Collaborative Landscape Data to Support Woodland Caribou Recovery Planning in Northwestern Alberta

Report to the Northwest Species at Risk Committee (NWSAR) and Forest Resource Improvement Program (FRIP)

March 2021

Executive Summary

Woodland Caribou populations are under threat in Alberta and across Canada. Recovery strategies have identified linear feature management as a priority action to recover caribou habitat and populations. Given the priority of caribou conservation and the diversity of human land uses occurring within caribou ranges, effective management requires the best available information on the status of caribou habitat. This project focused on caribou ranges in northwestern Alberta, and sought to address the following questions:

What is the accuracy of existing human footprint data?

What is the state of vegetation growth on vegetated footprint types?

Where should restoration efforts on seismic lines be targeted?

We collected high-resolution aerial imagery and associated ground-truthed data from four sampling blocks in two caribou ranges to assess human footprint accuracy and state of vegetation recovery. We used existing geospatial datasets and approaches developed for northeastern Alberta to address targeting restoration efforts. The collected aerial imagery resulted in a large geospatial dataset including orthophoto mosaics and 3D point clouds, which create three-dimensional visualizations and allow the identification of individual trees and their heights.

We found that the overall accuracy of the existing human footprint data was high (93.44%), with variations in accuracy across footprint types and blocks. Seismic lines, wells, and harvest areas had similar, high levels of overall accuracy; accuracy was lowest for “other human footprint” types such as pipelines. Our results indicate that regrowth is occurring not only on seismic lines, but on other types of human footprint as well. This regrowth varies locally in the type, height, and density of vegetation.

The township prioritization analysis identified that high priority restoration zones within the Chinchaga and Bistcho caribou ranges tended to be spatially clumped, suggesting that habitat restoration should be prioritized in these regions. Conversely, high priority zones in the Caribou Mountains and Yates caribou ranges tended to be more dispersed, making it less efficient to target the high priority zones within these ranges. A key next step for this work would be incorporating the information on vegetation recovery into this prioritization analysis.

We discuss a number of potential next steps ranging from further exploration and analysis of the data, opportunities for ongoing data collection, and the opportunity to create an information portal that facilitates the use of this type of data for seismic line restoration management. These results are an exciting demonstration of the level of precision possible in discriminating vegetation cover types, heights, and density on human footprint features. Using the photogrammetry approach tested in this project, we are able to detect these vegetation regeneration variables to a high level of spatial resolution. This data has useful applications for developing and subsequently tracking vegetation recovery thresholds used for sub-regional or range planning, such as defining critical caribou habitat, which ultimately inform land management decisions.

The good news for the Alberta Northwest Species at Risk Committee (NWSAR) and the Forest Resource Improvement Program (FRIP) is:

(i) ABMI's current human footprint inventory datasets are reasonably accurate and up to date, and can be used with confidence to identify the type and extent of land use in the region. Despite good accuracy today, improvements are still needed, and work is underway to further enhance data products in northwestern Alberta.

(ii) Vegetation regrowth is occurring on many types of footprint. Although there is local variability in the type, height, and density of vegetation regrowth, it can be precisely measured using the approach tested and developed in this project. If scaled up, this data can identify where restoration efforts will benefit Woodland Caribou the most, both at the landscape level and on specific footprint features (e.g. which segment of a seismic line).

(iii) We have suggested initial landscape units (townships) where Woodland Caribou restoration investments will be most effective (biggest "Bang-for-buck").

(iv) These methods can be scaled up to ensure the future success in tracking and reporting on the state of footprint and vegetation recovery in northwestern landscapes.

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1.0 Introduction

In Alberta and across Canada, many Woodland Caribou (*Rangifer tarandus caribou*) populations are in decline (Festa-Bianchet et al. 2011). Woodland Caribou are considered At Risk under the provincial *Wildlife Act* in Alberta, and are listed as Threatened under the federal *Species at Risk Act*. Caribou declines are hypothesized to be primarily driven by human-caused habitat alteration, leading to direct habitat loss and changes in predator-prey dynamics (Dzus 2001; Johnson et al. 2020; Sorensen et al. 2008). Predation is considered the ultimate threat to caribou recovery, largely facilitated by the cumulative effects of fragmented landscapes resulting from both human-caused and natural disturbances.

The proliferation of linear features—such as legacy seismic lines, pipelines, and roads—in the boreal forest increases the availability of travel corridors, facilitates hunting by wolves (Dickie et al. 2017), and facilitates access into peatlands that previously acted as refugia for caribou (DeMars & Boutin 2017). Despite the small direct footprint of these linear features, they represent the most pervasive disturbance feature created by humans. For these reasons, habitat restoration on linear features, particularly historic conventional seismic lines, has been identified as a priority action to recover caribou habitat and populations (Bentham & Coupal 2015; Environment Canada 2012).

Environment Canada’s 2012 Federal Recovery Strategy for Woodland Caribou required that habitat disturbance levels within all caribou ranges not exceed 35%, including both human-caused and natural (i.e. wildfire) disturbances. The 2019 amended recovery strategy for Woodland Caribou reaffirmed that disturbance levels cannot exceed 35%, with the exception of one range in Saskatchewan (Environment Canada 2019). Given the priority of caribou conservation and the diversity of human land uses occurring within caribou ranges, effective management requires the best available information on the status of caribou habitat.

The Alberta Biodiversity Monitoring Institute (ABMI) uses remote sensing to map human footprint and vegetation for Alberta. This data is used by the Government of Alberta to determine the percentage of anthropogenic disturbance within Woodland Caribou ranges, which informs decision-making for caribou range planning. Ensuring a high level of accuracy in the remote sensing data in turn ensures planning is guided by the best available information.

The Alberta Northwest Species at Risk (NWSAR) Committee is an inter-municipal sub-committee of five municipalities in northwestern Alberta: the Town of High Level, the Town of Rainbow Lake, Mackenzie County, County of Northern Lights, and Clear Hills County. The NWSAR region covers approximately 118,800 km^2 and includes extensive forested areas as well as large areas managed for natural resource development and its associated infrastructure (i.e. forestry, oil and gas development). In collaboration with the NWSAR Committee, the ABMI set out to generate updated, verified spatial datasets for human footprint and the state of vegetation in two northwestern caribou ranges, using ground-truthed aerial imagery (photogrammetry) to create high-resolution orthophotos and 3D point cloud datasets.

A previous, unpublished report from the ABMI mapped human footprint in the NWSAR region using 2017 satellite imagery. The most extensive footprint type (5.4% of the region) was agriculture, primarily in the south in the

Parkland Natural Region and around the town of Peace River; forestry was next most extensive (4.6%). However, when footprint recovery (i.e. natural regeneration over time) was taken into account, the extent of forestry footprint fell to 3.3%. Energy footprint occupied 1.6% of the region, while transportation, urban, rural, and industrial footprint and human-created waterbodies each occupied < 1.0%. The report also found that the density of linear footprint in the NWSAR region was 2.71 km/km^2. Conventional seismic lines were the predominant type of linear footprint type, representing 87% of lines in the region.

Habitat restoration can only target a fraction of human footprint features due to the high costs and limited equipment. In northeastern Alberta, the ABMI and Canada's Oil Sands Innovation Alliance (COSIA) developed a method for prioritizing townships within caribou ranges that maximizes the gain in undisturbed habitat at a minimal cost (Alberta Biodiversity Monitoring Institute 2016, 2017). This process allows land managers to focus restoration efforts in areas with the greatest ratio of gain:cost, and successively move to areas with lower ratios as restoration progresses. This prioritization exercise was undertaken in the Chinchaga and Caribou Mountains caribou ranges.

2.0 Objectives

The purpose of this project is to address the following questions within two caribou ranges in northwestern Alberta:

1. What is the thematic accuracy of existing human footprint data?
2. What is the state of vegetation regrowth on vegetated footprint types?
3. Where might restoration efforts on seismic lines be targeted?

3.0 Methods

3.1 Data collection

Aerial imagery was acquired at approximately 20 townships distributed across five areas (Figure 1) using a high-end, large-frame aerial digital camera sensor, DMC III. Aerial photos are captured using five cameras, each for a separate spectral band (Panchromatic, Red, Green, Blue, and Near-Infrared). The sensor's combination of large frame format and use of CMOS sensor technology produces high quality images. The spatial resolution of the image acquisition was under 15 cm, ensuring that the resulting ground sampling distance (GSD) of the orthophoto mosaic will be created by resampling to 15 cm. Images were captured with 80% of forward overlap to increase the number of instances per each subject point during the point cloud generation process. Average flight altitude was 3550 m.

Imagery was acquired on September 8, 10, and 22, 2020. The five areas were selected using the following criteria:

– Overlap with Forest Management Agreement (FMA) areas in the Chinchaga caribou range

– Overlap with existing high-density energy footprint

– Ease of ground access for ground-truthing protocols

We developed ground-truthing protocols to ensure comparability between the photogrammetry and ground-truthing locations. Ground-truthing was conducted at 120 locations encompassing a range of disturbance and vegetation classes distributed across the five blocks (Figure 1; more detailed maps in Appendix A).

At each ground-truthing location, we collected the following data:

– Georeferenced photos of three to five canopy-layer trees with either direct field measurements of species, height, and DBH, or inclusion of a reference pole in photos (if canopy-layer trees were present);

– Georeferenced photos of three to five saplings (DBH < 7cm) with either direct field measurements of species, height, and DBH, or inclusion of a reference pole in photos (if saplings were present);

– Georeferenced photos of the understory layer with either direct field measurements of average height, average density, and dominant species, or inclusion of a reference pole in photos; and

– Georeferenced photos and dominant shrub species on linear features.

Basic field metadata was also collected at each site (e.g. weather, date, presence of natural disturbance). Sites were visited between September and December of 2020.

Ground-truthing data was used to support vegetation inventory on seismic lines, to confirm human footprint interpretation during the accuracy analysis, and to provide a coefficient of correction for tree height generated from point clouds.

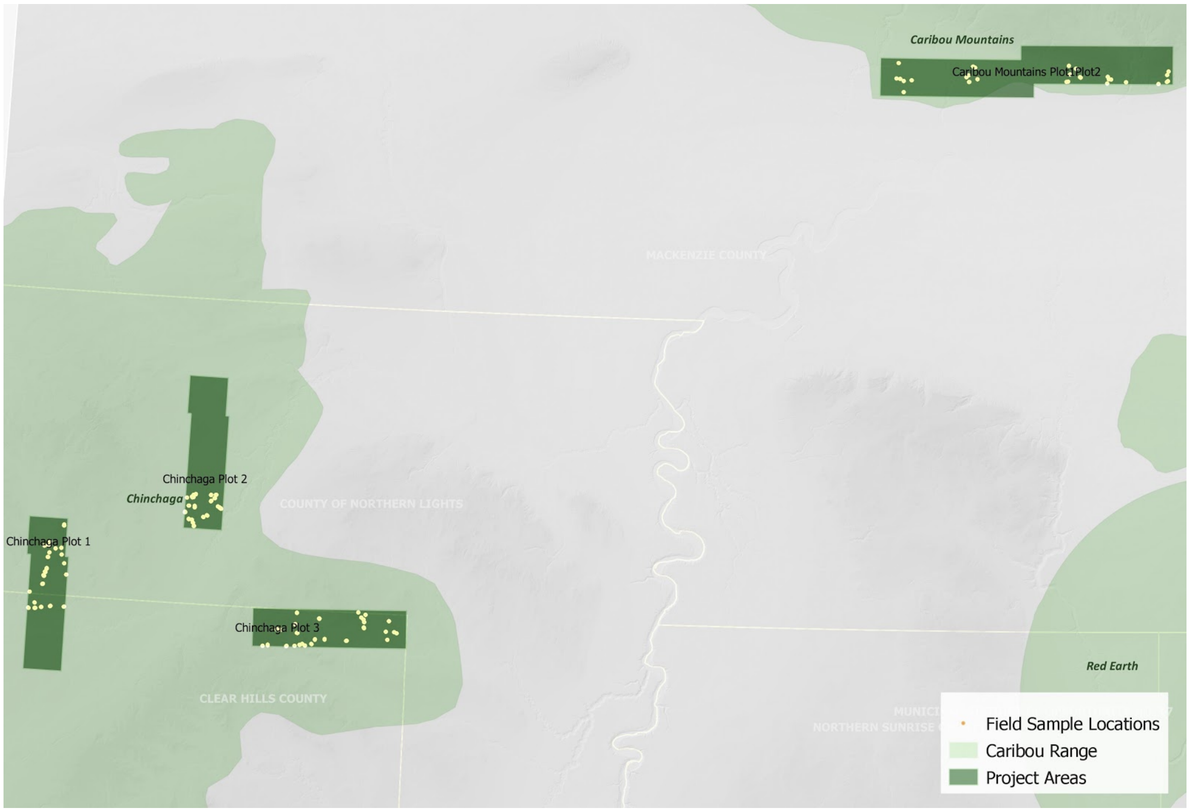

Figure 1. Overview of ground-truthing locations across project areas where aerial imagery was collected. The Caribou Mountains areas were merged into one block during analyses.

3.2 Data processing

The aerial imagery was processed to generate high-resolution multiband orthophoto mosaics and 3D point clouds for data extraction and analysis. The ultimate purpose of this processing was to generate high-resolution, three-dimensional data on ground cover, including information on vegetation height. This involved a number of steps, including:

Aerial triangulation — Aerial triangulation was done to generate three-dimensional coordinates for objects (e.g. tree heights) within the images. The aerial imagery was organized into four blocks (Chinchaga 1, Chinchaga 2, Chinchaga 3, Caribou Mountains) based on the direct georeferencing information. Each block was adjusted by an aerial triangulation bundle adjustment process, using photo projection centre locations (AGPS) and exterior orientation angles (IMU) as a part of weighted known variables within the iterations of the bundle block adjustment. No ground control points were used as an input into the aerial triangulation; accuracy of each block adjustment was determined by comparing randomly distributed elevation points with a bare earth elevation surface created from existing LiDAR point cloud (Figure 2; see Appendix B for triangulation details).

