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Divergent patterns of understory forage growth after seismic line exploration: Implications for caribou habitat restoration

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ABSTRACT

Seismic lines are one of the most pervasive disturbances across the boreal forest of western Canada, with densities in Alberta as high as 10 km/km^2. The effect of seismic lines and associated habitat fragmentation on boreal wildlife is generally well understood, and most recently seismic lines have been focus of habitat restoration efforts to conserve declining woodland caribou (*Rangifer tarandus caribou*) populations. However, despite decades of research assessing wildlife response to seismic lines, little is known about the effects of seismic line clearing on the quality of understory forage for wildlife, or about the resilience of boreal understory communities to seismic line clearing. Using field data collected from 351 seismic lines across west-central and north-western Alberta, Canada, and focusing on forage taxa preferred by moose and bears, we (1) investigated whether understory forage taxa composition differed among seismic lines, seismic line edges, and the interior forest, and (2) assessed how this relationship changed as a function of seismic line attributes (ecosite, orientation, level of motorized human use, regeneration). Although we found regional differences and differences among ecosites, generally disturbance-tolerant forbs and graminoids were more abundant on seismic lines, *Rhododendron* spp. and *Vaccinium vitis-idaea* were more abundant on edges, and *Alnus, Salix* and *Betula* spp. were more abundant on edges and seismic lines. Attributes of seismic lines did not explain patterns of understory forage abundance, although we found positive relationships between motorized human use and abundance of *Chamerion* spp. and non-target graminoids. With habitat restoration for caribou in mind, this study increases understanding of patterns of understory forage availability on seismic lines, which could help prioritize seismic line restoration efforts to reduce forage attractive to primary wolf prey (moose), and bears, and decrease the spatial overlap between caribou and predators. Overall, our results reveal that even decades after construction, understory forage on seismic lines is different from the interior forest, and is similar to that of harvest blocks. Silviculture and reforestation are recognized as key components for the recovery of harvested areas, and our results suggest that the same treatments may be needed to re-establish or maintain natural successional trajectories on seismic lines. By focusing on habitat changes that influence wildlife responses, such as changes in the presence and abundance of forage used by moose and bears, this study provides valuable insight into the need for active restoration of seismic lines to restore boreal forest ecosystems.

1. Introduction

The boreal forest of western Canada has been extensively altered by human activities (Pattison et al., 2016; Timoney and Lee, 2001). The effects of habitat alteration on boreal wildlife are well documented (Venier et al., 2014), and habitat restoration is recognized as a key tool for conservation of species at risk; in particular for woodland caribou (*Rangifer tarandus caribou*; Environment Canada, 2012). Although most habitat alterations are of concern, conventional seismic lines (hereafter 'seismic lines') are one of the most pervasive disturbances across the boreal forest of western Canada, and in Alberta can reach densities as high as 10 km/km^2 (Lee and Boutin, 2006; Pattison et al., 2016).

Seismic lines are 5–8 m wide, generally unmaintained, linear features constructed by the energy sector during exploration activities prior to 1990 (Revel et al., 1984). Soil on seismic lines is compacted by heavy machinery used during construction and often through continued motorized human use (Lee and Boutin, 2006). The resulting alterations to hydrology and microsite topography (Braverman and Quinton, 2016; Lee and Boutin, 2006) delay natural succession and alter species composition (Revel et al., 1984; van Rensen et al., 2015). Furthermore,

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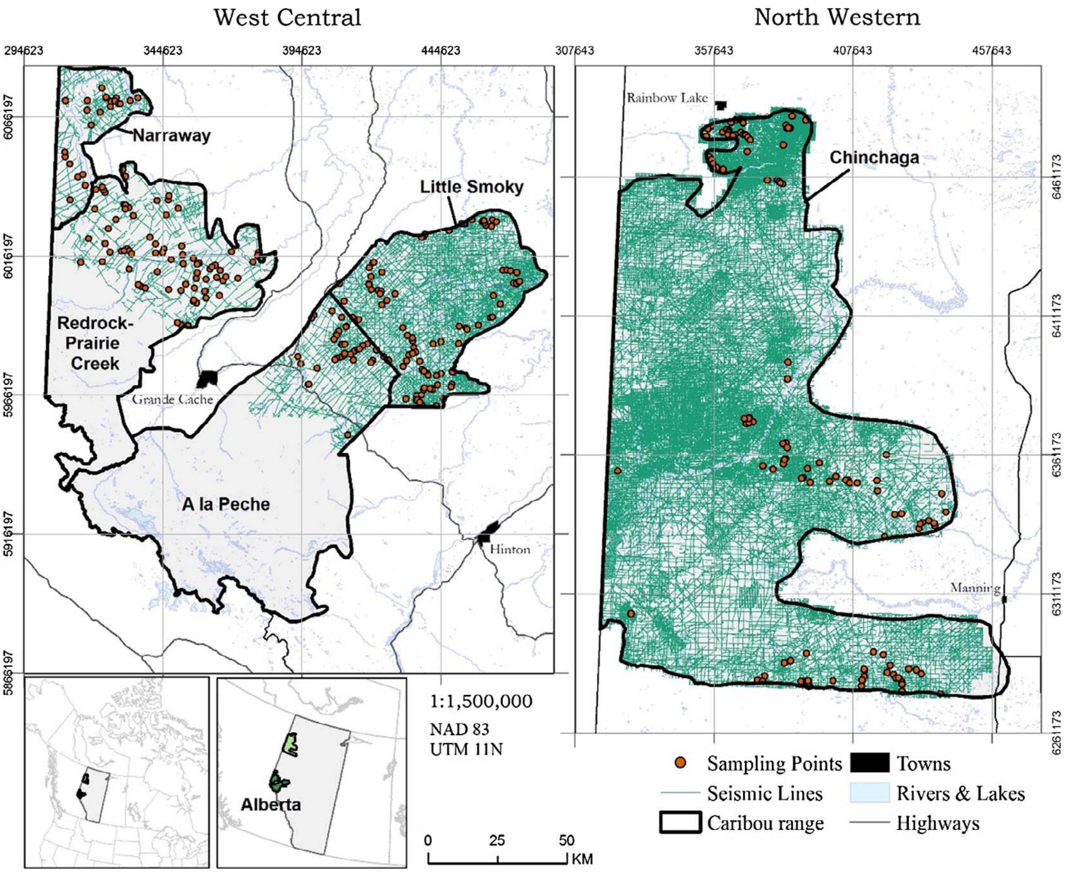

Fig. 1. Study area in west-central and north-western Alberta, Canada showing seismic line footprint, and the location of subplots sampled on seismic lines, at the edges of seismic lines and in the interior forest during the summers of 2014 and 2015.

Table 1
Taxa preferred by moose (Ms) and bears (B) sampled within 1 m² and 10 m² subplots located in the interior forest, at seismic line edges, and on seismic lines in west-central and north-western Alberta, Canada during the summers of 2014 and 2015.

1 m²			
Forbs and graminoids		**Dwarf shrubs**	
Carex spp. Linnaeus	Ms	*Arctostaphylos uva-ursi* Linnaeus (Sprengel)	B
Chamerion spp. Linnaeus	Ms	*Empetrum nigrum* Linnaeus	B
Equisetum spp. Linnaeus	Ms|B	*Rhododendron* spp. Linnaeus	Ms
Lathyrus spp. Linnaeus	B	*Vaccinium vitis-idaea* Linnaeus	Ms|B
Hedysarum spp. Linnaeus	B	*Vaccinium* spp. Linnaeus	B
Trifolium spp. Linnaeus	Ms|B		
Non-target graminoids[a]	Ms|B		
Non-target forbs[a]	Ms|B		
10 m²			
Large shrubs			
Alnus spp. Miller	Ms		
Betula spp. Linnaeus	Ms		
Lonicera spp. Linnaeus	B		
Ribes spp. Linnaeus	Ms|B		
Salix spp. Linnaeus	Ms		
Shepherdia canadensis Linnaeus (Nuttall)	B		
Viburnum edule Michaux (Rafinesque)	Ms|B		

[a] Forbs and graminoids that occurred within the subplot that were not classified as individual taxa preferred by moose and bears, but that were considered moose and bear forage.

increased light and soil temperature affects understory species growth, not only on seismic lines, but also in the forest adjacent to seismic lines (Dabros et al., 2017; Revel et al., 1984). Research in tundra and boreal habitats in the Northwest Territories and Alberta found that even 30–50 years after clearing, tree and understory communities on seismic lines remained dissimilar to the adjacent forest, indicating a failure to regenerate towards the original vegetative community (Joregenson et al., 2010; Kemper and Macdonald, 2009; Revel et al., 1984).

In addition to the fragmentation effect of seismic lines on habitat for boreal wildlife (Pattison et al., 2016), the long-lasting distributional shifts in understory species growth on seismic lines negatively impact wildlife like caribou, marten (*Martes americana*), and ovenbirds (*Seiurus aurocapilla*; Lankau et al., 2013; Polfus et al., 2011; Tigner et al., 2015) that are associated with late seral forest. Conversely, for large ungulates such as moose (*Alces alces*) and deer (*Odocoileus* spp.), and omnivores like black bears (*Ursus americanus*) and grizzly bears (*Ursus arctos*) that are associated with early seral forest, understory species on regenerating seismic lines and seismic line edges provide potentially beneficial vegetative food resources (Dawe et al., 2017; Franklin and Harper, 2016; Revel et al., 1984). Understory species growing on, and adjacent to seismic lines can also indirectly benefit ungulate specialists such as wolves (*Canis lupus*) and cougars (*Puma concolor*) by attracting ungulate prey (Hebblewhite et al., 2005; Knopff et al., 2014; Roffler et al. 2018).

Because regeneration on seismic lines is slow or in some cases stalled altogether, many seismic lines will require active restoration (i.e., tree planting) to reach a pre-disturbance state. Although recent efforts have focused on informing restoration targets using remote-sensing derived measurements of regeneration height on seismic lines (Dickie et al., 2017; van Rensen et al., 2015), it is still unclear how current species communities on seismic lines differ from the adjacent forest at a fine scale. Previous work in the grey literature has described boreal understory species growth relative to seismic line disturbance (Lankau, 2014; MacFarlane, 2003; Revel et al., 1984), but to our knowledge, with the exception of one study focused on *Vaccinium*

Table 2
Covariates used to model understory forage taxa preferred by moose and bears located on subplots in the interior forest (Offline), at seismic line edges (Edge), and on seismic lines (Online) sampled in west-central and north-western Alberta, Canada during the summers of 2014 and 2015. All covariates were sampled at field plots with the exception of NSR which was sampled using a GIS.

Covariate	Description	Type	Domain
Type	Subplot type – Online, Edge, Offline[a]	Factor	–
PlotID	Seismic line sampling plot ID	Factor	–
Taxa	Abundance (proportion cover, 0–1) of each focal taxa (see Table 1)	Continuous	$0 \le x \le 1$
Regen	Maximum regeneration height of trees and woody shrubs (m) within online subplots	Continuous	$x \ge 0$
HUse	Level of motorized human use: 0 no human[a], 1 human use	Binary	0 or 1
Orientation	Orientation of seismic line transformed to values between 0 (E/W)[a] and 1 (N/S)	Continuous	$0 \le x \le 1$
NSR	Natural subregion: North-western - Upper Boreal Highlands[a] (UBH), Boreal Highlands (BH), West-central - Subalpine (SA), Upper Foothills (UF)[a], Lower Foothills (LF)	Factor	–
Ecosite[b]	*Hydric* – k (subhydric/poor; bog), l (subhydric/rich; fen), m (subhydric/rich; rich fen) *Hygric* – g (subhygric/very rich; meadow), h (subhygric/poor; Labrador tea-subhygric), i (hygric/rich; horsetail), j (hygric/medium; Labrador tea/horsetail) *Mesic* – d (mesic/poor; Labrador tea-mesic), e (mesic/medium; low-bush cranberry), f (subhygric/rich; bracted honeysuckle)	Factor	–

[a] Reference category.,
[b] Defined in Beckingham et al. (1996).

Table 3
Candidate models used to assess differences in understory forage taxa preferred by moose and bears among subplots located in the interior forest (Type(Offline)) at seismic line edges (Type(Edge)) and on seismic lines (Type(Online)) in west-central and north-western Alberta, Canada during the summers of 2014 and 2015. Taxa are described in Table 1 and covariates are described in Table 2.

