PRIORITIZING ZONES FOR CARIBOU HABITAT RESTORATION IN THE CANADA'S OIL SANDS INNOVATION ALLIANCE (COSIA) AREA

July 2016

Prepared for Canada's Oil Sands Innovation Alliance (COSIA)
COSIA Land Environmental Priority Area
520 5th Avenue SW, Suite 1700
Calgary, AB T2P 3R7

Prepared by the Alberta Biodiversity Monitoring Institute
CW 405, Biological Sciences Building
University of Alberta
Edmonton, AB T6G 2E9

This report was prepared by the Alberta Biodiversity Monitoring Institute, for Canada's Oil Sands Innovation Alliance Land Environmental Priority Area.

Authors: Amanda Kellner, Robert Serrouya, Kendal Benesh, Jerome Cranston and Stan Boutin

Suggested Citation: Alberta Biodiversity Monitoring Institute. 2016. Prioritizing zones for caribou habitat restoration in the Canada's Oil Sands Innovation Alliance area. Prepared for Canada's Oil Sands Innovation Alliance. Edmonton, AB, 45 pp.

Executive summary

Boreal caribou populations are declining across Alberta and much of their Canadian range. Key factors causing this decline include a warming climate along with habitat change from industrial exploration and development. As such, habitat restoration has the potential to play a major role in the recovery of boreal caribou populations. The restoration of linear features associated with industrial development is likely to be a primary component of Range Plans for most caribou ranges in Alberta. Empirical evidence from the boreal forest indicates that vegetation recovery on many legacy linear features is unlikely to occur without active restoration.

The release of the Environment Canada Recovery Strategy for Woodland Caribou, Boreal population (*Rangifer tarandus caribou*) in Canada (2012) has highlighted the need to coordinate regional efforts into a larger framework in order to achieve the federal recovery strategy target of 65 % undisturbed habitat in each caribou range. The size of the landscape involved, the costs of restoration, and the finite resources available will require cooperative decisions and planning. Given the range of values to be managed on the landscape, some of which are mutually exclusive, there is a need to develop zones to prioritize habitat recovery within a working landscape, allowing optimal allocation of limited resources. To address this need in the northeast ranges of Alberta, Canada's Oil Sands Innovation Alliance (COSIA) initiated this project to assess a variety of important values and biophysical criteria that would support restoration efforts while achieving a working landscape, thus attempting to maintain both economic and ecological values. This work is being performed in advance of range planning that is led by the Government of Alberta, but it is expected that the information provided in this report will be useful for supporting range planning once it is released by the Government of Alberta.

The primary goal of this project was to prioritize restoration in defined zones in such a way as to maximally benefit caribou habitat given the resources available, while maintaining a working landscape. An objective method to identify and prioritize restoration zones was developed. Notable aspects of the process include:

- The use of entire townships as "base units" to consider for all analyses. The township was used as a minimum patch size to guide restoration. This large scale will allow for efficient grouping and economy of scale for restoration;
- The return per effort (i.e., "bang for buck") to restore each township was determined by:
    - Calculating the current percent (%) disturbed habitat by township, including disturbance due to conventional (i.e., 2D) seismic lines which are available to be restored plus all other disturbances such as forestry cut blocks, well pads, roads, railways, and town sites; disturbance was estimated based on ABMI GIS data, which provides higher human footprint values compared to older federal mapping that was based on Landsat imagery;
    - Calculating the % disturbed habitat remaining after all conventional seismic lines are restored, by township;

  - Identifying the % gain-in-undisturbed (GIU) habitat by complete restoration of conventional seismic lines in a township. This was calculated by subtracting the disturbed habitat once all conventional seismic lines are restored from the current disturbed habitat; and
  - Dividing the GIU by the effort required to achieve this gain, with effort assessed as the density of seismic lines (the "Cost") to restore in each township ("GIU-for-Cost");
- The Resource Valuation Layer (RVL) was incorporated, by township, based on the inverse of its economic potential, to avoid restoration in areas that are likely to see future resource extraction;
- Creation of five equal-area zones across the project area by grouping townships by their final ranking of disturbance reduction per kilometer of seismic line restored, and by the inverse of the RVL;
- Range-by-range assessment of the benefits obtained, in terms of the decrease in the percentage of disturbed habitat, by successively restoring the zones under various scenarios; and
- Accessible mapped results available for planning at strategic and operational levels delivered by GIS Shapefile and the COSIA Data Portal.

The effect on the "% disturbed habitat" of fully restoring all conventional seismic lines in each zone were assessed under four scenarios:

Scenario 1: An optimistic scenario, which ignores burned areas, current industrial activity, and future economic potential;

Scenario 2: The same as Scenario 1, but includes burns <40 years old as disturbed habitat;

Scenario 3: The same as Scenario 1, but including all operating and approved oil sands boundaries (all footprint in these boundaries are assumed to be unavailable for restoration), and removing all treated linear features from consideration (no longer considered human footprint); and

Scenario 4: Repeating Scenario 3, but also accounting for potential future development by specifying an inverse weighting of the RVL.

By restoring the townships with the highest "GIU-for-Cost" (Zone 1) under Scenario 1, current disturbance was projected to decrease from 87 % (East Side Athabasca River [ESAR] caribou range; the most heavily disturbed range under Scenario 1) and 36 % (Richardson caribou range; the least disturbed range under Scenario 1) to 83 and 32 %, respectively. Assuming $10,000 per km restored, this would cost $7,740,000 for ESAR $3,970,000 for Richardson. If all conventional seismic lines were restored across the 5 zones, the remaining disturbed habitat would mean that two of five ranges (Red Earth and Richardson) in the COSIA area would meet the federal 65% undisturbed target.

When fire was included in the percent disturbed (Scenario 2), disturbance values are predictably higher, but GIU ranges from being greater than 12 % in Scenario 1 (e.g. for WSAR) to almost no gain (Richardson, due to the large fire in that caribou range).

When recent restoration work and current industrial activities were considered under Scenario 3, the complete restoration of Zone 1 would lead to current disturbance levels decreasing from 86 % and 36 % to 81 % and 30 % (ESAR and Richardson, respectively). Restoration of all conventional seismic lines (i.e., restoring across all five zones) outside of current industrial areas resulted in remaining disturbed habitat of 55 % to 22 % (ESAR and Richardson, respectively), of each range.

Finally, consideration of potential future development under Scenario 4 led to a change in zonation for 129 of 894 (17 %) townships. Of the 129 townships affected by incorporating the Resource Valuation Layer, 119 of them shifted down one zone in priority for restoration, 9 townships shifted down two zones, and 1 township shifted down by three zones. Only 17 townships within Zone 1 (the highest zone) were affected. The relatively small impact of the Resource Valuation Layer reflected the fact that "GIU-for-Cost" already generally identified areas with high levels of human footprint (associated with resource exploration) as lower priority for restoration.

The final zonation developed for the COSIA lands provides an objective starting point for guiding future restoration planning.

Table of Contents

Table of Figures

List of Tables

1.0 Introduction

Boreal caribou (*Rangifer tarandus caribou*) are distributed across much of northern Canada, living at low densities in the boreal forests of nine provinces and territories. In spite of their broad distribution, boreal caribou numbers are declining rapidly across their range (Festa-Bianchet et al. 2011) and are now listed as Threatened by many provinces and at the federal level by the Species at Risk Act (SARA; Environment Canada 2012). Although various causes factor into this decline, human-induced changes to the landscape such as forestry and oil and gas exploration play a significant role by causing habitat loss, fragmentation and functional habitat loss. Due to changing habitat conditions, wolf foraging efficiencies (McKenzie *et al*. 2012) as well as wolf populations (Serrouya et al. 2011) are increasing, leading to unsustainable predation rates on caribou.

In an attempt to reverse the decline, one key focus of the federal "*Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal population, in Canada (2012)*" (the Recovery Strategy) is the restoration of habitat to an undisturbed condition. The Recovery Strategy mandates that critical habitat is based on the provision of <u>undisturbed</u> habitat across a minimum of 65 % of each caribou range, with disturbed habitat defined as the mapped footprint of human activity, visible on Landsat at a scale of 1:50,000 and buffered by 500 m, plus areas burned within the last 40 years (Environment Canada 2012). To meet this target, the Government of Alberta is currently working towards Range Plans that include restoration and establishment of relatively large tracts of undisturbed habitat within each range.

The Canada's Oil Sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA) is interested in better understanding where it makes most sense to undertake restoration in the seven ranges that are located within COSIA's area of interest which encompasses the Athabasca, Cold Lake and Peace River Oil Sands Areas. The seven boreal caribou ranges that overlap this area include Red Earth, Richardson, West Side Athabasca River, East Side Athabasca River, Cold Lake and parts of the Nipisi and Chinchaga ranges (Figure 1). Disturbance levels in all these ranges are already above the threshold identified in the Recovery Strategy, and therefore the Range Plans must describe a pathway to restoring habitat to the 65% undisturbed threshold over time.

Within these ranges, linear features such as seismic lines, pipelines, powerlines, railways, and roads are abundant on the landscape. Restoration of some of these linear features to a forested state is an achievable objective – particularly for conventional seismic lines[1] that pass through upland sites. Restoration will assist in meeting habitat targets by removing linear features and associated disturbance buffers from the proportion of a range that is considered disturbed, and is expected to contribute to

[1] Common terms are defined in the Glossary (Appendix B).

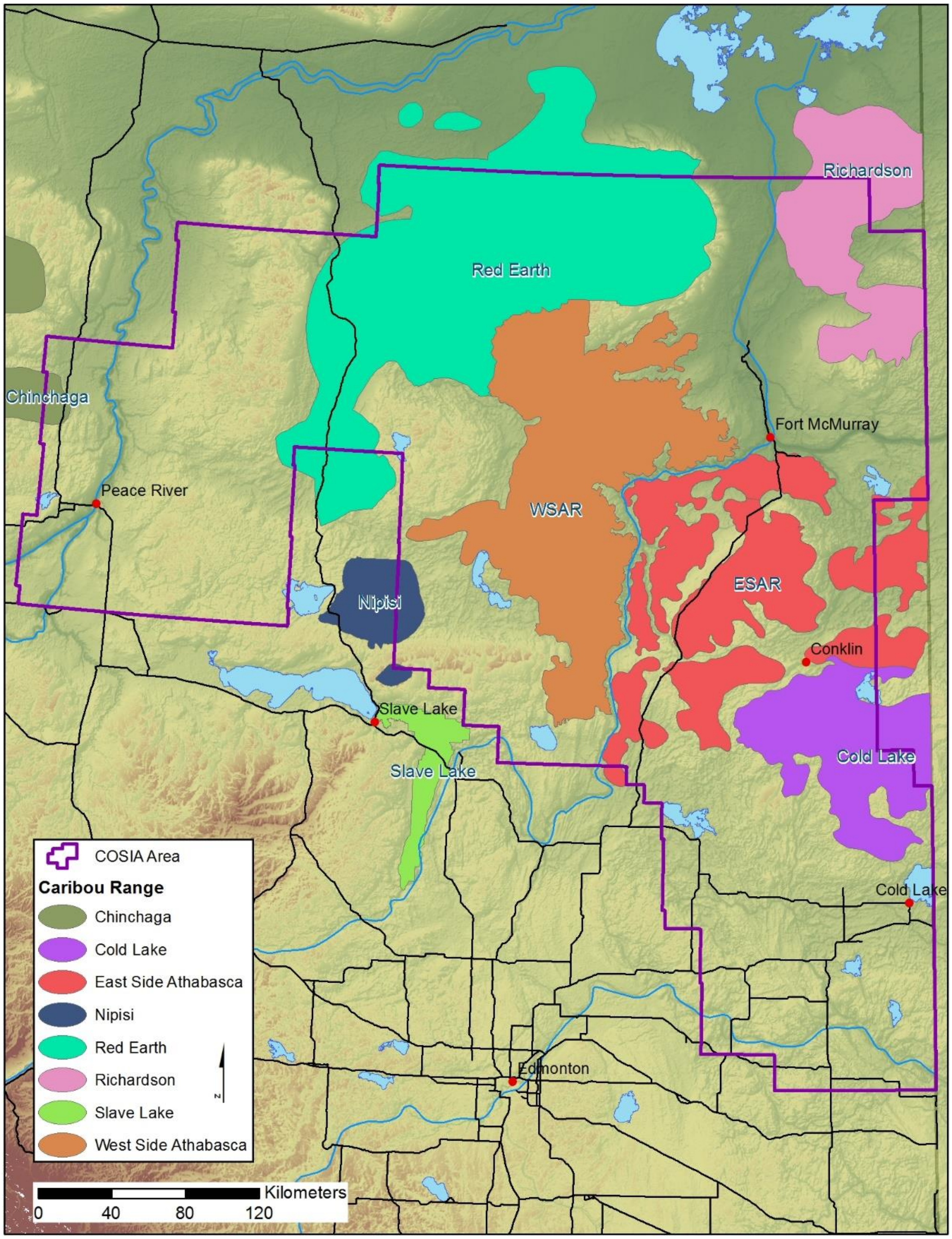


Figure 1. The COSIA area of interest for development of priority restoration zones, showing the COSIA boundary (purple polygon) and caribou ranges considered for analyses (those with > 75 % inside the area of interest; does not include Slave Lake, Nipisi, or Chinchaga ranges, or the two isolated segments of the Red Earth range to the northwest). This map corresponds with Step 1 (section 2.1.4).

caribou recovery by reducing predator foraging efficiency as well as early seral habitat preferred by moose and deer. Research into how wolves use linear features has suggested that linear features enable faster travel and increased search rates (Dickie et al. 2016; James 1999; McKenzie et al. 2012), and restoration of these features may reduce wolf encounter rates with caribou and other prey.