The spatial accuracy of the aerial adjustments—represented by RMS values—was within expected specifications (3x the ground sampling distance of 15 cm) (Appendix B). Checkpoints randomly distributed over the project areas confirmed vertical accuracy: we compared values of LiDAR raster elevation surface to the observed elevations on the stereomodels at locations where the terrain's topography had not changed between the acquisition date of the LiDAR dataset and the acquisition date of the imagery.

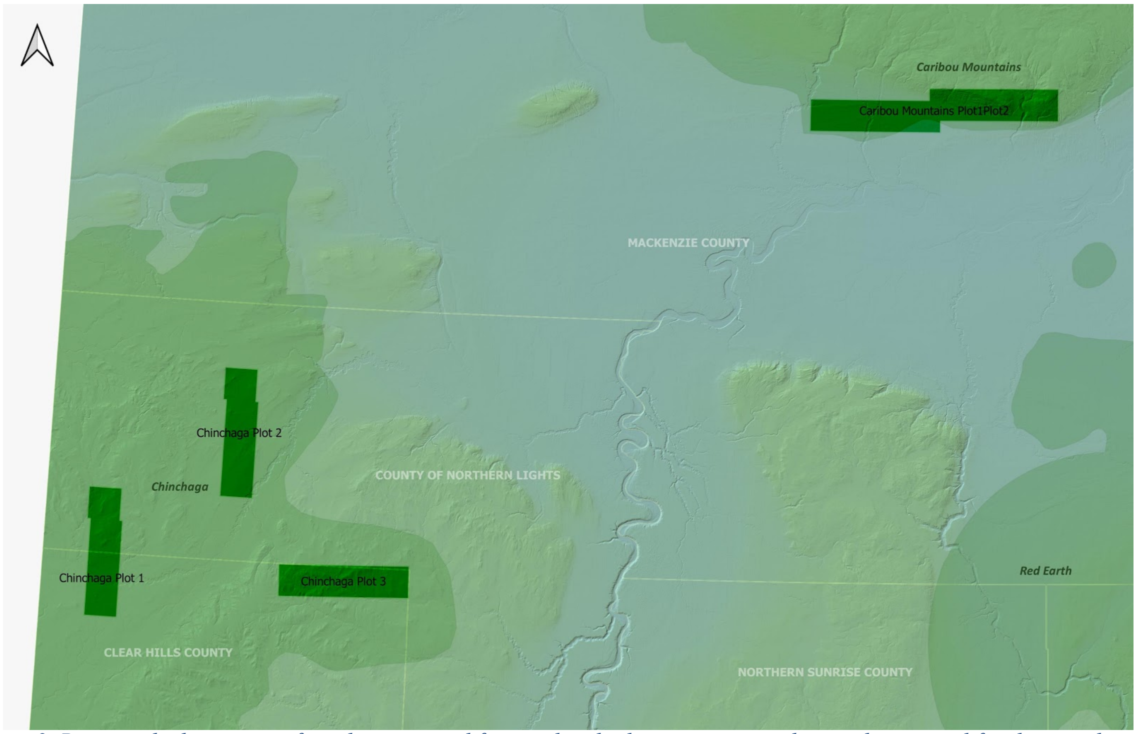

Figure 2. Bare earth elevation surface that was used for tree height determination and in quality control for the aerial triangulation process.

Orthorectification — We used a digital terrain model (DTM) dataset to create a seamless bare earth mosaic of elevation raster in geotiff file format. This file was used as a base for the orthorectification process. Orthorectification is the process of creating a constant scale across aerial photos, as aerial imagery is distorted by the tilt of the camera, the camera distortions, and elevation changes in terrain. The orthorectification process generated one orthophoto per aerial image with a spatial resolution of 15cm (GSD). Radiometric resolution was set to four spectral bands—red, green, blue, and near-infrared—in 8-bit geotiff file format. Consequently, the high-end color balancing processing was used to produce a seamless mosaic over the entire project area. This process was semi-automatic, with manual quality control of generated seamlines, which were edited wherever needed.

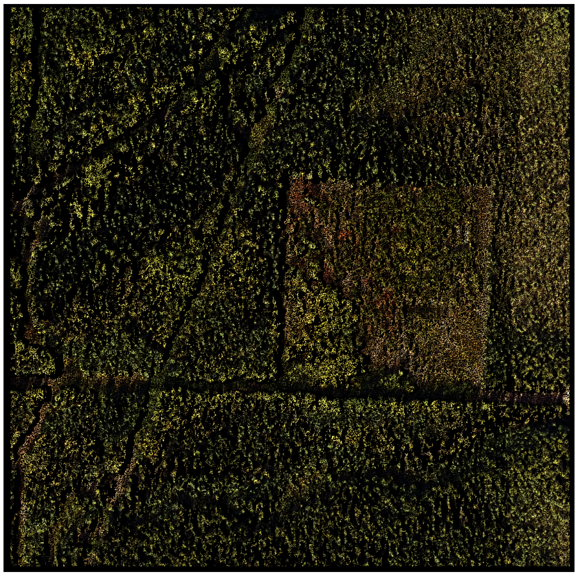

Figure 3. Point cloud generated by photogrammetry with an approximate density of 36 points/m^2.

3D Point Cloud Generation — Point clouds were generated by high-end photogrammetric software, using the Semi-Global Matching method. The density of the point cloud was set to the one-pixel size (GSD of 15 cm), resulting in an ultra-dense point cloud suitable for consequent vegetation analysis (Figure 3).

Point cloud files were then analyzed by the R package “lidR” (Roussel et al. 2020; Roussel & Auty 2021).

There were two key steps utilized in the data processing. First, point cloud files were normalized (all point elevations are relative to the ground surface) using the DTM file. The second step of analysis determined a location and height of the point cloud cluster to model tree top location. Tree tops can be detected by applying a Local Maximum Filter (LMF) on the loaded data set. The LMF is point cloud-based, meaning that it locates tree tops from the point cloud without any raster like a Canopy Height Model (CHM). The LMF can be applied with a constant size window (e.g. window size of 5 metres means that for a given point the algorithm looks to the neighbourhood points within a 2.5 radius circle to figure out if the point is the local highest). See Figure 5 for visualizations of point cloud data.

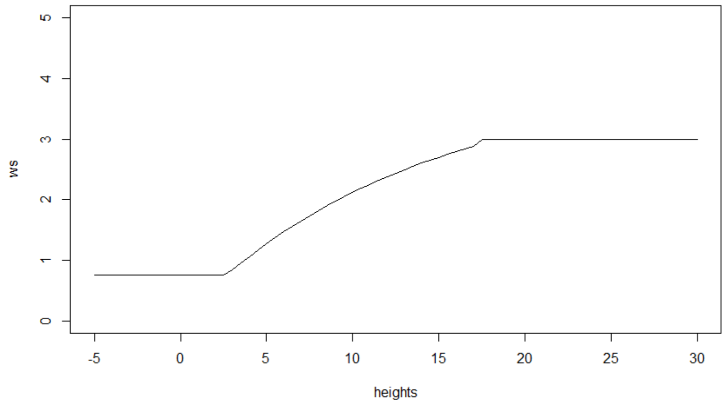

Figure 4. Variable window sizes function used to optimize tree top detection (X axis: tree heights [m]; Y axis: window size [m])

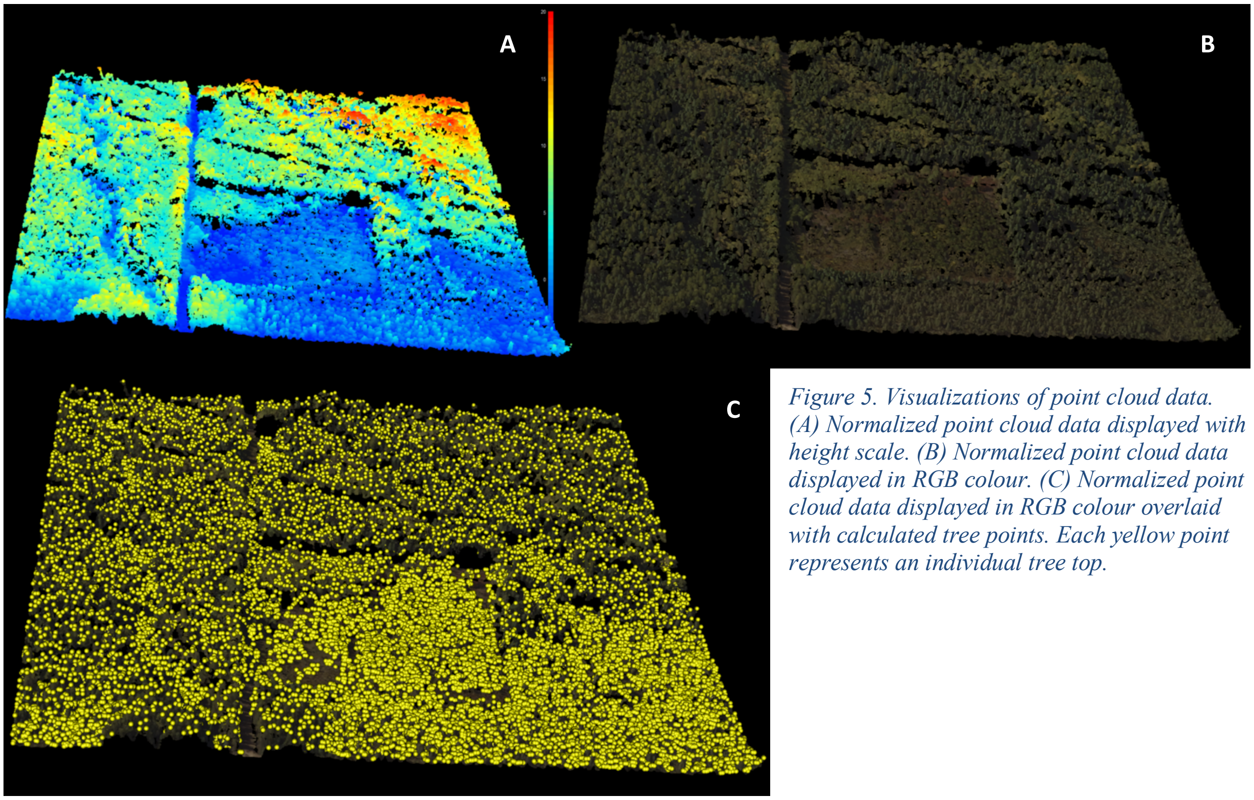

Figure 5. Visualizations of point cloud data. (A) Normalized point cloud data displayed with height scale. (B) Normalized point cloud data displayed in RGB colour. (C) Normalized point cloud data displayed in RGB colour overlaid with calculated tree points. Each yellow point represents an individual tree top.

3.3 Human footprint data analysis

We used the orthophotos to verify the thematic accuracy of the most current publicly available ABMI human footprint dataset, the ABMI Wall-to-Wall Human Footprint Inventory, referred to hereafter as the HFI 2018 (Alberta Biodiversity Monitoring Institute 2018). The HFI 2018 dataset was clipped to match the boundaries of the area-of-interest, and polygons smaller than 25 m^2 were removed as these areas were created by the integration process only and were too small to perform quality control by interpretation. The clipped human footprint dataset was overlaid on the orthophoto mosaic. The entire project area (Chinchaga 1, Chinchaga 2, Chinchaga 3, Caribou Mountains) was reviewed by trained ABMI personnel. Three of the areas (Chinchaga 1, Chinchaga 3, and Caribou Mountains) were consequently reviewed by subject matter experts from the GoA Alberta Human Footprint Mapping Program (AHFMP).

The HFI 2018 contains 20 human footprint sublayers, based on 117 feature types (ABMI 2018). For example, a feature type “low impact seismic lines” is part of the “seismic lines” sublayer. We compared the existing dataset to the orthophoto mosaics generated by this project and assigned each feature type to one of the following accuracy categories:

– Feature type (FT) correct: feature type interpretation is correct

– FT incorrect due to Clip/Buffer: feature type interpretation is incorrect due to processing steps—either clipping or buffering—during the creation of the dataset

– FT incorrect interpretation: feature type interpretation is incorrect

– FT incorrect, Sublayer correct: feature type interpretation is incorrect, but misinterpretation is limited to the same sublayer category (e.g. Conventional seismic lines => Low impact seismic lines)

– Missed FT: human footprint feature was missing from the HFI 2018 dataset

– No HF: the polygon did not represent human footprint

Accuracy is reported as a percentage, calculated from the areas of human footprint in each category, as area is the value by which ABMI reports human footprint.

Human footprint feature types were grouped into four categories in order to analyze thematic accuracy in greater detail for that particular human footprint group:

(i) Seismic Lines: Conventional seismic lines, low impact seismic lines, and trails were grouped together as the vast majority of polygons currently present in the human footprint dataset originated from the CUTLINE-TRAIL feature class in the Base Features Access dataset created and maintained by the GoA (available at altalis.com). A semi-automated geospatial process was applied to the CUTLINE-TRAIL feature class based on the sinuosity thresholds used to separate conventional seismic lines, low impact seismic lines, and trails at the time the ABMI's human footprint inventory was created. The results of this geospatial processing were updated during each annual update of the inventory, as this process had limitations with regard to fragmented features with varying degrees of sinuosity, which resulted in less accurate classification of conventional seismic lines, low impact seismic lines, and trails. Therefore, the accuracy category "FT incorrect, Sublayer correct" is considered as a correct classification at the sublayer level.

(ii) Wells: This includes oil and gas wells, well pad clearings, and abandoned wells.

(iii) Harvest Areas

(iv) Other Human Footprint: This category includes borrow pits (dry and wet), industrial camps, clearings, oil and gas plants and mines, facilities, pipelines, roads (gravel, paved, and winter), runways, transmission lines, vegetated edges of roads, truck trails, and sumps (artificial holding or treatment ponds for industrial wastewater).

3.4 Vegetation data analysis

The state of vegetation on successional human footprint was assessed using two different approaches:

For larger disturbance types like well pads, pipelines, and harvest areas, an automated process using the 3D point cloud data assigned a height to each individual tree above 1 m in height. Features below 1 m start to include non-canopy vegetation, dirt piles, etc, and thus were excluded. We then calculated tree density and the median height of vegetation for each human footprint polygon (Figure 6). Average height was ultimately not included as the polygon boundaries occasionally included trees adjacent to the human footprint, which artificially increased the average.