Model	Model name	Model structure[a]
M1	Null	Taxa ~ (1|PlotID),
M2	Type	Taxa ~ Type[b] + NSR + (1|PlotID)
M3	Human use	Taxa ~ Type[b] * HUse[b] + NSR[b] + (1|PlotID)
M4	Orientation	Taxa ~ Type[b] * Orientation + NSR[b] + (1|PlotID)
M5	Regeneration	Taxa ~ Type[b] * Regen + NSR[b] + (1|PlotID)
M6	Orientation and human use	Taxa ~ Type[b] * HUse[b] * Orientation + NSR[b] + (1|PlotID)
M7	Regeneration and human use	Taxa ~ Type[b] * HUse[b] * Regen + NSR[b] + (1|PlotID)

[a] The dispersion parameter was held constant in all models (σ ~ 1).
[b] Reference categories were – Type (Offline), HUse (0), NSR (UF) in west-central and NSR (UBH) in north-western.

myrtilloides (Dawe et al., 2017), there are no studies reporting on species communities growing on conventional seismic lines in the peer-reviewed literature, although Dabros et al. (2017) investigated plant communities established on recently constructed (< 4 years), and narrow (2–3 m), low-impact seismic lines. In the context of caribou recovery, caribou generally avoid seismic lines (Dyer et al., 2001; Johnson et al., 2015). However, as seismic lines increase the probability of encounters between caribou and their predators (Mumma et al., 2017), reducing predator use of seismic lines is the immediate focus of seismic line restoration efforts (Dickie et al., 2017). As ungulate specialists, wolves use habitats linked to habitat used by their prey (Seip, 1992; Roffler et al., 2018), while as omnivores, bears use habitats associated with vegetative food resources (Nielsen et al., 2010), and opportunistically feed on ungulates, including caribou (Bastille-Rousseau et al., 2011; Kinley and Apps, 2001). Despite the logical link between forage on seismic lines and use of seismic lines by caribou predators, to our knowledge no research to date has assessed patterns of forage availability on seismic lines; specifically forage preferred by primary wolf prey (moose), and forage preferred by bears. Targeting seismic line restoration efforts to reduce forage attractive to primary wolf prey and bears in caribou ranges could help to reduce the spatial overlap between caribou and shared predators, and contribute towards caribou conservation efforts.

With habitat restoration for caribou in mind, our objective was to assess patterns of wildlife forage growth on seismic lines. Using data collected on understory forage taxa preferred by a generalist herbivore (moose), and generalist omnivores (bears), we (1) determined whether understory forage species composition differed among seismic lines, seismic line edges, and the interior forest and (2) assessed how this relationship changed as a function of seismic line attributes. Because of increased solar radiation, mechanical damage, and altered microsite hydrology on seismic lines as a result of seismic line clearing (Braverman and Quinton, 2016; Lee and Boutin, 2006; Revel et al., 1984) we predicted that occurrence of understory forage taxa would differ between seismic lines, seismic line edges, and the interior forest, and that abundance of understory forage taxa would be different on seismic lines and seismic line edges when compared to the interior forest. Specifically we predicted that occurrence and abundance of understory forage taxa would be (1) higher in wetter areas where tree regeneration is limited (Revel et al., 1984; van Rensen et al., 2015), (2) higher on seismic lines with less motorized human use because motorized human use negatively affects plant growth (van Vierssen Trip and Wiersma, 2015), and (3) higher on north/south (N/S) orientated seismic lines and the edges of east/west (E/W) seismic line lines because of increased light intensity on a N/S orientation near midday (Chen et al., 1993; Matlack, 1993; Revel et al., 1984). Also, because boreal understory species are adapted to periodic disturbance, and are likely relatively resilient to moderate levels of ground disturbance (Harper et al., 2004; Hart and Chen, 2006), we predicted that (4) understory taxa composition and cover on seismic lines and seismic line edges would become more similar to the interior forest as regeneration height on the seismic line increased. Understanding how understory species differ among seismic lines, seismic line edges, and the forest interior could not only help define and direct restoration treatments on specific seismic lines to reduce the spatial overlap between caribou and predators, but also increases our overall understanding of the resilience of boreal understory species to seismic line disturbance.

2. Materials and methods

2.1. Study area

The study area was located in caribou ranges in west-central and north-western Alberta, Canada (Fig. 1). The west-central region included the lower foothills, upper foothills, and subalpine natural subregions (Natural Regions Committee, 2006). Forests in the west-central region are mainly coniferous and characterized by lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), and trembling aspen (*Populus tremuloides*) in upland areas, and black spruce (*Picea mariana*), larch (*Larix laricina*), and poorly drained muskeg in lowland areas (Natural Regions Committee, 2006; Smith et al., 2000). The north-western region included the lower and upper boreal highlands natural sub-regions (Natural Regions Committee, 2006), and forests were

Table 4
Final zero-inflated model structure and associated R^2 explaining absence (Abs) and abundance (Abn) of understory forage taxa preferred by moose and bears and sampled within subplots located in the interior forest, at seismic line edges, and on seismic lines in west-central and north-western Alberta, Canada during the summers of 2014 and 2015. Best models were identified using GAIC (see Section 2.3 and Appendix B). Models (M) are described in Table 3. Limited occurrence data in some ecosite and regional strata prevented statistical modelling for some taxa (see Appendices A and B).

	West-central			North-western	
	Hydric	Hygric	Mesic	Hygric	Mesic
Forbs and Graminoids	Abs|Abn, R^2	Abs|Abn, R^2	Abs|Abn, R^2	Abs|Abn, R^2	Abs|Abn, R^2
Carex spp.	M2|M2, 0.70	M1|M1, NA	M4|M4, 0.64	M2|M1, 0.80	M2|M2, 0.48
Chamerion spp.	–	–	M7|M3, 0.59	–	M2|M7, 0.70
Equisetum spp.	M5|M1, 0.86	M2|M1, 0.87	M2|M4, 0.62	M1|M3, 0.76	M3|M4, 0.74
Lathyrus spp.	–	–	M2|M2, 0.32	–	M5|M2, 0.75
Hedysarum spp.	–	–	–	–	–
Trifolium spp.	–	–	–	–	–
Non-target graminoids	M2|M3, 0.85	M1|M2, 0.76	M5|M4, 0.76	M2|M1, 0.45	M2|M4, 0.74
Non-target forbs	M2|M3, 0.76	M1|M2, 0.50	M2|M1, 0.73	M5|M1, 0.80	M2|M1, 0.76
Dwarf shrubs					
Arctostaphylos uva-ursi	–	–	M2|M1, 0.31	–	–
Empetrum nigrum	–	–	M4|M6, 0.53	–	–
Rhododendron spp.	M1|M2, 0.66	M1|M3, 0.69	M3|M4, 0.71	M5|M1, 0.74	M1|M1, NA
Vaccinium vitis-idaea	M4|M4, 0.74	–	M2|M5, 0.70	M1|M2, 0.72	M1|M2, 0.68
Vaccinium spp.	–	M1|M1, NA	M5|M1, 0.72	–	M2|M1, 0.52
Large shrubs					
Alnus spp.	–	–	M3|M5, 0.62	M1|M2, 0.63	M2|M1, 0.71
Betula spp.	M1|M1, NA	M1|M1, NA	M5|M4, 0.55	M2|M1, 0.68	–
Lonicera spp.	–	–	M2|M2, 0.45	–	–
Ribes spp.	–	–	M1|M1, NA	–	M3|M7, 0.88
Salix spp.	M2|M5, 0.83	M4|M1, 0.81	M4|M7, 0.74	M2|M2, 0.70	M2|M1, 0.49
Shepherdia canadensis[a]	–	–	M2|M1, 0.37	M2|M2, 0.69	M4|M2, 0.76
Viburnum edule	–	–	M2|M2, 0.39	–	M1|M1, NA

[a] In the north-western region as there were too few records within edge subplots to build models, comparisons were between offline and online subplots.

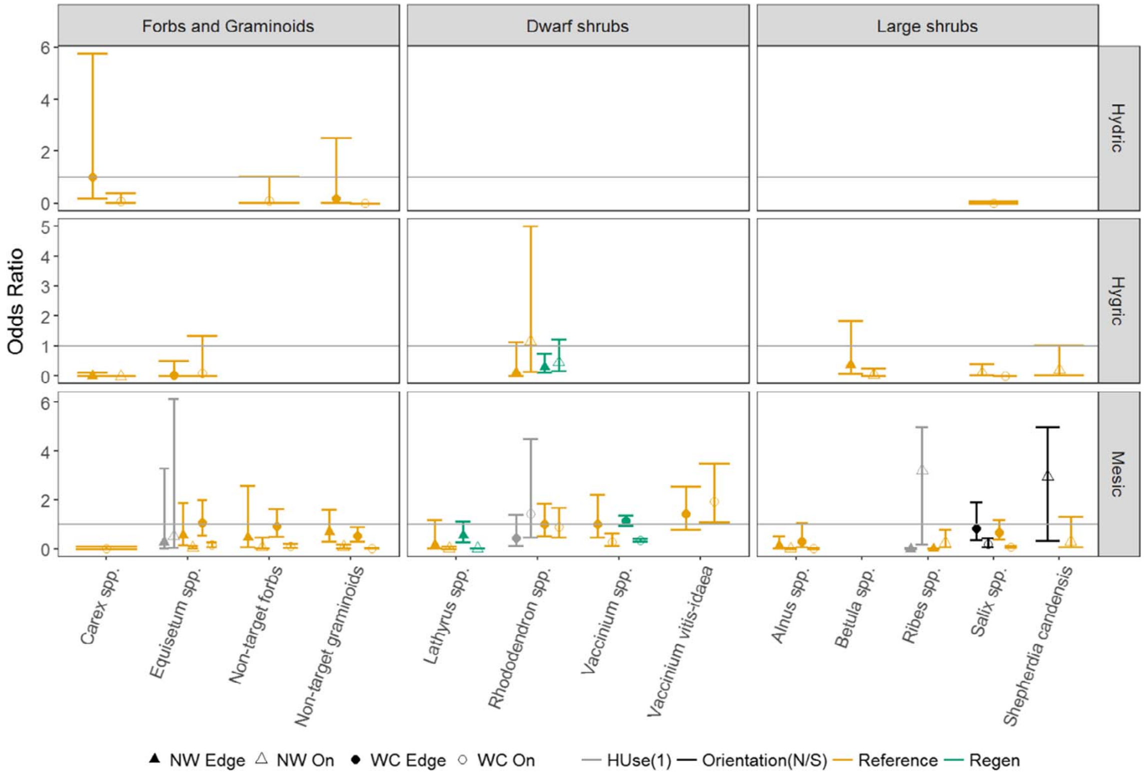

Fig. 2. Odds ratios (OR) and 95% confidence intervals (CI) for understory taxa absence in subplots located on seismic lines (On) and in the adjacent forest stand edge (Edge) relative to subplots located in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand (Off). Sites were sampled in west-central (WC) and north-western (NW) Alberta, Canada within Hydric, Hygric, and Mesic ecosites during the summers of 2014 and 2015. Notes: OR represent differences between offline and online/edge subplots (reference category only), or interactions between offline and online/edge subplots and levels of motorized human use (Reference: HUse(0) vs. HUse(1)), seismic line orientation (Reference: Orientation E/W vs. Orientation(N/S)), and regeneration (Reference: Regen 0 m vs. Regen 1 m). For data visualisation, we curtailed the upper 95% CI of *Ribes* spp. in mesic ecosites in the north-western region to 5, actual upper 95% CI for online subplots was 57. Results for edge subplots of *Salix* spp. in hygric ecosites, and for online and edge subplots of *Vaccinium vitis-idaea* in hydric ecosites are not shown because of extremely large upper 95% CI; in both cases 95% CI crossed 1.

