EcoSeis Phase 2

This project was jointly funded by OptiSeis, Alberta Innovates, CRIN, NRC-IRAP, PTAC, Canadian Natural Resources Ltd., Cenovus Energy, ConocoPhillips, Imperial Oil Resources Ltd., and Suncor Energy with datasets donated by several of the companies.

1.0 Executive Summary

OptiSeis Solutions Ltd., a subsurface visualization and analytics company, is the Canadian developer of the EcoSeis™ an OptiSeis trademarked product technology. EcoSeis is the Company's proprietary exploration footprint reduction design and analytics technology that allows operators to focus on their subsurface targets while reducing the environmental footprint including GHG and surface impacts. EcoSeis enables companies to accomplish their goal of providing environmentally sustainable and reliable energy for generations to come.

The focus of this project was to advance the EcoSeis methodology and software implementation. EcoSeis is an innovative land footprint reduction technology that allows any company with subsurface operations, including oil and gas operators, to sustainably acquire high resolution seismic images of their resources. The technology is a first of its kind collaboration that successfully brings environmental conservation and GHG accounting practices into the design and execution of data collection in the field. EcoSeis utilizes proprietary algorithms to rank biological, ecological, and geographical surface information to automatically guide the creation of custom survey designs.

The EcoSeis methodology results in up to a 50% reduction in land footprint and GHG/methane emissions. This is accomplished by utilizing irregular and alternative geometries that minimize the amount of line clearing all while maintaining subsurface data quality and reducing costs. Additionally, EcoSeis has the potential to reduce seismic data acquisition costs by 10-25%. This methodology was initially developed during the successful EcoSeis Phase 1 project. The EcoSeis Phase 2 project provided an opportunity to test the technology in conjunction with a conventional seismic program in order to fully quantify the benefits of EcoSeis and complete the technology validation process. The overall purpose of the project was to demonstrate that EcoSeis provides equal to or superior subsurface information while enabling the environmental footprint including surface disturbance in comparison to standard practice while meeting industry standards for safety thereby advancing towards commercial acceptance of the process. This report focuses on the PTAC-AUPRF funded environmental and emissions tracking studies.

The first of these studies was a seismic line re-growth study comparing the re-growth on seismic cut-lines vs. natural recovery after a forest fire vs. undisturbed forest. Results from this study were incorporated into the EcoSeis methodology to guide how future EcoSeis programs are implemented in different habitat types with a focus on reducing the impact of seismic cut lines in sensitive habitats and/or areas with slower natural regrowth, thus reducing the amount and cost of reclamation needed for seismic cut lines.

A second study was planned to evaluate how line preparation and geophysical data collection may influence vegetation and recovery in order to clearly identify best practices for operations along new and re-opened seismic lines. Unfortunately, due to lack of snow cover, an accurate test could not be completed during the timeframe of the PTAC-AUPRF funding, and this test has been delayed to 2025.

The third study included in the PTAC-AUPRF funded portion of the project included evaluating the land footprint reduction achieved with the EcoSeis project. This was accomplished by evaluating the total disturbance associated with both the conventional and EcoSeis seismic programs acquired during the project and comparing results.

2.0 Project Outcomes

The original project success metrics included a 35% or greater reduction in seismic linear disturbances and 20% or greater reduction in areal disturbances, and a 15% or greater reduction in GHG emissions associated with seismic acquisition. However, the project significantly exceeded this by demonstrating that land footprint and GHG emissions reductions of up to 50% are possible utilizing the EcoSeis technology.

The specific environmental performance metrics for the program are listed in the table below. These were set at the beginning of the program, and due to the success of the EcoSeis method, all project targets were exceeded with a 42% reduction in linear km and 37% reduction in total disturbance area achieved during the technical field trial. The GHG emissions were also estimated to be reduced by 36% relative to the conventional seismic program based on total emissions (direct from fuel and biomass decomposition), which is more than double the project target. However, even better results are expected on future projects since the results of this test were in part limited due to the existing geometry and large existing footprint in the area. Additional modeling suggests in a new-cut scenario the savings would be at least 46% for linear km, 42% for disturbance area, and 41% for GHG emissions utilizing similar equipment and in a similar operating environment.

Estimates were necessary since the conventional program was a permanent installation and the field operations between the conventional and the EcoSeis programs could not be fully separated. Normalizations were done to determine direct emissions reductions under similar operating conditions. Furthermore, the geometry analyses indicate that land disturbance area reductions and GHG emissions reductions of over 50%, are possible, depending on the program area (forested, open, marsh, etc.) and equipment type (conventional vs. miniaturized, explosive/Vibroseis/alternative source, etc.).

Success Metric	Commercialization Target	Project Target	Achievements to Date
Reduction in Linear km with maintenance of data quality	> 40%	> 35%	Results indicate 42% linear km reduction, with potential to optimize nearer 50%
Reduction in Disturbance Area (ha)	>35%	>20%	37% achieved in the field trial, with modeled potential of over 50% reduction with miniaturized sources.
Reduction in Emissions	>35%	>15%	36% reduction in the field trial, with potential to achieve or even exceed 50% with miniaturized sources
Reduction in Cost	5-10%	0%	Overlapped operations and existing lines in field trial did not allow clear separation of costs between conventional and EcoSeis operations, but estimates based on field rates suggest savings of at least 5%, based only on reduced cut kilometers

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3.0 Background

The initial driver for the technology included proposed changes to seismic regulations for new seismic cutlines in Alberta, including reducing line of sight to less than 100m and decreasing receiver line width to 0.75m after 2024 (draft Cold Lake Sub-Regional Plan). Additionally, there is a push to reclaim existing seismic lines with industry actively testing various reclamation methods. These efforts are costly, so industry is also pursuing methods to minimize the footprint of seismic data acquisition activities, which, as a result, would reduce the reclamation effort that may be required in future for new seismic programs.

Seismic data acquisition activity can also result in soil compaction and a higher water table, leading to elevated methane emissions (Strack et al. 2019, Feng et al. 2020). GHG emissions are also associated with seismic acquisition such as instantaneous fossil fuel emissions that occur during field operations (a single seismic program may use more than 100 litres of diesel per linear km of seismic line). The oil and gas industry has expressed interest in any seismic technology that can reduce both the environmental impact and the cost of acquiring good quality seismic data (COSIA Challenge, 2017). This is of particular importance in areas that would be impacted by the potential changes to seismic regulations as new technologies that meet the requirements would enable access to assets in sensitive areas that would otherwise be stranded. Many cleantech challenges have been initiated by industry to solve these problems, including the 2017 COSIA Land Challenge, the 2020 Imperial Challenge – CleanTech Alliance, and the 2021 COSIA-Foresight-Alberta Innovates Reducing Seismic Exploration Footprint challenge, in which EcoSeis won second place.

The proposed regulatory changes and the need to reduce seismic acquisition land footprint requires a new approach to acquiring seismic data, which has created opportunities for development of new seismic acquisition technologies. Some of the solutions that have been proposed to address these problems include minimizing cutting by flying equipment in with a helicopter, utilizing alternative sampling theorems to reduce the amount of equipment needed, and miniaturizing seismic equipment (energy sources and/or receivers). Individually, these solutions can provide benefits such as reduced line widths and less overall cutting of the boreal forest, but habitat fragmentation due to interconnected seismic lines remains a problem and the total reduction in cutting is often less than 25%.

4.0 Methodology

– including quality control and peer review process

The primary objective of the project was to complete a real-world, technical field trial of the technology. This involved acquisition of the two seismic datasets along with seismic processing, interpretation, inversion, environmental, and statistical analyses.

The project was divided into two milestones with the first focused on preliminary studies and field operations, and the second focused on data processing and analytics. Within each milestone, work was divided into four categories: Geophysics, Environment/Field Operations, Data Analytics, and Software. The following narrative describes the environmental work completed for each milestone along with the results.

Milestone 1: February 2022 – March 2023

Two environmental studies were planned as part of the project: a seismic line re-growth study and a seismic line cutting test. The office components of this work were completed at OptiSeis and subcontractor offices in Calgary, AB and the field work was completed at host company sites in northern Alberta.

<u>Re-growth Study</u>

A seismic line re-growth study was conducted to compare the re-growth on low-impact seismic cut lines (LIS) vs. natural recovery after a forest fire vs. undisturbed forest. Results from this were incorporated into EcoSeis program implementation with a focus on reducing the impact of seismic cut lines in sensitive habitats and/or areas with slower natural regrowth, thus reducing the amount and cost of reclamation needed for seismic cut lines. All the preparation for and collection of the field data for regrowth study was completed between May 2022 and September 2023. Previously, between 2010 and 2012, a series of low impact seismic (LIS) lines in the area were assessed to document natural vegetation recovery of LIS that were cut 8-10 years prior. During the 2022 growing season these same sites were re- sampled to quantify 18 to 20 years post cutting natural recovery. In addition, an area that was burned during the 2002 House River Fire, adjacent to the study area, was also assessed to quantify natural recover post cutting and post wildfire.

In the original study, percentage cover of shrubs (ericaceous shrubs and tree species), graminoids, lichen and mosses, as well as visual obstruction from vegetation measured along transects were assessed.

Findings on visual obstruction from the first study were published in Kansas et al. 2015 (Canadian Wildlife Biology and Management [4]:2:137-149). The current study expanded on this and included stem counts and heights of tree species in subplots along the transect. Field sampling for LIS and fire was grouped by Ecosite. A total of 170 plots were completed. Ninety plots (10 per Ecosite) were completed as re-sampling of the original lines cut only once, and 80 plots (10 per ecosite) were completed in areas affected by the House River Fire. Results from the study were analyzed in Milestone 2.

<u>Line Cutting Test</u>

During Q4 2022 detailed planning for the line cutting test was conducted. However, as a result of the changes in the host company’s operational priorities and timelines, the testing for the line cutting test had to be moved to another location. This required additional field approvals which, unfortunately, could not be obtained in time to complete the test prior to the end of the winter season. Therefore, the test was moved to the following seismic season (Q4 2023/Q1 2024).

EcoSeis 3D
Field operations for both the EcoSeis and conventional seismic programs began on October 24, 2022, and were safely and successfully completed on time and on budget on December 15, 2022. The conventional seismic program did not require line clearing as both the sources and receivers had cased shot holes. Sources were reloaded and receivers, which were only single component geophones, were connected for recording. The EcoSeis program, however, was cut at a narrower 1.75m wide line width and had explosive sources (both conventional and miniature) drilled in. Recording was conducted with surface three-component geophones. During the seismic acquisition field operations, all operational activities for both the conventional and EcoSeis geometries were tracked. This included location tracking of all equipment and personnel as well as tracking of fuel usage by operation type. This data was analyzed in Milestone 2 to determine the potential emissions reductions with the use of the EcoSeis methodology.

Milestone 2: April 2023 – April 2024
The objective of this milestone was to complete the statistical analyses of all data tracked during the field operations, and finish updating the software. Work completed included:

Re-growth Study
Results from the regrowth study were analyzed to determine the impact of seismic cutlines on various types of habitats. A report was prepared for the sponsoring companies and funding organizations and is provided in Appendix A. Plans are underway to have this study published in a peer-reviewed journal. This work was completed at OptiSeis and subcontractor offices in Calgary, Alberta.

Line Cutting Test
A location for the revised line cutting test in northern Alberta on a host-company 3D seismic program was selected and assessed based on imagery and ecosite mapping. The line cutting test was scheduled to mobilize to the field in February 2024, and all preparations were ready between OptiSeis, the subcontractor, and the host operator for that to happen. However, due to an unseasonably warm winter, no snow was on the ground at the beginning of February. As a result, a decision was made to delay the testing to next year since the line would either have been cut too low to provide useful data (some snow is necessary to increase the height of stems), or if cut high enough to generate larger stems for regrowth comparison, would have represented a safety risk for line travel after mulching. It was felt that proceeding under non-optimal conditions would potentially bias the test against the alternative cutting methods being evaluated and that it would be best to delay until the following season in order to conduct the test under standard operating conditions. Nonetheless, the detailed planning has provided value in determining the feasibility of conducting alternative line cutting operations, both from an operational perspective and a safety perspective

Data Analytics
A complete analysis of all data collected during the Milestone 1 3D/4D field trial was conducted in order to accurately quantify the difference between the EcoSeis and the conventional 3D seismic program. All tracked data was analyzed with a focus on three key metrics: linear km cut, ha cut, and GHG emissions. A third-party subcontractor specializing in GHG emissions calculations evaluated both the direct emissions associated with fuel usage and the emissions associated with biomass cutting and decomposition based on forest type.

5.0 Results

Project results and lessons learned from both milestones have been published in detail in two journal articles and 32 technical conference abstracts. References and links for these publications are provided in Appendix B. Specific project from the two completed studies include:

<u>Re-growth Study</u>

The analysis of the data collected during the regrowth study shows good recovery on the seismic lines that were cut ~18-20 years ago utilizing low-impact seismic (LIS) line cutting methods. Overall, comparison of LIS vs Reference for all 12-strata investigated reveals a high recovery rate for all ecosites as every ecosite showed no significant difference between LIS and reference for 10 or more of the structural strata evaluated. Although there are differences between the transitional (C and G) and wetter ecosites (I, J, and K), these are most evident higher off the ground (Figure 4). Given the stand ages at reference sites, it was not surprising that for all ecosites, mean tree height was significantly higher on reference plots than on either fire or LIS plots. Additionally, there were no significant differences between LIS and reference plots in any ecosite for either of the lower stratum/ground cover variables with the exception of other moss in the D ecosite. Full details on the regrowth study results are provided in Appendix A.

Figure 1: Seismic line regrowth showing recovery in two different ecosites. In Ecosite A, seismic lines recover fully as avoidance cutting (lines meander around larger trees) results in minimal disturbance. Ecosite D has rapid recovery with nearly full regrowth on previously cut seismic lines.

GHG Emissions Reduction

Comprehensive analysis of emissions reductions with EcoSeis was undertaken utilizing data acquired in the EcoSeis Phase 2 field demonstration as well as the results of the regrowth study. Separate algorithms for calculating emissions from line clearing, fuel use, and increased methane from peatlands were developed (Figure 5). Since the lines were pre-existing and shared between the conventional and EcoSeis surveys, a model survey was created assuming a new project done either conventionally or with EcoSeis. Applying the method shows that the largest emissions source by almost two orders of magnitude is the net loss of ecosystem carbon from line clearing, emphasizing the importance of methods that dramatically reduced line clearing like EcoSeis. Savings in the EcoSeis case for land use are estimated at 46%, and emissions savings are estimated to be around 36-50%, depending on line widths, equipment chosen, and line design choices. Results have been incorporated into OptiSeis software for designing EcoSeis programs. Further validation is underway as part of the Emissions Reduction Alberta funded project. More information on how to apply the methodology is available upon request.