Restoration projects to develop and test suitable treatments are already underway in northeastern Alberta, including the Algar Linear Restoration Program (Algar; COSIA 2016) and the Cenovus Linear Deactivation (LiDea) Program (Sutherland et al. 2015; McNay et al. 2014). Treatment methods have been reviewed and continue to be refined (Pyper et al. 2014). However, because both caribou ranges and industrial development cover large portions of northeastern Alberta, determining where to apply restoration for maximum benefit to caribou while establishing a zoned, working landscape, is essential. Further, strategic planning at an appropriate spatial scale will help to produce large, undisturbed areas within caribou range. Prioritization efforts, recommended for restoration planning (Pyper et al. 2014; Ray 2015), have already taken place on a small scale. For example, determining which specific linear features to restore has been the focus of the Regional Industry Caribou Collaboration (RICC) within the Cold Lake and East Side Athabasca (ESAR) caribou ranges. The RICC linear feature prioritization project began in 2015 to guide restoration efforts towards specific linear features to maximize benefit to caribou and their habitat. Townships within the Cold Lake and Christina portion of the ESAR ranges were prioritized for restoration using a set of criteria, including seismic line density, development boundaries of industry partners, and predictive mapping of existing vegetation regeneration (ABMI 2015).

At the broader scale within COSIA's area of interest, effective habitat restoration requires scaling up from prioritizing individual linear features to prioritizing broad geographic zones where restoration work can be focussed. Prioritization should consider factors important for caribou recovery and where future industrial development is likely to occur. Factors could include:

- The biophysical needs of caribou;
- The current condition of caribou ranges;
- The benefits of combining restoration efforts across company tenures both for caribou habitat and for operational efficiency; and
- Current and future industrial development plans; and existing land-use zoning (e.g., provincial parks and other protected areas).

This project aims to identify and prioritize zones for habitat restoration work across the COSIA area of interest by quantitatively incorporating habitat, land use, and oil and gas resource information. Specifically, the objectives are to:

1. Accurately determine the type and location of linear features in the COSIA area of interest and map those results in a Geographic Information System (GIS) environment;
2. Meet with other investigators conducting similar prioritization work, to compare approaches;
3. Develop defensible criteria to define restoration zones for the COSIA area of interest, including recommending and applying a minimum patch size for planning restoration work;

4. Develop a method for weighted consideration of selected criteria and optimal selection of restoration zones to direct restoration efforts for maximal benefit; and
5. Provide COSIA member companies with ranked restoration zones and potential project ideas for future restoration work.

2.0 Methods

2.1 Development of priority zones for restoration

The COSIA member companies requested that areas of similar restoration priority be grouped into zones. This request was based on the need to establish a zoned, working landscape model that allows for the co-existence of viable caribou populations and industry on the landscape. This process also aligns with the need of caribou for large areas of intact habitat and to facilitate operational implementation by spatially grouping areas of similar potential for restoration. For the purpose of this document, prioritizing restoration applies to any practice intended to benefit caribou recovery, including both functional and ecological restoration.

2.1.1 Data compilation

Data layers considered for this project had to cover the entire area of interest. Compiled GIS layers included:

- Alberta woodland caribou ranges (Environment Canada 2012);
- Existing human disturbance, including conventional seismic lines and all other disturbance not targeted for restoration as mapped and updated by the Alberta Biodiversity Monitoring Institute (ABMI);
- Fire history (Government of Alberta 2014);
- Oil Sands project boundaries (active and approved) from the Oil Sands Information Portal (OSIP 2013);
- Current active petroleum and natural gas agreements and current active oil sands agreements (Alberta Energy 2015);
- AlPac Projected Harvest Plan, which includes areas expected to be harvested in the next 5-25 years[2];
- Inventory of linear features already treated by COSIA member companies, including all features restored up to December 2015;
- Conservation areas, including national and provincial parks and protected areas and wildland parks; and
- Oil sands and conventional oil and gas Resource Valuation Layer summarized by township (CAPP 2016).

---

[2] These data were not formally incorporated into the analysis, but could be used in future iterations, and to visually compare with developed restoration priorities.

Several data layers may have been valuable to include but were not available for the entire study area so could not be incorporated. These included the provincial model of caribou resource selection and high intensity LiDAR (Light Detection and Ranging) data. Therefore, an implicit assumption is that caribou habitat quality was treated uniformly throughout each caribou range. However, a sensitivity analysis done as part of a separate project (ABMI 2015) revealed that caribou habitat quality affected only a minor component of restoration planning, likely because scaling up to the township level masked small scale variation in habitat quality.

Communication and information exchange occurred with similar projects occurring in the COSIA project area. This information included the Government of Alberta's draft caribou habitat restoration priority areas (2013), Nielsen et al.'s (2015) work on line feature prioritization (DART and LMP models[3]) for regional planning in the Lower Athabasca Region (LAR), the Canadian Boreal Forest Agreement (CBFA) harvest deferral zones, and the Regional Industry Caribou Collaboration's (RICC) development of methods for prioritizing seismic lines for restoration in the ESAR and Cold Lake ranges (ABMI 2015). In particular, in the Discussion of this report, we qualitatively compared the results of our analyses with those of van Rensen et al. (2015).

2.1.2 Mapping human disturbance

The Recovery Strategy (Environment Canada 2012) defines disturbance as all areas within 500 m of human footprint visible at a 1:50,000 scale, plus burned areas less than 40 years old. To identify seismic lines for this project, we created a map layer called "merged human footprint"; an amalgamation of the Government of Alberta's 2014 Access Base Features layer and the newest available ABMI seismic line data for the project area (created for various internal ABMI projects). Data from both sources were generated using satellite imagery to manually interpret and delineate human footprint[4] at a scale between 1:10,000 and 1:15,000, and is at a much finer scale than the Environment Canada disturbance mapping, which was created from 1:50,000 scale LANDSAT images (2008). The ABMI Wall-to-Wall Human Footprint Map (2012) was used to identify all other human footprint types, delineated at a scale of 1:15,000.

To calculate the percent disturbance within the project area, all data representing human footprint were merged and buffered by 500 m. Low-impact seismic lines were not included as human disturbance, except where they could not be manually removed from the GIS layer (only a small portion of the study area). Disturbance resulting from fire was considered separately because of the different natural regeneration patterns and timelines for burned areas. Human disturbance was further defined as

---

[3] DART (Disturbance And Recovery Trajectory) and LMP (Landscape Management Plan) models developed for use in the Stony Mountain area and Lower Athabasca Region (LAR).

[4] ABMI's definition of Human Footprint includes the geographic extent of areas under human use that either have lost their natural cover for extended periods of time (e.g., cities, roads, agricultural land, and surface mines) or whose natural cover is periodically reset to earlier successional conditions by industrial activities (e.g., cut blocks and seismic lines).

'candidate' features, (i.e., conventional seismic lines available for restoration), and 'non-candidate' features, which would likely not be restored in the near future (e.g., roads, well pads, facilities).

Because of the fine scale of the ABMI human footprint layers, the values for the percent habitat disturbed used in this project are greater than the values calculated for the same area using only the Environment Canada (2008) disturbance mapping. For example, the Red Earth range showed 80 % disturbed using the ABMI data, and 62 % disturbed using the Environment Canada data (Table C1). This difference has consequences when considering the restoration targets of 65 % undisturbed habitat mandated by the Recovery Strategy (Environment Canada 2012).

2.1.3 Scale of analysis and minimum patch size

Because of the large scope of the project and the size of the landscape, townships (six miles squared mapped units covering Alberta, equivalent to approximately 9,324 ha) were chosen as "pixels[5]" or minimum patch sizes for all analyses and subsequent rankings for restoration. Partial townships < 1000 ha in the project area were excluded, and the remainder were considered indivisible pixels, or units for analysis. Townships were considered to be an operationally appropriate scale because restoration should be most efficient when all the conventional seismic lines in an area no less than a township are treated, given the cost of moving people and equipment to remote worksites. In addition, restoration at the township scale is aligned with the spatial needs of caribou for large patches of intact forest. This approach ignores fine scale variation in line density and configuration, but is appropriate for coarse-filter strategic planning, as it may simplify logistics for on-the-ground work. It is likely that a subsequent process is required for fine scale operation and tactical planning.

2.1.4 Ranking of townships

Based on available data layers and discussion with other researchers, a set of criteria were developed and applied in series to effectively 'rank' townships. These criteria are outlined in the steps below.

Step 1. Define the project area

COSIA's area of interest encompasses 140,213 km^2 in northern Alberta. Overlapping with this area are seven caribou ranges (Figure 1). The project area (synonymous with COSIA's area of interest) was defined as the full extent of caribou ranges that predominantly lie within the COSIA boundary, with these ranges buffered by 500 m and clipped to the Alberta border. The ranges were buffered by 500 m to ensure that edge effects did not artificially affect line density calculations at the edge of caribou ranges. The project area included the entire contiguous Richardson, West Side Athabasca River (WSAR), East Side Athabasca River (ESAR), Red Earth[6] and Cold Lake ranges. Slave Lake, Nipisi and Chinchaga ranges were excluded from this analysis because the majority (>75 %) of these ranges were outside the

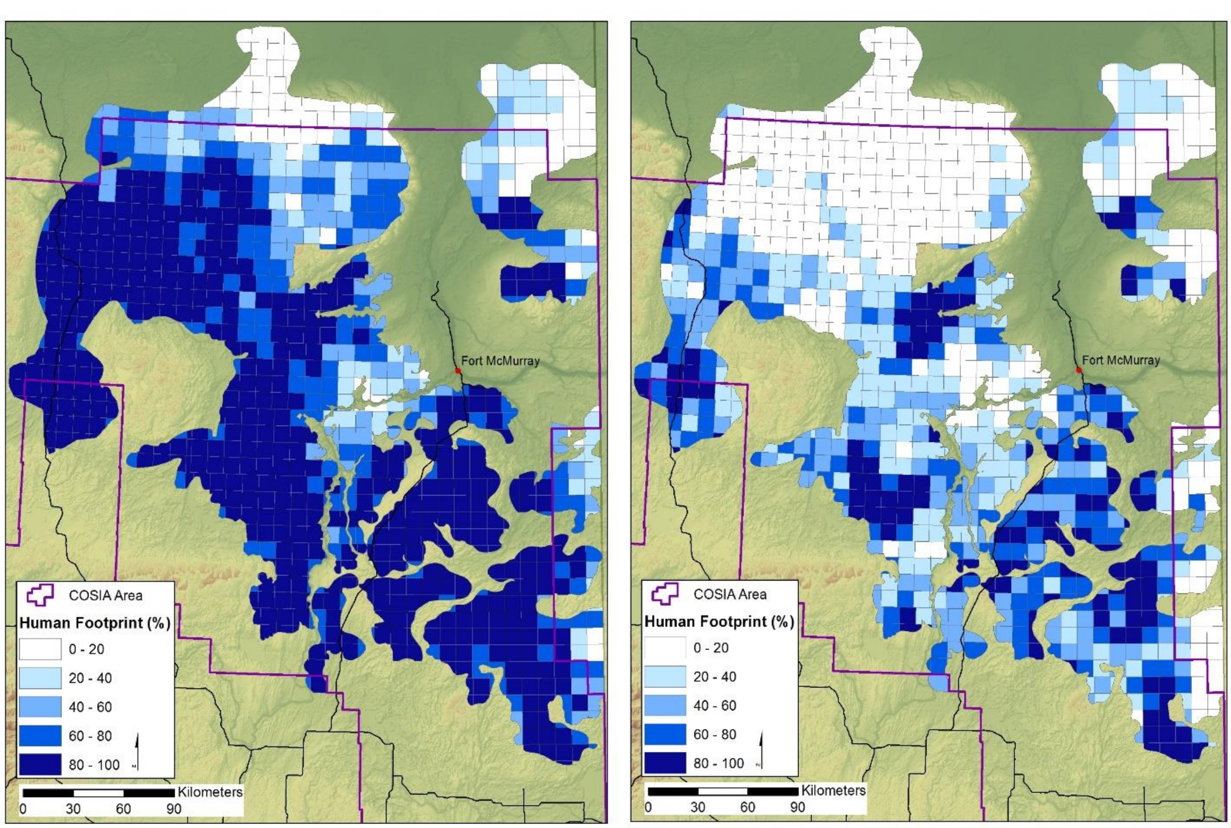
---

[5] This report uses the terms 'pixel' and 'township' interchangeably as a minimum patch size unit.
[6]We omitted two small isolated areas of the Red Earth range, equalling 335 km^2. These areas are approximately 15 km northwest of the main range portion, and were considered not a part of the study area for this project.

COSIA area of interest. The final project area was 69,309 km^2 and included 894 full or partial townships (i.e., >1000 ha) overlapping with caribou ranges.

Step 2. Calculate the current percent disturbed habitat by township, with and without the effect of fire.

The current percentage human disturbance of a pixel was determined based on the federal definition of caribou habitat disturbance, by calculating the disturbed area from the ABMI human footprint layers (2012 conditions, buffered by 500 m, and divided by the total area of the pixel). This percent (%) disturbed habitat (Figure 2a) includes all human footprints, including conventional seismic lines, well pads, pipelines, powerlines, roads, facilities, and railways. Note that we classify disturbance into two categories for analysis in this report: candidate features for restoration (conventional seismic lines), and non-candidate features (all other disturbance types – which are considered currently unavailable for restoration). The current percent disturbed including burned areas was also calculated for each pixel and presented separately (for fire spatial coverage, see Figure D1).



