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Original Research

Using LiDAR, Colour Infrared Imagery, and Ground Truth Data for Mapping and Characterizing Vegetation Succession on Disturbance Types: Implications for Woodland Caribou (*Rangifer tarandus caribou*) Habitat Management

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Abstract

Woodland caribou (*Rangifer tarandus caribou*) occur throughout Canada's boreal forest and have been declining both in distribution and population size along the southern extent of their range. Predation, hunting, and habitat loss/alteration due to industrial development are listed as potential causes of decline. Researchers have demonstrated that wolf (*Canis lupus*) movement rates are faster along human disturbances compared to adjacent forest and this poses increased predation risk for caribou. Light Detection and Ranging (LiDAR) is an optical scanning technology that uses lasers to measure distances between objects. This tool can be used to remotely measure vegetation cover and height over large areas. The objectives of this Alberta study were to: 1) utilize LiDAR and colour infrared imagery to map disturbances and to quantify and map levels of vegetation re-growth; 2) use field data to characterize vegetation structure and composition on different disturbance types and in different ecosites; and 3) correlate vegetation field data attributes with remotely sensed map data to assist in producing spatially explicit vegetation height and cover metrics that can be used for reclamation planning on a range of disturbance types and ecological site conditions. Our results indicate that there is a strong correlation between hiding cover data sampled in the field and hiding cover metrics derived by LiDAR. As such, land managers can use these light detection and ranging metrics

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as a tool for determining where restoration efforts should be prioritized. These metrics can also be used to describe access and line of sight conditions. In terms of vegetation recovery, upland ecosites showed the least residual effect from disturbance events. Conversely, bog and fen ecosites showed highest residual effect in terms of the lack of natural vegetation recovery. These results indicate that some habitat types in this part of Alberta do have substantial capacity for natural regeneration of anthropogenic disturbance footprint.

Key Words: Anthropogenic Disturbance, Footprint Mapping, LiDAR, Colour Infrared Imagery, Reclamation, Vegetation Recovery, Woodland Caribou

INTRODUCTION

One of the most significant resources of northeastern Alberta is oil and gas. As a result, this region has undergone extensive exploration and development activities since the 1960s and 1970s. The first oil and gas activities in this region targeted shallow natural gas exploration and development. Accompanying this was a proliferation of seismic exploration footprint (6-8-m-wide linear corridors) and infrastructure development that included well pads and pipeline gathering systems. Seismic exploration is the geophysical analysis of reflected energy that is created by surface or near surface explosions or mechanical vibrations that are used to map subsurface sedimentary structures and to determine the presence of suitable traps for oil and gas resources (PSAC 2015). The resulting footprint amounted to approximately 4.5 km/km^2 of linear development in our study area (HAB-TECH 2014). The seismic footprint associated with this type of development was highly linear in nature and was often created using bulldozers; it substantially affected the remaining soils, micro-topography as well as seed-bank material (Lee and Boutin 2006). More recent development, including additional seismic exploration, has occurred since successful pilot projects and commercial developments of steam-assisted gravity drainage (SAGD) oil projects were undertaken in the Cold Lake region during the 1960s and 1980s (AEUB 2000). Further improvements to this technology in the mid-1990s resulted in a substantial expansion and intensification of exploration and development of in-situ oil resources. This new footprint, compounded with legacy footprint, has a substantial impact on the landscape. The linear and corresponding polygonal footprint, including low-impact 2-4-m-wide seismic lines, generally ranges from 4.5 to 13 km/km^2 (Devon 2012; HAB-TECH 2014). Areas with lower footprint densities are generally located along the east side of the province, outside the bitumen fairway, or in environmental set-asides such as the Dillon River Conservation Area (Figure 1).

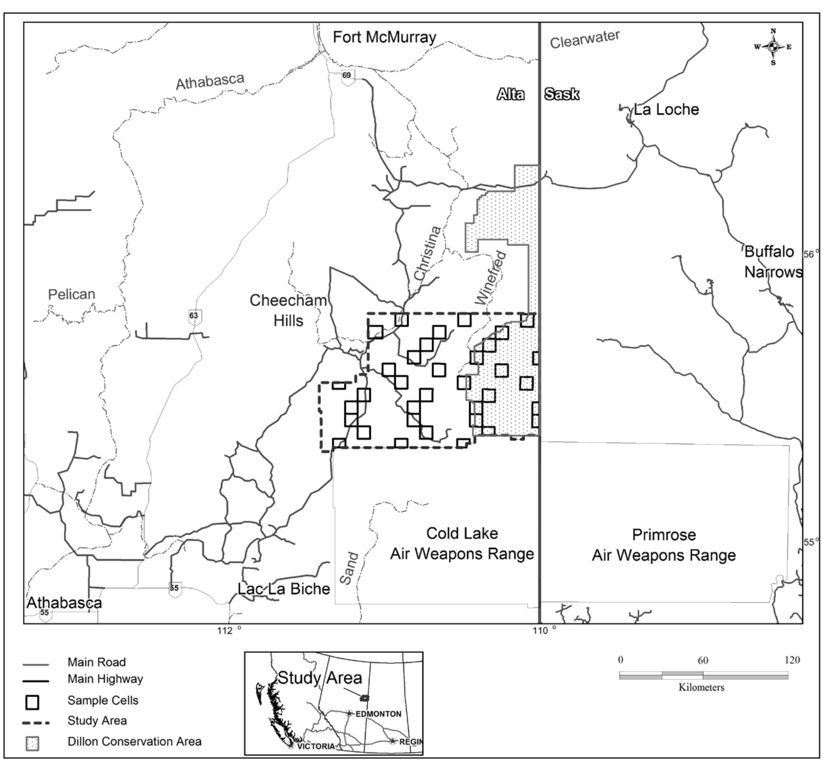

Figure 1. Location of study area.

This level of development and the corresponding fragmentation and habitat loss has affected several boreal wildlife species but none more than woodland caribou (*Rangifer tarandus caribou*). Woodland caribou occur throughout Canada's boreal forest and have been declining both in distribution and population size along the southern extent of their range (McLoughlin *et al.* 2003; Environment Canada 2008; Latham *et al.* 2011; Environment Canada 2012; Hervieux *et al.* 2013, 2014). This species is listed as Threatened in Canada (COSEWIC 2002) and in Alberta (AESRD 2014). Boreal woodland caribou are listed as threatened under Canada's Species at Risk Act (SARA), based on an observed, estimated, inferred or suspected reduction in population size of > 30% over 3 caribou generations (i.e., 20 years) (Environment Canada 2012). Predation, hunting, and habitat loss/alteration due to industrial development are listed as potential causes of decline (McLoughlin *et al.* 2003; AESRD and ACA 2010; Environment Canada 2008; Environment Canada 2012).

Environment Canada (2012) identified habitat alteration and/or loss and predation as 2 threats of high concern. Further, it established a target for the level of disturbance that caribou can tolerate to ensure sustainable populations. Specifically, buffered anthropogenic disturbance plus natural disturbance must not exceed 35% of a woodland caribou range. Environment Canada (2012) indicated that beyond this, the resultant effect will be a high probability of non-self-sustaining woodland caribou populations. Across Alberta, human-induced habitat alterations have caused an imbalance in predator-prey relationships and as a result, predation has been identified as the main proximate cause of boreal caribou decline across Canada (Environment Canada 2012; Hervieux *et al.* 2013, 2014). Several researchers have demonstrated that wolf movement rates were faster along human disturbances compared to adjacent forest, daily search distances increased and, as a result, caribou experienced an increased predation risk when close to these disturbances (Dickey 2015; Latham *et al.* 2011; James 1999). Further, wolves selected and moved faster on anthropogenic disturbances with shorter vegetation (Dickey 2015). Therefore, protection and management of boreal forest habitat, habitat restoration, and predator and alternate prey management, are all options that are being considered or implemented by jurisdictions in Alberta and across Canada. Given the time lag and slow response of reclamation activities, aggressive predator management has been implemented in the short term (Hervieux *et al.* 2014), but was strongly criticized (Brook *et al.* 2015). Regardless, footprint management and reclamation activities will be essential components of long-term land management strategies that will benefit caribou and other wildlife species. In particular, reclamation can be broadly used to offset ongoing or future footprint and/or for species-specific mitigation opportunities. Progressive reclamation and accelerated forest establishment or encouraged succession are strategies that are gaining momentum in Alberta (van Rensen *et al.* 2015). This need has been heightened by the release of Environment Canada's (2012) woodland caribou recovery strategy, which details the requirement for range improvement where disturbance thresholds have been exceeded. However, not all footprint is equal and not all footprint requires active reclamation/intervention (Lee and Boutin 2006; van Rensen *et al.* 2015).