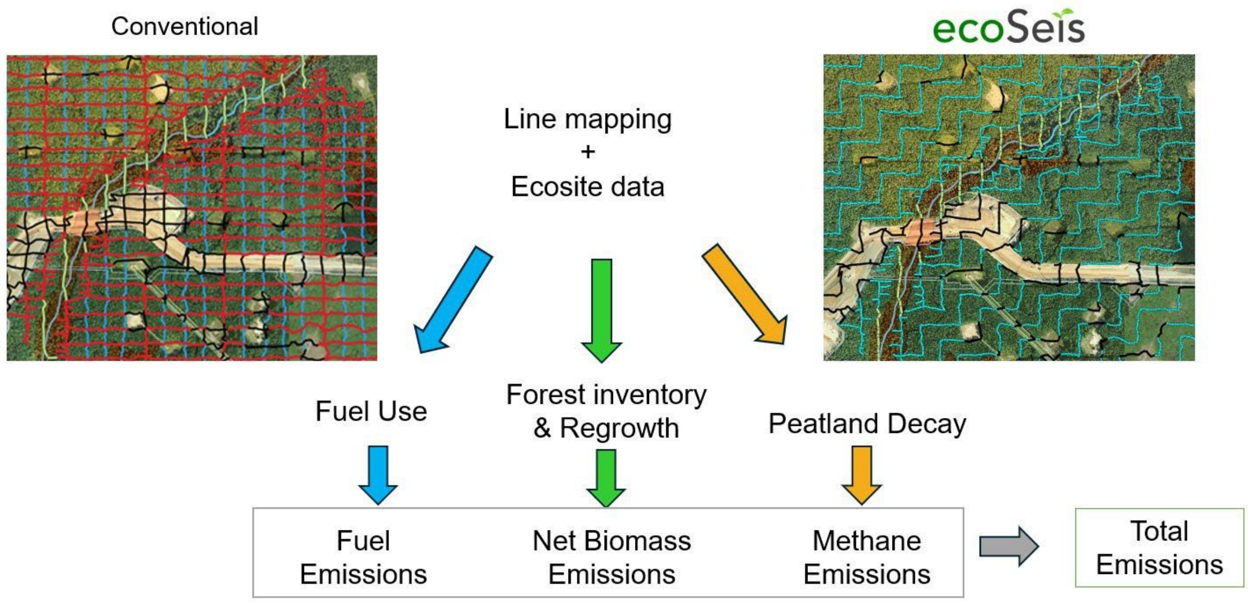

Figure 2: Methodology for determining emissions related to conventional and EcoSeis seismic acquisition.

<u>Software</u>
Results from the both the environmental studies and the field acquisition were incorporated into the OptiSeis osDesign™ software package. This included various seismic acquisition geometry layouts, new methods for survey evaluation such as Fresnel Fold (Naghizadeh et. al., 2022, Hons et. al., 2023), and algorithms for optimizing field layout for reduced environmental impact. An example of the software analysis and outputs is provided in Figure 3.

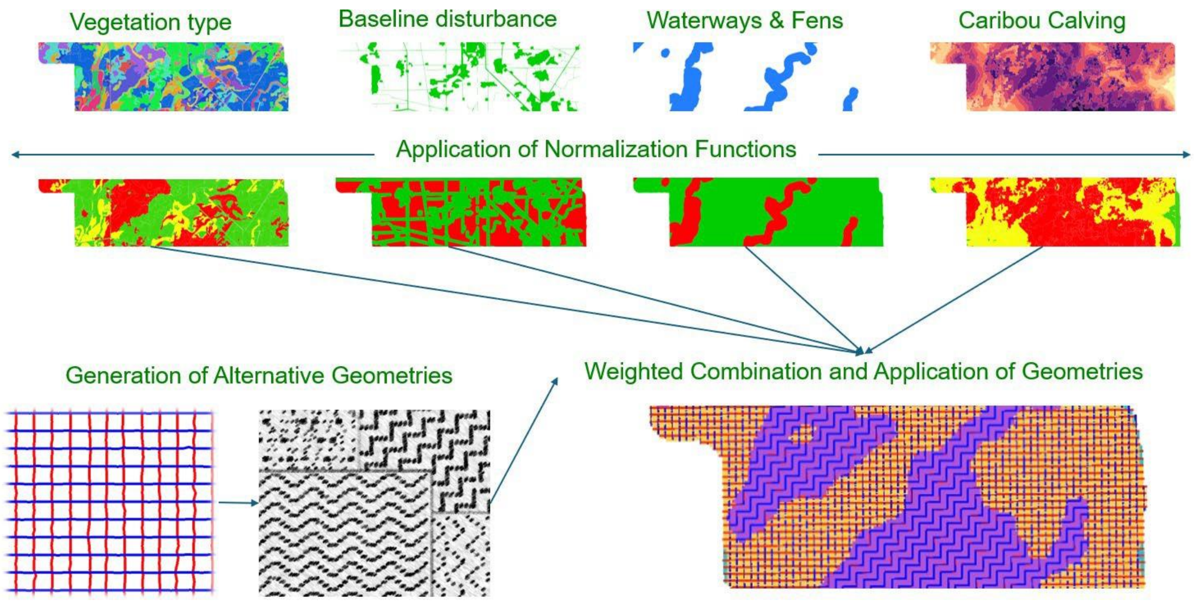

Figure 3: This is a real-world application of a combined EcoSeis and conventional seismic program. Inputs include various constraint maps that are normalized and then weighted based on sensitivity priority. EcoSeis geometries are generated and then applied in the most sensitive areas. Given the success of EcoSeis geometries in imaging the subsurface, combination programs are not required, and EcoSeis-only geometries may be deployed without loss of data quality.

Project Specific Performance Metrics

The specific environmental performance metrics for the program are listed in the table below. These were set at the beginning of the program, and due to the success of the EcoSeis method, all project targets were exceeded with a 42% reduction in linear km and 37% reduction in total disturbance area achieved during the technical field trial. The GHG emissions were also estimated to be reduced by 36% relative to the conventional seismic program based on total emissions (direct from fuel and biomass decomposition), which is more than double the project target. However, even better results are expected on future projects since the results of this test were in part limited due to the existing geometry and large existing footprint in the area. Additional modeling suggests in a new-cut scenario the savings would be at least 46% for linear km, 42% for disturbance area, and 41% for GHG emissions utilizing similar equipment and in a similar operating environment.

Estimates were necessary since the conventional program was a permanent installation and the field operations between the conventional and the EcoSeis programs could not be fully separated. Normalizations were done to determine direct emissions reductions under similar operating conditions. Furthermore, the geometry analyses indicate that land disturbance area reductions and GHG emissions reductions of over 50%, are possible, depending on the program area (forested, open, marsh, etc.) and equipment type (conventional vs. miniaturized, explosive/Vibroseis/alternative source, etc.).

Success Metric	Commercialization Target	Project Target	Achievements to Date
Reduction in Linear km with maintenance of data quality	> 40%	> 35%	Results indicate 42% linear km reduction, with potential to optimize nearer 50%
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Reduction in Cost	5-10%	0%	Overlapped operations and existing lines in field trial did not allow clear separation of costs between conventional and EcoSeis operations, but estimates based on field rates suggest savings of at least 5%, based only on reduced cut kilometers

6.0 Conclusions

The three primary goals of the project were to:

1. Complete technical validation of the EcoSeis methodology through a field trial that compared an EcoSeis seismic program with a conventional 3D seismic acquisition program. This was successfully achieved with full technical evaluation through processing, interpretation, and inversion.

2. Quantify the reduction in land footprint and GHG emissions achieved with EcoSeis. This was successfully achieved with EcoSeis exceeding the original performance metrics for reducing linear km and disturbance area while maintaining data quality. In fact, GHG emissions reductions were more than double the expected amount outlined in the project targets.

3. Implement the solution in OptiSeis' proprietary software. This was successfully completed with a commercial software package developed and new modules created for evaluating seismic acquisition parameters.

Results of the project (EcoSeis algorithm and methodology) provide a new way to acquire seismic data with up to a 50% reduction in land footprint (depending on the method of implementation) and the possibility of over 50% reduction in GHG emissions associated with seismic acquisition.

EcoSeis also aims to reduce the high-connectivity nature of seismic lines, which causes significant fragmentation of the forest, by reducing the number/width of lines and utilizing irregular line patterns which will result in less forest cover lost. The reduction in seismic line frequency and continuity, when applied using constraint mapping, also has the potential to lessen fragmentation effects which will benefit key wildlife species negatively affected by anthropogenic edge and those requiring larger interior forest patches. Additionally, by optimizing the seismic program layout using the EcoSeis algorithm, the interconnectivity of seismic lines can potentially be reduced, and the program can be designed to avoid areas with high biodiversity or sensitive habitats.

7.0 Recommendations

The next step is to demonstrate that EcoSeis provides equal or superior subsurface information in all types of geological settings and is both operationally efficient and safe to deploy on a commercial scale as well as operationally ready for commercialization. To achieve this, OptiSeis has secured a $5,000,000 grant from Emissions Reduction Alberta (ERA) to complete a $16,200,000 project that will involve completing phased testing to validate three key outstanding technical and operational questions:

1. Does the technology work for all subsurface targets, whether shallow or deep, and can it reduce the cost of Carbon Capture and Storage (CCS) monitoring,

2. Can the technology be deployed safely according to industry safety standards, and

3. Is the technology more efficient than conventional operations providing a cost-savings incentive for operators?

The phased approach enables development of proper safety procedures without compromising the technical or operational results, which is critical for industry acceptance. Based on the direction of project partners and their input with respect to the design of the project, upon completion, the technology will be ready for immediate, full-scale commercial implementation.

This project will involve collaboration with industry and not-for-profit organizations, and is expected to be funded by Optiseis, Industry partners, ERA, and other provincial and federal funding agencies. To date, two universities, four industry partners, and six SMEs will be directly contributing funding and in-kind contributions to the project.

8.0 Appendix A: Seismic Line Re-Growth Study Report

ECOLOGICAL SERVICES

A Comparison of Vegetation Establishment and Growth Following Low Impact Seismic Exploration and Natural Post Fire Recovery

An Assessment Twenty Years Later

Report Prepared for:

Andrea Crook, P.Geoph
Michael Hons, P.Geo.
David Simmons, Operations Manager

OptiSeis Solutions Ltd.
Calgary, Alberta

Report Prepared by:

Hans Skatter, P.Biol
Michael Charlebois, P.Biol

Omnia Ecological Solutions
Calgary, Alberta

Omnia Project ID: 2203-01

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Alberta Office
6244 Silver Ridge Drive NW, Calgary, AB
Canada T3B 3S7 403.475.2097

British Columbia Office
Box 945, Golden, BC
Canada V0A 1H0 250.344.1781

Consulting - Telemetry - Research
www.omniaeco.ca

1.0 EXECUTIVE SUMMARY

The first phase of this project was conceived in 2009 and the field component was completed between 2010 and 2012. The purpose of the work at that time was to improve understanding of recovery trajectory for in situ oil and gas exploration footprint, including low impact seismic lines (LIS) and oil sand exploration well pads (OSE), to assist with quantifying/mapping total footprint and to assist with targeting reclamation or mitigation strategies. The goal was to quantify the vertical and horizontal vegetation recovery on these features over time compared to reference conditions. This work was done between 2010 and 2012 on lines cut in 2002 and 2004, representing eight to 10 years of natural recovery following winter low-impact seismic activity.

The work was part of a larger project that was designed to classify and map the total disturbance footprint (linear, polygonal, and fire/timber harvest blocks) for the Cold Lake Regional Footprint Project area (4,315 km^2) using available digital technology. Automated processes were tested using remote sensing software for feature extraction and classification. Manual techniques were used for initial delineation and classification if the automated processes were found to be ineffective. The outcome of the natural recovery assessment and the footprint mapping was published in a peer-reviewed journal in 2015 (Charlebois et al. 2015 and Kansas et al. 2015).

As a follow up to the 2015 published work, this program was designed to re-sample all paired LIS sites (n=108). These sites now represent re-growth of 18 and 20 years post LIS. The amended federal recovery strategy for woodland caribou (ECCC 2020) considers areas affected by wildfire disturbed for 40 years post fire, after which the areas are no longer considered disturbed. This more detailed re-sampling provides insight into LIS seismic growth trajectories for tree and shrub species recovery (species, height and percent cover) at the ecosite level, and is then compared with recovery post fire.

The primary research questions, for this work included:

1. What is the status of natural regeneration of vegetation in upland sites?
2. Are there indications of vegetation establishment in lowland sites?
3. What is the time-lag response of re-growth in upland and lowland sites?
4. Has re-growth reached a stage to obstruct visual and travel advantages to predators?
5. What data & analysis is needed to inform seismic operations design & planning to best avoid impact to sensitive or low-growth areas?

Several studies have investigated vegetation regrowth on conventional seismic and LIS, but not long term (Felicetti and Nielsen 2018, 2019, 2022). This work will allow for a comparison to previously published data while also addressing data gaps and recommendations of previous research looking to address long term LIS recovery (18-20 years).

Overall, comparison of LIS vs Reference, for all 12-strata investigated, reveals a high recovery rate for all ecosites as every ecosite showed no significant difference between LIS and reference for 10 or more of the structural strata evaluated. Although there are differences between the transitional (C and G) and wetter ecosites (I, J, and K), these are most evident higher off the ground, and there were no significant differences between LIS and reference plots in any ecosite for either of the lower stratum/ground cover variables except for the category “other” moss species in ecosite D.

2.0 INTRODUCTION

The early work on this project was conceived in 2009. Following this, the field component was initiated in July and August 2010. The purpose of the work at that time was to improve understanding of the permanency of in situ oil and gas exploration footprint, including low impact seismic lines (LIS) and oil sand exploration well pads (OSE), to assist with understanding total footprint and to assist with targeting reclamation or mitigation strategies. The goal was to quantify the vertical and horizontal vegetation recovery on these features over time. This work was done between 2010 and 2012 on lines cut in 2002 and 2004, representing eight to 10 years of natural recovery following winter LIS activity.