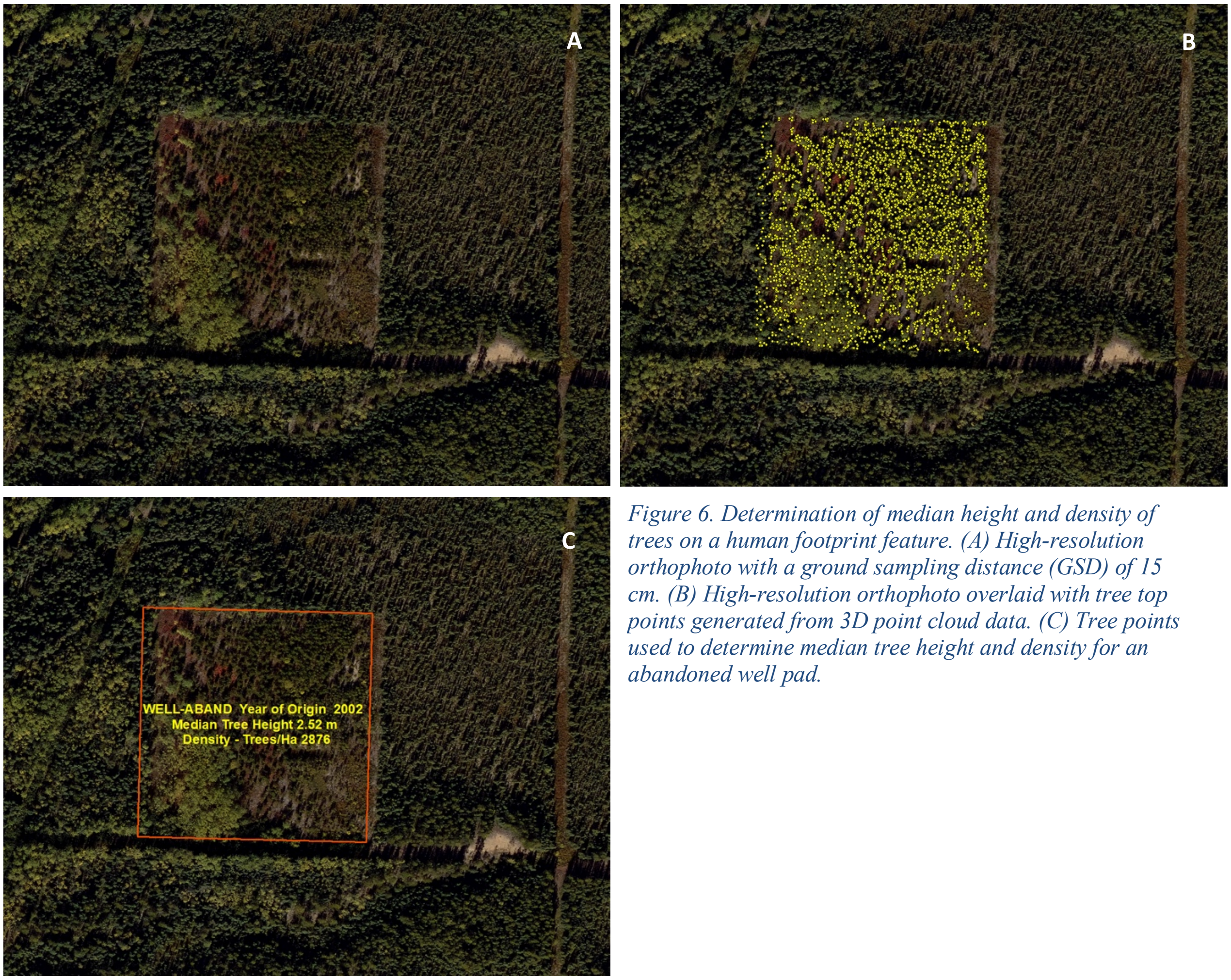

Figure 6. Determination of median height and density of trees on a human footprint feature. (A) High-resolution orthophoto with a ground sampling distance (GSD) of 15 cm. (B) High-resolution orthophoto overlaid with tree top points generated from 3D point cloud data. (C) Tree points used to determine median tree height and density for an abandoned well pad.

For seismic lines and trails, a manual classification process was used as these are thin features that are often overshadowed by adjacent trees, and which cannot be reliably classified via an automated process. The human footprint inventory was used as an initial indication of where seismic lines were located, but new centrelines for the seismic line corridors were created in the Softcopy program to improve the spatial accuracy of interpreted seismic lines. Delineation was done at a scale of approximately 1:3000 with a minimum segment length of 500 m; exceptions to the 500-m length were disconnected seismic lines or trails, and instances where the study area boundary cut short the linear feature. Three characteristics were manually measured by a stereo imagery interpreter: vegetation type (Table 1), general density of each vegetation type (assessed as canopy closure values; Table 2), and average height of each vegetation type (Table 3). The top three visible dominant regenerating vegetation types were recorded, with priority given to taller, more visible vegetation types.

Table 1. Vegetation type classes assigned to seismic line cover during manual classification.

Vegetation Class	Description
Graminoids	Grasses, sedges, rushes, and forbs
Shrubs	Woody plants that are not considered commercial forestry harvest species in Alberta
Deciduous	Woody broadleaved plants that are considered commercial forestry harvest species in Alberta
Coniferous	Woody needle-leaved plants that are considered commercial forestry harvest species in Alberta
Lichens	Non-arboreal lichens
Bryophytes	Non-vascular land plants
Water	Water that floods an area after disturbance; does not include pre-existing water features
Non-vegetated	Exposed parent material such as dirt or bedrock

Table 2. Canopy closure classes, in which the amount of sunlight restricted from reaching the forest floor is measured. Values were binned into one of four classes. Note that all percentages summed for a linear feature might be >100% as vegetation layers overlap.

Canopy Closure Class	Range of values
25%	>25%
50%	26-50%
75%	51-75%
100%	76-100%

Table 3. Average height categories for seismic line vegetation. Heights were binned into three categories. The lower limit, 1.5 m, reflects the level below which confidence in data accuracy decreases without significant time investment.

Vegetation Height Class	Description
<1.5m	Average height is less than 1.5 metres
1.5m – 5m	Average height is between 1.5 meters to 5 metres
>5m	Average height is greater than 5 metres

It is known that height is systematically underestimated in automated calculations. We calculated a general correction coefficient comparing field data measurements to heights generated by our models. We also compared heights determined from stereo imagery to automated heights and calculated a second general correction coefficient. These calculations were not incorporated into our analyses of height on human footprint due to the difficulty in adjusting individual heights by tree type (i.e. deciduous and coniferous trees have different correction coefficients). Corrections to the trees in the Caribou Mountains block would be between 1.52 and 2.17 m, and between 1.35 and 1.79 m in the Chinchaga blocks. These coefficients are presented in Appendix C, and could be incorporated in further steps.

3.5 Restoration prioritization analysis

We prioritized areas for restoration within the Bistcho, Caribou Mountains, Chinchaga, and Yates caribou ranges. We mapped current habitat disturbance and simulated the reduction in disturbance following restoration. We used townships to represent a scale whereby efficient groupings and economy of scale for restoration can be achieved. We used two scenarios: Scenario 1, which represents an optimistic scenario that includes current industrial activity but ignores burned areas; and Scenario 2, which includes both current industrial activity and burns < 40 years old as disturbed habitat. Scenario 1 ignores burned areas as these may already be on a trajectory to recovery and the spatial arrangement of future fire disturbances is difficult to predict.

We quantified human disturbance within each township using the HFI 2018. We calculated the current percent disturbance for each township, buffered by 500 m, using the definition of human disturbance in the Federal Recovery Strategy for Woodland Caribou (Environment Canada 2011, 2012). We estimated the remaining percent disturbance following complete habitat restoration by removing all conventional seismic lines and trails from the Human Footprint Inventory, buffering the remaining disturbances by 500 m, and calculating the percent of each township classified as disturbed. We then calculated the gain in undisturbed habitat (GIU) assuming that all conventional seismic lines and trails were restored. We subtracted the percent disturbance after all treatable features were restored from the current percent of altered habitat. This step identifies pixels that offer the highest potential to gain undisturbed habitat.

We assessed the benefit to cost ratio of restoration in each township, i.e. “Bang-for-Buck”, by calculating the reduction in percent disturbance and the effort, or cost, needed to achieve this result. The GIU was divided by the density of conventional seismic and trails within each range (“cost”), which indexes the cost of restoring all these features. The “Bang-for-Buck” depends on both the relative proportions of treatable features and the total amount of human alteration in the pixel.

Finally, we ranked townships from highest to lowest “Bang-for-Buck” and grouped similarly ranked townships into five hierarchical zones of ordered priority for restoration, such that an equal number of townships were in each zone. Lowest priority zones included townships with no potential benefits from restoration, either because there were no treatable features within a pixel, or because all treatable areas fell within other disturbances.

We repeated this process with fire included as a disturbance. We included fires < 40 years old (as of 2018, the year of the human disturbance data) compiled by the GoA’s Historical Wildfire Perimeter Spatial Data (http://wildfire.alberta.ca/resources/historical-data/spatial-wildfire-data.aspx), with no buffer, using the definition of total disturbance in the Federal Recovery Strategy for Woodland Caribou (Environment Canada 2011, 2012).

4.0 Results

4.1 Human footprint accuracy

The overall thematic accuracy of the HFI 2018 was **93.44%**; however, accuracy varied across footprint types (Table 4). Wells and harvest areas had the highest accuracy within each block, with overall accuracies of **96.09%** for wells and **94.51%** for harvest areas. The overall accuracy for seismic lines was **95.22%**. In each block, "other human footprint" had the lowest accuracy. The most common source of error was "Feature type incorrect, Sublayer correct" where the detailed feature type identification was incorrect, particularly for seismic lines (i.e. conventional vs. low impact seismic lines). As noted previously, when considering the accuracy of seismic lines at the sublayer level, this error type was ultimately considered correct as it derived from an error in the semi-automated classification process.

Overall, the percentage of human footprint that was either missed or not in fact human footprint was low, indicating a high level of accuracy in the ability of the HFI to capture footprint. The missed footprint features had a variety of origins. For instance, in the Chinchaga 1 block, three old airstrip runway polygons, discovered on old orthophotos (1980s and 2000s), significantly added to the size of the "missed HF" (>15% of the missed features). The most often overlooked features were seismic lines (>40% of missed features). Low impact seismic lines (LIS) are not updated in the annual HFI as they are too numerous and too narrow to be interpreted from satellite imagery with a high enough degree of confidence. Hence, many were missing from the HFI 2018, but were known to be missing. In Chinchaga 1, because the density of LIS is higher compared to the other blocks, the amount of missed LIS was also higher. Other examples of missed HF features include truck trails missed in-between harvest areas, missed and misattributed borrow pits, missed portions of the pipelines, and a missed telecom tower.

In the Caribou Mountains block, there was a relatively high percentage of features removed from the inventory (i.e. classified as "no human footprint") (5.75%). This is a very specific case: there is a cluster of harvest areas that originated from the old forest inventory map (Clear Cuts - Phase 3 Forest Inventory) in the human footprint dataset. It has since been determined with help of subject matter experts at AHFMP that these are in fact not harvest areas and should not have been included in the human footprint dataset.

The lumped category "other human footprint" had the lowest accuracy in each block. This category includes things like unidentified clearings and pipelines (see section 3.3 for the full list). There were some obvious errors (e.g. part of a pipeline was classified as miscellaneous oil and gas facility, most likely the result of merging two different polygons into one and not following up with cutting back the pipeline from the facility). There are some "clearing-unknown" polygons that were classified correctly at the time of the HFI update and that later became a pipeline; at the time of update, there was no indication that the clearing purpose was to build a pipeline. These polygons should have been reclassified as "pipeline", but never were. There were instances where borrow pits were classified incorrectly, and instances where reference data pointed at an existing powerline, but there was no evidence in the imagery such a powerline had been constructed—nevertheless, a "transmission-line" polygon existed in the HF dataset.

Table 2. Thematic accuracy of the 2018 ABMI human footprint dataset, broken down by error type. Error types are defined within section 3.3 of the Methods. Accuracy is reported as a percentage (%) of the total area occupied by each human footprint feature category in each block.

	Correct	Feature type incorrect, Sublayer correct	Incorrect interpretation	Missed	No human footprint	Incorrect due to clip/buffer
Chinchaga 1+						
Seismic lines	88.38*	5.65*	1.29	4.44	0.23	0.01
Wells	93.46	0	0	5.24	1.3	0
Other human footprint (HF)	79.35*	3.43*	7.71	8.53	0.9	0.08
OVERALL	85.73*	4.43*	3.36	5.89	0.55	0.04
Chinchaga 2+						
Seismic lines	93.82*	5.68*	0	0.37	0.13	0
Wells	96.37	0	0	3.63	0	0
Other HF	80.64	15.33	0.36	3.37	0.31	0
OVERALL	91.03*	7.42*	0.08	1.31	0.16	0
Chinchaga 3						
Seismic lines	89.17*	6.84*	0.96	2.55	0.48	0
Wells	99.32	0	0	0.68	0	0
Harvest areas	99.39	0	0.01	0.21	0.39	0
Other HF	81.46	4.75	3.86	9.35	0.56	0.01
OVERALL	95.34*	1.42*	0.77	2.04	0.42	0
Caribou Mountains						
Seismic lines	84.23*	1.08*	9.28	1.82	3.57	0.01
Wells	100	0	0	0	0	0
Harvest areas	91.72	0	0.01	2.52	5.75	0
Other HF	44.84	18.34	0.11	31.99	4.72	0
OVERALL	90.76*	0.32*	0.3	2.96	5.66	0

+There were no harvest areas in the Chinchaga 1 or 2 blocks.

*Note that for seismic lines, the accuracy category “Feature type incorrect Sublayer correct” is also considered as the correct classification at the sublayer level.

The following maps demonstrate the spatial variation in human footprint accuracy within each of the blocks.