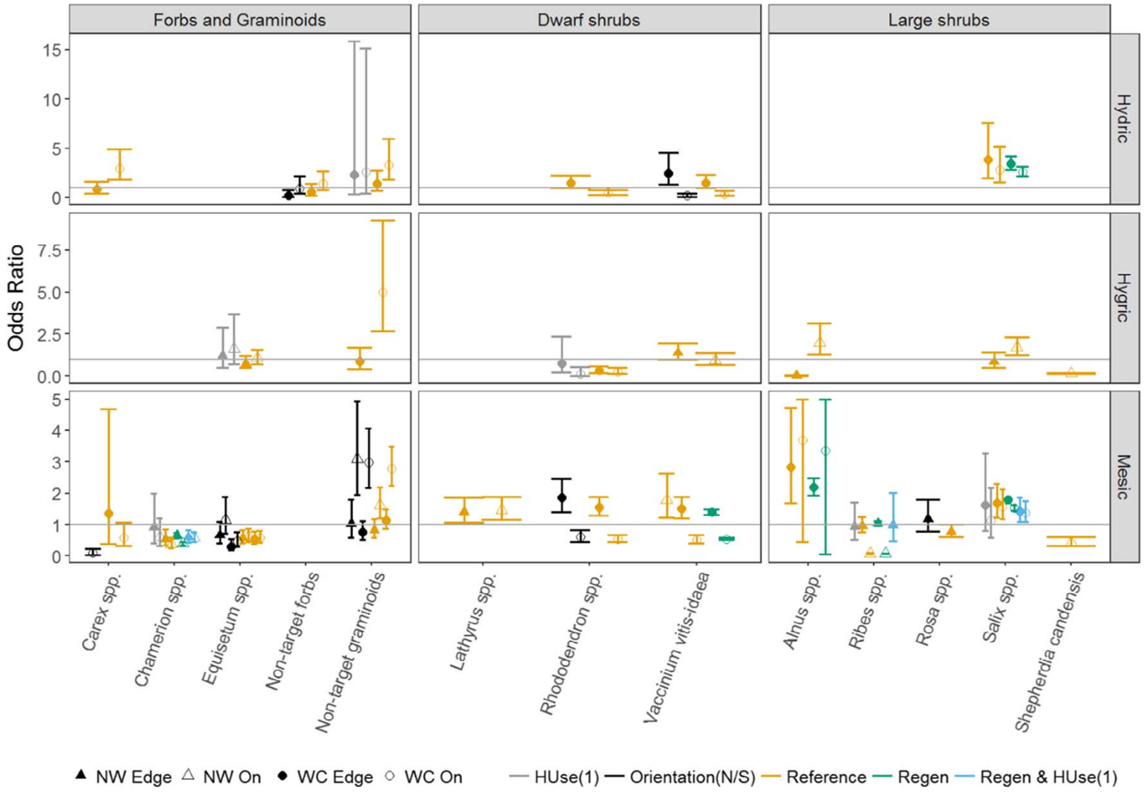

Fig. 3. Odds ratios (OR) and 95% confidence intervals (CI) for understory taxa abundance in subplots located on seismic lines (On) and in the adjacent forest stand edge (Edge) relative to subplots located in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand (Off). Sites were sampled in west-central (WC) and north-western (NW) Alberta within Hydric, Hygric, and Mesic ecosites during the summers of 2014 and 2015. Notes: OR represent differences between offline and online/edge subplots (reference category only), or interactions between offline and online/edge subplots and levels of motorized human use (Reference: HUse(0) vs. HUse(1)), seismic line orientation (Reference: Orientation E/W vs. Orientation(N/S)), regeneration (Reference: Regen 0 m vs. Regen 1 m), and regeneration and levels of motorized human use (Reference: Regen 0 m and HUse(0) vs. Regen 1 m and HUse(1)). For data visualisation, we curtailed the upper 95% CI of non-target graminoids in hydric ecosites in the west-central region to 5, actual upper 95% CI was 29 for online subplots with no regeneration and 192 for online subplots with regeneration.

primarily composed of white spruce, trembling aspen, and balsam poplar (*Populus balsamifera*) in upland areas, and black spruce, larch, and poorly drained muskeg and fen in lowland areas (Natural Regions Committee, 2006; Bayne et al., 2011).

2.2. Field data collection and covariates

Using a geographic information system (GIS), we selected seismic lines (~20–40 years old) that intersected active roads and used a random number generator to identify a subset for field data collection ($n = 351$). We carried out vegetation surveys between June and September 2014 (west-central), and 2015 (west-central and north-western). At each seismic line (covariate names in italics, *PlotID*), we recorded data within four subplots (10 m^2 or 1 m^2) within plots located 100 m from the intersection between the seismic line and the road. Two of the subplots were located on the seismic line (*Type(Online)*), one was located within the adjacent forest at the transition between the seismic line and the forest stand (*Type(Edge)*, edge side randomly assigned using a coin flip), and one subplot was located within the interior forest stand, 15 m from the seismic line (*Type(Offline)*). At each subplot, we recorded percent ground cover of understory taxa preferred by moose and bears (Munro et al., 2006; Nielsen et al., 2004; Renecker and Schwartz, 1998) within a 1 m^2 (forbs and graminoids, dwarf shrubs) or 10 m^2 (large shrubs) circular subplot (*Taxa*, Table 1). Within online subplots, we also recorded maximum regeneration height (*Regen*, meters), levels of motorized human use (*HUse*; see Pigeon et al. (2016) for a detailed description), and the orientation of the seismic line (degrees; Table 2). For data analysis, we calculated mean values for each taxa across both online subplots, and classified human use into a binary variable (*HUse(0)*: no signs of motorized human use; *HUse(1)*: signs of motorized human use; Table 2). Following van Rensen et al. (2015) we used a modified version of the Beers equation (Beers et al., 1966) to rescale seismic line orientation (*Orientation*) between 0 (east/west axis) and 1 (north/south axis) using the following formula:

$$Orientation = |(\cos(\theta \times 0.017453))|$$

where θ is the azimuth of the seismic line in degrees (Table 2).

To assess differences in understory taxa among ecosites, we used derived ecosite data (30 × 30 m resolution) provided by the Government of Alberta. Ecosites are ecological units grouped by similar environmental influences (moisture regime, nutrient regime, climate), and are used within the ecological land classification hierarchy of Alberta as a metric to describe ecosystems at a fine scale. Because of limited records within some ecosites, we pooled data into three ecosite groups (*Ecosite*) based on similarities in soil moisture regimes (Hydric [k, l, m], Hygric [g, h, i, j], Mesic [d, e, f]; Table 2; Beckingham et al., 1996), and because species occurrence and growth may be affected by broad-scale habitat characteristics (e.g., elevation and topography), we also attributed each sampling plot with its natural subregion (*NSR*; Alberta Parks, 2015). We used ArcGIS 10.2.2 (ESRI 2015) to extract natural subregions and ecosites that intersected with sampling plots. We sampled 235 seismic lines in the west-central region (19 hydric, 25 hygric, 191 mesic) and 116 seismic lines in the north-western region (40 hygric, 76 mesic).

2.3. Model building and validation

We carried out statistical analysis with R and RStudio (R Development Core Team, 2017; RStudio, 2015) and visualised results using the ggplot2 package (Wickham, 2009). Before analysing data, we screened explanatory covariates for outliers, collinearity, and correlations following methods outlined by Zuur et al. (2010).

We used beta regression (Ferrari and Cribari-Neto, 2004) to assess differences in understory species among subplots within each seismic line sampling plot. Beta regression is increasingly applied to analyse proportional data (e.g. Eskelson et al., 2011; Keim et al., 2017; Latifi et al., 2017), and the extension of the beta distribution to account for zero and one-inflation (Ospina and Ferrari, 2012) makes the approach especially useful for modelling presence–absence and abundance (proportional cover) of plant species. We fit beta regression models in the gamlss package (Rigby and Stasinopoulos, 2005) using maximum-likelihood-derived generalized additive models with zero-inflated (BEZI) distributions, and accounted for the clustered nature of the dataset (online, edge, and offline subplots) by including the seismic line sampling plot identifier (*PlotID*) as a random effect (Table 3).

Although multispecies models have been shown to improve prediction, particularly when species are rare (Hui et al., 2013), we wanted to provide flexible results that could be used to direct seismic line restoration based on a range of priorities (i.e., reduce total moose browse vs. reduce a single taxa), and that could also be used to assess the effects of seismic lines on individual forage taxa preferred by other boreal species (e.g. deer). Therefore, after testing for positive (cooperation) and negative (competition) associations between taxa, and finding no significant correlations ($r_s < 0.5$), we modelled each taxon separately. Before fitting individual models, we partitioned data by ecosite, and then fit individual taxon models within each ecosite and region, accounting for broad-scale differences in topography and elevation by adding natural subregion (*NSR*) as a factor within models (Table 3).

We used the Generalized Akaike Information Criterion (GAIC; Akaike, 1983) implemented in the gamlss package (Rigby and Stasinopoulos, 2005) to assess which of up to seven candidate models best explained understory taxa absence and abundance within each ecosite (Table 3). Because previous research described inconsistent relationships among seismic line age, growth of trees, and understory species (Lankau, 2014; MacFarlane, 2003; Revel et al., 1984; van Rensen et al., 2015), we did not consider seismic line age within models, but instead accounted for different patterns of understory species growth among seismic lines using a combination of regeneration height and assessments of motorized human use (Table 3).

We predicted that explanatory covariates for occurrence and proportional cover would differ, and therefore carried out model selection on each part of the zero-inflated equation in turn (probability of absence [ν], proportional cover [μ]), while holding the other side of the equation at the null ($\nu/\mu \sim 1$), and then fit a final model using the most parsimonious combination of covariates identified after model selection for each side of the zero-inflated equation. Although modeling the beta regression dispersion parameter (σ) may slightly improve model fit (Herpigny and Gosselin, 2015), to aid model convergence and to ease model interpretation, we held the dispersion parameter constant in all models ($\sigma \sim 1$).

We assessed goodness-of-fit of the final model using R^2 calculated in the gamlss package, where values closer to 1 indicate better model fit. We present all results as odds ratios (OR) and 95% confidence intervals (95% CI) relative to offline interior forest subplots. The presence–absence side of zero-inflated models the probability of absence rather than the probability of occurrence, therefore for zero-inflated models OR greater than one indicate a higher odds of species absence or higher species abundance when compared to offline subplots, and OR less than one indicate a lower odds of species absence or lower species abundance when compared to offline subplots.

3. Results

Detailed summaries of occurrence and abundance data are in Appendix A. Because the number of subplots with occurrence of different understory taxa differed across ecosites, and also among offline, edge and online subplots, we were unable to model all taxa across all ecosites and regions. For example there were insufficient occurrences of *Trifolium* spp. in offline subplots (n = 4) to enable comparisons to edge (n = 8) and online (n = 49) subplots. Likewise, although we were able to build models for *Lathyrus* spp. within mesic ecosites, there were insufficient *Lathyrus* spp. occurrences in hydric or hygric ecosites to build models in those ecosites (Appendices A and B: Table B.1). Furthermore, for some taxa the low number of occurrences in some ecosite and regional strata restricted the complexity of candidate models that we could compare using the GAIC (Table 3). Therefore, all 58 GAIC comparisons included the null model (M1) and *Type* (M2), 38 GAIC comparisons included the null model, *Type*, and models with 2-way interactions between *Type* and *HUse, Orientation* or *Regen* (M3, M4, M5 respectively), while 18 GAIC comparisons included all seven candidate models, including models with 3-way interactions between *Type*, *HUse* and *Orientation* (M6) and *Type*, *HUse* and *Regen* (M7; Table 3; Appendix B: Table B.1).

3.1. Model selection and performance

GAIC model selection indicated that the best models explaining forb and graminoid absence included *Type* (M2), *Type* ∗ *HUse* (M3), *Type* ∗ *Orientation* (M4), *Type* ∗ *Regen* (M5), and *Type* ∗ *HUse* ∗ *Regen* (M7). The best models explaining forb and graminoid abundance included *Type* (M2), *Type* ∗ *HUse* (M3), *Type* ∗ *Orientation* (M4), and *Type* ∗ *HUse* ∗ *Regen* (M7; Table 4, Appendix B: Tables B.2–B.7). For dwarf shrubs, the best models explaining absence included *Type* (M2), *Type* ∗ *HUse* (M3), *Type* ∗ *Orientation* (M4), and *Type* ∗ *Regen* (M5), while the best models explaining dwarf shrub abundance included *Type* (M2), *Type* ∗ *HUse* (M3), *Type* ∗ *Orientation* (M4), and *Type* ∗ *HUse* ∗ *Orientation* (M6; Table 4, Appendix B: Tables B.8–B.11). For large shrubs, the best models explaining absence included *Type* (M2), *Type* ∗ *HUse* (M3), *Type* ∗ *Orientation* (M4), and *Type* ∗ *Regen* (M5). The best models explaining large shrub abundance included *Type* (M2), *Type* ∗ *Orientation* (M4), *Type* ∗ *Regen* (M5), and *Type* ∗ *HUse* ∗ *Regen* (M7; Table 4, Appendix B: Tables B.12–B.17). Model performance was variable across taxa, ecosites and regions (Table 4). Focusing on informative models, only results of models with R^2 values greater than 0.6 are described here, the remainder is in Appendix C.

3.2. Hydric ecosites

Within hydric ecosites, we obtained sufficient data to build models for 8 taxa in the west-central region (we did not collect data for hydric ecosites in the north-western region; Table 4, Appendix A). Focusing on models with $R^2 > 0.6$, the presence–absence side of the model indicated that compared to offline subplots, online subplots were more likely than offline subplots to contain non-target graminoids, *Carex*, and *Salix* spp., but edges were similar to offline subplots (Fig. 2). The abundance side of the model indicated that, in comparison to offline subplots, *Carex* and *Salix* spp. were more abundant online, *Rhododendron* spp. and *Vaccinium vitis-idaea* were less abundant online, and non-target graminoids were more abundant on online subplots with no human use. The abundance side of the model also indicated that in comparison to offline subplots *Rhododendron* spp. were more abundant on edges, and *V. vitis-idaea* was more abundant on N/S edges (Fig. 3).

