4) a description of the forest composition and structure beside seismic lines. The variables that were used to describe offline vegetation were 1) tree density; 2) percentage of trees that were conifer; 3) volume of downed woody material (hereafter DWM); 4) horizontal cover at 0.5, 1, 2 and 3 metres in height; 5) shrub density; 6) percentage of shrubs that were coniferous; 7) canopy openness; and 8) canopy height. Controlling for the variables described above, we then analyzed which of the following online variables were significant predictors of bird use of seismic lines: 1) average height of trees on seismic lines; 2) canopy openness; 3) percentage of shrubs that were coniferous; 4) shrub density; 5) horizontal cover at 0.5, 1, 2 and 3 metres in height; 5) DWM; and 6) tree density.

In Table 4, we show the P-values and odds-ratios describing the relationship between bird use of seismic lines and each online vegetation variable controlling for the other variables in the model. We did not use variable reduction in this modelling approach as we were interested in determining the effect size of each vegetation covariate for each bird species. Species in bolded italics show increasing use of lines with greater vegetation recovery. Species underlined were more likely to be found on open lines with less vegetation recovery. Species that showed increase use of lines with greater vegetation cover include Alder Flycatcher, American Redstart, Bay-breasted Warbler, Fox Sparrow, Magnolia Warbler, Ovenbird, Red-breasted Nuthatch, Red-eyed Vireo and White-throated Sparrow. Species more likely to be found on lines with less vegetation cover included Chipping Sparrow, Dark-eyed Junco, Grey Jay, Hermit Thrush, Lincoln's Sparrow, Palm Warbler, Ruby-crowned Kinglet and Yellow-bellied Flycatcher. In Table 4, we show results that are significant at $P = 0.05$. However, in running models for this number of species using the same dataset, there is a possibility that we have spuriously concluded there is a statistically significant difference between the abundance of one or more species abundance and a particular environmental covariate simply because of chance (Type 1 error). Based on the fact that 34 species were analyzed using this approach, a more conservative approach is to use a Bonferroni correction coefficient for determining statistical significance. In this particular application, a $P < 0.001$ was used as the decision criterion for evaluating statistical significance.

The variable that was most likely to be a significant predictor of whether a species did or did not use the seismic line area was canopy openness, with 12 species showing a significant relationship with that variable. Canopy openness on seismic lines is a function of two factors. First, on lines where significant tree and/or tall shrub regrowth has occurred, vegetation cover overhead is recorded as contributing to canopy closure. Thus, stands with significant tree regrowth and tall shrubs may have low canopy openness. Canopy openness can also decrease when the crowns of mature trees grow into the gap created by the seismic line. Which element of canopy openness birds are reacting to is not clear but we expect crown closure is quite important because the species that reacted negatively to canopy openness did not generally react to shrub density or the horizontal cover factor. In general, vegetation conditions offline explained a far larger part of the variance in bird use of areas near seismic lines than conditions on the line *per se*.

Table 4 - Odds-ratio showing relationship between various descriptors of vegetation on seismic lines. Values greater than 1 indicate the species was more likely to be detected on seismic lines where vegetation recovery was more advanced. Species with values less than 1 are attracted to seismic lines with less vegetation recovery. Shaded species showed significant relationships. Species in bolded italics are more likely to use areas with greater recovery while those underlined are more likely to use areas with less vegetation on the lines.

Species	% Conifer Shrubs	P	Canopy Openness	P	DWM Volume	P	Horizontal Cover Factor	P	Tree Height	P	Shrub Density	P	Tree Density	P
ALFL	0.30	0.13	2.01	0.182	1.23	0.284	1.38	0.327	0.98	0.954	1.60	0.032	0.83	0.774
AMRE	0.64	0.097	0.43	0.001	0.92	0.536	1.88	0.001	1.33	0.018	1.24	0.092	1.03	0.807
AMRO	0.14	0.146	1.63	0.319	0.76	0.477	0.63	0.13	0.61	0.2	1.02	0.952	.	.
BAWW	0.32	0.026	1.10	0.711	0.83	0.356	1.10	0.56	0.89	0.449	1.10	0.536	0.87	0.538
BBWA	0.52	0.183	1.10	0.717	1.13	0.196	1.03	0.842	1.33	0.061	1.35	0.044	0.96	0.846
BOCH	1.27	0.143	1.17	0.7	1.08	0.724	1.06	0.824	1.06	0.811	1.14	0.553	0.21	0.367
CCSP	.	.	0.10	0.186	.	.	2.22	0.558	2.51	0.2	.	.	.	.
CEDW	.	.	1.00	0.496	.	.	0.21	0.358	1.43	0.866	0.03	0.325	.	.
CHSP	1.06	0.584	1.59	0.034	1.11	0.372	0.82	0.133	0.74	0.046	1.00	0.974	0.68	0.255
DEJU	1.33	0.006	1.89	0.016	0.92	0.741	0.64	0.008	0.79	0.184	0.93	0.581	0.54	0.277
FOSP	0.34	0.248	0.23	0.001	0.62	0.582	1.88	0.067	1.76	0.057	2.00	0.01	.	.
GCKI	1.49	0.228	0.79	0.785	1.12	0.59	0.78	0.647	1.91	0.1	1.10	0.826	1.43	0.092
GRAJ	1.19	0.22	1.16	0.675	0.90	0.775	0.60	0.022	0.95	0.835	0.76	0.192	0.94	0.851
HETH	1.30	0.074	3.35	0.025	0.12	0.165	0.99	0.982	1.16	0.607	0.87	0.573	0.18	0.488
LEFL	0.14	0.017	0.70	0.209	0.37	0.024	1.05	0.801	1.17	0.34	1.08	0.645	0.93	0.655
LISP	0.93	0.706	12.87	0.003	0.81	0.825	0.78	0.401	0.65	0.276	0.87	0.547	.	.
MAWA	0.66	0.012	0.73	0.052	1.10	0.267	1.44	0.001	1.11	0.262	1.29	0.011	0.93	0.552
OVEN	1.24	0.218	0.24	0.001	0.74	0.073	0.85	0.254	1.06	0.655	0.55	0.001	1.19	0.059
PAWA	0.92	0.54	6.80	0.001	0.41	0.303	0.79	0.217	1.15	0.48	1.27	0.091	0.60	0.521
PISI	0.03	0.085	2.05	0.139	1.48	0.058	1.21	0.515	1.09	0.761	1.64	0.07	.	.
RBGR	0.54	0.413	1.34	0.488	0.65	0.31	0.78	0.356	0.88	0.62	0.91	0.745	0.16	0.288
RBNU	0.72	0.78	0.67	0.667	1.31	0.052	2.58	0.198	1.07	0.891	2.04	0.046	.	.
RCKI	0.77	0.343	1.57	0.273	0.16	0.141	0.48	0.003	0.54	0.061	0.64	0.066	0.29	0.432
RESQ	1.22	0.244	0.78	0.381	1.16	0.139	1.05	0.817	1.15	0.362	1.02	0.906	0.96	0.716
REVI	0.41	0.097	0.57	0.048	0.77	0.202	0.97	0.848	1.70	0.001	0.90	0.545	1.31	0.009
SWTH	0.69	0.019	0.94	0.703	0.95	0.583	1.10	0.33	1.13	0.187	1.08	0.443	0.88	0.291
TEWA	0.99	0.865	1.18	0.234	0.98	0.805	1.15	0.129	0.97	0.701	1.06	0.496	0.97	0.723
WAVI	.	.	0.33	0.005	0.59	0.221	1.41	0.16	1.39	0.103	1.07	0.761	1.24	0.079
WETA	0.72	0.593	1.47	0.371	1.22	0.118	1.68	0.118	0.84	0.561	1.53	0.07	0.61	0.495
WIWR	0.97	0.958	1.02	0.981	1.05	0.892	1.74	0.457	1.19	0.742	0.97	0.953	.	.
WTSP	0.61	0.068	0.81	0.368	1.11	0.354	1.59	0.004	1.05	0.738	1.40	0.009	.	.
WWCR	0.77	0.531	0.83	0.718	1.06	0.73	1.19	0.62	1.11	0.732	0.97	0.924	1.20	0.239
YBFL	1.01	0.95	2.51	0.011	0.03	0.006	0.93	0.754	1.18	0.412	1.24	0.227	0.88	0.725
YRWA	1.10	0.336	1.03	0.867	1.15	0.125	0.85	0.171	0.90	0.358	0.81	0.078	0.93	0.579

Figure 6 - Example of bare (top) and open seismic lines in lowland (black spruce dominated) forest near Fort Liard, NWT.

Figure 7 - Example of moderate (top) and closed seismic lines in lowland (black spruce dominated) forest near Fort Liard, NWT.

4.3. - Seismic line density and relative abundance of birds

The analyses described above focused on examining bird behaviour at a local spatial scale. To evaluate whether we could detect changes in "populations" with increasing linear feature density at a larger scale, we evaluated the total number of birds in a systematic grid of nine point count stations. Stations were separated by 300 to 450 metres and were randomly placed with respect to linear features. Two projects were used for this analysis. Bayne *et al.* (2005a) collected data at 72 landscapes where the proportion of the landscape disturbed by seismic lines ranged from 0 to 6.4%. An even number of landscapes were selected in each 1% disturbance increment creating a completely balanced sample size. We found no significant changes in total bird abundance for any species using this dataset. A sample size of 72 is small, so we also added data from other clusters of data collected during the ESRF work as well as using data from the Alberta Biodiversity Monitoring Institute's Database (ABMI) to create a dataset that while unbalanced with respect to the number of replicates in areas with low versus high seismic line density, provided greater statistical power. The total number of landscapes surveyed was 262. There were no roads in any of these landscapes. Some of the linear features included in our calculations of the percentage of the area covered by linear features were pipelines. Forest harvesting occurred in some landscapes and we controlled for this by controlling for the amount of early seral-shrub habitat in the landscape. A buffer of 500 metres was drawn around the central point count station to calculate the percentage of the landscape disturbed by linear features (pipelines and seismic lines) and the percentage of bog, deciduous, mixedwood, coniferous, shrubs and water habitats as estimated from the EOSD data set described in section 4.1.2. We used percentage of the landscape covered by linear features rather than linear feature density because this was the value available from the ABMI to conduct these analyses.

Using negative binomial regression, we modelled whether there was a significant effect of proportion of landscape covered by linear features controlling for Julian day, spatial location, dominant forest type as a category (bog, deciduous, mixedwood or coniferous), and percentage of landscape in early seral habitat (% shrubs & % clearcuts). To evaluate whether there were thresholds (i.e. situations where change in bird abundance was constant along a certain range of seismic line densities and then sharply changed after a certain point), we used breakpoint modelling (Toms and Lesperance 2003). Breakpoints at each of the 1% seismic line categories were considered up to a maximum of 10%. We then compared the fit of these models to linear changes in species as a function of seismic line density. Comparing the breakpoint models to the linear change models, we found no evidence that threshold models provided a better fit to the data than simple linear relationships for any species.

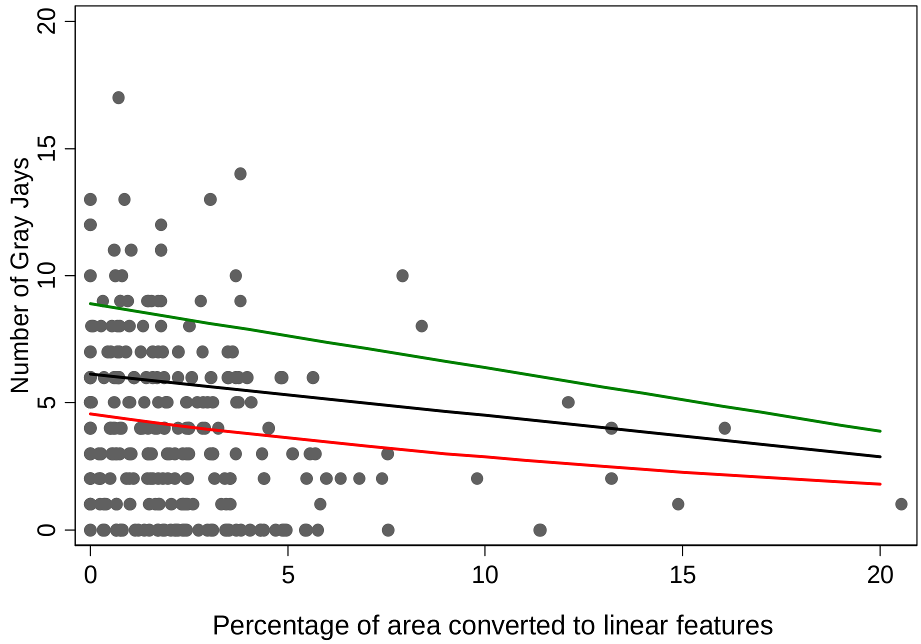
Table 5 shows the results for linear models. We found strong evidence that the mean number of American Robins increased with greater linear feature density. Warbling Vireo and Yellow Warbler both showed increased mean counts with greater linear feature density although the variance explained by these models was low. The only species to show a significant negative response to linear features at this spatial scale was the Grey Jay which was surprising given their positive behavioural response to pipelines (Ball *et al.* 2009a).

As models were created for 60 species, the same issue with Bonferroni corrections applies as discussed in section 4.2. The corrected rejection criteria in this case would be P = 0.0008.

Table 5 - Incident rate ratios showing relative change in mean with a 1% increase in the area of the landscape covered by linear features like seismic lines and pipelines. Those species highlighted show significant changes. No change with seismic line density would be a value of 1 so that species > 1 increase with linear features at this scale and < 1 decrease.

Species	IRR-Mean	P-Value
ALFL	1.07	0.126
AMGO	1.03	0.687
AMRE	1.04	0.435
AMRO	1.08	0.013
BAWW	0.96	0.321
BBWA	1.07	0.456
BCCH	0.96	0.4
BHCO	1.04	0.505
BHVI	0.96	0.405
BLJA	0.91	0.281
BOCH	1.00	0.951
BRCR	0.98	0.877
BTNW	1.04	0.607
CAWA	0.94	0.462
CCSP	1.04	0.544
CEDW	1.02	0.745
CHSP	1.02	0.309
CMWA	0.95	0.54
CONW	0.97	0.609
CORA	1.02	0.674
COYE	1.06	0.244
CSWA	0.83	0.588
DEJU	0.98	0.517
EVGR	0.95	0.679
FOSP	0.15	0.336
GCKI	0.99	0.784
GRAJ	0.96	0.03
HETH	0.97	0.412
LCSP	0.98	0.81
LEFL	1.00	0.967
LISP	1.05	0.11
MAWA	1.06	0.15
MOWA	0.97	0.568
NOWA	1.07	0.435

OCWA	1.00	0.948
OSFL	0.96	0.663
OVEN	0.97	0.317
PHVI	1.11	0.237
PISI	1.02	0.668
RBGR	0.97	0.385
RBNU	0.98	0.568
RCKI	1.01	0.718
RESQ	0.99	0.549
REVI	0.98	0.6
RWBL	1.13	0.074
SWSP	1.13	0.087
SWTH	1.00	0.861
TEWA	1.02	0.465
WAVI	1.10	0.007
WBNU	0.99	0.982
WETA	0.96	0.281
WEWP	1.08	0.313
WIWR	1.00	0.918
WTSP	1.02	0.53
WWCR	0.99	0.746
YBFL	1.00	0.986
YRWA	1.00	0.926
YWAR	1.17	0.036



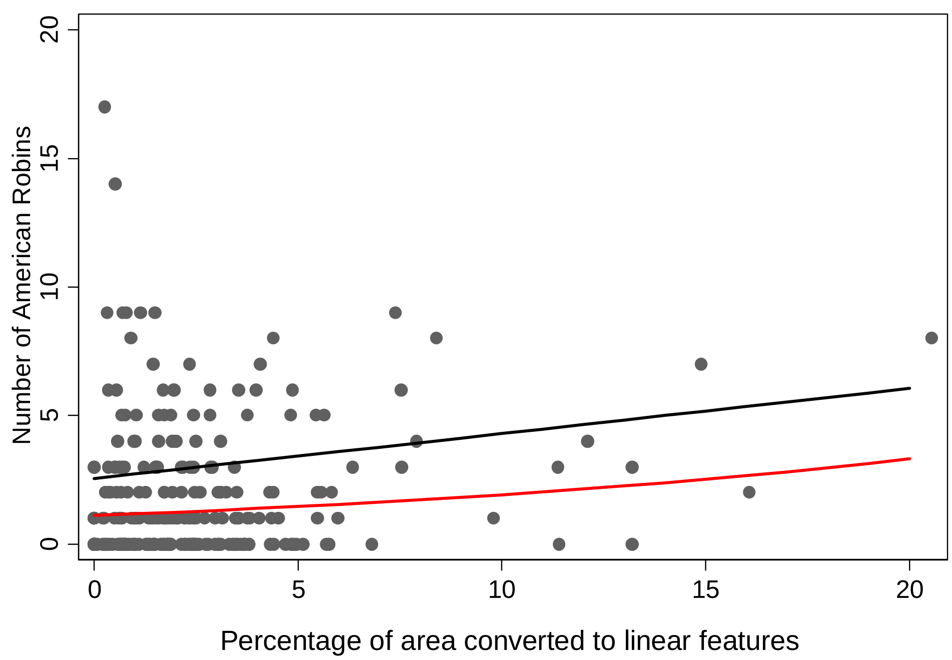


Figure 8 - Changes in mean count of Grey Jay and American Robin as a function of the area converted to linear features in an 80 hectare area. Red line shows change in mean. Black line shows change in 75% percentile while green line shows change in 90% percentile.**.4 - Summary of passerine research**

Songbirds reacted strongly to seismic lines at local scales. The behavioural response of songbirds varied widely among species with some avoiding open lines, others being attracted to open lines, and still others being attracted to regrowing lines. Our results are consistent with studies on edge responses by songbirds to other types of linear features in North America (Table 6). Species attracted to seismic lines generally are those typically found in early seral habitats created after fire or forest harvesting. As with virtually all human land-uses, seismic lines creates new habitat for some species and reduces it for others. Setting thresholds based on any one species becomes problematic as a result. Decisions made for one species will have negative effects on others. Ultimately, species predicted to show the greatest potential declines should be selected as candidates for setting seismic line thresholds to minimize negative impacts. This was our rationale for studying the Ovenbird in detail. In an effort to keep this report succinct, we did not provide the vegetation models for each bird species. However, recovery curves that determine when the level of vegetation recovery on a seismic line results in similar use by birds of forest interiors are available upon request.