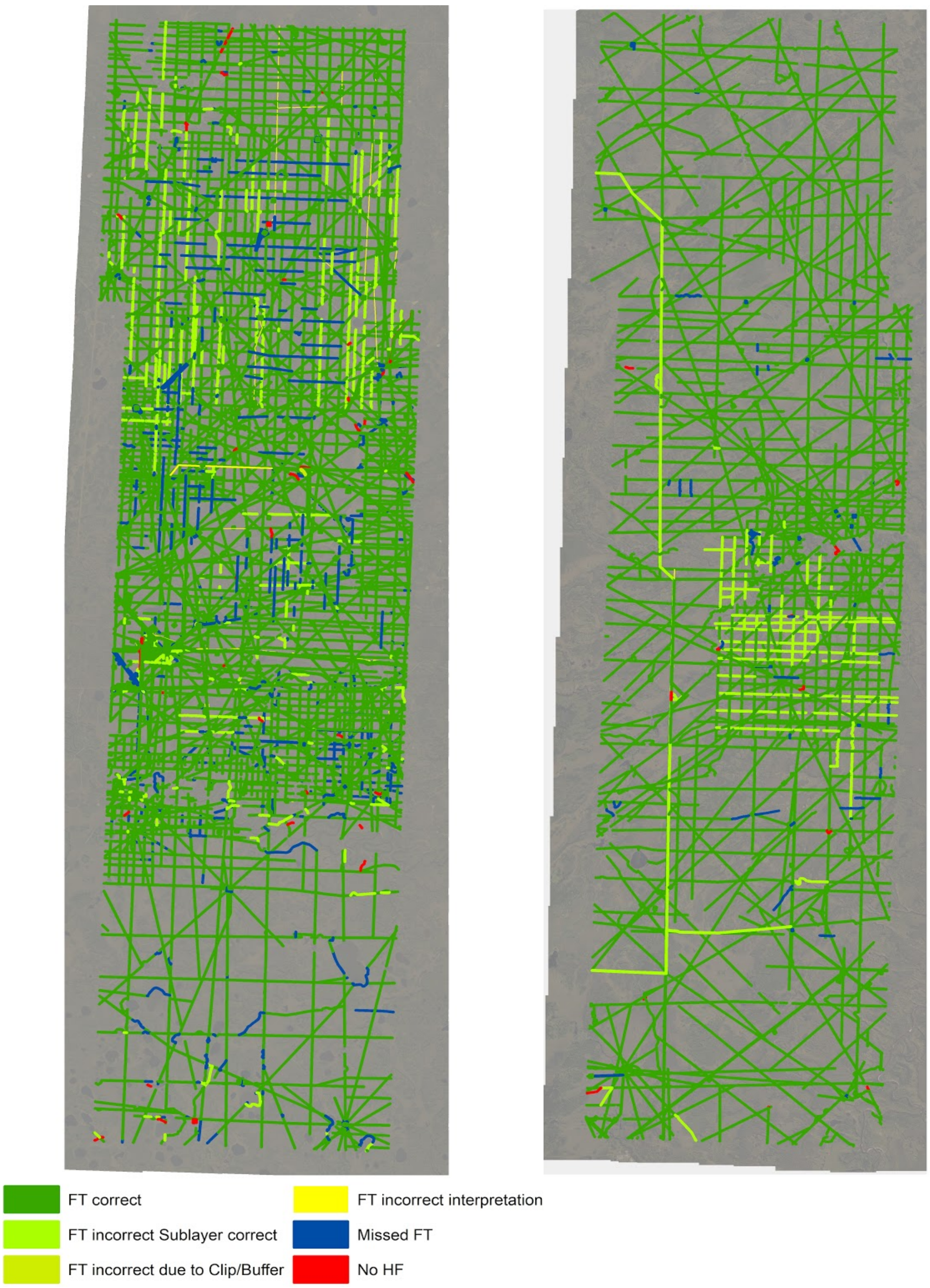

Figure 7. Accuracy of human footprint dataset in Chinchaga 1 (left) and Chinchaga 2 (right) blocks.

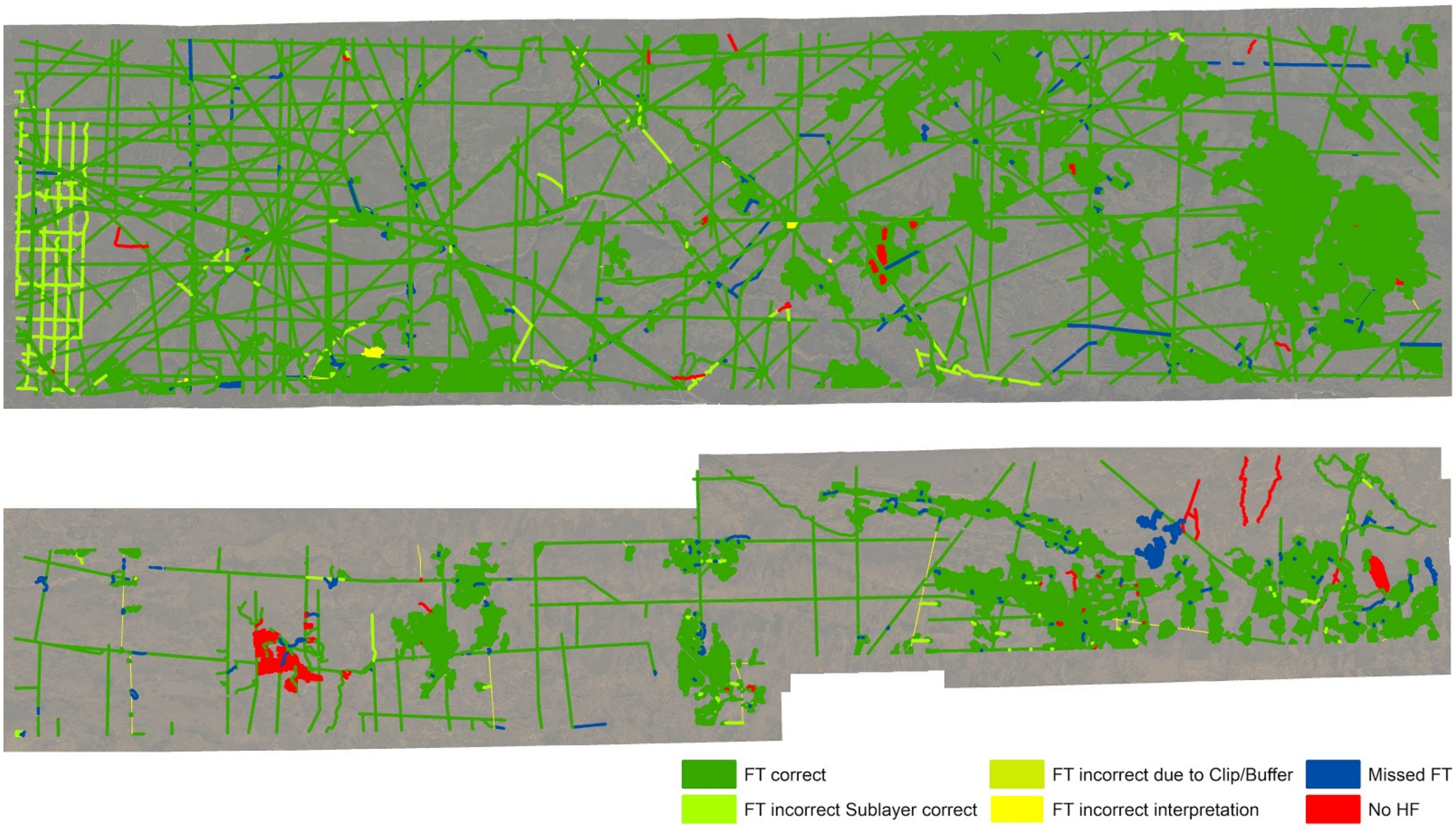

Figure 8. Accuracy of human footprint dataset for Chinchaga 3 (top) and Caribou Mountains (bottom) blocks.

4.2 State of vegetation recovery

The average mean median height was below 5 m for all non-linear human footprint feature types in all blocks (Table 5). The maps in Appendix D show the spatial variation in this value: all blocks had some small polygons with a median height between 10 and 24 m, for instance. Chinchaga 1 has the lowest mean median height on all feature types. It also has some of the lowest density for each feature type (trees/ha). Harvest areas had the highest mean median height and greatest mean density (except for "other human footprint" in Chinchaga 2). Three of the four lowest mean median height and density values were found on wells across the blocks.

Table 3. State of vegetation recovery on non-linear human footprint features (i.e. excluding seismic lines). Values are averages for all polygons within that feature type (i.e. average of all median heights of vegetation in harvest areas in Chinchaga 2 block).

	Pipelines		Wells		Harvest Areas		Other Human Footprint	
	Median height	Trees/ha	Median height	Trees/ha	Median height	Trees/ha	Median height	Trees/ha
Caribou Mountains	3.6	1320	2.0	973	-	-	2.9	943
Chinchaga 1	2.6	1072	1.9	910	-	-	2.1	976
Chinchaga 2	3.7	1458	3.4	1245	4.3	1746	3.4	1249
Chinchaga 3	-	-	2.2	636	4.1	1933	3.0	2009

The majority of seismic lines are shrub-dominated in the Chinchaga 3 and Caribou Mountains blocks (Table 6). In Chinchaga 1 and 2, the majority of seismic lines are either shrub-dominated or bryophyte-dominated. Very few seismic lines have lichens as their dominant vegetation type (only 0.12% of seismic lines in the Caribou Mountains blocks), and even fewer were non-vegetated (only 0.1% of seismic lines in the Chinchaga 1 block). More than 60% of seismic lines in the Chinchaga blocks had a dominant vegetation type with a height below 1.5 m.

Table 4. State of vegetation recovery on seismic lines. Values are percentages of the total area covered by seismic lines in each block.

	Caribou Mountains	Chinchaga 1	Chinchaga 2	Chinchaga 3
Height of dominant vegetation type (%)				
> 5 m	11.3	1.52	0.57	0.41
1.5 - 5 m	46.49	11.97	21.01	32.87
< 1.5 m	42.21	86.51	78.43	66.72
Cover of dominant vegetation type (%)				
Bryophytes	6.9	48.27	32.56	29.45

	Caribou Mountains	Chinchaga 1	Chinchaga 2	Chinchaga 3
Coniferous	4.5	1.44	-	0.31
Deciduous	8.9	7.53	-	0.13
Graminoids	7.65	9.16	18.89	0.66
Lichens	0.12	-	-	-
Non-vegetated	-	0.1	-	-
Shrubs	71.93	33.49	48.55	69.45

Maps for vegetation recovery are presented in Appendix D, following the information presented in the tables above. Each block has paired maps showing (a) median height and (b) tree density for each human footprint feature polygon. The first set shows vegetation recovery on seismic lines. Each block has paired maps showing (a) dominant vegetation type and (b) height of dominant vegetation type. The second set shows vegetation recovery on non-linear human footprint features (i.e. all features except for seismic lines).

4.3 Restoration prioritization

Suggested priority zones are presented in Figure 9 for both Scenario 1 (anthropogenic disturbance only) and Scenario 2 (anthropogenic disturbance and fires < 40 years old).

The NWSAR region had an abundance of linear features classified as trails, which are more typically classified as conventional seismic lines in other regions. This is due to the semi-automated classification process used by the AHFMP: many conventional seismic lines were classified as “trails'' as they were short and not straight enough (i.e. outside the sinusoidal threshold). For example, small trails around wetlands that connect conventional seismic lines are often classified as trails in the NWSAR region of the Human Footprint Inventory. This is also why the “FT incorrect Sublayer correct” category was considered correct within our assessment of human footprint accuracy for the region.

Restoration prioritization in the COSIA area simulated the removal of conventional seismic lines only, rather than conventional seismic and trails. We chose to simulate the removal of these trails along with conventional seismic lines to more accurately reflect changes in percent human footprint following restoration (i.e. trails are unlikely to be treated differently than the conventional seismic lines during operational treatment decisions). We also included trails when calculating the density of seismic lines to reflect the additional cost of restoring these trails. By doing so, we have most closely matched the process used to prioritize townships for restoration in other areas. However, to evaluate the sensitivity of the results to this decision, we have also included spatial files and maps that did not include trails in the deliverables. If these trails are not included in the prioritization exercise, the results erroneously show less of a benefit or “gain in undisturbed habitat” as these linear features would also be treated during restoration.

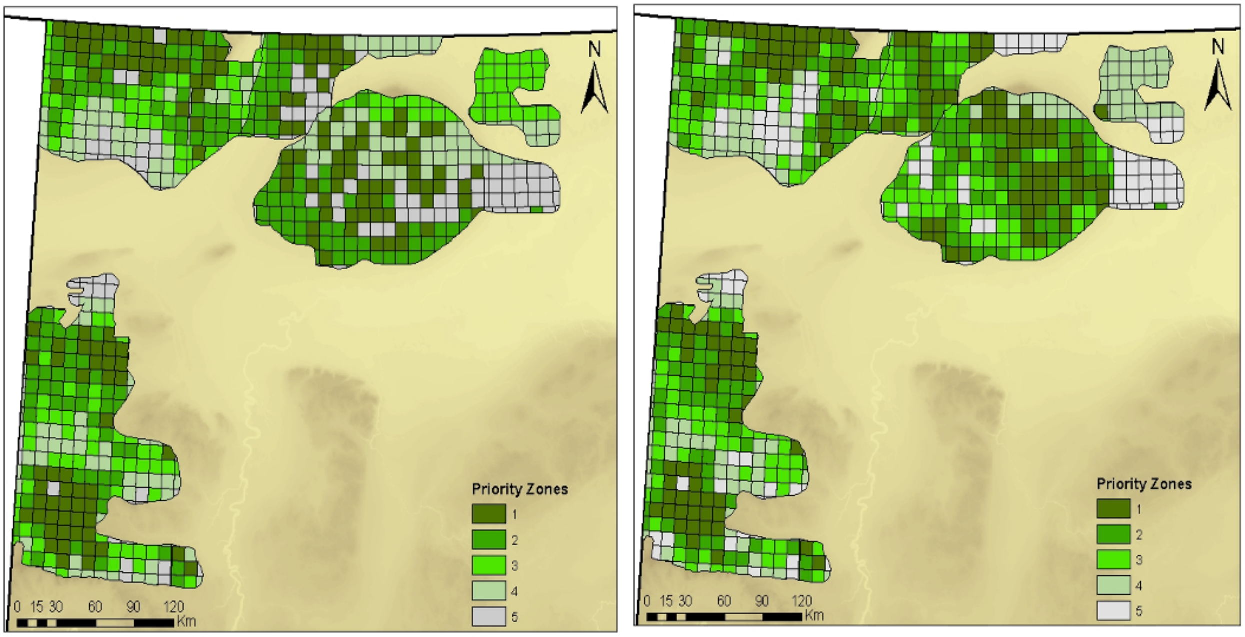

Figure 9. Suggested priority zones for restoration in the northwestern caribou ranges. (Left) Scenario 1: Anthropogenic disturbance only. (Right) Scenario 2: Anthropogenic disturbance + fires >40 years old. Restoration priorities are determined by “Bang-for-Buck”, calculated by the gain in undisturbed habitat (current percent disturbance – simulated percent disturbance with no conventional seismic lines or trails) for each township, divided by the cost of restoration (density of conventional seismic lines and trails). Townships are then grouped into five priority zones, whereby Priority Zone 1 is the highest Bang-for-Buck per range, and Priority Zone 5 is the lowest. To determine the sensitivity of Priority Zones to fire prevalence, prioritization is done with only anthropogenic disturbance (buffered by 500 m) considered, as well as anthropogenic disturbance (buffered by 500 m) and fire disturbance < 40 years old, to reflect ECCC’s definition of disturbance. Anthropogenic disturbance was characterized using the HFI 2018.