2 (a) (b)

Figure 2. (a) Human disturbance (%) calculated by township, based on ABMI Human Footprint data (2012). Darker blue townships (pixels) indicate higher human disturbance. This map corresponds with Step 2; (b) Human disturbance (%) calculated by township, after all seismic lines are removed. This map corresponds with Step 3.

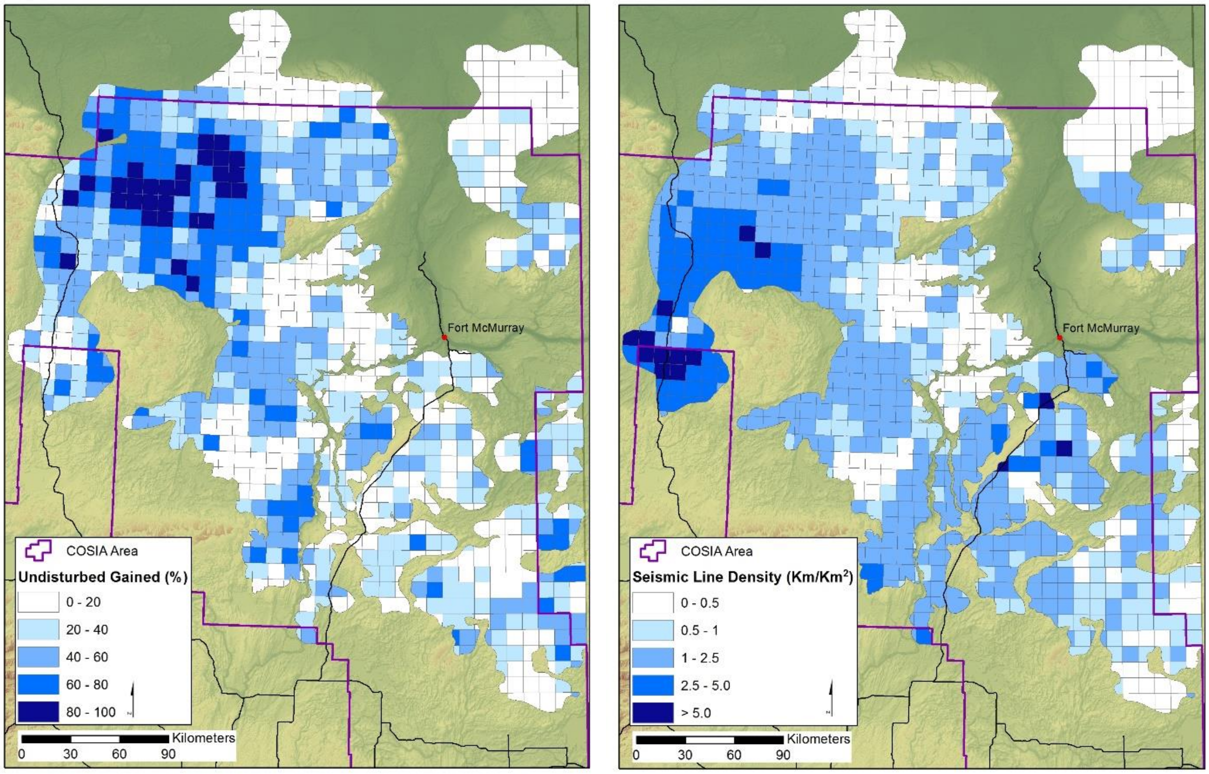
Step 3. Calculate percent disturbed (excluding fire) remaining after all conventional seismic lines are restored, by township.

A portion of the human footprint in northeastern Alberta is considered non-candidate or not available for restoration in the near term, including roads (year round and seasonal), active pipelines, central processing facilities, and commercial well pads. Therefore, Step 3 identifies the amount of disturbance that would remain once all conventional seismic lines have been restored (Figure 2b).

These values were calculated by township without considering the % disturbed by fire, because on a practical and operational level we assume that restoration will not be targeted in burned areas where natural succession is left to take place. In addition, many fires within the COSIA area of interest are close to being 40 years old (Figure D1), when they presumably will be removed as disturbance features according to the Recovery Strategy (Environment Canada 2012).

Step 4. Identify the potential gain in undisturbed habitat, by complete restoration of conventional seismic ("GIU").

The potential gain-in-undisturbed (GIU) habitat (excluding fire), if all conventional seismic lines were restored, was calculated by subtracting the % disturbed after all conventional seismic is restored (results from Step 3) from the current % disturbed (results from Step 2), by pixel. This calculation identifies pixels that offer the highest potential to gain undisturbed habitat exclusive of fire (Figure 3a). The results depend on the relative proportions of disturbance attributable to conventional seismic lines compared to total disturbance including non-candidate features.



3 (a) (b)

Figure 3. (a) The amount of undisturbed habitat (%) gained within each township by restoring all seismic lines ("GIU"). Darker blue pixels gain more undisturbed habitat as a result of restoring all conventional seismic lines. This map corresponds with Step 4; (b) The density of seismic lines by townships (km/km^2). Darker pixels have higher density of seismic lines, and therefore would require more "Cost" to be restored. This map corresponds with Step 5.

Step 5. Determine effort required to achieve this gain ("GIU-for-Cost").

This calculation assesses the effectiveness of restoration efforts in terms of reduction in % disturbed and the effort or cost needed to achieve this result. To include a measure of the effort or cost required to restore all the lines in a township, the potential gain ("GIU" – step 4) was divided by the density of conventional seismic lines in the township ("Cost"), which indexes the cost of restoring all the seismic lines (Figure 3b). The results depend on both the relative proportions of conventional seismic lines to other disturbances and the total amount of human disturbance in the pixel. For example, townships with a large amount of human disturbance may have an insignificant "GIU-for-Cost" if there is a lot of non-candidate human footprint, because complete restoration of conventional seismic lines may not result in much GIU habitat even if many dollars are spent restoring these seismic lines. In other words, restoring seismic lines within 500 m of non-candidate footprint does not contribute to a reduction in disturbed habitat due to the enduring effect of the 500 m buffer around the extant footprint.

Below is an example calculation for "GIU-for-cost," which was done for each pixel:

Disturbed (%)	86
Disturbed (%) with conventional seismic restored	21
Difference (%) (i.e., GIU)	65
Seismic line density (km/km^2) (i.e., cost)	1.27
GIU-for-cost (65 ÷ 1.27)	51

This calculation does not take the location of a township into account, because the logistical challenges of working in remote areas will either be increased or decreased depending on how many other townships in the area are targeted for restoration as well. The grouping of townships into zones in Step 8 partially mitigates this issue and facilitates restoration on a larger scale.

Step 6. Areas where it is assumed restoration will not occur in the foreseeable future.

Areas where no restoration will occur in the near term were identified and removed from the calculations of the potential reduction in % disturbed for each range. These included industrial areas as defined by Oil Sands Information Portal (OSIP) oil sands project boundaries, where active or approved (by 2013) projects[7] occur (buffered by 500 m under the definition of human disturbance). Also excluded during this step were seismic lines that had already been treated as part of existing restoration projects; for example, nearly six entire townships within the ALGAR and LiDea project areas (Figure 4). These lines and their 500 m buffers were removed from the human disturbance. For Scenarios 3 and 4 (Section 3.0), this step was completed prior to calculating current disturbance values by township (Step 2).

[7] At the time of writing this was the most up-to-date oil sands boundaries data available.

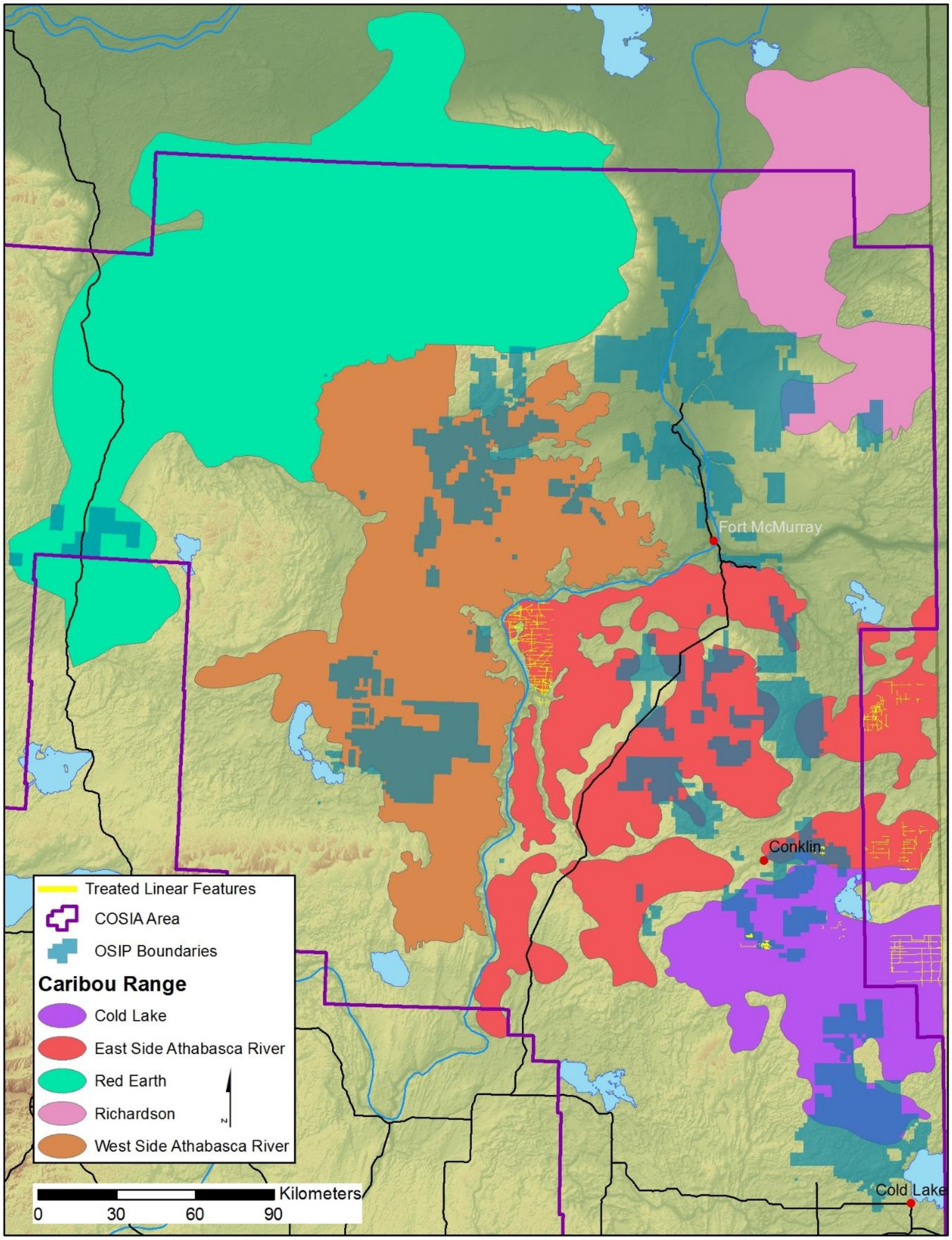


Figure 4. Boundaries of existing and approved oil sands projects (OSIP 2013) and already treated linear features (yellow lines). Seismic lines within OSIP boundaries and seismic lines that have already undergone some treatment for restoration are not considered for restoration. This map corresponds with Step 6.

Step 7. Consider the potential for future development in each township.

Incorporating the economic value of potential recoverable reserves of oil sands and conventional oil and gas is a fundamental step in the establishment of a working landscape approach, with zones prioritized for restoration as well as alternative zones where industrial values can be maintained. This directs restoration away from areas likely to be targeted by future resource extraction. In addition, this prevents the wasting of effort and money that would occur if restored seismic lines were re-disturbed or new lines were created nearby.

The resource valuation was provided to ABMI by Cenovus Energy (on behalf of the Canadian Association of Petroleum Producers (CAPP; 2016)) as the current dollar value in millions of Canadians Dollars ($ MM CDN as a $60 USD Western Texas Index (WTI)) of each township. This layer (termed the Resource Valuation Layer (RVL)) was normalized, by dividing the RVL for each pixel by the maximum value of all the pixels (maximum value was $16,814 MM CDN). An inverse weighting was used, by subtracting the normalized resource value from 1, and multiplying the value by the value from the “GIU-for-Cost” (Step 5 value). The formula is represented as:

(1 – RVL/16814) × Step 5

This approach essentially modifies the restoration value of a pixel based on its [high] resource value, and directs restoration priority toward other pixels with lower resource value (Figure 5). Below are two examples illustrating the inverse weighting effect of a high and low RVL value, and how a higher RVL value diminishes the final ranking of a township:

	High RVL example	Low RVL example
RVL	11250	5150
Max RVL value	16814	16814
Normalized RVL (RVL/max RVL)	0.67	0.31
1 - Normalized RVL	0.33	0.69
GIU for cost value from Step 5	51	51
Final ranking value	0.33 x 51=16.88	0.69 x 51=35.38

Step 8. Group townships into zones of restoration priority.

Each pixel received a value after processing with the weighted criteria described above. Similarly-ranked townships were grouped to create five hierarchical ‘zones’ of ordered priority for restoration, with Zone 1 as highest priority down to Zone 5 as lowest priority. Zone 5 includes areas with no potential benefits from restoration, either because there are no seismic lines within a pixel, or because all lines are within the 500-m buffer of non-candidate human footprint features, and therefore no GIU would occur by restoring such lines. The “GIU-for-Cost” cutpoints for creating each zone were developed to include approximately equal land areas (i.e., number of pixels) in each zone.

