2023 COSIA LAND EPA

Mine & In Situ Research Report

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cosia with Pathways Alliance

INTRODUCTION

Canada's Oil Sands Innovation Alliance (COSIA) is the innovation arm of Pathways Alliance, an organization created by Canada's major oil sands producers to advance responsible development of the industry, including addressing the critical challenge of climate change. For more than 10 years, COSIA has brought together innovative thinkers in industry, government, academia and the public to drive innovations that reduce impacts to air, water and land. COSIA continues this important work through Pathways Alliance and is the cornerstone of an ambitious plan to help meet Canada's climate commitments by reducing CO2 emissions from oil sands production to net zero by 2050.

This report is funded by members of COSIA's Land Environmental Priority Area (EPA):

Canadian Natural Resources Limited (Canadian Natural)
Cenovus Energy Inc. (Cenovus)
ConocoPhillips Canada Resources Corp. (ConocoPhillips)
Imperial Oil Resources Limited (Imperial)
Suncor Energy Inc. (Suncor)*
Syncrude Canada Ltd. (Syncrude)**

For 2023 COSIA published a combined research report, 2023 COSIA Land EPR — Mine and In Situ Research Report. This report summarizes progress for projects related to in situ and mine reclamation of the COSIA Land EPA. The project summaries included in this report do not include all projects completed under the Land EPA.

Please contact the Industry Champion identified for each research project if any additional information is needed.

2023 COSIA Land EPA — Mine and In Situ Research Report. Calgary, AB: COSIA Land EPA.

* Teck Resources sold its stake in the Fort Hills project to Suncor Energy in October 2022 and exited the oil sands business and its COSIA membership.

** Suncor Energy assumed operatorship of the Syncrude Joint venture in October of 2021, however Syncrude Research and Development remains a full member of COSIA.

Front cover image: A Wood Frog at Gateway Hills, Syncrude's certified reclaimed area, Alberta. Image courtesy of Syncrude Operated by Suncor.

WETLANDS

Removing the Wellsite Footprint (iFROG)

COSIA Project Number: LJ0216

In Situ

Research Provider: Circle T Consulting Inc.

Industry Champion: ConocoPhillips

Industry Collaborators: AOC Leismer Corner Partnership, Canadian Natural, CNOOC Petroleum North America ULC, Harvest Operations Corp., Cenovus, Imperial, Japan Canada Oil Sands Limited, MEG Energy Inc.

Status: Year 7 of 7

PROJECT SUMMARY

The purpose of the industrial Footprint Reduction Options Group (iFROG) is to develop, fund and implement a balanced portfolio of boreal wetlands research projects that:

- Follow the fundamental guiding principles of land stewardship, intelligent research, and collaboration;
- Demonstrate iFROG members are meeting the intent of the applicable wetland research conditions in their respective Environmental Protection and Enhancement Act (EPEA) Approvals (for oil sands in situ projects);
- Contribute to mitigating impacts to wetlands during operations; and
- Increase the knowledge base for, and confidence in, wetland reclamation efforts.

iFROG continued support of the Greenfire Road Reclamation Study in 2023 and extended support for two additional years to enable vegetation, hydrology, and greenhouse gas monitoring for a full five years after application of reclamation treatments, including vegetation recovery monitoring on moss donor areas. Field work and data analysis for the Pad TT Road Construction Best Practice project concluded in 2022, but final reporting carried over into early 2023. A report was submitted to Alberta Innovates, which also supported the project, in 2023. In addition, a presentation on the project was made to RE3 2023 in Quebec City in 2023. These are described more fully in the Presentations and Publications section below. While the From Dirt to Peat project was not funded in 2023, iFROG supported NAIT in acquiring additional funding from Natural Sciences and Engineering Research Council of Canada (NSERC) through the Campus Alberta Small Business Engagement (CASBE) Program, administered by Alberta Innovates, to produce extension materials for reclamation operators and practitioners.

Greenfire Road Reclamation Study (Year 5 of 7)

The JACOS/Greenfire Road Reclamation Study involves the continuation of reclamation work first initiated in 2010 within a bog peatland. Whereas the initial study restricted treatments to three treatment blocks established on only a subsection of the road, the entire road was reclaimed in the present study and examines two primary reclamation strategies. Partial fill removal is used in both strategies, where only enough fill was removed to establish a revegetation surface with an elevation that is continuous with the adjacent peat. One strategy attempts to establish peatland vegetation on the mineral fill surface, while the second attempts to establish peatland vegetation on varied depths of organic substrate.

The road was divided into two study areas, one for each of the revegetation strategies. Fill on the mineral substrate section was removed until the surface was continuous with the adjacent peatland and the surface was inoculated with fen peatland propagules from a nearby donor site and covered with straw mulch. Fill on the organic substrate section was excavated to below the elevation of the adjacent peatland to the desired depth of organic substrate, and then filled to the adjacent peatland elevation with stockpiled peat. The peat surface was inoculated with bog peatland propagules from a nearby donor site and covered with straw mulch.

The objectives of the mineral section are to compare revegetation success on two surface treatments (smooth and lightly scarified), to identify drivers of the emergent vegetation, and assess any physico-chemical effects of the exposed mineral surface on the adjacent peatland.

The objectives of the peat substrate study are to evaluate revegetation methods such as substrate depth and fertilization, as well as identify drivers of the emerging plant community (e.g., soil pH, electrical conductivity, water content, and soil and water chemistry).

Final analyses will compile and consolidate all observations for the five growing seasons from 2020 through 2024, with final reporting completed in 2025.

From Dirt to Peat (funding concluded, but iFROG support continued for development of extension materials and final reporting)

This study was a three-year, multi-site, meta-analysis that examined ecological recovery in response to a range of reclamation practices over a range of conditions, including both partial and complete removal of fill from roads and pads constructed within wetlands. Seven pads and two linear features were studied, including the iFROG Canadian Natural pad (2011) and the Greenfire road study sites.

The study objective was to characterize each site in terms of its functioning, or potential to function, as a healthy peatland based on emerging vegetation communities and peat accumulation potential. Ecological response variables included vegetation composition, accumulation of organic matter ("peat thickness"), above and below ground biomass productivity, biomass decomposition, peat accumulation potential (calculated) and GHG (greenhouse gas) balance. Explanatory variables included the site-specific treatments, as well as environmental conditions such as local climatic indicators, soil and water chemistry, soil moisture and soil temperature. Reclamation site response variables were compared with similar variables on reference peatlands within the oil sands areas in which the study sites are located.

Additional funding through CASBE enabled the project to be extended, allowing for the creation of extension materials for reclamation operators and practitioners. These materials include 360-degree videos of study sites, such as the Greenfire Road Reclamation site.

Pad TT Road Construction Best Practice (Concluded, final reporting completed in 2023)

Devon Canada constructed a road at the Jackfish 2 project (now named Canadian Natural Jackfish 2) intersecting several areas of deep fen peat that are each approximately 180 m long. Timber corduroy was used as road foundation over the soft peat sections in conjunction with several 600 mm steel culverts that were closely spaced within each section. High-density polyethylene (HDPE) pipe bundles or log bundles were installed among the culverts to facilitate additional drainage. Seventeen culverts and seven bundles were installed along the 1.5 km length of road.

Study objectives were to:

- Determine whether the road allows water to pass through effectively as a result of the corduroy and drainage conduit installations;
- Characterize flow rates and patterns in the vicinity and through the road to assess the effectiveness of the type and number of conduits; and
- Assess road performance in the corduroy sections as indicated by progressive road settlement over time and identify any problem areas.

PROGRESS AND ACHIEVEMENTS

Greenfire Road Reclamation Study

As noted above, the monitoring of vegetation succession, hydrology, and greenhouse gas exchange continued on the road reclamation area in 2023, along with continued monitoring of vegetation recovery on moss donor sites. Analyses of data collected in 2023 has not been completed but anecdotal observations indicate that vegetation succession on the reclamation area is very dynamic. However, moss persistence shows promise for eventual reclamation success.

Drought conditions in 2022 appeared detrimental to mosses established in previous years; however, the abundant moss observed in 2023 demonstrated the resiliency of established mosses to apparently adverse conditions. Similarly, increased *Scirpus cyperinus* (woolgrass) and *Carex spp*. cover in the organic treatment section, and increased *Trifolium hybridum* (alsike clover) and *Melilotus officinalis* (yellow sweet clover) cover in the mineral section was expected to diminish moss expansion due to light competition and accumulation of excess litter.

Nevertheless, mosses are persisting under these conditions, indicating their potential for eventual expansion over time as site vegetation communities continue to equilibrate. For example, planted trees should eventually begin to shade out graminoids and forbs, thereby reducing competition to mosses from these plants. The cover of mosses continued to increase on moss donor sites.

In 2023, it was observed that a number of temporary water diversion devices installed along the edges of the mineral section in the fall of 2022 to redirect water across the former road surface, proved to be successful in improving moisture conditions on the reclamation area. The diversion devices will be removed once bryophytes have become sufficiently established to self-regulate varying moisture conditions.

From Dirt to Peat

Analyses of study data was completed in 2023. Resulting manuscripts are presently under preparation with expected completion in late 2024.

There was a wide array of site types and treatments applied, but regardless of site type or reclamation treatment the following general conclusion was drawn: application of peat donor material, specifically sphagnum and true mosses, produced greater accumulation of peat on reclaimed sites than treatments without donor material. These results indicate the importance of active species reintroduction to ensure the success of peatland reclamation.

A number of 360-degree videos of the study sites were recorded during 2023. Currently, there is a limited amount of raw footage available. The footage will be edited to incorporate narration and links to data collected on site, to produce instructional videos that demonstrate outcomes of the various reclamation practices under various site conditions. The production of extension materials will continue through 2024.

Pad TT Road Construction Best Practice

Detailed results for this study are now published, Alternative Road Construction to Reduce Peatland Water Flow Obstruction. There are no new results to report for 2023.

LESSONS LEARNED

Greenfire Road Reclamation Study

As observed in the From Dirt to Peat Project, vegetation establishment on the reclaimed road surfaces emphasize the importance of inoculation with moss fragments from suitable donor sites. Further, the study demonstrates that moss transfer is an effective tool for revegetating wetland reclamation surfaces with indications so far that impact on moss donor areas is minimal.

Observations in 2023 emphasize the need for patience in wetland reclamation. Mosses are slow growing, yet resilient, while herbaceous species grow much faster and can have more dramatic responses to growing conditions. Persistence of mosses observed in 2023 inspired confidence that seemingly dire observations under adverse conditions in previous years are only temporary. Vegetation succession on reclaimed wetlands can be very dynamic, particularly in early years. Therefore, more time is required to demonstrate reclamation success on wetlands than uplands. In addition, trust in the resiliency of established bryophytes is warranted, and indeed required, in the face of what may look like revegetation failings during the first few years.

Finally, to ensure moisture conditions are favourable to desired vegetation establishment, wetland reclamation may require additional interventions until established vegetation can contribute more to moisture regulation.

While the water diversion devices installed in 2022 improved moisture conditions on the reclaimed road surface in 2023, they will eventually need to be removed because they are foreign materials. Mechanisms for water management might be incorporated directly as part of reclamation treatments using natural materials. For example, anticipating that the discontinuity between the bog and remaining road fill edges may cause channeling of runoff water, berms could be constructed from appropriate substrate (e.g., stockpiled peat) to redirect runoff onto the reclaimed surface. Such berms could be revegetated at the same time as the primary reclamation surface, eliminating the need for future removal. Instead, they would become an integral feature of the reclaimed area.

From Dirt to Peat

No new lessons were derived in 2023 since the project has moved on to the knowledge transfer stage. Lessons learned in 2022 still apply:

Successful wetland reclamation is a reasonable expectation based on the successful establishment of peatland vegetation and peat accumulation on the range of sites and practices studied. Inoculation with moss fragments from donor sites increases the likelihood of revegetation success and increases similarity between reclaimed sites and adjacent peatlands. Peatland vegetation establishment is equally viable on mineral or peat substrate, but a mix of substrates (i.e., both types present as opposed to blended) increases abundance of peatland species. Inoculation with moss fragments from donor sites hastens peat accumulation.

Pad TT Road Construction Best Practice

No new lessons were derived in 2023. The full report is available here. The lessons learned, as described in 2022, are outlined below.

All conduits, as well as corduroy contributed to increasing permeability of the road to water flow. However, corduroy alone was less effective than corduroy with the addition of a conduit closer to the ground surface. While conduits were somewhat similar in effectiveness, log bundles seemed less effective than culverts or pipe bundles. Reduced effectiveness of log bundles is likely because flow is limited to the spaces between logs, whereas pipe bundles have the spaces between pipes as well as the open tubular space to accommodate flow. Culverts of course are completely open with very little resistance to flow.

Conduits were most effective at higher water table conditions, where the water table could reach the elevation of the conduit to access the openings and flow through. This limitation impeded subsurface water flow, causing it to build up on the upstream side of the road. Therefore, additional subsurface drainage capacity needs to be integrated into road designs to address subsurface flow. Such designs could include larger diameter culverts, stacked culverts or culvert pyramids, larger pipe and/or log bundles, additional log layers in the corduroy, or rock fill foundations.

All the conduits examined are useful in promoting road permeability, but choice of conduit type and placement should be made based on enhanced assessment of peatland hydrologic conditions prior to road construction. Since most road drainage designs rely primarily on models of surface flow, assessment of subsurface flows should be integrated into drainage designs. Conduit type, size, depth, and spacing could then be selected based on a better estimate of water volumes required to be moved in conjunction with cost and availability of conduit materials.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Guerin, P. 2023. Restoration of a plant community with potential for peat accumulation on the mineral substrate of a peatland disturbed by a road. RE3 2023 (Reclaim, Restore, Rewild), Joint Conference of Society for Ecological Restoration, Canadian Land Reclamation Association, and Society of Wetland Scientists, June 11-15, 2023, Quebec City.

Isabel, C. 2023. Restoration of a Sphagnum-dominated peatland disturbed by a road. RE3 2023 (Reclaim, Restore, Rewild), Joint Conference of Society for Ecological Restoration, Canadian Land Reclamation Association, and Society of Wetland Scientists, June 11-15, 2023, Quebec City.

Osko, T. 2023. Alternative road construction to reduce peatland water flow obstruction. RE3 2023 (Reclaim, Restore, Rewild), Joint Conference of Society for Ecological Restoration, Canadian Land Reclamation Association, and Society of Wetland Scientists, June 11-15, 2023, Quebec City.

Xu, B. 2023. Evaluation of peatland restoration outcomes in Alberta's in-situ oil sands region. RE3 2023 (Reclaim, Restore, Rewild), Joint Conference of Society for Ecological Restoration, Canadian Land Reclamation Association, and Society of Wetland Scientists, June 11-15, 2023, Quebec City.

Reports & Other Publications

Osko, T. 2023. Alternative Road Construction to Reduce Peatland Water Flow Obstruction. Circle T Consulting Inc. Produced for Alberta Innovates. January 2023. 28 pp. https://albertainnovates.ca/projects/alternative-road-construction-to-reduce-peatland-water-flow-obstruction/

RESEARCH TEAM AND COLLABORATORS

Institution: Circle T Consulting Inc.

Principal Investigator: Terry Osko

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Line Rochefort	Université Laval	Professor of Peatland Ecology		
Bin Xu	NAIT Centre for Boreal Research	NSERC Industrial Research Chair in Peatland Restoration		
Melanie Bird	NAIT Centre for Boreal Research	Senior Research Technician		

Assessing the Ecological Potential of Wetlands Surrounding Reclaimed Pads

COSIA Project Number: LE0083

In Situ

Research Provider: Vertex Professional Services Ltd.

Industry Champion: Suncor

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Imperial, Syncrude

Status: Year 2 of 2

PROJECT SUMMARY

This project was initiated to inform in-place reclamation of in situ well site pads on wetlands (those without padded access roads) by using conventional oil and gas well site pads that have been reclaimed in place as a proxy. Few pads developed for in situ well sites and facilities have been reclaimed; thus, long-term information on the ecology and properties of wetlands surrounding them after they are reclaimed is not readily available or does not exist. Conventional oil and gas pads reclaimed in place are numerous and many have been reclaimed in place for 20 to 40 years. The ecology of the peatlands surrounding these pads can provide vital proxy information to guide the future reclamation of in situ pads.

The specific objectives of the study are to:

1. Determine if conventional oil and gas pads reclaimed in place, without a padded access road, have altered water and vegetation properties of the surrounding wetlands (peatland).
2. Determine key characteristics of pads that can be used to predict if the surrounding peatland may be impacted.
3. Determine key characteristics of peatland in which the pad is located that can be used to predict if a pad will impact the surrounding peatland.

PROGRESS AND ACHIEVEMENTS

This project has been completed in phases, with site selection completed in 2019, a pilot study in 2021, and a full study in 2023. Between the pilot study and full study, data were collected from 21 pads distributed among bogs, fens, and swamps. Data collection included characterizing the pad and surrounding peatland. Pad measurements included thickness, underlying peat thickness, and physical and chemical properties of the pad material (clay). Measurements of water depth, water chemistry, vegetation composition, tree density, and growth were taken in the peatland surrounding the pad at various distances and landscape positions relative to the pad.

Preliminary results indicate that the first two objectives of the study can be addressed. However, based on limited impacts to surrounding peatlands, the last objective may not be addressed. Full study findings support the findings of the pilot study:

- When compared to reference areas, increases in peatland surface water conductivity and soluble ions were observed downstream of pads at a limited number of locations.
- No change in vegetation was observed despite the differences in water chemistry.
- Increases in surface water conductivity and soluble ions were only detected in areas less than 50 m from the pad.

Data analyses are ongoing, and the final report will be completed in 2024.

LESSONS LEARNED

The project determined that the long-term ecological effect of conventional oil and gas pads, each less than one hectare in size and without padded access roads to the surrounding peatland, is slight. Changes to peatlands are typically limited to the water chemistry within 50 m downstream of the pad downstream areas. Over time, but not detected here, changes in water chemistry may shift the vegetation from one peatland type to another (e.g., poor to moderate-rich fen), but this shift is not readily apparent in the vegetation community.

Other learnings include:

- Without site-specific baseline data, the natural variability of regional reference data masks slight changes in peatland characteristics.
- Selecting appropriate reference data for each wetland type can be difficult due to various differentiating parameters such as wetland type, form, class, age, and disturbance history.
- Changes in peatland may be more likely to be detected by water chemistry than vegetation. If the vegetation is not affected by changes in water chemistry, or the changes are very slight and not easily detected, the changes in water chemistry are not ecologically significant.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2023.

RESEARCH TEAM AND COLLABORATORS

Institution: Vertex Professional Services Ltd.

Principal Investigator: Kevin Renkema

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dean MacKenzie	Vertex Professional Services Ltd.	VP Environment – Growth & Innovation		
Marcel Schneider	Vertex Professional Services Ltd.	Environmental Scientist		

Boreal Wetland Reclamation Assessment Program (BWRAP): Industrial Research Chair in Oil Sands Wetland Reclamation

COSIA Project Number: LE0037

Mine and In Situ

Research Provider: University of Calgary

Industry Champion: Suncor

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Imperial, Syncrude, Teck

Status: Year 4 of 5

PROJECT SUMMARY

The natural landscape of the Athabasca Oil Sands (AOS) region is dominated by wetlands and peatlands. Following the completion of mining activities, reclaiming these landscapes requires ongoing innovation to continue to develop operational best practices for reconstructing forests and wetlands to achieve equivalent land capability. While industry is creating new wetlands in the reclaimed landscape, more work is required to evaluate the success of these efforts and to guide adaptive management. The scientific and technical expertise needed to develop measures of success is being enabled by the Industrial Research Chair (IRC) program — the *Boreal Wetland Reclamation Assessment Program* (BWRAP), led by Dr. Jan Ciborowski.

Dr. Ciborowski's Senior Natural Sciences and Engineering Research Council of Canada (NSERC)/COSIA Industrial Research Chair in Oil Sands Wetland Reclamation was established on April 1, 2020, with support from NSERC, COSIA's oil sands industry partners, and the University of Calgary, to address the issues associated with wetland reclamation following bitumen mining in the AOS region. Additional support has been provided by Alberta Innovates. Dr. Ciborowski's research program is developing and testing the *Reclamation Assessment Approach*, a transformational method to characterize and assess the ecological condition of young wetlands in AOS reclamation landscapes and to ultimately enable industry to better reclaim land and promote wetland persistence and biodiversity as systems undergo succession.