5.0 Discussion and Applications

5.1 Human footprint accuracy and state of vegetation recovery

This project found that the overall accuracy of the existing HFI 2018 dataset was quite high (**93.44%**). The accuracy of the human footprint data was in line with our expectations. We were aware of the limitations in seismic line interpretation resulting from the semi-automated classification process, which we have been manually correcting since 2014. However, it is impossible to correct at a provincial scale without thorough review. Prior to the start of this project, the AHFMP recognized the need for and initiated this review.

Another project already initialized by the AHFMP is focused on the Harvest Areas sublayer. The human footprint dataset includes some harvest areas that are not connected to the forestry sector, which may have been created for non-forestry activities such as residential, agricultural, or mine expansion. It will be beneficial to clarify the purpose of each harvest area to further enhance the thematic accuracy of the human footprint data. As noted in the results, several falsely attributed harvest areas were identified and discounted during this project.

The two primary reasons for reclassification were misinterpretation and missed features. These reflect the limitations of the satellite imagery used to create the human footprint inventory and errors introduced from the semi-automated process used to create portions of the HFI, and include features outside the scope of the HFI. Seismic line restoration is of particular importance to caribou recovery planning. Thematic accuracy of seismic lines (including “FT incorrect, Sublayer correct”) was greater than 85% in every block. The higher-resolution imagery and data processing used in this project allowed us to increase the accuracy of seismic line mapping, both in terms of correctly interpreting the type of seismic line and in capturing more seismic lines that were missed within the initial dataset. However, the accuracy was already quite high to start.

The aerial imagery collected contains incredible detail on the state of vegetation recovery on multiple types of human footprint. These results indicate that regrowth is occurring not only on seismic lines, but also on other types of human footprint as well. This regrowth varies locally in i) the type of vegetation; ii) the height of the re-growing vegetation; and iii) the density or canopy closure of vegetation. Using the photogrammetry approach tested in this project, we are able to detect all of these regrowth variables to a high level of spatial resolution. This data has useful applications for developing and subsequently tracking vegetation recovery thresholds used for sub-regional or range planning (e.g. defining critical caribou habitat), which ultimately inform land management decisions.

At present, the township prioritization method doesn’t use the level of vegetation recovery information that this project has demonstrated is possible. The prioritization exercise is based on the level of disturbance within a township, and does not account for any recovery that has occurred on those features. Combining the vegetation recovery reclassification work with the prioritization exercise could allow a planner to downgrade priority zones based on the type and height of vegetation. Using the height thresholds mapped on seismic lines, we could discount linear features with regeneration above a certain height (e.g. 5 m) from the township prioritization exercise, as these features may not require additional restoration treatments. The aerial data collected could also be used to monitor the success of restoration treatments if repeat sampling was implemented over time.

Full recovery on human footprint features will take many years. Research into how mammals use human footprint has identified meaningful benchmarks before full recovery. Predators use linear features to move faster and further in the boreal forest, increasing their hunting efficiency and ultimately increasing predation on caribou; one aim in recovery planning is to achieve a level of recovery that impedes predators from using the lines (i.e. a “functional” recovery). One study showed that vegetation regrowth of at least 0.5 m significantly reduced wolf speed on seismic lines. It took until a height of ~4 m to slow wolf movements to those seen in undisturbed boreal forest (Dickie et al. 2017). The mean median height of vegetation regrowth on non-linear human footprint features for each block varied from 1.9 m to 4.3 m (Table 5). More than 60% of seismic lines in the Chinchaga blocks had a dominant vegetation type with a height below 1.5 m. Vegetation recovery on human footprint features varied by footprint feature type and by location throughout the four blocks. For instance, some individual non-linear human footprint features had vegetation with a median height between ~10 and 24 m, and more than 11% of seismic lines in the Caribou Mountains had a dominant vegetation type greater than 5 m in height.

5.2 Restoration prioritization

These results can be used in the planning process for cost-effective caribou habitat restoration by considering the return per effort (i.e. “Bang-for-Buck”). This process complements a similar program to rank restoration zones in northeastern Alberta by COSIA, providing a comprehensive ranking system common to nine of the twelve Woodland Caribou ranges in Alberta.

High priority zones within Chinchaga and Bistcho caribou ranges tended to be spatially clumped (Figure 9), suggesting that habitat restoration should be prioritized in these regions. Conversely, high priority zones in the Caribou Mountains and Yates caribou ranges tended to be more dispersed, making it less efficient to target the high priority zones within these ranges.

In Scenario 2, we assumed that natural successional post-fire will facilitate the recovery of these disturbances without additional restoration treatments. Including fire did not substantially change the ranking of townships for Chinchaga or Bistcho, but township rankings in Caribou Mountains and Yates appeared to be sensitive to the inclusion of fire. Including fire tended to increase the priority ranking for townships within the centre of Caribou Mountains and Yates. The variable sensitivity to the inclusion of fire reflects that Bistcho and Chinchaga have low disturbance by fire and high human-caused disturbance, whereas Caribou Mountains and Yates have high fire disturbance and low disturbance by human habitat alteration. Restoration in areas with high human habitat alteration will give a higher “Bang-for-Buck”, whereas ranges with substantial fire disturbance will have more disturbance coming "offline" in 40 years simply as the fires naturally regrow post-fire.

The effect of fire on linear feature vegetation recovery has yet to be fully understood (but see Dawe et al. 2017). However, if fire facilitates the recovery of historic seismic lines, restoration treatments on these features may not be an effective use of limited restoration resources. Future research on vegetation recovery on seismic lines in burned areas, as well as in various landcover types, will help to further prioritize specific features for restoration treatments.

Given habitat restoration is expensive, time consuming, and disturbances are widely distributed across caribou ranges, effective restoration planning should balance both the estimated benefits and costs of these activities. We used the gain in undisturbed habitat as the metric of the benefit of restoration, and the density of linear features, i.e. effort, as the metric of cost. However, there are a variety of ecological and socioeconomic considerations that should be incorporated. Areas that are likely to be developed in the future (e.g. by forestry or oil and gas) should be delegated to lower priority zones to reduce the potential for re-disturbing restored features. Likewise, the inclusion of areas with high social value, such as recreational or traditional areas, can increase the effectiveness of restoration planning. Habitat restoration can focus on areas in which human disturbance has been detrimental to traditionally valuable areas. Alternatively, recreational or traditional use of features should be considered when planning restoration of specific features. We also note that not all townships represent equal habitat for caribou, and therefore caribou habitat value or current caribou use of areas can be incorporated into the process to improve outcomes for caribou. The priority zones identified within this report therefore represent a starting point in which additional perspectives and values can be incorporated. This can be accomplished during the engagement phase of restoration planning, or in an iterative fashion whereby spatial layers representing other core values and costs can be explicitly incorporated in the township prioritization process.

5.3 Conclusion and next steps

These results are an exciting demonstration of the level of precision possible in discriminating vegetation cover types, heights, and density on human footprint features. The high level of resolution is inherent to the imagery: if different criteria are of interest (e.g. height thresholds on seismic lines), it is simply a matter of recategorizing the features rather than re-flying an area for new imagery.

These methods offer a very high level of detail on seismic line regeneration: we can identify specific vegetation types and the approximate cover and height of each type. Seismic line regeneration is affected by age, the physical environment, and the restoration treatment type; this level of precision in remote sensing will help us understand the interactions between all these factors and identify the most effective methods of restoration for particular environments. We can also use this data to understand the impact of fire on seismic line restoration. Does (and how does) natural regeneration occur after fires on linear features, and does that reduce or eliminate the need for additional treatments for these areas?

Right now, regeneration thresholds and how these hinder animal movement (particularly predator movement) are related solely to generic vegetation height, with no consideration of the different types of vegetation. With manual interpretation, we can discriminate vegetation cover types, and in some cases identify tree and shrub species and genera. We are developing methods to distinguish five taxonomic groups of trees: poplars (*Populus*), white spruce, black spruce, tamarack, and willows (*Salix*). This is done using a combination of tree spectral signature, tree morphology, and ecosite.

Having more ways to measure seismic line regeneration will facilitate a more thorough understanding of thresholds for predator and caribou use. The high resolution of the orthophoto mosaic also allows us to identify trails on and use of linear features, as animal and vehicle trails are visible. This level of detail could allow planners to consider recreational and animal use of features when planning restoration, and to understand if or at what point restoration treatments deter use of the linear features.

Similarly, gathering repeated aerial imagery over time in an area and undertaking this level of classification could allow us to track regeneration progress remotely over a large area. It would be useful to identify a pilot area where restoration has occurred and begin to implement repeat monitoring using photogrammetry in order to develop restoration trajectories for different seismic line treatments.

Another next step to refine the dataset would be the manual reclassification of human footprint features to remove boundary trees, which would enable a greater range of data analysis. Right now, tall trees immediately adjacent to human footprint features are at times included in the polygon boundaries, skewing data metrics like average tree height. We thus used median height to account for the influences of these trees. This level of error in the polygon boundaries is acceptable within the human footprint dataset, but is not conducive to generating summary statistics on vegetation recovery.

The ABMI is working to build a Caribou Habitat Restoration Information System (CHRIS) for Alberta to:

– Inventory and categorize legacy seismic lines

– Prioritize restoration

– Incorporate traditional and public access information

– Track restoration treatments

– Measure treatment success

– Evaluate progress against landscape level objectives

CHRIS would directly support identifying priority areas for restoration and support investigative trials on restoration methods, their effectiveness, and wildlife responses. The data and imagery collected in this project could be used to set up the data/knowledge platform for use by NWSAR. This type of information system would be useful to multiple partners, including NWSAR, the Regional Industry Caribou Collaboration (RICC), and others involved in caribou range planning. It would facilitate user-friendly interaction with the data presented in this report for local analysis and tracking. Currently, there are multiple government- and volunteer industry-led caribou habitat restoration programs, without significant linkages. All the while, the province of Alberta’s framework for the restoration of legacy seismic lines calls for “identifying a common approach to planning, restoration objectives and targets, and clear approaches to monitoring and data management.”