The LIS/OSE field work was part of a larger project that was designed to classify and map the total disturbance footprint (linear, polygonal, and fire/timber harvest blocks) for the Cold Lake Regional Footprint Project area (4,315 km^2) using available digital technology. Automated processes were tested using remote sensing software for feature extraction and classification. Manual techniques were used for initial delineation and classification if the automated processes were found to be ineffective for some feature types. The outcome of the natural recovery assessment and the footprint mapping was published in 2015 (Charlebois et al. 2015 and Kansas et al. 2015).

As a follow up to the 2010 to 2012 field work, this program was designed to re-sample all paired LIS sites (n=108). These sites now represented re-growth of 18 and 20 years post LIS. This more detailed re-sampling would provide insight into post mulching growth trajectories for tree and shrub species recovery (species, height and percent cover) at the ecosite level.

In addition to the 108 LIS sites, the program also included a sampling regime to include post-fire natural recovery. This portion of the program sampled ecosites within the House River fire boundary. This fire burnt forest in the same area of study during the summer of 2002 representing the same recovery timeline and providing a reference for comparison of results against regeneration from natural disturbance.

The primary research questions, following up on the published results in 2015, for this work included:

1. What is the status (survival/growth) of natural regeneration of tree species in upland sites?
2. Are there signs of tree species establishment (survival/growth) in lowland sites?
3. What has been the time-lag response (18-20 years) of re-growth in both sites?
4. Has re-growth reached a stage to obstruct visual and travel advantages to predators?
5. What data & analysis is needed to inform seismic operations design & planning to best avoid impact to sensitive or low-growth areas?

Several studies have investigated vegetation regrowth on conventional seismic and LIS, but not long term (Felicetti and Nielsen 2018, 2019, 2022). This study has the benefit of revisiting plots originally surveyed 10 to 11 years ago and now 18-20 years has passed since they were since LIS was completed. This work will allow for a comparison to previously published data while also addressing data gaps and recommendations of previous research looking to address long term LIS recovery.

3.0 MATERIALS AND METHODS

3.1 Study Area

The study area is located 15 km south of the Hamlet of Conklin in Lac La Biche County in northeastern Alberta, Canada (Figure 1). It occurs fully within the Central Mixedwood Natural Subregion of the Boreal Forest Natural Region of Alberta (Natural Regions Committee 2006). The Central Mixedwood is the largest Subregion in Alberta occupying 167,856 km^2 that amounts to 44% of the Boreal Forest Natural Region and 11% of the province of Alberta. The study area is characterized by rolling morainal plain with approximately 60% organic terrain. Upland moraine areas are dominated by aspen (*Populus tremuloides*), mixedwood and jack pine (*Pinus banksiana*) forest while in lowland bogs and fens, black spruce (*Picea mariana*) and tamarack (*Larix laracina*) trees and shrubs occur in association with organic soils. Several creeks and associated riparian habitats also occur.

The study area is located in the Cold Lake Caribou Range (Figure 1), which encompasses 6,724 km^2 (ECCC 2020). Based on inclusion of a 500 metre disturbance buffer from disturbance, ECCC (2020) described the Cold Lake Caribou Range presently as 87% disturbed (based on combined natural disturbance and buffered anthropogenic disturbance), leaving 13% undisturbed. As part of range planning for woodland caribou (*Rangifer tarandus caribou*) persistence and recovery, ECCC (2020) identified a target of 65% undisturbed habitat for the boreal caribou range to meet critical habitat requirements for this species. EcoSeis aims to minimize the impact from 3D seismic programs. This study adds to understanding of where minimization and avoidance may be most critical to align with the habitat goals.

The only major current industrial land use in the study area is petroleum development and primarily in-situ oil sands exploration and development. No timber harvest had taken place at the time of field sampling. Anthropogenic linear features associated with development include low-impact seismic lines (LIS), conventional seismic lines, gravel roads of various widths and classes, pipelines, power transmission lines, and bush trails. LIS lines are narrower and have comparatively lower ecological effects at the site-level (Schneider et al. 2003, Dabros et al. 2018)**.** The total area covered by LIS lines in the study area at the time of field sampling was 80.9 km^2 of which 69% had not been recut since initial survey (31% of the LIS has been recut twice or more since initial cut).

3.2 Sample Site Selection

Field sampling was completed from June to September 2022, during full vegetation green-up. Sampling sites were stratified by mapped ecosites (Figure 2). An ecosite is defined as a homogeneous land type that represents a combined interaction of biophysical factors that dictate the availability of moisture and nutrients for plant growth (Beckingham and Archibald 1996).

Due to a low number of available mapped polygons for the E and F ecosites, these were merged. This was considered acceptable for this analysis since their vegetation assemblages, moisture and nutrient regimes are similar (see Figure 2).

Two sets of sampling designs were used: one on seismic lines with natural, unburned regrowth since line creation, and one within an area of forest fire disturbance 20 years post-fire (not on LIS lines). For the unburned sites, sampling transects were located on east-west running seismic LIS at the centroid of an individual mapped ecosite polygon and centered between north-south running lines of LIS grids. This was done following the methods developed by Kansas et al. (2015) and van Rensen et al. (2015). Paired reference transects (undisturbed) were run along the same bearing and parallel to LIS (disturbance) transects in the same habitat 30 m to the north. If suitable reference habitat was not available to the north, transects were placed on the south side of LIS. For the post fire natural recovery sites, a single transect located within interior forest was measured. Ecosite classifications used historical mapping and were field validated.

LIS within natural/unburned forest were previously sampled between 2010 and 2012 (n=108) with plot centers marked with wooden stakes and high-resolution Garmin or Trimble GPS units (Kansas et al. 2015). Sixty-two of these sites were revisited and resampled in 2022, using the same plot center. If an original plot had been re-cut in the interim, a replacement plot was created of a corresponding ecosite (n=28). A total of 90 paired plots of nine ecosites (10 each) were sampled in the unburned forest and 80 single plots of eight ecosites (10 each) were sampled in the post-fire forest (i.e., burn). New unburned plots and new post-fire plots were located using a stratified random approach based on ecosite mapping. Similar to Filicetti et al. (2019), to avoid pseudo replication, the criteria for selecting sample sites on seismic lines were: (1) minimum distance between plots of 400 m; and (2), distance may be less between plots only if on a separate seismic line and/or if within a different ecosite and/or within a different ecosite polygon. There were no spacing restrictions between different ecosites on the same LIS and/or between separate ecosite polygons.

3.3 Sample Plot Layout and Sampling Design

Each sampling site consisted of a 30 m transect within which five 20 x 50 cm sub-plots; five 1 x 1 m sub-plots and three 2 x 5 m subplots were systematically distributed at 5 m intervals (Figure 3). Vegetation and structural information was collected along each transect and corresponding reference transect. In the 20 x 50 cm sub-plots, the variables that were quantified included: percent cover of feather moss, sphagnum moss, lichen, open water, litter (and depth), mulch (and depth) (Section 3.4), bare soil, and rock. In the 1 x 1 m sub-plots, the variables sampled included: percent cover of low shrubs <1 m, forbs, graminoids, and a stem count of tree species <1 m. In the 2 x 5 m sub-plots the variables sampled included stem count and height of tree species (1-5 m).

Additional site-specific information was collected including tree canopy closure and species composition, diameter at breast height (DBH), and height of key tree species using a Haglöf Vertex hypsometer as well as general notes describing the site. Visual obstruction from vegetation was measured in both east and west directions from the center and along each transect and corresponding reference transect adapting methods by Nudds (1977) as described in Kansas et al. (2015). A red and white color-coded cloth measuring 2.5 m in height was held upright 15 m from the observer at plot centre. The observer viewed the cloth from both caribou eye level height (1.8 m above ground) and wolf (*Canis lupus*) eye level height (1.3 m above ground). An estimate of the percent obstructed/hidden was recorded for each 25 cm x 25 cm block which make up the cloth.

3.4 Statistical Analysis

For each ecosite, plot type differences in tree species stem density (stems/ha), stem height, ground cover, and visual obstruction (% hidden) data were first visualized by plotting means and standard errors. Stem density means were calculated from stem count data for tree species, accounting for the different sizes in sampling plots for the different height classes (see Figure 3). These plot size differences were also accounted for when calculating the mean stem heights of tree species by weighting the mean tree height for each height class by the stem densities in the corresponding height class. In calculating the mean tree heights in the < 5 m class, the height was applied to all stems of the corresponding species in each plot.

Ten categories of ground cover variables were compared for each ecosite and plot type including: water, sphagnum moss, other moss, low shrub, litter cover, lichen, graminoid, forb, feathermoss, and bare soil. Rock and mulch ground cover were excluded from the visualization as these either did not occur in any plots (rock) or occurred in just two plots (mulch). The mean and standard error for visual obstruction was found for each combination of ecosite – plot type, and each combination of ecosite – plot type – height interval.

Following visualization, we statistically tested the data using Shapiro-Wilk's normality tests. This showed that much of the data was not normally distributed so we used Dunn's t-test which do not require the data to be normal. Using Dunn's t-tests we analyzed the difference between plot types within each ecosite for stem density, stem height, ground cover, and visual obstruction. Statistically significant differences ($p < 0.05$) were reported. Data visualization and statistical analysis was performed using R Statistical Software (v4.1.2; R Core Team 2022), and the packages ggplot2 (v3.4.0; Wickham 2016) and ggpubr (v0.4.0; Kassambara 2020).

4.0 RESULTS

4.1 All Stratum Combined for LIS vs Reference

Comparing LIS vs Reference for 12 different vegetation strata reveals a high recovery rate for all ecosites as every ecosite showed no significant difference between LIS and reference for 10 or more stratum (Table 1). Ecosites A and E+F ranked highest with no significant difference between LIS and Reference for all 12 strata (100% recovery); ecosites B, D, and G showed no significant difference in 11/12 strata (98%). All other ecosites showed no significant difference in 10 of 12 stratums (83%) (Table 1).

4.2 Stem Density

Tree stem density on fire plots was significantly higher than on reference or LIS plots for all ecosites, except for I and K ecosites where there was no significant difference between reference and fire plots. The higher stem density on fire plots was most obvious for A, B and C ecosites.

Stem density was significantly higher on reference plots than LIS plots for C, I, J, and K ecosites, while no significant differences between stem density on LIS and reference plots was found for A, B, D, E/F, and G ecosites (Figure 4, Table 1).

4.3 Tree Height

For all ecosites, mean tree height was significantly higher on reference plots than on either fire or LIS plots (Table 2). For ecosites D, J and K, there was also no significant difference in mean stem height between LIS and fire plots, while for the remaining ecosites (A, B, C, G, and I), mean stem height was significantly higher on fire plots.

4.4 Lower Stratum Recovery

There were no significant differences between LIS and reference plots in any ecosite for either of the lower stratum/ground cover variables, with the exception of other moss in D ecosite (Table 3, Figure 4). Feathermoss cover was significantly lower in fire plots than Reference/LIS plots for ecosites A, B, C, G, I and K. Forb cover was significantly lower in fire plots than Reference/LIS plots for ecosites B and D. Lichen cover was significantly higher in fire plots than Reference/LIS plots for ecosites B, C and G. Litter cover was significantly higher in fire plots than Reference/LIS plots for ecosites A, B, C, G and I. Low shrub cover was significantly higher in fire plots than Reference/LIS plots for ecosites B, C, G, I, J and K (Table 3, Figure 4).

4.5 Visual Obstruction

Visual obstruction from ground level to 2.5 m was not significantly different for three ecosites in the study area (A, D, and E+F), aligning with the results in stem density. Mean visual obstruction was generally higher on reference plots than on LIS plots (Table 2, Appendix 1). Although there were some ecosites where this pattern was not statistically significant (A and D ecosites for wolf and A and E/F ecosites for caribou), there were no instances of an ecosite where there was significantly more visual obstruction on the LIS plot than the reference plot. On average, LIS plots had 64% of the visual obstruction of the corresponding reference plot for wolf, and 62% for caribou. The difference in visual obstruction between LIS and reference plots was most pronounced further from the ground (Appendix 1).

Mean visual obstruction was consistently higher on fire plots than on reference plots for xeric and sub-xeric ecosites (A, B, C, D). Conversely, for hygric and sub-hygric ecosites, mean visual obstruction was either not significantly different from the corresponding reference plot (G, I, K), or was greater on the fire plot than on the reference plot (J). Specifically, visual obstruction cover on xeric reference plots (47.7 ± 4.1% for wolf, 48.9 ± 4.2% for caribou) was lower than on hygric reference plots (78.9 ± 2.9% for wolf, 81.6 ± 2.7%), and mean visual obstruction on xeric fire plots (87.9 ± 2.2% for wolf, 88.8 ± 2.4% for caribou) was higher than on hygric fire plots (72.8 ± 3.3% for wolf, 79.3 ± 2.9% for caribou). Where differences in visual obstruction did occur, these differences were generally most pronounced furthest from the ground (Appendix 1).

5.0 SUMMARY AND CONCLUSIONS

- Comparing LIS vs Reference for all 12-strata investigated reveals a high recovery rate for all ecosites as every ecosite showed no significant difference between LIS and reference for 10 or more structural strata evaluated
- Stem density on fire plots was significantly higher than on reference or LIS plots for all ecosites, except for I and K ecosites where there was no significant difference between reference and fire plots.
- The higher stem density on fire plots was most obvious for A, B and C ecosites.
    - These ecosites are dominated by dryer conifers.
    - Jack pine have serotinous cones.
- No significant differences between stem density on LIS and reference plots was found for ecosites A, B, D, E/F, and G ecosites. However, stem density was significantly higher on reference plots than LIS plots for ecosites C, I, J, and K.
- Given the stand ages at reference sites, it was not surprising that for all ecosites, mean tree height was significantly higher on reference plots than on either fire or LIS plots
    - For ecosites D, J and K, there was also no significant difference in mean stem height between LIS and fire plots
    - A, B, C, G, and I ecosite mean stem height was significantly higher on fire plots
- Transitional (C and G) and wetter ecosites (I, J, and K) show most difference between LIS and reference with differences more evident higher off the ground (stem counts and visual obstruction)
- There were no significant differences between LIS and reference plots in any ecosite for either of the lower stratum/ground cover variables, with the exception of other moss in the D ecosite

These results suggest that modified methods which selectively reduce LIS density may be employed to reduce the duration of vegetation disturbance in ecosites with slower vegetation recovery. Reduced overall time to recovery in these ecosites may reduce habitat loss and potential fragmentation in the short term. In addition, reduced footprint has the potential to reduce ongoing methane and carbon emissions associated with seismic line impacts in lowland, ecosites (Strack et al. 2019).