3.3. Hygric ecosites

Within hygric ecosites, we obtained sufficient data to build models for 18 taxa across both regions (Table 4, Appendix A). Focusing on models with $R^2 > 0.6$, in the north-western region the presence–absence side of the model indicated that online subplots were more likely than offline subplots to contain *Shepherdia canadensis*, *Carex*, and *Betula* spp., online subplots with no regeneration were more likely than offline subplots to contain *Rhododendron* spp., and edges were more likely than offline subplots to contain *Ribes* spp. (Fig. 2). The abundance side of the model indicated that in comparison to offline subplots *Chamerion* and *Alnus* spp. were more abundant online, while *S. canadensis* was less abundant online. The abundance side of the model also indicated that in comparison to offline subplots *Alnus* spp. and *V. vitis-idaea* were more abundant on edges, and *S. canadensis* was less abundant on edges (Fig. 3).

In the west-central region the presence–absence side of the model indicated that online subplots were more likely than offline subplots to contain non-target graminoids while edges were more likely than offline subplots to contain *Equisetum* spp. (Fig. 2). The abundance side of the model indicated that in comparison to offline subplots, non-target graminoids were more abundant online, *Rhododendron* spp. were less abundant online, and *Rhododendron* spp. were less abundant on edges with no human use (Fig. 3).

3.4. Mesic ecosites

Within mesic ecosites, we had sufficient data to build models for 32 taxa across both study areas (Table 4, Appendix A). Focusing on models with $R^2 > 0.6$, in the north-western region the presence–absence side of the model indicated that online subplots were more likely than offline subplots to contain non-target graminoids, *Chamerion*, *Lathyrus*, and *Alnus* spp., online subplots with no human use were more likely than offline subplots to contain *Ribes* spp., and edges were more likely than offline subplots to contain *Alnus*, *Lonicera*, *Lathyrus*, and *Ribes* spp. (Fig. 2). The abundance side of the model indicated that in comparison to offline subplots, non-target graminoids, *V. vitis-idaea*, and *Lonicera* spp. were more abundant online, *S. canadensis* and *Ribes* spp. were less abundant online, *Chamerion* spp. were less abundant on online subplots with no human use, and *Equisetum* spp. were less abundant on E/W online subplots. The abundance side of the model also indicated that in comparison to offline subplots *Chamerion* spp. were less abundant on edges with no human use, and *Equisetum* spp. were less abundant on E/W edges (Fig. 3).

In the west-central study area the presence–absence side of the model indicated that online subplots were more likely than offline subplots to contain non-target forbs, non-target graminoids, *Carex*, *Equisetum*, *Alnus*, *Salix*, and *Vaccinium* spp. The presence–absence side of the model also indicated that edges were more likely than offline subplots to contain non-target forbs, non-target graminoids, and *Equisetum* spp., and edges with regeneration were less likely than offline subplots to contain *Vaccinium* spp. (Fig. 2). The abundance side of the model indicated that, in comparison to offline subplots, non-target graminoids and *Salix* spp. were more abundant online, and *V. vitis-idaea*, *Equisetum*, and *Rhododendron* spp. were less abundant online. The abundance side of the model also indicated that *Alnus* and *Salix* spp. were more abundant on edges, and *V. vitis-idaea*, *Rhododendron* and *Equisetum* spp. were less abundant on edges (Fig. 3).

4. Discussion

Using field data collected in west-central and north-western Alberta, we found that understory forage differed between seismic lines and the forest interior, and that the effects of seismic lines extended beyond the seismic line into the edge of the adjacent forest. Specifically, we found that when compared to paired interior forest plots, seismic lines and edges provided more moose forage, while hydric and mesic seismic lines and edges also contained important bear food. We could not attribute differences in understory forage taxa cover between seismic lines, edges and the interior forest to re-disturbance of seismic lines through motorized human activities. However, because we found that disturbance-tolerant taxa were more abundant on seismic lines our results support the hypothesis that patterns of understory species cover on seismic lines are likely a legacy of mechanical damage during seismic line construction, combined with localized changes in soil moisture and light on seismic lines and along edges. In addition, because regeneration height on seismic lines failed to explain differences in abundance of the species examined, it is likely that active restoration (e.g., tree planting and silviculture) will be required to reduce restore natural equilibrium in forage availability and to re-establish natural trajectories of tree succession on seismic lines and along the edges of the adjacent forest stand.

4.1. Moose and bear forage on seismic lines and seismic line edges

In accordance with our prediction, we found that a number of understory forage taxa were more abundant on seismic lines and edges when compared to the interior forest. However, in contrast to our prediction, soil wetness (ecosite) did not predict understory forage taxa on seismic lines, but rather abundance varied more as a function of species or species groups. For example, forbs and graminoids that are key bear food during spring and summer (McLellan and Hovey, 1995; Munro et al., 2006), and important moose food throughout the plant growing period (Renecker and Schwartz, 1998), were generally more abundant on seismic lines irrespective of soil wetness. These growing patterns are consistent with previous findings describing post-disturbance growth of forbs and graminoids on seismic lines in aspen mixedwood forests (MacFarlane, 2003) and in other disturbed areas such as well pads (Caners and Lieffers, 2014), transmission lines (Eldegard et al., 2015; Wagner et al., 2014), cutblocks (Hart and Chen, 2006; Nielsen et al., 2004), and along the edges of roads (Roever et al., 2008).

In comparison to forbs and graminoids, occurrence and abundance of dwarf and large shrubs were more variable among species and between study areas (Appendix A). In accordance with previous findings from our study area, we generally found more cover of large shrubs preferred by moose (*Salix* spp., *Alnus* spp., *and Betula* spp.) on seismic lines and edges when compared to the interior forest (Revel et al., 1984). In contrast, Dabros et al. (2017) reported more cover of these large shrubs in the interior forest when compared to low-impact seismic lines. It is possible that the wider (5–8 m) seismic lines sampled in our study provide more favorable growing conditions than those of narrow low-impact seismic lines for disturbance-tolerant and shade-intolerant species like *Alnus* spp. and *Salix* spp. (Hart and Chen, 2006; Humbert et al., 2007; Nguyen-Xuan et al., 2000; Revel et al., 1984). However, as edge abundance of *Salix* spp. also increases with edge age (Harper and Macdonald, 2002), it more likely that the observed differences in large shrubs between seismic lines sampled in our study and those sampled by Dabros et al. (2017) are an artifact of differences in the ages of seismic lines sampled in the two studies (our study > 20 years, Dabros et al. (2017) < 4 years).

In contrast to large shrubs preferred by moose, large shrubs preferred by both moose and bears (*Ribes* spp.) and those preferred by bears only (*Lonicera* spp., *Shepherdia canadensis*) were generally less abundant on seismic lines and edges. These results complement previous work assessing understory species in cutblocks (Clason et al., 2008; Harper and MacDonald, 2002; Harvey et al., 1995), and potentially reflects the sensitivity of these particular taxa to mechanical damage (Nielsen et al., 2004; Roberts and Zhu, 2002).

Although *Rhododendron* spp. preferred by moose, and *V. vitis-idaea* preferred by both moose and bears were less abundant on seismic lines, those dwarf shrubs were more abundant on seismic line edges, a pattern similar to results reported on low-impact seismic lines (Dabros et al., 2017). Overall, growth of these dwarf shrubs on seismic line edges appears to be similar growth at the edges of cutblocks (Harper et al., 2004), forest paths (Hamberg et al., 2010), and power lines (Eldegard et al., 2015), but contrasts with growth at the edges of roads (Roever et al., 2008) and within cutblocks (Harper et al., 2004). The observed lower abundance on seismic lines and higher abundance on edges is probably an artifact of the direct negative effects of disturbance on growth and reproduction (Gonzalez et al., 2013; Haeussler et al., 1999;

Roberts and Zhu, 2002), combined with indirect positive effects of increased light at the edges of disturbances (Hebert et al., 2010; Humbert et al., 2007; Matlack, 1993).

4.2. Seismic line orientation and understory forage

Contrary to our prediction that seismic lines receiving direct sunlight near midday would have higher abundance of forage taxa (Chen et al., 1993; Matlack, 1993; Revel et al., 1984), we did not observe higher abundance of understory forage taxa on N/S orientated seismic lines, or on E/W orientated edges of seismic lines when compared to the interior forest, with the exception of *V. vitis-idaea* on hydric ecosites. The broad scale patterns that we observed here are in agreement with other seismic line vegetation assessments that did not find orientation to be an important factor explaining vegetation growth on seismic lines (Dabros et al., 2017). It is possible that in contrast to cutblocks (Chen et al., 1993; Hylander, 2005; Matlack, 1993), seismic lines are too narrow for orientation to have significant effects on plant growth.

4.3. Regeneration, human use and understory forage

Because of the relative resilience of boreal species (Harper et al., 2004; Hart and Chen, 2006), and because seismic lines are unmaintained, we predicted that with increasing regeneration occurring after the initial disturbance, understory taxa communities on seismic lines would increasingly resemble the interior forest (i.e., return to predisturbance state). Although in some regional and ecosite strata we identified taxa with similar abundances on seismic line and the interior forest subplots, patterns were inconsistent between regions (e.g. *Equisetum* spp.), and among ecosites (e.g. *V. vitis-idaea*; Fig. 2), and could not be explained using measurements of regeneration or motorized human use. In fact, of 56 GAIC comparisons, regeneration was only included within six of the best models explaining abundance, and did not predict differences in abundance between the interior forest and seismic lines, or between the interior forest and seismic line edges (Fig. 3). For motorized human use, ten of the best models included human use, but contrary to our prediction we observed positive relationships between motorized human use and understory forage abundance, albeit only for disturbance-tolerant non-target graminoids and *Chamerion* spp. (Fig. 2).

Because neither regeneration nor human use could explain observed patterns of abundance on seismic lines our results suggest that boreal understory vascular plants are largely not resilient to seismic line disturbance, and that after seismic line construction, plant communities may shift and remain indefinitely in a new successional state characterized by disturbance-tolerant forbs, graminoids, and shrubs. It is likely that the onset of disturbance-tolerant species on seismic lines, and the associated suppression of conifer tree germination on these lines (De Grandpre and Bergeron, 1997; Mallik, 2003; Nguyen-Xuan et al., 2000), has resulted in the observed long-term persistence of seismic lines across the boreal forest (Lee and Boutin, 2006; van Rensen et al., 2015). Detailed and regular community-level assessments of nonvascular and vascular plants on seismic lines *sensu* Dabros et al. (2017) will help to confirm these interpretations, and will provide a better understanding of the effects of seismic line disturbance on boreal understory species.

4.4. Conclusions and management implications

Our study demonstrated that even decades after construction, understory species on seismic lines and at seismic line edges are different from species present in the interior forest, and that seismic lines and edges contain more disturbance-tolerant forage species preferred by moose and bears. Specifically, we identified a number of forage taxa that were more abundant on seismic lines and edges when compared to the interior forest. Focusing on these forage taxa, fine-scale mapping of occurrence and abundance on seismic lines and seismic line edges using additional explanatory covariates (e.g. elevation, wet areas mapping, and adjacent stand age) may help identify seismic lines that could be prioritized for restoration to reduce spatial overlap between caribou, primary wolf prey (moose), and predators (bears). Ultimately, to restore ecosystem function for caribou, we need to understand how this forage availability on regenerating seismic lines is linked to primary prey (moose, deer, and elk) and predator use because use of seismic lines by predators shared between primary prey and caribou (bears, wolves, and cougars) could result in a higher probability of encounter between caribou and predators.

Overall we found that patterns of understory forage taxa growth on seismic lines and seismic line edges were similar to those of larger disturbances associated with forest harvesting (Hart and Chen, 2006; Nielsen et al., 2004; Harper et al., 2004). Silviculture and reforestation are recognized as key components for the recovery of harvested areas (Mallik, 2003; Nguyen-Xuan et al., 2000), and our results suggest that the same treatments may be needed to re-establish or maintain natural successional trajectories on seismic lines. Moving forward, avoiding the construction of conventional seismic lines may help to avoid long-term shifts in the distribution of boreal understory species. However, because even low-impact seismic lines affect understory species (Dabros et al., 2017), planning for the immediate reclamation of seismic lines after exploration may be required to ensure the appropriate successional trajectory to pre-disturbance states. In addition, recognizing the high edge to footprint ratio of linear features like seismic lines, and the cumulative and interactive effects of edges across landscapes (Pattison et al., 2016; Porensky and Young, 2013), the efficacy of restoration treatments should be assessed beyond seismic lines into the edge of the adjacent forest stand (Dabros et al., 2017). Understanding the responses of understory and tree species to disturbance, regeneration, and habitat restoration is critical to reduce the long-term impacts of human activities on boreal ecosystems. By focusing on habitat changes that influence wildlife responses, such as changes in the presence, abundance, and community composition of forage used by moose and bears, this study provides valuable insight into the need for active restoration of seismic lines to restore boreal forest ecosystems.