This study highlights the utility of using local and regional LiDAR (Light Detection and Ranging) mapping and specific LiDAR metrics, in conjunction with extensive empirical ground truthing data, for quantifying vegetation height and/or foliar hiding cover for example, as tools to identify the need for action or provide a decision making framework to effectively guide restoration activities. LiDAR is an active sensor that uses laser energy emitted in pulses from the sensor. The laser pulse hits objects on the ground and is returned to the sensor. The time it takes for the laser pulse to leave and return to the sensor is recorded. The on-board global positing system (GPS) receiver and the initial measurement unit (IMU) allow a precise measurement of location and elevation. A LiDAR survey generates a series (e.g., billions) of individual points consisting of ground and above-ground returns that is commonly referred to as a point cloud and can be used to summarize the vertical structure of a forested canopy.

This study had 3 objectives: 1) classify and map the total disturbance footprint; (2) use field data to compare and contrast the status and characteristics of vegetation structure and composition on different disturbance types and for a range of ecological site conditions; and 3) correlate vegetation field data attributes with LiDAR data to assist in producing spatially explicit vegetation recovery maps on disturbances types for reclamation planning in northeastern Alberta.

STUDY AREA

The study is located in the Lower Athabasca Region of northeastern Alberta approximately 140 km south-southeast of the City of Fort McMurray (Figure 1). The entire area lies within the Central Mixedwood Sub-region of the Boreal Forest Natural Region (Beckingham and Archibald 1996). The Central Mixedwood Subregion is characterized by generally low topographic relief with rolling to undulating surface expression. Dominant landforms are ground moraine, glacial outwash and organics (muskeg). Typical soils are Gray Luvisols and Organics which underlie vegetation dominated by fens, bogs, closed deciduous and coniferous forest and moist shrub lands (Beckingham and Archibald 1996).

Characteristic land uses in the area include in-situ oil sands exploration and production, natural gas exploration and production, forest harvesting, motorized recreation, hunting, fishing and trapping, and multi-use transportation corridors. The resulting footprint in the area includes linear and polygonal disturbance types such as conventional seismic lines, pipelines, trails, wells, forest harvest blocks, borrow pits, industrial clearings, roads/railways, power lines and low impact seismic lines. The Cold Lake Air Weapons Range and the Province of Saskatchewan form the southern and eastern boundaries of the study area, respectively.

The Lower Athabasca Regional Plan (Alberta Government 2012) established the Dillon River Conservation Area and Wildland Provincial Park (1,915 km^2) to secure large tracts of woodland caribou habitat. A large portion of this area is located in the eastern and southern portions of the study area and restricts industrial activities including oil and gas and forestry. Human footprint in the Dillon River Conservation Area and Wildland Park is generally of a much lower density and areal footprint than the actively developed lands in the western portion of our study area (Alberta Government 2012).

METHODS

Acquisition of LiDAR and imagery

LIDAR data was acquired for the entire study area in August 2012 using a fixed-wing platform. The LiDAR data collection parameters included: a 0.5 m point density, a flight altitude of 1,500 m, a scan rate of 48.8 Hz, a repetition rate of ~119,000 Hz, a half scan angle of 13 degrees, an air speed of 222 km/h, front/side overlap of 60/30%, a pulse footprint of 0.45 m, a projected vertical accuracy of 9.25 cm, and a multi-pulse mode. The LiDAR data was delivered in LAS 1.2 format and classified according to the American Society for Photogrammetry and Remote Sensing (ASPRS 2008) standard. It includes unclassified, ground (bare-earth), medium vegetation, high vegetation, low point (noise), and water. A review of the LiDAR data that was collected for this work indicated that overall it exceeded 2 pulses/m^2 with 95% of the area averaging 2.5 to 4 pulses/m^2.

Four-band colour infrared imagery (CIR) was also flown for a portion of the study area in August and September 2012 and additional imagery was obtained for portions of the study area. The use of aerial 4-band CIR imagery was used to support disturbance type detection and delineation, image segmentation, and for display within 3D work stations for manual validation. The colour infrared imagery data collection parameters included: Vexel UltraCam XP camera type, flight altitude at approximately 1,500 m above ground level, sun angle of 34 degrees, average air speed of 222 km/h, front/side overlap of 60% and 30% respectively, grid spacing distance of 0.3 m, and data collected under cloud-free conditions.

LiDAR and imagery processing

Remote sensing software, eCognition, was used in combination with LiDAR and CIR, where available, to test the feasibility to perform automated delineation of disturbance footprint as well as segmentation of the disturbance types into micro-stands. The micro-stand segmentation process consists of breaking up of large polygons into smaller homogenous polygons of similar height, stand structure, and spectral signature characteristics from the imagery.

The vertical structure of a forest is very important from a wildlife habitat perspective (Naylor *et al.* 1996; Weir *et al.* 2012). LiDAR provides information on vertical structure (Coops *et al.* 2007; Dubayah and Drake 2000). The micro-stands were processed so each polygon had a LiDAR-mean canopy height and canopy cover metrics at 6 height intervals (0.1-1 m, 1.01-2 m, 2.01-3 m, 3.01-4 m, 4.01-5m, and 5 m +) (Figure 2). These same metrics were also generated for the ground plots.

Mean canopy height

A 1 m x 1 m canopy height model (CHM) raster dataset was generated using a mean of the first returns minus the ground elevation with any outliers 40 m above the ground surface being removed. This canopy height model was then used to provide a mean canopy height within the micro-stand by averaging (by weighted area) the height values within the micro-stand.

Canopy cover metrics

The canopy cover metrics were defined by the number of returns (all returns) within a specified height range threshold divided by the total number of returns (all returns) within each raster cell, in this case 3 m x 3 m. All the returns were used in the cover calculation in an effort to represent the vertical structure within the forested stands as precisely as possible. The height thresholds included: 0.1-1 m, 1.01-2 m, 2.01-3 m, 3.01-4 m, 4.01-5m, and 5 m +. The canopy cover metrics were then averaged (by weighted area) to provide canopy cover metrics for each height threshold within the micro-stand.

To ensure sound relationships between the LiDAR and field data sets, plots were appropriately sized and located within 1-2 m with Trimble Geo GPS units (White *et al.* 2013).

Sampling design and plot configuration

The accuracy and precision of the output of any remote sensing product needs to be tested and verified with real world field data (Lillesand and Kiefer 2000). Vegetation field data collection was conducted to (1) document the status and characteristics of natural vegetation re-growth on different disturbance

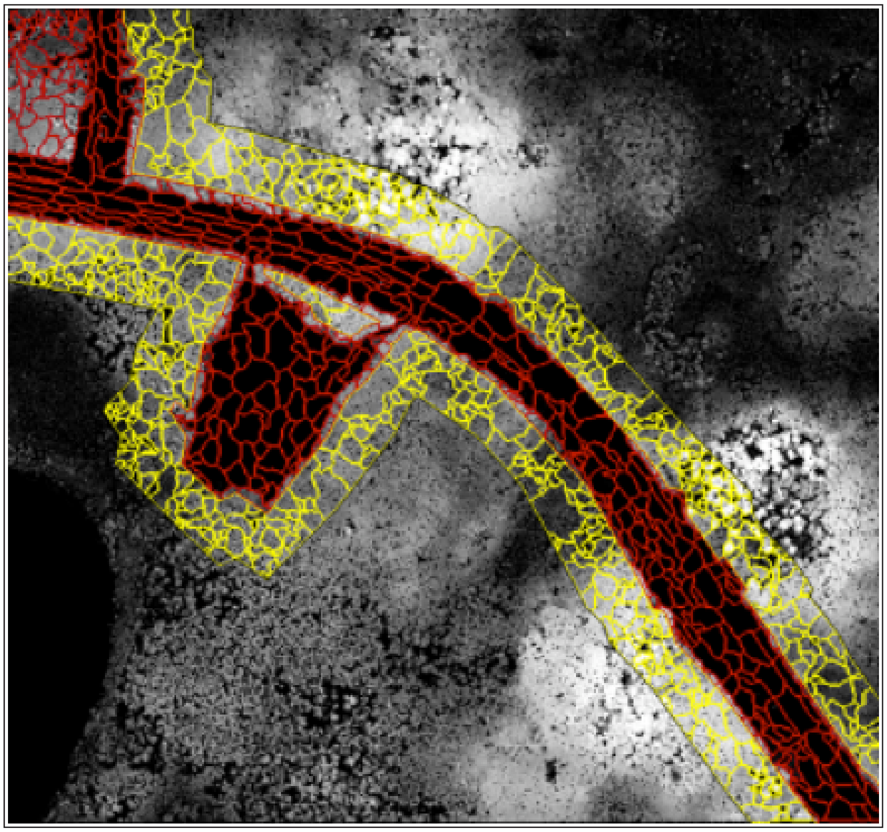

Figure 2. Example of high resolution disturbance type segmentation. This is a Canopy Height Model image derived from LiDAR first returns where the whitest areas indicate the highest surfaces hit by the LiDAR pulse and darker areas representing lower portions of the canopy. In this image, black is the ground, or an area without a return. The segmented polygons in red represent polygons within the disturbance area and the yellow segmented polygons highlight the polygons within a 100-m search radius for the disturbance polygons.

types and ecological site conditions; (2) compare metrics of vegetation re-growth on disturbance types to the same metrics in undisturbed areas; (3) test the accuracy of disturbance type classification; and (4) compare LiDAR metrics at sampling points with 'real-world' vegetation conditions as a means of testing LiDAR's ability to detect and measure vegetation re-growth on a range of disturbance types and ecological site conditions.