Results from the EcoSeis project have demonstrated that line density reductions of up to 50% are possible with alternative seismic line geometries (Naghizadeh et al., 2023) and miniaturized equipment (Crook et al. 2023), while maintaining data quality and safe, efficient operations. Applying novel techniques, with special focus on lower regrowth ecosites identified in this work, can assist in reducing impacts of LIS activity.

6.0 Further Studies

Future sampling of the same study area in 10 years from 2022 would be informative regarding the continued recovery timeline and in particular as it relates to visual obstruction and tree stem counts differences between LIS and reference areas. This can further refine tracking of LIS seismic line regeneration and eventual return to a recovered state.

7.0 REFERENCES

Beckingam, J.D. and J.H. Archibald. 1996. Field Guide to the Ecosites of Northern Alberta. Canadian Forest Service Northern Region. Northern Forestry Centre. Special Report 5. UBC Press. University of British Columbia, Vancouver, British Columbia.

Charlebois, M.L., Skatter, H.G., Kansas, J.L., and Crouse, D.P. 2015. Using LiDAR, Colour Infrared Imagery, and Ground Truth Data for Mapping and Characterizing Vegetation Succession on Disturbance Types: Implications for Woodland Caribou (*Rangifer tarandus caribou*) Habitat Management. Canadian Wildlife Biology and Management. 4-2: 119-136.

Crook, A., Naghizadeh, M., Vermeulen, P., Gagnier, D., and Reine, C. 2023. The use of miniaturised seismic sources for reduced environmental impact. First Break. 41. 77-84.

Dabros, A., Pyper, M., and Castilla, G. 2018. Seismic lines in the boreal and arctic ecosystems of North America: environmental impacts, challenges, and opportunities. Environmental Reviews: 26: 214-229.

Environment and Climate Change Canada (ECCC). 2020. Amended Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada. Species at Risk Act Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. xiii + 143pp.

Filicetti, A.T., M. Cody and S.E. Nielsen. (2019). Caribou Conservation: Restoring Trees on Seismic Lines in Alberta, Canada. Forests. 10(2): 185. doi:10.3390/f10020185

Kansas, J.L., Charlebois, M.L., and Skatter, H.G. 2015. Vegetation recovery on low impact seismic lines in Alberta's oil sands and visual obstruction of wolves (Canis lupus) and woodland caribou (Rangifer tarandus caribou). Canadian Wildlife Biology and Management. 4-2: 137-149

Kassambara, A. (2020). ggpubr: 'ggplot2' based publication ready plots. Natural Regions Subcommittee. 2006. Natural Regions and Subregions of Alberta. Compiled by D. J. Downing and W. W. Pettapiece. Government of Alberta. Publication No. T/852.

Naghizadeh, M., Vermeulen, P., Crook, A., Birce, A., Ross, S., Stanton, A., Rodriguez, M., and Cookson, W. 2023. EcoSeis: A novel acquisition method for optimizing seismic resolution while minimizing environmental footprint. The Leading Edge. 42(1). 61-68.

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

Nudds, T. D. 1977. Quantifying the vegetative structure of wildlife cover. Wildlife Society Bulletin. 5: 113- 117.

R Core Team. (2022). R: A language and environment for statistical computing. Vienna, Austria. URL https://www.R-project.org/

Strack, M., Hayne, S., Lovitt, J. *McDermid, G.J., Rahman, M.M., Saraswati, S. and B.Hu. 2019.* Petroleum exploration increases methane emissions from northern peatlands. *Nature Communications.* 10: 2804 (2019).

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 boreal habitats in Alberta's oil sands region. Biological Conservation 184:127-135.

Wickham, H. (2016). ggplot2: Elegant graphics for data analysis. Springer-Verlag New York, 2016.

8.0 FIGURES

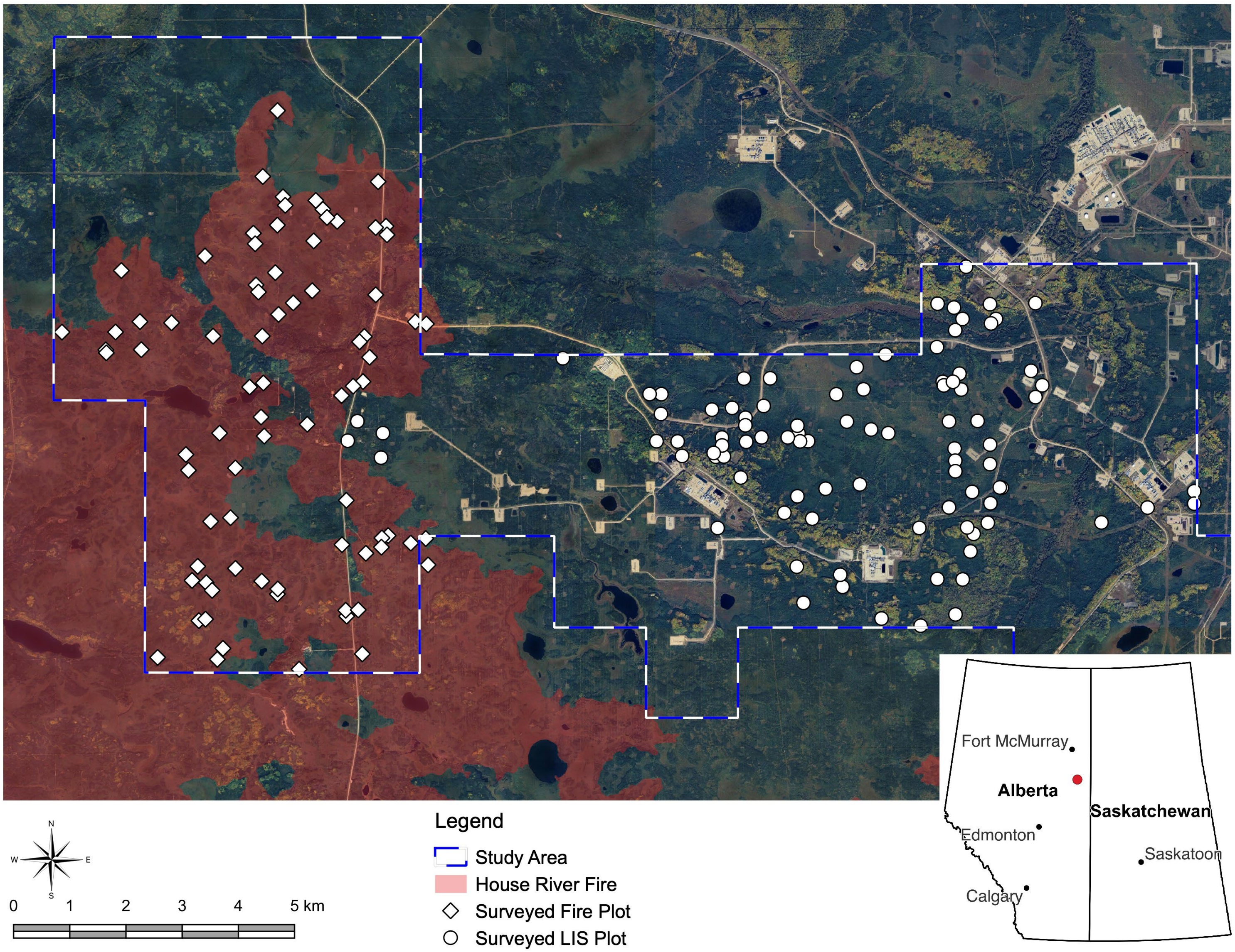
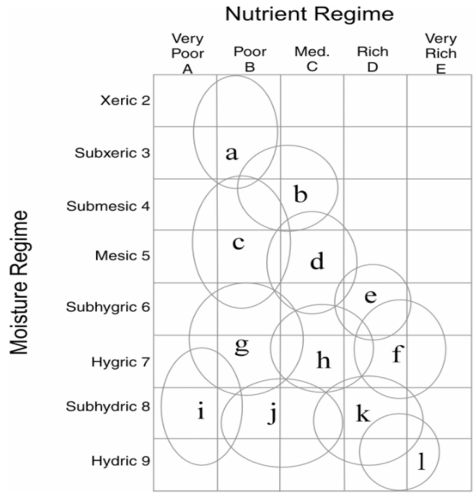


Figure 1. Location of study area in northeastern Alberta.



Ecosite Code	Ecosite Description	Dominant Tree Species
A	Lichen	Jack pine
B	Blueberry	Aspen/Jack pine
C	Labrador Tea	Jack pine/Black spruce
D	Low-bush cranberry	Aspen/White spruce
E	Dogwood	Balsam poplar/White spruce
F	Horsetail	Balsam poplar/White spruce
G	Labrador tea – subhygric	Black spruce/Jack pine
H	Labrador tea/horsetail	White spruce/Black Spruce
I	Bog	Black spruce
J	Poor Fen	Black spruce/Tamarack
K	Rich Fen	Tamarack
L	Marsh	N/A

Figure 2. Biophysical description of ecosites for the Boreal Mixedwood in Northern Alberta (Beckingham and Archibald (1996).

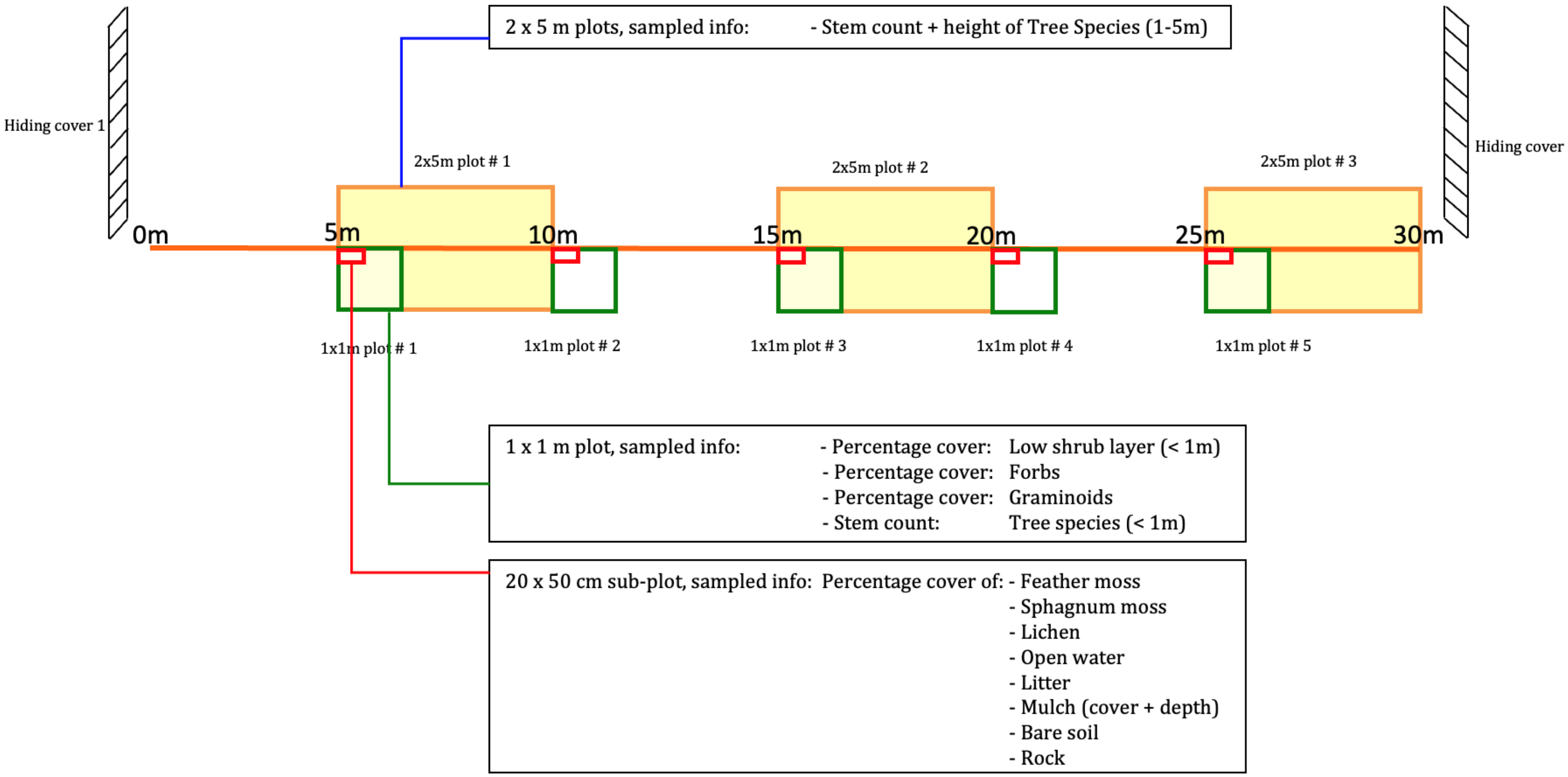


Figure 3. Sample plot layout.