BWRAP is addressing the following questions:

1. How can industry best predict the early development, biodiversity, and persistence of wetlands in a reclaimed landscape?
2. What environmental or biological indicators best reflect long-term resilience and/or persistence in young wetlands?
3. What reclamation features will promote young wetlands' formation, resilience, and persistence?

COSIA members require an assessment of the effectiveness or 'functionality' of constructed wetlands against reclamation targets. Several attributes are recognized as either modulators or indicators of a wetland's successional state or its environmental or biological condition. This program is measuring a suite of environmental and biological characteristics of newly formed and maturing wetlands and their surroundings, in order to document the range of natural variation. These ranges will form the basis of comparison against which to assess the 'success' of constructed wetlands in the post-mining landscape and by which to determine if adaptive management may be required.

The following wetland features are recognized as being important measures of ecological condition:

Time to Recovery: Recovery rates of wetlands vary primarily with respect to wetland size. In a meta-analysis of 621 globally-distributed wetland sites, Moreno-Mateus et al. (2012) reported that hydrological features become similar to reference values and vertebrate and macroinvertebrate species recolonize within five to ten years. In contrast, community composition and biogeochemical processes had not fully recovered after 50 years. Further, the rate of recovery was strongly related to wetland area: biological structure in wetlands greater than or equal to 100 hectares (ha) become similar to reference wetlands within five years of reclamation. Perhaps counterintuitively, the meta-analysis found that created wetlands became similar to reference wetlands much more quickly than restored wetlands.

Water quality Influences: Water quality constrains the abundance and composition of wetland biota. Most undisturbed wetlands in the AOS have low conductivity, but natural seeps increase salinity and contain halophilic communities. Wetlands forming on saline-sodic overburden storage areas are also saline enough to influence community composition. Some biota may appear to tolerate higher salinity from natural or runoff sources, because water in reclaimed areas may also contain residual bitumen extraction byproducts.

Landscape and Microtopography Influences: Wetland persistence depends on receiving and maintaining an adequate water supply. Evapotranspiration often exceeds precipitation in the ecozone in which the AOS resides, emphasizing the need to trap and store water during precipitation events. Constructed wetlands have been hypothesized to need at least a two-to-one ratio of watershed to wetted area for precipitation to sustain fen habitat in the AOS (Price et al., 2010). Land disturbance (altered forest cover, soil, or drainage pattern) is also a key stressor. For example, roads and culverts alter both hydrology and habitat use by biota. Wetland geometry (e.g., slope, emergent zone width, microtopography) influences the abundance, richness, and distribution of aquatic communities.

Permanence: Marsh-like wetlands are a focus of AOS reclamation because they are persistent and relatively easy to design. However, seeps and naturally-forming minerotrophic wetlands comprise 10% to 17% of the surface area of reclaimed areas (Little-Devito et al., 2019; Hawkes et al., 2020), leading to questions of the determinants of where 'opportunistic' wetlands occur and the extent to which they match prescriptions and predictions.

Biological indicators of wetland condition: No integrated criteria exist to assess the overall effectiveness of wetland reclamation for the mineable AOS, despite extensive surveys and adoption of biological integrity indices from previous studies (vegetation, aquatic invertebrates, birds, amphibians), and a framework to assess toxicological risks (Arciszewski et al., 2017). Current wetland impact assessment initiatives designed to detect risks to mature off-lease wetlands (difference from wetlands in the Reference Condition) are not necessarily applicable to young, constructed wetlands or to those formed opportunistically in reclaimed areas.

Overall Objective: Formulating a *Reclamation Assessment Approach* for Oil Sand Reclaimed Wetlands

Since reference locations identified using the Reference Condition Approach (RCA) focus on 'climax', a stable state, or a mosaic of successional states, recovering or newly reclaimed areas require a different frame of reference. The BWRAP is compiling data from suites of wetlands at early time points since their formation or creation. These data, essential as a frame of reference for assessing developing landscapes, are being collected and summarized to document the range of natural variation in indicator variables for opportunistically-forming and purposefully-reclaimed (i.e., constructed from the ground up) wetlands. Such information will inform guidelines that will determine whether adaptive management may be needed to achieve closure outcomes (maximize the likelihood of a wetland becoming functional and exhibiting the desirable ecological properties of natural systems).

Over the course of the three-phase, five-year BWRAP program, up to 120 candidate reclaimed wetlands (minerotrophic fens, swamps, and marsh-like areas) approximately three, eight, 20- and 40-years post-formation, and 'mature' (age-indeterminate), will be assessed. Some of these age-states are similar to those used for assessing upland forest stands in Alberta and broadly correspond to times since various pilot reclamation projects were undertaken by COSIA partners.

Phase 1 — Recruiting and Database Creation: The first phase has entailed compiling and harmonizing existing data — a 20-year record of research conducted on natural and reclaimed wetlands in and around the Fort McMurray oil sands leases. As well, remote sensing imagery of reclaimed lease areas and reference areas collected by the partner companies are being analyzed and used to create an inventory of the number, size, age, and permanence of the constructed and opportunistic reclaimed wetlands. A representative set of wetlands varying in age, size, permanence, disturbance history, and water quality have been selected for field studies over the next three years (Phase 2).

Phase 2 — Field Investigations: Each year, teams of fieldworkers have assessed a suite of approximately 40 wetlands (minerotrophic fens and swamps and marsh-like areas) using in situ instrumentation, field sampling, and drone surveys to assess wetland morphometry, water chemistry and balance, and riparian disturbance. The biological conditions of each wetland are characterized by surveying the communities of aquatic invertebrates, aquatic vegetation, and birds.

Phase 3 — Data Compilation, Analysis and Synthesis: During the third phase, the environmental data will be compiled to align the wetlands of different ages with respect to three gradients of environmental stress —permanence, water quality, and topographic heterogeneity (disturbance). Differences in the composition of biota among wetlands across each stress gradient will be used to identify benchmarks of biological characteristics (bioindicators) of each wetland age class, distinguishing 'acceptable', 'intermediate', and 'unacceptable' classes of wetland condition. "Successful" wetlands will have environmental conditions and associated biota characteristics of ''acceptable" (equivalent to reference) conditions for their successional stage of development. These features (and the landscape features that promote or sustain them) can be used to guide future reclamation protocols and ultimately provide objective criteria by which to anticipate the longer-term persistence of reclaimed wetlands.

PROGRESS AND ACHIEVEMENTS

Phase 1 - Recruiting and Database Creation

In 2022, working in collaboration with the Boreal Ecosystem Recovery and Assessment (BERA) NSERC Alliance-funded project, project researchers developed and beta-tested a georeferenced, relational database that is accessible by both on-campus and off-campus collaborators. The database is housed on University of Calgary virtual machine servers with an architecture designed to be compatible with information of the Alberta Biodiversity Monitoring

Institute, with whom project researchers will ultimately share data. The BWRAP and BERA researchers, collaborators and students are compiling a common database management plan and relevant standards that will maximize inter-operability and comparability of datasets, aligning with data record conventions used by the ABMI database where feasible. Various mapping, search and synthesis database tools are being developed to simplify database queries and data summaries. Syncrude and Suncor have provided detailed imagery and mapping information from which various mapping products are being derived by team members.

The imagery of reclaimed lease areas and reference areas was used to identify suitable wetlands to sample during the 2023 field season. The success in locating 40 suitable study sites was greatly aided by recommendations from collaborators, and Syncrude, Suncor and Canadian Natural field staff as well as other local experts.

Phase 2 - Field Investigations

In 2023, two new graduate students, six undergraduate students and two summer research assistants joined BWRAP and completed the field training necessary to begin their research in mine lease areas. In early May, lab members revisited the 40 wetlands instrumented in 2022 to redeploy data loggers and census the spring wetland bird communities. They subsequently located and sampled the water characteristics, soils, aquatic invertebrates and the vegetation of the open water, emergent vegetation, and wet meadow zones of an additional 37 young wetlands. Data loggers were moved from their spring position to the new set of wetlands in July to record daily variation in water level, conductivity, dissolved oxygen, temperature, and photoperiod and were left in place until late September. Loggers were removed to avoid overwinter freezing.

The combined suite of 117 wetlands surveyed between 2021 and 2023 has encompassed a broad range of ages (two years to > 40 years), hydroperiods (ranging from ephemeral to permanent), salinities (specific conductance ranging from < 2,000 uS/cm to > 7,000 uS/cm) and disturbance types. Equal numbers of wetlands situated within and outside of mine-lease areas were sampled. However, the distribution of sample points along each stress gradient differed between the suite of wetlands sampled within versus those assessed outside of reclaimed areas. In particular, the most saline wetlands were more prevalent in reclaimed areas than in reference areas. Similarly, a greater proportion of wetlands in reclaimed areas had short hydroperiods than were found in reference areas.

The 2023 field data have been uploaded to the geodatabase and are being analyzed. Preliminary summaries broadly corroborate the earlier interpretations of archival data collected through the early 2000s. Plant community richness and biomass of dominant species appear to increase with age, whereas community composition shows no clear pattern of change. Soil salinity has a complex influence on biomass. In youngest wetlands (< five years), biomass was uniformly low across the salinity gradient. Yet, a salinity threshold was clearly apparent in older wetlands. Biomass at maturity increased as a function of age in low-conductivity wetlands but remained low in wetlands that had saline soils. Similar patterns are evident in the relative frequency of occurrence of three families of snails in the wetlands surveyed. They were absent from the youngest wetlands surveyed, and older saline wetlands (conductivity > 2,200 uS/cm) but were abundant in older, less saline wetlands.

Analyses of surface and groundwater radon concentrations (indicating how much of a wetland's water comes from groundwater rather than surface flow) and isotopes of oxygen and deuterium (an independent measure of precipitation versus groundwater inputs) clearly show a broad range of among-wetland variation in the proportion of water derived from surface water (precipitation, overland, and stream flow) versus groundwater sources. This information will contribute to an assessment of each wetland's resilience to interannual and seasonal variation in precipitation. Evaporative processes seem to exceed groundwater contributions from the watershed in wetlands found in reclaimed areas, similar to the hydrodynamics observed in Alberta's prairie pothole region (Wendlandt 2023).

Surveys of vegetation provided estimates of community composition, biomass, and relative cover of the three zones. In all, over 160 species have been identified across the 117 wetlands. The dominant species (those with consistently greatest cover) were Blue Joint Grass (*Calamagrostis canadensis*), three sedge species (*Carex aquatilis*, *C. atherodes*, and *C. utriculata)*, Softstem Bulrush (*Schoenoplectus tabernaemontani*), and Cattail (*Typha latifolia*). Over 180 benthic macroinvertebrate samples were collected and preserved over the course of the summer. Processing and enumeration are in progress. Avian surveys were conducted at 40 wetlands in 2023. Acoustic recording units were set up to monitor songs and calls, and in-person observations were made at three points per wetland on at least two occasions between early May and late June, using Marsh Monitoring protocols.

Phase 3 - Data Compilation, Analysis and Synthesis: State-and-Transition Modelling to Synthesize and Interpret Wetland Development and Persistence

The model is in development. Phases of progress are being disseminated in monthly webinars presented to individuals who have registered for a course on the use of state-and-transition simulation models as an ecological forecasting tool for wetlands reclamation assessment.

The following tasks/objectives are in progress:

- populating the database with archival and recently collected field data, including data anticipated for the third year of fieldwork. Three field seasons of invertebrate and vegetation data, and one field season of avian data have been collected and are being standardized for inclusion in the database. Archival data are also being quality-checked to meet contemporary database standards and uploaded into the database.
- identifying 'reference', 'degraded' and 'at risk' biological community states relative to each gradient of environmental stress for four classes of wetland age; analyses are in progress.
- forming and convening workshops of a Created Wetland Research and Information Group Community of Practice to corroborate putative biological classes and their relationship to environmental gradients.
- parameterizing state-and-transition models of wetland development for each biological attribute.

LESSONS LEARNED

This program is near the end of the data accumulation stage, with 2.5 of three field seasons completed. Therefore, few conclusive statements can be made. The most current season's field work has confirmed that many aquatic invertebrate taxa can occupy local natural wetlands with much greater salinity ranges than has been documented in preliminary studies of lease area landscapes. Wetland hydroperiod (the length of time a wetland retains surface water) seems to be the most important determinant of aquatic invertebrate community composition in reclaimed landscapes.

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PRESENTATIONS AND PUBLICATIONS

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Ciborowski, J. J. H., M. Wendlandt, A. Mombourquette, E. Gillis, H. Porter, M.M. Rahman, J. Birks, I Vander Muelen, J. Headley. 2023. Defining and quantifying stress/disturbance gradients for young wetlands forming in reclaimed oil sands landscapes. Canadian Ecotoxicity Conference, 2-5 October 2023, Ottawa, ON.

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RESEARCH TEAM AND COLLABORATORS

Institution: University of Calgary

Principal Investigator: Dr. Jan J. H. Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Camille Sinanan	University of Calgary	BWRAP Admin Manager		
Mir Mustafizur Rahman	University of Calgary	Post-Doctoral Scholar/ Research Scientist		
Jeremy Hartsock*	Southern Illinois University	Post-Doctoral Scholar		
Qing Ye (Richard) Zeng	University of Calgary	Post-Doctoral Research Associate – Programmer/ Developer		
Gillian Donald	University of Calgary	Research Scientist - State-and-Transition modeling; Community of Practice Co-Convener		
Zach Wang	University of Calgary	Research Assistant (Drones)		
Ian Perry	University of Calgary	Research Assistant (Drone pilot)		
Kwok Kei (Maverick) Fong	University of Calgary	Technician - Programmer/Developer		
Sydney Trimming	Mount Royal University	Research Assistant (Avifauna)	2023	2023
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Erik Biederstadt	University of Calgary	MSc	2021	2024
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Courtney Smith	University of Calgary	BSc (thesis)	2017	2022
Megan Mercia	University of Calgary	Hon. BSc	2016	2021
Elizabeth Gillis	University of Calgary	MSc	2021	2024
Ashlee Mombourquette	University of Calgary	MSc	2020	2023
Brenten Vercruysse	University of Calgary	MSc	2019	2022
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Hunter Jackson	University of Calgary	BSc (thesis)	2020	2024
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Veronica Dvorak	University of Calgary	BSc	2021	2024
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Laura Van't Reit	University of Calgary	BSc (thesis)	2023	2024

* Travel restrictions associated with the COVID-19 pandemic prevented Dr. Hartsock from travelling to Canada and resulted in his leaving the program at the end of August 2020.

Research Collaborators:

The following collaborators indicated their willingness to participate in the program as envisioned during the proposal phase of the research plan. The timing and extent of collaboration will vary according to the stage of research and the individuals' expertise. New collaborations have developed since the start of the program. These collaborators are marked with an *.

Name	Institution or Company	Role/Expertise
Greg McDermid	Geography, University of Calgary	Remote sensing (BERA program)
Laura Chasmer	Geography, University of Lethbridge	Wetland ecosystem change detection
Kevin Devito	Biological Sciences, University of Alberta	Landscape controls on boreal ecohydrology
Alice Grgicak-Mannion	Earth Sciences, University of Windsor	Disturbance mapping and analysis
Bernhard Mayer	Geosciences, University of Calgary	Stable isotope analyses
Leland Jackson	Biological Sciences, University of Calgary	Nutrient and water chemistry analyses
Jean Birks	InnoTech, Alberta, Calgary	Isotope techniques to quantify water balance
Christopher Weisener	School of Environment, University of Windsor	Microbial controls on wetland biogeochemistry
Dale Vitt	Biological Sciences, S. Illinois University	Wetland succession and biogeochemistry
Rebecca Rooney	Biological Sciences, University of Waterloo	Bioindicator development; Fuzzy Cognitive Mapping; State and transition modelling
Lee Foote	Renewable Resources, University of Alberta (emeritus)	Community structure and bioindicators
Colin Daniel	Apex Resource Management Solutions	Wetland state and transition modelling
Leonardo Frid	Apex Resource Management Solutions	Wetland state and transition modelling
Diego Bilski*	Apex Resource Management Solutions Ltd.	State & Transition model developer (collaborator)
Jabed Tomal	Thompson Rivers University	Statistical modelling
Erin Bayne*	Biological Sciences, University of Alberta	Cumulative ecological impacts of human activities on biodiversity
Peter Dunfield*	Biological Sciences, University of Calgary	Aquatic Microbial Ecology
Virgil Hawkes*	LGL Ltd.	Wildlife & habitat assessment of reclaimed landscapes
John Headley*	National Hydrology Research Centre (NHRC) Environment and Climate Change Canada	Analytical Chemistry of acid extractable organic compounds
Felix Nwaishi*	Earth & Environmental Sciences, Mount Royal University	Role of plant-soil processes in regulating ecosystem functions
Faramarz Samavati*	Computing Science, University of Calgary	Computer/spatial modelling of wetland persistence

SOILS AND RECLAMATION MATERIAL

Topsoil Replacement Depth Study

COSIA Project Number: LJ0335

In Situ

Research Provider: NAIT Centre for Boreal Research

Industry Champion: ConocoPhillips

Industry Collaborators: CNOOC Petroleum North America ULC

Status: Year 3 of 5

PROJECT SUMMARY

Approvals issued for in situ facilities under the Alberta Environmental Protection and Enhancement Act typically require operators to place a minimum of 80% of site pre-disturbance topsoil to ensure that the entire area has a uniform placement of topsoil during reclamation. The topsoil depth target of 80% relative to pre-disturbance native soil depth is also part of the 2010 reclamation criteria for well sites and associated facilities.

The application of approaches developed under an agricultural context often results in reclaimed areas being uniformly capped with topsoil, however, heterogeneity in placement depth is more desirable and similar to a natural forest system. Though heterogeneity of both site and plant community targets are acceptable and even desirable goals in the 2010 reclamation criteria — and the guidelines allow for stratification during certification assessments — no guidance is provided on how to achieve these goals. The ability to vary soil-cover design depths also has implications for optimizing the placement of available topsoil where the objective is to achieve the best reclamation outcomes across multiple sites where some may be locally deficient in available topsoil. In addition, depending on the target forest ecosystem and plant community desired, a thick placement of topsoil may be counterproductive as individual species may be more, or less well suited to richer soil conditions. Ongoing work on an interim reclamation study of subsoil and topsoil supports this notion (LJ0226 Interim Reclamation).

There has been significant interest in cover soil placement depths in mining (i.e., Farnden et al., 2013), but less attention has focused on the evaluation of recommended topsoil capping depths (80% threshold target) for smaller-scale industrial disturbances such as those at in situ and conventional oil and gas sites. This study encompasses four trials aimed at investigating both the effect of limited capping depths on forest establishment (Trial 1), as well as alternative approaches to mitigate for potential limitations associated with shallow topsoil capping on industrial disturbances in the boreal region (Trials 2 to 4). The study site is a former gravel pit, approximately 15 hectares in size, which allowed for sizeable plot installations with replication of treatments.

The specific context and objectives of each trial are described below.

Trial 1: Effects of topsoil replacement depth on forest establishment

The purpose of this investigation is to evaluate the effect of capping depth on forest regeneration and soil properties. This trial comparatively evaluates three topsoil capping depth targets (no topsoil, shallow [5 cm] and standard [15 cm]) in a randomized complete block design. Recognizing that there will be variation around these targets, a ground survey was also conducted to confirm realized placement depths.

A lack of native seed propagules as well as early invasion by non-native species are two potential constraints with limited (or no) topsoil placement. This trial will attempt to mitigate these concerns using two approaches.

First, numerous plant species were planted (at a density of 4,800 stems per hectare) to evaluate species-specific survival and growth responses. In addition, intentional planting of native forbs specifically was accomplished through hitchhiking with jack pine (*Pinus banksiana*) or white spruce (*Picea glauca*), since this planting prescription may be beneficial to increasing the initial coverage and diversity of native understory species. Hitchhiking, in the plant context, is a nursery stock production treatment whereby two plant species are co-grown in the same nursery container. This approach has been tested previously with white spruce and multiple native forbs (Mathison 2018, Hudson 2020) and this study applied the same principles in terms of seedling production (timing of sowing the forb after the conifer) to hitchhiking jack pine with native forbs.

The second approach was an operational-scale test of a pre-emergent herbicide that was applied in strips as a split-plot treatment within each capping depth plot replicate. This treatment is anticipated to create growing space for nursery stock seedlings, thereby potentially speeding the development of woody plant cover while concurrently reducing the cover and dominance of non-native species.