Each sampling site consisted of a 30-m transect along which 5, 20 cm x 50 cm sub-plots, 5, 1 m x 1 m sub-plots and 3, 2 m x 5 m sub-plots were systematically distributed at 5 m intervals (Figure 3). A series of vegetative and structural attributes were estimated or measured. Visual estimates along a continuous scale to the nearest percent were made at each sub-plot as described in British Columbia Ministry of Forests (1998). Because several different field personnel collected the data, observers would work together to estimate cover and minimize bias.

The percent cover of bare soil, rock/stones, litter, mulch, terrestrial lichen, feather moss, and sphagnum moss were recorded in the 5, 20 cm x 50 cm subplots. The depth of litter and mulch were also recorded. In each of the 1 m x 1 m subplots, the 10 most abundant low shrubs (<1 m in height) were recorded and given a rank order from 1 (most abundant) to 10 (least abundant). Forbs, grasses and sedges/rushes were grouped together and recorded and ranked in the same manner. Total percent cover and median height of low shrubs, forbs, grasses, sedges/rushes and standing water was recorded for each sub-plot. Tall shrub saplings were surveyed in the 2 m x 5 m plot. Saplings were divided into 2 groups: 1-<3-m and ≥3-5-m heights. Species and height were recorded for each sapling that was recorded.

Structural data included coarse woody debris frequency of occurrence and hiding cover. Coarse woody debris was recorded along the length of the 30-m transect. The total number of intercepts, the diameter and the decay class (1-7) of all >10 cm-pieces were measured (Lee *et al.* 1995). Hiding cover or horizontal foliar vegetation cover, as represented by the percentage hidden, was estimated in both east and west directions from plot centre using the methods outlined by Nudds (1977). This estimate is taken to describe vertical and horizontal foliar complexity and occurrence. Estimates of foliar complexity and occurrence were made from 2 heights to represent the perspective of a woodland caribou (1.75 m) and wolf (1.25 m).

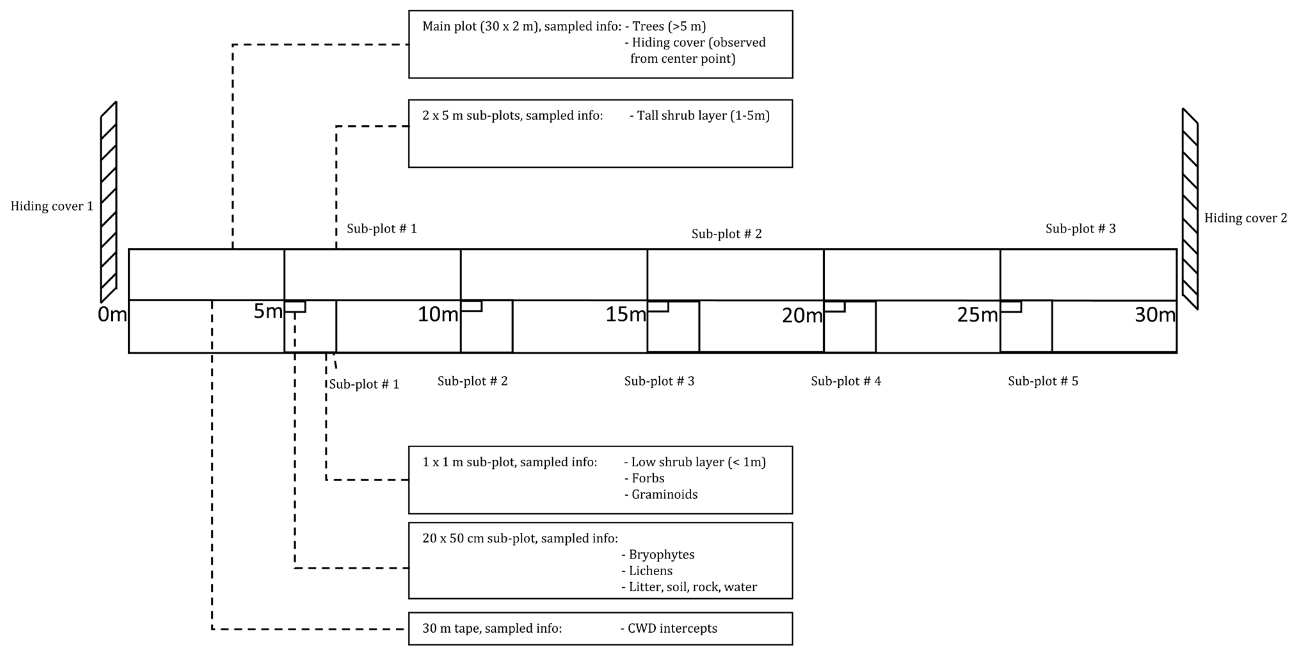

Figure 3. Ground sampling plot layout.

Additional site-specific information was also collected, at the stand level, in the undisturbed area adjacent to disturbance types including tree canopy closure (> 5 m) and composition (visual estimate), diameter at breast height, height, age and Ecosite phase (Beckingham and Archibald 1996).

Sample site selection

The 4,315 km^2 study area was delineated into 5 x 5 km grid cells and each cell was assigned a unique identifier. From these, a systematic random selection of 35 grid cells was completed to ensure coverage across the study area. All anthropogenic disturbance types within each cell were labelled and 5 sample points for each disturbance type and reference sites were randomly selected. The disturbance types sampled included: natural (reference), burned areas, conventional seismic lines, pipelines, trails, wells, forest harvest blocks, borrow pits, industrial clearings, roads/railways, power lines and low impact seismic lines. Field sampling transects (30 m in length) were laid out perpendicular to the edges of disturbances when they were wide enough (i.e., greater than 30 m). When disturbance types were < 30-m wide (e.g., a conventional seismic line), transect were oriented at a left-bearing that permitted transects to extend from edge to edge. Transects were located in the centre of disturbances that were < 5-m wide (e.g., a low impact seismic line). Transects were always laid in an easterly direction on east-west running disturbances, southerly on north-south running disturbances

A total of 476 individual sites (e.g., disturbance and reference sites), within 31 grid cells, were surveyed between July 4 and September 17, 2013. Sample sizes ranged from 3 to 92 (mean = 39.7) per disturbance type.

Data analysis

Disturbance type mapping accuracy

An accuracy assessment of LiDAR disturbance mapping was completed by comparing LiDAR derived mapping with disturbance type classifications obtained from ground truthing data in the field. Each of the 476 randomly selected ground sampling plots was classified (in the field) as one of the mapped disturbance type classes. Plot locations were then overlain onto the disturbance type map to determine the mapped class. The disturbance type accuracy assessment was conducted by determining the percentage of field plots per disturbance type that matched the final mapping classification.

Given their narrow widths (< 3 m) and adjacent forest canopy overhang, the automated detection of low-impact seismic lines using LiDAR and other imagery was not reliable. These disturbance types were therefore manually digitized, and not included in the mapping accuracy tests.

Differences in natural recovery

Ecosite type – We explored the potential relationship between the level of natural regeneration and Ecosite type. Ecosites are ecological units that develop under similar environmental influences such as climate, moisture, and nutrient regime and are frequently named after plant species that are common or typical of the ecosite (Beckingham and Archibald 1996). For this analysis we first calculated the average cover and/or stem density values for each vegetation layer by Ecosite. This comparison was only made using data collected from plots on conventional seismic lines. Conventional lines were selected for this analysis because a relatively large number of plots were completed over a wide range of ecosites. Ecosites with 4 or more samples were used in the analysis. Eight different vegetation cover/stem density metrics (lichens, mosses, forbs, graminoids, shrubs < 1 m, shrubs 1-2 m, shrubs 3-5 m, and trees) and 2 vegetation structure metrics (wolf hiding cover and caribou hiding cover) were analyzed. Two-sample *t*-tests, not assuming equal variance, were run to verify whether or not differences in mean values between compared groups were statistically significant. The precision of this mean value was quantified by calculating standard error of the mean (SE). All data was analyzed using Minitab v. 17.1.0 (Minitab Inc., State College, PA, USA).