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Appendix A. Summary of occurrence and abundance data

Table A.1.

Table A.1

Number subplots with species occurrence (Occ.) and associated mean abundance (percent cover, Abd.) on seismic lines (On), in the adjacent forest stand edge (Edge) and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand (Off) sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. The number of seismic lines sampled within each ecosite and study area is in parenthesis.

Taxa		West-central (235)			North-western (116)	
		Hydric (19)	Hygric (25)	Mesic (191)	Hygric (40)	Mesic (76)
Forbs and Graminoids		Off|Edge|On	Off|Edge|On	Off|Edge|On	Off|Edge|On	Off|Edge|On
Carex spp.	Occ.	5|5|13	6|6|8	16|15|38	7|14|25	6|3|16
	Abd.	3|2|11	9|13|15	3|3|6	2|4|6	0.4|0.3|1
Chamerion spp.	Occ.	2|3|9	1|3|3	29|42|68	3|7|22	17|20|52
	Abd.	0.3|1|2	0.6|2|1	1|2|2	0.3|0.4|2	1|2|3
Equisetum spp.	Occ.	16|13|22	9|13|12	42|41|86	18|21|23	25|28|42
	Abd.	13|11|16	10|14|10	3|3|4	2|3|5	4|2|3
Lathyrus spp.	Occ.	0|0|2	3|2|3	7|9|14	0|1|9	13|13|38
	Abd.	0|0|0.2	0.7|0.9|0.3	0.3|0.3|0.4	0|0.1|0.4	0.4|0.6|1
Hedysarum spp.	Occ.	0|0|1	0|1|2	3|6|16	0|0|1	0|0|5
	Abd.	0|0|0.1	0|0.1|0.3	0.1|0.1|0.4	0|0|0.02	0|0|0.1
Trifolium spp.	Occ.	2|0|4	0|0|4	2|7|45	0|0|2	0|1|14
	Abd.	0.2|0|0.5	0|0|0.3	0.4|0.6|2	0|0|0.1	0|0.03|0.7
Non-target graminoids	Occ.	12|14|22	9|11|12	68|86|156	10|17|28	38|42|63
	Abd.	11|13|26	6|6|24	3|4|12	4|6|14	3|2|8
Non-target forbs	Occ.	19|14|23	15|16|18	137|139|175	31|30|40	66|68|72
	Abd.	9|7|16	17|12|9	10|11|13	8|9|7	10|10|12
Dwarf shrubs						
Arctostaphylos uva-ursi	Occ.	1|3|4	1|1|0	8|10|19	1|1|3	0|0|5
	Abd.	0.1|2|3	0.2|0.1|0	0.2|0.6|0.5	0.2|0.4|0.3	0.1|0.05|0.5
Empetrum nigrum	Occ.	3|0|1	0|0|0	17|28|31	2|1|3	1|0|2
	Abd.	2|0|0.5	–	2|2|2	0.4|0.1|0.5	0.2|0|0.01
Rhododendron spp.	Occ.	19|19|15	11|11|8	108|110|102	22|24|27	9|7|15
	Abd.	19|25|7	15|9|4	13|17|7	10|11|9	2|2|2
Vaccinium vitis-idaea	Occ.	18|18|13	2|1|5	107|99|92	28|26|24	5|2|21
	Abd.	9|12|5	8|15|2	5|6|3	7|8|5	2|1|3
Vaccinium spp.	Occ.	4|2|7	5|6|6	113|104|124	3|2|7	6|8|14
	Abd.	3|3|2	7|5|4	10|9|11	5|1|0.7	0.3|0.6|0.6
Large shrubs						
Alnus spp.	Occ.	2|2|1	0|1|2	15|24|48	6|7|8	17|26|36
	Abd.	2|2|0	0|3|0.3	2|3|7	0.6|1|1	3|3|4
Betula spp.	Occ.	9|10|14	6|7|8	27|33|35	10|13|20	5|2|10
	Abd.	5|8|7	5|7|5	1|1|1	1|2|2	0.1|0.1|0.8
Lonicera spp.	Occ.	0|0|3	1|3|4	26|24|36	0|32|0	4|56|4
	Abd.	0|0|0.2	0.05|0.2|1	1|2|1	0|8|0	0.1|5|0
Ribes spp.	Occ.	0|1|0	1|1|1	9|15|17	3|15|2	14|64|18
	Abd.	0|0.1|0	0.1|0.3|0.1	0.2|0.4|0.3	0.3|1|0.1	0.5|7|0.3
Salix spp.	Occ.	13|10|20	9|13|15	62|76|142	22|9|35	23|17|50
	Abd.	6|7|11	14|13|14	5|7|9	3|1|7	4|3|5
Shepherdia canadensis	Occ.	0|2|2	3|2|3	7|14|18	5|1|10	24|0|29
	Abd.	0|1|0.6	1|3|1	0.3|0.5|0.6	1|0.1|1	4|0|2
Viburnum edule	Occ.	0|1|0	1|1|2	15|8|17	4|0|4	16|0|37
	Abd.	0|0.1|0	0.05|0.1|0.2	0.6|0.3|0.2	0.2|0|0.3	6|0|5

Appendix B. GAIC model tables

Tables B.1–B.17

Table B.1

Summary of candidate models compared using GAIC to identify the best model to explain species absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models are described in Table 3.

	West-central			North-western	
	Hydric	Hygric	Mesic	Hygric	Mesic
Forbs and Graminoids					
Carex spp.	M1–M2	M1–M2	M1–M5	M1–M2	M1–M2
Chamerion spp.	–	–	M1–M7	–	M1–M7
Equisetum spp.	M1–M5	M1–M5	M1–M7	M1–M5	M1–M5
Lathyrus spp.	–	–	M1–M2	–	M1–M5
Hedysarum spp.	–	–	–	–	–
Trifolium spp.	–	–	–	–	–
Non-target graminoids	M1–M5	M1–M5	M1–M7	M1–M5	M1–M7
Non-target forbs	M1–M5	M1–M5	M1–M7	M1–M5	M1–M7
Dwarf shrubs					
Arctostaphylos uva-ursi	–	–	M1–M2	–	–
Empetrum nigrum	–	–	M1–M7	–	–
Rhododendron spp.	M1–M5	M1–M5	M1–M7	M1–M5	M1–M5
Vaccinium vitis-idaea	M1–M5	–	M1–M7	M1–M5	M1–M5
Vaccinium spp.	–	M1–M2	M1–M7	–	M1–M2
Large shrubs					
Alnus spp.	–	–	M1–M5	M1–M2	M1–M7
Betula spp.	M1–M2	M1–M2	M1–M5	M1–M2	–
Lonicera spp.	–	–	M1–M5	–	–
Ribes spp.	–	–	M1–M2	–	M1–M7
Salix spp.	M1–M5	M1–M5	M1–M7	M1–M5	M1–M7
Shepherdia canadensis	–	–	M1–M2	M1–M2	M1–M5
Viburnum edule	–	–	M1–M2	–	M1–M5

Table B.2

Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Carex spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**2**	**36**	**54.79**	**0.99**	**2**	**32**	**55.22**	**0.99**
		1	28	63.79	0.01	1	28	63.79	0.01
	Hygric	**1**	**24**	**41.74**	**0.96**	**1**	**24**	**41.74**	**0.95**
		2	32	48.02	0.04	2	29	47.63	0.05
	Mesic	**4**	**155**	**163.78**	**0.60**	**4**	**155**	**163.79**	**0.58**
		2	155	164.93	0.34	2	155	164.93	0.33
		3	161	168.67	0.05	3	161	168.67	0.05
		1	135	189.99	0	5	158	168.71	0.05
		Did not converge				1	135	189.99	0
North-western	Hygric	**2**	**65**	**18.9**	**1**	**1**	**50**	**27.44**	**0.74**
		1	50	27.4	0	2	53	29.49	0.26
	Mesic	**2**	**72**	**60.17**	**1**	**2**	**66**	**72.69**	**0.55**
		1	63	73.11	0	1	63	73.11	0.44

Table B.3
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Chamerion spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Mesic	**7**	**219**	**65.19**	**0.83**	**3**	**194**	**84.58**	**0.36**
		2	202	69.29	0.11	6	200	84.84	0.32
		4	205	71.46	0.04	7	200	84.86	0.32
		5	206	72.27	0.02	1	186	97.45	0.00
		3	205	74.59	0.01	5	193	103.04	0.00
		6	212	82.35	0.00	2	189	103.83	0.00
		1	186	97.45	0.00	4	192	106.45	0.00
North-western	Mesic	**2**	**89**	**−100.57**	**0.54**	**7**	**73**	**−85.58**	**1.00**
		3	94	−99.46	0.31	5	65	−70.60	0.00
		4	93	−96.73	0.08	3	66	−68.28	0.00
		5	91	−96.15	0.06	6	72	−63.33	0.00
		6	102	−91.04	0.00	2	61	−63.30	0.00
		7	99	−90.86	0.00	4	64	−59.72	0.00
		1	58	−58.17	0.00	1	58	−58.17	0.00

Table B.4
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Equisetum spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**5**	51	−15.57	0.99	**1**	36	6.97	0.55
		2	40	−4.17	0.00	2	39	8.87	0.21
		3	45	−2.95	0.00	5	42	9.05	0.19
		4	43	−0.16	0.00	4	42	13.18	0.02
		1	36	6.97	0.00	3	41	13.76	0.02
	Hygric	**2**	**34**	**−12.20**	**0.45**	**1**	**30**	**−10.91**	**0.90**
		4	35	−10.92	0.24	2	34	−5.83	0.07
		1	30	−10.91	0.24	5	37	−3.03	0.02
		3	38	−8.72	0.08	4	37	−2.10	0.01
		5	Did not converge			3	37	−0.46	0.00
	Mesic	**2**	**219**	**193.39**	**0.72**	**4**	**205**	**257.67**	**0.37**
		5	222	196.77	0.13	1	201	257.69	0.36
		4	222	197.46	0.09	2	202	258.59	0.23
		3	222	198.56	0.05	5	205	263.41	0.02
		7	228	204.41	0.00	3	205	264.26	0.01
		6	228	207.21	0.00	6	212	267.89	0.00
		1	201	257.69	0.00	7	211	270.03	0.00
North-western	Hygric	**1**	**54**	**−87.92**	**0.52**	**3**	**62**	**−93.51**	**0.83**
		2	58	−86.63	0.28	5	61	−88.08	0.06
		4	62	−84.82	0.11	1	54	−87.92	0.05
		3	60	−83.75	0.07	4	61	−86.87	0.03
		5	61	−81.80	0.02	2	57	−86.78	0.03
	Mesic	**3**	**104**	**−75.81**	**0.95**	**4**	**100**	**−74.74**	**1.00**
		2	99	−68.33	0.02	2	93	−52.57	0.00
		4	103	−67.94	0.02	1	91	−49.26	0.00
		5	101	−65.03	0.00	5	96	−48.03	0.00
		1	91	−49.26	0.00	3	96	−46.46	0.00

Table B.5
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Lathyrus spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Mesic	**2**	**97**	**102.36**	**1.00**	**2**	**108**	**123.18**	**0.74**
		1	104	125.26	0.00	1	104	125.26	0.26
North-western	Mesic	**5**	**105**	**−157.96**	**0.78**	**2**	**88**	**−96.64**	**0.45**
		2	101	−154.97	0.17	1	84	−96.33	0.39
		4	105	−151.41	0.03	5	91	−93.36	0.09
		3	104	−150.19	0.02	6	90	−91.60	0.04
		1	84	−96.33	0.00	3	91	−91.55	0.04