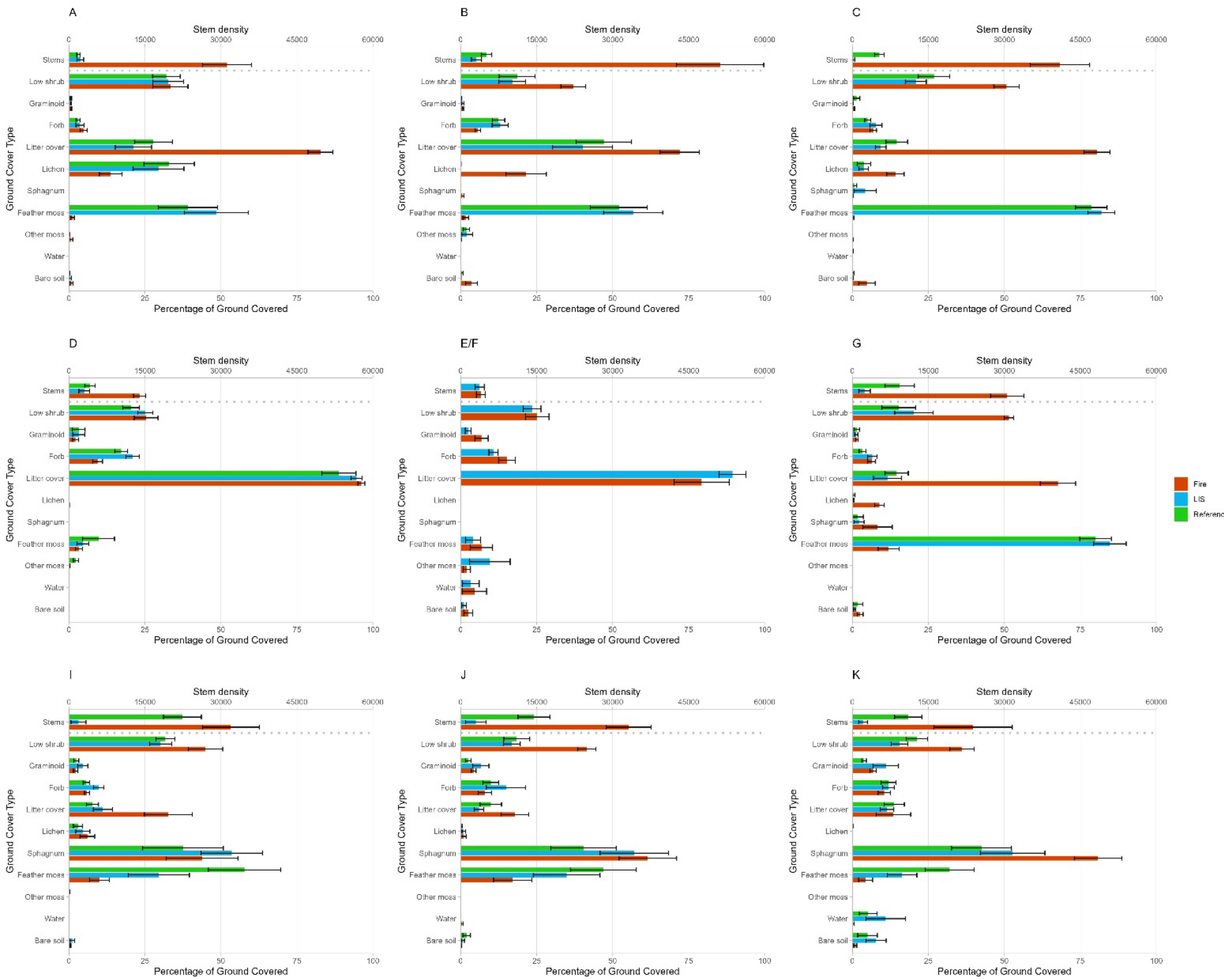


Figure 4. Stem density (mean number of stems per ha) and percentage cover of ground cover variables by ecosite in fire and on low-impact seismic lines (LIS) twenty years post disturbance versus reference transects in undisturbed forest. The error bars are standard errors around the means.

9.0 TABLES

Table 1. Differences between LIS and Reference plots for the 12 different strata investigated. Check mark (√) indicates no significant difference between LIS and Reference. An x indicates where there is a difference between LIS and reference.

Stratum	A	B	C	D	E+F	G	I	J	K
Visual obstruction	√	X	X	√	√	√	X	X	X
Tree stem count	√	√	X	√	√	X	X	X	X
Low shrub cover	√	√	√	√	√	√	√	√	√
Forbs	√	√	√	√	√	√	√	√	√
Graminoids	√	√	√	√	√	√	√	√	√
Lichen	√	√	√	√	√	√	√	√	√
Feathermoss	√	√	√	√	√	√	√	√	√
Sphagnum moss	√	√	√	√	√	√	√	√	√
Other moss	√	√	√	X	√	√	√	√	√
Litter cover	√	√	√	√	√	√	√	√	√
Bare soil	√	√	√	√	√	√	√	√	√
Open water	√	√	√	√	√	√	√	√	√
Recovered/No significant difference in:	12/12	11/12	10/12	11/12	12/12	11/12	10/12	10/12	10/12
Percentage of descriptors demonstrating recovery:	100	92	83	92	100	92	83	83	83

Table 2. Dunn's test p-values for tree heights, tree density, and visual obstruction for each ecosite. Visual obstruction refers to the mean percent hidden values from 0 – 2.5m from ground. Ref – reference plots, LIS = low impact seismic plots, fire = plots in the burn area of the 2002 House River Fire. A visual representation is provided in Appendix 1.

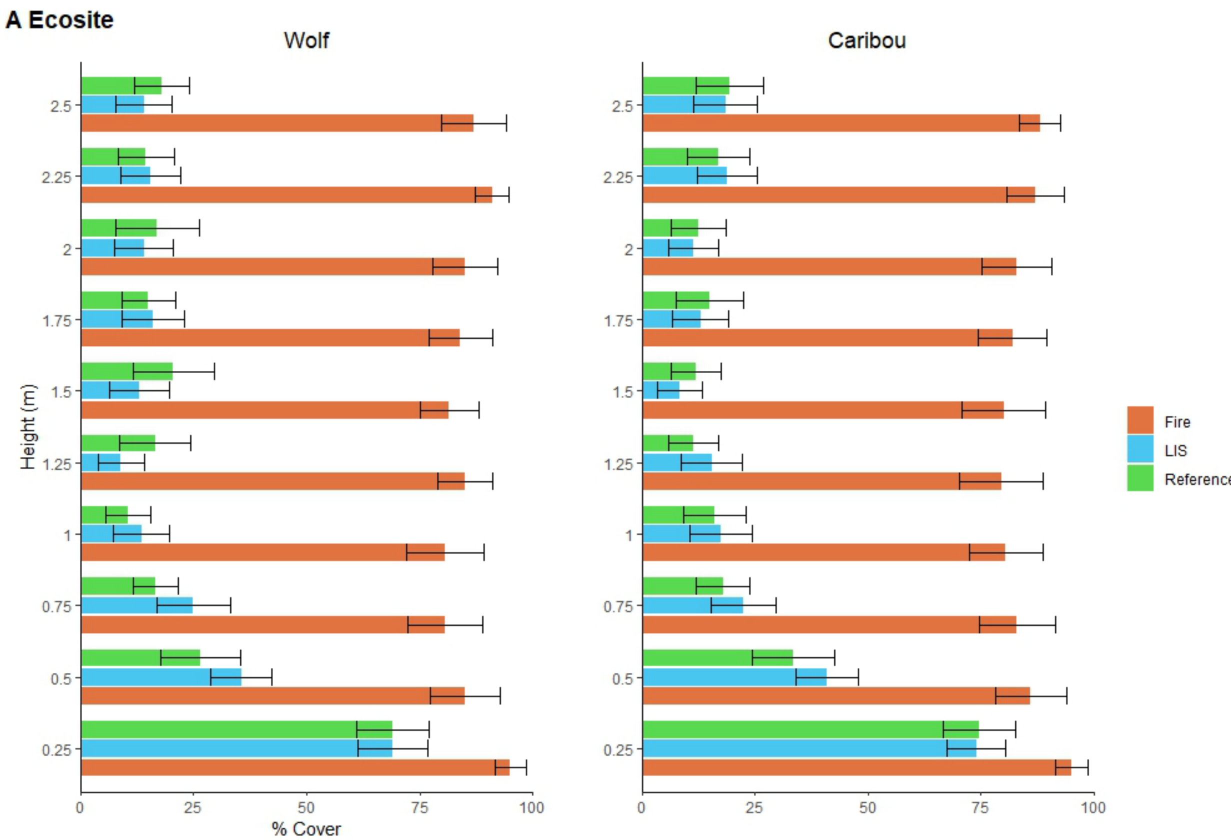
	Visual Obstruction: Wolf	Visual Obstruction: Caribou	Stem Density	Stem Height
A Ecosite				
LIS – Fire	< 0.001	< 0.001	< 0.001	< 0.001
Ref – Fire	< 0.001	< 0.001	< 0.001	0.001
Ref – LIS	0.67	0.99	0.612	< 0.001
B Ecosite				
LIS – Fire	< 0.001	< 0.001	< 0.001	0.003
Ref – Fire	< 0.001	< 0.001	< 0.001	0.006
Ref – LIS	< 0.001	< 0.001	0.223	0.004
C Ecosite				
LIS – Fire	< 0.001	< 0.001	< 0.001	< 0.001
Ref – Fire	< 0.001	< 0.001	< 0.001	0.002
Ref – LIS	< 0.001	< 0.001	< 0.001	< 0.001
D Ecosite				
LIS – Fire	< 0.001	< 0.001	< 0.001	0.322
Ref – Fire	< 0.001	< 0.001	< 0.001	0.024
Ref – LIS	0.35	0.047	0.400	0.019
E+F Ecosite				
Ref - LIS	0.005	0.069	0.810	0.047
G Ecosite				
LIS - Fire	< 0.001	< 0.001	< 0.001	< 0.001
Ref - Fire	0.54	0.43	0.004	< 0.001
Ref - LIS	< 0.001	< 0.001	0.058	< 0.001
I Ecosite				
LIS - Fire	< 0.001	< 0.001	< 0.001	< 0.001
Ref - Fire	0.79	0.42	0.082	0.034
Ref - LIS	< 0.001	< 0.001	< 0.001	0.002
J Ecosite				
LIS - Fire	< 0.001	< 0.001	< 0.001	0.097
Ref - Fire	< 0.001	< 0.001	0.005	0.005
Ref - LIS	< 0.001	< 0.001	0.004	0.005
K Ecosite				
LIS - Fire	< 0.001	< 0.001	0.023	0.873
Ref - Fire	0.24	0.11	0.163	0.034
Ref - LIS	< 0.001	< 0.001	0.005	0.024

Table 3. Dunn's test p-values for ground cover variables for each ecosite: Ref – reference plots, LIS = low impact seismic plots, fire = plots in the burn area of the 2002 House River Fire. Only significant values are shown.

	Low Shrub	Forb	Graminoid	Sphagnum Moss	Feather Moss	Other Moss	Lichen	Litter Cover	Litter Depth
A Ecosite									
LIS – Fire					0.001			< 0.001	
Ref – Fire					0.006			< 0.001	
Ref – LIS									
B Ecosite									
LIS – Fire	0.016	0.031			< 0.001		0.002	0.031	
Ref – Fire	0.028				< 0.001		0.002		
Ref – LIS									
C Ecosite									
LIS – Fire	< 0.001				< 0.001		0.008	< 0.001	< 0.001
Ref – Fire	0.001				< 0.001		0.009	< 0.001	0.003
Ref – LIS									
D Ecosite									
LIS – Fire		0.001							
Ref – Fire		0.028				0.011			
Ref – LIS						0.017			
E+F Ecosite									
Ref - LIS									
G Ecosite									
LIS - Fire	< 0.001				< 0.001		< 0.001	< 0.001	0.019
Ref - Fire	< 0.001				< 0.001		< 0.001	< 0.001	0.033
Ref - LIS									
I Ecosite									
LIS - Fire	0.052							0.014	0.021
Ref - Fire					0.003			0.004	0.022
Ref - LIS									
J Ecosite									
LIS - Fire	< 0.001								
Ref - Fire	< 0.001								
Ref - LIS									
K Ecosite									
LIS - Fire	< 0.001								
Ref - Fire	0.014			0.022	0.005				
Ref - LIS									

10.0 APPENDICES

Appendix 1A. Visual obstruction in A Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstrcution were found in any height layers for caribou or wolf (P>0.05) in LIS versus control. Visual obstruction was significantly higher in fire areas than both LIS and reference for all height layers except for the 0.25 m reference layer for wolf (P=0.067).