Disturbance type – We also explored the potential relationship between the level of natural regeneration and disturbance type. Ecosites and disturbance types with 4 or more samples were used to test for differences between reference and disturbance sites based on the type of disturbance. Disturbance types included trails, conventional seismic lines and pipelines. Ecosites included "D" (deciduous or mixed wood forest types), "H" (coniferous forest types), and "J" (poor fens). Ten different vegetation growth metrics were compared for each Ecosite and disturbance type (i.e., 30 comparisons). Two-sample *t*-tests, not assuming equal variance, were run to verify whether or not differences in mean values between compared groups were statistically significant. The precision of this mean value was quantified by calculating standard error of the mean (SE). All data was analyzed using Minitab v. 17.1.0 (Minitab Inc., State College, PA, USA).

Effects of persistent use of disturbance types

Recent and/or on-going human use of disturbances could also have a considerable influence on vegetation recovery. As such, analysis was conducted on the differences between an area with disturbance types that are predominantly old and were presumed to have had limited human use/access over the last few decades (Dillon Nature Reserve), versus disturbance types in an area with active in-situ oil sands leases. Only plots on conventional seismic lines were analyzed as this was the only disturbance type with a sufficient number of plots within both areas to allow for comparisons of any precision. Test statistics were conducted for differences in average vegetation metric values for conventional seismic lines between the Dillon area (n=39) and the active in-situ oil sands lease area (n=53). Two-sample *t*-tests (not assuming equal variances) were run to investigate potential differences in average values between treatment areas.

LiDAR metrics and field data

Several LiDAR metrics, as derived at field sampling sites, were compared with vegetation and hiding cover field values to identify potential correlations between metrics. The metrics analyzed and compared included:

1. Percentage cover/stem density for each vegetation layer versus % LiDAR returns.
2. Percentage cover/stem density for vegetation layers versus LiDAR mean height.
3. Hiding cover from wolf and caribou heights versus % LiDAR returns
4. Hiding cover from wolf and caribou heights versus LiDAR mean height.

The values from the 2 data sets were plotted and a regression analysis was conducted to identify possible correlation values between the 2 data sets. The metrics that showed the best fit were identified and used to classify and map segmented micro-stands on disturbance types. All data was analyzed using Minitab v. 17.1.0 (Minitab Inc., State College, PA, USA).

RESULTS

Disturbance type mapping accuracy

Semi-automated disturbance footprint mapping accuracy using LiDAR and CIR ranged from 88 to 100% (mean = 96.2%). Borrow pits, harvest blocks, railways, and roads had the highest accuracies (100%), followed by conventional seismic lines and wells (98%), burns and trails (96%), pipelines and power transmission lines (92%), and industrial clearings (88%).

Differences in natural recovery

Ecosite type

Based on the number of metrics that tested significantly different between disturbance and control (Table 1), the ecosites ranked as follows:

Low-bush cranberry (D) - 1 out of 10 metrics (10%)
Dogwood/horsetail (E/F) - 2 out of 10 metrics (20%)
Labrador tea-mesic (C) - 3 out of 10 metrics (30%)
Bog (I) - 5 out of 10 metrics (50%)
Fen (K) - 5 out of 10 metrics (50%)
Labrador tea-sub-hydric (G) - 6 out of 10 metrics (60%)
Poor fen (J) - 7 out of 10 metrics (70%)

Ecosites D and E/F had the least number of statistically significant differences in vegetation metrics between disturbed and control samples. The bog and fen habitats (ecosites I, J and K) demonstrated poor vegetation recovery of shrub and tree layers.

Table 1. Test statistics by ecosite for analysis of differences in estimated average metric values for conventional seismic lines vs. natural areas. Two-sample *t*-tests were run to verify whether or not differences in average values between compared groups were statistically significant (*P*<0.05) - (C = Labrador tea-mesic; D = Low-bush cranberry; E = Dogwood; F = Horesetail).

Ecosite	Metric	*n* (disturb)	*n* (natural)	mean (disturb)	mean (natural)	Diff. in mean	df	*t*-value	*P*-value	Comments
C	Lichens	9	20	26.7	14.6	12.1	12	1.05	0.315	
	Mosses			29.4	67.7	-38.3	20	-4.93	<0.001	Significantly higher moss cover in control
	Forbs			13.2	7.5	5.7	13	1.87	0.084	
	Graminoids			10.2	1.0	9.1	8	1.80	0.110	Trend towards higher graminoid cover in disturbed
	Shrubs <1m			20.5	18.4	2.2	16	0.48	0.636	
	Shrubs 1-3m			16.2	6.4	9.8	9	1.48	0.174	
	Shrubs 3-5m			4.9	2.5	2.4	10	0.77	0.458	
	Trees			0.3	37.3	-37.0	19	-9.93	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			43.4	61.4	-17.9	13	-1.31	0.213	
	Caribou hiding cover			27.3	57.5	-30.1	13	-2.21	0.046	Significantly higher caribou cover in control
D	Lichens	8	23	0.5	<0.1	0.5	7	1.34	0.222	
	Mosses			14.9	12.2	2.7	13	0.41	0.695	
	Forbs			39.6	39.0	0.6	18	0.10	0.925	
	Graminoids			12.4	5.9	6.5	8	1.09	0.309	
	Shrubs <1m			14.1	17.4	-3.3	14	-0.69	0.500	
	Shrubs 1-3m			22.0	20.2	1.8	9	0.20	0.849	
	Shrubs 3-5m			2.3	3.0	-0.8	12	-0.46	0.652	
	Trees			0.0	62.6	-62.6	22	-15.61	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			51.4	75.9	-24.5	8	-1.74	0.121	
	Caribou hiding cover			41.5	61.5	-20.0	9	-1.50	0.169	
E + F	Lichens	4	11	0.0	0.1	-0.1	10	-3.13	0.011	Significantly higher lichen cover in control
	Mosses			21.6	14.4	7.2	12	0.89	0.395	
	Forbs			34.4	32.8	1.6	4	0.10	0.921	
	Graminoids			37.7	8.3	29.4	3	2.26	0.108	Trend towards higher graminoid cover in disturbed
	Shrubs <1m			14.6	19.0	-4.4	5	-0.55	0.605	
	Shrubs 1-3m			47.0	11.5	35.5	3	2.14	0.121	
	Shrubs 3-5m			7.5	2.2	5.3	3	1.56	0.218	
	Trees			0.0	65.5	-65.5	10	-15.86	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			62.0	79.9	-17.9	4	-1.38	0.239	
	Caribou hiding cover			49.3	63.2	-13.9	4	-0.75	0.496	
G	Lichens	13	35	10.9	1.7	9.2	13	2.14	0.051	Trend towards higher lichen cover in disturbed
	Mosses			57.8	79.4	-21.6	14	-2.32	0.036	Significantly higher moss cover in control
	Forbs			21.0	4.7	16.3	13	4.02	0.002	Significantly higher forb cover in disturbed
	Graminoids			6.7	1.5	5.2	14	2.94	0.011	Significantly higher graminoid cover in disturbed
	Shrubs <1m			22.5	15.5	7.1	27	1.38	0.179	
	Shrubs 1-3m			16.9	18.1	-1.1	32	-0.25	0.802	
	Shrubs 3-5m			3.1	6.6	-3.6	30	-1.75	0.091	Trend towards higher shrub density (3-5m) in control
	Trees			0.0	51.8	-51.8	34	-15.25	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			50.7	80.0	-29.3	29	-4.61	<0.001	Significantly higher wolf cover in control
	Caribou hiding cover			44.7	74.3	-29.7	24	-3.84	<0.001	Significantly higher caribou cover in control
I	Lichens	6	22	4.1	7.3	-3.3	15	-0.89	0.387	
	Mosses			63.8	83.7	-19.9	6	-1.97	0.096	Trend towards higher moss cover in control
	Forbs			13.8	5.9	7.9	8	3.87	0.005	Significantly higher forb cover in disturbed
	Graminoids			14.4	3.7	10.6	6	1.58	0.164	
	Shrubs <1m			29.0	36.2	-7.2	11	-1.25	0.236	
	Shrubs 1-3m			23.3	34.1	-10.8	12	-1.30	0.218	
	Shrubs 3-5m			0.3	10.0	-9.7	23	-7.06	<0.001	Significantly higher shrub density (3-5m) in control
	Trees			0.0	9.4	-9.4	21	-3.48	0.002	Significantly higher tree cover in control
	Wolf hiding cover			53.0	94.1	-41.1	6	-4.05	0.006	Significantly higher wolf cover in control
	Caribou hiding cover			28.2	88.6	-60.5	8	-6.94	<0.001	Significantly higher caribou cover in control
J	Lichens	20	38	0.2	1.8	-1.6	42	-2.63	0.012	Significantly higher lichen cover in control
	Mosses			73.4	81.6	-8.2	25	-1.26	0.218	
	Forbs			13.9	14.5	-0.6	44	0.84	0.410	
	Graminoids			31.5	9.1	22.4	22	4.64	<0.001	Significantly higher graminoid cover in disturbed
	Shrubs <1m			19.8	33.9	-14.1	44	-4.12	<0.001	Significantly higher shrub cover (<1m) in control
	Shrubs 1-3m			16.5	35.1	-18.6	49	-3.53	<0.001	Significantly higher shrub density (1-3m) in control
	Shrubs 3-5m			0.8	8.1	-7.3	40	-5.33	<0.001	Significantly higher shrub density (3-5m) in control
	Trees			0.0	12.3	-12.3	37	-5.43	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			62.3	91.8	-29.5	5	-2.15	0.084	Trend towards higher wolf cover in control
	Caribou hiding cover			45.0	82.6	-37.6	6	-3.03	0.023	Significantly higher caribou cover in control