We found strong evidence that the Ovenbird uses seismic lines as a territory boundary. However, Ovenbirds will cross seismic lines and in some cases will include them in their territories. This indicates that seismic lines do recover from the perspective of the Ovenbird. However, absolute threshold values of vegetation recovery cannot be estimated because of the added complexity of knowing whether or not there are multiple Ovenbirds in an area. Seismic lines provide a very clear territorial boundary for birds in high-density populations and this behaviour persists, albeit at a reduced rate, 30-40 years after seismic lines are cleared. Bare lines that are recently cleared have a negative effect on Ovenbirds. Increasing leaf litter on seismic lines and achieving greater canopy closure over seismic lines seem to be the strongest predictors of whether Ovenbirds use areas near seismic lines. Planting shrubs and/or trees on recently cleared seismic lines will influence bird communities and will increase diversity of birds locally. However, decreasing the width of seismic lines seems to be the easiest thing to do to mitigate negative effects on birds. It is clear that a threshold of seismic line width of about 3 to 4 metres does not disturb the canopy in mature forest and is the best way of minimizing effects of seismic exploration on the Ovenbird and presumably other species.

Bayne *et al.* (2005a) demonstrated that species using seismic lines as territory boundaries have to incur a decline in population size at some seismic line density. Thus, the lack of population change in section 4.4 could be caused by issues with statistical power. However, we sampled 262 landscapes along an extensive range of linear feature densities and have previously demonstrated that this sample size should be able to detect a 20 to 25% decline in population size (Bayne *et al.* 2005a) if it occurs. The largest population reduction caused by seismic lines was observed by Machtans (2006), who found a significant 25% reduction in Ovenbird abundance the year immediately after seismic lines were cleared. Bayne *et al.* (2005a) found a non-significant 13% decrease in one study area and a 5% non-significant increase 5-8 years after clearing. We suspect that immediately after clearing, bare lines result in avoidance of seismic lines by Ovenbirds for a short period of time. As lines get some vegetation regrowing, Ovenbirds seem to place their territories directly up to the edge of seismic lines which mitigates population level declines to somewhere < 10%, an effect size that is difficult to detect.

While we did not study them in detail, the Western Tanager, Bay-breasted Warbler and Red-breasted Nuthatch showed evidence of reduced use of seismic line edges. All of these species are found in older mixedwood and white spruce dominated forests. It would be interesting to study their territorial behaviour in relation to seismic lines to see if they behave in a similar way as the Ovenbird, particularly whether they incorporate low-impact seismic lines. Importantly, none of these species showed a negative effect on the total number of individuals detected in landscapes with higher seismic line densities.

For species behaviourally attracted to seismic lines, it should be easier to detect increased population sizes if those species specialize exclusively on seismic lines as habitat. The vegetation variables that best predicted increased use of seismic lines was canopy openness, followed by horizontal cover attributes and shrub density. Species like the Dark-eyed Junco, Chipping Sparrow and Lincoln’s Sparrow seem to prefer more open lines where the canopy was open and grass dominates the lines. Both the Dark-eyed Junco and Lincoln’s Sparrow nest on the ground and other studies have found them nesting on pipelines (Ball *et al.* 2009b). However, the species showing increased use of seismic lines along a vegetation recovery pathway are not solely reliant on these areas as habitat. The vegetation attributes preferred by these species exist throughout the boreal as natural edges and openings. Given the relatively small area converted to “new habitat” by seismic lines, the changes observed seem to be sufficiently small that no detectable change in population size occurs for species attracted to seismic lines.

Table 6 - Response of North American passerines to forest edge created by roads, powerlines, pipelines, seismic lines or trails in studies as well as the results of this research. Values are number of studies finding neutral (Edge=Interior), positive (Edge>Interior) or negative (Interior>Edge) response. Adapted from Bayne and Dale (2010). References associated with this table are marked with a star in the literature cited.

Species	E=I	E>I	I>E
Inconsistent edge response			
American Crow	8	1	1
American Redstart	6	3	3
Black & White Warbler	8	1	3
Black-capped Chickadee	3	1	4
Blue Jay	11	1	1
Blue-headed Vireo	3	1	1
Grey Jay	0	1	1
Hooded Warbler	3	1	3
Mourning Warbler	0	1	1
Scarlet Tanager	7	1	2
Swainson's Thrush	4	1	1
More likely to have positive edge response			
American Robin	10	3	0
Chestnut-sided Warbler	1	3	0
Chipping Sparrow	3	2	0
Common Yellowthroat	11	2	0
Dark-eyed Junco	0	2	0
Eastern Towhee	8	3	0
Least Flycatcher	4	2	0
Lincoln's Sparrow	0	2	0
Magnolia Warbler	3	3	0
Northern Cardinal	0	2	0
Red-eyed Vireo	5	5	0
White-throated Sparrow	5	3	0
Alder Flycatcher	1	1	0
American Goldfinch	3	1	0
Blue Grosbeak	0	1	0
Blue-grey Gnatcatcher	1	1	0
Brown Thrasher	6	1	0
Brown-headed Cowbird	8	1	0
Carolina Wren	1	1	0
Cedar Waxwing	3	1	0
Eastern Meadowlark	0	1	0
Field Sparrow	0	1	0
Indigo Bunting	2	1	0
Pine Warbler	5	1	0
Prairie Warbler	7	1	0
Purple Finch	1	1	0
Song Sparrow	2	1	0
Summer Tanager	5	1	0
Tennessee Warbler	1	1	0
Western Tanager	1	1	0
White-breasted Nuthatch	10	1	0
Yellow Warbler	4	1	0
Yellow-breasted Chat	0	1	0
Yellow-throated Vireo	0	1	0

Species	E=I	E>I	I>E
More likely to have negative edge response			
Black-th. Green Warbler	1	0	4
Ovenbird	7	0	9
Prothontary Warbler	2	0	3
Red-breasted Nuthatch	1	0	2
Wood Thrush	8	0	3
Winter Wren	3	0	2
Worm-eating Warbler	2	0	3
Yel-throated Warbler	2	0	3
Bay-breasted Warbler	2	0	1
Blackburnian Warbler	3	0	1
Black-th. Blue Warbler	4	0	1
Connecticut Warbler	0	0	1
Golden-crowned Kinglet	2	0	1
Hermit Thrush	3	0	1
Le Conte's Sparrow	0	0	1
Townsend's Warbler	0	0	1
Yel-bellied Flycatcher	0	0	1

No reported edge effect	
Black-billed Cuckoo	Ruby-crowned Kinglet
Blackpoll Warbler	Rusty Blackbird
Blue-winged Warbler	Sedge Wren
Boreal Chickadee	Swamp Sparrow
Brown Creeper	Tree Swallow
Canada Warbler	Tufted Titmouse
Carolina Chickadee	Veery
Common Grackle	Warbling Vireo
Eastern Kingbird	White-eyed Vireo
Eastern Phoebe	Willow Flycatcher
Eastern Wood-Pewee	Yellow-billed Cuckoo
Fish Crow	Yellow-rum. Warbler
Fox Sparrow	
Grey Catbird	
Great-cr. Flycatcher	
Kentucky Warbler	
Marsh Wren	
Nashville Warbler	
Northern Oriole	
Northern Parula	
Northern Waterthrush	
Palm Warbler	
Pine Grosbeak	
Pine Siskin	
Red-winged Blackbird	
Rose-br. Grosbeak	

5 - MAMMAL RESPONSE TO SEISMIC LINES

The benefit of birds as ecological indicators is that they react very strongly to changes in vegetation structure and composition at local scales and do so quickly. However, bird populations did not seem to react to larger-scale changes caused by seismic lines. Animals with small home ranges may be better able to adapt to larger-scale changes in human footprint because of their ability to find suitable habitat away from human disturbance. Medium-to-large-sized mammals that move over larger areas may show different patterns.

5.1. - Sampling methods

We used remote camera trapping to see how various mammals react to seismic lines at varying spatial scales. To select where cameras were located in the landscapes, we used a Geographic Information System (ArcGIS 9.3) to determine the dominant forest type, cumulative seismic density and cumulative energy sector footprint in a roving window analysis. Sites were selected from the roving window in a hierarchical way. First, sampling locations were selected at the landscape level to be either upland or lowland forest and existed across a continuum of cumulative seismic line density. At this landscape scale, clusters of 6 remote cameras were deployed around a common centre point that varied in seismic line density. At the local scale, cameras were then set on and off seismic lines in pairs to measure species' use of particular types of seismic lines. In the pairs, one camera was located at the forest-seismic line edge and the other 450m away in the forest interior. Line cameras were pointed onto or along the seismic line. All interior cameras were located a minimum of 200 metres from the nearest seismic line. Online cameras were placed in one of seven seismic line categories: 1) bare/open conventional (≥ 6m wide); 2) moderately closed conventional; 3) closed conventional line; 4) open narrow (≤ 2m); 5) open mid-width (3-4m); 6) open wide (> 5m) or 7) forest interior. Clusters were placed away from any logging activity, open wetlands or sparsely forested areas. Examples of line types can be seen in Figures 4-7.

Cameras were baited with a small amount of canned dog food and sardines packed in water at set up, programmed to collect data 24 hrs/day and left to sample for a minimum of 10 trap nights (set day 1, retrieved roughly the same time day 11).

5.2 - Mammal behaviour near seismic lines of different widths & regeneration

Controlling for whether cameras were in upland versus lowland forest, spatial location (north) in the study area and spatial autocorrelation between cameras in a cluster, we found significant differences in the use of different line types by marten and black bear. An additional 15 species were detected. However, the number of detections was insufficient to build robust statistical models for these species.

Marten avoided open seismic lines greater than 3 metres in width. In contrast, lines ≤ 2m were used as much as the forest interior locations. Marten also responded to vegetation recovery on conventional seismic lines; vegetation recovery increased marten use of conventional seismic lines. Moderately vegetated lines were not significantly different than either open or closed lines with the odds-ratio intermediate in value. Completely vegetated lines were used as much as forest interiors.

Black bears showed the opposite pattern. Bears used open lines greater than 3 meters in width more than forest interiors, and their use of those features increased with increasing line width. Use of open conventional seismic lines was dramatically higher than forest interiors. As conventional lines regenerated, bear use declined so that on completely vegetated lines, bear use was not significantly different than forest interiors. Like marten, lines less than 2 metres in width were not used significantly more or less than forest interiors by bears. Odds-ratios showing differences in use between treatments are shown in Table 7.

Table 7– Odds-ratios and 95% confidence intervals showing differences in use for marten and black bear at varying widths of seismic lines and levels of regeneration relative to forest interiors.

Location	Marten	Black Bear
Forest Interior	1.00	1.00
Open conventional (>= 6 metres)	0.25 (0.09-0.69)	5.40 (2.92-10.00)
Partially vegetated conventional	0.65 (0.33-1.27)	3.51 (2.01-6.15)
Completely vegetated conventional	1.56 (0.77-3.18)	1.78 (0.88-3.59)
2 metres or less - Open	1.03 (0.36-2.93)	1.81 (0.74-4.49)
3 to 4 metres mulched - Open	0.17 (0.03-0.86)	3.02 (1.27-7.15)
5 to 6 metres bladed – Open	0.09 (0.01-0.75)	4.83 (2.08-11.23)
P-Value	0.004	< 0.001

5.3 - Mammal response to vegetation conditions on conventional seismic lines

To evaluate which vegetation attributes on regenerating seismic lines influenced whether marten or bear used those lines, we used the same vegetation attributes collected at the bird points. Analytical methods are identical to those used for birds. Despite reduced use of closed lines by bear, no single vegetation variable we measured at the camera location predicted whether a picture of a bear was taken (Table 8). In contrast, marten showed a very clear response to shrub density and horizontal cover. Of these variables, shrub density explained the most variance. Increasing shrub density resulted in increased used of seismic lines by marten (Tables 8, 9 and 10 and Figure 9). The horizontal cover factor has a correlation of 0.4 with shrub density. However, when including both terms in the model, horizontal cover factor was no longer significant. Figure 9 shows the relationship between marten use of seismic lines and shrub density. The black lines on the graph show the probability of occurrence of marten in the matched forest interior sites. If the goal of a vegetation recovery threshold was to have marten occurrence on seismic lines be equivalent to marten occurrence in the forest interior, then shrub density of between 4.5 and 6 stems per square metre are required to call a line “recovered” from the perspective of having marten “use” the line equivalently to the forest interior. The range shown reflects different model assumptions about what the probability of detection is in the forest interior.

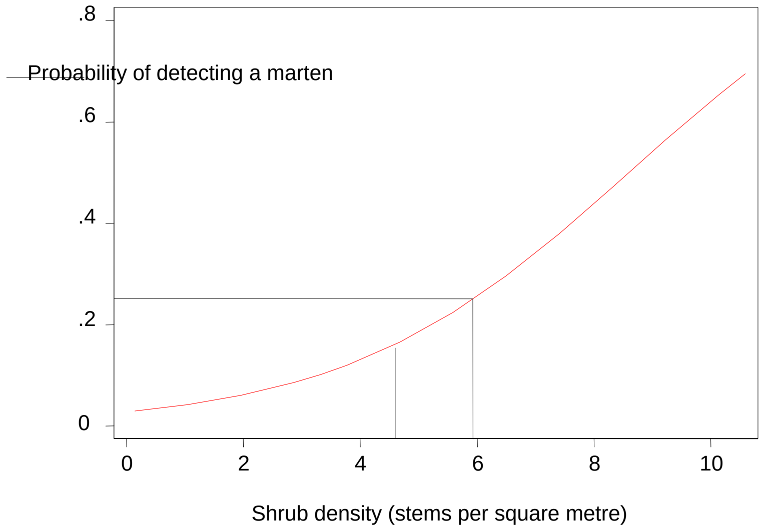


Figure 9 - Relationship between probability of photographing a marten and shrub density. Black lines indicate the point where the probability of detecting a marten on a seismic line with that level of shrub density is equal to the forest interior. Different lines reflect different model assumptions when predicting value for forest interior.

Table 8– Odds-ratios showing change in probability of photographing black bear or marten on seismic lines as a function of vegetation conditions. An odds-ratio of 1 indicates the variable has no influence. An odds-ratio > 1 indicates increased use of lines with those conditions and an odds-ratio < 1 indicates avoidance of those conditions. P-values showing statistical significance are also shown.

Variable	OR	P
Black Bear		
Canopy Openness	0.64	0.230
DWM Volume	1.19	0.489
Canopy Height	0.91	0.737
% Conifer Shrubs	0.67	0.176
Shrub Density	1.27	0.338
Tree Density	0.97	0.926
Horizontal Cover	1.11	0.676
Marten		
Canopy Openness	0.85	0.557
DWM Volume	1.36	0.110
Canopy Height	1.35	0.148
% Conifer Shrubs	1.14	0.518
Shrub Density	2.14	0.001
Tree Density	0.87	0.582
Horizontal Cover	1.87	0.008

5.4 - Home range occupancy of marten as a function of seismic line density

To evaluate whether the occupancy of marten and bear at a home range level was influenced by seismic line density, we used the presence or absence in each cluster of 6 cameras as our unit of measurement. Here we calculated the seismic line density in a 3.8 km buffer around the cluster centroid (mid-point between all 6 cameras). The detection of a bear or marten at any camera in the six was our measure of whether this landscape was occupied. We then modelled whether seismic line density, forest type and Julian date influenced occurrence of these species. All seismic lines of all types were included in this model. Bears showed no response to any of our human disturbance metrics at this scale.

Controlling for Julian day sampled and forest composition in the home range, we tested for whether marten occurrence was predicted by: seismic line density, pipeline density, road density, total human footprint (w/o seismic) and total human footprint (w/ seismic). All of these variables were significant predictors of marten occurrence, with a sharp decline in marten occurrence as disturbance from oil and gas activities increased. However, the two predictors that best predicted marten occurrence were seismic line density and total human footprint including seismic line density (Table 9). For every 1 km per km^2 change in seismic line density, the odds of detecting a marten at the home range scale changed by 0.91 (95% CI: 0.85-0.97). This pattern was consistent if we controlled for distance to road or distance to nearest town neither of which were statistically significant (Figure 10).

The only variable that changed the relationship between marten occurrence and seismic lines or total human disturbance was latitude. Marten occurrence increased (OR 1.002: 0.997-1.009) for every kilometre north you moved in the study area. The odds-ratio for seismic line density controlling for north was 0.95 (0.85-1.04) but was no longer significant when we controlled for north ($P = 0.27$). Importantly, north was not significant either ($P = 0.33$). The reason for this is north and seismic line density were strongly negatively correlated ($r = -0.76$) creating strong co-linearity in the model. This result was not unexpected, as sampling had to occur along a north–south gradient to obtain a continuum of seismic line density in our sample.

In the study area there are few areas of high-density seismic lines the further north you go and there are far fewer low-density seismic areas to the south.

Three lines of evidence suggest that seismic line density is related to the causal mechanism responsible for this pattern rather than unexplained environmental factors correlated with spatial location. First, forest productivity is higher in the southern portion of our study area than the north. If climate conditions and resulting vegetation were driving these results, we expected that controlling for vegetation type should adjust for such variation. Second, marten diet is fairly liberal but is often dominated by small mammals (Thompson and Colgan 1994). There is no compelling evidence that suggests small mammals or any other prey source would be more abundant in the northern portion of our study area. In fact, it seems more likely that forests further south are more productive and would support more prey. Finally, the model containing seismic line density explained more variance (pseudo r^2 = 0.0657) than the model including north (pseudo r^2 = 0.0597).