Table B.6
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain non-target graminoid absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**2**	**43**	**31.57**	**0.75**	**3**	**43**	**53.66**	**0.50**
		5	46	35.69	0.09	2	39	54.45	0.34
		3	46	35.69	0.09	1	34	57.33	0.08
		4	46	36.49	0.06	4	43	58.07	0.06
		1	34	57.33	0.00	6	42	59.81	0.02
	Hygric	**1**	**20**	**36.21**	**0.71**	**2**	**31**	**28.70**	**0.59**
		3	29	38.49	0.23	4	33	30.84	0.20
		2	24	40.84	0.07	5	35	31.56	0.14
		4	Did not converge			3	34	33.24	34
		5	Did not converge			1	20	36.21	20
	Mesic	**5**	**269**	**−90.44**	**0.99**	**4**	**226**	**20.40**	**0.83**
		7	276	−80.82	0.01	2	221	24.76	0.09
		2	260	−78.01	0.00	5	224	25.92	0.05
		3	263	−74.86	0.00	6	232	28.13	0.02
		4	262	−74.01	0.00	3	223	30.69	0.00
		6	269	−65.37	0.00	7	229	36.58	0.00
		1	0.00	0.00	0.00	1	205	87.25	0.00
North-western	Hygric	**2**	**40**	**−3.33**	**0.70**	**1**	**27**	**12.48**	**0.71**
		4	42	0.41	0.11	4	45	15.58	0.15
		5	43	0.53	0.10	2	39	16.39	0.10
		3	42	0.69	0.09	3	43	18.90	0.03
		1	27	12.48	0.00	5	42	22.04	0.01
	Mesic	**2**	**103**	**−202.91**	**0.73**	**4**	**100**	**−186.72**	**0.88**
		3	107	−199.13	0.11	6	106	−182.39	0.10
		6	115	−198.39	0.08	3	99	−177.22	0.01
		5	106	−197.24	0.04	2	95	−176.36	0.00
		4	106	−196.93	0.04	5	99	−174.53	0.00
		7	113	−189.32	0.00	7	105	−168.52	0.00
		1	88	−166.28	0.00	1	88	−166.28	0.00

Table B.7
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain non-target forb absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**2**	**40**	**–33.06**	**0.63**	**3**	**40**	**−31.13**	**0.93**
		4	43	−31.41	0.28	2	36	−25.06	0.04
		5	43	−27.74	0.04	5	39	−21.87	0.01
		3	42	−27.70	0.04	1	31	−21.83	0.01
		1	31	−21.83	0.00	4	39	−21.57	0.01
	Hygric	**1**	**18**	**−49.04**	**0.85**	**2**	**19**	**−53.15**	**0.45**
		2	24	−45.46	0.14	3	22	−52.28	0.29
		3	28	−39.81	0.01	4	24	−51.22	0.17
		4	Did not converge			1	18	−49.04	0.06
		5	Did not converge			5	22	−47.40	0.03
	Mesic	**2**	**251**	**−461.54**	**0.66**	**1**	**240**	**−406.11**	**0.68**
		5	253	−458.91	0.18	5	245	−403.10	0.15
		4	256	−458.12	0.12	2	243	−402.61	0.12
		3	254	−456.03	0.04	3	245	−399.72	0.03
		7	259	−448.12	0.00	4	246	−398.45	0.01
		6	264	−447.94	0.00	7	250	−395.79	0.00
		1	240	−406.11	0.00	6	251	−390.52	0.00
North-western	Hygric	**5**	**72**	**−231.99**	**0.68**	**1**	**49**	**−218.34**	**0.46**
		2	63	−229.57	0.20	4	56	−217.77	0.35
		3	68	−227.92	0.09	5	55	−216.20	0.16
		4	67	−225.73	0.03	2	52	−213.24	0.04
		1	49	−218.34	0.00	3	55	−207.54	0.00
	Mesic	**2**	**106**	**−426.72**	**0.48**	**1**	**102**	**−425.53**	**0.49**
		1	102	−425.53	0.26	2	104	−424.68	0.32
		3	108	−423.79	0.11	5	108	−422.66	0.12
		5	110	−423.00	0.07	4	107	−420.06	0.03
		4	110	−422.85	0.07	3	107	−420.02	0.03
		6	114	−415.83	0.00	6	114	−416.73	0.01
		7	114	−415.38	0.00	7	114	−412.75	0.00

Table B.8
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Arctostaphylos uva-ursi and Empetrum nigrum absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Taxa	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
Arctostaphylos uva-ursi	Mesic	**2**	**126**	**187.03**	**0.60**	**1**	**120**	**187.88**	**0.87**
		1	120	187.88	0.40	2	124	191.73	0.13
Empetrum nigrum	Mesic	**4**	**134**	**179.19**	**0.50**	**6**	**160**	**218.25**	**0.87**
		2	131	179.68	0.39	7	160	224.51	0.04
		6	141	183.57	0.06	4	154	224.78	0.03
		5	134	184.30	0.04	3	154	225.96	0.02
		3	134	185.55	0.02	2	151	226.09	0.02
		7	141	193.31	0.00	5	154	226.20	0.02
		1	147	229.78	0.00	1	147	229.78	0.00

Table B.9
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Rhododendron spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**1**	**25**	**37.46**	**0.26**	**2**	**35**	**27.88**	**0.70**
		2	29	37.56	0.25	4	38	31.23	0.13
		3	29	37.75	0.23	5	39	31.70	0.10
		5	33	37.89	0.21	3	37	32.58	0.07
		4	141	183.57	0.06	1	25	37.46	0.01
	Hygric	**1**	**24**	**32.65**	**0.86**	**3**	**31**	**28.98**	**0.38**
		2	28	37.08	0.09	5	31	29.63	0.27
		4	31	40.48	0.02	2	27	29.96	0.23
		3	30	40.62	0.02	1	24	32.65	0.06
		5	31	41.83	0.01	4	31	32.73	0.06
	Mesic	**3**	**237**	**322.16**	**0.49**	**4**	**249**	**254.20**	**0.46**
		2	233	324.02	0.19	7	254	255.82	0.21
		1	231	324.56	0.15	5	248	256.91	0.12
		5	235	325.08	0.11	2	244	257.06	0.11
		4	236	327.58	0.03	3	247	258.46	0.06
		6	242	328.66	0.02	6	256	259.03	0.04
		7	243	330.30	0.01	1	231	324.56	0.00
North-western	Hygric	**5**	**62**	**3.27**	**0.86**	**1**	**53**	**9.14**	**0.44**
		4	60	8.48	0.06	2	56	10.17	0.27
		1	53	9.14	0.05	4	59	11.09	0.17
		2	56	10.94	0.02	5	59	12.36	0.09
		3	60	12.20	0.01	3	59	14.40	0.03
	Mesic	**1**	**77**	**96.84**	**0.61**	**1**	**77**	**96.84**	**0.68**
		3	84	98.44	0.28	4	86	98.69	0.27
		2	80	101.81	0.05	2	80	102.35	0.04
		5	84	101.92	0.05	6	85	105.82	0.01
		6	82	104.57	0.01	3	83	107.04	0.00

Table B.10
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Vaccinium vitis-idaea absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**4**	**39**	**−28.74**	**0.53**	**4**	**39**	**−28.74**	**0.53**
		2	35	−27.53	0.29	2	35	−27.53	0.29
		5	39	−25.96	0.13	5	39	−25.96	0.13
		1	28	–23.48	0.04	1	28	–23.48	0.04
		3	38	−21.77	0.02	3	38	−21.77	0.02
	Mesic	**2**	**222**	**−179.38**	**0.60**	**5**	**234**	**−211.40**	**0.58**
		3	225	−176.64	0.15	2	229	−210.28	0.33
		5	225	−176.38	0.13	4	233	−207.00	0.06
		4	225	−175.91	0.11	3	232	−204.43	0.02

(*continued on next page*)

Table B.10 (*continued*)

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
		6	231	−170.29	0.01	7	241	−201.83	0.00
		7	231	−169.55	0.00	6	239	−197.33	0.00
		1	224	−163.89	0.00	1	254	255.82	0.21
North-western	Hygric	**1**	**55**	**−78.96**	**0.63**	**2**	**58**	**−79.52**	**0.44**
		2	57	−76.73	0.21	1	55	−78.96	0.33
		4	59	−75.16	0.09	3	60	−76.29	0.09
		5	61	−73.77	0.05	5	61	−76.15	0.08
		3	60	−72.22	0.02	4	62	−75.40	0.06
	Mesic	**1**	**81**	**9.42**	**0.44**	**2**	**81**	**33.60**	**0.38**
		5	87	10.34	0.28	1	78	33.72	0.36
		2	83	11.23	0.18	4	83	35.85	0.12
		3	86	13.10	0.07	3	83	36.79	0.08
		4	86	14.89	0.03	5	84	37.36	0.06

Table B.11

Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Vaccinium spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hygric	**1**	**24**	**17.45**	**0.83**	**1**	**24**	**17.45**	**0.71**
		2	26	20.64	0.17	2	26	19.24	0.29
	Mesic	**5**	**246**	**6.99**	**0.79**	**1**	**240**	**24.64**	**0.76**
		2	242	11.22	0.10	2	246	27.78	0.16
		4	245	11.39	0.09	4	249	30.52	0.04
		7	253	14.99	0.01	3	249	31.82	0.02
		3	245	16.01	0.01	5	249	32.09	0.02
		6	252	19.27	0.00	6	256	40.63	0.00
		1	240	24.64	0.00	7	256	40.67	0.00
North-western	Mesic	**2**	**70**	**23.32**	**0.94**	**1**	**64**	**28.99**	**0.68**
		1	64	28.99	0.06	2	68	30.50	0.32

Table B.12

Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Alnus spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Mesic	**3**	**188**	**278.68**	**0.95**	**5**	**177**	**317.13**	**0.81**
		2	187	285.84	0.03	2	174	320.71	0.14
		5	190	286.17	0.02	4	177	322.89	0.05
		4	190	290.49	0.00	3	177	325.78	0.01
		1	170	336.42	0.00	1	170	336.42	0.00
North-western	Hygric	**1**	**40**	**−1.68**	**0.91**	**2**	**43**	**−3.83**	**0.75**
		2	43	2.94	0.09	1	40	−1.68	0.25
	Mesic	**2**	**97**	**2.38**	**0.46**	**1**	**87**	**37.60**	**0.85**
		4	101	4.00	0.21	2	90	41.83	0.10
		3	100	4.05	0.20	4	93	44.14	0.03
		5	100	5.51	0.10	3	93	46.41	0.01
		7	106	8.65	0.02	5	93	47.16	0.01
		6	108	9.89	0.01	7	99	53.17	0.00
		1	87	37.60	0.00	6	99	54.60	0.00

Table B.13
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Betula spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**1**	**34**	**8.91**	**0.78**	**1**	**34**	**8.91**	**0.78**
		2	38	11.46	0.22	2	38	11.46	0.22
	Hygric	**1**	**25**	**8.99**	**0.91**	**1**	**25**	**8.99**	**0.91**
		2	28	13.66	0.09	2	28	13.66	0.09
	Mesic	**5**	**153**	**92.58**	**0.61**	**4**	**159**	**91.31**	**1.00**
		2	147	93.85	0.32	3	159	106.19	0.00
		3	150	97.79	0.05	5	158	108.39	0.00
		4	150	99.52	0.02	1	151	109.39	0.00
		1	151	109.39	0.00	2	155	113.22	0.00
North-western	Hygric	**2**	**54**	**−33.75**	**1.00**	**1**	**48**	**−22.22**	**0.85**
		1	48	−22.22	0.00	2	51	−18.78	0.15

Table B.14
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Lonicera and Ribes spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and northwestern Alberta, Canada in mesic ecosites between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Taxa	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	*Lonicera* spp.	**2**	**162**	**251.37**	**0.68**	**2**	**169**	**242.86**	**0.64**
		5	164	254.68	0.13	3	173	244.88	0.23
		3	164	255.03	0.11	4	173	246.78	0.09
		4	165	255.69	0.08	5	173	248.57	0.04
		1	164	263.59	0.00	1	164	263.59	0.00
	Ribes spp.	**1**	**15**	**4.71**	**0.58**	**1**	**124**	**137.71**	**0.97**
		2	16	5.38	0.42	2	128	144.53	0.03
North-western	*Ribes* spp.	**3**	**105**	**−86.26**	**0.79**	**7**	**79**	**−153.29**	**0.93**
		2	50	−81.96	0.09	6	78	−147.92	0.06
		5	53	−80.69	0.05	5	72	−141.94	0.00
		7	103	−80.32	0.04	4	72	−139.82	0.00
		6	111	−78.14	0.01	2	67	−107.13	0.00
		4	53	−78.03	0.01	3	70	−101.13	0.00
		1	47	11.54	0.00	1	47	11.54	0.00

Table B.15
Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Salix spp. absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Hydric	**2**	**40**	**−12.38**	**0.82**	**5**	**40**	**5.55**	**0.95**
		3	43	−7.72	0.08	1	31	11.79	0.04
		4	43	−7.02	0.06	2	35	17.04	0.00
		5	43	−6.74	0.05	4	38	22.15	0.00
		1	31	11.79	0.00	3	37	22.43	0.00
	Hygric	**4**	**38**	**12.72**	**1.00**	**1**	**26**	**27.52**	**0.89**
		3	37	25.55	0.00	2	29	32.54	0.07
		2	32	25.69	0.00	4	33	35.11	0.02
		1	26	27.52	0.00	3	32	37.01	0.01
		5	35	30.08	0.00	5	33	37.80	0.01
	Mesic	**4**	**257**	**67.62**	**0.68**	**7**	**221**	**186.85**	**0.96**
		2	252	69.51	0.27	5	214	194.41	0.02
		5	255	74.23	0.03	1	207	195.57	0.01
		3	255	74.60	0.02	2	211	198.70	0.00
		5	262	77.52	0.00	3	214	199.00	0.00
		6	260	83.23	0.00	4	214	204.09	0.00
		1	207	195.57	0.00	6	221	205.40	0.00
North-western	Hygric	**2**	**54**	**−73.20**	**0.54**	**2**	**33**	**−44.61**	**0.42**
		3	57	−72.37	0.35	5	37	−43.78	0.28