Table 1 (cont.). Test statistics by ecosite for analysis of differences in estimated average metric values for conventional seismic lines vs. natural areas. Two-sample *t*-tests were run to verify whether or not differences in average values between compared groups were statistically significant (P<0.05) - (C = Labrador tea-mesic; D = Low-bush cranberry; E = Dogwood; F = Horesetail).

Ecosite	Metric	*n* (disturb)	*n* (natural)	mean (disturb)	mean (natural)	Diff. in mean	df	*t*-value	*P*-value	Comments
K	Lichens	10	26	0.0	0.2	-0.2	26	-2.95	0.007	Significantly higher lichen cover in control
	Mosses			74.3	71.6	2.6	18	0.29	0.773	
	Forbs			18.6	15.1	3.5	10	0.54	0.599	
	Graminoids			29.4	22.7	6.8	17	1.07	0.301	
	Shrubs <1m			26.4	24.7	1.7	11	0.24	0.816	
	Shrubs 1-3m			26.6	61.1	-34.5	33	-3.01	0.005	Significantly higher shrub density (1-3m) in control
	Shrubs 3-5m			2.2	5.5	-3.3	28	-2.02	0.053	Trend towards higher shrub density (3-5m) in control
	Trees			0.0	9.4	-9.4	25	-3.37	0.003	Significantly higher tree cover in control
	Wolf hiding cover			74.1	91.5	-17.4	13	-2.19	0.047	Significantly higher wolf cover in control
	Caribou hiding cover			43.6	75.4	-31.8	16	-3.77	0.002	Significantly higher caribou cover in control

Disturbance type

The ecosites with the highest number of metrics with significant differences between disturbance and control were as follows:

Low-bush cranberry (D) - 7 out of 30 metrics (23%)

Labrador tea-sub-hydric (G) - 12 out of 30 metrics (40%)

Poor fen (J) - 21 out of 30 metrics (70%)

The deciduous-dominated D ecosite showed the least difference between vegetation metrics on and off of disturbance types. Further, all 3 disturbance types had a very similar number of vegetation metrics that were significantly different between control and disturbed sites (Tables 2, 3 and 4).

Trail - 13 out of 30 metrics (43%)

Conventional seismic line - 14 out of 30 metrics (47%)

Pipeline - 13 out of 30 metrics (43%)

Effects of persistent use of disturbance types

Results show significantly higher amounts of low shrub cover and tall shrub densities on conventional seismic lines in the Dillon area compared to conventional seismic lines in busier in-situ lease areas (Table 5). Conversely, significantly lower forb cover was recorded on conventional seismic lines in the Dillon area than for plots in the more actively used areas to the west (Table 5).

LiDAR metrics and field data

The strongest correlation between the remotely sensed LiDAR data and field data at sample sites was observed between the percent LiDAR returns in the 0-3 m layer and hiding cover (from the perspective of wolf and caribou) between 0 and 2.5 m. Figures 4 and 5 provide scatter plots with regression fit for correlation between values for hiding cover (as viewed at caribou height) in the 0 to 2.5 m interval and LiDAR returns in the 0 to 3 m interval by disturbance type and ecosite, respectively. Regression fit and test statistics for analysis of correlation between values for hiding cover (from caribou height) in the 0 to 2.5 m interval (y) and LiDAR returns in the 0 to 3 m interval (x) are provided in Table 6. The lowest correlations between LiDAR and field data were found for railway/road, low impact seismic lines and borrow pits.

DISCUSSION

Mapping accuracy and utility

This study demonstrated that semi-automated disturbance type mapping using a combination of LiDAR and CIR accuracy was very high (88-100%) for most classes. Although these disturbances could be located and mapped accurately, testing indicated that boundary delineation was problematic in areas where the spectral signature and height between the disturbance and the surrounding vegetation types was minimal. When boundary delineation was problematic, disturbance edges were manually edited. However, compared to larger disturbance types (e.g., conventional seismic lines), semi-automated detection of low-impact seismic lines using LiDAR and CIR was determined to be unreliable. We determined that the most effective approach for delineating and mapping low impact seismic is to use field survey data. Our experience is that survey data for low-impact lines is more readily available compared to historic conventional seismic line locations. We do not view this as a serious limitation because the inclusion of low-impact seismic lines in reclamation planning may not be desirable. We observed that in several ecosite types, natural recovery on low-impact lines, 6-7 years post mulching, appears to be on a positive trajectory. Further, results indicated that, within several upland (D/E) and lowland (K/J) ecosites, ≤1 m-high shrub cover, as measured by a hiding cover cloth (Nudds 1977), was not significantly different when compared to reference sites. It is generally acknowledged that vertical and horizontal distribution of vegetation cover is an important aspect of wildlife habitat selection and that this has been a gap in wildlife habitat modelling (Martinuzzi *et al.* 2009; Rahme1991). Structural heterogeneity is most conducive to increased animal richness and abundance, and increased complexity of vertical vegetation structure is more positively

Table 2. Test statistics of differences in estimated average metric values for three disturbance types in the D ecosite. Two-sample *t*-tests were run to verify whether or not differences in average values between compared groups were statistically significant (*P*<0.05) – (TRA = trail; CON = conventional seismic line; PIP = pipeline).

Feature Type	Metric	*n* (disturb)	*n* (natural)	mean (disturb)	mean (natural)	Diff. in mean	df	*t*-value	*P*-value	Comments
TRA	Lichens	4	23	0.0	<0.1	<0.1	22	-1.66	0.110	
	Mosses			5.5	12.4	-6.8	7	-1.19	0.272	
	Forbs			17.7	39.0	-21.3	7	-3.10	0.020	Significantly higher forb cover in control
	Graminoids			28.7	5.9	22.8	3	2.11	0.125	
	Shrubs <1m			28.2	17.4	10.8	3	1.01	0.193	
	Shrubs 1-3m			40.5	20.2	20.3	5	2.63	0.047	Significantly higher shrub density (1-3m) in disturbed
	Shrubs 3-5m			10.0	3.0	7.0	3	1.64	0.200	
	Trees			0.8	62.6	-61.9	23	-15.16	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			96.0	75.9	20.1	21	4.21	<0.001	Significantly higher wolf cover in disturbed
	Caribou hiding cover			77.5	61.5	16.0	4	1.57	0.192	
CON	Lichens	8	23	0.5	<0.1	0.5	7	1.34	0.222	
	Mosses			14.9	12.2	2.7	13	0.41	0.695	
	Forbs			39.6	39.0	0.6	18	0.10	0.925	
	Graminoids			12.4	5.9	6.5	8	1.09	0.309	
	Shrubs <1m			14.1	17.4	-3.3	14	-0.69	0.500	
	Shrubs 1-3m			22.0	20.2	1.8	9	0.20	0.849	
	Shrubs 3-5m			2.3	3.0	-0.8	12	-0.46	0.652	
	Trees			0.0	62.6	-62.6	22	-15.61	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			51.4	75.9	-24.5	8	-1.74	0.121	
	Caribou hiding cover			41.5	61.5	-20.0	9	-1.50	0.169	
PIP	Lichens	8	23	1.9	0.0	1.8	7	1.06	0.322	
	Mosses			10.7	12.2	-1.5	10	-0.17	0.868	
	Forbs			20.4	39.0	-18.6	18	-2.95	0.009	Significantly higher forb cover in control
	Graminoids			24.5	5.9	18.5	8	2.03	0.077	Trend towards higher graminoid cover in disturbed
	Shrubs <1m			13.6	17.4	-3.8	11	-0.63	0.543	
	Shrubs 1-3m			10.8	20.2	-9.4	15	-1.60	0.131	
	Shrubs 3-5m			5.3	3.0	2.2	8	0.75	0.477	
	Trees			16.3	62.6	-46.4	10	-4.45	0.001	Significantly higher tree cover in control
	Wolf hiding cover			69.5	75.9	-6.4	10	-0.62	0.552	
	Caribou hiding cover			51.3	61.5	-10.3	9	-0.89	0.399	

Table 3. Test statistics of differences in estimated average metric values for three disturbance types in the G ecosite. Two-sample *t*-tests were run to verify whether or not differences in average values between compared groups were statistically significant (*P*<0.05) – (TRA = trail; CON = conventional seismic line; PIP = pipeline).