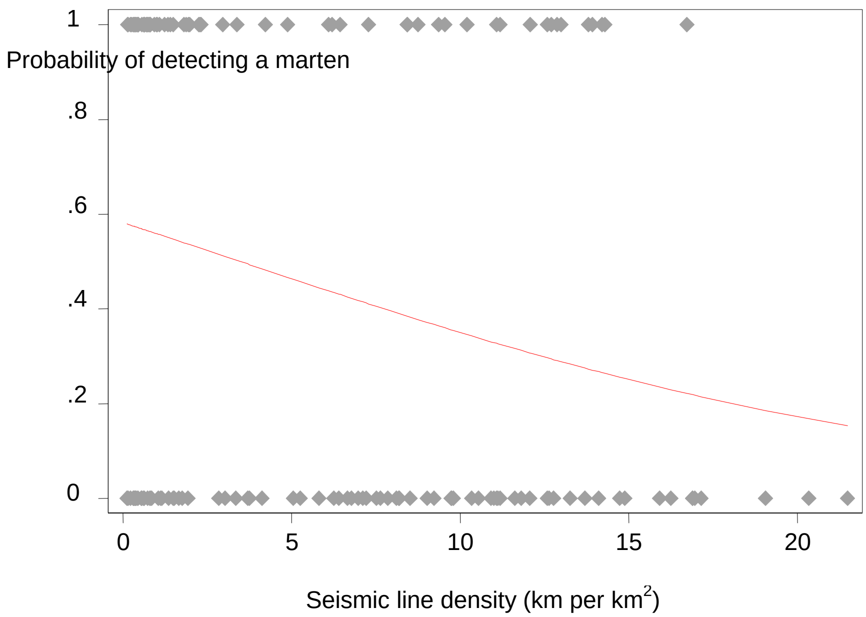


Figure 10 - Change in probability of detecting a marten as a function of seismic line density within 3.8 kilometre radius of the central camera point. Dots represent each home range and whether marten was or was not detected (1 indicates marten was detected).

Table 9 – Odds ratio showing relationship between various measures of energy sector disturbance and marten occupancy at a home range scale. An odds-ratio < 1 indicates a decline in occurrence in marten per 1 unit increase in each metric.

	OR	P-Value	L95	U95	Pseudo r2
Pipeline Density	0.51	0.018	0.30	0.89	0.0466
Road Density	0.21	0.026	0.05	0.83	0.0413
Well Density	0.36	0.01	0.16	0.78	0.0557
Seismic Density	0.91	0.004	0.85	0.97	0.0657
Footprint withoutseismic	0.72	0.009	0.57	0.57	0.0542
Footprint With seismic	0.87	0.002	0.80	0.95	0.0677

Table 10 – Summary vegetation statistics for conventional seismic lines where bears, marten and Ovenbird were present versus absent. Also shown are average vegetation conditions of seismic lines in the major habitat types.

Treatment/ Habitat Type	Statistic	Forest height (m)	Line Vegetation Height (m)	Shrub Stem Density (stems per m2)	% Deciduous Shrubs	% Conifer Shrubs	Canopy Openness	Line Width (m)	Tree Density (stems/ha)	% DECD Trees	% CONF Trees	Tree DBH (cm0	DWM Volume (m2)	Leaf Litter Depth	Bare Ground (% Cover)	Horizontal Cover 0.5m	Horizontal Cover 1.0m	Horizontal Cover 2.0m	Horizontal Cover 3.0m
Ovenbirds Present	Mean	24.5	4.7	2.3	97.7	2.3	18.6	8.5	88.9	45.2	0.0	10.4	0.3	6.0	2.3	3.9	3.0	2.2	2.0
	SD	5.1	4.1	1.2	7.6	7.6	9.7	1.7	176.7	50.6	0.0	1.5	0.5	2.5	6.9	0.8	1.0	1.1	1.0
	Min	13.7	0.0	0.2	58.3	0.0	3.0	5.0	0.0	0.0	0.0	8.5	0.0	0.5	0.0	2.0	0.5	0.0	0.0
	Max	34.1	15.6	5.3	100.0	41.7	34.5	12.0	811.2	100.0	0.0	13.5	2.8	11.4	33.9	5.0	4.5	4.5	4.2
	Count	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	14.0	31.0	30.0	31.0	31.0	31.0	31.0	31.0
Ovenbirds Absent	Mean	23.9	4.1	2.1	98.6	1.4	25.7	8.0	54.4	98.6	1.5	10.4	0.4	6.6	8.5	4.2	3.0	2.0	1.9
	SD	5.6	4.9	1.3	3.2	3.2	16.3	1.5	113.1	45.9	7.1	1.0	0.5	3.6	14.6	0.7	0.9	0.9	0.9
	Min	13.8	0.0	0.4	88.1	0.0	2.0	5.0	0.0	0.0	0.0	9.2	0.0	0.5	0.0	2.7	1.2	0.3	0.3
	Max	30.9	19.3	5.8	100.0	12.0	68.0	10.5	442.5	100.0	33.3	11.5	1.9	13.7	41.0	5.0	4.5	4.0	4.3
	Count	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	7.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Marten Present	Mean	20.8	4.0	4.3	82.0	18.0	43.4	8.6	53.7	36.7	18.8	10.1	0.5	7.6	3.0	4.4	3.7	2.8	2.3
	SD	8.5	2.2	2.2	24.2	24.2	27.0	2.0	98.4	47.1	37.0	1.1	0.8	4.8	8.7	0.7	1.0	1.3	1.3
	Min	7.0	0.8	1.5	6.8	0.0	4.8	4.0	0.0	0.0	0.0	8.3	0.0	1.7	0.0	2.0	1.0	0.0	0.0
	Max	36.6	9.3	10.9	100.0	93.2	92.7	12.5	406.9	100.0	100.0	11.6	4.1	18.8	41.7	5.0	5.0	5.0	4.7
Marten Absent	Mean	16.9	3.2	3.1	74.7	25.3	46.7	8.8	55.7	18.0	9.7	9.8	0.2	5.7	3.6	4.2	3.2	2.0	1.8
	SD	8.8	2.5	1.7	28.7	28.7	28.3	3.0	235.6	37.2	27.8	1.1	0.6	4.1	9.6	0.9	1.3	1.4	1.4
	Min	0.0	0.2	0.1	0.0	0.0	0.4	4.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	1.2	0.0	0.0	0.0
	Max	34.8	14.0	7.8	100.0	100.0	95.9	30.0	1828.9	100.0	100.0	12.8	3.9	19.7	68.3	5.0	5.0	4.7	4.5
Bears Present	Mean	18.5	3.3	3.4	77.0	23.0	42.4	9.2	90.7	26.2	5.8	9.5	0.3	6.0	2.9	4.2	3.4	2.3	2.0
	SD	7.7	2.5	2.0	30.1	30.1	23.7	4.0	363.8	43.7	21.4	0.9	0.7	3.6	6.9	1.0	1.3	1.4	1.4
	Min	0.0	0.3	0.3	0.0	0.0	0.4	5.0	0.0	0.0	0.0	8.3	0.0	1.0	0.0	1.2	0.0	0.0	0.0
	Max	34.8	14.0	10.9	100.0	100.0	94.8	30.0	1828.9	100.0	100.0	10.6	3.9	16.2	41.7	5.0	5.0	5.0	4.7
Bears Absent	Mean	17.2	3.4	3.3	75.8	24.2	47.7	8.5	40.0	20.3	14.2	10.0	0.3	6.2	3.7	4.2	3.2	2.2	1.9
	SD	9.3	2.5	1.8	27.1	27.1	29.7	2.0	93.2	38.5	32.9	1.2	0.6	4.6	10.4	0.8	1.2	1.4	1.4
	Min	0.0	0.2	0.1	0.0	0.0	1.2	4.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	1.2	0.3	0.0	0.0
	Max	36.6	11.7	8.2	100.0	100.0	95.9	14.0	409.7	100.0	100.0	12.8	4.1	19.7	68.3	5.0	5.0	5.0	4.5
Bog	Mean	8.1	2.1	4.3	65.0	34.6	76.4	8.6	6.1	2.3	8.5	9.7	0.0	8.1	3.5	4.0	2.6	1.3	1.0
	SD	4.4	1.9	2.6	27.2	26.9	18.5	2.1	27.9	14.0	27.4	1.3	0.1	5.3	8.0	0.9	1.3	1.1	1.0
	Min	0.0	0.0	0.0	0.0	0.0	2.8	5.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	Max	24.9	12.3	13.1	100.0	100.0	96.0	13.0	314.7	100.0	100.0	12.8	0.5	24.3	50.0	5.0	5.0	4.7	4.3
Conifer	Mean	17.8	3.3	3.6	70.0	28.8	50.6	9.2	79.2	20.8	14.5	9.7	0.2	6.6	3.3	4.1	3.1	2.1	1.9
	SD	7.3	2.7	2.5	33.3	32.6	26.2	1.8	183.0	37.5	31.4	0.9	0.5	4.6	8.7	0.8	1.3	1.4	1.3
	Min	4.8	0.0	0.0	0.0	0.0	1.7	5.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	1.8	0.2	0.0	0.0
	Max	34.8	13.3	15.2	100.0	100.0	94.2	13.0	1032.4	100.0	100.0	12.0	3.3	21.5	44.2	5.0	5.0	5.0	5.0
Deciduous	Mean	22.3	3.9	2.2	92.2	6.0	26.9	8.6	64.2	32.2	1.1	10.3	0.2	6.0	8.3	4.3	3.4	2.3	2.1
	SD	6.0	3.8	1.1	18.9	14.1	20.4	2.4	199.1	46.1	5.7	1.2	0.4	3.1	15.2	0.8	1.1	1.1	1.1
	Min	5.0	0.0	0.4	0.0	0.0	0.4	5.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	2.0	0.5	0.0	0.0
	Max	36.4	19.3	5.0	100.0	77.8	90.8	19.0	1828.9	100.0	33.3	13.5	2.1	16.2	84.0	5.0	5.0	5.0	5.0
Mixedwood	Mean	23.3	4.7	3.6	84.3	14.1	25.9	9.2	119.0	36.9	3.4	10.1	0.6	7.3	3.7	4.4	3.6	2.7	2.5
	SD	7.3	3.6	2.3	24.9	22.5	19.6	4.5	253.0	47.3	14.9	1.2	1.0	4.2	9.8	0.8	1.2	1.4	1.3
	Min	0.0	0.0	0.0	0.0	0.0	0.3	4.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	1.2	0.0	0.0	0.0
	Max	36.6	15.6	13.8	100.0	95.2	83.0	50.0	1655.2	100.0	100.0	15.0	6.2	18.5	68.3	5.0	5.0	5.0	5.0
All forest	Mean	16.3	3.4	3.6	76.6	22.3	48.1	8.9	57.7	20.1	6.4	10.0	0.3	7.2	4.5	4.2	3.1	2.0	1.8
	SD	9.1	3.2	2.4	28.3	27.2	30.7	3.0	178.2	39.0	22.6	1.2	0.6	4.6	10.5	0.9	1.3	1.4	1.3
	Min	0.0	0.0	0.0	0.0	0.0	0.3	4.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	Max	36.6	19.3	15.2	100.0	100.0	96.0	50.0	1828.9	100.0	100.0	15.0	6.2	24.3	84.0	5.0	5.0	5.0	5.0

5.5 - Summary of mammal research

Marten are typically associated with mature or late successional conifer forests at broad spatial scales, though stable populations have been reported in young deciduous forests (Poole *et al.* 2004). Marten are consistently shown to be highly sensitive to habitat alteration at fine spatial scales where they strongly select near ground structural complexity and overhead cover (Potvin *et al.* 2000). Throughout their range they avoid forest openings, habitats with marginal overhead cover or habitats that are structurally simple (Potvin *et al.* 2000). Our results are consistent with these findings. Why marten show this behaviour is unclear, however. Forest openings like seismic lines may have less prey than forest interiors. Marten have a relatively general diet but do tend to prey on small mammals and nests of birds (Ball *et al.* 2009a). Given that many species of birds are more abundant near edges, it seems unlikely that reduced prey is a good explanation. Small mammal prey was also higher near pipeline edges near Fort Simpson, NWT (Darling 2008). Alternatively, marten may avoid open areas because of perceived predation risk. Marten are killed by a variety of species, but mainly raptors. Past studies have shown many species of raptors hunt along cut block edges, and personal observations point to the same along pipeline and seismic line edges.

Bears are omnivores and show a marked seasonal use of different habitats to exploit different resources. One explanation for use of linear features by bears may be the fact that seismic lines are often the first habitats to green up in the spring. However, we found increased bear use of seismic lines throughout the season. This suggests that black bears are using linear features as movement corridors much like has been seen for wolves in northern Alberta. Although line use is reduced with vegetation regrowth, black bears still show high use of revegetated linear features. We found that black bears were far more likely to be detected in upland habitat than lowland forests. Nearly every detection of black bears in lowlands occurred on linear features. This suggests that linear features may be allowing black bears to move through lowlands, which creates concerns for caribou management.

The response of marten and black bear to seismic lines reveals a strong case for settting seismic line recovery and minimum width thresholds. Both species show a strong response to open lines ≥ 3m wide, and a consistent dampening of that response as lines recover over time and assimilate back into the surrounding forest. This suggests that from a threshold perspective, seismic lines after a given length of time or sufficient amount of regeneration is achieved should be removed from a density calculation for these species. Of even greater interest is that neither species shows a response to lines that are ≤ 2m in width. This clearly suggests there is a minimum width below which lines are not impacting certain species and provides some support to the idea that narrowing lines reduces impact on biodiversity.

6 –VEGETATION STRUCTURE ON SEISMIC LINES OF DIFFERENT AGES

To evaluate seismic line recovery for wildlife, we collected a large amount of vegetation data. While our goal was to associate online vegetation attributes with wildlife responses, these data also allowed us to evaluate whether the age of a seismic line was a good predictor of vegetation recovery. We conducted vegetation surveys on both the seismic line (hereafter online) and a vegetation plot 30m into the forest on one side of the line (edge), so that we could compare seismic line vegetation conditions with the forest immediately beside the line. The same variables measured in the forest are measured online except that vegetation plots are linear so as to fit on the seismic line (Figures 11 & 12). Online plots consisted of three repeated measures (subplots) of the same data to account for the high variability in online vegetation growth. One subplot was located at the GPS location on the centre of the line and the other two subplots were located 40m away from the GPS location, one on the sunnier side of the line and one on the shadier side. In total, each online vegetation plot spanned 100m of seismic line at each point. The total area of each online plot depended on the line width but was comparable to the forest plot area. Details of our vegetation protocol are available upon request. Here we analyze the data for the entire line segment. Future analyses will examine how line aspect and subsamples influence estimates of plant recovery. To model vegetation attributes as a function of line age, we used a mixed-effects model with line as the random effect. Data were ln-transformed when required to ensure normality. For each online vegetation variable, we controlled for forest type as a categorical variable, height of trees beside the line, density of shrubs beside the line, downed woody material in forest, easting, northing and line age. This allowed us to test how the forest type adjacent to the line influenced recovery over time.

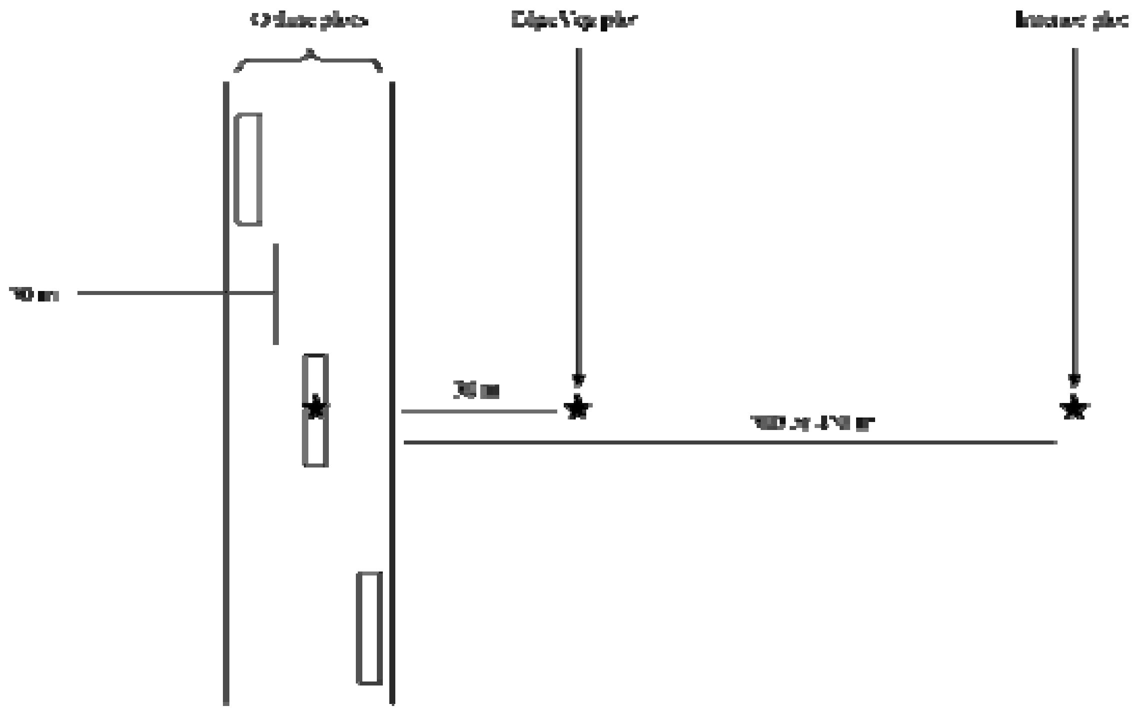


Figure 11 - General survey design and vegetation plot layout. Edge veg plots are centered 30m from the edge of a seismic line, and Interior plots are centered 300 to 450m from the edge of the seismic line depending on the specific question and taxa.