The inclusion of each township within a particular zone may have changed over the course of the ranking process. For example, zones produced after Step 5 indicate which townships provide the best "GIU-for-Cost", if all lines in that township are restored. Those townships may have been eliminated from consideration in the generation of the higher priority zones if they occurred in high resource-value areas, where there is a high probability of future development.

Step 9. Determine the cumulative benefit of restoring each zone in succession.

The cumulative benefit of restoring successive zones was then calculated for each caribou range, and expressed as the progressive reduction of disturbed habitat (%). For each caribou range, we calculated the effects on % disturbed of restoring all seismic lines in each zone, separately for four scenarios:

1) An optimistic scenario, where burned areas are not considered disturbed, and approved (near term) industrial activity and future economic potential are ignored; although this is not a realistic scenario, it was run as a baseline sensitivity “best case” for comparison with the other scenarios
2) The same as Scenario 1, but considers burned areas <40 years old as disturbed; this was run to quantify the magnitude of fire on disturbance levels
3) The same as Scenario 1, but including active and approved oil sands boundaries (now considered non-candidate footprint for restoration), and removing all treated linear features from consideration (no longer considered human footprint); and
4) Repeating Scenario 3, but also accounting for potential future development by including the Resource Valuation Layer.

2.1.5 Alternate/additional analyses

1. Exclude tenured areas from restoration and calculate % disturbed if all remaining conventional seismic lines were restored.

A separate analysis was conducted to assess the effectiveness of only restoring conventional seismic lines that are on lands without any resource development agreements, leases or tenures. The types of development agreements, leases or tenures that were included for consideration were active petroleum and natural gas agreements, current active oils sands agreements, and Forest Management Areas (FMAs), within the COSIA area of interest. For the purposes of this report these have been collectively referred to as ‘tenured area’. The term ‘tenured area’ is a generalization, however, and it is critical to distinguish the significant differences between the various types of resource dispositions and tenure systems. Leases or ‘tenure’ for subsurface minerals are not synonymous with the approval for or the size, shape and distribution of surface disturbance. Therefore, even though mineral leases are in-place for major proportions of the COSIA area of interest, this does not imply surface disturbance. Similarly, there is a large FMA in NE Alberta held by forest industry, but the amount of commercially productive forest, and the area harvested annually, are only a fraction of the total FMA. For example, only a small fraction (≈ 2.5%) of the landscape is disturbed as a result of oil and gas activity and a slightly larger fraction (≈3.1%) as a result of forest industry (ABMI 2014).

In this alternate analysis, areas with some type of resource development tenure were identified and excluded from available areas for restoration (Figure 5). For the purpose of this alternative analysis, these areas, hereafter identified together as 'tenured areas', are considered to be areas where potential future mineral or fibre resource development may occur in the foreseeable future.

A small amount of conventional seismic lines were inside of tenured areas but also overlapped with conservation areas (provincial and national parks and protected areas). We still considered these seismic lines available for restoration, because industrial development and forestry is unlikely to occur inside of conservation areas. These areas of overlap totalled only 490 km^2, and included 4 km of conventional seismic lines in the Cold Lake range, 142 km in Red Earth, 136 in ESAR, 1 km in Richardson, and none in WSAR. The kilometres of seismic lines available for restoration, and the % disturbed habitat remaining after all candidate seismic lines are restored, were calculated for all areas outside of tenure for each caribou range.

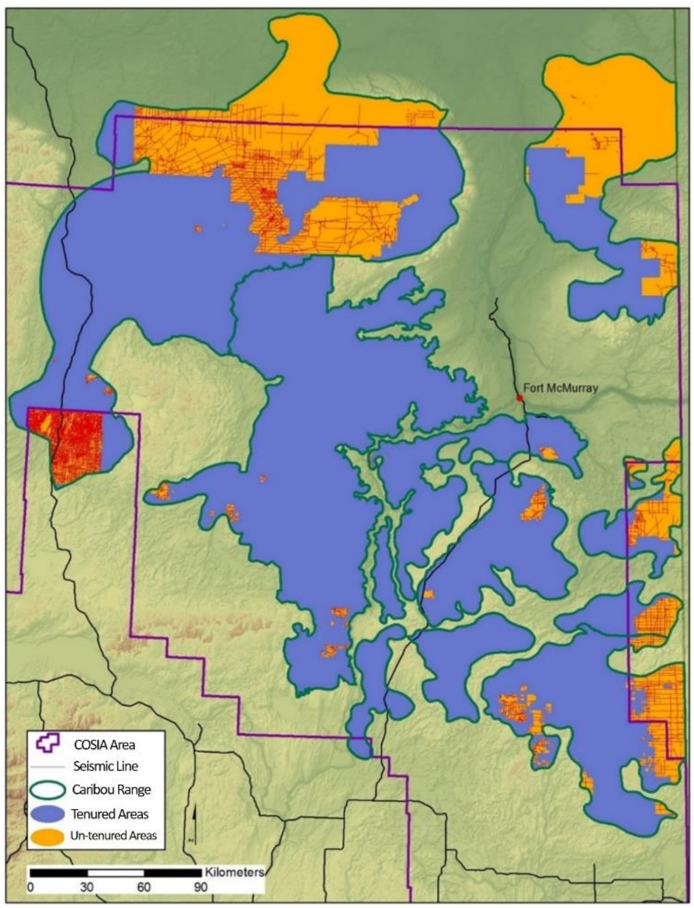


Figure 5. Tenured area (blue) in the study area. An additional analysis considered the effectiveness of only restoring conventional seismic lines that are on lands without any resource development agreements, leases or tenures. Under this scenario tenured areas (active petroleum and natural gas agreements, current active oils sands agreements, and Forest Management Areas (FMAs)) were identified and excluded from available areas for restoration. Note that tenured area is not synonymous with surface disturbance.

3.0 Results

The results from all four scenarios described in Step 9 are presented in Tables 1 to 4, respectively. Percentages (disturbance values) within Zone 1 represent the remaining disturbance once all the conventional seismic lines are restored in townships classified as Zone 1. The disturbance values shown in Zone 2 assume that all lines within Zones 1 + 2 have been restored. This pattern is repeated, such that values shown in Zone 5 represent the disturbed habitat once *all* conventional seismic lines have been restored within that particular caribou range, i.e., across Zones 1 to 5. Likewise, kilometers of seismic lines restored are calculated cumulatively across the zones, such that Zone 5 values represent the kilometers of seismic that were available in restoration within that particular caribou range across all zones. Shapefiles for the following maps can be viewed in detail on the COSIA Data Portal.

All tables also include calculations for remaining disturbance and kilometers of seismic lines restored under the alternate analysis where only seismic lines outside tenured areas are available for restoration.

Scenario 1 – Optimistic analysis, which treats burned areas as undisturbed, and does not take into account active and approved industrial boundaries, restoration treatments that have already been applied, and future economic potential.

Table 1 illustrates the cumulative effect of restoring seismic lines within Zones 1 through 5, under a scenario where only ABMI human footprint data is considered. The reduction in the '% remaining disturbed' habitat after restoration of a zone decreases as more zones are restored (moving from left to right across the table). The cumulative benefit of restoring seismic lines within all zones (rightmost column) ranges from 21 % remaining disturbed habitat (Red Earth) to 52 % remaining disturbed (ESAR) – this assumes that all 104,106 km of conventional seismic lines in the project area under this scenario are restored.

Only considering the restoration of seismic lines outside of tenured areas (Table 1), illustrates similar results to only restoring Zone 1 (i.e., just 1/5th of the available pixels for restoration). The notable exception is the Red Earth range, where restoring Zone 1 requires fewer treated kilometers (4,144 km vs 10,609 km) to achieve the same % disturbed.

Scenario 2 – The same as Scenario 1, but includes burned areas <40 years old.

Table 2 calculates values based on the above analysis, but with fire polygons <40 years old added as disturbance. This predictably increases the disturbance values for each range, particularly the Richardson Range, where current % disturbed increases from 36 % (Table 1; human disturbance) to 91 % (human and fire disturbance combined; Table 2). Complete restoration of all conventional seismic lines (Zone 5) results in 43 to 85 % remaining disturbed habitat, as many of the 'restored' seismic lines remain inside fire disturbance polygons. It should be noted that a substantial amount of the fires included in this analysis are nearing the 40 year threshold (Figure D1), though this is not the case for the Richardson range.

Table 1. Scenario 1: The current % disturbed habitat by caribou range in the project area, but treating burned areas as undisturbed. The % remaining disturbed habitat is presented after restoration of all available seismic lines on untenured areas, and then for the cumulative effects of restoring all available conventional seismic lines in the prioritized zones. "GIU-for-Cost" cutpoints are based on areas of equal size (e.g., an equal number of townships). 'Total % disturbed (current)' represents the total disturbance (%) based on the current scenario. Km refers to km of conventional seismic lines available to be restored.

		Untenured areas Restored		**Zone 1 Restored**			**Zones 1 and 2 Restored**			**Zones 1 to 3 Restored**			**Zones 1 to 4 Restored**			**Zones 1 to 5 Restored**		
GIU-for-Cost cutpoint				**>64**			**>41**			**>25**			**>14**			**>0**		
Range	**TOTAL % disturbed (current)**	**% remaining disturbed**	**km seismic**	**% remaining disturbed**	**Zone 1 km**	**cumulative km**	**% remaining disturbed**	**Zone 2 km**	**cumulative km**	**% remaining disturbed**	**Zone 3 km**	**cumulative km**	**% remaining disturbed**	**Zone 4 km**	**cumulative km**	**% remaining disturbed**	**Zone 5 km**	**cumulative km**
RED EARTH	68	54	10609	54	4285	4285	42	6283	10568	33	6209	16777	26	9143	25920	21	17320	43240
RICHARDSON	36	33	261	32	397	397	27	648	1045	24	713	1758	23	212	1970	22	1843	3813
WSAR	82	82	405	80	679	679	67	4272	4951	47	9225	14176	40	5379	19555	39	1480	21035
ESAR	87	82	1156	83	774	774	78	1479	2253	69	3763	6016	58	7772	13788	52	14636	28424
COLD LAKE	86	70	1600	74	1027	1027	62	1672	2699	58	1048	3747	52	1849	5596	51	1998	7594
Total			14031		7162	7162		14354	21516		20958	42474		24355	66829		37277	104106

Table 2. Scenario 2: The current % disturbed habitat by caribou range in the project area, considering all human disturbance (Table 1) plus the disturbance from fires within the past 40 years. The % remaining disturbed habitat is presented after restoration of all available seismic lines on untenured areas, and then for the cumulative effects of restoring all available conventional seismic lines in the prioritized zones. Fire polygons are based off of the Government of Alberta's 2014 fire data.

		Untenured areas Restored		**Zone 1 Restored**			**Zones 1 and 2 Restored**			**Zones 1 to 3 Restored**			**Zones 1 to 4 Restored**			**Zones 1 to 5 Restored**		
GIU-for-Cost cutpoint				**>44**			**>26**			**>15**			**>2**			**>0**		
Range	**TOTAL % disturbed (current)**	**% remaining disturbed**	**km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**
RED EARTH	80	70	10609	71	3495	3495	65	4560	8055	57	9604	17659	51	18813	36472	50	6768	43240
RICHARDSON	91	90	261	90	72	72	87	613	685	85	650	1335	84	1582	2917	85	896	3813
WSAR	83	82	405	71	3571	3571	51	9462	13033	44	5658	18691	43	2345	21036	43	0	21036
ESAR	89	84	1156	81	1756	1756	76	2034	3790	67	6165	9955	62	11014	20969	62	7455	28424
COLD LAKE	92	84	1600	85	771	771	78	1416	2187	73	1735	3922	70	2575	6497	70	1098	7595
Total			14031		9665	9665		18085	27750		23812	51562		36329	87891		16217	104108

Scenario 3 – The same as Scenario 1, but include active and approved oil sands boundaries (here, considered non-candidate human footprint), and removing all treated linear features from disturbance (no longer considered human footprint).

The analysis for Table 3 builds on the optimistic analysis (Table 1), but also accounts for areas considered currently unavailable for restoration. This includes active and approved oil sands boundaries identified by OSIP (considered as non-candidate human footprint that is not expected to be available for restoration in the near-term) and linear features that had already undergone restoration treatment and were considered restored and no longer human disturbance. This results in the cumulative kilometers of seismic lines restored to change from 104,106 km (Table 1) to 86,196 km (Table 3).

Under this scenario, though less seismic lines are available for restoration across ranges, human footprint of lines already restored are also removed from the landscape. This causes the final remaining disturbed habitat (%) to increase in the WSAR, ESAR and Cold Lake ranges, while the Red Earth and Richardson ranges do not change (Tables 1 and 3). The Red Earth and Richardson ranges have very few OSIP boundaries and no identified treated seismic lines compared to the other ranges (Figure 4).

The cumulative benefit of restoring seismic lines within all zones range from 21 % remaining disturbed habitat (Red Earth) to 55 % remaining disturbed (ESAR). Townships classified by Table 3 zones are presented in Figure 6a.

Scenario 4 – Repeating Scenario 3, but also accounting for potential future development by including the Resource Valuation Layer.