Feature Type	Metric	*n* (disturb)	*n* (natural)	mean (disturb)	mean (natural)	Diff. in mean	df	*t*-value	*P*-value	Comments
TRA	Lichens	9	35	8.2	1.7	6.5	8	1.20	0.265	
	Mosses			47.1	79.4	-32.4	9	-2.75	0.022	Significantly higher moss cover in control
	Forbs			22.1	4.7	17.4	8	1.88	0.100	
	Graminoids			17.3	1.5	15.8	8	1.78	0.112	
	Shrubs <1m			21.1	15.5	5.6	17	1.03	0.313	
	Shrubs 1-3m			20.0	18.1	2.0	11	0.24	0.818	
	Shrubs 3-5m			5.3	6.3	-1.0	15	1.88	0.100	
	Trees			2.2	51.8	-49.5	42	-13.07	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			65.0	80.0	-15.0	14	-1.85	0.085	Trend towards higher wolf cover in control
	Caribou hiding cover			48.0	74.3	-26.3	16	-3.34	0.004	Significantly higher caribou cover in control
CON	Lichens	13	35	10.9	1.7	9.2	13	2.14	0.051	Trend towards higher lichen cover in disturbed
	Mosses			57.8	79.4	-21.6	14	-2.32	0.036	Significantly higher moss cover in control
	Forbs			21.0	4.7	16.3	13	4.02	0.002	Significantly higher forb cover in disturbed
	Graminoids			6.7	1.5	5.2	14	2.94	0.011	Significantly higher graminoid cover in disturbed
	Shrubs <1m			22.5	15.5	7.1	27	1.38	0.179	
	Shrubs 1-3m			16.9	18.1	-1.1	32	-0.25	0.802	
	Shrubs 3-5m			3.1	6.6	-3.6	30	-1.75	0.091	Trend towards higher shrub density (3-5m) in control
	Trees			0.0	51.8	-51.8	34	-15.25	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			50.7	80.0	-29.3	29	-4.61	<0.001	Significantly higher wolf cover in control
	Caribou hiding cover			44.7	74.3	-29.7	24	-3.84	<0.001	Significantly higher caribou cover in control
PIP	Lichens	8	35	3.1	1.7	1.4	9	0.66	0.523	
	Mosses			42.2	79.4	-37.2	8	-4.06	0.004	Significantly higher moss cover in control
	Forbs			24.4	4.7	19.7	7	2.29	0.056	Trend towards higher forb cover in disturbed
	Graminoids			16.5	1.5	15.0	7	2.33	0.053	Trend towards higher graminoid cover in disturbed
	Shrubs <1m			19.2	15.5	3.7	13	0.64	0.536	
	Shrubs 1-3m			23.5	18.1	5.4	12	0.89	0.389	
	Shrubs 3-5m			13.0	6.6	6.4	9	1.63	0.138	
	Trees			6.9	51.8	-44.9	27	-9.94	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			54.5	81.3	-26.8	13	-2.92	0.012	Significantly higher wolf cover in control
	Caribou hiding cover			53.8	74.0	-20.3	12	-1.74	0.108	

Table 4. Test statistics of differences in estimated average metric values for three disturbance types in the J ecosite. Two-sample *t*-tests were run to verify whether or not differences in average values between compared groups were statistically significant (*P*<0.05) – (TRA = trail; CON = conventional seismic line; PIP = pipeline).

Feature Type	Metric	*n* (disturb)	*n* (natural)	mean (disturb)	mean (natural)	Diff. in mean	df	*t*-value	*P*-value	Comments
TRA	Lichens	6	38	1.2	1.8	-0.6	9	-0.52	0.616	
	Mosses			60.4	81.6	-21.1	5	-1.61	0.168	
	Forbs			7.3	11.5	-4.1	17	-1.50	0.150	
	Graminoids			29.1	9.1	19.9	5	1.70	0.142	
	Shrubs <1m			15.5	33.9	-18.4	9	-4.19	0.002	Significantly higher shrub cover (<1m) in control
	Shrubs 1-3m			3.7	35.1	-31.4	24	-6.71	<0.001	Significantly higher shrub density (1-3m) in control
	Shrubs 3-5m			0.0	8.1	-8.1	37	-5.80	<0.001	Significantly higher shrub density (3-5m) in control
	Trees			0.0	12.3	-12.3	37	-5.43	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			43.2	91.8	-48.7	5	-4.65	0.006	Significantly higher wolf cover in control
	Caribou hiding cover			18.7	82.6	-64.0	8	-11.44	<0.001	Significantly higher caribou cover in control
CON	Lichens	20	38	0.2	1.8	-1.6	42	-2.63	0.012	Significantly higher lichen cover in control
	Mosses			73.4	81.6	-8.2	25	-1.26	0.218	
	Forbs			13.9	14.5	-0.6	44	0.84	0.410	
	Graminoids			31.5	9.1	22.4	22	4.64	<0.001	Significantly higher graminoid cover in disturbed
	Shrubs <1m			19.8	33.9	-14.1	44	-4.12	<0.001	Significantly higher shrub cover (<1m) in control
	Shrubs 1-3m			16.5	35.1	-18.6	49	-3.53	<0.001	Significantly higher shrub density (1-3m) in control
	Shrubs 3-5m			0.8	8.1	-7.3	40	-5.33	<0.001	Significantly higher shrub density (3-5m) in control
	Trees			0.0	12.3	-12.3	37	-5.43	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			62.3	91.8	-29.5	5	-2.15	0.084	Trend towards higher wolf cover in control
	Caribou hiding cover			45.0	82.6	-37.6	6	-3.03	0.023	Significantly higher caribou cover in control
PIP	Lichens	6	38	0.0	1.8	-1.8	37	-3.00	0.005	Significantly higher lichen cover in control
	Mosses			44.4	81.6	-37.2	6	-3.75	0.010	Significantly higher moss cover in control
	Forbs			14.2	11.5	2.8	16	1.00	0.331	
	Graminoids			48.0	9.1	38.9	5	4.72	0.005	Significantly higher graminoid cover in disturbed
	Shrubs <1m			10.9	33.9	-23.0	7	-4.23	0.004	Significantly higher shrub cover (<1m) in control
	Shrubs 1-3m			17.0	33.9	-16.9	7	-2.87	0.024	Significantly higher shrub density (1-3m) in control
	Shrubs 3-5m			0.7	8.1	-7.4	40	-4.80	<0.001	Significantly higher shrub density (3-5m) in control
	Trees			0.0	12.3	-12.3	37	-5.43	<0.001	Significantly higher tree cover in control
	Wolf hiding cover			62.3	91.8	-29.5	5	-2.15	0.084	Trend towards higher wolf cover in control
	Caribou hiding cover			45.0	82.6	-37.6	6	-3.03	0.023	Significantly higher caribou cover in control

Table 5. Percent cover/stem counts by vegetation layer on conventional seismic lines in and out of the Dillon Conservation Area.

Metric	*n* (Dillon)	*n* (outside)	mean (Dillon)	Mean (outside)	Difference in mean	*t*-value	Df	*P*-value
Lichens	39	53	6.0	5.0	1.0	0.35	82	0.726
Mosses			55.9	46.3	9.6	1.39	76	0.168
Forbs			14.7	23.8	-9.0	-2.82	89	0.006
Graminoids			16.8	21.3	-4.5	-1.1	87	0.277
Shrubs <1m			27.8	18.9	8.9	2.78	76	0.007
Shrubs 1-3 m			35.9	15.7	20.2	3.57	59	0.001
Shrubs 3-5 m			5.5	2.2	3.3	2.33	72	0.023
Trees			3.0	1.5	1.5	0.61	79	0.547

influential compared with traditionally measured canopy cover (Davies and Asner 2014). However, Rahme (1991) also indicated that for most wildlife species, the precise role of cover remains ambiguous and poorly understood. In the same region as this study, Dickey (2015) demonstrated that wolves selected nearly all linear feature classes more than the surrounding forest. In addition, it was noted that wolves, on average, selected areas on linear features with shorter vegetation. Given the link between increased disturbance on the landscape and woodland caribou survival (Environment Canada 2012), these results suggest that the revegetation of linear features reduces the benefit of linear features to wolf movement. Although no empirical links between increased movement rates or daily distances and kill rates are available, it is important to understand the current state of the regeneration on the landscape to facilitate reclamation and reduce wolf use of linear features. As such, reclamation planning

Table 6. Regression fit and test statistics for analysis of correlation between values for hiding cover (from caribou height) in the 0-2.5 m interval (y) and LiDAR returns in the 0-3.0 m interval (x).