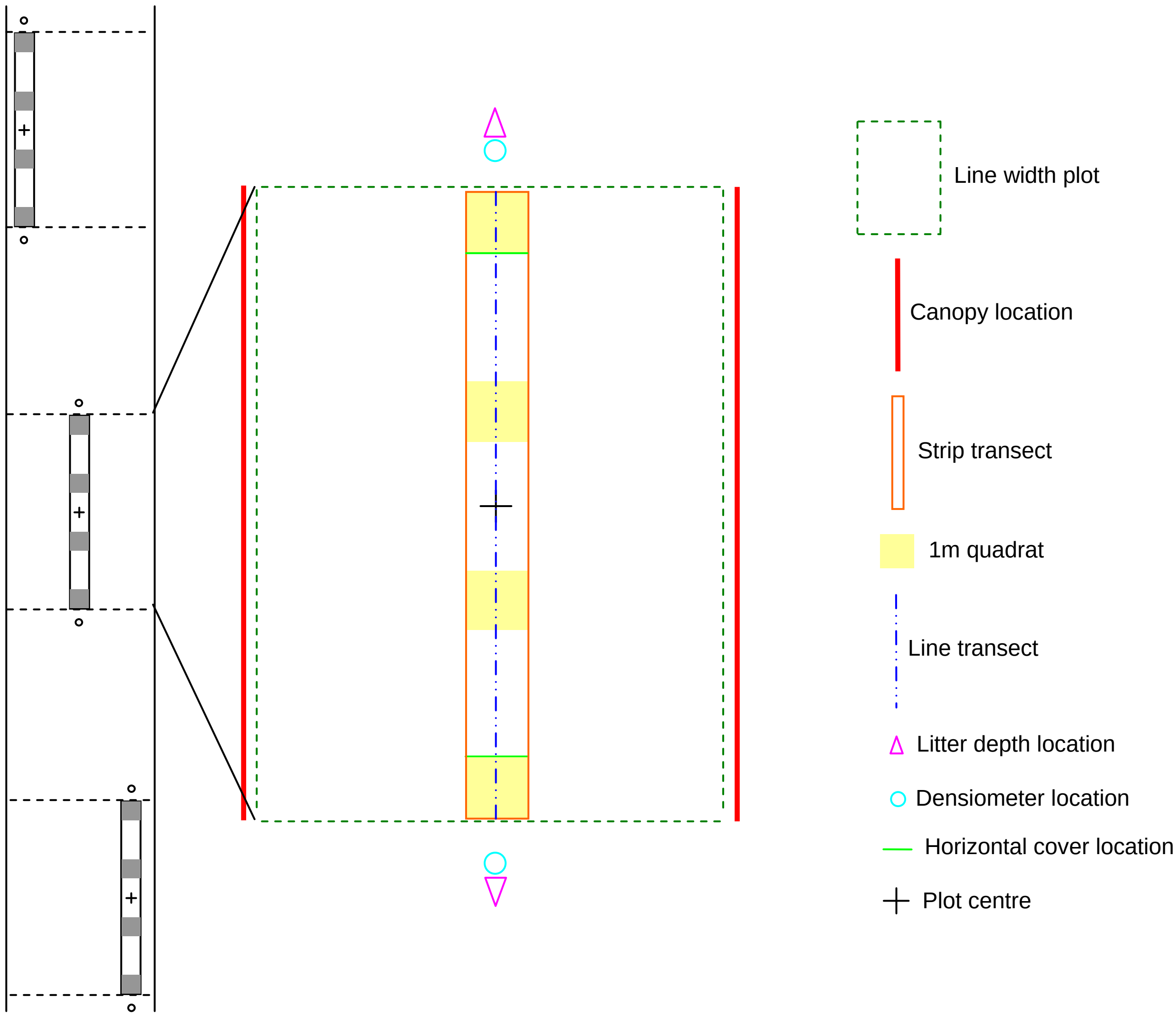


Figure 12 - Example of online vegetation plot. Each subplot strung along a seismic line segment is shown on the left. The centre subplot is enlarged and depicted in colour for detail (each subplot is identical). Each line subplot is 22.6 m long.

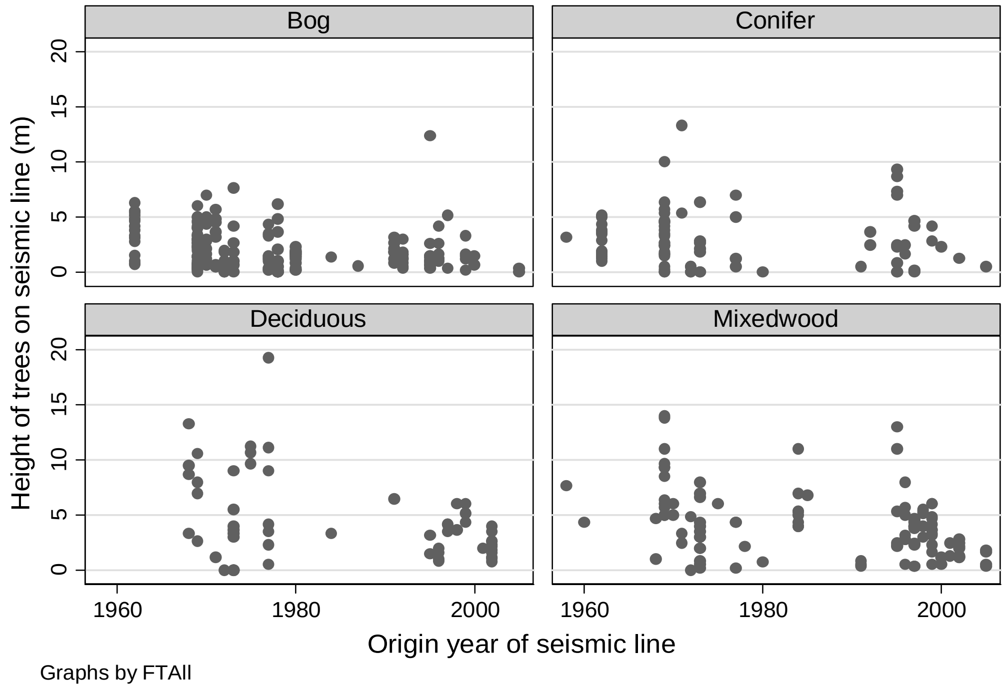
Table 11 shows the mean and standard deviations for each vegetation variable in each forest type for young and old lines, respectively. In general, older lines have greater vegetation on them than younger lines but there is a large amount of unexplained variation. Figure 13 shows the raw data for each forest type as a function of seismic line age. Table 12 shows the results from a mixed-effects model predicting online attributes as a function of line age and forest attributes. Line age was a significant predictor of the height of trees on seismic lines and density of trees on the seismic line. Tree density and tree height on line tended to be higher in stands with taller trees and greater canopy closure suggesting more productive stands had faster regrowth on the seismic line.

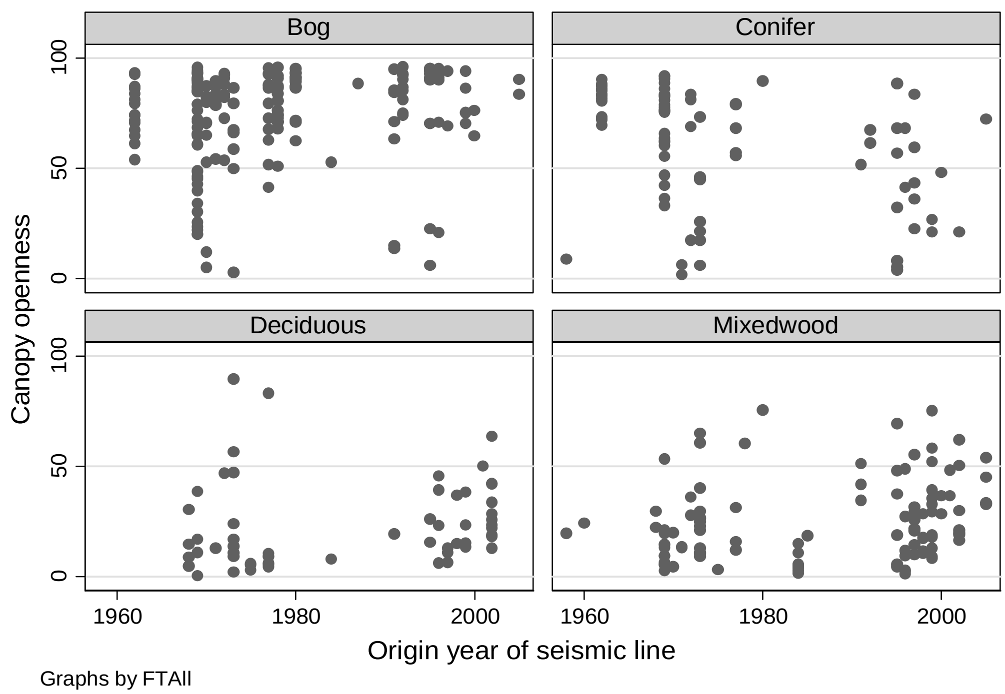
Shrub attributes and canopy openness, which were the primary factors influencing wildlife, were not significantly influenced by age indicating that age should not be the only criteria used to define recovery. Shrub density online was a function of shrub density in the surrounding forest, suggesting most shrub growth comes from ingress from the surrounding forest. Forests with a more closed canopy tended to have greater closure over the seismic line. This was caused in part by trees from the surrounding forest growing into the seismic line gap creating “connected” crowns. Forests with larger trees were more likely to grow into the seismic line gap. Downed woody material on lines was a function of forest age and height, with stands dominated by large, old trees more likely to have downed woody material on the line, presumably due to trees falling onto the line. Horizontal structure to a height of 3 metres was a function of shrub density (greater structure with higher shrub density). More open forest stands were less likely to have developed a complex online horizontal structure.

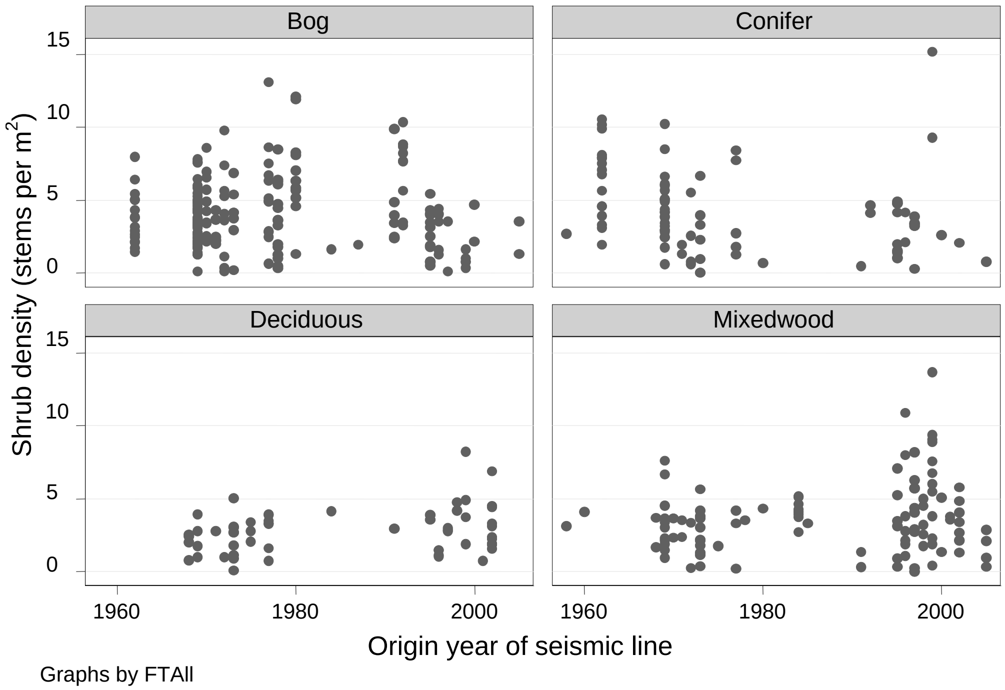
Overall, we found shrub density on older lines was relatively similar between all forest types, and across all lines sampled was similar or higher than in the surrounding forest. Tree density was far lower on lines than in the surrounding forest, but should be expected as we only counted a woody plant as a tree if it had a dbh >= 8 cm. Aspen and mixedwood forests were far more likely to have trees than conifer stands or bogs, and there was a greater chance of finding “tall trees” in these stand types with trembling aspen being the species most likely to have reached heights of greater than a few metres.

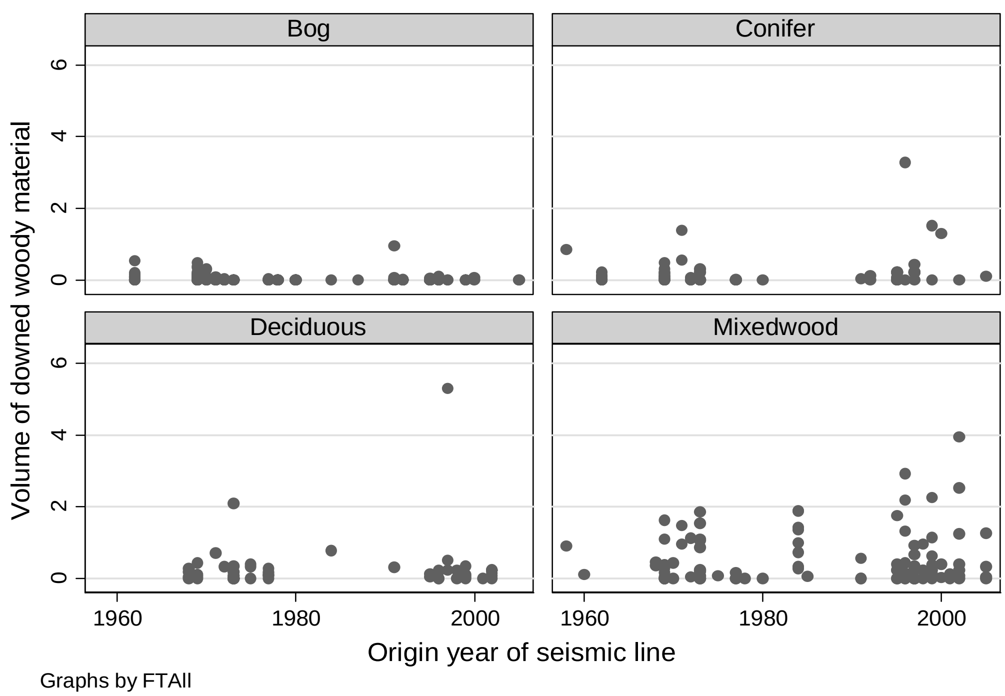
Table 11 - Mean and standard deviation for vegetation attributes in the four major forest types on old (cut before 1985) and young (cut after 1985) seismic lines relative to the forest edge.

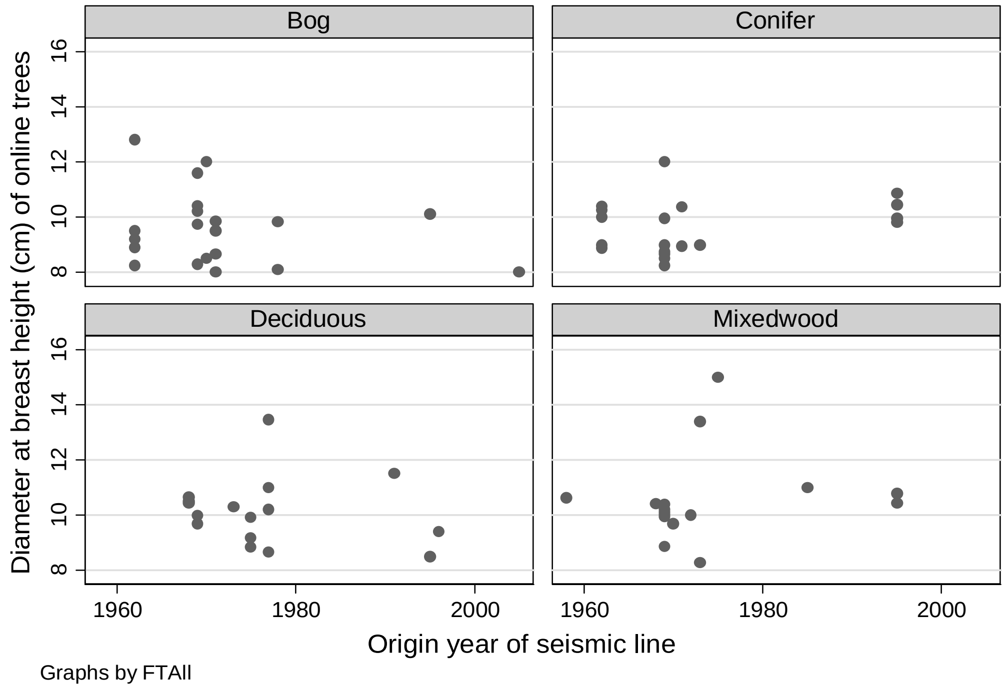
	Line Width (m)	Canopy Ht (m)	Canopy Openness	% Coniferous Shrubs	Shrub Density (per m^2)	Horizontal (0.5 m)	Horizontal (1 m)	Horizontal (2 m)	Horizontal (3 m)	DWM Volume (m^3 per ha)	Tree Density (per ha)	Horizontal Cover Factor	Recovery Factor
Bogs													
Old	8.7 ± 1.8	2.1 ± 1.8	73 ± 20	9 ± 11	4.3 ± 2.5	4.0 ± 0.9	2.8 ± 1.3	2 ± 1.2	1.8 ± 1.1	0.04 ± 0.09	61 ± 269	-0.28 ± 0.86	-0.37 ± 0.83
Young	8.1 ± 1.4	1.7 ± 1.9	77 ± 24	6 ± 10	3.8 ± 2.8	3.8 ± 1	2.6 ± 1.3	1.4 ± 1.1	1.1 ± 1.2	0.03 ± 0.14	7 ± 45	-0.68 ± 0.91	-0.75 ± 0.88
Forest	.	10.2 ± 4.9	53 ± 30	34 ± 27	4 ± 2.7	7.1 ± 51.4	5.7 ± 38.6	4.4 ± 25.9	5.5 ± 51.7	0.3 ± 0.4	389 ± 402	.	.
Coniferous Forest													
Old	9.3 ± 1.7	2.9 ± 2.5	66 ± 25	9 ± 10	4.4 ± 2.7	4.2 ± 0.7	3.1 ± 1	2.3 ± 1.1	2.2 ± 1	0.11 ± 0.23	34 ± 139	0.01 ± 0.76	-0.06 ± 0.73
Young	8.1 ± 1.5	3.1 ± 2.8	45 ± 27	3 ± 5	3.5 ± 3.2	4.2 ± 0.8	3.4 ± 1.1	2.5 ± 1.5	2.2 ± 1.5	0.35 ± 0.74	66 ± 174	0.14 ± 1.13	0.13 ± 1.12
Forest	.	14.7 ± 6.6	44 ± 29	30 ± 29	3.0 ± 2.0	4.2 ± 0.8	3.5 ± 0.9	3 ± 1	2.9 ± 0.9	0.6 ± 1	859 ± 558	.	.
Deciduous Forest													
Old	8.3 ± 1.8	6 ± 4.8	21 ± 23	1 ± 4	2.4 ± 1.2	4.4 ± 0.7	3.5 ± 1.2	2.8 ± 1.2	2.6 ± 1.1	0.22 ± 0.4	166 ± 351	0.37 ± 0.86	0.5 ± 0.89
Young	7 ± 1.4	3 ± 1.7	25 ± 14	1 ± 3	3.2 ± 1.7	4.6 ± 0.7	4 ± 0.9	2.7 ± 1	2.4 ± 1	0.36 ± 0.96	12 ± 36	0.46 ± 0.71	0.45 ± 0.69
Forest	.	23 ± 6	12 ± 13	5 ± 14	2.8 ± 1.6	4.3 ± 0.9	3.7 ± 1.1	2.9 ± 1	2.8 ± 1	0.7 ± 0.9	967 ± 574	.	.
Mixedwood Forest													
Old	8.4 ± 1.8	5 ± 3.5	23 ± 18	6 ± 11	3.0 ± 1.6	4.4 ± 0.7	3.6 ± 1.1	2.7 ± 1.2	2.7 ± 1.2	0.42 ± 0.54	270 ± 530	0.38 ± 0.91	0.51 ± 0.9
Young	7.7 ± 1.6	3.6 ± 2.6	26 ± 18	5 ± 9	4.0 ± 2.8	4.4 ± 0.9	3.8 ± 1.4	2.8 ± 1.5	2.5 ± 1.5	0.58 ± 0.81	183 ± 463	0.4 ± 1.17	0.47 ± 1.13
Forest	.	22 ± 8	12 ± 12	12 ± 21	2.8 ± 1.7	4.3 ± 0.8	3.7 ± 0.9	2.9 ± 1	2.8 ± 1.0	1.6 ± 1.8	930 ± 504	.	.