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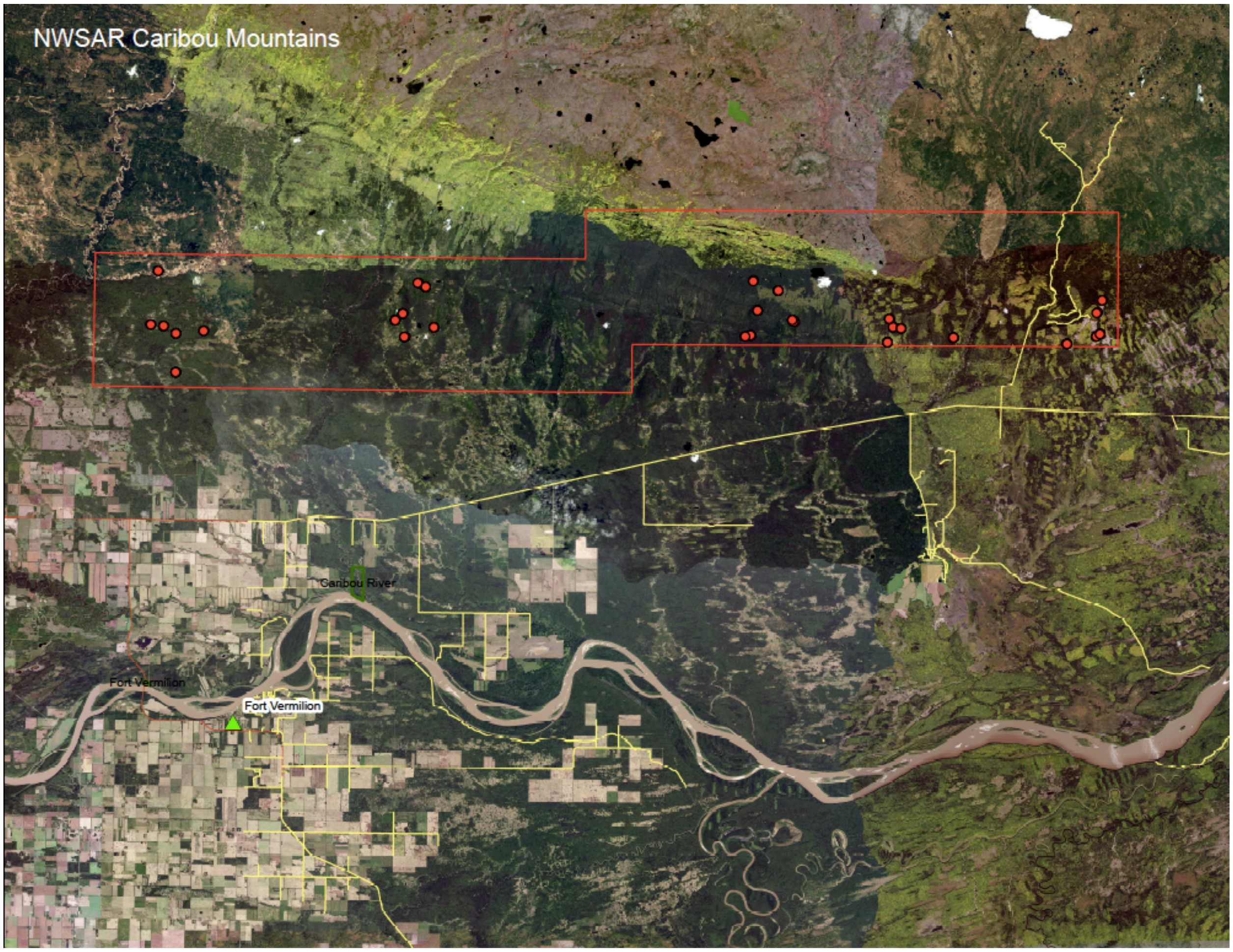
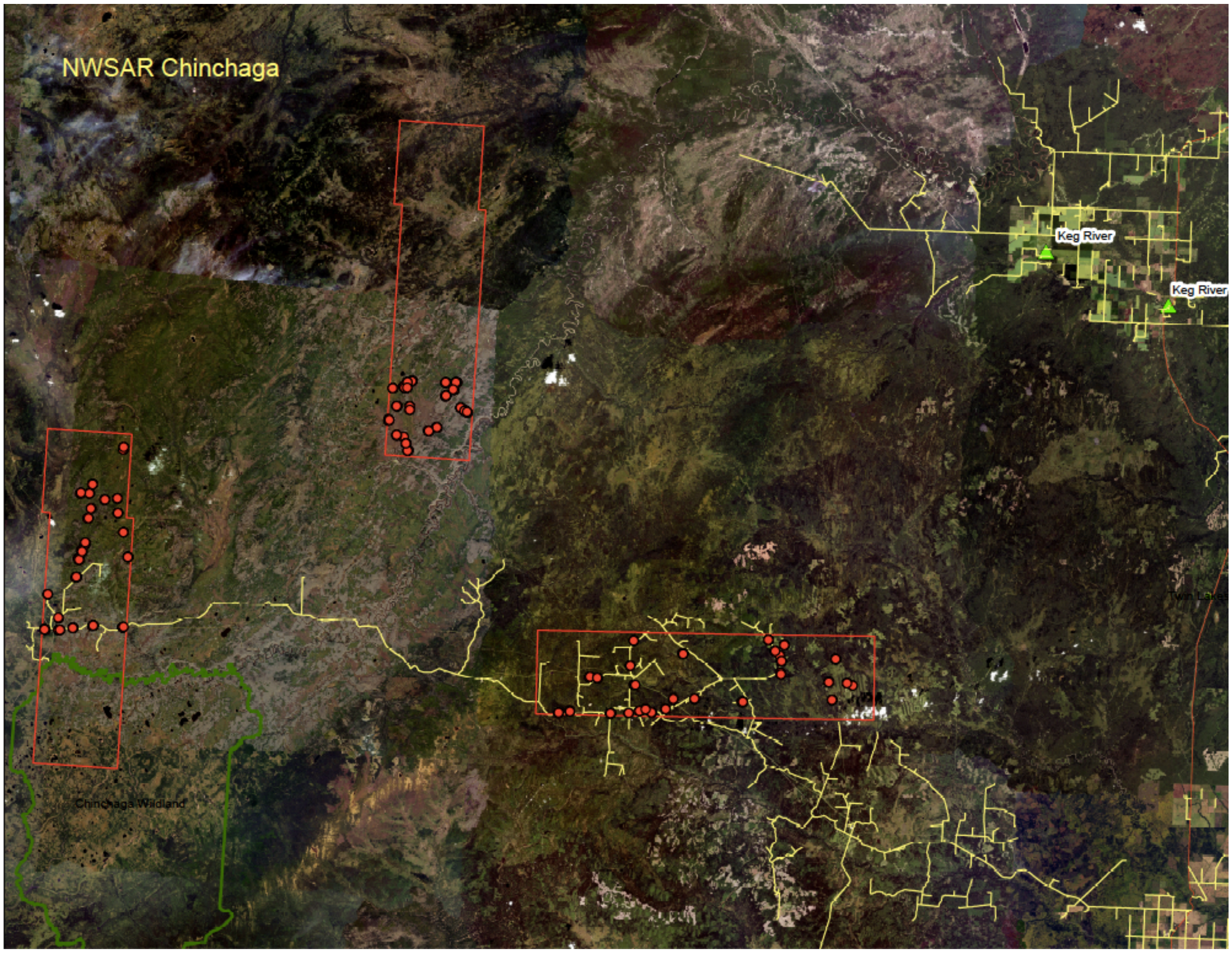
Appendix A

Detailed overview of the locations of ground-truthing field sites in the Caribou Mountains and Chinchaga blocks.




NWSAR Chinchaga
Keg River
Keg River
Chinchaga Wildland

Appendix B

Results of an aerial triangulation bundle adjustment:

<u>Chinchaga 1:</u>
Block: 2020_008_NWSAR_Chinchaga1
Number of strips: 5

Adjustment parameters:
bundle adjustment
coordinate system: NAD83 / UTM zone 11N
manual point on image measurements accuracy, pix.: 0.3
automatic point on image measurements accuracy, pix.: 0.3
tie point measurements weight: 1
ground control point coordinates not used
projection centers (GPS) coordinates weight: 1
exterior orientation angles weight (Alpha, Omega, Kappa): (1, 1, 1)
adjustment accuracy: 0.5
Measurement units: metre

General adjustment accuracy estimation

Sigma_0 = 0.990

Control projection centers residuals

		Xm-Xg		Ym-Yg		Zm-Zg		Exy (metre)	
mean absolute:			0.195	0.270*		0.051	0.351*		
	RMS:	0.220*		0.302*		0.072	0.374*		
	maximum:		0.517*		0.683*		0.340*		0.737*
number of points (differences):									
	488 (	488	488	488	488)				

<u>Chinchaga 2:</u>
Block: 2020_008_NWSAR_Chinchaga2
Number of strips: 5

Adjustment parameters:
bundle adjustment
coordinate system: NAD83 / UTM zone 11N
manual point on image measurements accuracy, pix.: 0.35
automatic point on image measurements accuracy, pix.: 0.35
tie point measurements weight: 1
ground control point coordinates not used
projection centers (GPS) coordinates weight: 1
exterior orientation angles weight (Alpha, Omega, Kappa): (1, 1, 1)
adjustment accuracy: 0.5
Measurement units: metre

General adjustment accuracy estimation

Sigma_0 = 0.895

Control projection centers residuals

	Xm-Xg		Ym-Yg		Zm-Zg		Exy (metre)	
mean absolute:	0.217*		0.255*		0.052	0.353*		
RMS:	0.244*		0.288*		0.074	0.378*		
maximum:		0.553*		0.649*		0.438*		0.714*

number of points (differences):
495 (495 495 495 495)

<u>Chinchaga 3:</u>
Block: 2020_008_NWSAR_Chinchaga3
Number of strips: 4

Adjustment parameters:
bundle adjustment
coordinate system: NAD83 / UTM zone 11N
manual point on image measurements accuracy, pix.: 0.35
automatic point on image measurements accuracy, pix.: 0.35
tie point measurements weight: 1
ground control point coordinates not used
projection centers (GPS) coordinates weight: 1
exterior orientation angles weight (Alpha, Omega, Kappa): (1, 1, 1)
adjustment accuracy: 0.5
Measurement units: metre

General adjustment accuracy estimation

Sigma_0 = 0.829

Control projection centers residuals

	Xm-Xg		Ym-Yg		Zm-Zg		Exy (metre)
mean absolute:	0.141	0.197	0.058	0.256*			
RMS:	0.160	0.216	0.073	0.269*			
maximum:		0.408*		0.480*		0.243	0.486*

number of points (differences):
433 (433 433 433 433)

Caribou Mountains:
Block: 2020_008_NWSAR_CarbMtn
Number of strips: 6
Number of stereopairs: 4221

Adjustment parameters:
bundle adjustment
coordinate system: NAD83 / UTM zone 11N
manual point on image measurements accuracy, pix.: 0.35

automatic point on image measurements accuracy, pix.: 0.35
tie point measurements weight: 1
ground control point coordinates not used
projection centers (GPS) coordinates weight: 1
exterior orientation angles weight (Alpha, Omega, Kappa): (1, 1, 1)
adjustment accuracy: 0.5
Measurement units: metre

General adjustment accuracy estimation

Sigma_0 = 0.913

Control projection centers residuals

		Xm-Xg		Ym-Yg		Zm-Zg		Exy (metre)	
mean absolute:		0.185	0.172	0.057	0.269*				
RMS:		0.212*		0.198	0.080	0.290*			
maximum:			0.512*		0.545*		0.428*		0.615*
number of points (differences):									
997 (	997	997	997	997)					

Appendix C

Table 5. Height correction coefficients using field data measurements. SD = standard deviation. Coefficients differ between the Chinchaga and Caribou Mountains blocks due to differences in aerial imagery flights.

	Coniferous			Deciduous			Total		
	#	Height Difference		#	Height Difference		#	Height Difference	
Area		**Average**	**SD**		**Average**	**SD**		**Average**	**SD**
Chinchaga 1	25	2.21	1.45	39	1.66	1.80	64	1.88	1.69
Chinchaga 2	22	2.80	2.10	30	1.16	1.27	52	1.85	1.85
Chinchaga 3	23	1.67	1.66	26	1.60	1.36	49	1.64	1.47
Total		**2.23**			**1.47**		**165**	**1.79**	
Caribou Mountains	32	**2.18**	2.70	24	**2.17**	1.70	56	**2.17**	2.31

Table 6. Height correction coefficients using stereo imagery measurements. SD = standard deviation. Coefficients differ between the Chinchaga and Caribou Mountains blocks due to differences in aerial imagery flights.

	Coniferous			Deciduous			Total		
	#	Height Difference		#	Height Difference		#	Height Difference	
Area		**Average**	**SD**		**Average**	**SD**		**Average**	**SD**
Chinchaga 1	30	-1.15	1.03	33	-1.34	1.04	63	-1.25	1.03
Chinchaga 2	20	-1.46	0.96	20	-1.05	0.96	40	-1.25	0.97
Chinchaga 3	20	-1.17	1.23	21	-1.91	1.24	41	-1.55	1.26
Total		**-1.26**			**-1.43**			**-1.35**	
Caribou Mountains	21	-1.27	1.34	20	-1.78	1.18	41	-1.52	1.28

Appendix D

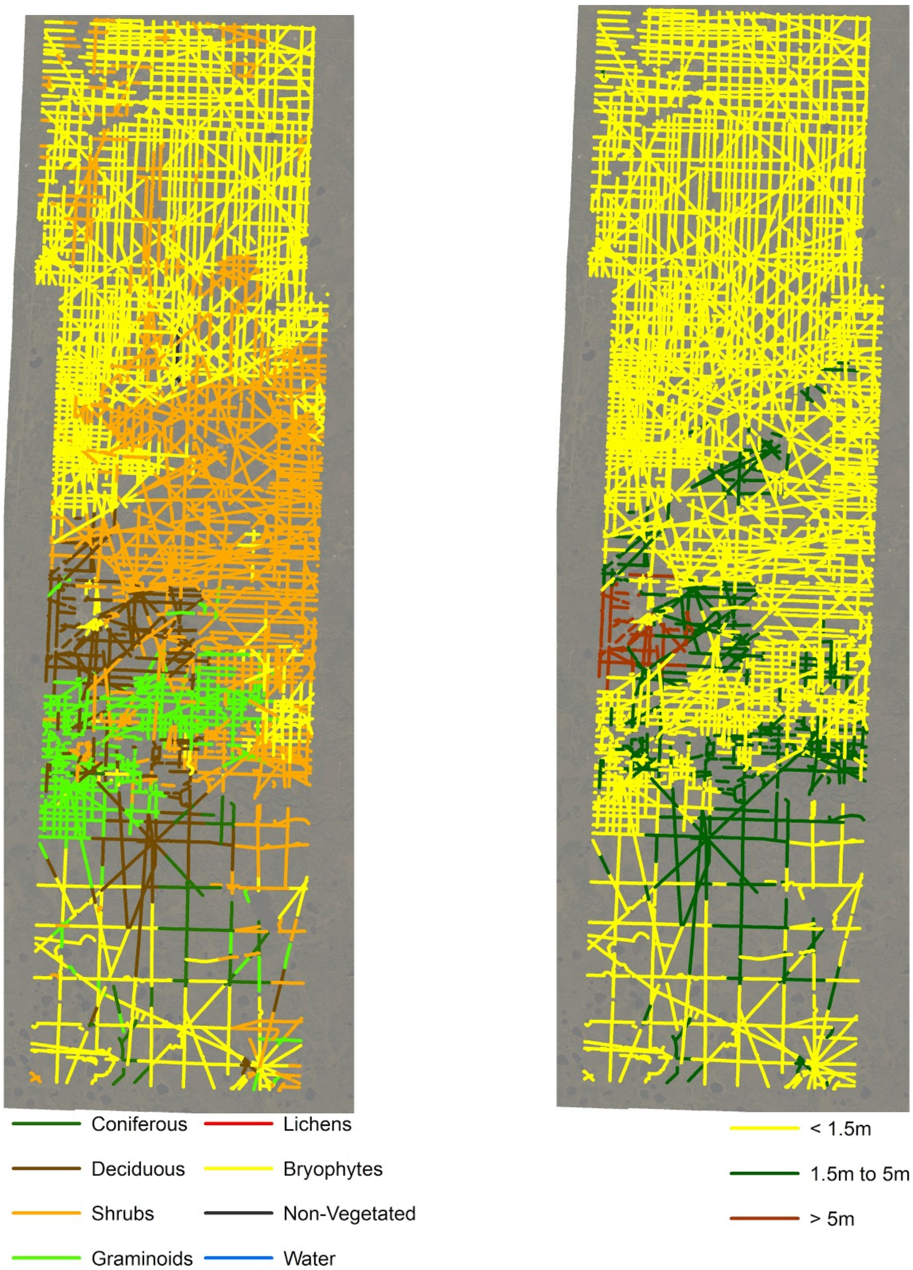


Figure 10. State of vegetation recovery on seismic lines in the Chinchaga 1 block. Figures depict (a) dominant vegetation type and (b) height of dominant vegetation type on 500 metre sections of seismic line, except where seismic lines were disconnected or truncated.