Table 4 incorporates the addition of resource value, by township, into Scenario 3. The “GIU-for-Cost” of townships or pixels with high resource value decreases, shifting them to a lower priority zone (Figure 6b). For this reason, the same “GIU-for-Cost” cutpoints were used in Tables 3 and 4, so the change in zonation between these scenarios best represents the effect of applying RVL to a township. Figure 7 identifies 129 of a total 894 townships that have shifted *down* in zonation (i.e., have less priority for restoration due to high resource value). Only 17 of these shifts occurred in Zone 1 pixels; the RVL primarily affected pixels with relatively lower “GIU-for-Cost” (those already in Zones 2 through 5).

Kilometers of seismic lines available for restoration and the final remaining disturbed habitat (%) are consistent with Table 3[8], as the same considerations are applied (e.g., human footprint only, OSIP boundaries, treated linear features); however, change in “GIU-for-Cost” redistributes townships across the zones (compare Figures 6a and 6b). For example, the total kilometers of seismic lines needed to restore Zone 1 and achieve a nearly identical reduction in % disturbed habitat across ranges decreases

[8] The total kilometers of seismic available for restoration in Tables 3 and 4 differ by 1 km in both WSAR and Cold Lake. This is due to a rounding error in GIS and is considered trivial.

to 7,122 km, compared to 7,809 km in Table 3; a 687 km reduction[9]. Figure D2 illustrates Table 4 zones with fires <40 years old overlaid, including spring 2016 fires.

To help estimate the dollar cost of restoration for each zone, we multiply the total km of conventional seismic available to be restored by $10,000 (an estimated cost per km), and then divide that value by the GIU (Table 5). This analysis shows how many dollars have to be spent to gain one percent of undisturbed land (GIU). GIU costs increase substantially from Zone 1 through 5. Costs range from as little as $843,000 to gain 1 % in undisturbed habitat (Cold Lake, Zone 1) to 43 Million (Red Earth, Zone 5). This analysis highlights the importance of prioritizing areas and limited resources for restoration.

We also summarized the total resource value by zone by caribou range (Table 6). This was completed by totalling the resource value of all townships within Zones 1 through 5, within each caribou range. Townships that straddled two ranges had resource values calculated for each ranges' portion of the township.

[9] To estimate general cost of restoration, multiply kilometers of seismic lines restored by $10,000. This estimate is based on industry experience and does not incorporate any additional logistical costs based on location (e.g., remoteness).

Table 3. Scenario 3: As in Table 1, the current % disturbed habitat by caribou range in the project area, considering all human disturbance but treating burned areas as undisturbed. Seismic lines within active and approved oil sands (OSIP) boundaries are considered not available for restoration and individual lines that had already undergone restoration treatments are considered restored[10] (no longer contribute to human footprint), lowering the current % disturbed relative to Table 1. The % remaining disturbed habitat is presented after restoration of all available seismic lines on untenured areas, and then for the cumulative effects of restoring all available conventional seismic lines in the prioritized zones.

		Untenured areas Restored		Zone 1 Restored			Zones 1 and 2 Restored			Zones 1 to 3 Restored			Zones 1 to 4 Restored			Zones 1 to 5 Restored		
GIU per cost cutpoint				>58			>35			>20			>7			>0		
Range	**TOTAL % disturbed (current)**	**% remaining disturbed**	**km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**
RED EARTH	67	54	10609	53	4921	4921	37	8592	13513	29	7359	20872	22	12743	33615	21	8044	41659
RICHARDSON	36	33	261	30	557	557	26	567	1124	23	713	1837	23	204	2041	22	803	2844
WSAR	84	83	405	81	598	598	65	5948	6546	51	7145	13691	49	2507	16198	48	886	17084
ESAR	86	81	919	81	712	712	77	1146	1858	66	5391	7249	56	8260	15509	55	3920	19429
COLD LAKE	83	70	1381	72	1021	1021	62	1469	2490	57	1302	3792	54	1181	4973	54	207	5180
Total			13575		7809	7809		17722	25531		21910	47441		24895	72336		13860	86196

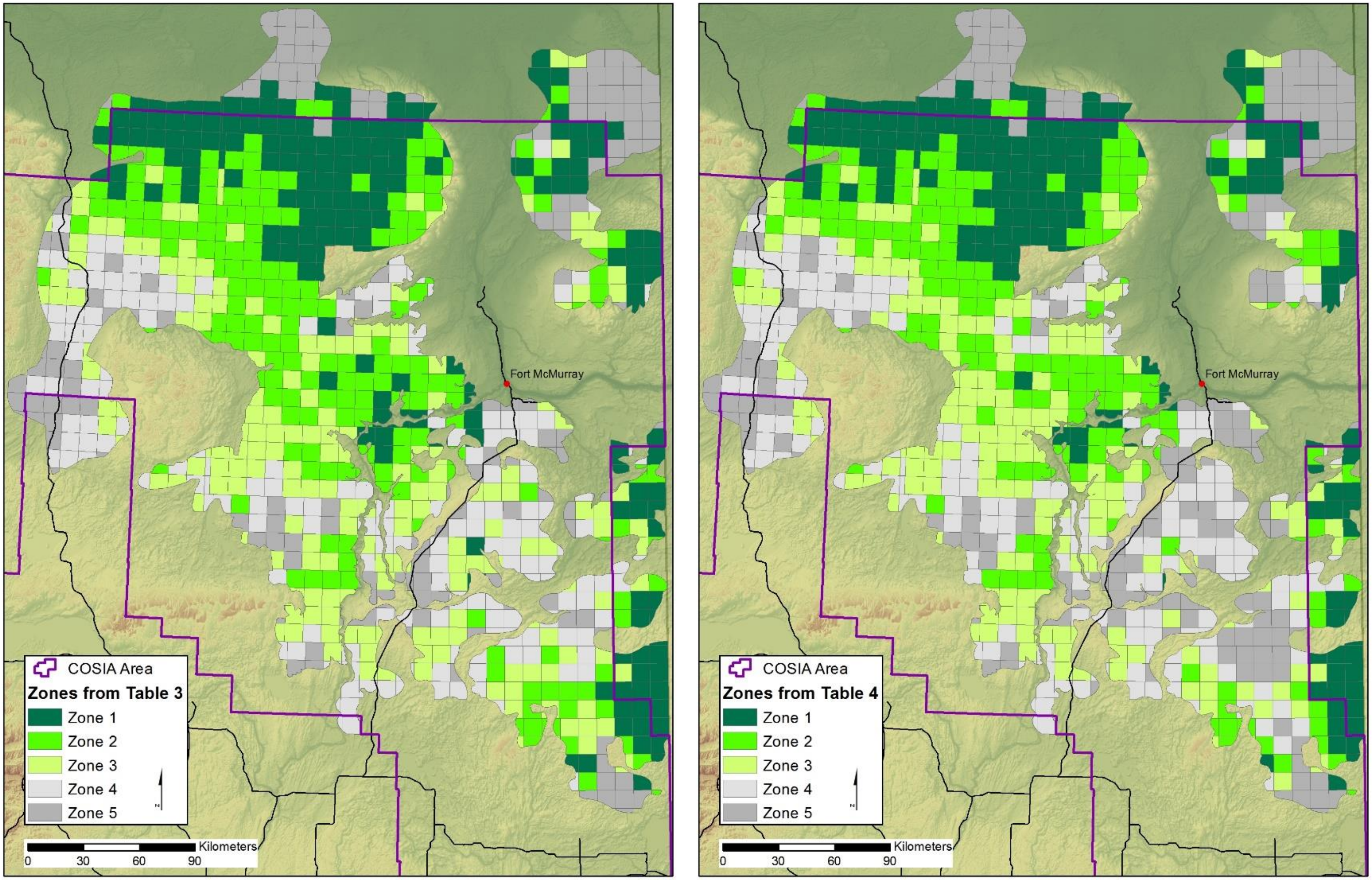
[10] Some seismic lines within restored townships that were not treated are included here. These include: seismic lines, or portions of, that were already on a trajectory for natural revegetation; seismic lines left as research lines, or lines that are used to visit treatment areas, and seismic lines left for use by trappers. These segments are not considered for future restoration in this analysis, recognizing that as more inventories are completed for future restoration projects, more of these types of seismic lines will be identified.

Table 4. Scenario 4: As in Table 3, the current % disturbed habitat by caribou range in the project area, considering all human disturbance but treating burned areas as undisturbed. Seismic lines within active and approved oil sands (OSIP) boundaries are considered not available for restoration, individual treated lines that had already undergone restoration treatments are considered restored (no longer contribute to human footprint) and finally, the ranking of townships is adjusted based on the Resource Valuation Layer. The % remaining disturbed habitat is presented after restoration of all available seismic lines on untenured areas, and then for the cumulative effects of restoring all available conventional seismic lines in the prioritized zones.

		Untenured areas Restored		**Zone 1 Restored**			**Zones 1 and 2 Restored**			**Zones 1 to 3 Restored**			**Zones 1 to 4 Restored**			**Zones 1 to 5 Restored**		
GIU-for-Cost cut point					**>58**			**>35**			**>20**			**>7**			**>0**	
Range	**TOTAL % disturbed (current)**	**% remaining disturbed**	**km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**	**% remaining disturbed**	**km seismic**	**cumulative km seismic**
RED EARTH	67	54	10609	53	4860	4860	37	8276	13136	30	6456	19592	23	13290	32882	21	8777	41659
RICHARDSON	36	33	261	31	411	411	28	499	910	26	474	1384	24	402	1786	22	1058	2844
WSAR	84	83	405	82	461	461	69	4224	4685	52	8530	13215	49	2982	16197	48	886	17083
ESAR	86	81	919	82	547	547	79	885	1432	70	3781	5213	58	7539	12752	55	6677	19429
COLD LAKE	83	70	1381	73	843	843	67	879	1722	60	1221	2943	56	1226	4169	54	1010	5179
Total			13575		7122	7122		14763	21885		20462	42347		25439	67786		18408	86194

Table 5. The estimated cost of each % "Gained-in-Undisturbed" habitat when restoring all available conventional seismic lines in Zones 1 through 5 for each caribou range. Kms of seismic lines restored are based on Scenario 4 (Table 4). Cost estimates assume an average of $10,000 per km restored.

	Zone 1			Zone 2			Zone 3			Zone 4			Zone 5		
Range	km	GIU (%)	$MM per GIU	km	GIU (%)	$MM per GIU	km	GIU (%)	$MM per GIU	km	GIU (%)	$MM per GIU	km	GIU (%)	$MM per GIU
Red Earth	4860	67–53=14	$3.47	8276	53–37=16	$5.17	6456	37–30=7	$9.22	13290	30–23=7	$18.99	8777	23–21=2	$43.89
Richardson	411	36–31=5	$0.82	499	31–28=3	$1.66	474	28–26=2	$2.37	402	26–24=2	$2.01	1058	24–22=2	$5.29
WSAR	461	84–82=2	$2.31	4224	82–69=13	$3.25	8530	69–52=17	$5.02	2982	52–49=3	$9.94	886	49–48=1	$8.86
ESAR	547	86–82=4	$1.37	885	82–79=3	$2.95	3781	79–70=9	$4.20	7539	70–58=12	$6.28	6677	58–55=3	$22.26
Cold Lake	843	83–73=10	$0.84	879	73–67=6	$1.47	1221	67–60=7	$1.74	1226	60–56=4	$3.07	1010	56–54=2	$5.05



6 (a) (b)

Figure 6. Townships ranked by priority Zone according to values and "GIU-for-Cost" cutpoints from (a) Table 3, which is based on treating all footprint within active and approved oil sands boundaries as non-candidate, and considers treated lines as "restored"; (b) Table 4, which includes the values from Table 3, but multiplied by the inverse of the RVL, so as to downgrade the priority of townships with high economic potential.

Table 6. Summary of total resource value ($MM CDN) within each Scenario 4 zone, for caribou ranges inside the COSIA area of interest (CAPP 2016).

Range	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Total
RED EARTH	8,429	22,557	14,738	22,043	18,736	86,503
RICHARDSON	6,280	10,939	17,929	35,227	76,565	146,940
WSAR	5,076	92,999	146,193	76,918	36,117	357,303
ESAR	14,575	30,367	59,881	271,010	251,145	626,978
COLD LAKE	5,752	34,243	48,269	82,365	227,003	397,632
Total	40,112	19,1105	287,010	487,563	609,566	1,615,356

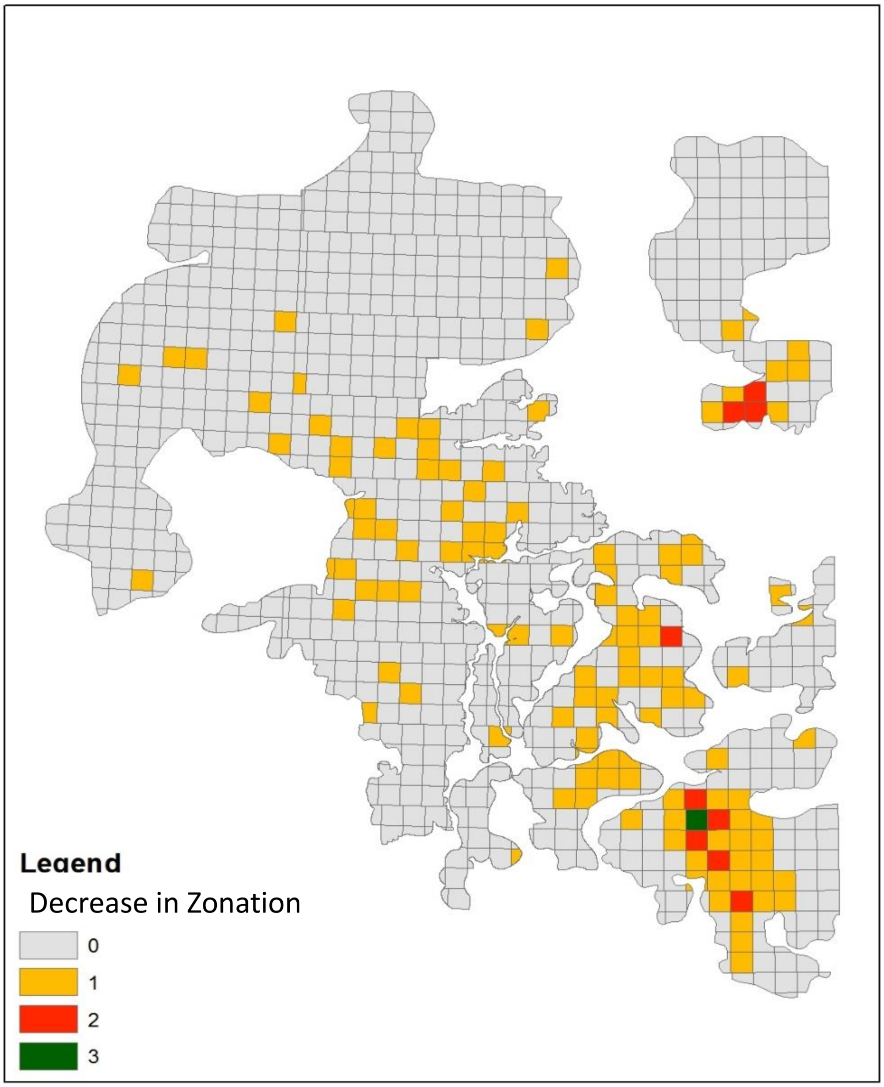


Figure 7. The change in zonation of each township based on the inclusion of the RVL. Townships with high resource value decreased the priority of some townships. Grey indicates no change to zonation, where the RVL did not have a large enough effect to change the zone. For example, a value of 2 means that the township could have decreased from zone 1 to zone 3.