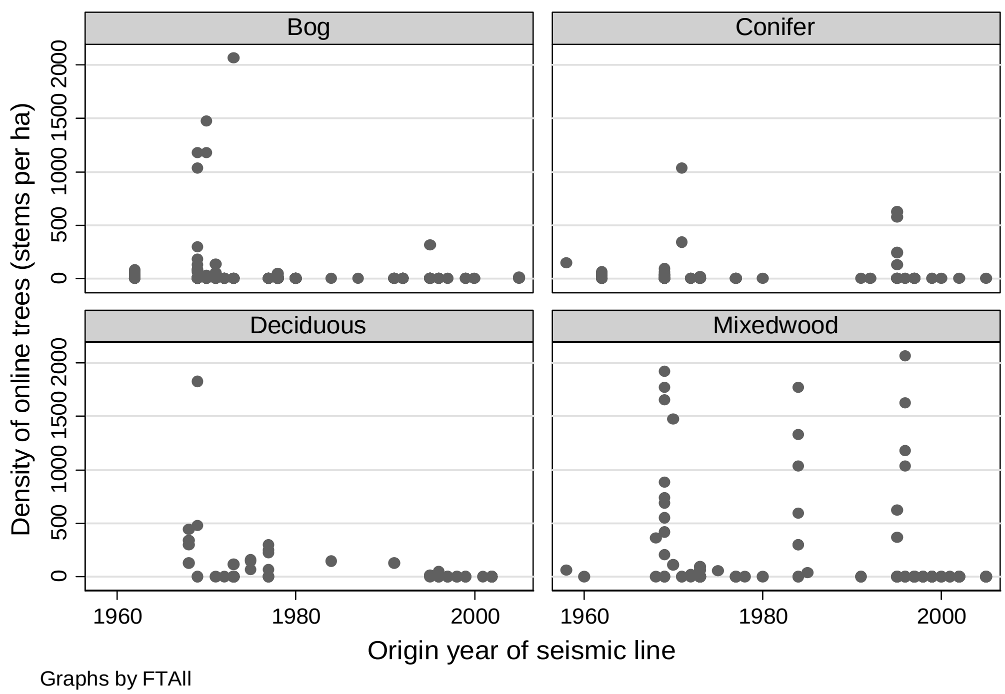

Bog
Conifer
Deciduous
Mixedwood
Height of trees on seismic line (m)
0
5
10
15
20
1960
1980
2000
Origin year of seismic line
Graphs by FTAll


Bog
Conifer
Deciduous
Mixedwood
Canopy openness
0
50
100
1960
1980
2000
Origin year of seismic line
Graphs by FTAll


Bog
Conifer
Deciduous
Mixedwood
Shrub density (stems per m²)
0
5
10
15
1960
1980
2000
Origin year of seismic line
Graphs by FTAll


Bog
Conifer
Deciduous
Mixedwood
Volume of downed woody material
0
2
4
6
1960
1980
2000
Origin year of seismic line
Graphs by FTAll


Bog
Conifer
Deciduous
Mixedwood
Diameter at breast height (cm) of online trees
8
10
12
14
16
1960
1980
2000
Origin year of seismic line
Graphs by FTAll


Bog
Conifer
Deciduous
Mixedwood
Density of online trees (stems per ha)
0
500
1000
1500
2000
1960
1980
2000
Origin year of seismic line
Graphs by FTAll

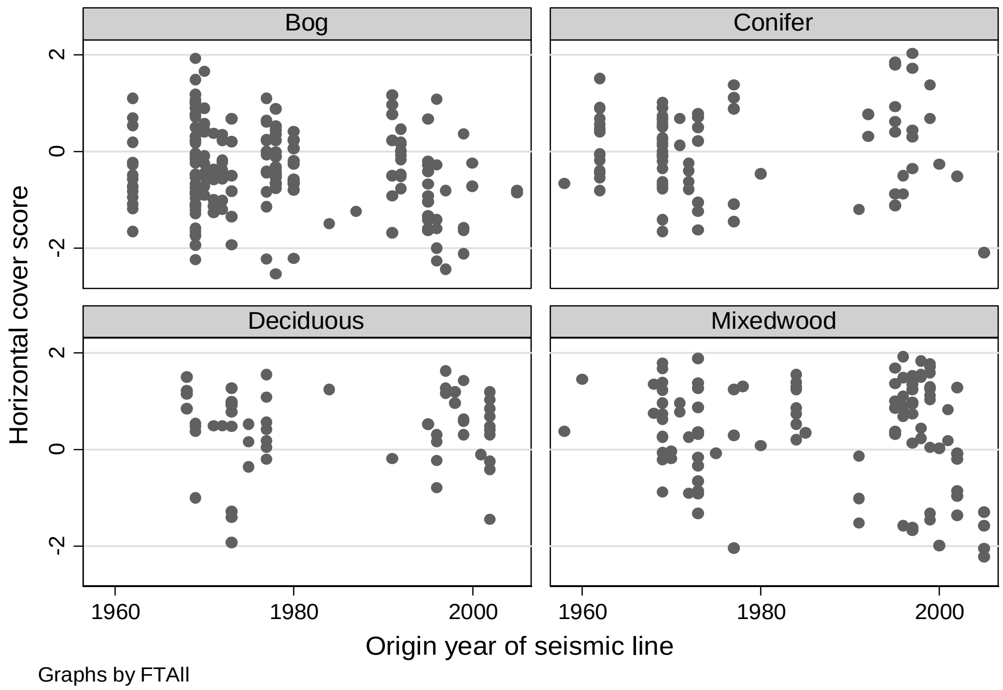


Figure 13 - Scatterplots showing relationship between the year a seismic line was cut and various measures of vegetation recovery on seismic lines. Graphs show response for each of the major forest types visited.

Table 12 - Mixed effects regression models predicting online vegetation attributes as a function of line age, spatial location, dominant forest type around line, shrub density in forest around line, openness of the canopy in the forest adjacent to the line, shrub density in the forest in the area around the line, height of the forest and amount of downed woody material (DWM) in the forest. Values are standardized to zero mean and unit variance so that the variable with the largest value has the largest effect on the online vegetation attribute that was modelled.

	Coefficient.	SE	z	P	L95	U95
Height of trees on seismic line (metres): ln-transformed – r^2 = –0.29						
Forest Type						
Conifer	0.038629	0.061744	0.63	0.532	-0.08239	0.159646
Deciduous	0.318061	0.094131	3.38	0.001	0.133566	0.502555
Mixedwood	0.128088	0.081381	1.57	0.116	-0.03142	0.287592
Origin year	-0.10336	0.003363	-2.32	0.02	-0.01441	-0.00123
Easting	-0.05807	0.070606	-0.82	0.411	-0.19646	0.080312
Northing	0.218347	0.070419	3.1	0.002	0.080329	0.356365
Shrub density	0.024045	0.02183	1.1	0.271	-0.01874	0.066832
Canopy openness	-0.10991	0.032475	-3.38	0.001	-0.17356	-0.04626
Height of forest	0.05866	0.032752	1.79	0.073	-0.00553	0.122853
DWM	0.010214	0.026329	0.39	0.698	-0.04139	0.061817
Constant	16.61867	6.659496	2.5	0.013	3.566301	29.67105
Canopy openness on seismic line – r^2 = 0.75						
Forest Type						
Conifer	-8.21247	2.179295	-3.77	<0.001	-12.4838	-3.94113
Deciduous	-21.2397	3.254901	-6.53	<0.001	-27.6192	-14.8602
Mixedwood	-16.31	2.807464	-5.81	<0.001	-21.8125	-10.8075
Origin year	2.099061	0.104141	1.52	0.127	-0.04538	0.362846
Easting	6.636455	1.956992	3.39	0.001	2.800821	10.47209
Northing	-3.65382	1.940906	-1.88	0.06	-7.45793	0.150283
Shrub density	0.11113	0.769847	0.14	0.885	-1.39774	1.620002
Canopy openness	8.634028	1.138026	7.59	<0.001	6.403538	10.86452
Height of forest	-7.36491	1.134171	-6.49	<0.001	-9.58785	-5.14198
DWM	-2.38786	0.928966	-2.57	0.01	-4.2086	-0.56712
Constant	-257.912	206.1986	-1.25	0.211	-662.054	146.2297

Shrub density on seismic line (stems per m2): ln-transformed – $r^2 = 0.23$

Forest Type						
Conifer	0.036874	0.062103	0.59	0.553	-0.08485	0.158592
Deciduous	0.022436	0.092556	0.24	0.808	-0.15897	0.203843
Mixedwood	0.020822	0.079824	0.26	0.794	-0.13563	0.177274
Origin year	.0008398	0.002931	0.02	0.983	-0.00568	0.005809
Easting	0.05412	0.054641	0.99	0.322	-0.05297	0.161214
Northing	0.092914	0.054168	1.72	0.086	-0.01325	0.199081
Shrub density	0.112525	0.021936	5.13	<0.001	0.069532	0.155519
Canopy openness	0.052681	0.032404	1.63	0.104	-0.01083	0.116191
Height of forest	0.010531	0.032262	0.33	0.744	-0.0527	0.073763
DWM	0.047295	0.026472	1.79	0.074	-0.00459	0.099179
Constant	1.264588	5.804074	0.22	0.828	-10.1112	12.64036

Downed woody material on seismic line (m3) – ln-transformed – $r^2 = 0.37$

Forest Type						
Conifer	0.046303	0.031993	1.45	0.148	-0.0164	0.109008
Deciduous	0.016177	0.047674	0.34	0.734	-0.07726	0.109616
Mixedwood	0.129062	0.041115	3.14	0.002	0.048478	0.209647
Origin year	0.019374	0.019952	0.97	0.332	-0.01973	0.058479
Easting	0.003456	0.028106	0.12	0.902	-0.05163	0.058543
Northing	-0.00287	0.027862	-0.1	0.918	-0.05748	0.051742
Shrub density	0.010745	0.0113	0.95	0.342	-0.0114	0.032893
Canopy openness	-0.00059	0.016692	-0.04	0.972	-0.03331	0.032122
Height of forest	0.074335	0.016618	4.47	<0.001	0.041765	0.106905
DWM	0.031907	0.013638	2.34	0.019	0.005178	0.058636
Constant	0.126582	0.027653	4.58	0	0.072383	0.180782

Horizontal structure factor on seismic line -

Forest Type						
Conifer	0.283369	0.107133	2.65	0.008	0.073391	0.493346
Deciduous	0.622395	0.162097	3.84	<0.001	0.304692	0.940099
Mixedwood	0.463506	0.139985	3.31	0.001	0.189141	0.73787
Origin year	-.080528	0.005544	-1.1	0.272	-0.01696	0.004776
Easting	0.031676	0.11076	0.29	0.775	-0.18541	0.248762
Northing	0.125712	0.110198	1.14	0.254	-0.09027	0.341696
Shrub density	0.150783	0.037868	3.98	<0.001	0.076564	0.225002
Canopy openness	-0.14143	0.056206	-2.52	0.012	-0.2516	-0.03127
Height of forest	0.089946	0.056412	1.59	0.111	-0.02062	0.200512

DWM	0.042237	0.045675	0.92	0.355	-0.04728	0.131758
Constant	11.81244	10.97841	1.08	0.282	-9.70485	33.32973

Density of trees (stems per hectare) – ln transformed – r^2 = 0.21

Forest Type						
Conifer	0.096226	0.236952	0.41	0.685	-0.36819	0.560643
Deciduous	0.63768	0.360134	1.77	0.077	-0.06817	1.343531
Mixedwood	0.274458	0.311202	0.88	0.378	-0.33549	0.884404
Origin year	-0.42979	0.167069	-2.57	0.01	-0.75724	-0.10234
Easting	-0.15826	0.259551	-0.61	0.542	-0.66697	0.350454
Northing	0.463491	0.25859	1.79	0.073	-0.04334	0.970318
Shrub density	-0.01873	0.083768	-0.22	0.823	-0.18292	0.145449
Canopy openness	-0.29496	0.124503	-2.37	0.018	-0.53898	-0.05093
Height of Forest	0.228942	0.125311	1.83	0.068	-0.01666	0.474547
DWM	-0.02521	0.101031	-0.25	0.803	-0.22323	0.172803
Constant	1.129311	0.234111	4.82	0	0.670463	1.588159

7 - INVASIVE PLANT MONITORING

If sufficiently large numbers of species are affected by energy sector development, either behaviourally or numerically, then shifts in the structure of the community may be observed. Community shifts should be viewed as the worst case impact of energy sector development. A large shift in a community may indicate that species are disappearing and being replaced by generalist species. With species replacement, complex interactions and feedbacks can be expected. Community shifts are often driven by invasion of non-native species that are able to colonize an area because of the disturbances created by forest clearing or soil disturbance. We observed few non-native birds or mammals in our surveys and when observed were only found in our most southerly study sites near the agriculture-forest transition.

As part of our plant surveys in 2010, we conducted inventories of non-native plants. This is part of an ongoing project across the western boreal to evaluate the spread of non-native plants along linear feature networks. Our hypothesis is that invasive species tend to become established in highly disturbed sites with vehicle traffic like well-pads and campgrounds and then spread down linear features. These data come from aspen–leading stands between 60 to 90 years of age. The table below shows frequency of occurrence of invasive plants near seismic lines as you move away from roads in the NWT. At each site, we sampled plots located on the seismic line, in the forest edge and > 300 m into the forest. Each plot was 10m by 10m, and non-native plant occurrence (to species) was recorded in twenty 1m by 5m strips running across the plot (i.e. giving a score between 1 and 20 for each site). The results shown in Table 13 demonstrate clearly that invasive species are common at the junction between roads and seismic lines, but very little penetration of the forest interior has occurred. Significance testing cannot be done with logistic regression for most species because they are not present in one or more habitat (typically forest interior). The only non-native species ever found in the forest interior was the Common Dandelion and Annual Hawk's Beard.

Table 13 - Probability of detecting invasive species on seismic lines and forest interiors. Distance Class 0 = road origin of seismic lines (0m from road); Distance Class 1 = 300m from road on seismic line; Distance Class 2 = 600m from road; Distance Class 3 = forest interior (minimum of 300m from any linear feature). All plots covered $10m^2$. Online plots are located on the linear feature. Edge plots are located beside Online plots but inside the forest, immediately beside the linear feature. Interior plots are in the forest interior.

8 – CAN SEISMIC LINE IMPACTS BE REMOTELY MEASURED?

Vegetation on seismic lines does grow over time and a number of bird and mammal species do not differentiate between closed lines and forest interiors as a

Distance Class	**0 (n = 21)**		**1 (n = 21)**		**2 (n = 26)**		**3 (n = 21)**
Plot Type	**Online**	**Edge**	**Online**	**Edge**	**Online**	**Edge**	**Interior**
Scentless Chamomile	0	0	0.047	0	0.038	0	0
Canada Thistle	0.047	0	0	0	0	0	0
Annual Hawk's Beard	0.523	0.095	0.142	0.047	0	0	0.047
Hemp Nettle	0	0.047	0	0	0	0	0
Foxtail Barley	0.142	0	0	0	0	0	0
Pineapple weed	0.095	0	0	0	0	0	0
Black Medick	0.142	0	0	0	0	0	0
Alfalfa	0.095	0	0	0	0	0	0
Timothy	0.190	0	0.047	0	0	0	0
Common Plantain	0.333	0	0.047	0	0.038	0	0
Perennial Sow thistle	0.047	0.047	0	0	0	0	0
Common Chickweed	0.142	0	0.095	0	0.038	0	0
Common Dandelion	0.761	0.380	0.190	0.095	0.115	0	0.047
Stinkweed	0.095	0	0.047	0	0	0	0
Sweet Clover	0.714	0.190	0	0	0	0	0
Other Clover	0.666	0	0.095	0	0.038	0	0

result. Thus, understanding and accounting for seismic line recovery needs to be an integral component of a threshold management framework. However, the high degree of variability inherent to line recovery makes it impossible to confirm a seismic line as recovered based on seismic line age alone. Further, given the inaccessibility of most seismic lines, it is not possible to conduct field visits to all seismic lines to visually assess recovery at a reasonable cost. Other tools are required if we want to efficiently evaluate rates of seismic line recovery. Previous attempts to document the state of seismic line recovery using remote sensing techniques like air photos or multi-spectral satellite imagery have failed because they do not quantify the height or density of vegetation on seismic lines. Without such information, any distinction of recovery is a biological over-simplification as vegetation height and density rather than vegetation presence are key attributes to measuring seismic line recovery for wildlife. This section describes how a new remote sensing technology called LiDAR might be used to estimate seismic line recovery.