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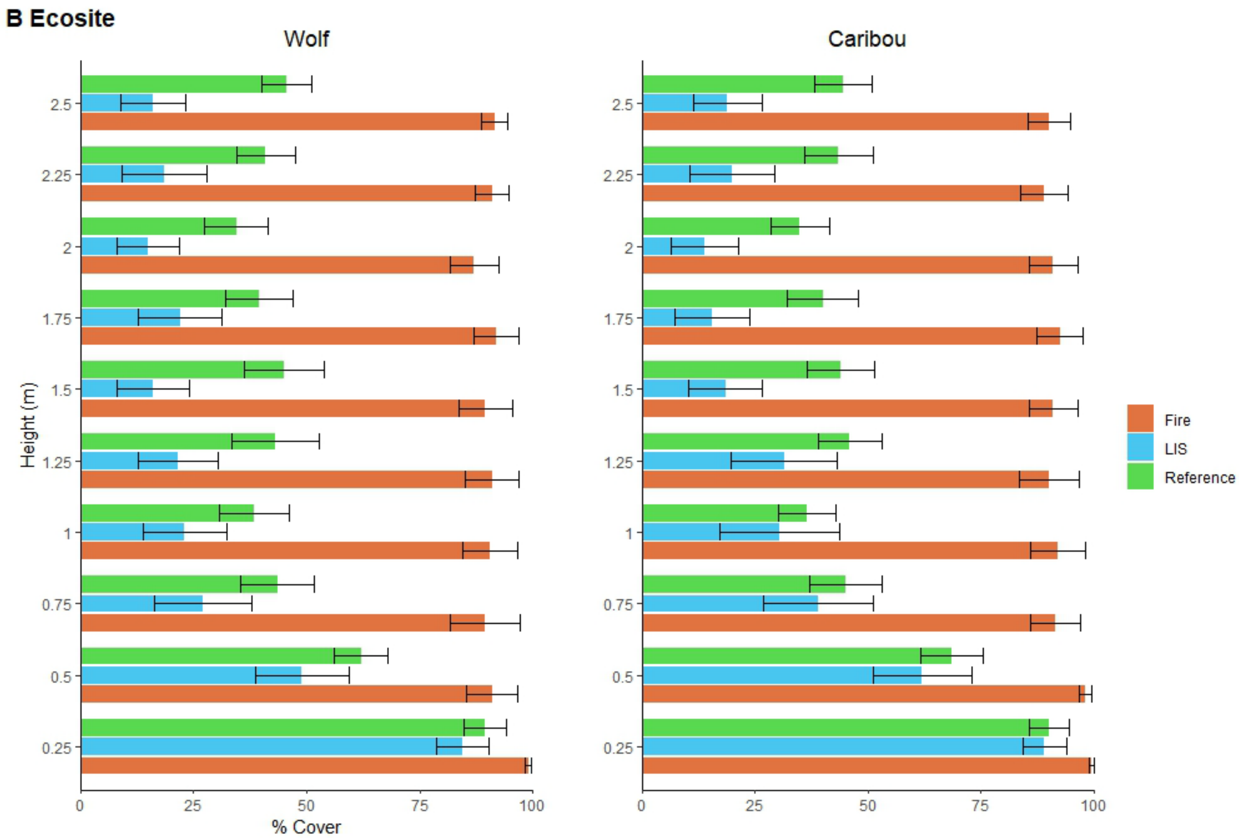
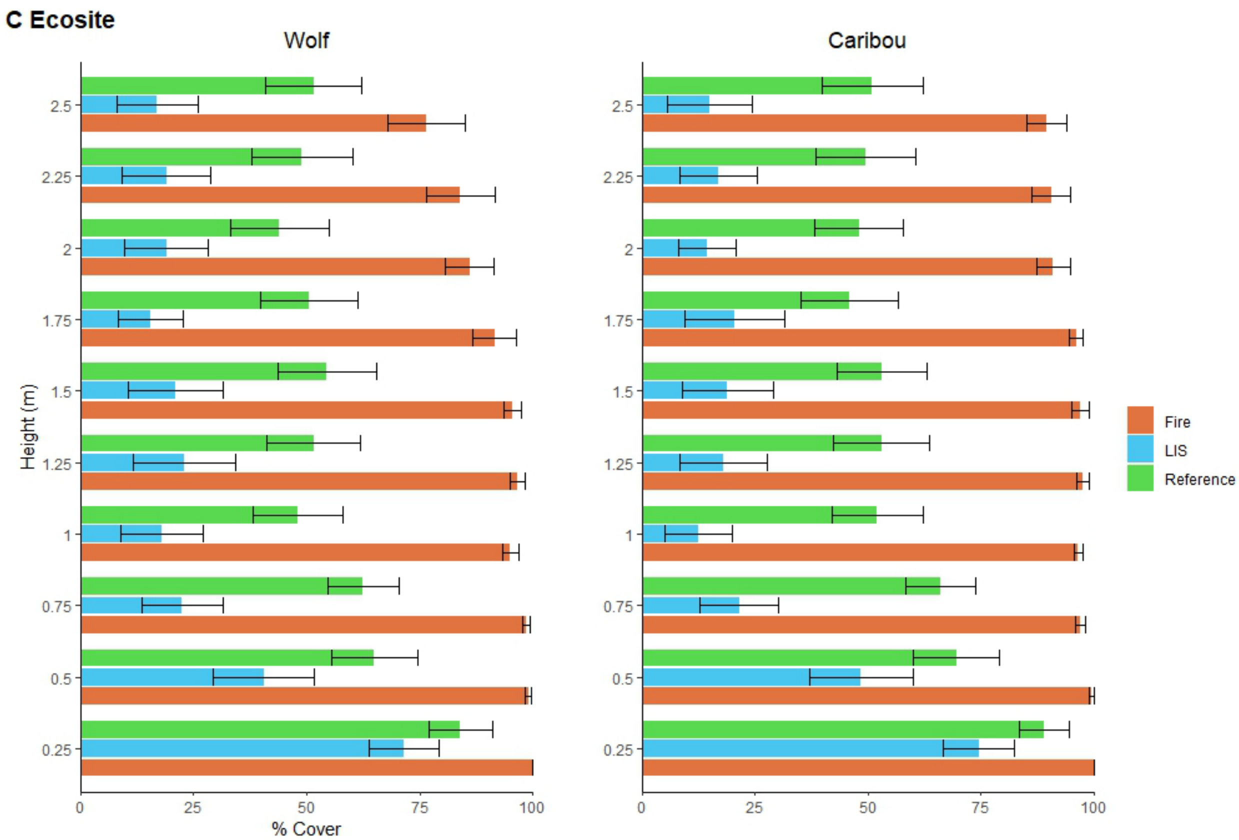
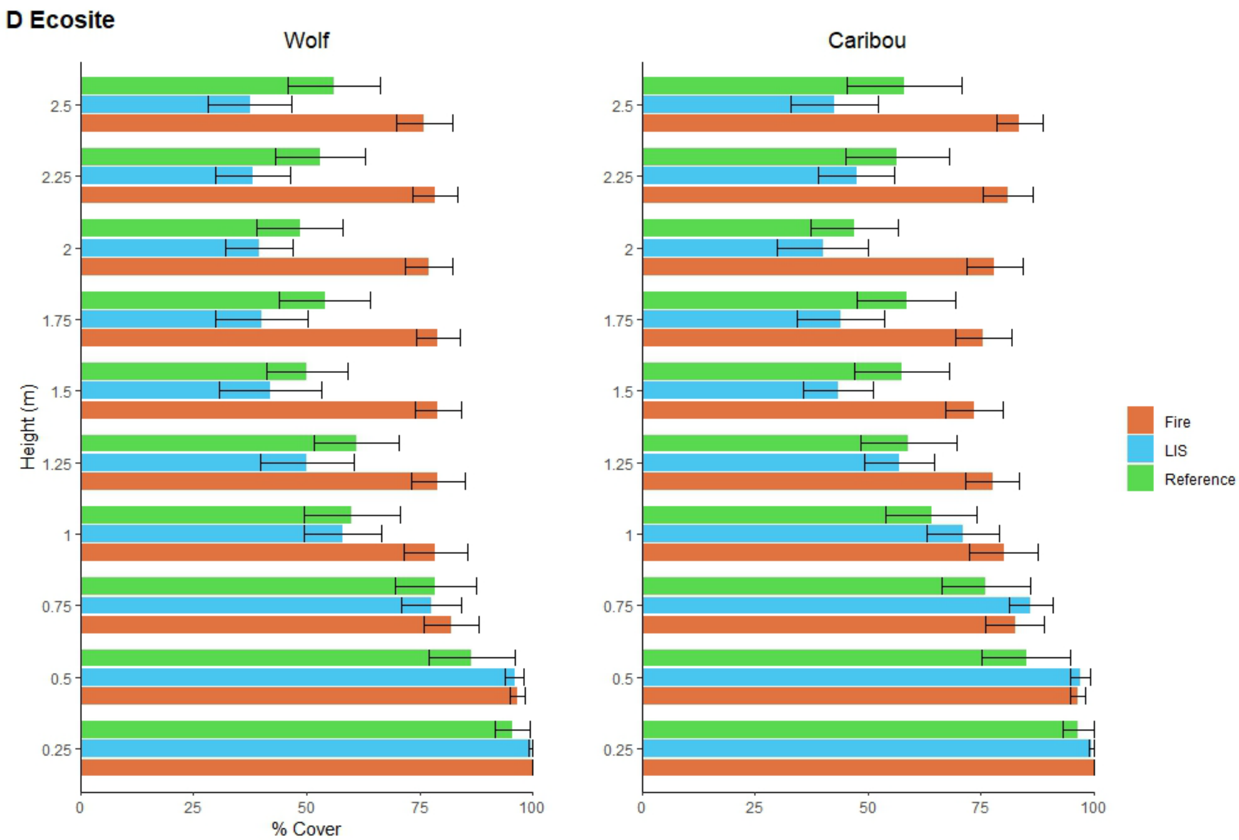
Appendix 1B. Visual obstruction in B Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. Visual obstruction was overall higher in reference than LIS for all height layers for both caribou and wolf, although not significantly in the 0.25 m (P=0.077) and 1.75 m (P=0.146) layers for wolf, and the 0.25 m (P=0.115), 0.50 m (P=0.103), 1.25 m (P=0.077), and the 2.00 m (P=0.062) layers for caribou. Visual obstruction was overall higher in fire plots compared to both LIS and reference for all height layers for both caribou and wolf, although not significantly to reference in the 0.25 m layer for wolf (P=0.061).



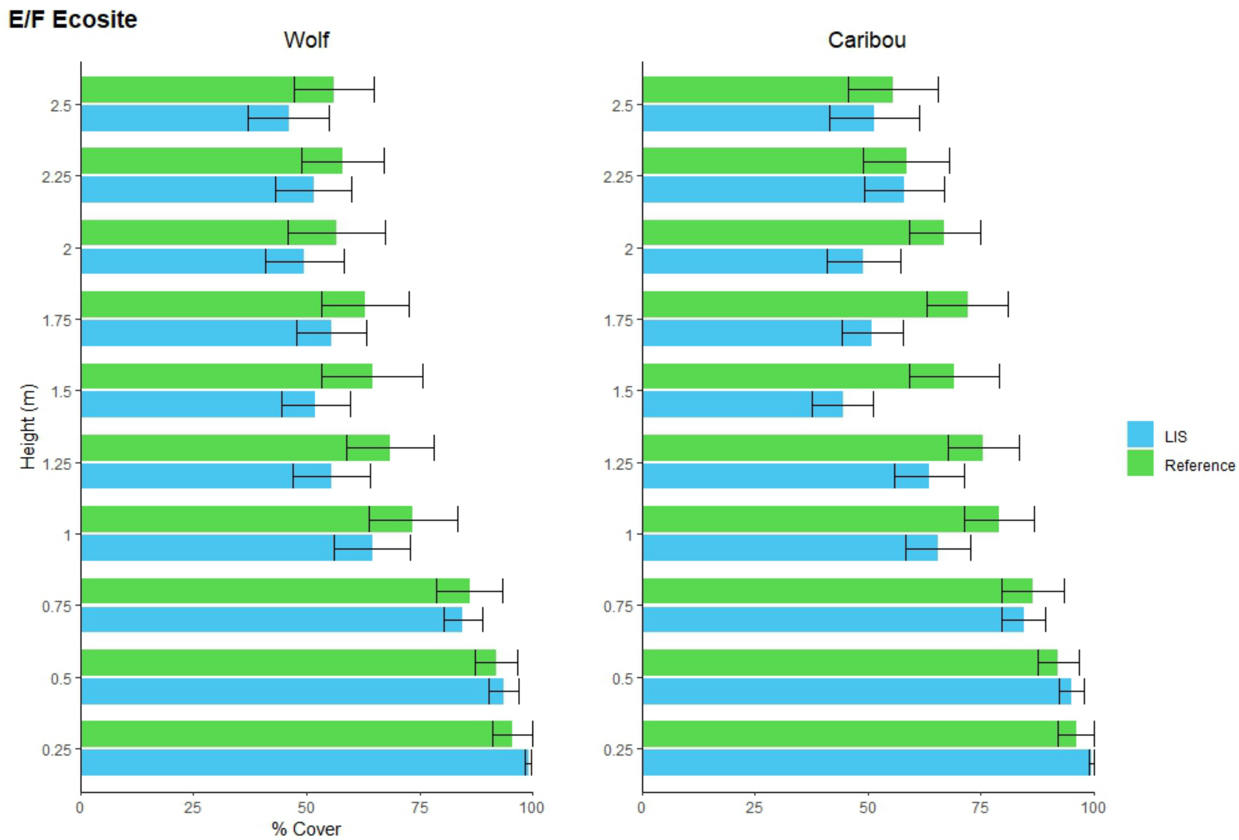
Appendix 1C. Visual obstruction in C Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. Visual obstruction was overall higher in reference than LIS for all height layers for both caribou and wolf, although only significantly in the 2.50 m layer for wolf (P=0.045). Visual obstruction was overall higher in fire plots compared to both LIS and reference for all height layers for both caribou and wolf, although not significantly to reference in the 0.25 m layer for wolf (P=0.077).



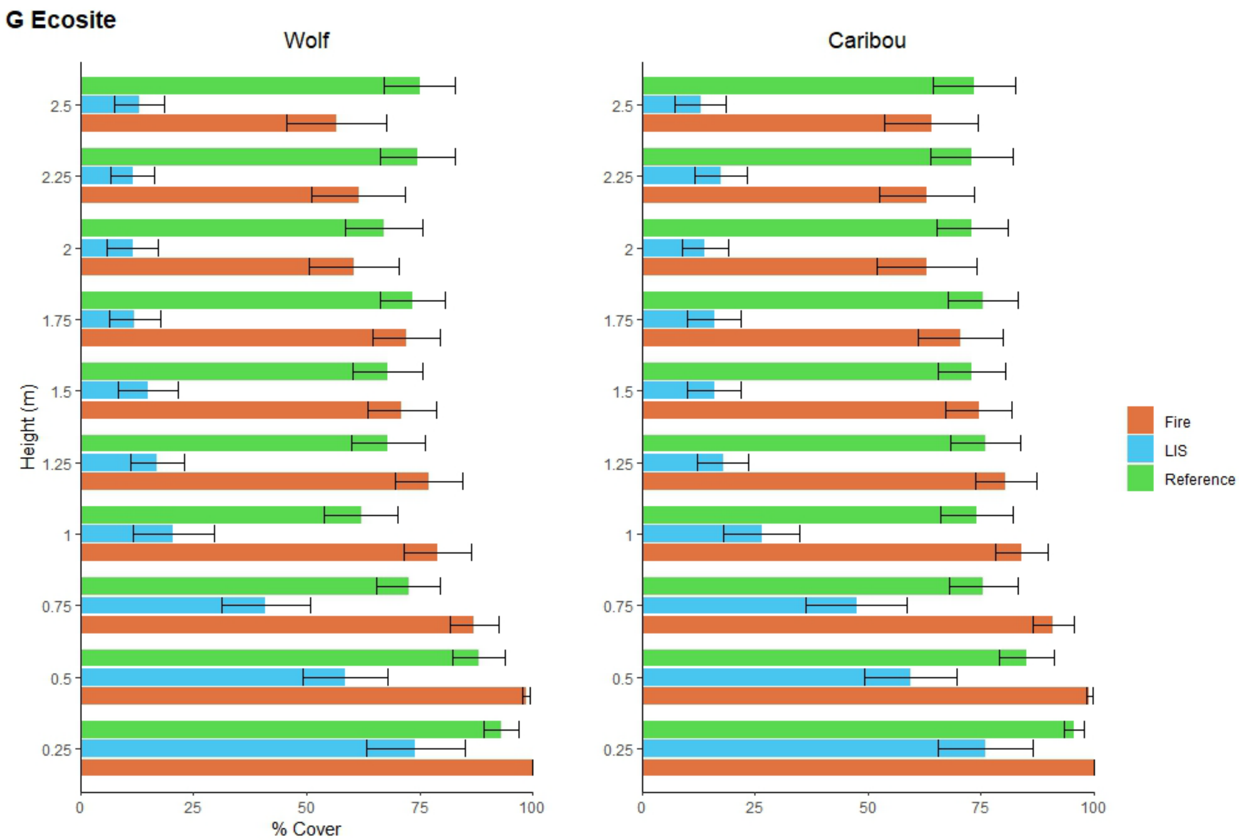
Appendix 1D. Visual obstruction in D Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. There were no significant differences in visual obstruction between LIS and reference in any layer for either wolf or caribou. There were ni significant differences between fire, LIS and reference for wolf and caribou up to and including 1.25 m. For caribou, visual obstruction in fire was significantly higher than reference in the 1.25 m (P=0.040) and the 2.00 m (P=0.063) layers, and significantly higher than LIS in the 1.75 m (P=0.009), 2.00 m (P=0.005) and the 2.5 m (P=0.015) layers. For wolf, visual obstruction in fire was significantly higher than LIS in the 2.00 m to 2.50 m layers (P=0.036, 0.032, and 0.017, respectively).