4.0 Discussion

Outlining how to reduce the amount of human disturbance across the ranges of boreal caribou in northeastern Alberta will be a key element of range planning for caribou recovery. A cooperative, well-organized approach will be required because of the extensive areas involved, the cost of habitat restoration efforts, the many human interests in the area, and the substantial value of developed and undeveloped mineral resources in the oil sands. Developing a basic method to prioritize areas for restoration across a large working landscape (i.e., COSIA area of interest) will assist in making restoration efforts as efficient and effective as possible.

We presented a process for developing zones to prioritize restoration efforts across a broad scale. Using townships instead of individual seismic lines as a base unit, we explored the reduction in the % disturbed habitat per kilometre of seismic line restored, assuming all lines in a township are restored. The resulting measure of the effectiveness of restoring a township, termed the "GIU-for-Cost," formed the basis for grouping townships to create zones of similar "GIU-for-Cost." Several recovery documents recognize that prioritizing areas based on a "return on investment" is the most efficient approach to pursue (e.g., Ray 2014).

The final step of the ranking process for each township incorporated the resource value of a township into the equation, to guide restoration away from areas that may be targeted for future oil sands development. This was a valuable exercise in terms of explicitly incorporating mineral resource potential, and represents one means of spatially organizing zones by combining economic and ecological objectives across the landscape. However, the end result was a modest change in prioritization among townships. Out of 894 pixels, 129 were downgraded in priority (17 of which were in Zone 1) as a result of the RVL. This result is not surprising, because areas with the highest current levels of human footprint, which makes them inefficient to restore, roughly coincide with the highest resource value.

We also explored the alternate approach of restoration occurring only outside of tenured areas. The resulting reductions in % disturbed habitat, if all conventional seismic lines outside of tenured areas were restored, were similar to the results of restoring all of Zone 1. With this alternate approach, however, once those lines are restored, no further reductions in % disturbed could be achieved by restoring conventional seismic lines outside of tenured area.

With all conventional seismic lines restored across all five zones, two of five caribou ranges meet the target of 65 % undisturbed habitat (Richardson and ESAR; Tables 1, 3, 4). When disturbance associated with fire is included in this analysis, none of the ranges meet the federal target (Table 2). However, many of the fires represented in GIS basemaps are nearing the 40 year benchmark (Figure D1), some of which may no longer be considered disturbance once they are past that time period. Therefore, the disturbance values in Table 4 are likely reliable in the near-term. Our analysis did not consider the 2016 Ft. McMurray wildfire (Figure D2). Note that most of the caribou range burned by this fire was in the northern portion of ESAR (Egg-Pony herd), which was ranked as a low priority (Zones 4 & 5) for restoration. Also, several townships in the eastern portion of the WSAR range were ranked highly (zones 1 & 2) for restoration, but were burned in the Ft. McMurray fire (Figure D2).

Restoring all seismic lines within Zone 1 provides the greatest return on investment (i.e., greatest "GIU-for-Cost"), with diminishing returns (i.e., more km to restore with less gain in undisturbed area) as Zones 2 to 5 are restored. Restoring zone 5 provides the least return on investment, with the greatest expenses incurred and the least effect on GIU (Table 5). Even though not all ranges will be restored at the level of 65%, over time, human footprint that is considered "relatively permanent" or "non-candidate" features will also be reclaimed as oil sand projects near their end-of-life. This additional reclamation will further contribute to increasing undisturbed lands. In the meantime, techniques to reduce predator efficiencies on seismic lines could be employed to reduce predator and alternate prey travel (i.e., functional restoration such as snow fencing or tree bending). We note in the Future Projects section that it will be important to conduct sensitivity analyses to predict how restoring these additional footprint types would further reduce disturbance levels across caribou ranges.

We also acknowledge that boundaries for active and approved oil sands developments will change, and new projects will add area to what we considered 'unavailable' for restoration. Likewise, additional linear feature restoration projects are already underway. For example, Cenovus's LiDea South project began restoration treatments on seismic lines within four townships in January of 2016, and has not been accounted for under these analyses.

Natural regeneration of human-disturbed habitats may contribute to a reduction of % disturbed habitat in some ranges. The contribution of natural regeneration was not incorporated in this analysis because of the long time span and low success rate of natural regeneration to-date in the boreal forest. Natural regeneration is hampered by wet, low-lying areas which are abundant, and only 5 – 10 % of seismic lines are regenerating naturally (Cranston, unpublished LiDar analysis in the RICC study area). Collecting sufficient data to monitor natural regeneration is costly (e.g., LiDAR, plus site visits for verification) and data can be difficult to interpret. Nevertheless, van Rensen et al. (2015) were successful in predicting trajectories of vegetation recovery on seismic lines using a number of factors. These included LiDAR Wet Areas Mapping (WAM), depth to water, distance to road, width of seismic line, surrounding forest stand characteristics and age of disturbance. Nielsen et al. (2015) are also working to parse out areas that should be slated for active (versus passive or non-interfering) restoration in the Lower Athabasca Region. Once techniques are established, further work on the identification of areas capable of timely natural regeneration, areas requiring active restoration, and prioritization and prescription of restoration techniques at the feature scale should be completed. In contrast, the objective of this project is a courser scale of resolution; strategic planning at the landscape scale.

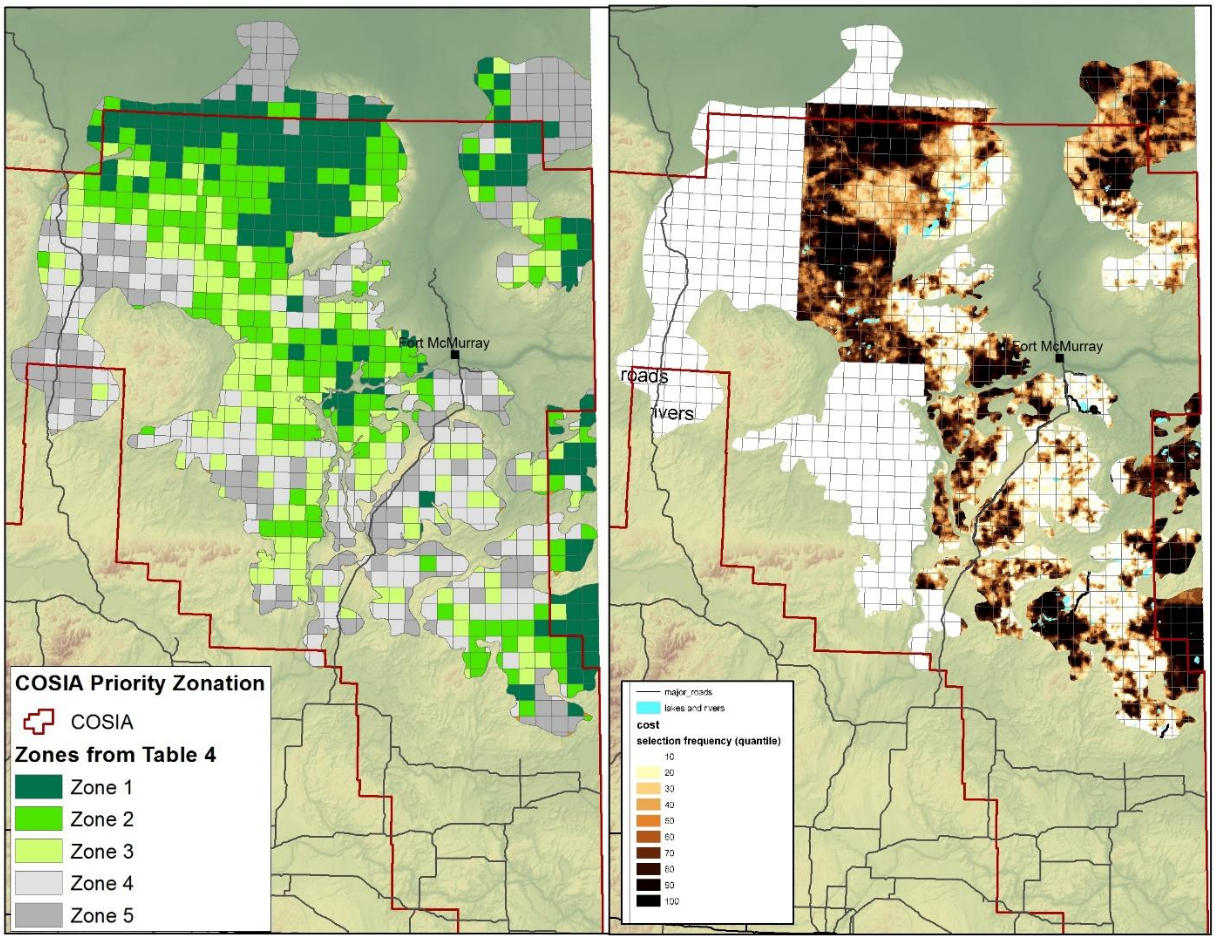
Comparisons with other restoration initiatives

Comparing our approach with parallel initiatives will help avoid redundancy, but also reveals areas for improvement and collaboration. Here we provide a visual, qualitative comparison with the initiative led by Cassidy van Rensen (Alberta Environment and Parks) Scott Nielsen (University of Alberta) and Tim Vinge (Government of Alberta). Their output represents one scenario using the optimization software

MARXAN (Ball et al. 2009) (Figure 8). MARXAN seeks to achieve representation of biodiversity features across the study area, while, where possible, minimizing conflict with human disturbance. The maps show the selection frequency of planning units in 200 MARXAN runs, indicating that areas with a high selection frequency are key to supporting biodiversity. The scenario shows priority conservation areas where development constraints (bitumen pay thickness, footprint, forest harvest) and biodiversity are considered. These results are preliminary and refined scenarios will be completed to support planning for the Landscape Management Plan under the Lower Athabasca Regional Plan.

Figure 8 presents the results from our Table 4 analysis (Figure 8a) and that of the van Rensen approach (Figure 8b). The MARXAN mapping was not conducted across the entire extent of the COSIA area of interest (i.e., white areas in Figure 8b contain no data). The results between the two approaches are quite similar, with the exception of the northeast portion of the Richardson range, where there is very little human footprint, hence our approach identifies very little "GIU-for-Cost" in that area. Overall however, the similar output provided by the two different approaches is not surprising, given that some of the key inputs (e.g., line density) would have been the same for both projects.

In another similar initiative led by the RICC, LiDAR was used to estimate how well vegetation is recovering on conventional seismic lines within the Cold Lake and parts of the ESAR caribou ranges (ABMI 2015). This work was focused on the scale of individual lines and was used as a criterion to prioritize areas for restoration. LiDAR was used to directly measure vegetative regeneration, based on an index termed 'roughness.' Roughness is an estimate of the vegetation canopy height compared to the ground surface along a "least cost path," or path that has the lowest vegetation canopy height along a seismic line. Because high intensity LiDAR only existed on a small portion of the COSIA area of interest, this technique was not used in our analysis. However, the utility of LiDAR for prioritization is unclear, because field assessments are always needed, even after a particular township is identified as a high priority for restoration. Furthermore, the RICC LiDAR analysis revealed that only a relatively small portion of individual lines were regenerating on their own, suggesting that the township scale presented here is still the most appropriate context for regional and strategic planning.



9 (a) (b)

Figure 8. Comparison of final COSIA restoration priority zones and preliminary priority biodiversity areas as developed for the Landscape Management Plan (LMP) under the Lower Athabasca Regional Plan. LMP scenario illustrates priority areas where development constraints (e.g., bitumen pay thickness, human footprint, and forest harvest) are considered in addition to biodiversity.