8.1 – What is Light Detection and Ranging (LiDAR)?

Light Detection and Ranging, or LiDAR, is an optical scanning technology that uses lasers to measure distances between objects (Hudak *et al.* 2009; Sumerling 2011). Specifically, pulses of infrared light are emitted from an aircraft- or satellite-mounted sensor travel to and reflect off a target surface, and ultimately return to the sensor (Lefsky *et al.* 2002; Evans *et al.* 2009). Distances are measured as the length of time elapsed between light emission and subsequent return, and represent the relative distances between target objects and the LiDAR sensor (Lefsky *et al.* 2002). Those surfaces that are farther away from the sensor get assigned a greater distance measure, and those that are closer are assigned a smaller measure. Ultimately, these relative distances are converted to the actual height of aboveground objects, and it is this three-dimensional characterization of surface objects, or surface “texture” that represents the fundamental advancement of LiDAR (Vierling *et al.* 2008).

The surface texture provided by LiDAR can be used to directly ascertain a wide variety of stand characteristics at extremely fine spatial scales including canopy height, density and volume and complex attributes like the canopy species composition, and the height and density of sub-strata layers (Hudak *et al.* 2009). A number of different LiDAR systems exist, each one having different capabilities of representing the landscape (Evans *et al.* 2009). A detailed review of each LiDAR technology is beyond the scope of this report, but several excellent reviews exist (see Lefsky *et al.* 2002; Evans *et al.* 2009; Hudak *et al.* 2009).

8.2 – LiDAR Data Sources & Locations

LiDAR data used in this report come from EOG Resources Canada Incorporated in the Maxhamish area of the Horn River Basin in northeast British Columbia. Raw data were obtained by Terrapoint Airborne LiDAR Surveying Services in the summer of 2007. The LiDAR footprint for this survey was approximately 40 cm (small footprint), with a point spacing of approximately 50 cm (high-pulsation density) and was obtained from a sensor mounted on a fixed-wing aircraft. Terrapoint post-processed these data into two distinct raster-based surface models, the Digital Surface Model (DSM) and the Digital Elevation Model (DEM) at a $1m^2$ pixel resolution.

In post-processed LiDAR data, each individual pixel is assigned a unique value by averaging the distance measurements of all data within a $1m^2$ cell. The DSM was built using first return data and represents the maximum height surface of all objects above the ground surface, while the DEM was built using the last return data and represents the interpolated bare earth surface devoid of vegetation or other objects (Figure 14). From these two elevation models, we developed a canopy height model (CHM) by subtracting the DEM from the DSM. The CHM represents the tallest aboveground vegetation height of a given $1m^2$ raster cell.

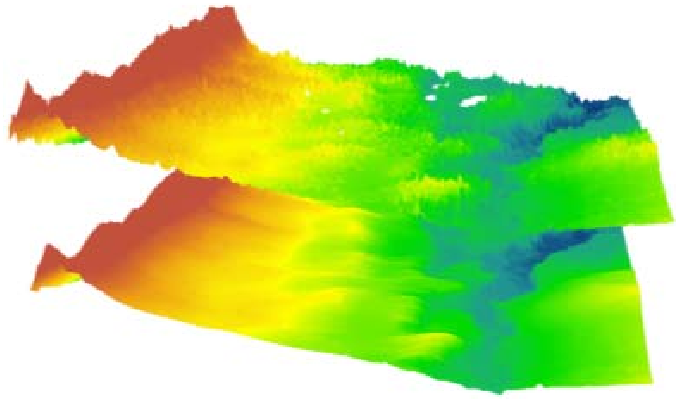


Figure 14 - A Digital Surface Model (DSM; top) and Digital Elevation Model (DEM; bottom). The DSM represents the top surface elevation of all objects above ground and the DEM represents the bare ground layer. The vertical spacing between layers is exaggerated for clarity. Higher elevations are represented in red and lower in blue.

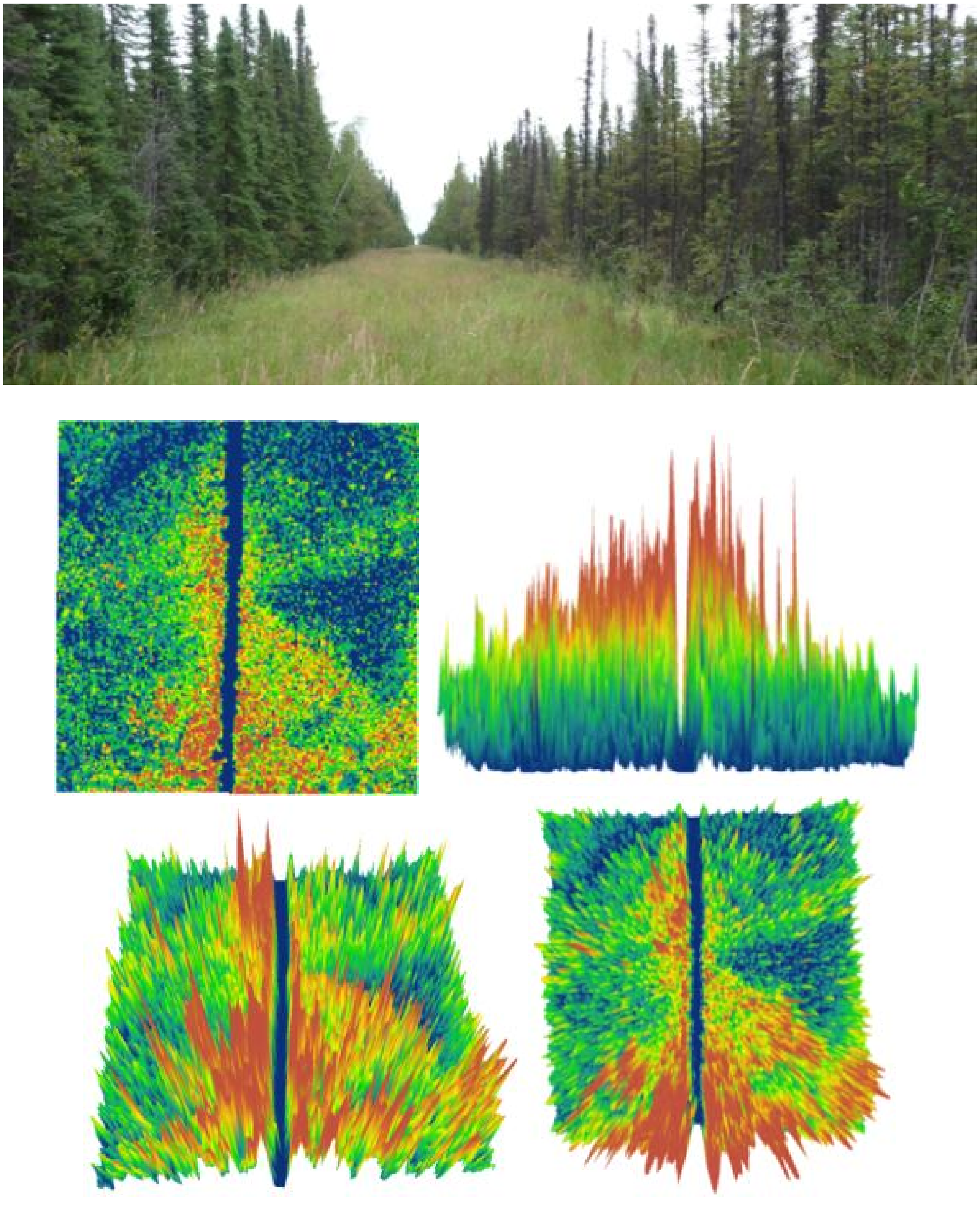


Figure 15 - A typical open seismic line in a lowland forest (top) as depicted in a LiDAR view. A 2-dimensional CHM representation of the line (mid L) shows the higher canopy heights in red and lower ones in blue. The seismic line is clearly distinguishable from the surrounding continuous forest canopy. In 3-dimensions (mid R), the seismic line footprint is clearly visible as a disturbance feature separate from the natural heterogeneity of the continuous forest canopy. Also, the canopy “height-scape” is clearly

captured in LiDAR (bottom) and matches the view in the photograph where the forest on the right side of the line is tall but quickly falls away, and on the left side is tall for a greater distance from the line edge.

8.3 – Automating seismic line recovery assessments

Our original objective was to determine the state of all seismic lines in the Maxhamish area so that we could correlate LiDAR height with our wildlife data from that region. Several automation processes were tried including height differentials and edge detection (Zheng *et al.* 2007; Gaulton and Malthus 2010). None were satisfactory as they missed known seismic lines. This occurs for many reasons that are described in another report that is available upon request. We then attempted to semi-automate the process by buffering all known seismic lines within our GIS layers and using these buffers to extract the CHM. Conventional seismic lines were buffered by 8m to approximate line widths typical of the study region. This approach did not work because of inconsistencies in spatial alignment of the GIS vector layers and the LiDAR. LiDAR is depicted at an extremely fine grain size so that small inaccuracies in the spatial alignment between the seismic line and LiDAR layers produces a buffer that does not accurately represent the linear footprint, but rather extracts undisturbed forest interior as part of the linear feature (Figure 16). These errors were not caused by the LiDAR but by the inaccuracies in digitizing the seismic lines from other imagery.

As we could not automate the process, we were unable to determine the state of all seismic lines in the Maxhamish study area because of the time involved. We are manually processing all lines where we currently have vegetation and wildlife data. Below, we describe the efficacy of a manual approach to evaluating line recovery that can be used but that is time-consuming. First, we adjusted known seismic lines to spatially match seismic line features with LiDAR imagery. Once aligned, the linear features were buffered and the resulting buffers used to extract CHM. Actual seismic line widths collected during site visits were used to create the buffers. Figure 17 shows the results of layer alignment.

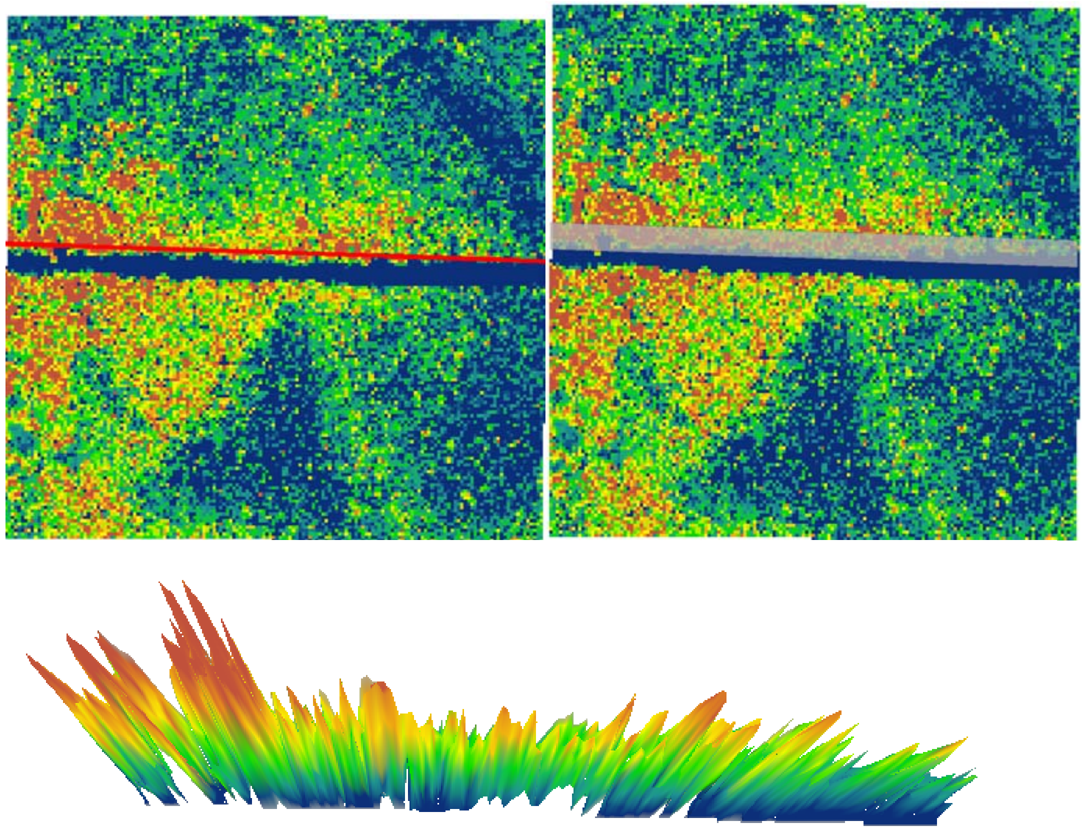


Figure 16 - Even when the spatial mismatch between a seismic line feature and the LiDAR imagery is < 6 m as shown here (top L; line feature in red), the resulting area assigned to a line footprint by the buffering technique does not accurately represent actual line footprint (top R; line area in translucent grey). As a result, when the buffered area is used to extract LiDAR data, forest heights rather than line height are represented (bottom). This obviously flaws any interpretation of line recovery.

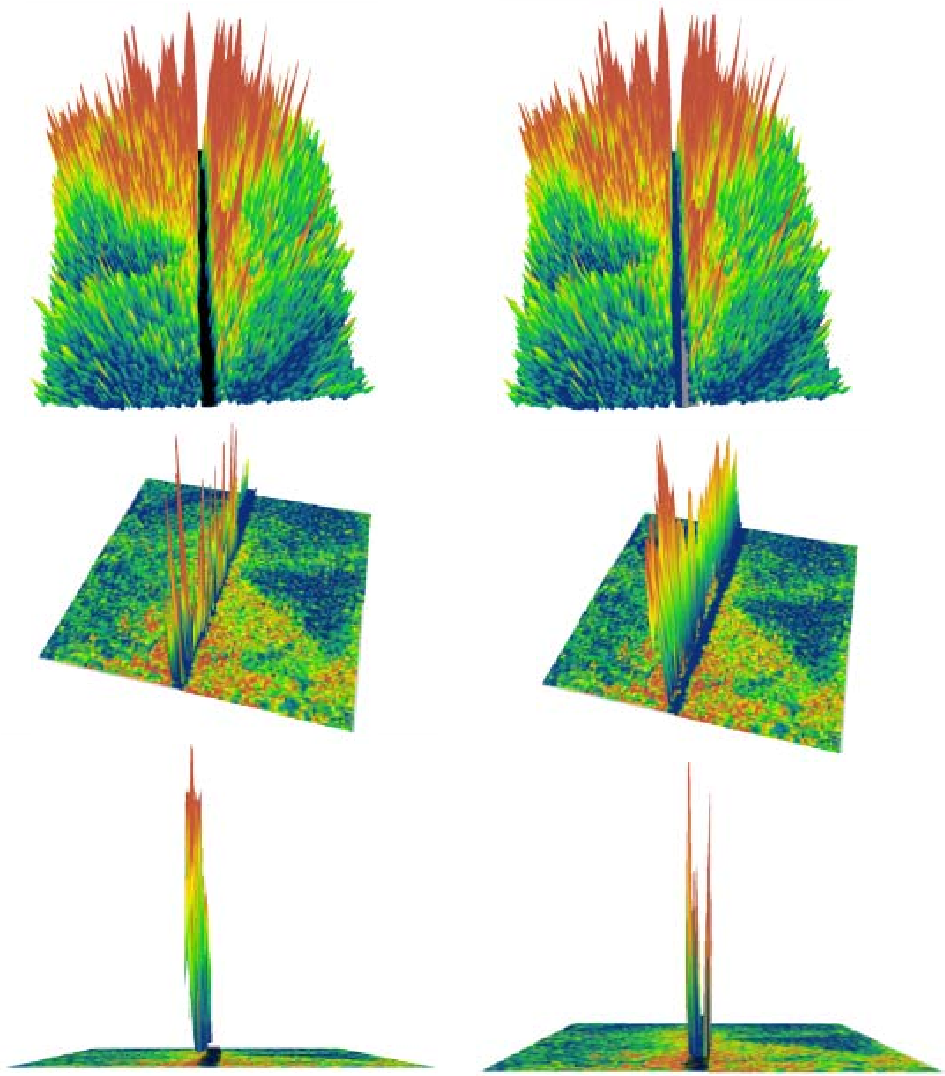


Figure 17 - A seismic line representation built from spatially aligned layers (L) and spatially mismatched layers (R). Top and Middle: the line footprint created by the buffering procedure clearly matches the line footprint depicted in the LiDAR after alignment, but not before. The top images show the line footprints as 2-D (black footprint for aligned layers are grey for mis-matched) and the surrounding forest in 3-D. The middle image shows the extracted line footprint in 3-D and the surrounding forest in 2-D. Bottom: the aligned layers produce a clearly “hollow” seismic line footprint that is visibly open and representative of the actual open line feature in reality; the

mismatched layers produced a closed-line footprint representative of the surrounding forest.

8.4 - Assessing Seismic Line Recovery in Practice

Using the manual approach to CHM extraction, we tested seismic line recovery on a series of six conventional seismic lines that we surveyed in our wildlife studies. These were open, moderately-closed and closed lines in upland and lowland forest. We used two different quantification methods to assess recovery: a line-of-sight analysis and a comparison of height values along linear features relative to the adjacent forest.

8.4.1 - Line of Sight

Line–of-sight analysis is an assessment of what can and cannot be seen from a given observation point. Essentially, this is a 3D visualization of the seismic line from the ground and might be equivalent to field measurements of horizontal cover. From our field data, we know a variety of species respond to the visual obstruction along a seismic line so if we could estimate this from LiDAR a very effective tool for estimating line recovery could be created. Line-of-sight analysis is done by selecting an observation and a target point and building a height profile along that linear field of view using 3D Analyst in ArcGIS. The height profile reflects the height of each pixel within the designated line of sight at distances down the line. We tested a straight line of sight using observation points 1 and 2m off the surface of the seismic line. The profile shown is for a strip 1m wide along the middle of the seismic line.