The following questions will be answered through this trial:

1. In an operational setting with placement of soil under frozen conditions, how closely does the resultant topsoil depth match the planned topsoil depth and how does this change through time? As measured later in the same year after placement and thawing, and again after one and four years.
2. What is the impact of topsoil depth placement on native understory species?
   a. Does the absence of topsoil preclude development of a forest plant community?
3. What are the impacts of topsoil placement depth on the;
   a. Survival of planted woody species?
   b. Natural ingress of woody species?
   c. Growth of woody species?
4. How does the application of a pre-emergent herbicide affect;
   a. The ingress of non-native species, particularly where no topsoil has been placed?
   b. Survival and growth of planted woody species?

Trial 2: Nutrient loading with organic forms of nutrition to improve early growth following fieldoutplanting (i.e., giving seedlings a lunchbox before their field trip)

Another often cited motivation for utilizing topsoil is the soil nutrition present in this medium. In a separate investigation (LJ0226 Interim Reclamation), researchers have observed some evidence, in some species, that supports this assertion. While broadcast application of fertilizers or other forms of organic amendments is possible, there are often unintended consequences. Namely, there may be increased competition from the grasses and other herbaceous species that are quick to capitalize on the abundant nutrient availability. An alternative approach could be to provide a more localized source of nutrition to the seedlings, thereby reducing the site-wide flux in soil nutrients.

Recently at the NAIT Centre for Boreal Research (CBR) in Peace River, a preliminary study was conducted to examine the concept of creating a 'lunchbox' for seedlings by incorporating different rates of alfalfa pellets in containers planted with two deciduous tree species (aspen and paper birch). This study found that alfalfa pellets applied at 10% and 20% of the total planting container cavity volume led to a 50% increase for all measured plant growth parameters — including seedling height, root collar diameter, leaf biomass and stem biomass — when compared to plants grown in containers with lower rates of alfalfa pellet incorporation.

Although the pilot study confirmed that it was possible to grow these seedlings, a field test to validate real-world growth is still required. Utilizing the positive results from this bench scale test, a plot-scale field study was initiated to further validate this 'lunchbox' approach to seedling growth against conventionally grown seedlings, as well as against nutrient loaded seedlings developed with inorganic fertilizers (following Schott et al., 2013; Schott et al., 2016). Four commonly occurring tree species were evaluated including white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*).

The objectives of this trial are to:

1. Compare the post outplanting growth and survival of nursery tree seedlings that are nutrient loaded through conventional means (inorganic fertilizer) versus those grown with the inclusion of an organic form of nutrition (alfalfa pellets).
2. Evaluate these 'improved' stock types under contrasting reclamation conditions;
   a. the span of soil placement depths (no topsoil, shallow or standard); and
   b. high versus low competition (no topsoil treatment only).

Trial 3: Hitchhiking native forbs with contrasting woody species: using the principle of hitchhiking forbs for varying purposes

Hitchhiking multiple plant species in the same nursery plug has two key benefits including a direct increase in on-site species diversity and a cost reduction associated with planting. Even though larger containers are utilized, raising the per seedling cost and concurrently reducing the rate at which planters can plant these seedlings, the overall cost is still approximately 20% lower due to increased efficiency (i.e., shared plug, two plants established in one planting hole). There is also added logistic simplicity in reducing the number of individual plant orders made and coordinated. Incorporating or 'hitchhiking' native forbs into the same container as a shrub or tree is a potential means of efficiently establishing native forbs on a disturbed site. This concept was previously explored with white spruce (*Picea glauca*) and two different native forbs (*Chamerion angustifolium* and *Eurybia conspicua*), where these mixed-species plugs were successfully grown and established in a variety of reclamation sites (Mathison, 2018). Three different deciduous species (*Betula papyrifera, Alnus viridis* and *Salix discolor*) were also hitchhiked with fireweed with some success — though the interspecific competition was more challenging (Hudson, 2020). While these studies have provided a framework from which to provide guidance on the use of this type of nursery stock, much of this research had focused on hitchhiking with fireweed and additional research is still required to examine other woody plant-forb mixtures and optimize their production.

This trial will evaluate three deciduous species, each representing different growth forms or growth strategies, in combination with one of three native forbs that also vary in their growth morphology as well as in known rates of spread. These seedlings were established within contrasting condition types within the Trial 1 study design to evaluate the utility of these stock types across the span of capping depths (no topsoil, shallow, or standard) and in high versus low competition.

Trial 4: Hitchhiking ericaceous shrubs with conifers

As described above, a concern with not placing topsoil is the potential lack of seed propagules of native species. As in Trial 3, the concept of planting additional species is one approach to mitigate for this concern. Trial 4 will examine another configuration of hitchhiker seedlings. It will combine low-growing ericaceous shrubs (bog cranberry [*Vaccinium vitis-idaea*], common blueberry [*Vaccinium myrtilloides*] or Labrador tea [*Rhododendron groenlandicum*]) with coniferous tree species (jack pine [*Pinus banksiana*] or white spruce [*Picea glauca*]). Although, NAIT Centre for Boreal Research has previous experience growing these mixtures of species the logistics of combining two slow-growing species are quite distinct from the constraints and challenges found in Trial 3 using deciduous species.

The ericaceous shrubs must be started six to eight weeks ahead of the conifers due to their extremely slow growth. These shrubs can either be grown in trays or mini-blocks and then transplanted into the primary container with the emerging conifer, or they can potentially be grown in this cavity from the beginning thereby reducing the number of handling times required. A potential issue with this second approach is the development of mosses or liverworts that may inhibit seed emergence of the conifer which will be sown many weeks after sowing the shrub. This trial utilized the former approach as it was more practical from the perspective of seed emergence and in reducing issues with mosses and liverwort colonization.

The goal of this trial is to comparatively evaluate ericaceous shrubs grown singly, as well as hitchhiked shrubs (co-grown with one of two conifer species) and will also test the effect of soil inoculation on plant survival and growth. These seedlings will be outplanted across the range of capping depths to evaluate the conditions that are conducive to the healthy growth and persistence of these combinations of species.

Relevance of study to industry

The product of this work can be used as the basis to support soil cover design for both in situ and conventional operations that incorporate varying topsoil depths. This study should also provide evidence to support increasing flexibility for operators to move topsoil between dispositions to focus on reclamation outcomes rather than following a prescriptive approach to topsoil placement (i.e., use the topsoil where it is most needed). In addition, this study will also provide practical tools that operators will be able to employ to mitigate potential concerns with areas of limited topsoil placement. Overall, the results of this study are envisioned to support improved reclamation outcomes across the boreal forest.

PROGRESS AND ACHIEVEMENTS

While the research team has completed a preliminary statistical analysis of all three years of data collected thus far (Table 1), the discussion of results will focus on Year 3 outcomes from Trial 1. Readers are encouraged to review the experimental layout (Figure 1) as it will facilitate a stronger understanding of the experimental design and the discussion of findings.

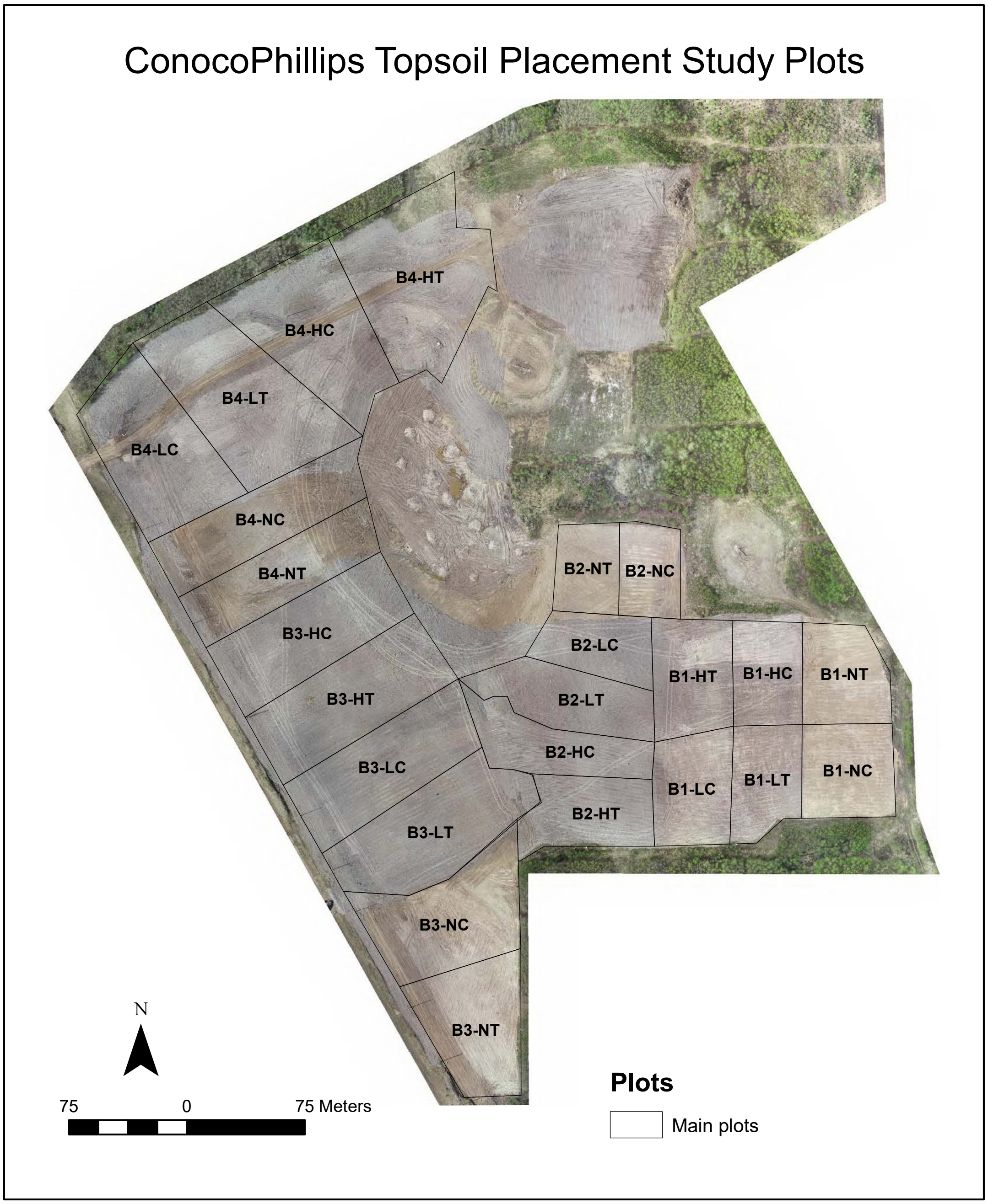

Figure 1: Layout of Trial 1 experimental treatment plots. The seedling stock Trials (2-4) are nested within these larger experimental units and are not shown to reduce crowding of the image. Treatment notations are as follows: B1-4 refers to the replicate study blocks, H/L/C refer to the standard (H), shallow (L), or no-topsoil treatment (C), and T/C refer to treatment with pre-emergent herbicide (T) or untreated (C).

Table 1: Generalized linear mixed-effects model (GLMM) output associated with stem counts, total understory vegetation cover, relative abundance (RA) by vegetation class and tree height by species. Factors tested included: topsoil, herbicide (herb) and year of assessment (Year) treated as an ordinal factor. Random effects included the replicate block with topsoil and herbicide treatments nested within each block to reflect the hierarchical structure of the data set. R statistical software (R core team, 2023) was utilized for all analyses and GLMMs were fitted using the function glmmTMB (package glmmTMB, Brooks et al., 2017).

Response	Factor	Chisq	Df	P-value	Response	Factor	Chisq	Df	P-value
Total cover	Topsoil	7.6796	2	0.0215	*Populus tremuloides* height	Topsoil	0.7196	2	0.6978
	Herb	12.6050	1	0.0004		Herb	6.7355	1	0.0095
	Year	291.2521	2	0.0000		Year	2594.5588	2	0.0000
	Topsoil x Herb	1.7093	2	0.4254		Topsoil x Herb	10.5306	2	0.0052
	Topsoil x Year	11.5151	4	0.0213		Topsoil x Year	6.9873	4	0.1366
	Herb x Year	2.6204	2	0.2698		Herb x Year	9.9143	2	0.0070
	Topsoil x Herb x Year	1.1369	4	0.8884		Topsoil x Herb x Year	3.8163	4	0.4314
Total woody count	Topsoil	0.4863	2	0.7842	*Betula papyrifera* height	Topsoil	0.2440	2	0.8851
	Herb	9.5915	1	0.0020		Herb	5.4945	1	0.0191
	Year	26.3112	2	0.0000		Year	2367.2508	2	0.0000
	Topsoil x Herb	3.7003	2	0.1572		Topsoil x Herb	0.9512	2	0.6215
	Topsoil x Year	5.0908	4	0.2781		Topsoil x Year	9.1951	4	0.0564
	Herb x Year	0.4497	2	0.7986		Herb x Year	22.3692	2	0.0000
	Topsoil x Herb x Year	1.6251	4	0.8043		Topsoil x Herb x Year	2.6641	4	0.6155
Total tree count	Topsoil	0.9779	2	0.6133	*Alnus viridis* height	Topsoil	2.2382	2	0.3266
	Herb	4.6912	1	0.0303		Herb	8.5431	1	0.0035
	Year	42.8606	2	0.0000		Year	2626.7018	2	0.0000
	Topsoil x Herb	10.5239	2	0.0052		Topsoil x Herb	6.1428	2	0.0464
	Topsoil x Year	2.0247	4	0.7312		Topsoil x Year	18.5341	4	0.0010
	Herb x Year	0.9724	2	0.6150		Herb x Year	0.2129	2	0.8990
	Topsoil x Herb x Year	1.4071	4	0.8430		Topsoil x Herb x Year	0.7409	4	0.9462

Total tall shrubs	Topsoil	0.1935	2	0.9078	*Populus balsamifera* height	Topsoil	1.6285	2	0.4430
	Herb	4.5011	1	0.0339		Herb	14.9400	1	0.0001
	Year	20.3069	2	0.0000		Year	2791.0079	2	0.0000
	Topsoil x Herb	0.5042	2	0.7772		Topsoil x Herb	19.2376	2	0.0001
	Topsoil x Year	7.8359	4	0.0978		Topsoil x Year	8.4653	4	0.0759
	Herb x Year	0.3933	2	0.8215		Herb x Year	4.0954	2	0.1290
	Topsoil x Herb x Year	1.3553	4	0.8519		Topsoil x Herb x Year	5.3479	4	0.2534
Pinus banksiana height	Topsoil	7.9842	2	0.0185	*Picea glauca* height	Topsoil	10.6580	2	0.0048
	Herb	2.7355	1	0.0981		Herb	8.4902	1	0.0036
	Year	922.1416	2	0.0000		Year	1244.5268	2	0.0000
	Topsoil x Herb	0.5258	2	0.7688		Topsoil x Herb	5.0000	2	0.0821
	Topsoil x Year	6.1429	4	0.1887		Topsoil x Year	8.3319	4	0.0801
	Herb x Year	1.9183	2	0.3832		Herb x Year	4.5864	2	0.1009
	Topsoil x Herb x Year	1.1454	4	0.8870		Topsoil x Herb x Year	5.0786	4	0.2793

Understory Vegetation Responses

Understory vegetation cover development increased substantially in Year 3 relative to Years 1 and 2 (Table 1) and was visually apparent across the site (Figure 2 through 4). While Years 1 and 2 showed no difference in total cover across topsoil depth treatments, Year 3 illustrated strong divergence between standard and shallow treatments (approximately 35% to 40% cover) compared with no-topsoil treatments (approximately 25% cover; Figure 5a). Across the first three growing seasons, the use of pre-emergent herbicide has reduced total plant cover to 15%, on average, compared with a mean total cover of 20% in the no-herbicide treatment (Figure 5b).

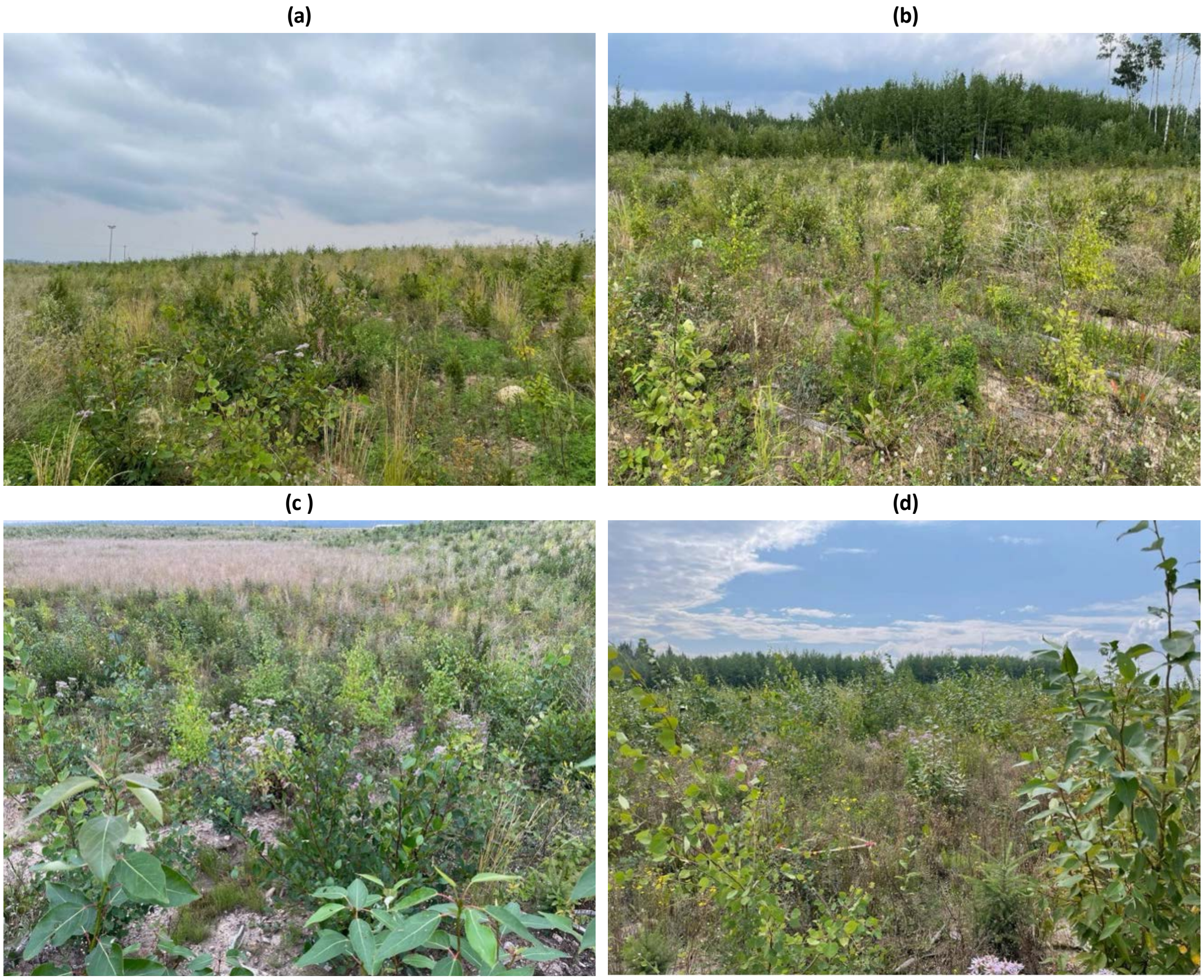

Figure 2: Treatment images from the third growing season in early August 2023 for the **standard topsoil** treatment and grouped by herbicide treatment — (a-b) no-herbicide and (c-d) herbicide. Pink arrows denote observation of hitchhiked native forbs.