Future projects

We recommend three complementary analyses to the one presented here. The first project was mentioned above – simulations to identify which additional non-candidate human disturbance features would have to be restored to achieve the federal target in each caribou range within the COSIA area of interest. This would involve conducting sensitivity analyses by simulating the restoration of other non-candidate human footprint features (e.g., forestry cut blocks, well pads, certain pipelines) to predict how such actions would reduce disturbance levels. Although forestry cutting units are clearly not permanent, they are not very abundant (911 km^2 in the area of interest) and are concentrated in a few caribou ranges (Figure D 3). Therefore, restoring these features would be unlikely to reduce disturbance in areas such as the Cold Lake range, where the primary human footprint is from oil and gas activity.

The second project would be to compare human footprint levels between the ABMI database and those used in the federal Recovery Strategy. The ABMI human footprint layers used in this analysis indicate higher levels of human disturbance than the coarser Environment Canada disturbance data used for crafting the Recovery Strategy and habitat targets (Environment Canada 2012; see Table C1). This discrepancy leads to relatively high values for % disturbed habitat in Tables 1-4, and apparent difficulties in reaching target levels. We recommend calibrating ABMI and Environment Canada disturbance levels so that the same measure of disturbance is used across the two GIS basemaps (ABMI vs. Environment Canada).

A third project is the development of approaches to operational and tactical planning at the sub-township or feature scale. Planning systems for a finer spatial scale are desirable in order to account for matters such as 1) unpredictable natural regeneration success in the boreal, 2) spatial relationships between different habitat types such as upland mixed woods, creeks and drainages, and bog and fen complexes, 3) appropriate silvicultural prescriptions at the feature scale, and 4) prioritization at the feature scale based on knowledge of predator and prey responses to treatment and regeneration status.

Many recovery processes recognize that no single management approach will result in caribou recovery (Boutin and Merrill 2016; Serrouya 2013). In fact, concurrent population manipulation measures such as predator control or predator exclusion fencing will also be required to recover caribou (Seip 1992; Wittmer et al. 2005; Hervieux et al. 2014; Boutin & Serrouya 2014). Nonetheless, it is recognized that caribou recovery cannot be sustained on a social, economic, or biophysical basis without habitat restoration. Furthermore, the intended outcome of habitat restoration will be to reduce the duration and intensity of these other recovery tools.

Summary

Five objectives were identified at the outset of the project, and each of these objectives was realized in the following ways:

1) Linear features were updated, mapped, and consolidated in a GIS;
2) Meetings and comparisons were conducted with products from other research teams pursuing similar objectives, particularly the work done by van Rensen et al. that was highlighted in the Discussion;
3) Criteria to rank restoration, and minimum patch size for analysis, were identified and formed the basis of the prioritization;
4) A weighting method was implemented for key criteria, particularly the inverse weighting applied to the RVL to help guide restoration away from areas with higher economic potential; and
5) As part of this report and accompanying digital maps, ranked restoration zones were provided to COSIA companies, along with suggestion for future projects.

5.0 Acknowledgements

We thank Michael Cody (Cenovus Energy) and Lori Neufeld (Imperial) for continuous improvements to this process throughout the project, and Jack O'Neil (COSIA) for additional support and feedback. Lisa Bridges (Statoil), Michael Cody, Scott Grindal (ConocoPhillips), Jon Gareau (CNRL), Lori Neufeld, and Amit Saxena (Devon Canada) submitted comments on a draft report. In addition to the abovementioned individuals, Robert Albricht (ConocoPhillips), Mark Boulton (Suncor), Jenna Dunlop (COSIA), Patrick McDonald (CAPP), Jeremy Reid (Devon Canada), and Shawn Williams (Nexen) of the COSIA Land EPA working group provided feedback on an early draft of priority zones.

We thank Cassidy van Rensen, Brandan Hemens and Tim Vinge (Government of Alberta) for discussing their process for biodiversity planning in the L and for sharing a draft map of their prioritized areas, Greg Cave and Astra Arts (CAPP) for delivering resource values by townships for our area of interest, Craig DeMars for providing editorial assistance, and Jahan Kariyeva and the ABMI Geospatial Centre for support throughout the project.

6.0 Literature cited

Alberta Biodiversity Monitoring Institute. 2014. The Status of Biodiversity in the Oil Sands Region of Alberta: Preliminary Assessment. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at www.abmi.ca.

Alberta Biodiversity Monitoring Institute (ABMI). 2015. First Annual Report for the Regional Industry Caribou Collaboration. ABMI Caribou Monitoring Unit report 15-002.

Ball, I.R., H.P. Possingham, and M. Watts. 2009. Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.

Boutin, S., and E. Merrill. 2016. A Review of population-based management of Southern Mountain caribou in BC. Submitted to: Columbia Mountain Institute of Applied Ecology. March, 2016. 17pp.

Boutin, S., and R. Serrouya. 2014. A Cost-Benefit Analysis of Woodland Caribou Recovery Options in Alberta. Prepared for Canada's Oil Sands Innovation Alliance. 20pp.

Canadian Association of Petroleum Producers. (2016). Northeast Alberta Resource Valuation; CAPP Assessment of Energy Resources in Northeastern Alberta Caribou Ranges. Northeast Alberta Valuation Task Group. Modelling and Mapping completed by Cenovus Energy Inc. Calgary, Alberta.

COSIA (Canadian Oil Sands Innovation Alliance). 2016. Land: Caribou Habitat Restoration. Website: http://www.cosia.ca/caribou-habitat-restoration. Accessed: March 2016.

Dickie, M., Serrouya, R., McNay, R., and S. Boutin. 2016. Faster and farther: wolf movement on linear features and implications for hunting behavior. Journal of Applied Ecology doi:10.1111/1365-2664.12732

Environment Canada. 2012. Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. xi + 138pp.

Festa-Bianchet, M., J.C. Ray, S. Boutin, S.D. Côté, and A. Gunn, A. 2011. Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Canadian Journal of Zoology 89:419-434.

Hervieux, D., M. Hebblewhite, D. Stepnisky, M. Bacon, and S. Boutin. 2014. Managing wolves (Canis lupus) to recover threatened woodland caribou (Rangifer tarandus caribou) in Alberta. Canadian Journal of Zoology 92:1029-1037.

James, A. R. C. 1999. Effects of industrial development on the predator-prey relationship between wolves and caribou in northeastern Alberta. University of Alberta, Edmonton.

McKenzie, H. W., E.H. Merrill, R.J. Spiteri, and M.A. Lewis. 2012. How linear features alter predator movement and the functional response. *Interface focus*, *2*(2), 205-216.

McNay, R.S., G.D. Sutherland, G. Sherman, B. Nielsen, and L. Giguere. 2014. Multi-scale responses by predators and prey to deactivation/restoration of habitat disturbance features within the Cold Lake caribou herd area: Project plan. Report No. 448v8. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada and Woodlands North Inc., Whitecourt, Alberta.

Nielsen, S., C. van Rensen, and T. Vinge. Line feature prioritization (DART & LMP models). Presented at RICC Technical Advisory Committee Meeting. June, 2015.

Pyper, M., J. Nishi, and L. McNeil. 2014. Linear feature restoration in caribou habitat: a summary of current practices and a roadmap for future programs. Prepared for COSIA, Calgary, AB. 99pp.

Ray, J. (2014). Defining habitat restoration for boreal caribou in the context of National recovery: a discussion paper, (December), 54. Retrieved from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/Boreal caribou habitat restoration discussion paper_dec2014.pdf

Seip, D. R. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology 70:1494-1503.

Serrouya, R. 2013. An adaptive approach to endangered species recovery based on a management experiment: reducing moose to reduce apparent competition with woodland caribou. PhD thesis. University of Alberta, Edmonton.

Serrouya, R., B. N. McLellan, S. Boutin, D. R. Seip, and S. E. Nielsen. 2011. Developing a population target for an overabundant ungulate for ecosystem restoration. Journal of Applied Ecology 48:935-942.

Sutherland, G., R.S. McNay, L. Giguere, J. Gollner, K. Sittler, F. MacDonald, and V. Brumovsky. 2015. The LiDea Forest and Habitat Restoration Project - Monitoring Multi-scaled Responses by Predators and Prey to Deactivation & Restoration of Disturbance Features – Individual and population components. Interim Report 2014-2015. Wildlife Infometrics Report 511, Wildlife Infometrics Inc., Mackenzie, British Columbia.

van Rensen, C.K., S.E. Nielsen, B. White, T. Vinge, and V.J. Lieffers. 2015. Natural regeneration of forest vegetation on legacy seismic lines in Alberta’s oil sands region. Biological Conservation 184: 127–135.

Wittmer, H. U., A. R. E. Sinclair, and B. N. McLellan. 2005. The role of predation in the decline and extirpation of woodland caribou. Oecologia 144:257-267.

7.0 Appendices

Appendix A List of Acronyms

Abbreviation/Acronym	Description
ABMI	Alberta Biodiversity Monitoring Institute
Al-Pac	Alberta Pacific Forest Industries
CAPP	Canadian Association of Petroleum Producers
CBFA	Canadian Boreal Forest Agreement
COSIA	Canada's Oil Sands Innovation Alliance
DART	Disturbance and Recovery Trajectory
ESAR	East Side Athabasca River caribou range
FMA	Forestry Management Area
GIS	Geographic Information System
GIU	Gained-in-Undisturbed (habitat)
JIP	Joint Industry Project
LAR	Lower Athabasca Region
LiDea	Linear Deactivation (project, Cenovus Energy)
LiDAR	Light Detection and Ranging
LMP	Landscape Management Plan
OSIP	Oil Sands Information Portal
RICC	Regional Industry Caribou Collaboration
SARA	Species at Risk Act
WAM	Wet Areas Mapping
WSAR	West Side Athabasca River caribou range
WTI	West Texas Intermediate

Appendix B Glossary of Terms

Action plan: A document that demonstrates to the public and stakeholders how a boreal caribou recovery strategy will be implemented; not necessarily range-specific.

Adaptive management: An evidence-based approach to managing complex systems in which a management objective is addressed through a complimentary combination of research and management experimentation.

Buffer: The zone of influence, or distance which a species is expected to be influenced by human disturbance. All human disturbance within caribou habitat is buffered by 500-m buffer.

Candidate disturbances: Conventional seismic lines, i.e. the only disturbance type that is considered available for restoration under the scope of this project.

Conventional seismic: A conventional method of seismic exploration where line-of-site is used to navigate the seismic line. This requires a wider corridor to be created, and creates a larger linear feature than low-impact seismic does. Generally > 5m wide.

COSIA area of interest: The entire area encompassing the Athabasca, Peace River and Cold Lake Oil Sands areas.

Disturbed habitat: As per the Federal Recovery Strategy (2012), habitat with anthropogenic disturbance visible on Landsat (at a scale of 1:50,000) including habitat within a 500-m buffer of the anthropogenic disturbance and/or fire disturbance in the last 40 years, as identified in data from each provincial and territorial jurisdiction (without buffer). The analyses in this document used ABMI Human Footprint mapping (2012) to identify disturbances.

GIU-for-Cost: The potential gain in undisturbed habitat divided by the density of conventional seismic line, by township. This translates into a measure of effectiveness of restoration relative to the effort (and cost) needed to achieve that effectiveness. A township with high "GIU-for-Cost" achieves more reduction in disturbance relative to the cost of restoring all conventional seismic lines within it.

Human footprint: The geographic extent of areas under human use that either have lost their natural cover for extended periods of time (e.g., cities, roads, agricultural land, and surface mines) or whose natural cover is periodically reset to earlier successional conditions by industrial activities (e.g., cut blocks and seismic lines).

Linear features: Human footprint features such as seismic lines, pipelines, powerlines, railways and roads.

Low-impact seismic: Seismic line methods that use GPS technology to navigate, requiring a much smaller corridor to be disturbed, and can also navigate around large trees easily and use smaller equipment. Can be as narrow as 2 m wide.

Non-candidate disturbance: Human footprint features that are not considered available for restoration under the scope of this project. These include roads (winter and all-weather), well pads, forestry cut blocks, pipelines, facilities etc.

Permanent Disturbance: Disturbance features that are considered to be longer lasting in time than seismic lines, and are not considered for restoration treatments under this project scope (e.g., roads (winter and all-weather), well pads, forestry cut blocks, pipelines, facilities etc.

Pixel: The unit of analysis, equivalent to a township.

Potential gain: The percent of undisturbed habitat theoretically gained by restoring all conventional seismic lines (within a township).

Project Area: The full extent of caribou ranges (plus a 500-m buffer) that are >75 % contained within the COSIA area of interest. This includes the contiguous Red Earth, Richardson, WSAR, ESAR and Cold Lake caribou ranges.

Range: The area occupied by a group of woodland caribou, as determined by geographic positioning system telemetry.

Range plan: A document that outlines how land and resource activities within a specific caribou range will be managed to ensure protection of boreal caribou critical habitat.

Recovery Strategy: A planning document prepared under SARA that outlines the goals, objectives, and overall recovery strategy for an endangered, threatened, or extirpated species.

Resource Valuation Layer: An assessment of potential recoverable reserves of oil sands and conventional oil and gas within caribou range. Resource value is presented the current dollar value in millions of Canadians Dollars ($ MM CDN as a $60 USD Western Texas Index (WTI), by township.

Restoration: Land management activities that either: a) Returns anthropogenic linear features to functional caribou habitat or puts them on a trajectory towards returning to functional caribou habitat (termed ‘ecological restoration’), and includes techniques such as mounding, tree planting, and course woody debris treatments; or b) deactivates a linear feature so as to deter use by humans and wildlife (termed ‘functional restoration’), and includes techniques such as line-blocking and fencing.