Once we have completed extraction of the CHM of all of our vegetation plots, we intend to test whether the ratio of visible versus not visible above different height criteria is correlated with our horizontal cover board estimates. Figures 18 & 19 show a line-of-sight estimate in graphical form. However, as can be seen from the photo of this seismic line, there are areas where you can see above and below the line-of-sight threshold suggesting that the highest height in each 1 m^2 cell may overestimate how much the line of sight is blocked. An improved estimate may be possible if each of the

$1m^2$ strips of cells along each seismic line was estimated separately and is something we are currently investigating.

Other types of LiDAR data are even more likely to correlate with horizontal cover estimates. The processing done by Terrasoft does not provide a depth or volume estimate. In other words, all surfaces are represented as solid opaque features that are described simply as the maximum height in that cell. Waveform data and the raw point cloud data from LiDAR can provide depth or volume estimates in three dimensions that remove this limitation. With respect to a line-of-sight type of analysis, it may be possible to exploit that additional resolution of such data to measure an even more realistic line-of-sight type of attribute.

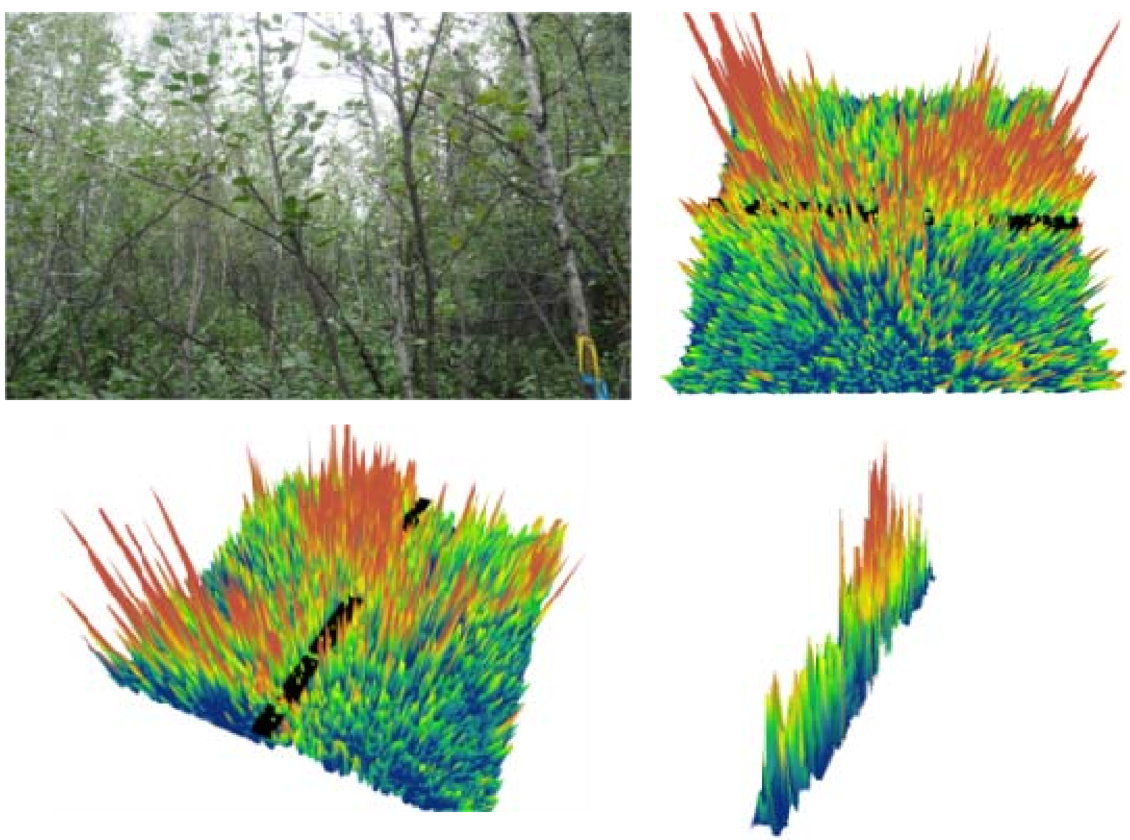


Figure 18 - A closed seismic line in a lowland forest (top L) and the landscape depiction in a CHM (top R and bottom L). The actual seismic footprint is in black and elevated for clarity. Once the spatial layers are aligned, the actual line footprint can be extracted from the CHM and displayed in 3D (bottom R).

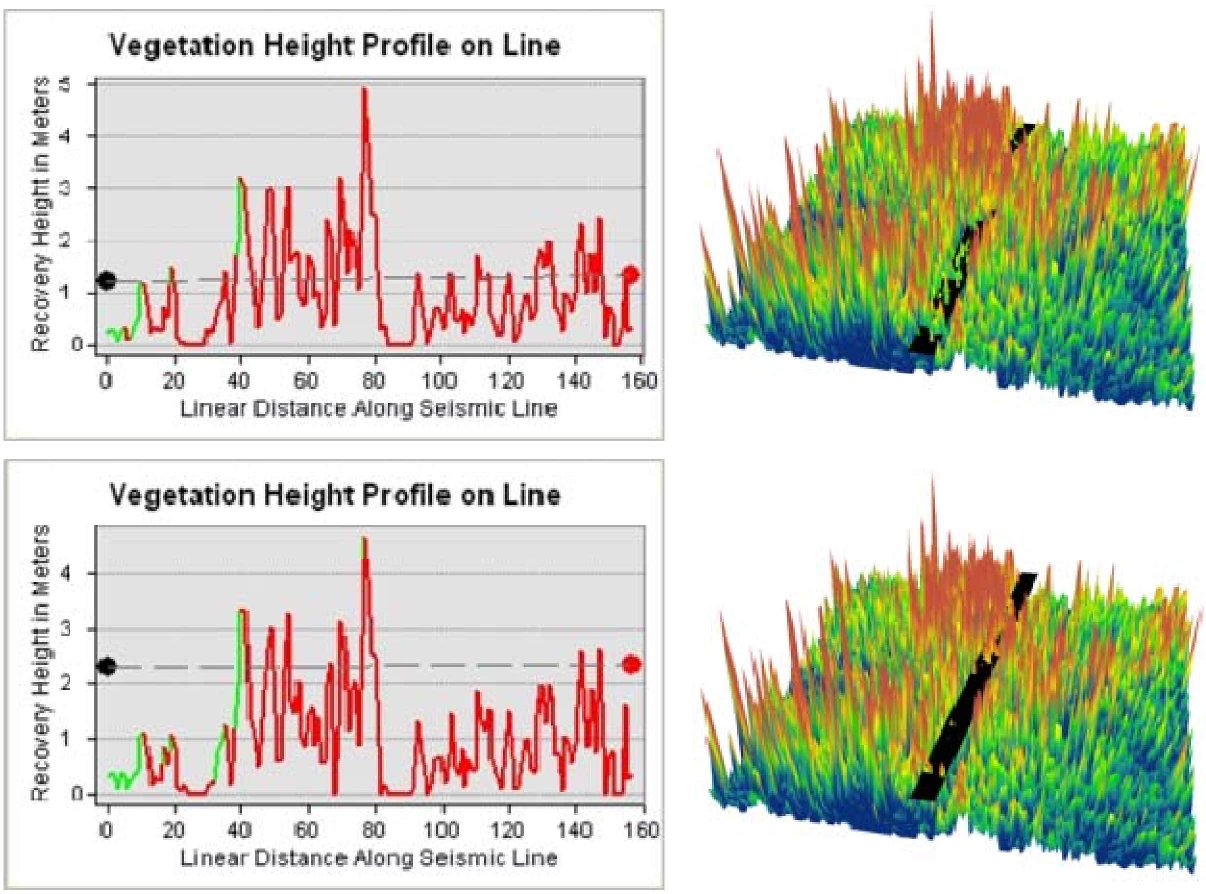


Figure 19 – Line-of-sight analyses conducted at 1m (top) and 2m (bottom). In each graph, the black dots represent the observation point and the red the target point. Along the line of sight (dashed grey line), those portions of the CHM that are visible are

in green and those portions that are obscured are in red. The accompanying CHM images show the exact elevation at which the line of sight analysis was conducted.

8.4.2 - Proportion of Height Values

The second method we used to quantify line recovery was to compare the proportion of pixels with near-ground height values relative to the adjacent forest canopy height. First, the CHM for the seismic line was extracted as described above. We then moved this buffer into the forest on either side of the seismic line to extract the canopy surface heights. The proportion of height values within each extraction were then calculated and compared to track line recovery relative to the adjacent forest. The metric of comparison was the proportion of pixels at ground or near ground levels versus those at higher canopy level elevations.

This method accurately captured both the difference between lines and adjacent forests and the decreasing ratio of low to high pixel values for lines at different recovery states (Table 14). Lowland forests show lower height elevations and a higher proportion of ground- or near ground-level pixels as compared to upland forests, but the proportion of higher elevation pixel values increased with line recovery (closure) across both forest types.

Table 14 – Proportion of pixels from LiDAR image in 9 height classes on seismic lines relative to the same strip width in adjacent forest. LIR is the ratio of pixels on line relative to interior in each height class. Lines with LIR close to 1 in all height classes have a forest structure on line similar to that in the forest interior.

	0 m	**0.5 m**	**1 m**	**1.5 m**	**2 m**	**2.5 m**	**3 m**	**3.5 m**	**4+ m**
					Lowland Forest				
Open seismic line									
Line	0.79	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.06
Interior	0.09	0.03	0.05	0.05	0.06	0.07	0.07	0.08	0.49
LIR	8.91	0.29	0.36	0.45	0.35	0.33	0.31	0.35	0.12
Semi-open seismic line									
Line	0.75	0.13	0.05	0.04	0.01	0.01	0.01	0.00	0.01
Interior	0.40	0.12	0.13	0.10	0.08	0.07	0.05	0.02	0.03
LIR	1.89	1.06	0.35	0.38	0.13	0.18	0.14	0.07	0.26
Closed seismic line									
Line	0.43	0.12	0.12	0.09	0.07	0.08	0.05	0.02	0.04
Interior	0.35	0.09	0.11	0.10	0.09	0.09	0.06	0.04	0.07
LIR	1.21	1.34	1.07	0.91	0.71	0.88	0.81	0.42	0.55
					Upland Forest				
	0 m	0.5 m	1 m	1.5 m	2 m	2.5 m	3 m	3.5 m	4+ m
Open seismic line									
Line	0.70	0.07	0.03	0.02	0.02	0.02	0.01	0.00	0.13
Interior	0.22	0.07	0.06	0.06	0.05	0.04	0.02	0.01	0.47
LIR	3.22	0.94	0.48	0.36	0.36	0.43	0.52	0.43	0.28
Semi-open seismic line									
Line	0.29	0.09	0.08	0.07	0.06	0.03	0.02	0.01	0.36
Interior	0.35	0.06	0.04	0.04	0.03	0.02	0.01	0.01	0.45
LIR	0.81	1.50	2.04	1.63	2.23	1.72	1.85	1.65	0.80
Closed seismic line									
Line	0.15	0.08	0.04	0.05	0.05	0.05	0.04	0.03	0.51
Interior	0.20	0.10	0.02	0.02	0.02	0.02	0.02	0.02	0.58
LIR	0.72	0.77	2.19	2.49	2.21	2.58	2.38	1.82	0.88

8.5 – Conclusions regarding LiDAR

This work is a first step. The data available for this assessment were post-processed and delivered as a DSM and DEM only. The resulting CHM is a simple way of describing vegetation on seismic lines as all aboveground surfaces are represented as the highest point above the ground and are treated as opaque objects. With raw LiDAR, it is possible to go from a canopy surface model to measuring vegetation volume which we believe will correlate better with our vegetation measurements in the field (Lefsky 2002; Miura and Jones, 2010). We caution that the lack of below canopy information may lead to an overestimation of line recovery using CSM as side closure or the leaning of vegetation over a seismic line from the adjacent forest canopy will be problematic. In upland forest, side closure may be erroneously depicted in a CHM as tree growth on the seismic line when in reality that vegetation is not rooted there (Figure 20).

Although our tests using CHM matched our definitions of when seismic lines were and were not recovered, we believe a better assessment could be developed using point cloud data to interpret whether vegetation height is continuous to the ground or not. Point cloud data would show side closure as “floating” above a line. Multiple discrete vegetation strata or continuous point cloud data would increase LiDAR utility in two other important ways. Because our attempts at automated line detection were based on a CHM, we were limited simply to identifying a height differential between lines and the surrounding forests. Using cloud data, we could estimate whether there are multiple height strata. This type of information could be used to automate line detection as the difference between the canopy and subcanopy in the forest interior are likely to be very different than the canopy and ground cover on a seismic line. Second, cloud data is capable of showing the volume of vegetation growing on a line. While this information has been used exclusively to interpret vegetation height and vertical volume to date, there is no reason volume cannot be interpreted along a horizontal plane to create line-of-sight measurements. This is important, as it is a combination of recovery height and horizontal visibility that indicates line recovery for wildlife.

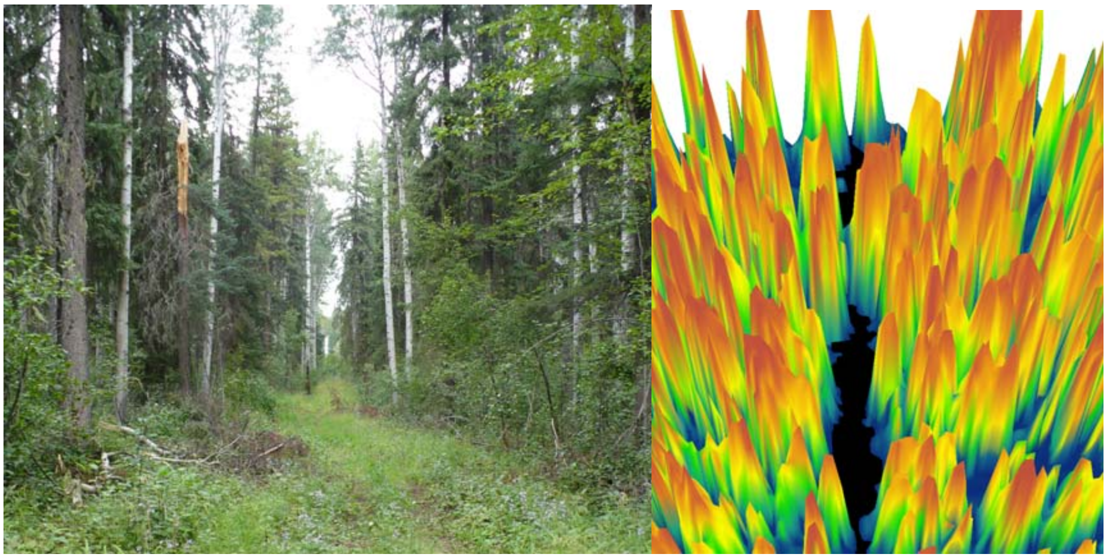


Figure 20 - Canopy closure, in this case from the canopy over an open seismic line (L), can be misrepresented in a CHM (R). The vegetation that grows over a line footprint is shown as emanating from the ground and continuous to height in the CHM even when that does not accurately represent truth. In the CHM, the seismic line edges are clearly obscured, thereby minimizing footprint extent and, in some instances, show high recovery heights as a result of canopy and subcanopy side closure, respectively. This clear misrepresentation is obvious when checked against an actual photograph of the seismic line, but such a level of detailed cross-referencing would be impossible when interpreting line recovery across a broad geographic region.

9 – GENERAL CONCLUSIONS

Our research clearly demonstrates that narrowing seismic lines reduces avoidance and selection behaviour by various birds and mammals. We recommend using narrow seismic lines as best practice whenever possible. Thresholds in seismic line width of < 3 metres seem to minimize changes in the greatest number of species. Wider linear features are more likely to be perceived as barriers or areas to be avoided (i.e. Ovenbird and marten), create habitat for early seral species (i.e. American Robin, Lincoln's Sparrow) and facilitate movement by generalist species (i.e. black bear).

Wide and narrow lines recover over time as vegetation succession occurs. Thus, when evaluating whether seismic line thresholds have been surpassed, it is not appropriate to count all lines. Older lines generally will have incurred some level of vegetation recovery that needs to be considered. However, there is a large amount of variation in regeneration rates between seismic lines of the same age and even along sections of the same seismic line. This means that seismic lines cut in year *X* should not be arbitrarily deleted from threshold calculations. Evaluation of vegetation conditions on each seismic line is needed because of the highly variable recovery of line sections.

Vegetation thresholds required to call a line recovered depend on the wildlife species considered. However, the conditions described for moderately-closed and closed seismic lines (Table 2 & Table 10) achieve similar or beneficial functions for many birds and mammals. Importantly, the vegetation variables that wildlife responded to were not trees *per se*. Horizontal structure, canopy openness and shrub density were the variables that primarily influenced wildlife, suggesting that a planting strategy aimed at achieving tall trees may not be the best strategy for minimizing seismic line impacts on wildlife. Working to minimize line of sight and creating protective and nesting cover seem to be more important than growing tall trees on seismic lines. As we finish our LiDAR work, we plan to provide remote-sensed criteria that correlate with our on-the-ground vegetation measurements so that more complete evaluations of seismic line recovery at a landscape scale can be done.

Seismic lines clearly have an impact on wildlife behaviour. Thus, if the objective is to have "no change" in behaviour of wildlife, our recommendation is conventional seismic line techniques should not be used. Encouraging technology that narrows seismic line width seems to be the most cost-effective way for the energy sector to reduce risks to biodiversity. Efforts to recover seismic lines through vegetation reclamation are likely to have ecological benefits, but will take time to materialize unless aggressive revegetation strategies and access management are implemented.