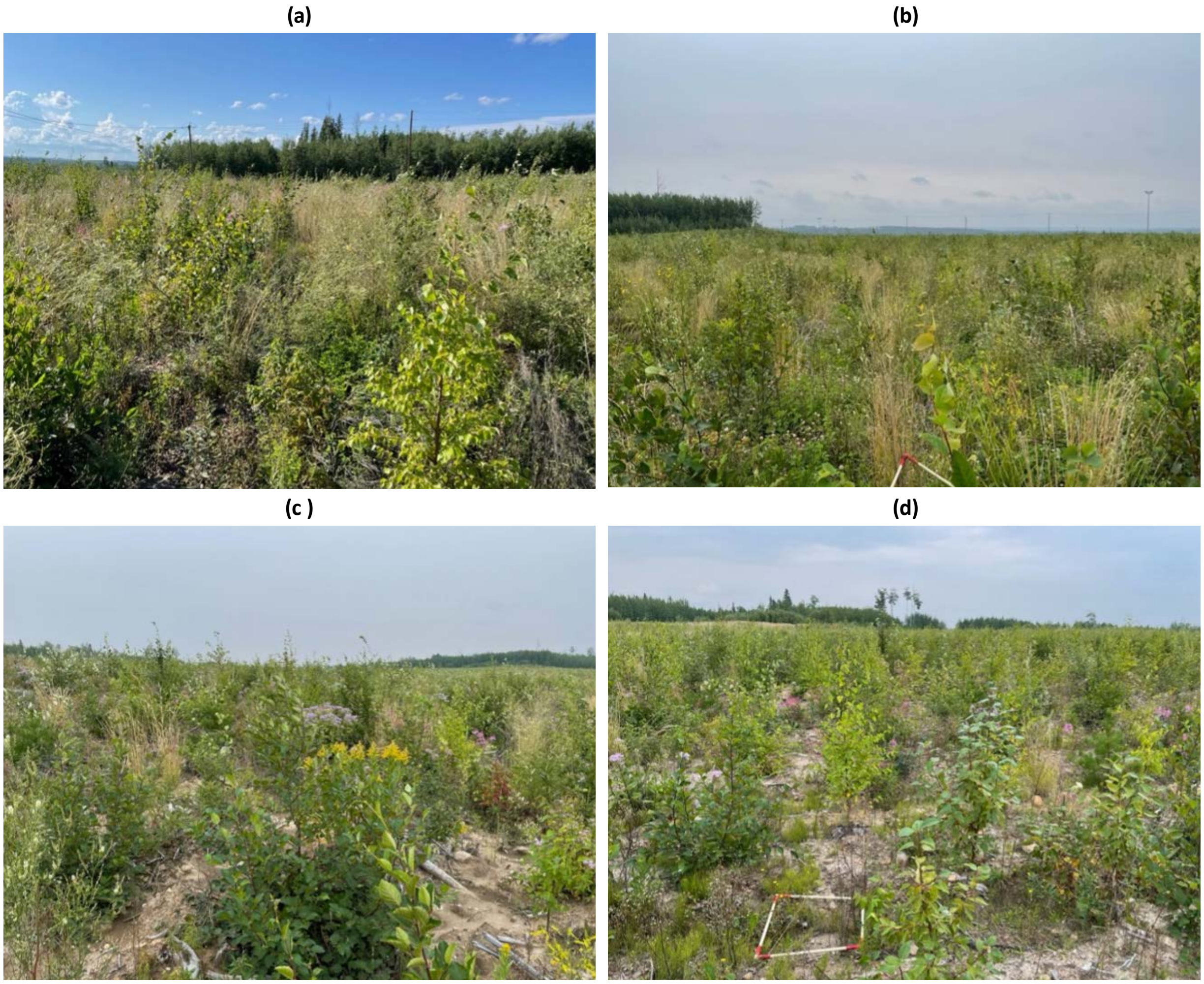

Figure 3: Treatment images from the third growing season in early August 2023 for the **shallow topsoil** treatment and grouped by herbicide treatment — (a-b) no-herbicide and (c-d) herbicide. Pink arrows denote observation of hitchhiked native forbs.

(a)

(b)

(c)

(d)

Figure 4: Treatment images from the third growing season in early August 2023 for the **no topsoil** treatment and grouped by herbicide treatment — (a-b) no-herbicide and (c-d) herbicide. Pink arrows denote observation of hitchhiked native forbs.

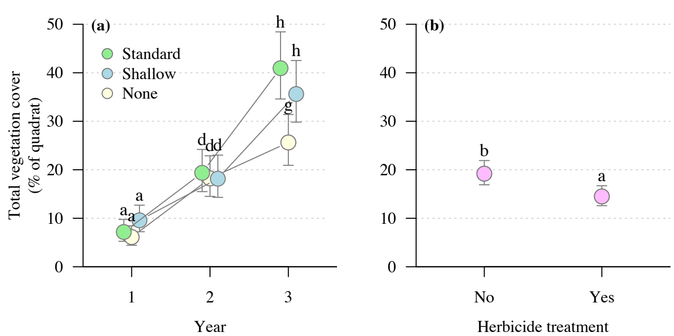

Figure 5: Estimated marginal mean total vegetation cover by (a) year and topsoil depth treatment (standard, shallow or none) and (b) no-herbicide (No) pre-emergent herbicide (Yes) across three growing seasons. Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Note that for (a) mean comparisons were made within the year of assessment only. Error bars represent 95% confidence intervals on the treatment mean (n = 4 replicate blocks). Estimated means were generated from a split-plot three-factor generalized linear mixed effects model (fitted with a gamma distribution).

Relative abundance of vegetation classes has shown varying responses to topsoil depth and herbicide treatments, with the following key trends noted below:

- Across years, topsoil depth treatments have maintained similar relative abundances of woody vegetation (Figure 6b) while pre-emergent herbicide has consistently increased the relative abundance of woody vegetation relative to no-herbicide (Figure 6c).
- Relative abundance of grasses has been higher in no-topsoil compared with the standard topsoil treatment (Figure 6e) while pre-emergent herbicide has consistently decreased the relative abundance of grasses relative to no-herbicide (Figure 6f).
- Across years, both native and non-native forbs have shown interacting effects due to topsoil depth and herbicide treatments (Table 1), with each interaction illustrating contrasting effects (Figure 7b,d). For native forbs, there was no difference in relative abundance across topsoil depth treatments when pre-emergent herbicide was used (Figure 7b). However, with the use of pre-emergent herbicide, the no-topsoil treatment had a significantly higher proportion of native forbs compared with the standard topsoil depth treatment (Figure 7b). The relative abundance of non-native forbs was also similar across topsoil depth treatments when employed with pre-emergent herbicide but in the absence of herbicide, both standard and shallow topsoil depth treatments had higher proportions of non-native forbs compared with no-topsoil (Figure 7d).

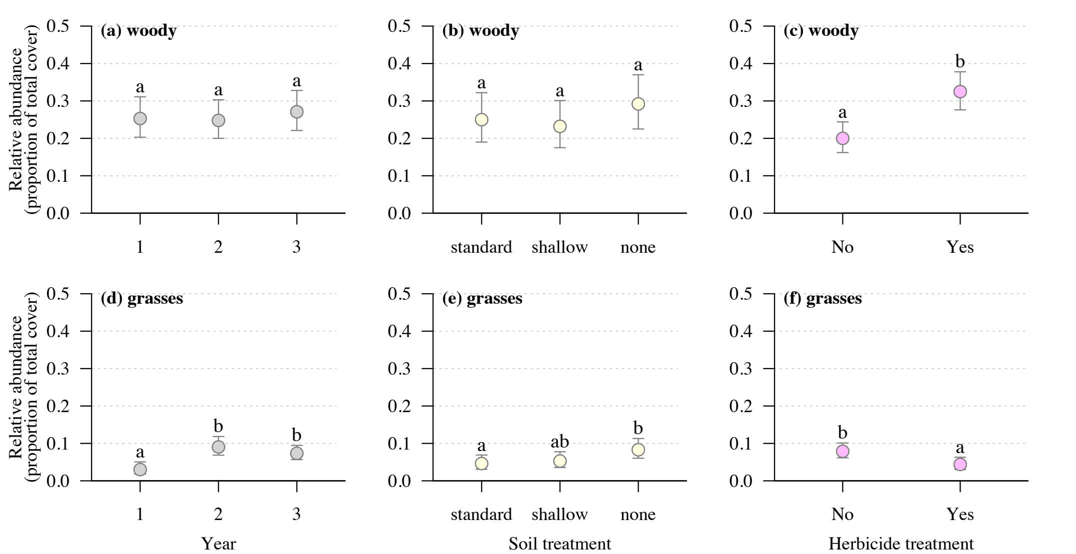

Figure 6: Estimated marginal mean relative abundances of (a-c) woody vegetation and (d-f) grasses expressed as a proportion of total cover organized by main effects: year of measurement, topsoil depth treatment (standard, shallow or none) and herbicide treatment (none [No] or pre-emergent herbicide [Yes]). Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean (n = 4 replicate blocks). Estimated means were generated from a split-plot three-factor generalized linear mixed effects model (fitted with a beta distribution).

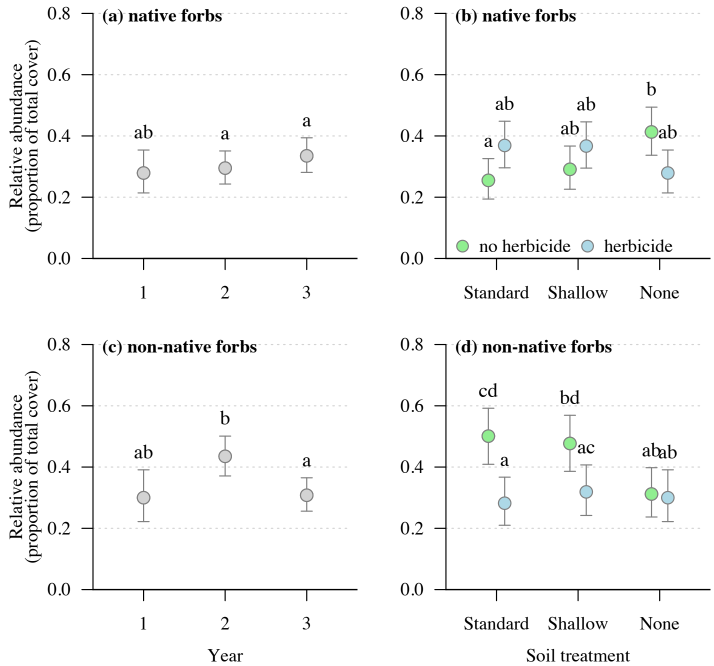

Figure 7: Estimated marginal mean relative abundances of (a-b) native forbs and (c-d) non-native forbs expressed as a proportion of total cover organized by main effects: year of measurement, topsoil depth treatment (standard, shallow or none) and herbicide treatment (none [No] or pre-emergent herbicide [Yes]). Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Note that for (n) the non-native forb class had a significant topsoil X herbicide treatment interaction therefore these treatments are presented in the same subpanel. Error bars represent 95% confidence intervals on the treatment mean (n = 4 replicate blocks). Estimated means were generated from a split-plot three-factor generalized linear mixed effects model (fitted with a beta distribution).

Woody Vegetation Responses

Stem counts of woody vegetation in Year 3 were similar across topsoil depth and herbicide treatments (Figure 8). Nevertheless, averaged across years there were significant differences associated with pre-emergent herbicide for total woody stem and tall shrub stem counts (Table 1), where pre-emergent herbicide had, on average, 10% to 20% higher stem counts compared with the control treatment (data not shown). For total tree counts across all three years, there was a significant interaction between topsoil depth and herbicide treatments. The shallow topsoil treatment had significantly higher average stem counts when combined with pre-emergent herbicide compared with no-herbicide (averaging 76 versus 89 stems per plot, respectively).

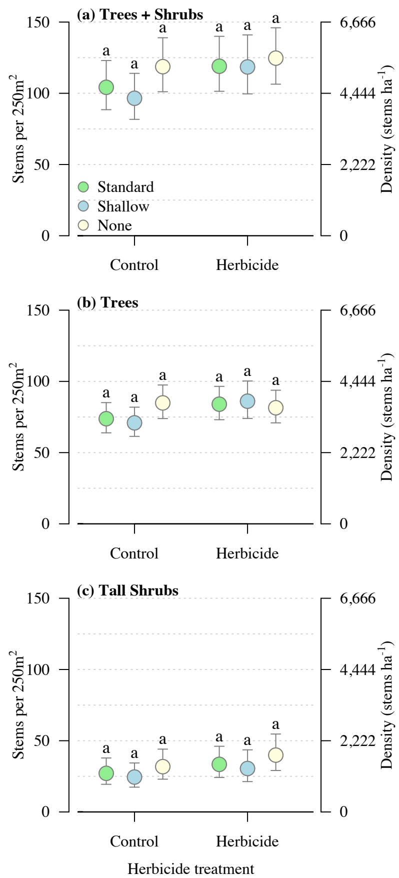

Figure 8: Estimated marginal mean woody stem counts after three growing seasons by (a) trees and shrubs, (b) trees and (c) tall shrubs by topsoil depth treatment (standard, shallow or none) and herbicide treatment (none [No] or pre-emergent herbicide [Yes]). Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean ($n = 4$ replicate blocks). Estimated means were generated from a split-plot three-factor generalized linear mixed effects model (fitted with a poisson distribution).

In terms of tree growth responses, Year 3 total height for the planted tree and shrub species were varied and should be considered preliminary at this time. Though, the following observations are noted:

- *Populus tremuloides, P. balsamifera* and *Betula papyrifera* all showed a significant increase in total height for the no-topsoil treatment when pre-emergent herbicide was utilized compared with the no-herbicide treatment (Figure 9a-c). A similar trend was observed in the standard topsoil treatment though not in the shallow treatment (Figure 9a-c). For these species, within the pre-emergent herbicide treatment there was no difference amongst topsoil depth treatments. However, in the absence of herbicide, the no-topsoil treatment tended to result in shorter trees relative to standard and shallow treatments (Figure 9a-c).
- *Alnus viridis* showed similar total height in Year 3 with the exception of taller seedlings associated with the no-topsoil control compared with no-topsoil herbicide treatment (Figure 9d).
- For *Pinus banksiana* in the presence of pre-emergent herbicide*,* Year 3 total height was significantly less for no-topsoil treatment seedlings compared with standard and shallow topsoil treatments (Figure 9e). Additionally, while the same trend was present for topsoil depth treatments in the no-herbicide treatment, the differences were not statistically significant (Figure 9e).

Conversely, Picea glauca seedlings showed stronger height reductions amongst topsoil depth treatments (shortest trees in no-topsoil) in the no-herbicide treatment relative to pre-emergent herbicide treatment (Figure 9f).

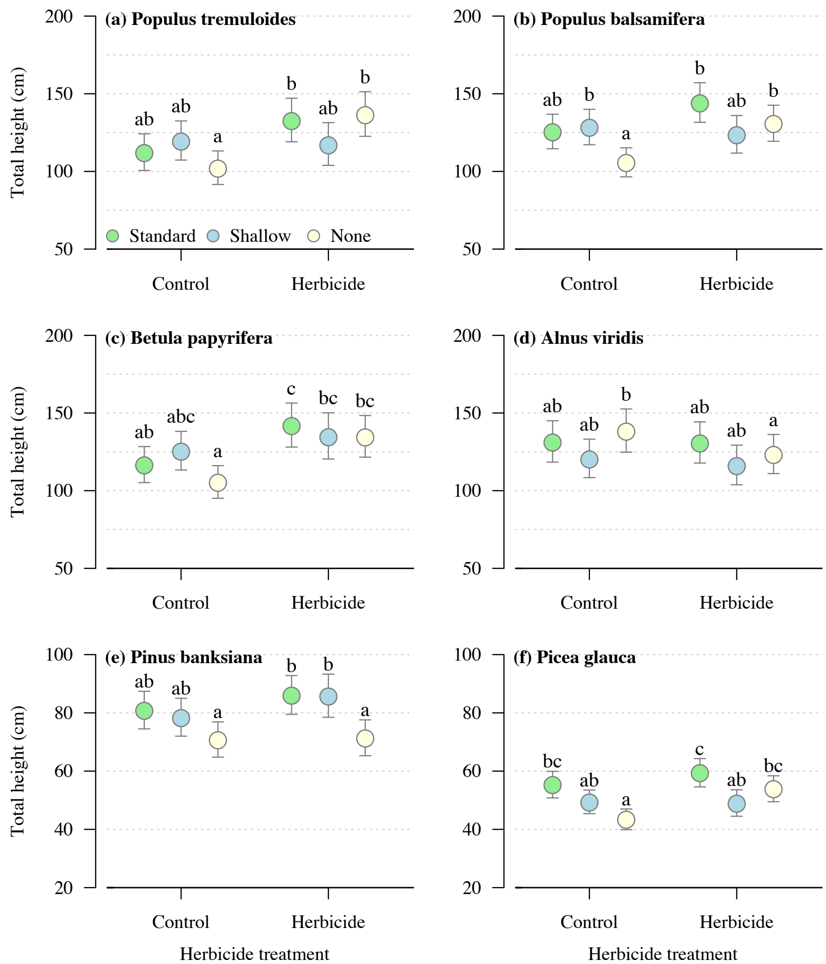

Figure 9: Estimated marginal total tree height after three growing for planted species by topsoil depth treatment (standard, shallow or none) and herbicide treatment (none [No] or pre-emergent herbicide [Yes]). Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean (n = 4 replicate blocks). Estimated means were generated from a split-plot three-factor generalized linear mixed effects model (fitted with a gamma or lognormal distribution).

LESSONS LEARNED

While it is premature to draw any firm conclusions from this project, given that only three growing seasons of data have been collected, the results so far suggest that the lack of topsoil has not been a severe limitation to the development of the planted tree and shrub species. In several cases, total height is progressing at a similar pace across topsoil depth treatments with stronger differences attributed to the competition-mediated effects of using a pre-emergent herbicide. Total understory vegetation is beginning to diverge amongst the no-topsoil compared with shallow and standard topsoil depths, though what this means for plant community composition and structure will require longer-term study.

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PRESENTATIONS AND PUBLICATIONS

No public presentations or publications in 2023.

RESEARCH TEAM AND COLLABORATORS

Institution: NAIT Centre for Boreal Research

Principal Investigator: Dr. Amanda Schoonmaker

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Research Collaborators: Dr. Dani Degenhardt and Dr. Jaime Pinzon (Canadian Forest Service, Natural Resources Canada)

High Quality Shrub Seedlings

COSIA Project Number: LE0087

Mine

Research Provider: Syncrude

Industry Champion: Syncrude

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Imperial, Suncor

Status: Ongoing

PROJECT SUMMARY

Concerns exist with inconsistent outplanting performance of broad-leaved tree and shrub seedlings used in mine site reclamation in Alberta. It is expected that native plants will have variability, but industry needs base line quality specifications on seedling stock provided by nurseries. This study focuses on few species of broadleaf plants growth regimes provided by three different nurseries. Data will help establish guidance on parameters to define acceptable seedling quality.

Specific research questions have been developed for each component of the study (i.e., seedling stock quality and seedling mowing). The research questions for seedling stock quality are the following:

1. Are there differences in field performance by nursery source, which have different stock and growing practices?
2. Are there visible indicators of seedling quality (prior to planting) that are correlated to field performance that can be used in developing standards to select acceptable seedlings for outplanting?
3. Are there physiological or morphological differences (e.g., seedling size, shoot to root ratio, root carbohydrate reserves, seedling tissue nutrient content) that can be correlated to field performance and used to improve nursery practices?

PROGRESS AND ACHIEVEMENTS

Randomized and replicated treatment plots were established in newly reclaimed areas at Syncrude in the spring of 2023. Seedling stock from three nurseries were used for the study, with six species: *Alnus viridis* (green alder), *Betula papyrifera* (white birch), *Populus tremuloides* (aspen), *Salix bebbiana* (Bebb's willow), *Salix discolor* (pussy willow) and *Shepherdia canadensis* (buffaloberry).

In the fall of 2023, plant growth measurements from the first growing season were conducted. The results are currently being analyzed. Growth measurements in the following growing season(s) will be evaluated based on the results of the first growing season.

LESSONS LEARNED

There are no lessons learned available for the 2023 as data analyses have not been completed.

RESEARCH TEAM AND COLLABORATORS

Institution: Syncrude

Principal Investigators: Eric Girard

Development of Soft Tailings Reclamation Technologies to Create Stable and Sustainable Boreal Landscapes

COSIA Project Number: LJ0341

Mine

Research Provider: Department of Natural Resources Canada

Industry Champion: Imperial

Status: Year 4 of 5

PROJECT SUMMARY

At Imperial's Kearl Operation, tailings are managed by thickening the middlings (specific gravity of 1.05 to 1.2) with a secondary, in-line chemical treatment applied to the underflow prior to deposition. Thickened tailings (TT) are generated with a sand-to-fine ratio (SFR) of 0.5 to 2 and a solids content greater than 65%. Overall, TT are considered suitable for capping with solid materials (e.g., coarse sand tailings or suitable overburden). A substrate cap is required to increase the strength and stability of the landform while hydraulically isolating the tailings from the soil surface and vegetation rooting zone (Alberta Energy Regulator 2018; Sutton and Price 2020). A land surface reclamation cap (cover soil) is placed above the substrate cap to provide essential organic matter and other desired soil characteristics required to support vegetation establishment and development of a productive ecosystem through the retention of moisture and nutrient cycling.