(*continued on next page*)

Table B.15 (*continued*)

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
		5	59	−69.11	0.07	4	36	−43.31	0.22
		4	58	−67.76	0.04	1	27	−40.15	0.05
		1	27	−40.15	0.00	3	36	−39.92	0.04
	Mesic	**2**	**77**	**13.90**	**0.50**	**1**	**64**	**39.19**	**0.58**
		7	87	15.64	0.21	5	72	41.07	0.23
		5	82	16.46	0.14	7	79	42.53	0.11
		3	79	16.80	0.12	4	71	44.46	0.04
		4	80	19.05	0.04	2	67	44.54	0.04
		6	85	27.14	0.00	3	70	49.58	0.00
		1	64	39.19	0.00	6	76	53.46	0.00

Table B.16

Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Shepherdia canadensis absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Mesic	**2**	**125**	**135.48**	**0.95**	**1**	**121**	**141.30**	**0.95**
		1	121	141.30	0.05	2	125	147.23	0.05
North-western	Hygric	**2**	**39**	**41.53**	**0.70**	**2**	**39**	**19.40**	**1.00**
		1	35	43.24	0.30	1	35	43.24	0.00
	Mesic	**4**	**89**	**19.84**	**0.75**	**2**	**86**	**20.14**	**0.34**
		5	89	22.87	0.17	4	89	20.49	0.29
		2	84	25.44	0.05	5	89	20.87	0.24
		3	87	26.36	0.03	3	87	22.01	0.13
		1	83	29.35	0.01	1	83	29.35	0.00

Table B.17

Generalized Akaike Information Criterion (GAIC), degrees of freedom (df), and GAIC weights (ω) for candidate models used to explain Viburnum edule absence and abundance on seismic lines, in the adjacent forest stand edge and in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand sampled in west-central and north-western Alberta, Canada between June and September of 2014 and 2015. Models (M) are described in Table 3. The best model is in bold.

Region	Ecosite	Absence				Abundance			
		M	df	GAIC	ω	M	df	GAIC	ω
West-central	Mesic	**2**	**116**	**125.74**	**1.00**	**2**	**125**	**125.76**	**1.00**
		1	120	145.72	0.00	1	120	145.72	0.00
North-western	Mesic	**1**	**93**	**5.12**	**0.50**	**1**	**93**	**5.12**	**0.56**
		2	95	6.31	0.27	3	98	6.22	0.33
		4	98	7.97	0.12	2	95	9.04	0.08
		5	97	9.32	0.06	5	97	11.83	0.02
		3	97	9.81	0.05	4	97	12.96	0.01

Appendix C. Graphs of odds ratios of absence and abundance for taxa with model performance (R2) < 0.6

Figs. C.1 and C.2

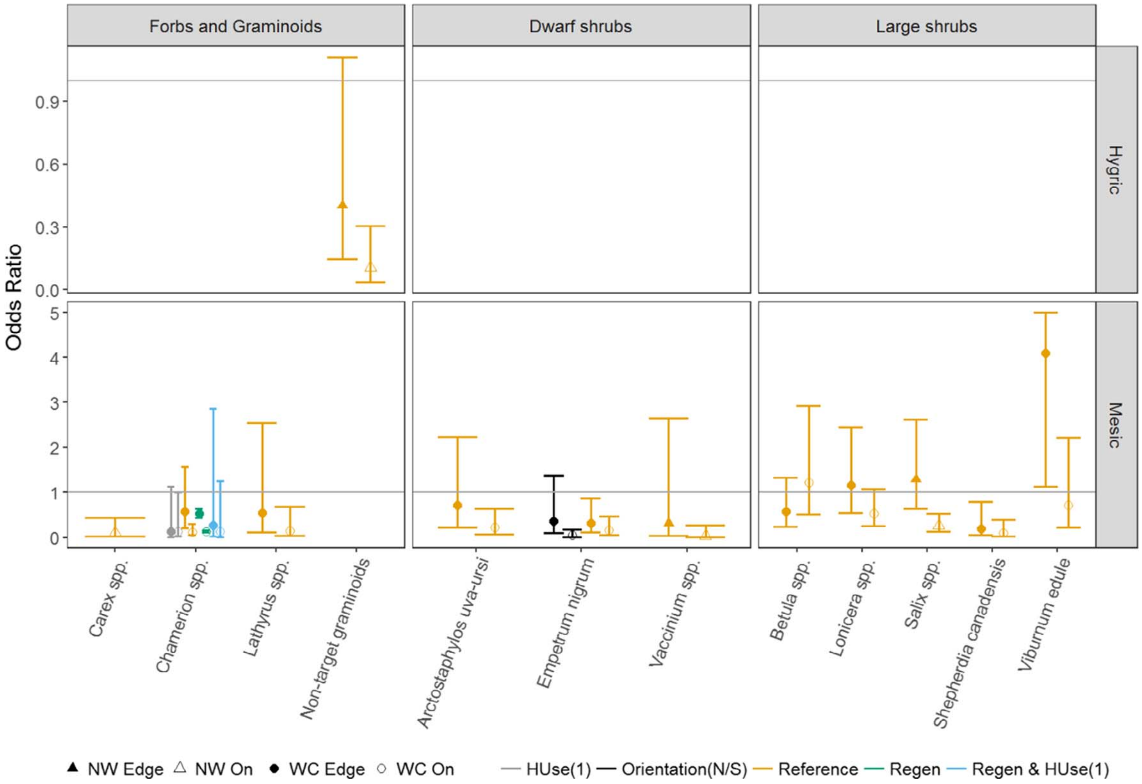

Fig. C.1. Odds ratios (OR) and 95% confidence intervals (CI) for understory taxa absence in subplots located on seismic lines (On) and in the adjacent forest stand edge (Edge) relative to subplots located in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand (Off). Sites were sampled in west-central (WC) and north-western (NW) Alberta, Canada within Hygric and Mesic ecosites during the summers of 2014 and 2015. Notes: OR represent differences between offline and online/edge subplots (reference category only), or interactions between offline and online/edge subplots and levels of motorized human use (Reference: HUse(0) vs. HUse(1)), seismic line orientation (Reference: Orientation E/W vs. Orientation(N/S)), regeneration (Reference: Regen 0 m vs. Regen 1 m), and regeneration and levels of human use (Reference: Regen 0 m and HUse(0) vs. Regen 1 m and HUse(1)). For data visualisation, we curtailed the upper 95% CI of *Viburnum edule* in mesic ecosites to 5, actual upper 95% CI was 14.7.

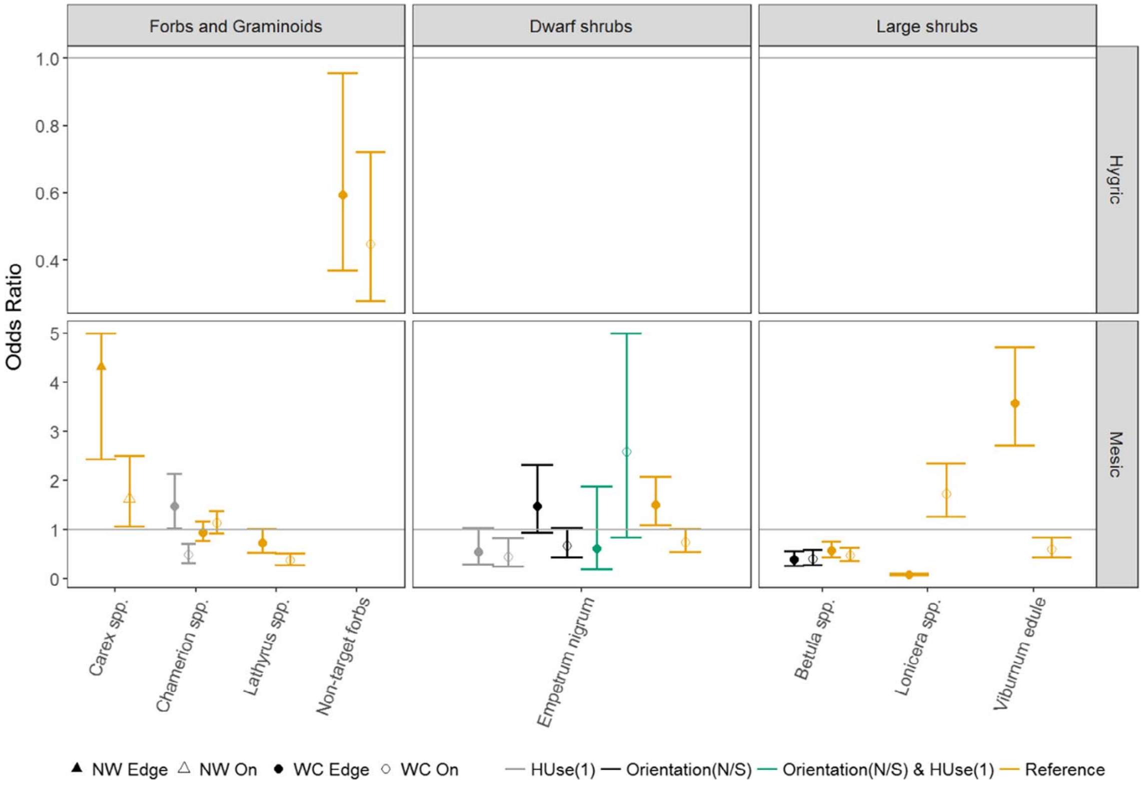

Fig. C.2. Odds ratios (OR) and 95% confidence intervals (CI) for understory taxa abundance in subplots located on seismic lines (On) and in the adjacent forest stand edge (Edge) relative to subplots located in the interior forest > 15 m from the transition between the seismic line and the adjacent forest stand (Off). Sites were sampled in west-central (WC) and north-western (NW) Alberta, Canada within Hygric and Mesic ecosites during the summers of 2014 and 2015. Notes: OR represent differences between offline and online/edge subplots (reference category only), or interactions between offline and online/edge subplots and levels of motorized human use (Reference: HUse(0) vs. HUse(1)), seismic line orientation (Reference: Orientation E/W vs. Orientation(N/S)), and seismic line orientation and levels of human use (Reference: Orientation E/W and HUse(0) vs. Orientation(N/S) and HUse(1)). For data visualisation, we curtailed the upper 95% CI of (i) *Carex* spp. in mesic ecosites in the north-western region to 5; actual upper 95% CI was 7.6, and (ii) *Empetrum nigrum* in mesic ecosites in the west-central region to 5; actual upper 95% CI was 7.9.

Appendix D. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foreco.2017.12.010.

References

Akaike, H., 1983. Information measures and model selection. Bull. Int. Stat. Inst. 50, 277–290.

Alberta Parks, 2015. Natural Regions and Subregions of Alberta. A Framework for Alberta's Parks. Edmonton, Alberta, Canada.

Bastille-Rousseau, G., Fortin, D., Dussault, C., Courtois, R., Ouellet, J.-P., 2011. Foraging strategies by omnivores: are black bears actively searching for ungulate neonates or are they simply opportunistic predators? Ecography 34, 588–596.

Bayne, E., Lankau, H., Tigner, J., 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, Alberta, Canada.

Beckingham, J., Corns, I., Archibald, J., 1996. Field guide to the ecosites of West-central Alberta. Natural Resources Canada Canadian Forest Service, Northwest Region, Nothern Forestry Center, Edmonton, Alberta, Canada.

Beers, T.W., Dress, P.E., Wensel, L.C., 1966. Aspect transformation in site productivity research. J. For. 64, 691–692.

Braverman, M., Quinton, W.L., 2016. Hydrological impacts of seismic lines in the wetland-dominated zone of thawing, discontinuous permafrost, Northwest Territories, Canada. Hydrol. Process. 30, 2617–2627.

Caners, R.T., Lieffers, V.J., 2014. Divergent pathways of successional recovery for in situ oil sands exploration drilling pads on wooded moderate-rich fens in Alberta, Canada. Restor. Ecol. 22, 657–667.

Chen, J., Franklin, J.F., Spies, T.A., 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. Agric. For. Meteorol. 63, 219–237.