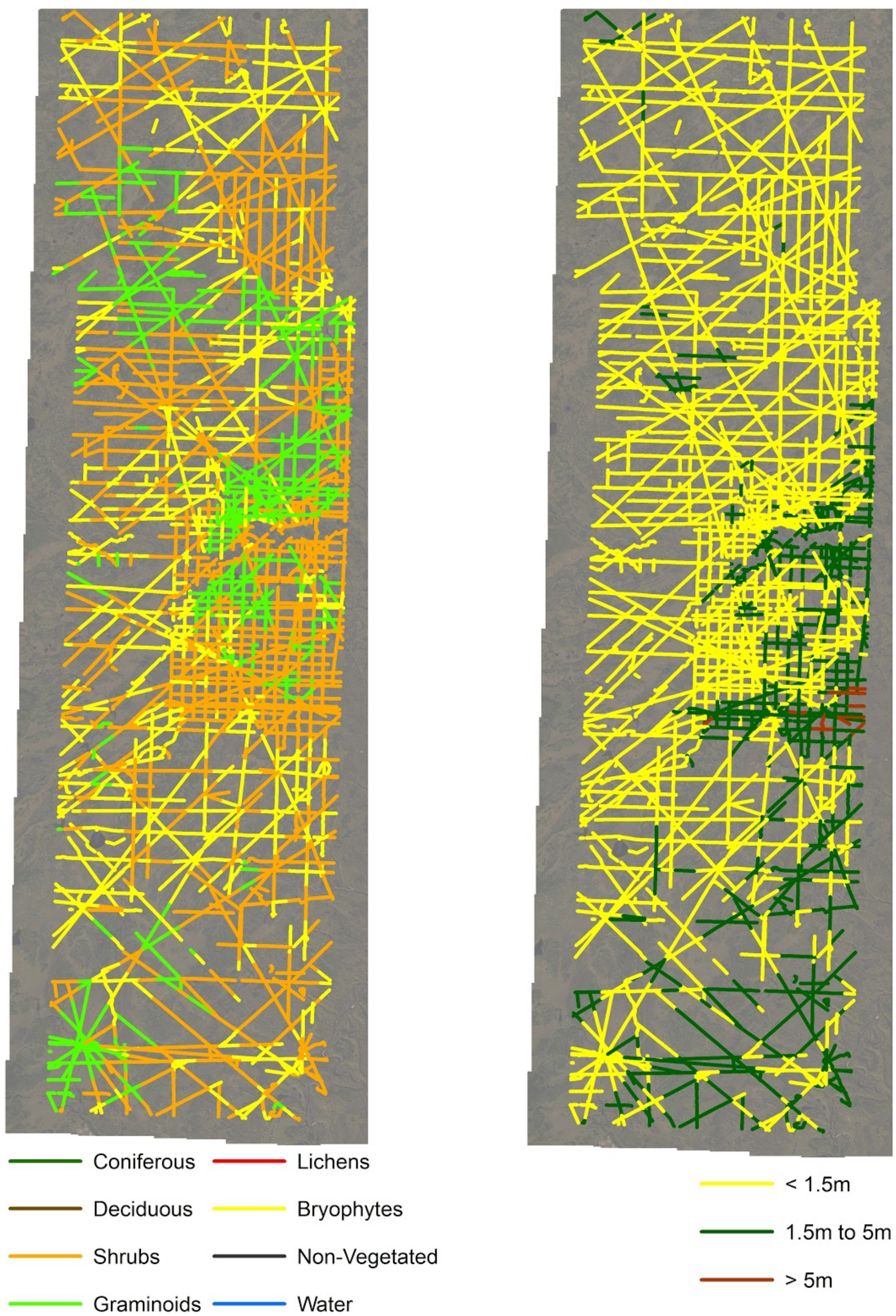


Figure 11. State of vegetation recovery on seismic lines in the Chinchaga 2 block. Figures depict (a) dominant vegetation type and (b) height of dominant vegetation type on 500 metre sections of seismic line, except where seismic lines were disconnected or truncated.

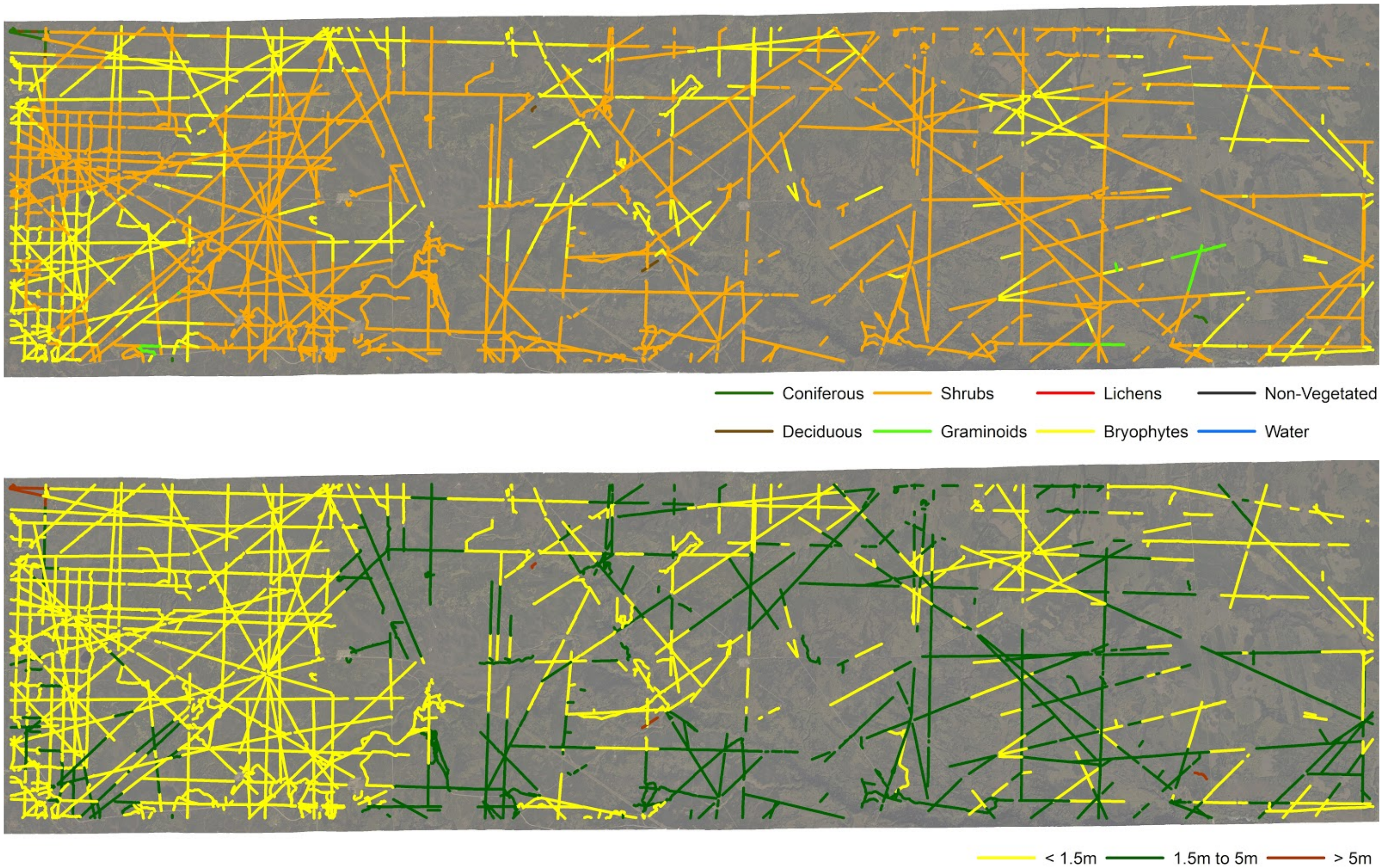


Figure 12. State of vegetation recovery on seismic lines in the Chinchaga 3 block. Figures depict (a) dominant vegetation type and (b) height of dominant vegetation type on 500 metre sections of seismic line, except where seismic lines were disconnected or truncated.

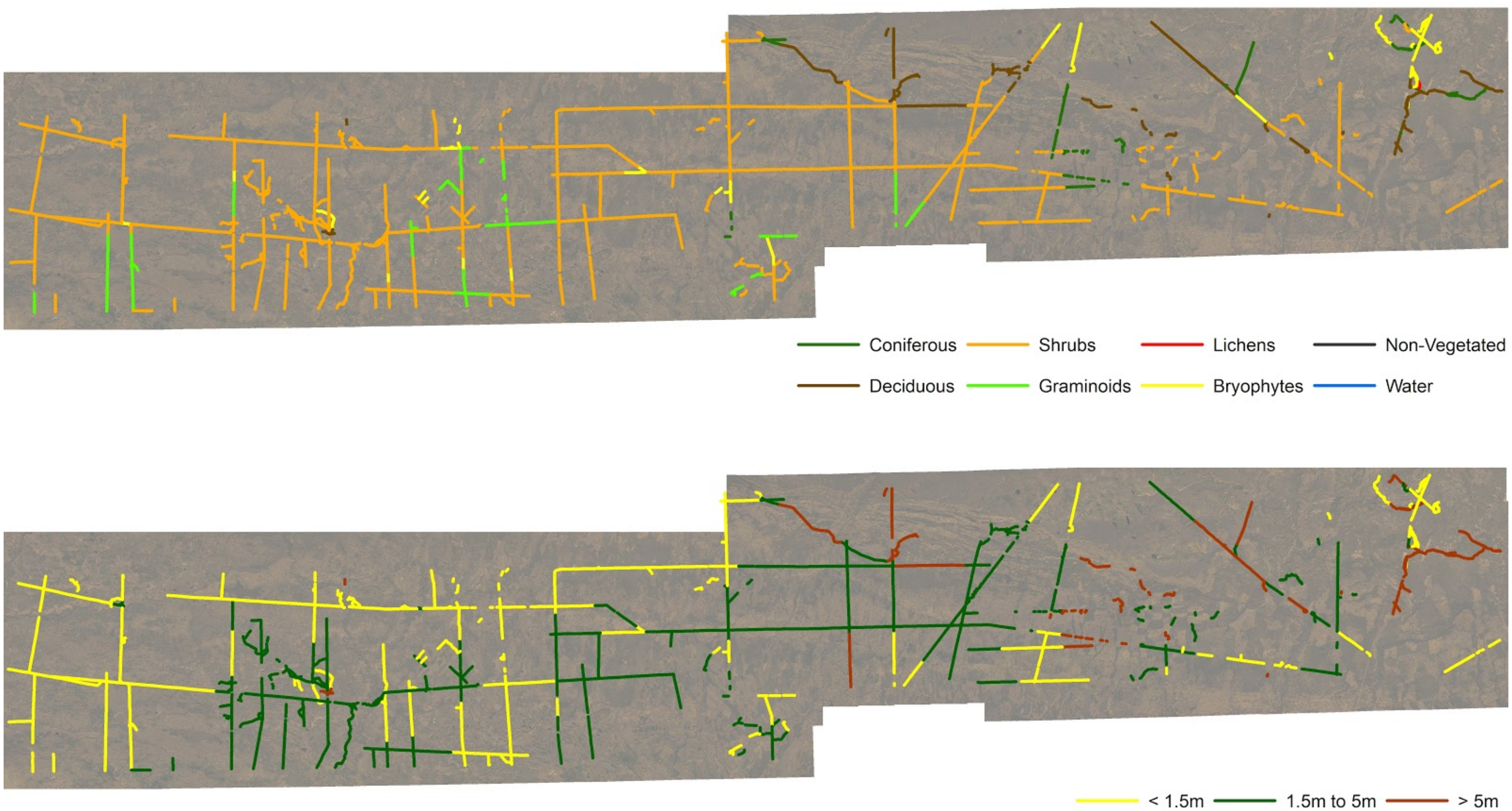


Figure 13. State of vegetation recovery on seismic lines in the Caribou Mountains block. Figures depict (a) dominant vegetation type and (b) height of dominant vegetation type on 500 metre sections of seismic line, except where seismic lines were disconnected or truncated.