While some mines such as Syncrude's Sandhill Fen, South Bison Hill, and Gateway Hill (Wytrykush et al., 2012; Grant et al., 2013; Syncrude Canada Ltd., 2013) have successfully reclaimed tailing sands, the reclamation of treated fine tailings deposits is still in progress. Tailings capping studies have been conducted in greenhouse facilities using centrifuge tailings (Lalonde et al., 2020; Omari et al., 2020; Degenhardt et al., 2023). However, centrifuge tailings have different chemical and physical properties from TT (Cossey et al., 2021). Published studies involving TT (also referred to as consolidated tailings) have focused on the phytotoxicity of its release water (Renault et al., 1998, 2003; Armstrong et al., 2010; Cutter, 2013) or its physical properties and consolidation behaviours (McKenna et al., 2016; Wilson et al., 2018; Demoz, 2022).

A better understanding of the chemical and physical properties of TT and their impacts on native plant establishment, along with the effectiveness of reclamation cover soil caps on mitigating these limitations, is needed to inform reclamation capping designs. Meso-scale greenhouse studies can provide an opportunity to assess plant performance in tailings with different soil caps in a controlled environment and offer reduced complexity relative to field studies. In the present work, researchers omitted the recommended substrate cap between the tailings and reclamation soil cover cap to represent a scenario where tailings are not isolated from the rooting zone.

The objective of this three-year, meso-scale column greenhouse study was to understand the effect of TT on the survival and growth of native plant communities and evaluate the potential improvement in plant response with the addition of a relatively thin reclamation cap of peat mineral mix (PMM).

Columns were assembled in 55-gallon (208 L) cylindrical plastic barrels (54 cm in diameter and 90 cm in height), using TT and PMM freshly salvaged at Imperial's Kearl Operations. Three different PMM capping treatments were tested: 0 cm, 10 cm, and 30 cm. Each column was planted with one of two plant communities — wetland or upland — comprised of common species found in the boreal forest.

The upland community included *Populus tremuloides* Michx. (aspen), *Pinus banksiana* Lamb, (jack pine), *Cornus sericea* L. also referred to as *Cornus stolonifera* Michx. (red-osier dogwood), and *Elymus trachycaulus* ssp. *trachycaulus* (Link) Malte (slender wheat grass). The wetland community included *Salix bebbiana* Sarg. (Bebb's willow), *Scirpus microcarpus* J. Presl and C. Presl (small-fruited bulrush), *Triglochin maritima* L. (seaside arrow grass), *Rumex salicifolius* Weinm. (willow dock), and *Carex aquatilis* Wahlenb (water sedge).

Each of the three capping depth treatments was replicated in four columns for each of the two plant communities, for a total of 24 columns. One-year-old seedlings were planted into the columns in May 2019. In the upland community, three individual plants per species were planted for a total of 12 plants per column. In the wetland community, three plants per species were planted, except for *S. bebbiana* where only two plants were planted, for a total of 14 plants per column.

PROGRESS AND ACHIEVEMENTS

Initial characterization of the TT material found relatively high concentrations of petroleum hydrocarbons (PHCs), and other physical properties which may challenge plant growth. However, the probability of plant survival after three growing seasons was high (> 75%) across all capping treatments in both communities. There was a significantly higher (P = 0.005) probability of plant survival in the 30 cm PMM capped tailings compared to the uncapped tailings for both plant communities.

Statistically significant differences between species were not tested in this analysis since the objective of this study was to evaluate the effect of the capping treatments on overall plant performance. However, descriptive statistics were completed to highlight differences among species, which give an indication of the ability of some species to survive and grow in capped TT.

In the upland community, *P. tremuloides* and *C. sericea* were the top performing species in terms of survival and above-ground biomass in the capped TT treatments. While high survival rates were observed for all upland species, the woody species generated more above-ground biomass compared to the grass, *E. trachycaulus*. Furthermore, *P. tremuloides* and *C. sericea* each doubled the mean height of *P. banksiana,* achieving heights over 1.5 m tall on TT capped with 30 cm PMM. The ability of *C. sericea* to grow from sprouts or root shoots, and *P. tremuloides* through vigorous root suckering, make them good candidates for revegetating reclamation sites (Hardy BBT Limited 1989).

In the wetland community, *S. bebbiana* and *S. microcarpus* were the top performing species in terms of survival and above-ground biomass in the capped TT. *T. maritima* achieved high survival rates but very low above-ground biomass. *S. microcarpus* is a perennial wetland sedge that establishes quickly and spreads rapidly from rhizomes, potentially outcompeting other species (Smreciu et al., 2013; Turnbull and Bridgham, 2015). As such, this plant species may be useful for revegetation of reclaimed TT tailings deposits. *S. bebbiana* was the tallest species in this study, reaching more than three metres tall on the TT capped with 30 cm PMM. *S. bebbiana* is an adaptive species tolerant of a wide range of soil conditions (Hardy BBT Limited, 1989), and the ability to easily reproduce vegetatively also make it a good candidate for reclamation (Alberta Environment 2010).

LESSONS LEARNED

Results from this study indicate that a thin (10 cm) reclamation cap comprised of PMM can significantly improve vegetation growth on TT compared to uncapped TT. Furthermore, plant growth response increases significantly by increasing the PMM cap thickness to 30 cm.

The top performing species, with regards to survival and above-ground biomass on capped tailings, were *P. tremuloides* and *C. sericea* in the upland community, and *S. bebbiana* and *S. microcarpus* in the wetland community. No differences in survival and growth response were found between the upland and wetland communities, except in terms of woody species incremental growth, where *S. bebbiana* in the wetland achieved higher incremental growth than the upland woody species.

Although the study was limited to a small sample size, three growing seasons, and the reduced complexity of an isolated column system lacking the full range of hydrological and climatic factors which influence plant growth and nutrient cycling, this work contributes to the understanding of the reclamation capability and best reclamation practices for TT and other by-products generated from oil sands mining with high PHC's (e.g., lean oil sands). In addition, these findings support the requirement of a soil reclamation cap over TT tailings to improve growth of both upland and wetland plant communities.

Additional greenhouse and field research on optimal capping depth of TT will also help to inform TT reclamation best practices.

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PRESENTATIONS AND PUBLICATIONS

Journal Publications

Degenhardt, D., Van Dongen, A., Schreiber, S. G., Bekele, A. 2023. Growth and survival of native upland and wetland species in shallow capped thickened tailings: a meso-scale greenhouse study. Canadian Journal of Soil Science. 103(4): 567-617. https://doi.org/10.1139/cjss-2022-0113

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RESEARCH TEAM AND COLLABORATORS

Institution: Department of Natural Resources

Principal Investigator: Dani Degenhardt

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Stefan Schreiber	EnviroStats Solutions Inc.	Owner		
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REVEGETATION

Interim Reclamation

COSIA Project Number: LJ0226

Mine and In Situ

Research Provider: NAIT Centre for Boreal Research

Industry Champion: ConocoPhillips

Status: Year 9 of 10

PROJECT SUMMARY

This program of research encompasses study topics of: (1) interim reclamation (also known as temporary reclamation); as well as (2) final reclamation. Even though there is a distinction between interim and final reclamation, it should be recognized that much of the interim reclamation research is applicable to final reclamation. Each study (and projects therein) is described below.

Study 1: Interim Reclamation of a Facility Soil Stockpile

Industrial site disturbances, whether in the mining or oil and gas sector, typically result in the clearing of forests and stockpiling of surface soils during the development and operational phases. Ongoing management of these stockpiles is required until the site is decommissioned, and final reclamation is undertaken. This is where the facilities are removed, the site is recontoured and stockpiled soils are redistributed. Historical and current practices include seeding stockpiled soils with grasses and the use of chemical herbicides to eradicate or control prohibited and noxious weeds. In principle, the temporary reforestation of soil stockpiles will provide; root and seed propagules; coarse woody materials; long-term soil erosion control; reduced use of chemical herbicides for noxious weed management; and increase biodiversity. Temporary reforestation of soil stockpiles is an alternative, though not widely used, practice that may better fit the fundamental long-term final reclamation goals in forested settings, which is to re-establish a self-sustaining functional boreal forest.

This temporary (or interim) reclamation project is situated on an eight-hectare topsoil and subsoil stockpile that is anticipated to be in place for several decades. The intent of this study is to advance interim reclamation a step beyond historical recontouring and seeding practices to include the establishment of woody species on non-active areas of an in situ project (e.g., soil stockpiles) during the life of the facility. It is hypothesized that this will speed establishment of forest cover and reduce the need for ongoing and repeated weed management. To date, this practice is not something that has been commonly implemented at in situ facilities in the oil sands region. This project provides an on-site demonstration of the effect of site preparation (dozer to create furrows and backhoe to mound soil on steeper slopes), varying planting densities (0, 2,500, 5,000 and 10,000 stems per hectare), and the use of coarse woody material as a reclamation material (present or absent). Rather than assessing one combination of interim reclamation techniques, the experimental trials have been structured to support the development of best practices that will have a high probability of success at final in situ specific reclamation and will be cost effective to implement.

This project is also designed to question assumptions about species suitability for use (in terms of the out-planting of different nursery stock species) in a reclamation context. Industrial disturbances do not necessarily follow the same early vegetation dynamic patterns found after fires or forest harvesting. Industrial disturbances require soil to be moved during construction and again during reclamation prior to final revegetation. This anthropomorphic soil redistribution forces the system into being a largely seed-based regeneration/revegetation system rather than root based. This has consequences for the native species being established and will favour those species that are able to tolerate competition as young seedlings. The project plots are situated on a big hill with soil and aspect variability which should help inform tolerance ranges for each of the planted species in a reclamation context.

While the long-term goal of this project is to initiate forest development, in the short term, three separate projects were initiated at this site to ask specific questions related to initial planting density, how to include desirable native herbaceous species, and alternative methods of planting deciduous trees.

Specific objectives and study questions for these projects are further described below.

Project 1: Site preparation and establishment density

1. Compare three densities of container stock planting (2,500, 5,000 and 10,000 stems per hectare) and monitor natural regeneration (within unplanted controls).
   a. Which native tree and shrub species will provide speedy establishment, produce viable seed within the time frame of facility life and have capacity to regenerate aggressively through root fragments following reclamation activities?
   b. Which species are best suited to different combinations of slope position and aspect on reclamation soils?
   c. Is natural regeneration a viable approach for forest plant establishment?
   d. How does the speed of canopy development and structure compare with different densities over time?
   e. Does the overstory density impact development of understory vegetation?
   f. Does aspect or slope position interact with plant establishment through these methods?
2. Compare use of soil adjustment to create a rough and heterogeneous soil surface against track-packed "smooth" reclamation approach.
   a. Does soil adjustment impact the growth and production of planted woody species?
   b. Does soil adjustment improve natural ingress and regeneration of desirable woody species?
3. Demonstrate the utility of coarse woody material in conjunction with soil treatments to create a rough and heterogeneous soil surface.
   a. Does coarse woody material impact growth and production of planted woody species?
   b. Does coarse woody material increase the stability of sloped soils and reduce erosion?
   c. Does coarse woody material improve the natural ingress and regeneration of desirable woody species?
4. Examine the impact of wildlife browsing (and presence) on establishment and development of planted woody species.
   a. Which species are preferentially browsed?
   b. What is the impact of browsing on plant performance?
   c. Does browsing significantly impact canopy development?

Project 2: Cover crop establishment through planting

1. Evaluate two methods of planting native forbs including: individual planting of container stock and co-planting native forbs with a woody species (produce plants in same plug).
   a. Does the forb develop (increase in vegetation cover) equally well with both approaches?
   b. Is there a positive, neutral, or negative impact for the woody species which shares the plug initially?
2. Compare the effect of the addition of native forbs during the early phase of forest development.
   a. Do they facilitate ingress of other desirable species?
   b. Do they reduce ingress of undesirable species?
   c. Do they aid in soil stabilization?
   d. What is incremental cost of planting native forbs?
3. Optimize production of mixed-species container stock for three different woody species (green alder, willow, and paper birch) each co-grown with fireweed.
   a. What is the best time to sow the forb into container with woody species?
   b. Is mixed-species container stock appropriate for all woody species or only for specific species?

Project 3: Aspen establishment through container stock, optimizing plant deployment through grouped planting

This study was conducted as a pilot project to further the concept of cluster planting of deciduous trees (see project Cluster Planting (page 18), 2018 COSIA Land EPA — In Situ Report).

The objective of this project was to compare localized cluster planting of aspen with conventional planting at uniform spacing. In this project, the question of how many plants are required for a "cluster" to positively impact survival and growth of aspen container stock will be addressed.

Study 2: Vegetation Management Solutions for Final Reclamation

Noxious weeds and other undesirable vegetation (e.g., sweet clover [*Melilotus* sp.], alsike clover [*Trifolium hybridum*], creeping red fescue [*Festuca rubra*], timothy [*Phleum pretense*] and smooth brome [*Bromus inermis*]) are transported to reclamation sites by a variety of mechanisms. These include historical presence in the soil seed bank from previous decades of utilization in cover crop mixes, contaminated equipment, wind, wildlife and in some cases intentional broadcasting. Collectively, these undesirable species present challenges to the development of forest plant communities. In northern Alberta, management of aggressive agronomic species is a significant issue to forest development and the certification of reclaimed wellsites (Bressler, 2008). Regulatory criteria and legislation clearly define the need to control and eradicate noxious weed species (Weed Control Act, 2010; Environment and Sustainable Resource Development, 2013), as well as undesirable species (Environment and Sustainable Resource Development, 2013). Site preparation, cultural control (cover crop establishment) and chemical management represent a range of approaches to control or eradicate undesirable species.

The objective of this study was to examine the ability of combinations of native plant cultural controls (cover crop) and herbicide-based approaches to reduce and eliminate undesirable plant ingress. In this study, approaches that are appropriate for use in the early stages of revegetation development following soil replacement will be evaluated.

Each of these approaches was initiated in the first year following reclamation with plans to monitor the study for three growing seasons. At the completion of the study, the following questions will be answered:

1. Which approaches are most effective at reducing the initial establishment of undesirable species?
2. By controlling ingress of undesirable plants, are there also differences in native plant establishment through natural ingress?
3. Is there a reduction in the growth and productivity of desirable native woody species when utilizing a treatment that is aimed at reducing undesirable plant development (i.e., a trade-off)?
4. What is the potential return on investment of the vegetation management approaches considering relative benefit/success at managing undesirable species?

PROGRESS AND ACHIEVEMENTS

Study 1: Interim Reclamation of a Facility Soil Stockpile

Project 1: Site preparation and establishment density

This section focuses on the findings from Project 1 based on results collected between the first and eighth growing seasons towards objectives 1d and 1e. Researchers are presently working through the final analyses related to this project. For the Year 9 report they focused on two key components: comparisons between density treatments in terms of stem densities of woody species and understory vegetation development, addressing aspects of objectives 1d and 1e.

Each response type (stem count, height, cover, or relative abundance of cover) was analyzed using generalized linear mixed-effects models with two-way interactions on year X density and year X soil type. While effects related to the density treatment are the focus of the current discussion, the researchers have presented the soil type responses in all figures and noted relevant findings throughout.

As this study was established across both a topsoil and subsoil soil stockpile, it was important to include this factor in the statistical analyses as a key explanatory variable.

Objective 1d: How does the speed of canopy development and structure compare with different densities over time?

Intentional planting of trees and shrubs has significantly increased the total tree plus shrub stem counts after eight years relative to the unplanted (leave for natural) treatment (Figure 1a). The 10,000 stems ha^{-1} treatment has been consistently higher relative to the other density treatments, while the 2,500 stems ha^{-1} and 5,000 stems ha^{-1} treatments were similar with respect to total stem counts and tree stem counts (Figure 1a and 1c). The unplanted treatment has continued to lag the planted treatments with about 50% fewer tree and shrub stems compared with the 2,500 stems ha^{-1} and 5,000 stems ha^{-1} treatments (Figure 1a). Nevertheless, it has experienced recruitment over the eight-year time frame with over 2,000 stems ha^{-1} observed, on average, by Year 8 (Figure 1a). While we expect that a proportion of the stem counts in the planted treatments also reflect natural recruitment, the precise balance of planted versus natural recruitment requires further analysis.

This recruitment has been largely in the form of wind-dispersed deciduous tree species (*Populus balsamifera* and *P. tremuloides*), though recruitment of tall shrubs has been observable more recently (Years 6 and 8) in the unplanted treatment (Figure 1e). It is suspected that the observed *Alnus viridis* recruitment in the unplanted treatment within the tall shrub category is occurring due to seed rain from the adjacent planted plots, while *Salix* recruitment is occurring by wind-dispersed seeds, similar to deciduous tree species.

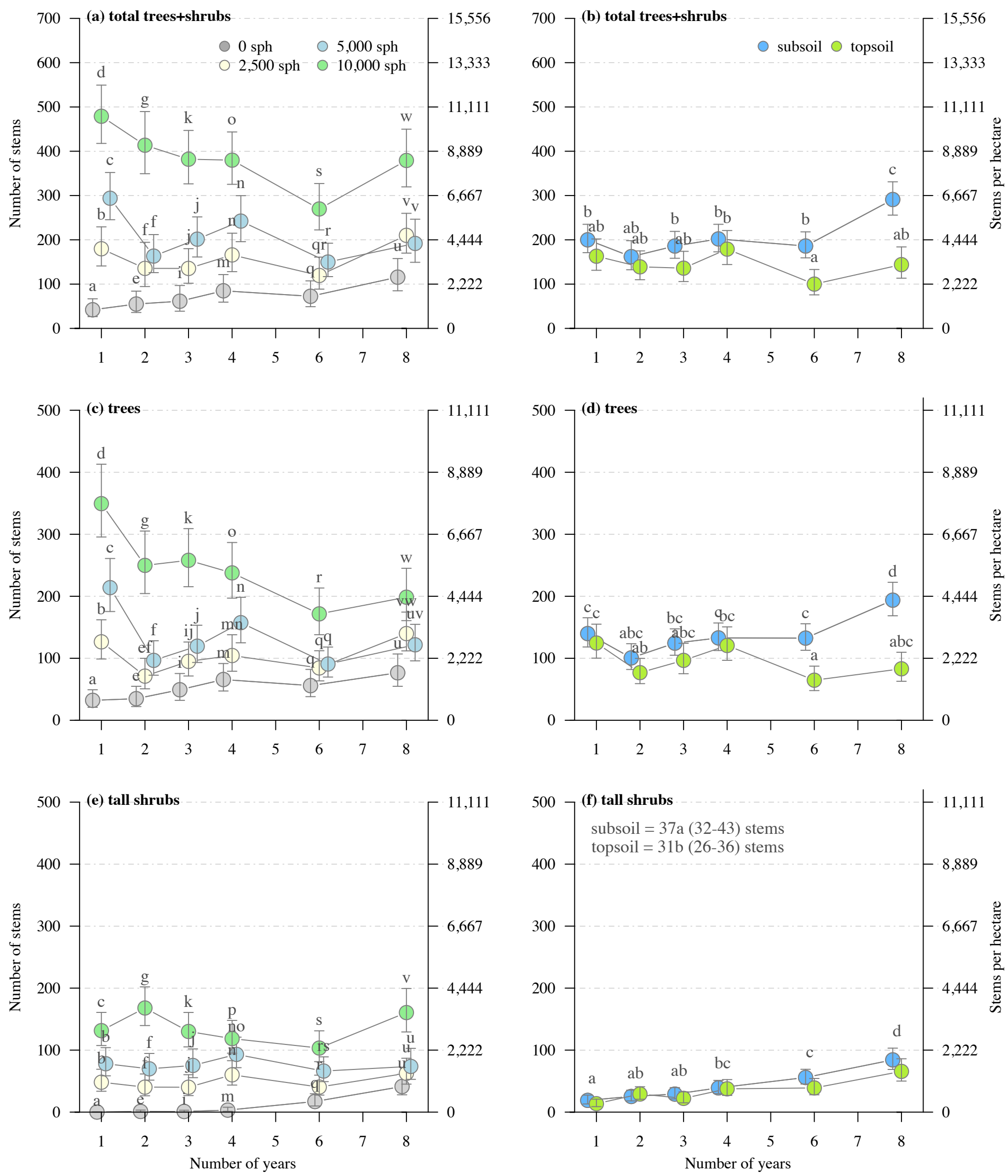

Figure 1: **Estimated marginal mean stem counts (per 450 m²) of (a-b) total trees+shrubs, (c-d) trees and (e-f) tall shrubs across eight growing seasons.** Groups are presented by density treatment (control [0], low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}] except for [e] where the control was omitted due to lack of observations) or soil type (subsoil or topsoil). The total woody and shrub densities excludes raspberry stem counts which were exceptionally high throughout the study site (approximately 8,000 stems ha^{-1}, on average in Year 6) and tended to mask density treatment effects. Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. For plots of density treatments (a, c, e), comparisons were made within the year of measurement whenever there was a significant density X year effect while all means were compared for soil type comparisons. For panel (f) as there was no significant interaction between soil type and year, main effect differences were instead compared. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a lognormal distribution) on plot-level stem counts (package glmmTMB, Brooks et al., 2017).