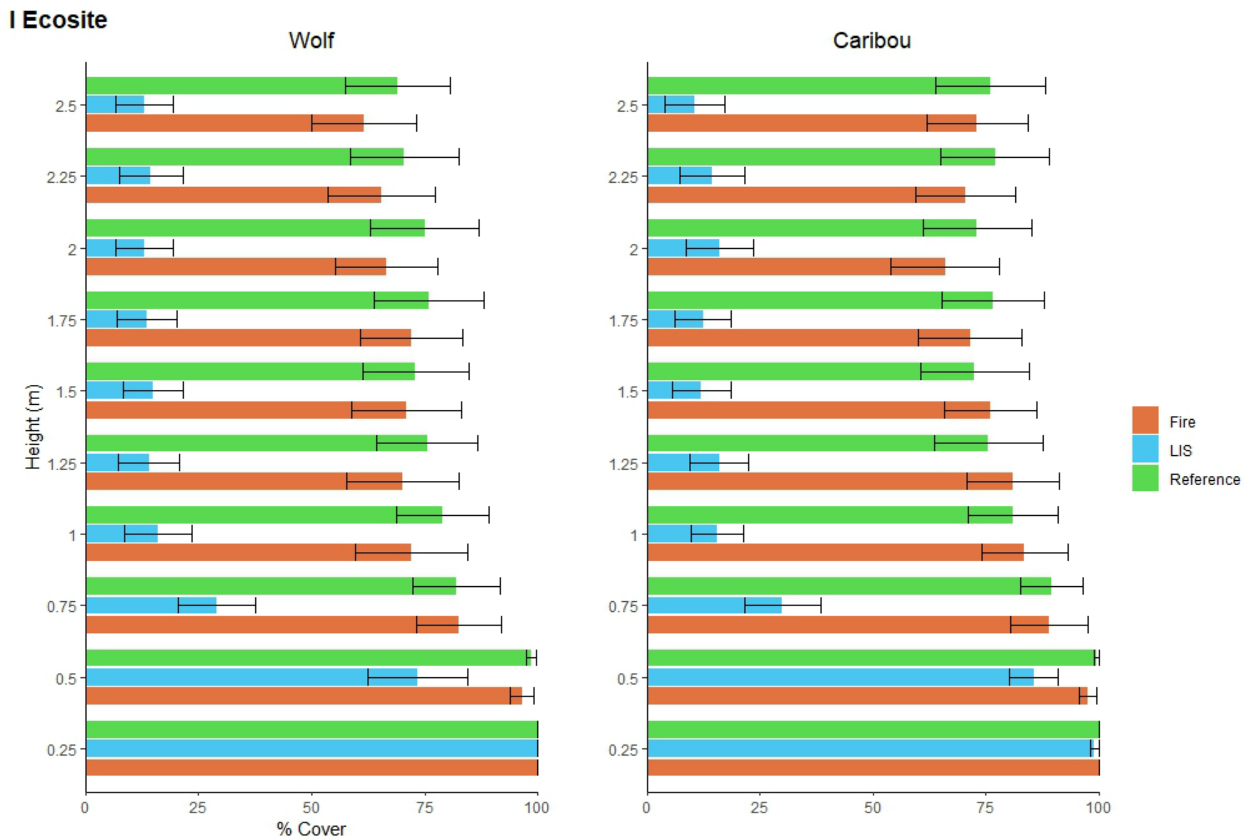
Appendix 1E. Visual obstruction in E+F Ecosite on LIS versus reference, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstruction in any layers were found for caribou or wolf (P>0.050) in LIS versus reference.



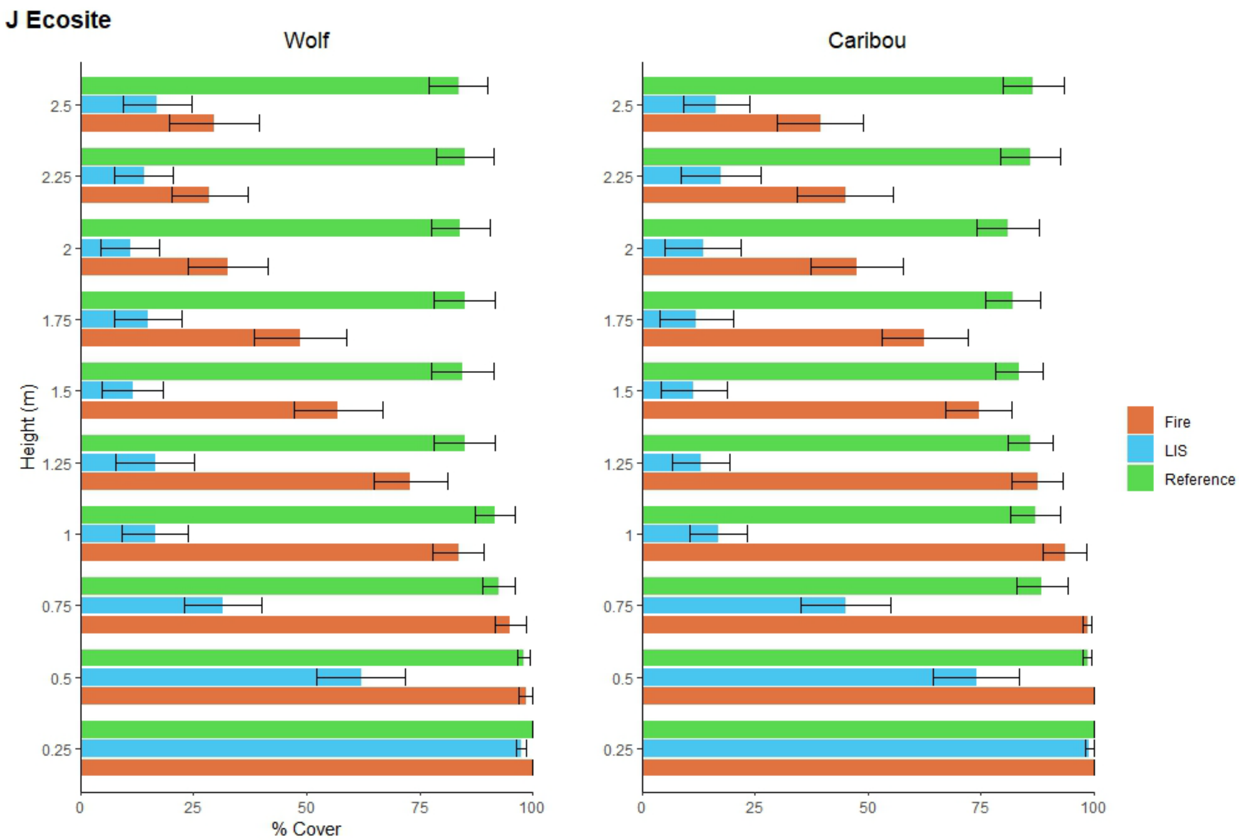
Appendix 1F. Visual obstruction in G Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstruction in any layers were found for caribou or wolf (P>0.050) in fire versus reference with the with the exception of layer 0.50 m for wolf (P=0.043) and 0.75 m for caribou (P=0.007). LIS was significantly lower (P<0.050) than both reference and fire for all height layers for both species.



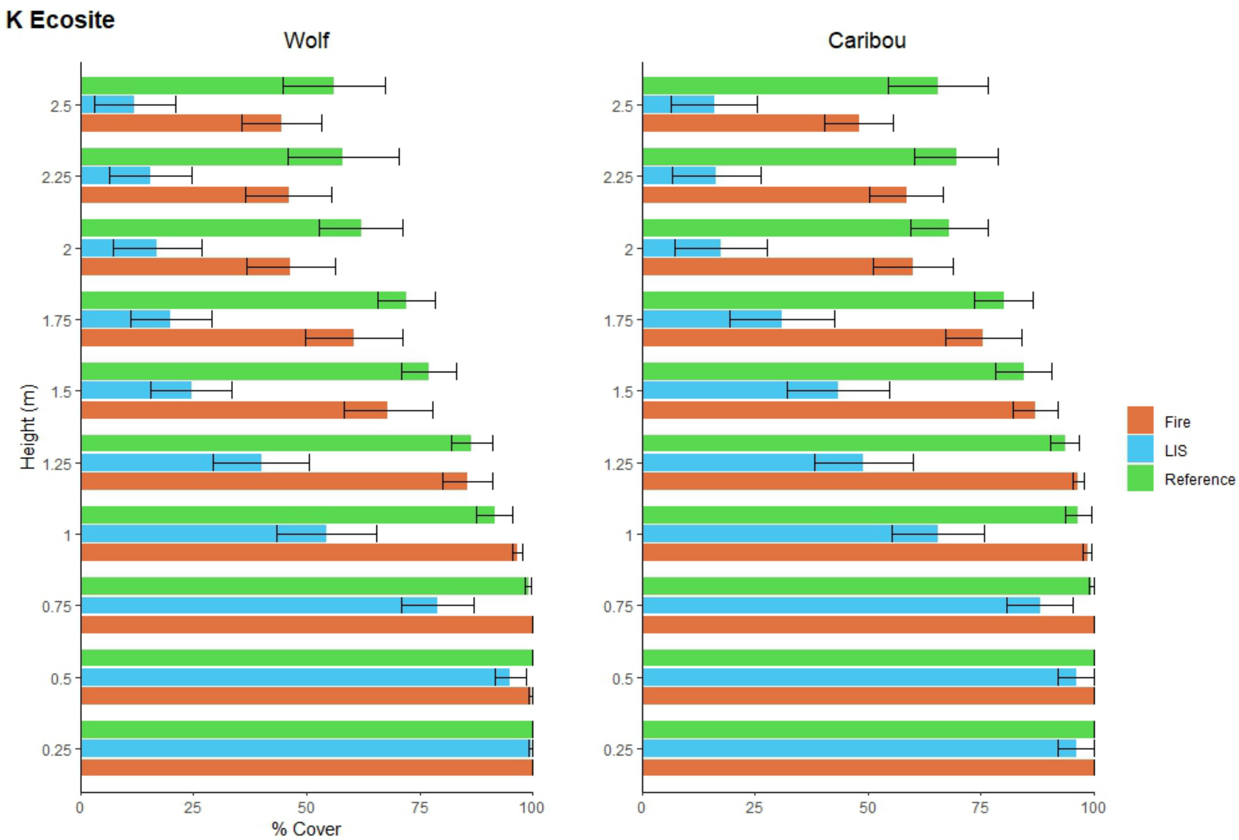
Appendix 1G. Visual obstruction in I Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstruction in any layers were found for caribou or wolf (P>0.050) in fire versus reference. LIS was significantly lower (P<0.050) than both reference and fire for both species in all height layers with the exception of the 0.25 m and 0.50 m layers for both species.



Appendix 1H. Visual obstruction in J Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstruction were found in layers 0.25 m to 1.75 m (wolf) and 0.25 m to 1.25 m (caribou) in fire versus reference. In the higher levels reference was significantly higher than fire for both species. LIS was significantly lower (P<0.050) than both reference and fire for both species in all height layers with the exception of the 0.25 m, 2.25 m and 2.50 m layers for both species.



Appendix 1I. Visual obstruction in K Ecosite on LIS versus reference versus fire, from caribou and wolf perspectives. The error bars are standard errors around the means. No significant differences in visual obstruction in any layers were found for caribou or wolf (P>0.050) in fire versus reference. LIS was significantly lower (P<0.050) than both reference and fire for both species in all height layers with the exception of the 0.25 m to 0.75 m layers for both species.



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Appendix 2. Example photographs of vegetation recovery on LIS by Ecosite.

To be added.

9.0 Appendix B: Project Communications

The following is a list of all project communications as of June 30th, 2024.