Disturbance Type	Regression equation	R-Sq value
Borrow Pit	y = -69.4x + 20.5	23.6
Burn	y = 2.9x + 42.0	36.8
Conventional	y = 3.7x + 20.0	55.0
Cutblock	y = 3.3x + 33.1	60.0
Industrial Clearing	y = 4.2x + 8.0	36.3
LIS	y = 0.9x + 11.3	3.5
Natural	y = 2.8x + 48.5	31.2
Pipeline	y = 3.5x + 25.4	37.4
Powerline	y = 2.7x + 14.5	56.2
Road/Railway	y = 3.8x + 19.5	3.3
Trail	y = 4.5x + 16.4	66.2
Well	y = 4.4x + 19.6	58.0
Ecosite		**R-Sq value**
A - Lichen	y = - 1.5x + 2.5	9.6
B - Blueberry	y = 3.9x + 20.7	56.9
C – Labrador-tea mesic	y = 5.6x + 14.3	65.0
D – Low-bush cranberry	y = 3.6x + 26.2	38.6
E + F - Dogwood/Horsetail	y = 5.0x + 15.6	78.2
G – Labrador-tea-sub-hydric	y = 3.7x + 24.0	36.7
H – Labrador-tea/horsetail	y = 5.2x + 26.2	72.1
I - Bog	y = 4.9x + 18.6	50.1
J – Poor fen	y = 3.9x + 19.7	55.5
K –Rich fen	y = 4.2x + 23.0	71.3
Bog/fen Regeneration	y = 2.2x + 23.4	30.1
Coniferous Regeneration	y = 3.5x + 34.8	39.1
Deciduous Regeneration	y = 3.9x + 29.8	71.0
Mixed Regeneration	y = 4.3x + 29.3	58.7

should consider if low-impact seismic lines will be treated and if so, be diligent as to where resources are allocated to ensure we target intervention and not impede/delay naturally recovering lines.

Differences in natural recovery

Field sampling data indicated that ecosites D and E/F had the least number of statistically significant differences in vegetation metrics between disturbed and control samples (Table 1). This is not surprising since these ecosites are moist and nutrient rich and support relatively rapid re-growth of deciduous shrubs and forbs (van Rensen *et al.* 2015; Beckingham and Archibald 1996). Similar results were reported for upland deciduous-dominated stands by van Rensen *et al.* (2015) and Lee and Boutin (2006). The transitional ecosites (C/G) are pine- and spruce-dominated, have a substantial cover of feather mosses (*Pleurozium*, *Hylocomium* and *Ptilium* genera), and minimal amounts of deciduous shrub cover (Beckingham and Archibald 1996). The mesic sites (C) had fewer significantly different growth metrics than that at the sub-hydric (G) sites (Table 1). This was due to a significantly greater amount of forb and graminoid cover and an increased amount of hiding cover below 1.25 m on disturbed sites compared to reference sites. Disturbed sites in both the C and G ecosites also had significantly less moss cover compared to reference sites. These changes are likely the results of post-disturbance changes in soil, light and moisture regimes as a result of how these disturbance types were created (Lee and Boutin 2006). The lowland bog and fen habitats (ecosites I, J and K) demonstrated poor vegetation recovery of shrub and tree layers.

The increased amount of shrub cover in the Dillon area was not unexpected and is likely attributable to longer time frames since disturbance and the fact that the area is located further away from all season access (van Rensen *et al.* 2015). The lower amount of forb cover on the lesser used types is likely due to decreased light/moisture caused by higher shrub cover competition (Table 5). These results demonstrate that in addition to distance from all season access, time since disturbance is likely an important metric to consider when gauging the success of, or potential for, natural recovery.

Analysis for differences between disturbance sites and reference sites for trails, conventional seismic lines and pipeline located in D (deciduous or mixed wood), G (coniferous), and J (bog/fen) indicated that the nutrient-rich and deciduous-dominated D ecosite showed the least difference between vegetation metrics on and off of disturbances while the G and J ecosites demonstrated poor vegetation recovery (Tables 2, 3, and 4). All 3 disturbance types had a very similar number of vegetation metrics that were significantly different between reference and disturbed sites. This indicates that, in addition to ecological site type, time since last disturbance or use of disturbance type may have a greater effect on vegetation recovery than the type of disturbance itself. Although time since disturbance appears to be a very important factor in assessing the status of re-growth, we did not have sufficient information to quantify this for any of our disturbance types. Van Rensen *et al.* (2015) suggested that time since disturbance and depth to water may better explain the degree of recovery. Results also indicated that natural vegetation recovery in bog and fen types is substantially less compared with upland sites, particularly in deciduous sites. This is not surprising given the propensity for seed and coppice regeneration in deciduous forest types (AESRD 2013; Rudolph and Pardy 1990). As such, these results suggest that recovery efforts geared towards re-establishing forest cover, and decreasing linear density and fragmentation should be concentrated in bog, poor-fen and pure conifer sites.

LiDAR metric and field data

A significant advantage of LiDAR, beyond the mapping and classification of disturbance type, is that it can provide a high resolution, spatially explicit map that outlines segments of homogeneous vegetation height and density on disturbances (e.g., micro-stands) (Figure 2). A strong correlation between ground truth data and the LiDAR derived metric was observed. The consistent and positive slope of the regression lines in Figures 4 and 5 demonstrates that LiDAR return data reflects

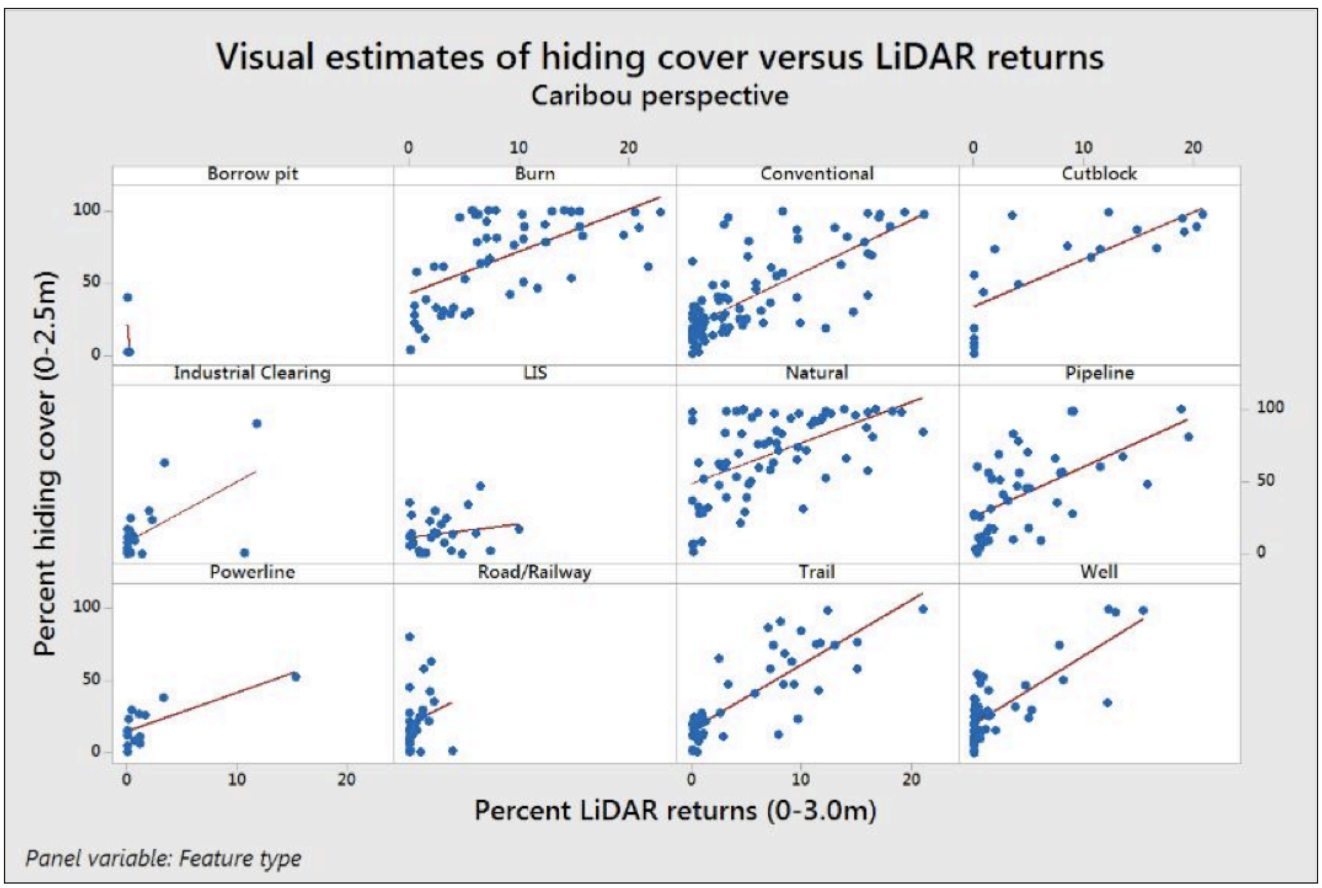

Figure 4. Correlation between LiDAR returns (0 to 3 m) and hiding cover field data (0 to 2.5 m), by disturbance type from the perspective of a caribou.