Planting seedlings continues to exert a strong effect on mean height development of all species. *Populus balsamifera* averaged 200 cm in Year 8 in the unplanted treatment compared with over 300 cm for the 10,000 stems ha^{-1} treatment (Figure 2a). Similarly, *Populus tremuloides* was on average about 40% smaller in the unplanted treatment compared with planted treatments (Figure 2c). Of the treatments that were planted, there has been no effect of planting density on growth for most species including *Betula papyrifera*, *Alnus viridis*, *Pinus banksiana* and *Picea glauca* (Figures 2 to 4). While there were short-term differences observed for *Salix*, these effects were no longer apparent by Year 8 (Figure 4c).

However, soil type has had a strong effect with most species growing taller in topsoil compared with subsoil (Figures 2 and 4). *Pinus banksiana* showed similar rates of growth regardless of soil type (Figure 3b) and though it appeared that *Picea glauca* was beginning to grow taller in topsoil in Year 6, heights began converging again by Year 8 (Figure 3d). For *P.glauca* this may be attributable to increased competition for light from the surrounding deciduous trees, all of which were substantially taller (Figure 2). For *Pinus banksiana*, it may be a combination of factors including competition with herbaceous species early on (Figure 5b) coupled with deciduous tree competition in later years (Figure 2). It could also be due to fewer observations in the topsoil treatment plots, as survival was low for this species.

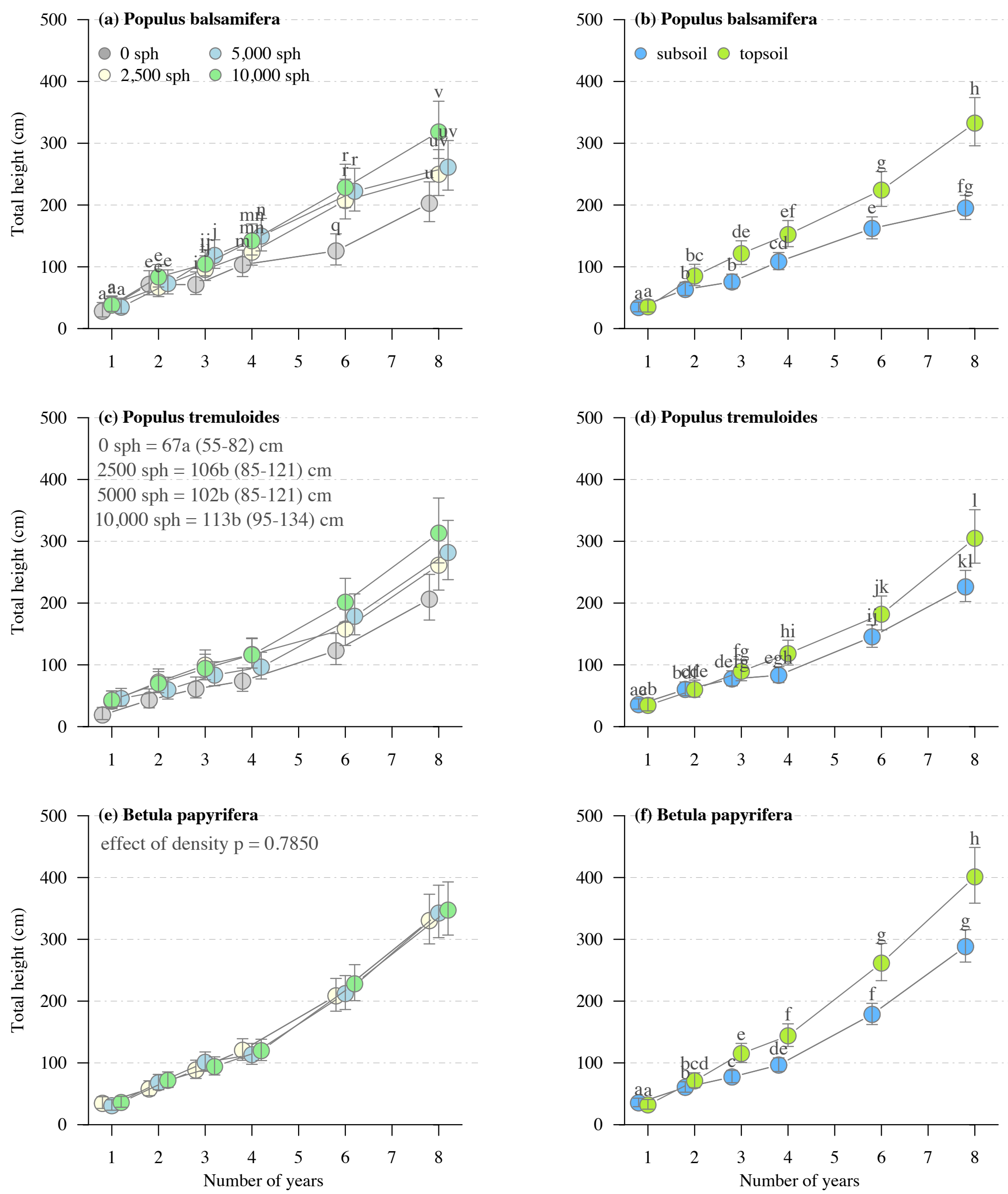

Figure 2: **Estimated marginal mean height of (a-b)** ***Populus balsamifera*****, (c-d)** ***P. tremuloides*** **and (e-f)** ***Betula papyrifera*** **across eight growing seasons.** Groups are presented by density treatment (control [0], low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}]) or soil type (subsoil or topsoil). Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. For plots of density treatments (a, c, e), comparisons were made within the year of measurement whenever there was a significant density X year effect while all means were compared for soil type comparisons. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a lognormal distribution) on plot-level mean heights (package glmmTMB, Brooks et al., 2017).

Note: *Betula papyrifera* was observed in the control (0 sph [stems ha^{-1}]) treatment in two to three plot-level replicates in Years 6 and 8 with arithmetic mean heights of 153 cm (80 SD) and 228 cm (129 SD).

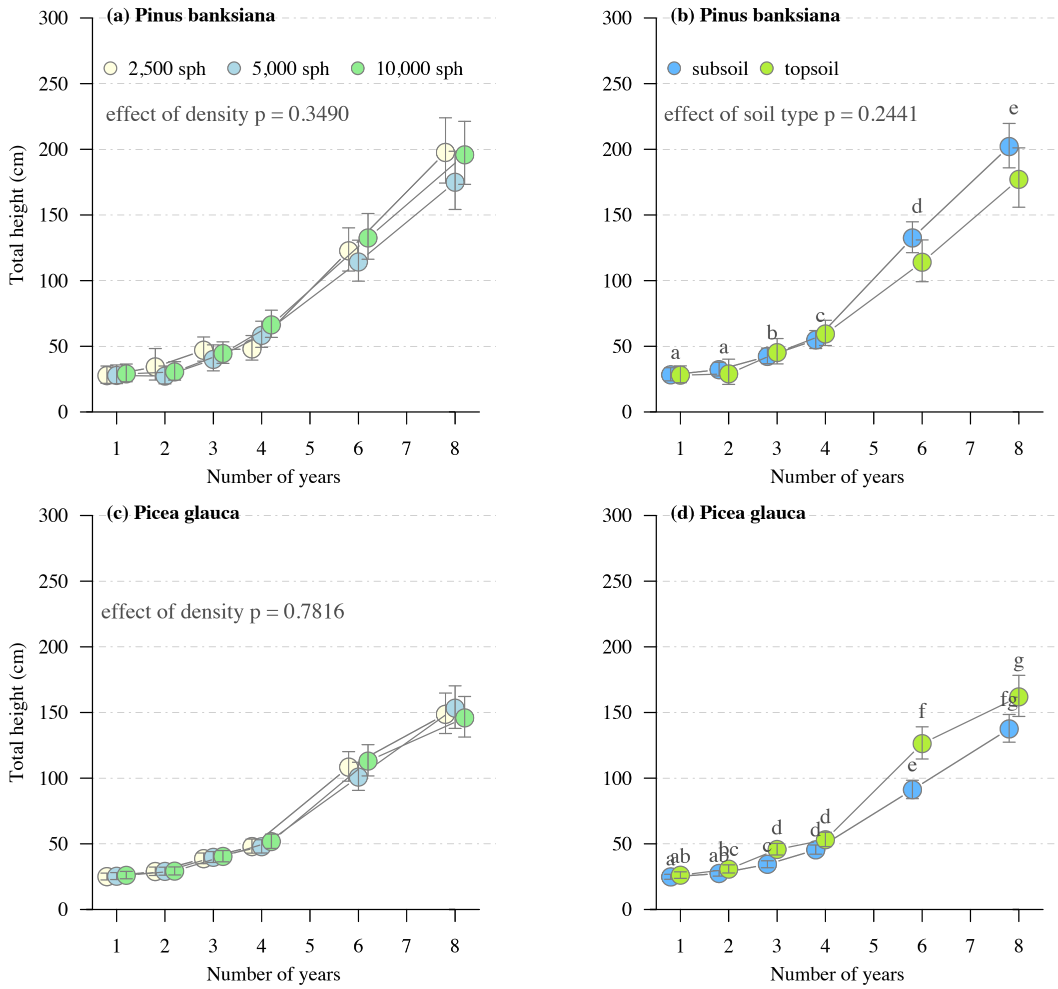

Figure 3: Estimated marginal mean height of (a-b) *Pinus banksiana* and (c-d) *Picea glauca* across eight growing seasons. Groups are presented by density treatment (low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}]) or soil type (subsoil or topsoil). Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. For plots of density treatments (a, c), comparisons were made within the year of measurement whenever there was a significant density X year effect while all means were compared for soil type comparisons. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a lognormal [*Pinus banksiana*] or gamma [*Picea glauca*] distribution) on plot-level mean heights (package glmmTMB, Brooks et al., 2017).

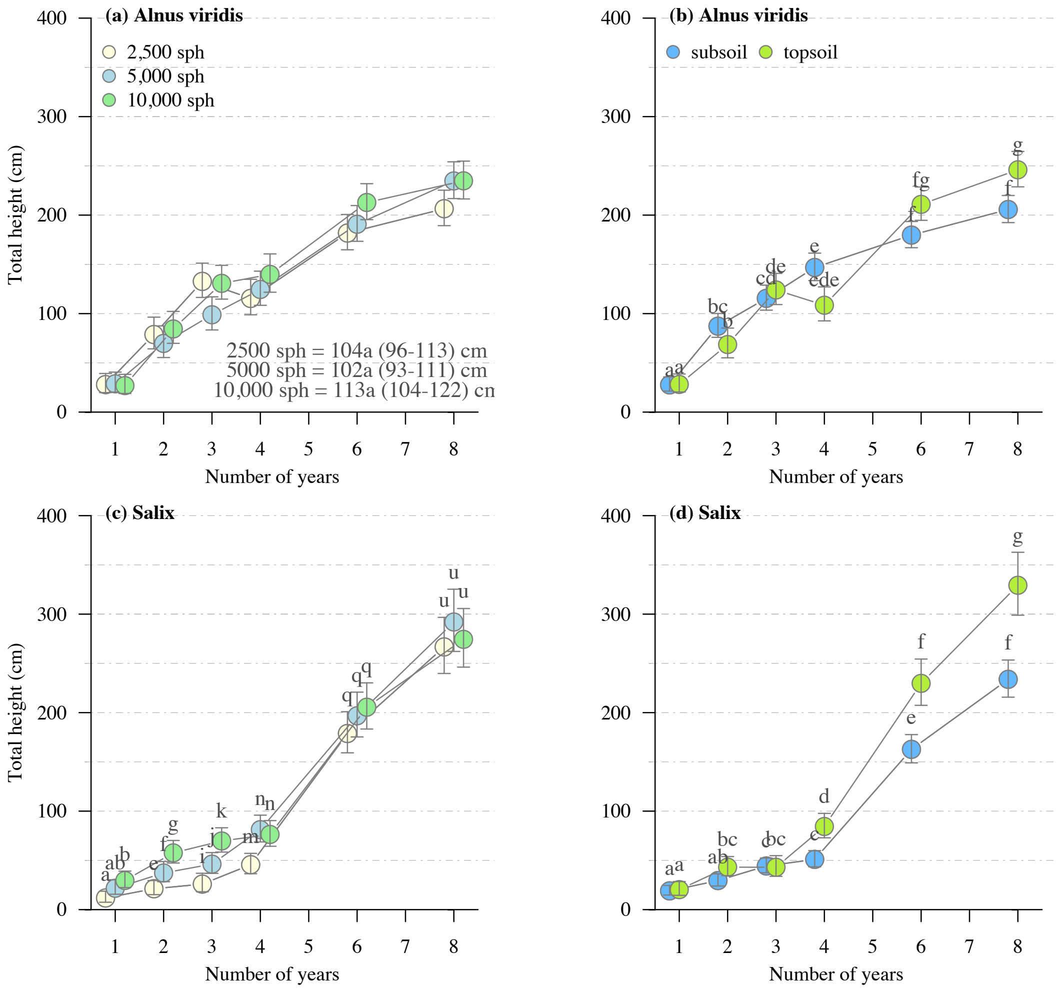

Figure 4: Estimated marginal mean height of (a-b) *Alnus viridis* and (c-d) *Salix sp.* across eight growing seasons. Groups are presented by density treatment (low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}]) or soil type (subsoil or topsoil). Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. For plots of density treatments (a, c), comparisons were made within the year of measurement whenever there was a significant density X year effect while all means were compared for soil type comparisons. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a lognormal distribution) on plot-level mean heights (package glmmTMB, Brooks et al., 2017).

Note: *Alnus viridis* was observed in the control (0 sph) treatment in three to four plot-level replicates in Years 6 and 8 with arithmetic mean heights of 119 cm (65 SD) and 170 cm (59 SD). *Salix* was observed in three to six plot-level replicates with arithmetic mean values of 5.2 cm (3.5 SD) in Year 2, 17 cm (10 SD) in Year 3, 8.2 cm (2.5 SD) in Year 4, 155 cm (28 SD) in Year 6 and 191 cm (93 SD) in Year 8.

Objective 1e: Does overstory density impact the development of understory vegetation?

Total vegetation cover across density treatments has followed similar patterns over time with no significant treatment effect due to planting density, though in Year 8 there was an approximately 10% decline in total cover for the 10,000 stems ha^{-1} treatment relative to all others (Figure 5a). However, soil type has had a strong impact on total understory vegetation cover with consistently higher cover in topsoil (approximately 80%) compared with approximately 60% cover in subsoil after eight years (Figure 5b). In terms of relative abundance, key patterns of development for each vegetation class are noted below:

- The relative abundance of graminoids was not affected by planting density and tended to decline from the Years 1 through 4, relative to Years 6 and 8 (Figure 5a-b).
- The relative abundance of native forbs resulted in a significant two-way interaction between planting density and year of measurement (Table 1). In Years 1 through 3, no differences were observed amongst density treatments. However, in Years 4, 6 and 8, both the 0 stems ha^{-1} and 2,500 stems ha^{-1} treatments showed higher relative abundance within the year of assessment, although this lacked a consistent pattern (Figure 5c). The 10,000 stems ha^{-1} treatment did have the lowest relative abundance of all density treatments during the time period encompassing Years 4 through 8 (Figure 5c).
- Density treatments have resulted in consistent differences in the relative abundance of woody vegetation overall, with the 0 stems ha^{-1} being the lowest, followed by the 2,500, 5,000 and 10,000 stems ha^{-1} treatments showing the highest relative abundances up to eight years post-planting (Figure 5e).
- Conversely, the relative abundance of non-native forbs has remained proportionally lowest for the 10,000 stems ha^{-1} treatment and highest for the 0 stems ha^{-1} treatment with the 2,500 and 5,000 stems ha^{-1} density treatments showing intermediate responses (Figure 5g).

Table 1: Generalized linear mixed-effects model (GLMM) output associated with stem counts, total understory vegetation cover, relative abundance (RA) by vegetation class and tree heights by species. Factors tested included: soil type (ST), year of assessment (YR) treated as an ordinal factor and planting density (DY) treated as an ordinal factor. Random effects included the replicate block with density nested within each block to reflect the hierarchical structure of the data set. R statistical software (R core team, 2023) was utilized for all analyses and GLMMs were fitted using the function glmmTMB (package glmmTMB, Brooks et al., 2017).

Response	Factor	Chisq	Df	P-value	Response	Factor	Chisq	Df	P-value
total stem count	ST	15.339	1	<0.0001	*Populus balsamifera* height	ST	32.75	1	<0.0001
	YR	54.989	5	<0.0001		YR	1504.037	5	<0.0001
	DY	260.856	3	<0.0001		DY	19.367	3	0.0002
	ST x YR	21.31	5	<0.0001		ST x YR	25.26	5	0.0001
	DY x YR	44.781	15	<0.0001		DY x YR	34.204	15	0.0032
tree stem count	ST	8.6693	1	0.0032	*Populus tremuloides* height	ST	8.2909	1	0.0040
	YR	90.6646	5	<0.0001		YR	1690.0061	5	<0.0001
	DY	139.7973	3	<0.0001		DY	15.3303	3	0.0016
	ST x YR	35.7716	5	<0.0001		ST x YR	13.512	5	0.0190
	DY x YR	78.7581	15	<0.0001		DY x YR	21.0327	15	0.1358

tall shrub stem count	ST	6.0276	1	0.0141	*Betula papyrifera* height	ST	21.879	1	<0.0001
	YR	21.6749	5	0.0006		YR	4986.4	5	<0.0001
	DY	325.8027	3	<0.0001		DY	0.484	2	0.7851
	ST x YR	8.0759	5	0.1521		ST x YR	19.1	5	0.0018
	DY x YR	138.9592	15	<0.0001		DY x YR	10.54	10	0.3944
total under-story cover	ST	59.3621	1	<0.0001	*Picea glauca* height	ST	17.6827	1	<0.0001
	YR	475.3275	5	<0.0001		YR	4348.0588	5	<0.0001
	DY	4.2731	3	0.2334		DY	0.5661	2	0.7535
	ST x YR	43.5728	5	<0.0001		ST x YR	21.7052	5	0.0006
	DY x YR	24.5119	15	0.0569		DY x YR	4.7034	10	0.9101
graminoid RA	ST	9.5262	1	0.0020	*Pinus banksiana* height	ST	1.3569	1	0.2441
	YR	144.7644	5	<0.0001		YR	2780.647	5	<0.0001
	DY	0.3394	3	0.9525		DY	2.1051	2	0.3490
	ST x YR	31.7866	5	<0.0001		ST x YR	9.095	5	0.1053
	DY x YR	20.8068	15	0.1431		DY x YR	15.8047	10	0.1054
native forb RA	ST	3.366	1	0.0666	*Alnus viridis* height	ST	6.2907	1	0.0121
	YR	34.2745	5	<0.0001		YR	654.9751	5	<0.0001
	DY	7.7848	3	0.0507		DY	11.4752	2	0.0032
	ST x YR	47.8675	5	<0.0001		ST x YR	27.5235	5	<0.0001
	DY x YR	30.3086	15	0.0109		DY x YR	15.0858	10	0.1290
woody RA	ST	19.698	1	<0.0001	*Salix* sp. height	ST	29.2867	1	<0.0001
	YR	320.87	5	<0.0001		YR	2400.5172	5	<0.0001
	DY	31.849	3	<0.0001		DY	3.5248	2	0.1716
	ST x YR	79.744	5	<0.0001		ST x YR	14.2968	5	0.0138
	DY x YR	16.55	15	0.3464		DY x YR	86.9047	10	<0.0001
non-native forb RA	ST	21.562	1	<0.0001					
	YR	256.58	5	<0.0001					
	DY	13.234	3	0.0042					
	ST x YR	42.05	5	<0.0001					
	DY x YR	11.988	15	0.6799					

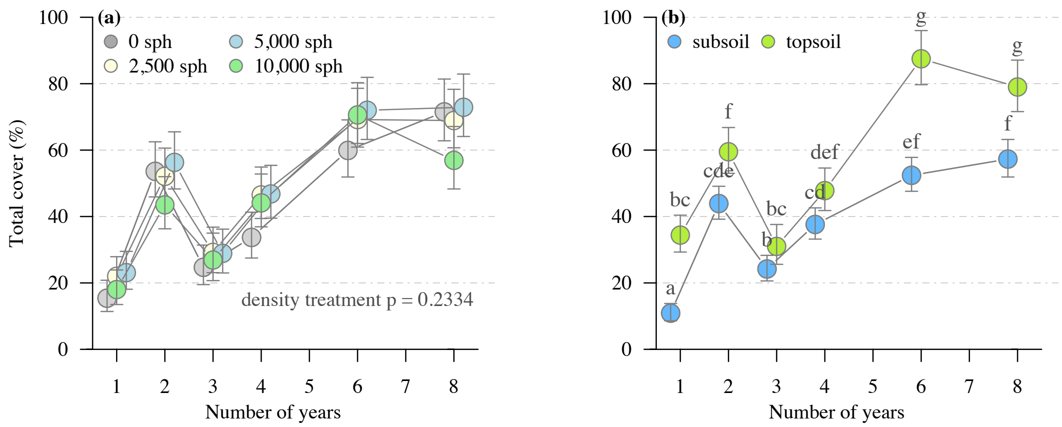

Figure 5: Estimated marginal mean total understory vegetation cover across eight growing seasons. Groups are presented by (a) density treatment (control [0], low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}]) or (b) soil type (subsoil or topsoil). Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a lognormal distribution) on plot-level data where individual plots were composed of 11 to22 quadrat-based measurements (package glmmTMB, Brooks et al., 2017).