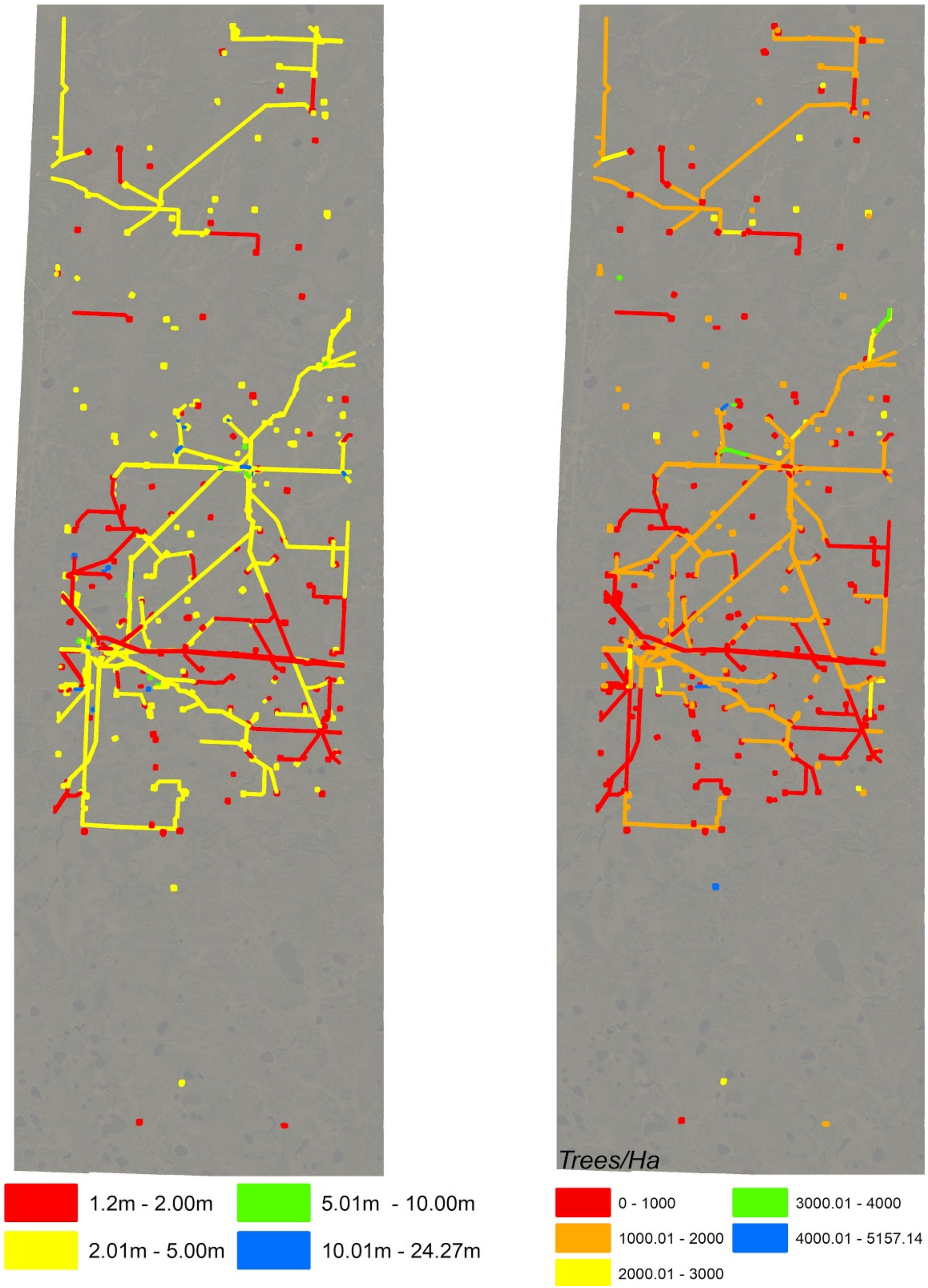


Figure 14. Median height and density (trees/ha) on non-linear human footprint features in the Chinchaga 1 block.

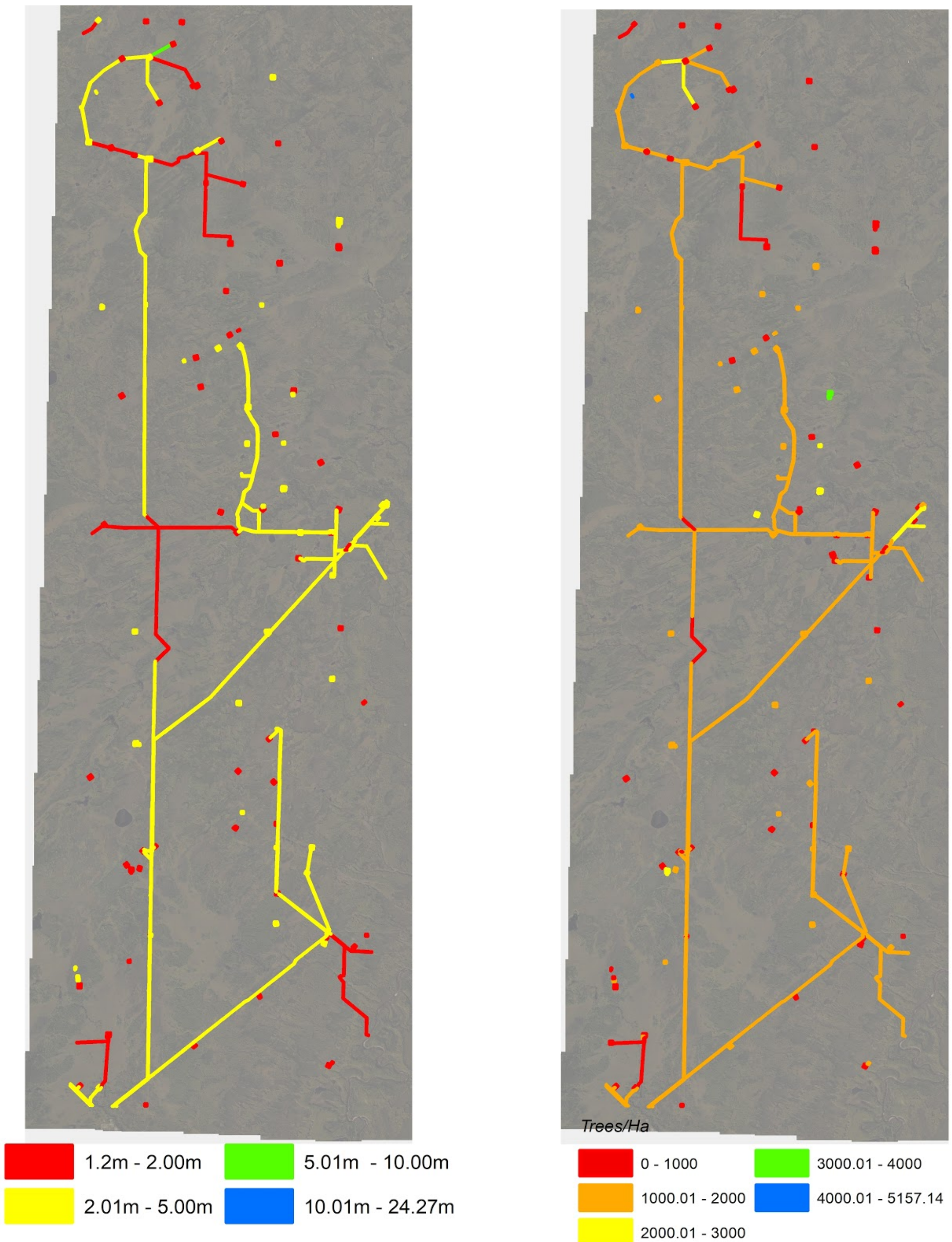


Figure 15. Median height and density (trees/ha) on non-linear human footprint features in the Chinchaga 2 block.

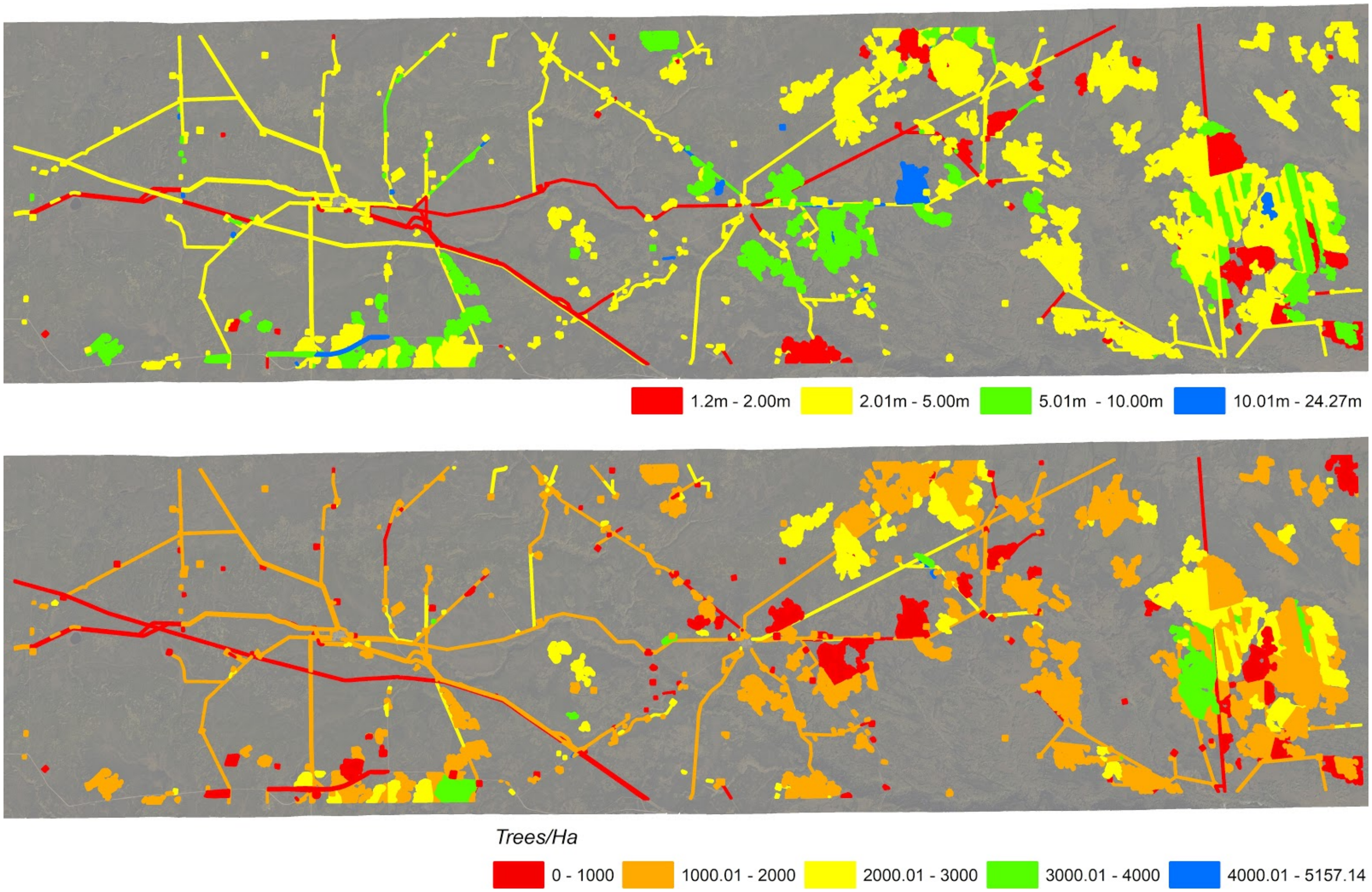


Figure 16. Median height and density (trees/ha) on non-linear human footprint features in the Chinchaga 3 block.

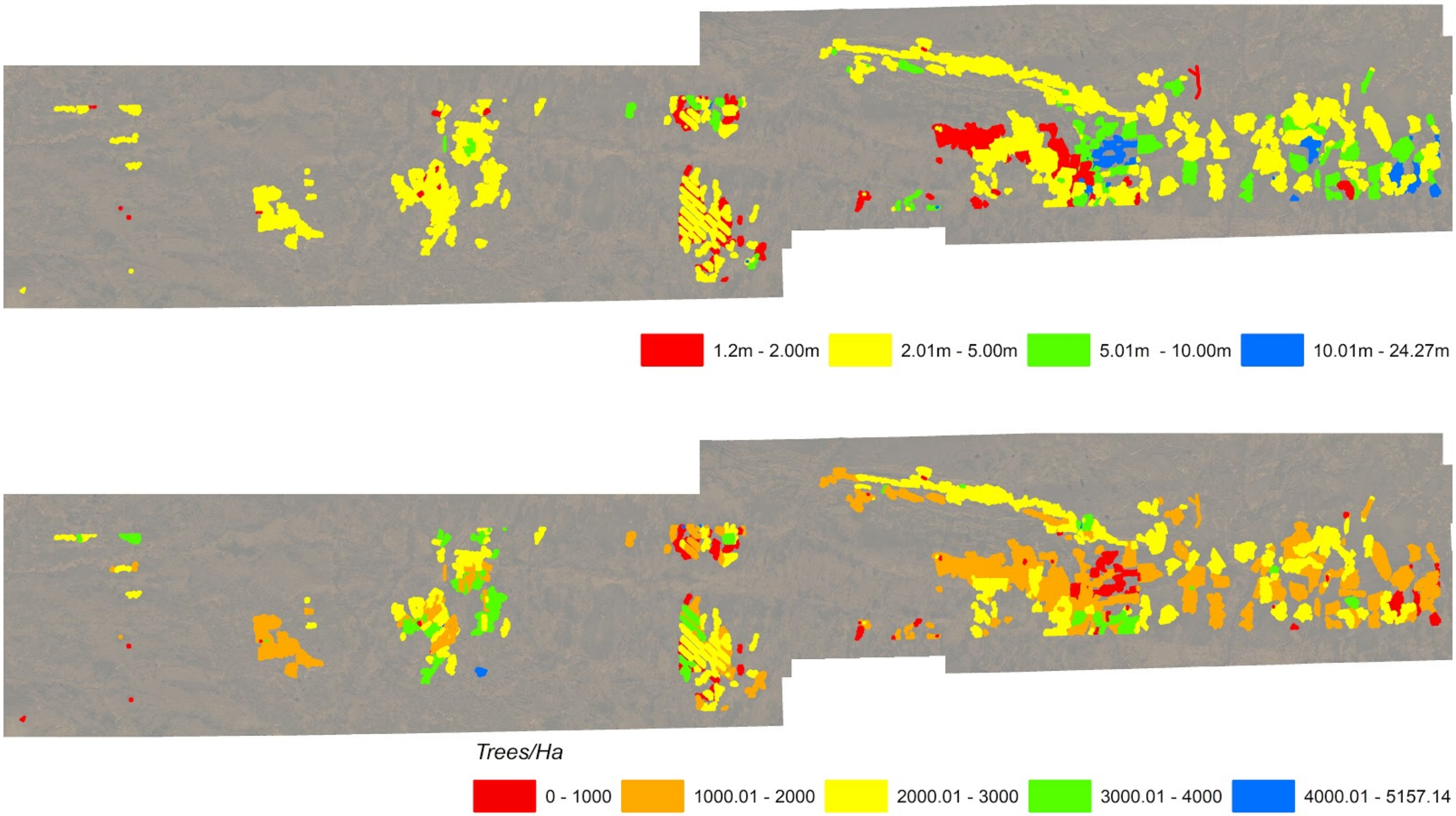


Figure 17. Median height and density (trees/ha) on non-linear human footprint features in the Caribou Mountains block.