- 2 journal publications
  - 2023 (January): First Break, Vol. 41, No. 1: 77-86. The use of miniaturised seismic sources for reduced environmental impact. https://issuu.com/eage/docs/23046- fb23_january_complete
  - 2023 (January): The Leading Edge, Vol. 42, No. 1: 61-68. EcoSeis: A novel acquisition method for optimizing seismic resolution while minimizing environmental footprint. EcoSeis: A Novel Acquisition Method for Optimizing Seismic Resolution While Minimizing Environmental Footprint – Optiseis Solutions Ltd.
- 2 other publications
  - 2023 (March): PPDM article. Land Seismic Data: Why you should keep everything you paid for! https://optiseis.com/2023/03/land-seismic-data-why-you-should-keep- everything-you-paid-for/
  - 2022 (August): Alberta Innovates Public Report on Phase 1 – submitted February, publication was scheduled for 6 months later. https://albertainnovates.ca/impact/publications/
- 33 technical presentations at conferences and workshops
  1. 2024 (June): GeoConvention, The Impact of 3D Sampling on McMurray Formation Imaging, Andrea Crook, https://site.pheedloop.com/event/geoconvention2024/schedule
  2. 2024 (June): GeoConvention (Calgary), Multi-Technology Imaging for Efficient & Effective MMV Plans, Andrea Crook, https://site.pheedloop.com/event/geoconvention2024/schedule
  3. 2024 (June): GeoConvention (Calgary), Reducing the Impact of Seismic: Our primary subsurface tool, Michael Hons, https://site.pheedloop.com/event/geoconvention2024/schedule
  4. 2024 (June): A Solution for Low-Impact Seismic Imaging, Global Energy Show Canada 2024, Andrea Crook, 2024 Technical Program (globalenergyshow.com)
  5. 2024 (May): The Evolution of Seismic Acquisition, CSEG GIFT 2024, Andrea Crook, https://cseg.ca/wp-content/uploads/Schedule-GIFT-2024.pdf
  6. 2024 (May): Sustainable Solutions for CCS Monitoring, AAPG Canada workshop, Andrea Crook, https://www.aapg.org/career/training/in-person/workshops/workshop- details/articleid/66145#program
  7. 2024 (May): Canada Gas Exhibition and Conference (Vancouver), Carbon capture and sequestration in Canada - application of new seismic technologies for injection hub planning, target reservoirs monitoring, Mostafa Naghizadeh, https://canadagaslng.com/about/schedule-at-a-glance/
  8. 2024 (April): Next Generation Geophysical Land & Shallow Water Acquisition (Oman, Virtual Presentation), Minimizing the Impact of Explosive Sources Utilizing Miniaturization of Equipment and Dispersed ArraysAndrea Crook, https://seg.org/wp-content/uploads/2024/04/GALS-Technical-Program.pdf
  9. 2024 (April): CSEG Symposium (Calgary), Miniaturized seismic sources and dispersed source arrays, Mostafa Naghizadeh, https://cseg.ca/professional-development/cseg-

symposium/symposium-schedule/

10. 2024 (February): CSEG-CHOA Joint Symposium (Calgary), Cost-effective 4D solutions for low-impact seismic imaging, Andrea Crook, https://cseg.ca/cseg-choa-joint-symposium/
11. 2023 (December): URTEC LATAM (Argentina), Decarbonization of seismic survey acquisitions, Mostafa Naghizadeh, https://urtec.org/latinamerica/2023/Program/Technical-Program/Monday-Program
12. 2023 (September) - SEG Women's Network (Virtual), Decarbonizing Subsurface Imaging, Andrea Crook Recorded: https://www.youtube.com/watch?v=fjz5NAtdPAM
13. 2023 (September): EOR, Decarbonizing Subsurface Imaging, Andrea Crook, https://www.eortcp2023.com/conference/agenda/
14. 2023 (September): CAGC (Red Deer), Maintaining seismic as the primary subsurface imaging tool by reducing environmental footprint, Michael Hons and David Simmons.
15. 2023 (September): IMAGE (Houston), Designing alternative 3D seismic surveys for reduced environmental footprints using the seismic trace density parameter, Mostafa Naghizadeh, https://imageevent.aapg.org/portals/26/3907102.pdf
16. 2023 (May): GeoConvention (Calgary), Evaluating Innovations in Geophysical Acquisition, Andrea Crook, https://geoconvention.com/wp-content/uploads/abstracts/2023/11115-sustainable-and-innovative-geophysics- acquisition.pdf
17. 2023 (May): GeoConvention (Calgary), EcoSeis: Seismic Surveys for Reduced Environmental Impact, Alyson Birce, https://geoconvention.com/wp-content/uploads/abstracts/2023/91521-ecoseis-can-lower-environmental-fo.pdf
18. 2023 (May): GeoConvention (Calgary), Choosing the Right Seismic Acquisition Geometry for Your Survey: Line Intervals & Distribution Comparison, Mostafa Naghizadeh, https://geoconvention.com/wp-content/uploads/abstracts/2023/91485-choosing-the- right-seismic-acquisi.pdf
19. 2023 (May): GeoConvention (Calgary), What does Fresnel Fold mean?, Michael Hons, https://geoconvention.com/wp-content/uploads/abstracts/2023/91516-what-does- fresnel-fold-mean.pdf
20. 2023 (May): WBPC (Regina), Carbon Capture and Sequestration in Alberta - injection hub planning, target reservoirs, and the application of new seismic technologies, Andrea Crook, Henry Williams, Mostafa Naghizadeh, Alyson Birce, and Michael Hons, https://www.wbpc.ca/conference/technical-program/
21. 2023 (March): AEGC (Australia). Designing Seismic Surveys for Reduced Environmental Impact. https://2023.aegc.com.au/cms/wp-content/uploads/AEGC-2023-Detailed- Program-3.3.23.pdf
22. 2023 (March): AEGC (Australia). Using seismic trace density for optimal 3D seismic survey design. https://2023.aegc.com.au/cms/wp-content/uploads/AEGC-2023-Poster- Program.pdf

23. 2023 (February): AAPG Workshop (Barranquilla). Sustainable Subsurface Imaging Technology Part 1: Design, Processing, and Interpretation. https://optiseis.com/2023/02/caribbean-2023-geosciences-technology-workshop- february-8-2023/
24. 2023 (January): ACGGP Workshop (Bogota). Reducing the environmental impact of acquiring seismic data. https://www.linkedin.com/feed/update/urn:li:activity:7026918017326350336
25. 2022 (November) – CHAO/CSEG Symposium (Calgary). EcoSeis – Reducing the environmental impact of acquiring seismic while maintaining data quality https://optiseis.com/2022/10/cseg-choa-joint-symposium/
26. 2022 (November) – EAGE Near Surface (Colombia, Virtual). https://optiseis.com/2022/10/second-eage-conference/
27. 2022 (November) – GSH 3D Design Symposium. Reducing the Environmental Impact Of Acquiring Seismic Data: An Ecoseis case study. https://www.gshtx.org/SharedContent/Events/Event_Display.aspx?EventKey=2ffd2ae2- 32d0-4fd5-9341-6e2bbeb3c3e2&iSearchResult=true&WebsiteKey=955f17e6-46ad- 4401-acbd-2af6c393752b
28. 2022 (September) – Carbon Capture Canada (Edmontona), EcoSeis: A Solution for Lowering the Environmental Footprint of Seismic Imaging Carbon Capture Canada Sept. 20-22, 2022 – Optiseis Solutions Ltd. https://www.carbonexpocanada.com/
29. 2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference (Houston), Workshop; Evaluating Acquisition Innovations: A Guide for Accurate Assessments.
30. 2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference (Houston), Technical Presentation; Optimal Infilling of seismic station using Fresnel zone binning analysis. https://library.seg.org/doi/10.1190/image2022-3750648.1
31. 2022 (June) – GeoConvention Conference (Calgary). Turn your seismic program into a lean, green, resolution machine. https://optiseis.com/2022/06/turn-your-seismic- program-into-a-lean-green-resolution-machine/
32. 2022 (June): GeoConvention (Calgary). Fresnel zone binning analysis for determining optimal seismic infill stations. https://optiseis.com/2022/06/fresnel-zone-binning- analysis-for-determining-optimal-seismic-infill-stations/
33. 2022 (April) – ICE AAPG Conference (Cartagena, Colombia), Miniaturized Sources and Their Applications. https://cartagena2022.iceevent.org/program/technical-program/on-demand-only

- 24 General EcoSeis Presentations, Panel Discussions, Pod Casts, and Pitches
  1. 2024 (June): GeoConvention, Showcase Stage 1: Is exact source and receiver repeatability necessary for timelapse (4D) seismic surveys: Learnings from EcoSeis phase II, Andrea Crook, https://geoconvention.com/wp-

content/uploads/documentation/2024/2024-showcase-stage.pdf

2. 2024 (June): GeoConvention, Showcase Stage 1: Understanding Linear Seismic Acquisition Geometries, Andrea Crook, https://geoconvention.com/wp-content/uploads/documentation/2024/2024-showcase-stage.pdf
3. 2024 (March): Ecoseis, Trade mission Colombia-Canada, Jason Dagenais, https://export.alberta.ca/event-items/approved-events/2023/colombia-and-guyana- energy-trade-mission/
4. 2024 (February): Innovation Day: Forging the future: where digital innovation meets mining excellence. Andrea Crook, PlugandPlay Mica. https://www.plugandplaytechcenter.com/events/innovation-day/
5. 2023 (November) PTAC Ecological Forum presentation. Andrea Crook, https://www.ptac.org/current-events/2023-ecological-forum/
6. 2023 (November) CRIN Interview for COP 28 https://www.dropbox.com/scl/fi/z41r4a07zvwl3xgnqjx8k/18-OptisSeis-Third-Delivery- V01-Subtitles.mp4?rlkey=uxry268fdgvuod09od4xuevxq&dl=0
7. 2023 (November) Platts Capital Crude podcast with S&P , New underground mapping may mean more oil and gas, fewer cut trees. Andrea Crook, https://www.spglobal.com/commodityinsights/en/market-insights/podcasts/crude/231120-underground-mapping-oil-gas-cut-trees-optiseis- canada-seismic-survey
8. 2023 (October) PTAC Digital Innovation Forum, Andrea Crook, https://www.linkedin.com/events/digitalinnovationforum7084969631806877696/com ments/
9. 2023 (September): WPC, Clean Resource Innovation Network: Cleaner Fuels, Land Theme Overview & Innovator presentations, Andrea Crook, Carbon Tech Expo: CRIN booth #3317
10. 2023 (September): WPC, CEO Strategic Session 6: Driving Innovation in a Net Zero World, This panel addressed research and development of next-generation technologies and investment in breakthrough research across a broad spectrum of other energy technologies and across sectors, Deborah Yedlin, President and CEO - Calgary Chamber of Commerce (moderator), Matthew Crocker, Senior Vice President, Product, Strategy and New Assets – ExxonMobil, USA, Andrea Crook, Co-Founder and CEO - OptiSeis Solutions Ltd., Canada, Tiago Homem, Head of Reservoir Management – Petrobras, Brazil, and Elizabeth Rogo, Founder and CEO, TSAVO Oilfield Services, Kenya, https://www.24wpc.com/congress-programme
11. 2023 (September): WPC, Pathways Alliance: CEO Strategic Session 6: Driving Innovation in a Net Zero World - Q&A with Andrea Crook, Pathways booth #2015,
12. 2023 (September): WPC, Pathways Alliance: Subsurface Imaging + Net Zero, Andrea Crook, Pathways booth #2015
13. 2023 (September): WPC, B2B Program - Cleantech Pitches: Digital Solutions Theme. The path to net zero is challenging, and it's also filled with opportunity, Andrea Crook, https://www.24wpc.com/b2b-programme-details, https://www.linkedin.com/feed/update/urn:li:activity:7110439824200798208

https://www.linkedin.com/feed/update/urn:li:activity:711030340076380569 6

14. 2023 (September): WPC, Carbon Tech Expo Session 6: Commercializing CCUS technologies. The panel discussed key challenges faced by technologies as they move to commercialization and what the process looks like, Breanne O'Reilly, Communications and Marketing – Carbon Management Canada (moderator), Greg Maidment, Director, Operations and Applied Research – Carbon Management Canada, Andrea Crook, CEO and Co-founder – Optiseis, Rob Baillargeon, Innovation Lead – Cenovus, Brett Henkel, Co-founder and SVP – Svante, https://www.24wpc.com/carbon-tech-expo-details
15. 2023 (May): GIFT, Geophysical Innovations for the New Energy Economy, Andrea Crook.
16. 2023 (May): GIFT, Seismic reflection Acquisition: Sampling, Sources, and Sensors. Mostafa Naghizadeh
17. 2023 (March): Crownsmen Partners's Interview. Optimizing Seismic surveys and the application of seismic methods in carbon capture and storage.
18. 2023 (January): GeoWomen. https://www.linkedin.com/feed/update/urn:li:activity:70222793719 65038592
19. 2023 (January): Pathways-COSIA
20. 2022 (November) – CSPC Panel https://optiseis.com/2022/10/canadian-science-policy- conference/
21. 2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Presentation; reducing environmental impact of Acquiring Seismic – The EcoSeis Approach.
22. 2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Panel Discussion; Imaging Acquisition and Interpretive Technologies: Surface and Subsurface.
23. 2022 (August): Crowsmen interview. https://optiseis.com/2023/02/building-energy- optiseis-solutions-is-changing-seismic-exploration-landscape/
24. 2022 (March) – CRIN Announcement. https://cleanresourceinnovation.com/news/new- technologies-funded-by-crin-competition-to-address-environmental-and-economic- challenges-of-canadas-oil-and-gas-industry

- 1 Workshops
  - 2023 (March): Workshop at AEGC. Advances in Seismic Acquisition: Innovations, Resolution, and Sustainability Applications for Mining. https://2023.aegc.com.au/workshops/
- 9 pitches
  1. 2023 (October) CarbonNEXT – Foresight Pitch: EcoSeis https://www.youtube.com/watch?v=f3dZUu ND50M
  2. 2023 (September): WPC, 2023 PROPEL Energy Tech Forum, Andrea Crook, CEO and Co- founder, Optiseis, https://www.24wpc.com/programming https://www.linkedin.com/feed/update/urn:li:activity:711043982420079820

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3. 2023 (May): Plug & Play, Reducing the environmental impact of subsurface seismic imaging, Andrea Crook.
4. 2023 (April): Foresight Pitch event, Reducing the Environmental Impact Of subsurface imaging, Andrea Crook. https://www.youtube.com/watch?v=nktIsoLKHwQ
5. 2023 (March): HETI Pitch Competition & Award. https://optiseis.com/2023/03/heti- energy-ventures-pitch-competition-march-8-2023/
6. 2023 (January): Plug and Play. https://www.plugandplaytechcenter.com/startups/our- startups/
7. 2022 (November) – Foresight Demo Day
8. 2022 (November) - Foresight Top50 Foresight 50 - Meet Canada's Most Investable Companies - Foresight (foresightcac.com)
9. 2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; U-pitch New Technology Showcase; EcoSeis: A lower Carbon Solution for Seismic Acquisition
10. 2022 (June) – Propel Conference https://propelenergytech.com/

- 105 announcements/updates on OptiSeis linked in and 40 on OptiSeis website since June 2022 when we began tracking.
- 10 conference booths showcasing EcoSeis. Numerous presentations on EcoSeis were given at each conference:
  1. 2024 (June) Booth at GeoConvention in Calgary, AB
  2. 2024 (April) Booth at CSEG Symposium in Calgary, AB
  3. 2023 (September): Booth at Carbon Capture Canada in Edmonton, AB
  4. 2023 (August): Booth at IMAGE '23 in Houston TX
  5. 2023 (April) Booth at CSEG Symposium in Calgary, AB
  6. 2023 (May) Booth at GeoConvention in Calgary, AB
  7. 2023 (March): Booth at 3D Seismic Symposium in Denver, CO
  8. 2023 (February): Booth at AAPG Workshop in Barranquilla, Colombia
  9. 2022 (August): Booth at IMAGE '22 in Houston, TX
  10. 2022 (June) Booth at GeoConvention in Calgary, AB