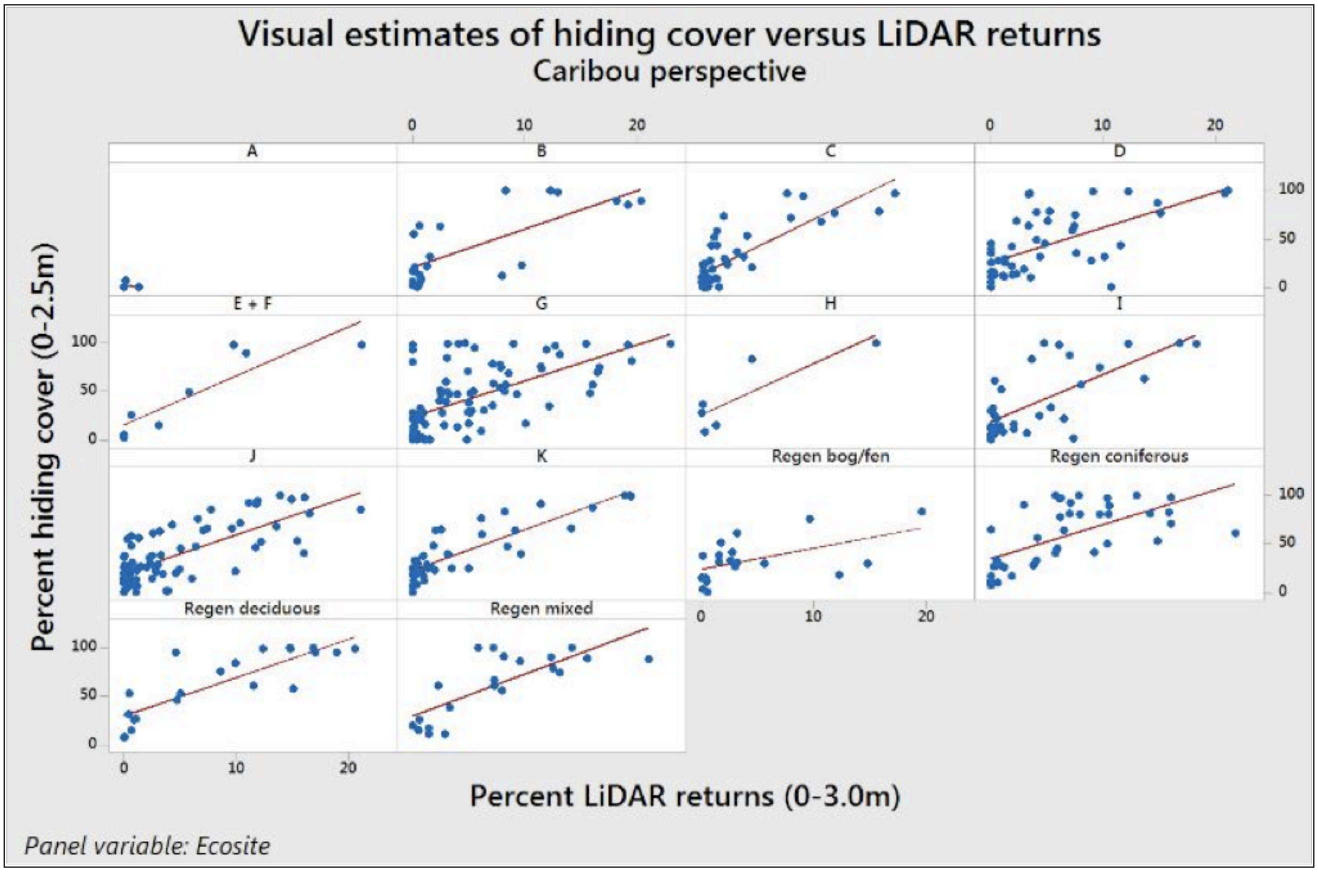

Figure 5. Correlation between LiDAR returns (0 to 3 m) and hiding cover field data (0 to 2.5 m) by Ecosite type from the perspective of a caribou.

hiding cover in most ecological and land use settings. This result was not unexpected since both hiding cover measures and LiDAR returns reflect vegetation foliar cover and density. The correlation between field plot data and LiDAR derived metrics indicate that it is feasible and reliable to use LiDAR to spatially map and characterize disturbances, including their state of vegetation, and to extract plot/LiDAR-derived data across the regional study area. Consequently, these data and associated mapping products can be used as a decision support tool for the prioritization of areas for reclamation treatments.

MANAGEMENT CONSIDERATIONS

In addition to reclaiming wildlife habitat, reclamation targets can serve to reduce linear disturbance density while eliminating access corridor use by humans and predators. For example, Bayne *et al.* (2005) identified a conventional seismic line threshold of 8.5 km/km^2 as the point where ovenbird (*Seiurus aurocapillus*) density decreased by 19% for each 1 km/km^2 increase in seismic line density. Environment Canada (2012) identified 65% undisturbed habitat in a woodland caribou range as the disturbance management threshold; this level of disturbance has been identified as the point at which there is measurable probability (60%) for a local population to be self-sustaining. Semi-automated LiDAR/colour infrared imagery disturbance and segmentation mapping, in conjunction with ecological land classification mapping, can serve as an efficient tool for spatially locating and prioritizing reclamation targets for 3 reasons: 1) the mapping accuracy, with the exception of low impact seismic lines, was very high; 2) there was a positive correlation between field data plots and LiDAR-derived metrics; and 3) it is feasible and reliable to extract plot/LiDAR-derived data across the regional study area and to use this tool to characterize vegetation recovery in other areas. This tool, in conjunction with empirical ground data, fulfills gaps identified by van Rensen *et al.* (2015) and permits for informed land management actions.

The accuracy and feasibility of LiDAR for use in ecological studies has been demonstrated in this study and others (e.g., Davies and Asner 2014). Given this, and the fine scale resolution of the data, this information allows land managers to use LiDAR metrics, particularly vegetation height and hiding cover, as tools for determining where restoration efforts should be prioritized, to measure vegetation recovery and to characterize access and line of sight parameters. Although vegetation structure influences predator prey relations in different ways, at least 2 species, fisher (*Pekania pennanti*) and mule deer (*Odocoileus hemionus*), have demonstrated a positive response to increased canopy vertical heterogeneity (Davies and Asner 2014). Results presented by Dickey (2015) also suggest that if the goal is to functionally restore linear features from the perspective of wolf use and movements, and subsequently benefit caribou, efforts should be directed towards conventional seismic lines and pipelines because wolves selected these types of linear features with shorter vegetation. LiDAR metric maps can also be used as a planning tool for the identification of access corridors that take into consideration naturally recovering areas and non-recovered areas.

More research is required to develop processes and tools for fully automated disturbance type identification and provision of accurate boundary delineation in all ecosites, including low impact seismic disturbances. Having consistent high-resolution CIR data for the entire study area would be valuable in this research.

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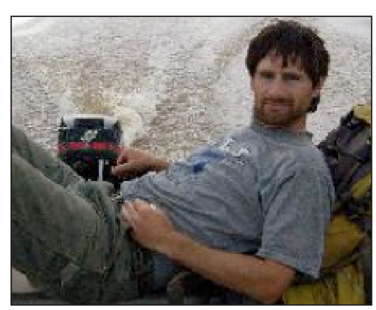

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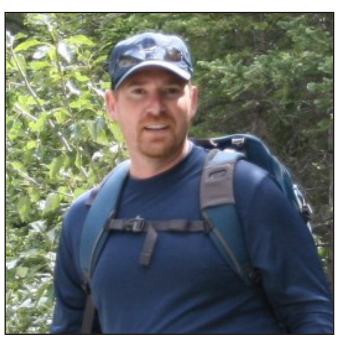

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