However, if the objective is to have less than *X*% change in habitat suitability for species *,* then more dynamic planning and decision-making has to occur. The only species for which we found strong evidence of a population change were marten. Importantly, changes in marten populations with increasing seismic line density seem to be linear. A threshold where occurrence was stable and then marten declined rapidly would have been ideal as it would have provided a clear basis by which to say when marten perceive there to be too many seismic lines. However, with a slow degradation of habitat quality for this species with more seismic lines, there is "no safe" and "no catastrophic" level of seismic line development. Marten can be found in areas with lots of seismic lines but do so less regularly than in areas with no seismic lines.

Threshold-setting when human impact-biodiversity relationships are based on linear models becomes a social rather than an ecological decision. Participants have to decide how many units of habitat for species *Y* are enough. To do this, landscape simulations need to be done to identify the landscape level change in habitat availability that will occur based on proposed levels of oil and gas development in regions of interest. The data provided in this report facilitate such simulations, as they quantify how the effects of oil and gas development should be incorporated in the model. With such models, managers can make decisions and use science to inform the magnitude of change that is likely to happen under any given development scenario. By way of example, we point the reader to a report co-authored by Dr. Bayne at http://www.borealcanada.ca/documents/report-MkSA0108_FINAL.pdf. In this report, we used the landscape simulator ALCES to project the future state of boreal birds as a function of forest age and forest type, and assumptions about how birds respond to oil and gas development. Many of those assumptions about how birds would react to oil and gas development were based on opinions rather than any scientifically credible data. We are currently updating these projections based on the results found in this report. A similar effort is required for marten and black bears.

10 - ACKNOWLEDGEMENTS

We would like to thank the members of our Technical Advisory Group for their support of our research. Karen Halwas, Ray Case, Chandra Venables, Karin Clark, Craig Machtans, Tom Lakusta and David Kerr participated in stimulating discussions at various stages of project development. Nicole McCutchen and two anonymous reviewers provided excellent comments on earlier drafts of the report. We would especially like to thank all of the hard-working field technicians: James Campbell, Martin Lankau, Simon Valdez, Bryce Hoye, Doug MacNearney, Melanie Wilson, Emily Hamble, Kaela Perry, Jenny Atamanick, Logan McLeod, Alexandre MacPhail, Joshua See, Trey McCuen, Calvin Chueng, Jake Hayden, Sean O'Donovan, Jason Masserone, Dave Huntzinger, Marija Minic and Sam Leslie.

Remote sensing and GIS products were provided by Petr Cizek of the Dehcho First Nation, Tom Lakusta and Lisa Smith of GNWT Environment and Natural Resources, Forest Management Division, Conrad Thiessen of BC Ministry of Environment, Fish and Wildlife Branch, IHS, and Shannon Hazard of Ducks Unlimited Canada.

Various organizations and their staff provided equipment and other in-kind field support including Apache Canada, Canadian Natural, Nabors International, Scott Grindall of ConocoPhillips Canada, Denis Dufresne of EOG, Scott Wagner of Nexen, Craig Machtans of Environment, Danny Allaire Jr., Nic Larter and Floyd Bertrand of GNWT-ENR, Indian and Northern Affairs Canada (INAC), Gilbert Capot-Blanc of Acho Dene Koe First Nation, and Deh G'ah Got'ie First Nations Integrated Landscape Management (ILM).

The primary source of funding for this project was the Environmental Studies Research Fund. Additional funding was provided by Environment Canada, Paramount Resources, Circumpolar/Boreal Alberta Research, Alberta Sport, Recreation, Parks, and Wildlife Foundation, Alberta Upstream Petroleum Research Fund, and Natural Sciences and Engineering Research Council.

11 – LITERATURE CITED

Antoniuk, T., Kennett, S., Aumann, C., Weber, M., Davis-Schuetz, S., McManus, R. McKinnon, K., and K. Manuel. 2009. Valued Component Thresholds (Management Objectives) Project. Environmental Studies Research Fund Report No. 172. Calgary, Alberta.

Ball, J.R., E.M. Bayne, and C.M. Machtans. 2009a. Identification of boreal forest songbird nest predators and discordance with artificial nest studies. In Rich, T.D., Carizmendi, D. Demarest and C. Thompson [eds.] Tundra to Tropics: Connecting Birds, Habitats and People, pp 37-44, Proceedings of the 4th International Partners in Flight Conference. Partners in Flight.

Ball, J.R., E.M. Bayne, and C.M. Machtans. 2009b. Energy sector edge effects on songbird nest fate and nest productivity in the boreal forest of western Canada: A preliminary analysis. In Rich, T.D., Carizmendi, D. Demarest and C. Thompson [eds.] Tundra to Tropics: Connecting Birds, Habitats and People, pp 161-170, Proceedings of the 4th International Partners in Flight Conference. Partners in Flight.

Basset-Touchell C. A. 2008. Anthropogenic influences on the ecology of forest songbirds within Sleeping Bear Dunes National Lakeshore: Focusing on roads. Michigan Technological University (http://gradworks.umi.com/33/39/3339423.html) *

Bayne, E.M. and B. Dale. 2010. Will energy demand too much of songbirds? In: Energy Development & Wildlife Conservation in Western North America. Island Press. Ed. John Naugle.

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

Bayne, E.M., Van Wilgenburg, S.L., Boutin, S., and Hobson, K.A., 2005a. Modeling and field-testing of ovenbird (Seiurus aurocapillus) responses to boreal forest dissection by energy sector development at multiple spatial scales. Landscape Ecology 20: 203-216.

Bradford, D.F., S.E. Franson, A.C. Neale, D.T. Heggem, G.R. Miller, and G.E. Canterbury. 1999. Bird species assemblages as indicators of biological integrity in Great Basin rangeland. Environmental Monitoring and Assessment 49: 1-22.

Chasko, G.G, and J.E. Gates. 1982. Avian Habitat Suitability along a Transmission-Line Corridor in an Oak-Hickory Forest Region. Wildlife Monographs 82: 3-41. *

Confer, J. L., and S. M. Pascoe. 2003. Avian communities on utility rights-of-ways and other managed shrublands in the northeastern United States. Forest and Ecology Management 185: 193-205. *

Darling, A. 2008. Linear feature effects on small mammal abundance and resources in the boreal forest. MSc thesis, University of Alberta.

DCLUPC – The Dechcho Land Use Planning Committee, 2006. Respect for the Land: The Dehcho Land Use Plan -- Final Draft. Fort Providence, Northwest Territories.

Dyer, S.J., O'Neill, J.P., Wasel, and S.M., Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80: 839-845.

Evans, J.S., Hudak, A.T., Faux, R., and A.M.S. Smith. 2009. Discrete return Lidar in natural resources: recommendations for project planning data processing, and deliverables. Remote Sensing 1: 776-794.

Fahrig, L., 2002. Effects of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications 12: 346-353.

Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society **14**(1): 21. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art21/

Ferris, C. R. 1979. Effects of Interstate 95 on Breeding Birds in Northern Maine. Journal of Wildlife Management 43: 421-427 *

Fleming, W.D. and F.K.A. Schmiegelow. 2003. Response of bird communities to pipeline rights-of-way in the boreal forest of Alberta. In The Seventh International Symposium on Environmental Concerns in Rights-of-Way Management. Elsevier Science, pp 431-437. *

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

Gaulton, R., and T.J. Malthus. 2010. LiDAR mapping of canopy gaps in continuous cover forests: a comparison of canopy height model and point cloud based techniques. International Journal of Remote Sensing 31: 1193-1211.

Groffman, P.M., Baron, J.S., Blett, T., Gold, A.J., Goodman, I., Gunderson, L.H., Levinson, B.M., Palmer, M.A., Paerl, H.W., Peterson, G.D., Poff, N.L., Rejeski, D.W., Reynolds, J.F., Turner, M.G., Weathers, K.C., and J. Wiens. 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application? Ecosystems 9: 1-13.

Hudak, A.T., Evans, J.S., and A.M.S. Smith. 2009. LiDAR utility for natural resource managers. Remote Sensing 1: 934-951.

Huggett, A.J., 2005. The concept and utility of 'ecological thresholds' in biodiversity conservation. Biological Conservation 124: 301-310.

James, A.R.C., and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64: 154-159.

Kearey, P., Brooks, M., and I. Hill. 2002. An Introduction to Geophysical Exploration, 3rd Edition. Wiley-Blackwell.

Kennett, S. 2006. From science-based thresholds to regulatory limits: implementation issues for cumulative effects management. Canadian Institute of Resource Law, Prepared for Environment Canada, Northern Division, Calgary, Alberta.

Kroodsma R. L. 1987. Edge Effect on Breeding Birds along Power-line Corridors in East Tennessee. American Midland Naturalist 118: 275-283. *

Kroodsma, R. L. 1982. Bird community ecology on power-line corridors in east Tennessee. Biological Conservation 23: 79-94. *

Kroodsma, R. L. 1982. Edge effect on breeding forest birds along a power-line corridor. Journal of Applied Ecology 19: 361-370. *

Kroodsma, R. L. 1984. Ecological factors associated with degree of edge effect in breeding birds. Wildlife Management 48: 418-425. *

Kroodsma, R. L. 1984. Effect of edge on breeding forest bird species. Wilson Bulletin 96: 426-436. *

Latham, A.D.M., Latham, M.C., Boyce M.S., and S. Boutin. 2011. Movement responses by wolves to industrial linear features and its effect on woodland caribou in northeastern Alberta. Ecological Applications. Preprint at: http://www.esajournals.org/doi/pdf/10.1890/11-0666.1

Lee, P., and S. Boutin. 2006. Persistence and developmental transition of wide seismic lines in the western Boreal Plains of Canada. Journal of Environmental Management 78: 240-250.

Lefsky, M.A., Cohen, W.B., Parker, G.G., and D.J. Harding. 2002. Lidar remote sensing for ecosystem studies. Bioscience 52: 19-30.

Lindenmayer, D.B., Fischer, J., and R.B. Cunningham. 2005. Native vegetation cover thresholds and species responses. Biological Conservation 124: 351-354.

MacFarlane, A.K., 2003. Vegetation response to seismic lines: edge effects and on-line succession. M.Sc. Thesis, Department of Biological Sciences, University of Alberta, Edmonton, Alberta.

Machtans, C.S. 2006. Songbird response to seismic lines in the western boreal forest: a manipulative experiment. Canadian Journal of Zoology 84: 1421-1430. *

Marshall, J. S. and L. W. Vandruff. 2002. Impact of selective herbicide right-of-way vegetation treatment on birds. Environmental Management 30: 801-806. *

Miller, S.G. Knight, R. L., Miller, C. K. 1998. Influence of recreational trails on breeding bird communities. Ecological Applications 8: 162-169. *

Miura, N., and S.D. Jones. 2010. Characterizing forest ecological structure using pulse types and height of airborne laser scanning. Remote Sensing of Environment 114: 1069-1076.

National Road Authority. 2008. Environmental impact assessment of national road schemes – A practical guide. Available at: http://www.nra.ie/Publications/DownloadableDocumentation/Environment/file,3488,en.pdf

Nielsen, S.E., Herrero, S., Boyce, M.S., Benn, B., Mace, R.D., Gibeau, M.L., and S. Jevons. 2004. Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation 120: 101-113.

Niemi, G. J. and J. M. Hanowski. 1984. Relationship of breeding birds to habitat characteristics in logged areas. Journal of Wildlife Management 48: 438-443. *

Nitschke, C.R., 2008. The cumulative effects of resource development on biodiversity and ecological integrity in the Peace-Moberly region of northeast British Columbia, Canada. Biodiversity and Conservation 17: 1715-1740.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 2000. Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications 10: 1706-1721.

Ortega, Y. K., and D. E. Capen. 2002. Roads as edges: Effects on birds in forested landscapes. Forest Science 48: 381-390. *

Poole, K.G., A.D. Porter, C. Maundrell, S.D. Grindall, and C.C. St Clair. 2004. Suitability of a young deciduous-dominated forest for American marten and the effects of forest removal. Canadian Journal of Zoology 82: 423-435.

Potvin, F. L. Belanger, and K. Lowell. 2000. Marten habitat selection in a clearcut boreal landscape. Conservation Biology 14: 844-857.

Revel, R.D., Dougherty, T.D., and D.J. Downing. 1984. Forest Growth and Revegetation along Seismic Lines. The University of Calgary Press, Calgary, Alberta.

Rich, A. C., Dobkin, D. S., and L. J. Niles. 1994. Defining Forest Fragmentation by Corridor Width: The Influence of Narrow Forest-Dividing Corridors on Forest-Nesting Birds in Southern New Jersey. Conservation Biology 8: 1109-1121. *

Salmo Consulting, Axys Environmental Consulting, Forem Technologies, Wildlife and Company, 2004. Deh Cho cumulative effects study, Phase I: management indicators and thresholds. Salmo Consulting, Calgary, Canada..

Santilo, D.J. 2000 Effects of pipeline right-of-way construction on wetland vegetation and breeding birds in Northern New York State" –State University of New York, M.Sc. thesis) *

Schneider, R.S. 2002. Alternative futures: Alberta's boreal forest at the crossroads. The Federation of Alberta Naturalists and The Alberta Centre for Boreal Research, Edmonton, Alberta.

Seip, D.R., and D.B. Cichowski. 1996. Population ecology of caribou in British Columbia. Rangifer 9:73-80.

Small, M. F., and M. L. Hunter. 1989. Response of Passerines to Abrupt Forest-River and Forest-Powerline Edges in Maine. Wilson Bulletin 101: 77-83. *

Sumerling, G., 2011. Lidar Analysis in ArcGIS 10 for Forestry Applications. An ESRI Whitepaper, ESRI, Redlands, California.

Tertzakian, P., and K. Baynton. 2011. Turmoil and renewal: the fiscal pulse of the Canadian upstream oil and gas industry, a five-year outlook. Arc Financial Corp. published for CAPP (Canadian Association of Petroleum Producers), Calgary, Canada.

Thompson, I.D., and P.W. Colgan. 1994. Marten activity in uncut and logged boreal forests in Ontario. Journal of Wildlife Management 58:280-288.

Toms, J.D. and M.L. Lesperance. 2003. Piecewise regression: A tool for identifying ecological thresholds. Ecology 84: 2034-2041.

Turner, M.G., and R.H. Gardner. 1991. Quantitative methods in landscape ecology: an introduction. In M.G. Turner and R.H. Gardner (eds), Quantitative methods in landscape ecology, pp 3-14. Springer-Verlag, New York, USA.

Vierling, K.T., Vierling, L.A., Gould, W.A., Martinuzzi, S., and R.M. Clawges. 2008. Lidar: shedding new light on habitat characterization and modeling. Frontiers in Ecology and the Environment : 90-98.

Whitaker D.M., and D. M. Montevecchi. 1997. Breeding bird assemblages associated with riparian, interior forest, and nonriparian edge habitats in a balsam fir ecosystem. Canadian Journal of Forest Research-Revue Canadienne de recherche Forestiere 27: 1159-1167. *

With, K.A., Gardner, R.H., and M.G. Turner. 1997. Landscape connectivity and population distributions in heterogeneous environments. Oikos 78: 151-169.

Wulder, M.A., White, J.C., Cranny, M., Hall, R.J., Luther, J.E., Beaudoin, A., Goodenough, D.G., and J.A. Dechka. 2008. Monitoring Canada's forests. Part 1: Completion of the EOSD land cover project. Canadian Journal of Remote Sensing 34: 549-562.

Yahner, R. H. 2000. Ecology and Wildlife Conservation, Second Edition. University of Minnesota Press*

Zheng, S., Shi, W.Z., Liu, J., and G.X. Zhu.2007. Facet-based airborne light detection and ranging data filtering method. Optical Engineering 46: 066202

APPENDIX 1 -LATIN NAMES OF SPECIES IN THIS REPORT

ENGLISH NAME	Scientific Name
BIRDS	
Alder Flycatcher	*Empidonax alnorum*
American Redstart	*Setophaga ruticilla*
American Robin	*Turdus migratorius*
Black-and-white Warbler	*Mniotilta varia*
Bay-breasted Warbler	*Dendroica castanea*
Boreal Chickadee	*Poecile hudsonica*
Clay-coloured Sparrow	*Spizella pallida*
Cedar Waxwing	*Bombycilla cedrorum*
Chipping Sparrow	*Spizella passerina*
Dark-eyed Junco	*Junco hyemalis*
Fox Sparrow	*Passerella iliaca*
Golden-crowned Kinglet	*Regulus satrapa*
Grey Jay	*Perisoreus canadensis*
Hermit Thrush	*Catharus guttatus*
Least Flycatcher	*Empidonax minimus*
Lincoln's Sparrow	*Melospiza lincolnii*
Magnolia Warbler	*Dendroica magnolia*
Ovenbird	*Seiurus aurocapilla*
Palm Warbler	*Dendroica palmarum*
Pine Siskin	*Carduelis pinus*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Red-breasted Nuthatch	*Sitta canadensis*
Ruby-crowned Kinglet	*Regulus calendula*
Red-eyed Vireo	*Vireo olivaceus*
Swainson's Thrush	*Catharus ustulatus*
Tennessee Warbler	*Vermivora peregrina*
Warbling Vireo	*Vireo gilvus*
Western Tanager	*Piranga ludoviciana*
Winter Wren	*Troglodytes troglodytes*
White-throated Sparrow	*Zonotrichia albicollis*
White-winged Crossbill	*Loxia leucoptera*
Yellow-bellied Flycatcher	*Empidonax flaviventris*
Yellow-rumped Warbler	*Dendroica coronata*

ENGLISH NAME	Scientific Name
PLANTS	
Scentless Chamomile	*Tripleurospermum perforatum*
Canada Thistle	*Cirsium arvense*
Annual Hawk's Beard	*Crepis tectorum*
Hemp Nettle	*Galeopsis tetrahit*
Foxtail Barley	*Hordeum jubatum*
Pineapple Weed	*Matricaria discoidea*
Black Medick	*Medicago lupulina*
Alfalfa	*Medicago spp.*
Timothy	*Phleum pratense*
Common Plantain	*Plantago major*
Perennial Sow thistle	*Sonchus arvensis*
Common Chickweed	*Stellaria media*
Common Dandelion	*Taraxacum officinale*
Stinkweed	*Thlaspi arvense*
Sweet Clover	*Melilotus spp.*