Self-sustaining population: A population of boreal woodland caribou that over a short timescale (≤20 years), demonstrates stable or increasing numbers, and is large enough to persist over the long-term (≥50 years) without active management.

Tenured areas: Areas with resource development agreements, leases or tenure. This includes mineral, petroleum, natural gas, or forestry surface agreements. Note that although surface agreements are in-place for major proportions of the COSIA area of interest, this does not imply surface disturbance.

Threatened: A species that is likely to become endangered if nothing is done to mitigate factors leading to its decline (e.g., habitat loss and increased predation).

Undisturbed habitat: As per the Federal Recovery Strategy (2012), habitat without anthropogenic disturbance visible on Landsat (at a scale of 1:50,000) including habitat within a 500-m buffer of the anthropogenic disturbance, and/or fire disturbance in the last 40 years (without buffer). The analyses in this document used ABMI Human Footprint mapping (2012) to identify disturbances.

Untenured areas: Areas without resource development agreements, leases or tenure (i.e., mineral, petroleum, natural gas, or forestry surface agreements), and are considered to not have immediate potential to be developed for resource extraction.

Zone: The rank of a township with respect to restoration priority. A zone is a group of townships that hold the same restoration priority based on analyses. Zone 1 is highest restoration priority; Zone 5 is lowest restoration priority.

Appendix C Supplementary Tables

Table C1. Anthropogenic and fire disturbance by caribou range as reported by the Recovery Strategy (2012) and this project (Table 2).

		Recover Strategy disturbance values				ABMI disturbance values	
Range	Area (km^2)	Fire	Human	Total	*Undisturbed*	Total	*Undisturbed*
Red Earth	24,700	30	44	62	38	80	20
Richardson	7,100	67	22	82	18	91	9
WSAR	15,700	4	68	69	31	83	17
ESAR	13,200	26	77	81	19	89	11
Cold Lake	6,700	32	72	85	15	92	8

Appendix D Supplementary maps

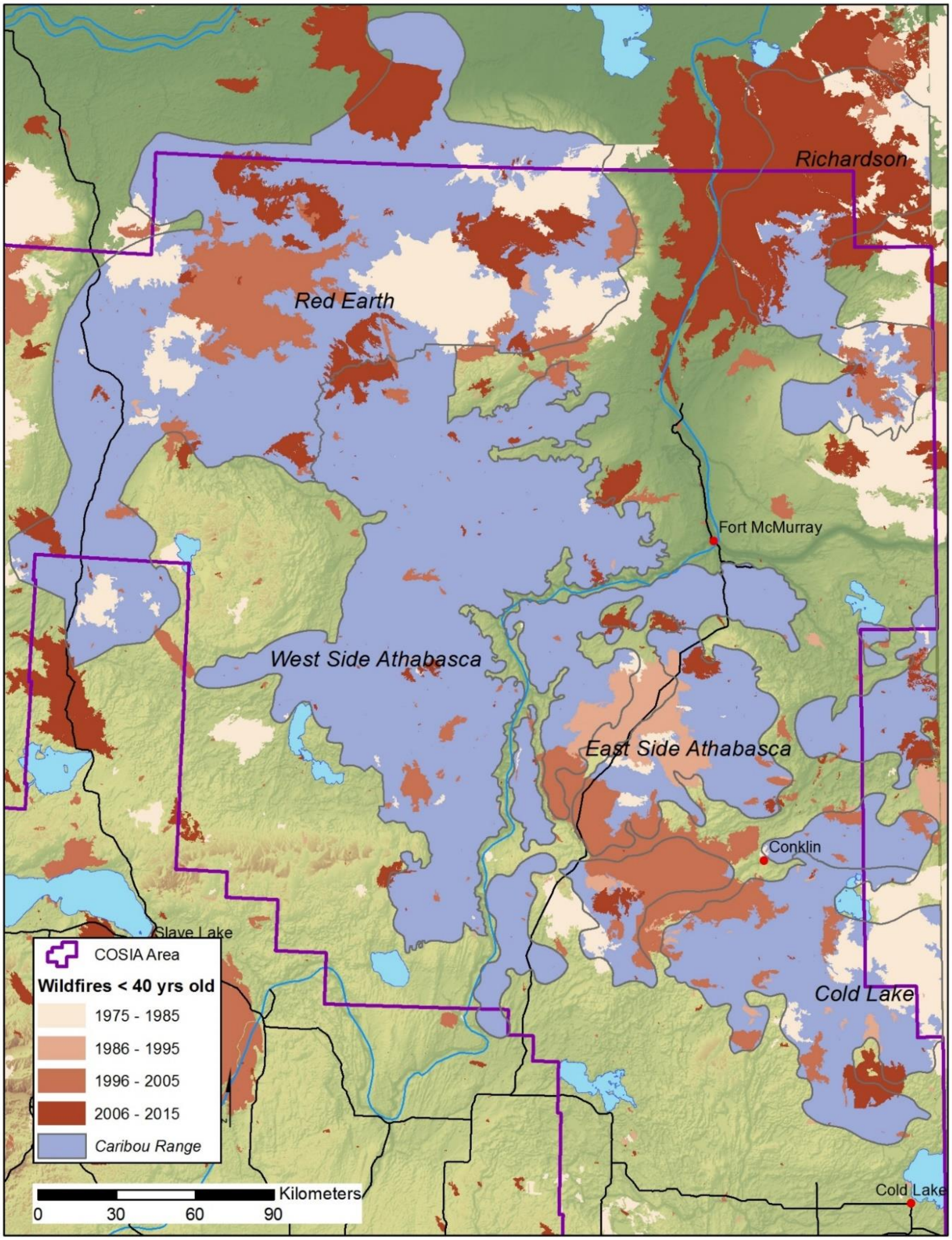


Figure D 1. Fires in the COSIA area of interest, stratified by year burnt.

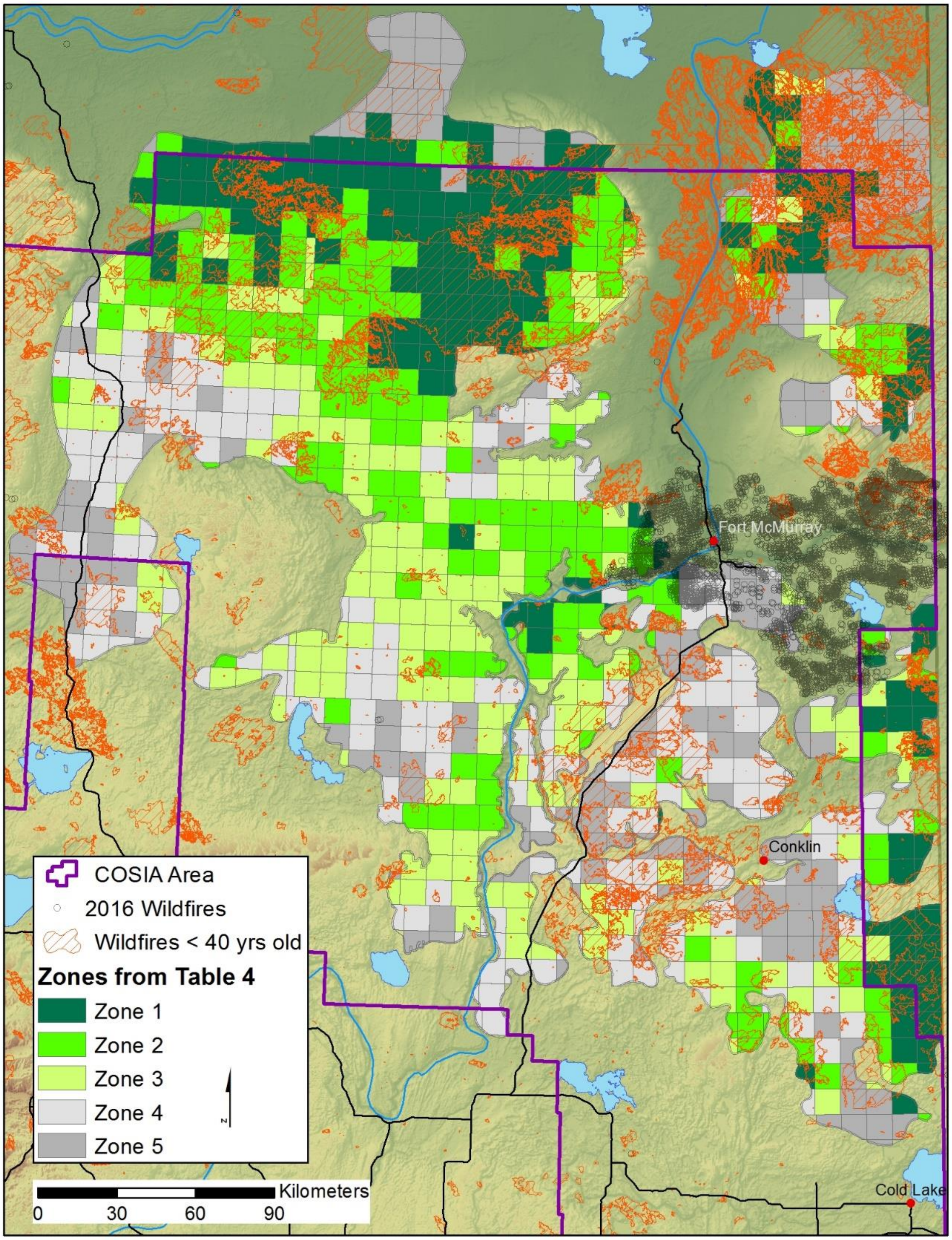


Figure D 2. Fire disturbance in the COSIA area of interest. Orange cross-hatched indicate fires that are between 6 months and 40 years old, and black circles indicate areas that have been burned in 2016. Most notable is the large 2016 fire in the Fort McMurray area.

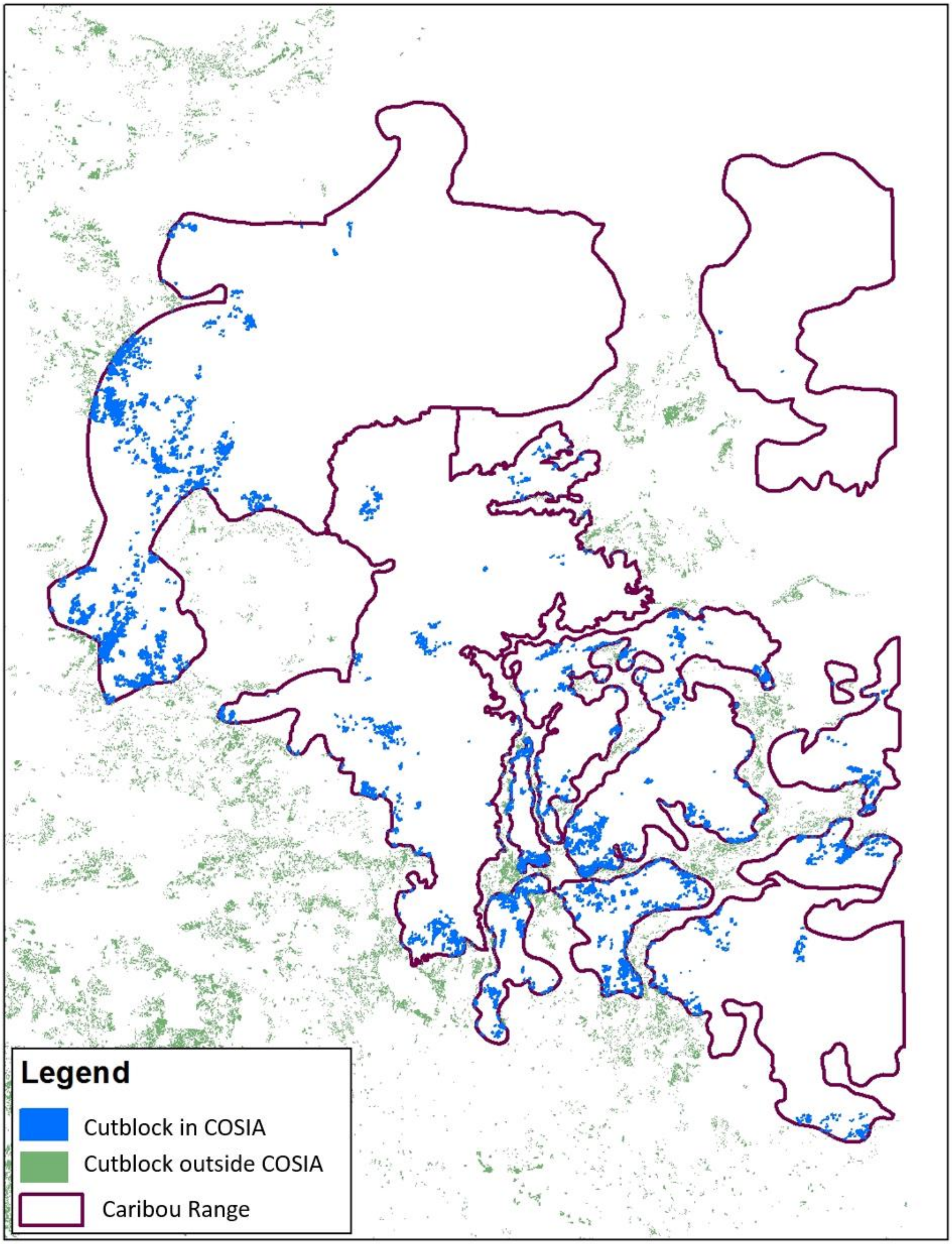


Figure D 3. Forestry cutblocks within the COSIA area of interest, indicated by blue polygons.