Non-metric multi-dimensional scaling (NMDS) of the understory plant community has shown a significant and progressive shift over time (Table 2) where several early successional species, including native forbs (e.g., *Geranium bickenelli*, *Collomia linearis*) and non-native forbs (e.g., *Matricaria* sp., *Melilotus* sp., *Trifolium* sp.), were associated with Years 1 and 2 (Figure 7a) and were ultimately displaced by several woody species and other native forbs (*Urtica diocia, Chamerion angustifolium*). While density treatments were largely overlapping, there was a more subtle effect that tended to follow the planting treatment patterns (Figure 7c).

NMDS of the understory plant community has also illustrated broad groupings by soil type that interacted with time. Although the R2 value was still low at 0.072 (Table 2), the topsoil was most strongly associated with the forbs *Urtica diocia, Chamerion angustifolium, Galeopsis tetrahit,* and *Rubus idaeus,* while subsoil tended to be more associated with woody species (*Pinus banksiana, Alnus viridis,* and *Salix*), a graminoid (*Festuca ovina*), and the non-native forb *Taraxacum officinale* (common dandelion) (Figure 7c).

Table 2: PERMANOVA results for understory community composition. The R package vegan (function adonis2) was utilized with 1000 permutations using a Bray-Curtis dissimilarity matrix as input for the analysis. A chi-square transformation was applied to the community data (relative abundances of vegetation cover that sum to 1) before computing Bray-Curtis distances.

Factor	Degrees of freedom	Sum of Squares	R2	F-value	P-value
Year	5	11.303	0.291	13.772	0.001
Soil type	1	2.280	0.059	13.889	0.001
Density	3	1.865	0.048	3.786	0.001
Year x Soil type	5	2.806	0.072	3.418	0.001
Year x Density	15	1.897	0.049	0.771	0.991
Residual	114	18.714	0.482		
Total	143	38.865	1.000		

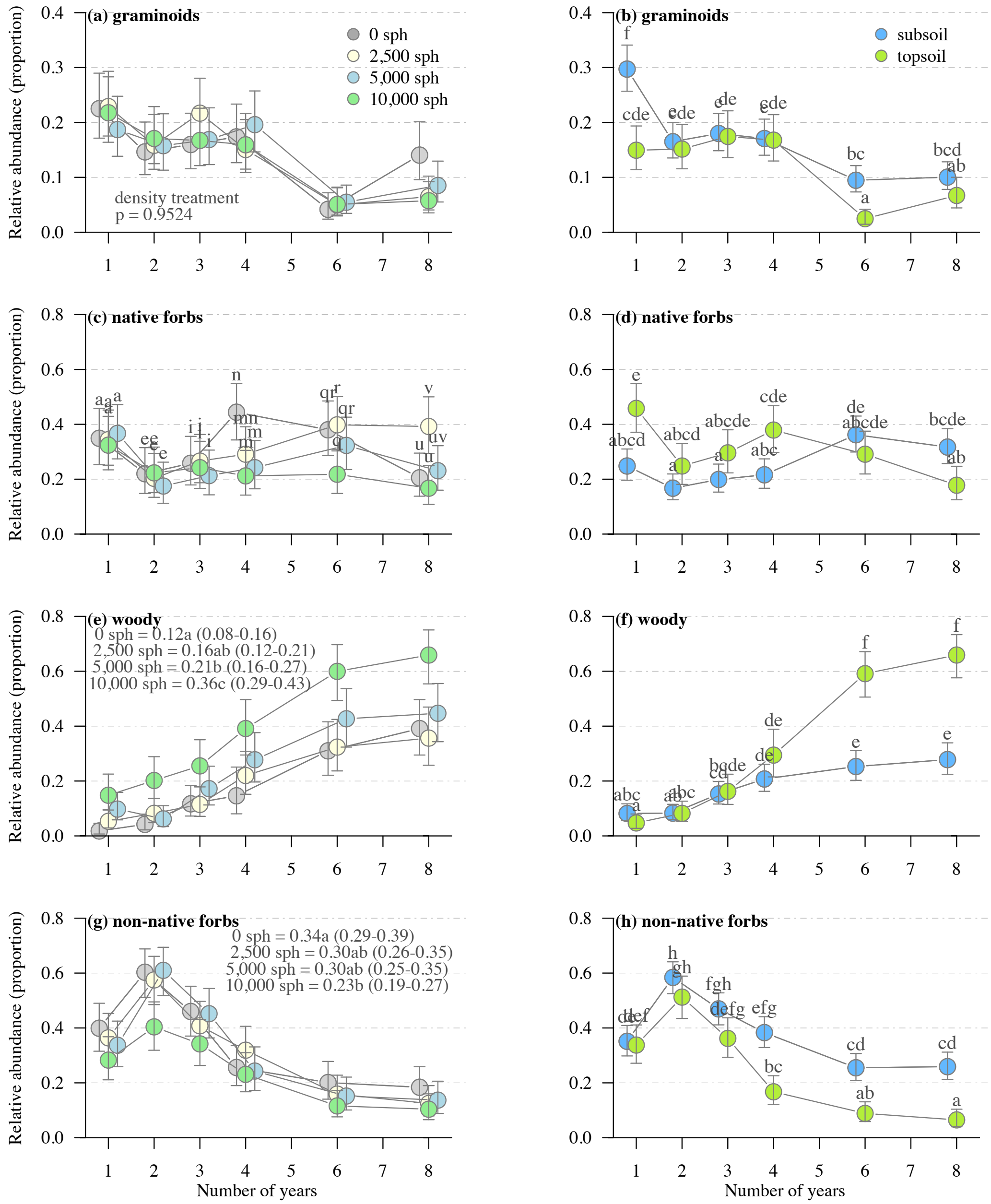

Figure 6: Estimated marginal mean relative abundance (proportion of total understory vegetation cover) across eight growing seasons. Groups are presented by (a) density treatment (control [0], low density [2,500 stems ha^{-1}], moderate density [5,000 stems ha^{-1}], and high density [10,000 stems ha^{-1}]) or (b) soil type (subsoil or topsoil). Treatment means not sharing the same letters indicate a significant ($p < 0.05$) difference in means. For plots of density treatments (a, c, e, g), comparisons were made within the year of measurement whenever there was a significant density X year effect while all means were compared for soil type comparisons. Values in brackets represent 95% confidence intervals on the treatment mean (n = 6 by density treatment or n = 9-15 by soil type). Estimated means were generated from a three-factor generalized linear mixed effects model (fitted with a beta distribution) on plot-level data where individual plots were composed of 11 to 22 quadrat-based measurements (package glmmTMB, Brooks et al., 2017).

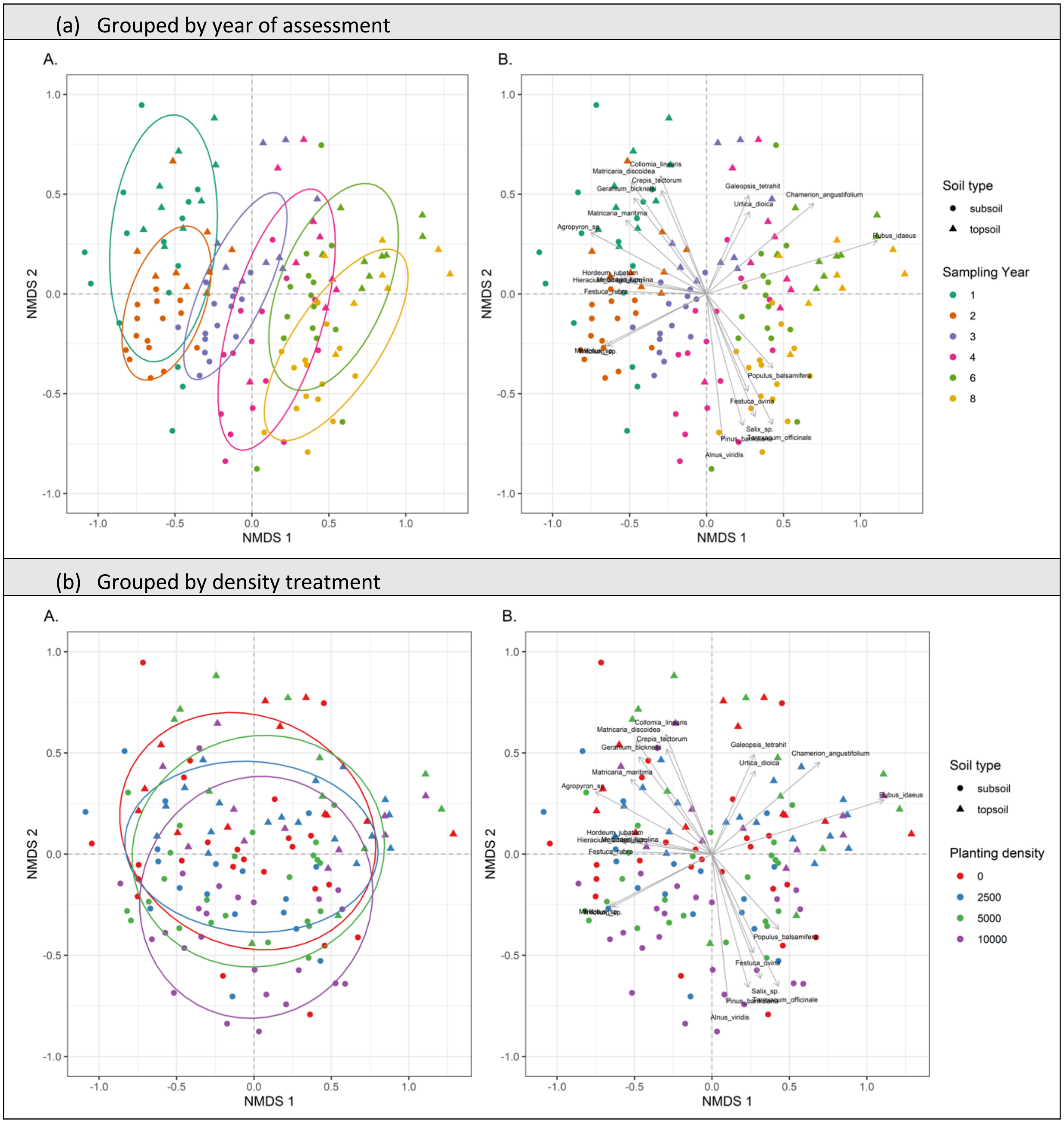

Figure 7: Continued on next page.

(c) Grouped by soil type

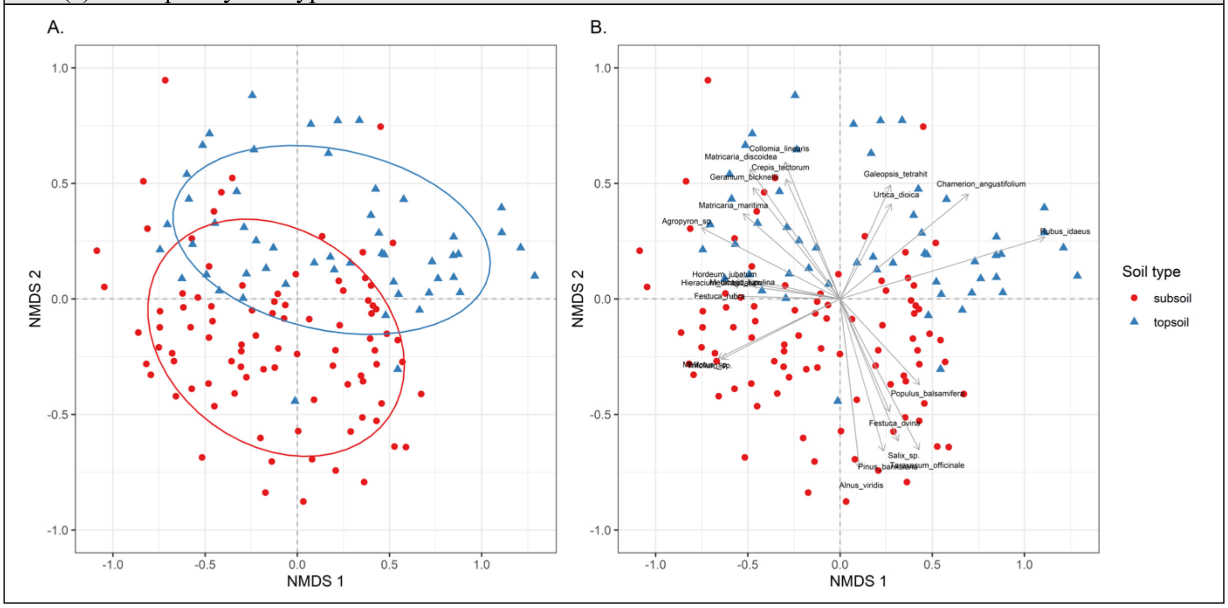

Figure 7: NMDS ordination of understory communities using a Bray-Curtis dissimilarity matrix as input. Each point is compositional (i.e., a relative abundance of vegetation cover that sums to 1, refer also to Figure 6 to see relative abundance of vegetation classes). A chi-squared transformation was applied to the data before generating the distance matrix. A single large outlier has been removed from the plots. Ellipses represent one standard deviation from the centroid. Arrows represent positive correlations between NMDS axes and species ($p < 0.001$), calculated using the envfit function from the R package vegan (Oksanen et al., 2022). The length of the arrow represents the strength of the correlation.

LESSONS LEARNED

Emerging lessons: This project has demonstrated that there are benefits to actively planting nursery stock seedlings on a previously disturbed reclamation area (in this case a soil stockpile). High-density planting (10,000 stems ha^{-1} treatment) is clearly the candidate for the speediest development of forest canopy vegetation, and after eight growing seasons, it continues to lead in terms of total woody stem counts and relative abundance of understory woody vegetation. At lower planting densities, the differences between unplanted and the 2,500 stems ha^{-1} or 5,000 stems ha^{-1} treatments are still rather subtle though there was a notable increase in understory woody vegetation coverage as the planting treatment density increased. Without intentional planting, natural plant establishment is at the mercy of site conditions and chance events, resulting in high spatial variation in recruitment levels (e.g., Figures 8 and 9). Moreover, tree species recruitment, thus far, has been largely restricted to wind-dispersed species in the current study whereas intentional planting has ensured a wider diversity of tree and shrubs are represented.

(a) **(b)** **(c)** **(d)**

Figure 8: Examples of images from the **subsoil treatment** where (a) 0 stems ha^{-1}, (b) 2,500 stems ha^{-1}, (c) 5,000 stems ha^{-1} and (d) 10,000 stems ha^{-1} density treatments in August 2023.

(a)

(b)

(c)

(d)

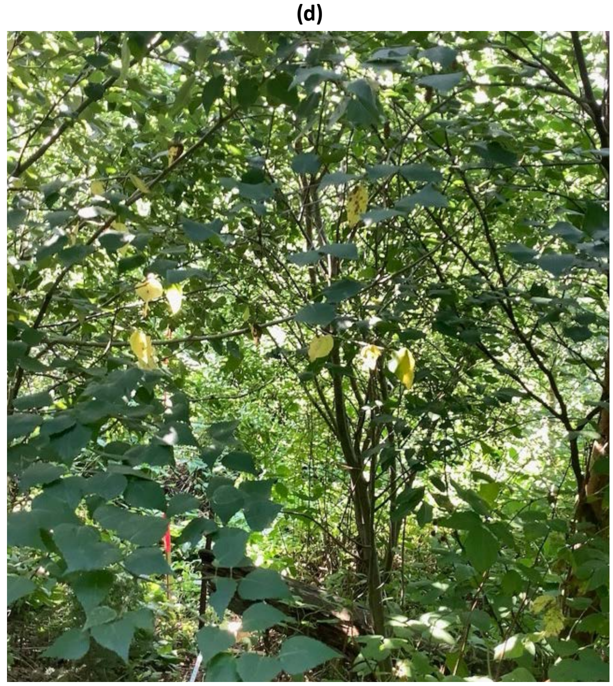

Figure 9: Examples of images from the **topsoil treatment** where (a) 0 stems ha^{-1}, (b) 2,500 stems ha^{-1}, (c) 5,000 stems ha^{-1} and (d) 10,000 stems ha^{-1} density treatments in August 2023.

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PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Schoonmaker, A. L. (2023) Taking a long-term approach: A case study of non-chemical noxious weed management. Alberta Invasive Plant Council Conference, Olds, Alberta.
https://abinvasives.ca/wp-content/uploads/2023/03/AISC_noxious-weeds_v2_Schoonmaker.pdf

RESEARCH TEAM AND COLLABORATORS

Institution: NAIT Centre for Boreal Research

Principal Investigator: Dr. Amanda Schoonmaker

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Kyle Grant	NAIT Centre for Boreal Research			
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Jenna Halladay	NAIT Centre for Boreal Research	Research Assistant		
Chris Arrotti	NAIT Centre for Boreal Research	Research Assistant		
Kristine Ladislao	NAIT Centre for Boreal Research	Student Research Assistant		
Camille Chartrand-Pleau	NAIT Centre for Boreal Research	Student Research Assistant		
Olivia Bettencourt	NAIT Centre for Boreal Research	Student Research Assistant		
Xavier Quantz	NAIT Centre for Boreal Research	Student Research Assistant		

Research Collaborators: Dr. Brad Pinno, University of Alberta; Dr. Derek MacKenzie, University of Alberta

Oil Sands Vegetation Cooperative

COSIA Project Number: LE0014

Mine and In Situ

Research Provider: Wild Rose Consulting Inc.

Industry Champion: Canadian Natural

Industry Collaborators: Cenovus, ConocoPhillips, Imperial, Suncor, Syncrude

Status: Ongoing

PROJECT SUMMARY

Fourteen years ago, the Oil Sands Vegetation Cooperative (OSVC) was established to enable collaborative harvesting and banking of native boreal forest seed for use in revegetation and research. In 2014, the OSVC became a project led by Canada's Oil Sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA). The OSVC supports seed collection initiatives in the northern Athabasca Oil Sands (NAOS), Southern Athabasca Oil Sands (SAOS) and Cold Lake (COLK) regions.

The OSVC's strategic objectives include working with industry to identify knowledge gaps, and to propose and support research programs to optimize seed harvest, storage, propagation, and field establishment. In addition, the OSVC provides open communication regarding our project with COSIA members and to a wider audience.