Clason, A.J., Lindgren, P.M.F., Sullivan, T.P., 2008. Comparison of potential non-timber forest products in intensively managed young stands and mature/old-growth forests in south-central British Columbia. For. Ecol. Manage. 256, 1897–1909.

Dabros, A., James Hammond, H.E., Pinzon, J., Pinno, B., Langor, D., 2017. Edge influence of low-impact seismic lines for oil exploration on upland forest vegetation in northern Alberta (Canada). For. Ecol. Manage. 400, 278–288.

Dawe, C., Filicetti, A., Nielsen, S., 2017. Effects of linear disturbances and fire severity on velvet leaf blueberry abundance, vigor, and berry production in recently burned jack pine forests. Forests 8, 398.

De Grandpre, L., Bergeron, Y., 1997. Diversity and stability of understory communities following disturbance in the southern boreal forest. J. Ecol. 85, 777–784.

Dickie, M., Serrouya, R., DeMars, C., Cranston, J., Boutin, S., 2017. Evaluating functional recovery of habitat for threatened woodland caribou. Ecosphere 8, e01936.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., Boutin, S., 2001. Avoidance of industrial development by woodland caribou. J. Wildl. Manage. 65, 531–542.

Eldegard, K., Totland, Ø., Moe, S.R., 2015. Edge effects on plant communities along power line clearings. J. Appl. Ecol. 52, 871–880.

Environment Canada, 2012. Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada. Species at Risk Act Recovery Strategy Series. Ottawa, Ontario, Canada.

Eskelson, B.N.I., Madsen, L., Hagar, J.C., Temesgen, H., 2011. Estimating riparian understory vegetation cover with beta regression and copula models. For. Sci. 57, 212–221.

Ferrari, S.L.P., Cribari-Neto, F., 2004. Beta regression for modelling rates and proportions. J. Appl. Stat. 31, 799–815.

Franklin, C.M.A., Harper, K.A., 2016. Moose browsing, understory structure and plant species composition across spruce budworm-induced forest edges. J. Veg. Sci. 27, 524–534.

Gonzalez, E., Hébert, F., Boucher, J.-F., Sirois, P., Lord, D., 2013. Lichen-spruce woodland early indicators of ecological resilience following silvicultural disturbances in Québec's closed-crown forest zone. Am. J. Plant Sci. 4, 749–76543.

Haeussler, S., Bedford, L., Boateng, J.O., Mackinnon, A., 1999. Plant community responses to mechanical site preparation in northern interior British Columbia. Can. J. For. Res. 29, 1084–1100.

Hamberg, L., Malmivaara-Lämsä, M., Lehvävirta, S., O'Hara, R.B., Kotze, D.J., 2010. Quantifying the effects of trampling and habitat edges on forest understory vegetation – a field experiment. J. Environ. Manage. 91, 1811–1820.

Harper, K.A., Lesieur, D., Bergeron, Y., Drapeau, P., 2004. Forest structure and composition at young fire and cut edges in black spruce boreal forest. Can. J. For. Res. 34, 289–302.

Harper, K.A., Macdonald, S.E., 2002. Structure and composition of edges next to regenerating clear-cuts in mixed-wood boreal forest. J. Veg. Sci. 13, 535–546.

Hart, S.A., Chen, H.Y.H., 2006. Understory vegetation dynamics of North American boreal forests. CRC. Crit. Rev. Plant Sci. 25, 381–397.

Harvey, B.D., Leduc, A., Bergeron, Y., 1995. Early postharvest succession in relation to site type in the southern boreal forest of Quebec. Can. J. For. Res. 25, 1658–1672.

Hebblewhite, M., Merrill, E.H., McDonald, T.L., 2005. Spatial decomposition of predation risk using resource selection functions: an example in a wolf- elk predator-prey system. Oikos 111, 101–111.

Hebert, F., Thiffault, N., Ruel, J.-C., Munson, A.D., 2010. Comparative physiological responses of *Rhododendron groenlandicum* and regenerating *Picea mariana* following partial canopy removal in northeastern Quebec, Canada. Can. J. For. Res. 40, 1791–1802.

Herpigny, B., Gosselin, F., 2015. Analyzing plant cover class data quantitatively: customized zero-inflated cumulative beta distributions show promising results. Ecol. Inform. 26, 18–26.

Hui, F.K.C., Warton, D.I., Foster, S.D., Dunstan, P.K., 2013. To mix or not to mix: comparing the predictive performance of mixture models vs. separate species distribution models. Ecology 94, 1913–1919.

Humbert, L., Gagnon, D., Kneeshaw, D., Messier, C., 2007. A shade tolerance index for common understory species of northeastern North America. Ecol. Indic. 7, 195–207.

Hylander, K., 2005. Aspect modifies the magnitude of edge effects on bryophyte growth in boreal forests. J. Appl. Ecol. 42, 518–525.

Johnson, C.J., Ehlers, L.P.W., Seip, D.R., 2015. Witnessing extinction – cumulative impacts across landsapes and the future loss of an evolutionary significant unit of woodland caribou in Canada. Biol. Conserv. 186, 176–186.

Jorgenson, J.C., Ver Hoef, J.M., Jorgenson, M.T., 2010. Long-term recovery patterns of arctic tundra after winter seismic exploration. Ecol. Appl. 20, 205–221.

Keim, J.L., DeWitt, P.D., Fitzpatrick, J.J., Jenni, N.S., 2017. Estimating plant abundance using inflated beta distributions: applied learnings from a lichen–caribou ecosystem. Ecol. Evol. 7, 486–493.

Kemper, J., Macdonald, S.E., 2009. Directional change in upland tundra plant communities 20–30 years after seismic exploration in the Canadian low-arctic. J. Veg. Sci. 20, 557–567.

Kinley, T.A., Apps, C.D., 2001. Mortality patterns in a subpopulation of endangered mountain caribou. Wildl. Soc. Bull. 29, 158–164.

Knopff, A.A., Knopff, K.H., Boyce, M.S., St. Clair, C.C., 2014. Flexible habitat selection by cougars in response to anthropogenic development. Biol. Conserv. 178, 136–145.

Lankau, H., 2014. Songbird Responses to Regenerating Seismic Lines in the Boreal Forest (MSc Thesis). University of Alberta.

Lankau, H.E., Bayne, E.M., Machtans, C.S., 2013. Ovenbird (*Seiurus aurocapilla*) territory placement near seismic lines is influenced by forest regeneration and conspecific density. Avian Conserv. Ecol. 8.

Latifi, H., Hill, S., Schumann, B., Heurich, M., Dech, S., 2017. Multi-model estimation of understorey shrub, herb and moss cover in temperate forest stands by laser scanner data. Forestry 90, 496–514.

Lee, P., Boutin, S., 2006. Persistence and developmental transition of wide seismic lines in the western Boreal Plains of Canada. J. Environ. Manage. 78, 240–250.

MacFarlane, A.K., 2003. Vegetation Response to Seismic Lines: Edge Effects and On-Line Succession (MSc Thesis). Univeristy of Alberta.

Mallik, A.U., 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: role of disturbance, seedbed limitation, and keytsone species change. CRC. Crit. Rev. Plant Sci. 22, 341–366.

Matlack, G.R., 1993. Microenvironment variation within and among forest edge sites in the Eastern United States. Biol. Conserv. 66, 185–194.

McLellan, B.N., Hovey, F.W., 1995. The diet of grizzly bears in the Flathead River drainage of southeastern British Columbia. Can. J. Zool. 73, 704–712.

Mumma, M.A., Gillingham, M.P., Johnson, C.J., Parker, K.L., 2017. Understanding predation risk and individual variation to risk avoidance for threatened boreal caribou. Ecol. Evol. http://dx.doi.org/10.1002/ece3.3563.

Munro, R.H.M., Nielsen, S.E., Price, M.H., Stenhouse, G.B., Boyce, M.S., 2006. Seasonal and diel patterns of grizzly bear diet and activity in West-Central Alberta. J. Mammal. 87, 1112–1121.

Natural Regions Committee, 2006. Natural Regions and Subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Nguyen-Xuan, T., Bergeron, Y., Simard, D., Fyles, J.W., Paré, D., 2000. The importance of forest floor disturbance in the early regeneration patterns of the boreal forest of western and central Quebec: a wildfire versus logging comparison. Can. J. For. Res. 1353–1364.

Nielsen, S.E., Munro, R.H.M., Bainbridge, E.L., Stenhouse, G.B., Boyce, M.S., 2004. Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Alberta, Canada. For. Ecol. Manage. 199, 67–82.

Nielsen, S.E., McDermid, G., Stenhouse, G.B., Boyce, M.S., 2010. Dynamic wildlife habitat models: Seasonal foods and mortality risk predict occupancy-abunance and habitat selection in grizzly bears. Biol. Conserv. 143, 1623–1634.

Ospina, R., Ferrari, S.L.P., 2012. A general class of zero-or-one inflated beta regression models. Comput. Stat. Data Anal. 56, 1609–1623.

Pattison, C.A., Quinn, M.S., Dale, P., Catterall, C.P., 2016. The landscape impact of linear seismic clearings for oil and gas development in boreal forest. Northwest Sci. 90, 340–354.

Pigeon, K., Anderson, M., MacNearney, D., Cranston, J., Stenhouse, G., Finnegan, L., 2016. Towards the restoration of caribou habitat: understanding factors associated with human motorized use of legacy seismic lines. Environ. Manage. 58, 821–832.

Polfus, J.L.L., Hebblewhite, M., Heinemeyer, K., Heinemeyer, M.H.K., 2011. Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. Biol. Conserv. 144, 2637–2646.

Porensky, L.M., Young, T.P., 2013. Edge-effect interactions in fragmented and patchy landscapes. Conserv. Biol. 27, 509–519.

R Development Core Team, 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.

Renecker, L.A., Schwartz, C.C., 1998. Food habits and feeding behavior. In: Franzmann, A., Schwartz, C.C. (Eds.), Ecology and Mangement of the North American Moose. Smithsonian Institution Scholarly Press, Washington, DC, pp. 403–439.

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

Rigby, R.A., Stasinopoulos, D.M., 2005. Generalized additive models for location, scale and shape. Appl. Stat. 54, 507–554.

Roberts, M.R., Zhu, L., 2002. Early response of the herbaceous layer to harvesting in a mixed coniferous–deciduous forest in New Brunswick. Canada. For. Ecol. Manage. 155, 17–31.

Roffler, G.H., Gregovich, D.P., Larson, K.R., 2018. Resource selection by coastal wolves reveals the seasonal importance of seral forest and suitable prey habitat. For. Ecol. Manage. 409, 190–201.

Roever, C.L., Boyce, M.S., Stenhouse, G.B., 2008. Grizzly bears and forestry I: road vegetation and placement as an attractant to grizzly bears. For. Ecol. Manage. 256, 1253–1261.

RStudio, 2015. RStudio: Integrated Development Environment for R (version 0.95.501).

Seip, D., 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. C. J. Zool. 70, 1494–1503.

Smith, K.G., Ficht, E.J., Hobson, D., Sorensen, T.C., Hervieux, D., 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Can. J. Zool. 78, 1433–1440.

Tigner, J., Bayne, E.M., Boutin, S., 2015. American marten respond to seismic lines in northern Canada at two spatial scales. PLoS One 10, e0118720.

Timoney, K., Lee, P., 2001. Environmental management in resource-rich Alberta, Canada: first world jurisdiction, third world analogue? J. Environ. Manage. 63, 387–405.

van Rensen, C.K., Nielsen, S.E., White, B., Vinge, T., Lieffers, V.J., 2015. Natural regeneration of forest vegetation on legacy seismic lines in boreal habitats in Alberta's oil sands region. Biol. Conserv. 184, 127–135.

van Vierssen Trip, N., Wiersma, Y.F., 2015. A comparison of All-Terrain Vehicle (ATV) trail impacts on boreal habitats across scales. Nat. Areas J. 35, 266–278.

Venier, L., Thompson, I., Fleming, R., Malcolm, J., Aubin, I., Trofymow, J., Langor, D., Sturrock, R., Patry, C., Outerbridge, R., Holmes, S., Haeussler, S., De Grandpré, L., Chen, H., Bayne, E., Arsenault, A., Brandt, J., Venier, L.A., 2014. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. Environ. Rev 22, 457–490.

Wagner, D.L., Metzler, K.J., Leicht-Young, S.A., Motzkin, G., 2014. Vegetation composition along a New England transmission line corridor and its implications for other trophic levels. For. Ecol. Manage. 327, 231–239.

Wickham, H., 2009. ggplot2: Elegant Graphics for Data Analysis. Springer, New York, USA.

Zuur, A.F., Ieno, E.N., Elphick, C.S., 2010. A protocol for data exploration to avoid common statistical problems. Meth. Ecol. Evol. 1, 3–14.