The scope of work for this project includes preparation of seed harvest needs, coordination of the annual seed harvest program, management of records for the OSVC seed inventories in the provincial seed bank, provision of technical expertise on identification, collection, storage and deployment of native seed, technical guidance to the OSVC regarding research needs, coordination and record keeping for ongoing discussions related to research project development, preparation of support documents such as literature reviews and data summaries, and preparation of a bi-annual newsletter.

PROGRESS AND ACHIEVEMENTS

Seed Banking

In 2023 (14th season) the OSVC did not conduct a cooperative harvest. Following the end of the existing harvester contract, a new contractor was not procured. Instead, companies commissioned their own harvests internally or by contracting separate harvesters. Seed was registered, as in past, and will be tested for viability early in 2024 following a minimum of one month in storage.

Nine seedlots harvested in 2022 were tested for viability in early 2023 following registration.

Progress on Strategic Objectives

- OSVC members held nine meetings in 2023 to discuss knowledge gaps and propose research.
- In 2023, a detailed literature review was initiated for four species deemed a priority by members: green alder, Labrador tea, dwarf blueberry and lowbush cranberry.
- Work on the Operational Monitoring program (initiated in 2018) to determine survival of outplanted shrubs over the oil sands area continued. This monitoring program examines survival by species on various reclamation materials. Six new plots were added. An inventory of information in the database was conducted to fill gaps regarding site preparation to allow for more direct comparisons of results.
- In 2021 a trial (in cooperation with Smoky Lake Forest Nursery) was initiated to improve operational production methods for *Viburnum edule* (lowbush cranberry), a particularly difficult species to produce. In 2023, this experiment was completed, and results documented. Longer stratification times (a combination of warm and cold) significantly improved emergence, although results were still less than ideal (< 50%). It was also demonstrated that older seed (up to nine years) was still as viable as fresh seed.

Communications

- Two editions of the Oil Sands Vegetation Cooperative Newsletter (May and November 2023) were published.

LESSONS LEARNED

- For the seed bank to be successful, it is important that the banked seeds are of the highest quality possible. Harvest and handling of native seed is expensive and labour intensive. Boreal shrub species exhibit strong dormancies and require excessive time periods for germination testing and production. Moreover, standard protocols for testing do not exist. Therefore, the OSVC is having all seedlots assessed by a third-party, accredited seed testing laboratory using a standardized TZ viability test. Seed quality continues to be invaluable in determining seeding rates, improving seed harvesting and handling operations, and evaluating longevity.
- While substantial knowledge exists regarding seedling survival of outplanted commercial tree species (aspen, spruce, pine), our understanding of the survival dynamics for native shrubs on reclaimed sites remains limited. Operational level monitoring plots have been installed and monitored but a wider variety of sites and species is needed. The first plots have been monitored for five years, and new plots will be installed in 2024. Ongoing monitoring will continue to inform deployment decisions for individual species on various substrates and sites.
- Results from the *Viburnum edule* emergence trial found that initial emergence was greatest following a combination of months of warm and cold stratification periods (1ws:2cs:3ws:3cs). The most complete emergence was observed in the oldest seedlot (stored frozen at -20°C for nine years), however there was little variation among seedlots regardless of age. In all seedlots, a fraction of observed seedlings (ranging from 6% to 93%) did not develop to the two-leaf stage. This was more prevalent in less successful treatments (those with lower emergence).

PRESENTATIONS AND PUBLICATIONS

Newsletters

Wild Rose Consulting, Inc. 2023. Oil Sands Vegetation Cooperative Newsletter. May 8(1). 4 pages.

Wild Rose Consulting, Inc. 2023. Oil Sands Vegetation Cooperative Newsletter. November 8(2). 4 pages.

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Kimberly Gould	Wild Rose Consulting, Inc.	Field Ecologist		

Research Collaborators: Peggy Popel, Smoky Lake Forest Nursery

Syncrude Upland Vegetation Monitoring Program

COSIA Project Number: LJ0343

Mine

Research Provider: Syncrude

Industry Champion: Syncrude

Status: Ongoing

PROJECT SUMMARY

This project is a long-term vegetation monitoring initiative, started in 1980, on Syncrude's reclaimed lands at the Mildred Lake mine site. The program consists of remeasured plots distributed across a diverse set of reclaimed starting conditions and reflecting a wide range of reclaimed landforms and reclamation treatments. Each monitoring plot combines a forestry-style growth and yield plot and a vegetation community assessment where the presence and abundance (percentage cover) of every species are tallied. Almost 200 sampling locations have been established, with roughly 125 currently active as of 2023. Each plot is planned for reassessment at a five-year interval.

Objective 1: Quantify diversity and trends by age for species composition in reclaimed plant communities for the purposes of (i) validating that reclaimed communities are converging with those of locally common boreal forest ecosystems, (ii) validating metrics and assumptions that are proposed for use in reclamation certification, and (iii) providing an empirical basis for continuous improvement of best reclamation practices that impact plant community composition and diversity.

Objective 2: Validate the achievement of timber yields comparable to those found on natural landscapes and provide an empirical basis for continuous improvement of best reclamation practices that impact timber yields.

Objective 3: Develop and implement reporting structures for effectively communicating learnings from this program with respect to variations in plant community development and potential causal factors, and de-risking achievement of lease-level expectations for reclaimed plant community composition.

In 2021 a major project milestone was reached, consisting of the analysis and reporting on 39 years of plant community trends observed at the Mildred Lake mine site.

PROGRESS AND ACHIEVEMENTS

Annual monitoring activities were completed in 2023. Updated results from the recent synthesis report (described below) were not reported.

LESSONS LEARNED

This project documents comprehensive empirical validation related to the success of reclamation practices. Specifically, it quantifies the development of plant community composition and tree growth performance, and offers meaningful opportunities to make defensible assertions regarding the achievement of end land uses that focus on things such as wildlife habitat, biodiversity, and commercial forestry.

A recent synthesis report summarizes up to 39 years of plant community development trends on Syncrude's reclaimed mine sites near Fort McMurray, Alberta (Farnden, 2021). These trends are contrasted with a target condition, defined within the report as the Natural Range of Variability for species composition on older (60 years or older) closed canopy forests having similar mesic and sub-mesic site conditions within 200 km of the mine sites.

The primary outcome of the study is that patterns of plant community development on reclaimed sites are consistent with Alberta's objectives for reclamation, which require increasing similarity between reclaimed and reference plant community structure over time. The evidence demonstrates a strong influence of a developing tree canopy on these patterns, where native, forest-dependent species gain an increasing competitive advantage over time as compared to early-arriving ruderal or weedy species. Overall, it is concluded that expected natural processes, consistent with conventional ecological theory, are leading to reclaimed sites demonstrating substantial convergence with locally common boreal forest ecosystems. Please see the document cited below for more details of the specific learnings from the monitoring study.

LITERATURE CITED

Reports & Other Publications

Farnden C. 2021. Reclaimed upland vegetation community trends on Syncrude's mine sites. Syncrude Canada Ltd, Edmonton, Alberta. 61 p. https://era.library.ualberta.ca/items/e4af0e03-e6f8-4fd5-8838-21a26541c66a

RESEARCH TEAM AND COLLABORATORS

Institution: Syncrude

Principal Investigators: Marty Yarmuch

WILDLIFE RESEARCH AND MONITORING

A Portable Testing Device for Wildlife Conservation

COSIA Project Number: LJ0334

Mine and In Situ

Research Provider: McMaster University, University of Calgary

Industry Champion: ConocoPhillips

Industry Collaborators: Imperial, Teck

Status: Year 4 of 5

PROJECT SUMMARY

The goal of this project is to develop an affordable (less than CAN $1.00 per assay), simple to use, paper-based device, capable of extracting and identifying DNA from biological samples, in the field, in real time. Once developed, the device can be employed by non-specialist users without the need for access to laboratory facilities. Important applications of this technology include the detection of pathogenic bacteria in food and the analysis of biological samples (feces, skin, and mucus) for real-time wildlife detection. For example, it can be used to identify species from fecal remains in the wild, which will assist in wildlife monitoring activities and in the detection of illegal trafficking of wildlife parts.

This project builds on several technologies that have been and are continuing to be developed by the research team from McMaster University (McMaster) and the University of Calgary. These technologies have proven to be effective in; extracting DNA directly onto paper; concentrating the DNA and linking it to a simple colour change; and the ability to print, dry and therefore stabilize reagents at any temperature. The challenge for this project is to integrate these technologies into a simple-to-use paper-based device that can detect species-specific DNA from non-invasively collected samples.

For proof-of-concept, the research team is using caribou (as a test species), an elusive animal that can be difficult to survey and whose fecal pellets are sometimes indistinguishable from those of other ungulate species with which it shares its range. Caribou are considered a Species at Risk (Environment Canada, 2011) and are therefore highly relevant in the Canadian context, particularly for areas with a high development interest. However, the approach is easily transferrable to the identification of other species of elusive wildlife or to other species of conservation concern. This device offers a non-invasive and potentially cost-effective technology to monitor wildlife in reclamation areas in Northeast Alberta where oil sands development occurs.

The overall objective of the proposed research is to engineer an all-in-one paper-based device for the detection of animal DNA in the field. Researchers are pursuing this objective with the following specific aims:

Aim 1: Paper-based DNA extraction method - to establish a simple and effective paper-based method to extract genomic DNA from fecal samples of caribou.

Aim 2: Paper-based amplification and detection method - to develop a simple method capable of amplifying DNA and generating a visual signal in the presence of caribou-specific DNA sequence.

Aim 3: Device integration - to combine the paper-based extraction and amplification systems above into a one paper device.

Aim 4: Device testing in lab setting - to test the device in the laboratory using caribou fecal samples that have been collected from the field and archived at University of Calgary.

Aim 5: Device optimization - to test the device in the field through consultation with COSIA stakeholders and optimize its field usability by non-specialists.

The device will provide researchers, environmental managers, indigenous communities, citizen scientists and industries with a cost-effective tool capable of producing real-time presence/absence data for species without the need for complex analytical processes. The direct output will be a highly useful device for targeted monitoring of a highly sensitive flagship species. The broader outcome will be a novel platform technology with the potential to make a transformational contribution to the field of conservation biology internationally. As an example, researchers were contacted by the South African government, as they are interested in the potential for using these tools to detect illegal trade of wildlife parts.

The first field trials for the technology are scheduled to take place in mid-January 2024 in far Northeast British Columbia (BC) with the Provincial Caribou Recovery Program in mid-January 2024. The team is conducting genetic transect surveys to estimate population abundance in full partnership with local First Nations. This is the first step to verify that the technology works well in challenging environmental conditions, and after further optimization, the tests will be repeated with non-experts to ensure it can be implemented in the real-world.

PROGRESS AND ACHIEVEMENTS

In 2023, progress was made on Aims 1 through 4 as listed above.

Researchers now have a simple-to-use and equipment-free device (i.e., no need for additional lab equipment in the field) that can accurately determine if a fecal sample originates from caribou. To reach this stage, the team of post-docs and graduate students accomplished the following tasks:

- developed and tested simple sample preparation techniques;
- identified highly specific sets of primers for caribou (note that researchers also have a different set of primers for deer);
- integrated these into an assay that uses an isothermal DNA amplification process that rapidly makes a large number of copies of DNA, if the sample came from caribou; and
- integrated all previous assays with a lateral flow strip (similar to a pregnancy test) to generate a visual signal (a blue line) to report a positive result — the entire assay can be performed in less than 45 minutes.

In the Fall of 2023, the portable device was successfully field tested at the Toronto Zoo (Figure 1). In January of 2024, the team will be travelling to Northeast BC to test the assay in remote locations near Fort Nelson with the Provincial Caribou Recovery Program. Based on the results achieved thus far, the team has a high level of confidence that the assay will perform well in these final stages of testing.

Two manuscripts pertaining to this research are in final stages of preparation.

Finally, Natalie Schmitt was invited by Federica Di Palma (Chief Scientific Officer and Vice President) of Genome BC to co-run a workshop on eDNA technologies and methodologies in September of 2023. The workshop was designed to help understand the needs of various stakeholders interested in the use of species detection technologies like this one, as well as some of the barriers in place that prevent these types of technologies being more broadly implemented. Stakeholders included representatives from academia, industry, government, non-governmental organizations, and Indigenous communities.

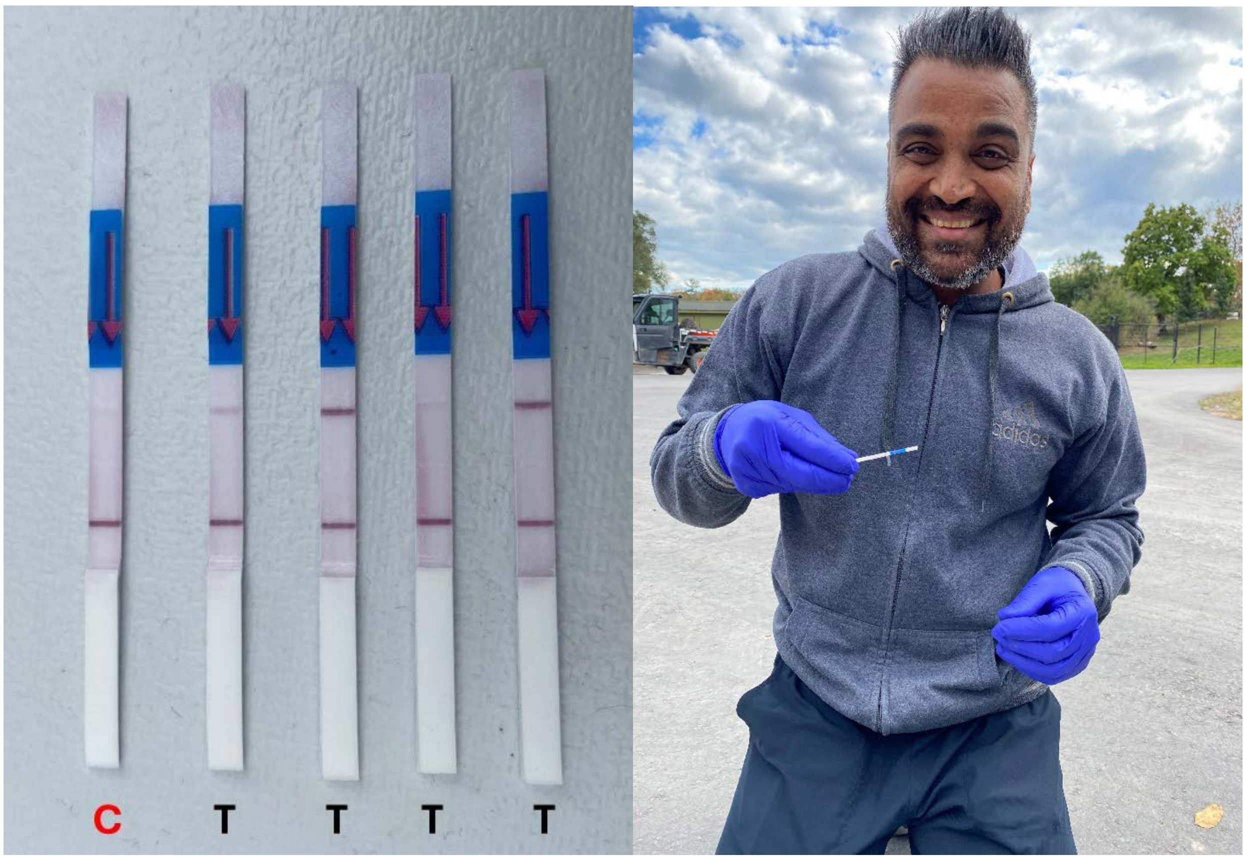

Figure 1: Lateral flow strips show positive tests for caribou fecal samples (labelled 'T') as indicated by the second band (the first band is a positive control band for the lateral flow assay as seen in the negative control test labelled 'C'). The second band is faint in some of the strips due to variations in incubation temperature (using our own body heat in very cold outdoor temperatures). From these initial tests, researchers realized that consistent incubation temperature is important for clear band results so an inexpensive heating device will be included on future platforms.

LESSONS LEARNED

Most of the work towards achieving study objectives has been completed.

A successful portable device has been developed to detect, in under 45 minutes and without the need of any lab-equipment, whether a fecal sample collected in the field came from a caribou. This technology can be easily adapted to detect other animal species by testing fecal samples, as well as tissue samples. Some optimization remains to make the assay more user-friendly for non-trained individuals. The test read-out is in the form of a blue line on a lateral-flow paper strip.

Canadian industries are committed to performing Environmental Impact Assessments and are also interested in monitoring additional impacts of industrial activities at the regional level. Regional assessments are conducted, for Species at Risk in Canada, such as caribou. The detection method developed by this project will contribute to wildlife monitoring, including the presence of caribou in Canadian regions, in a non-invasive and rapid way.

Furthermore, this equipment-free tool will be deployable by field personnel directly, eliminating the need to send samples to a lab or involve area experts. This accessibility will enable broader sections of the public to gather data and information, marking a positive move towards increased stewardship of resources.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Michalak A. An Assessment of Caribou (Rangifer tarandus) Genomic Diversity and Structure in Western Canada to Guide Species Conservation and Management. MSc Thesis, University of Calgary, Canada

Journal Publications

Chang D., Li J., Liu R., Liu M., Tram K., Schmitt N., Li Y. A Colorimetric Biosensing Platform with Aptamers, Rolling Circle Amplification and Urease-Mediated Litmus Test. Angewandte Chemie. 2023 Oct: e202315185.

Cavedon M., Neufeld L., Finnegan L., Hervieux D., Michalak A., Pelletier A., Polfus J., Schwantje H., Skinner G., Steenweg R., Thacker C. Genomics of founders for conservation breeding: the Jasper caribou case. Conservation Genetics. 2023 Dec;24(6):855-67.

Conference Presentations/Posters

A portable, affordable, rapid DNA technology for wildlife detection – presented by Natalie Schmitt at Toronto Zoo in October 2023.

A portable, affordable, rapid DNA technology for wildlife detection – presented by Natalie Schmitt as part of the Northern Boreal Caribou Knowledge Consortium special cross-over meeting with the Caribou Health Knowledge Network and Indigenous Knowledge Consortium in November 2023.

The DNA Revolution: helping to solve the global extinction crises together – presented by Natalie Schmitt as part of the Genome BC Workshop on eDNA methodologies, in September 2023.

AWARDS

Natalie Schmitt was recently invited to become an ambassador of the Earth Foundation, a global organization that inspires, mentors, educates and empowers youth around environmental protection - https://www.earth-foundation.org/ambassadors

RESEARCH TEAM AND COLLABORATORS

Institution: McMaster University[1] and the University of Calgary[2]

Principal Investigator: Dr. Carlos Filipe[1]

Co-Principal Investigators: Dr. Marco Musiani[2] and Dr. Yingfu Li[1]

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Natalie Schmitt	McMaster University	Post-Doctoral Fellow		
Samuel Deakin	University of Calgary	Post-Doctoral Fellow		
Rahul Chaudhari	McMaster University	Post-Doctoral Fellow		
Letizia Dondi	McMaster University	PhD Student	2021	Estimated 2025

Johne's Disease in Bison

COSIA Project Number: LJ0342

Mine

Research Provider: University of Calgary

Industry Champion: Syncrude

Status: Year 3 of 4

PROJECT SUMMARY

The Beaver Creek Wood Bison Ranch started operations in 1993 when a herd of 30 wood bison arrived at Syncrude's Mildred Lake site from Elk Island National Park near Edmonton. The original wood bison herd has grown into a larger herd of approximately 300 animals, living on more than 300 hectares of reclaimed land on Syncrude's former Base Mine about 50 kilometers north of Fort McMurray.

A partnership between Syncrude and Fort McKay First Nation manages the herd which has maintained tuberculosis and brucellosis disease-free status since inception. However, these bacterial diseases are present in free-ranging bison in other locations, including those found in Wood Bison National Park. Being free of these two reportable diseases is important for most producers since there is a risk of these infections spreading to other livestock and to humans (zoonotic).

Other diseases known to infect bison can be classified as production limiting, such as *Mycobacterium avium* subspecies *paratuberculosis* (*Map*). This is a bacterial pathogen that causes chronic intestinal inflammation and wasting in ruminants known as Johne's disease (JD) (Barkema et al., 2018). The correct diagnosis of JD can be challenging due to the prolonged incubation period, which is characterized by a subclinical stage. During this stage, animals typically appear clinically normal but they are shedding *Map* in their feces (Fecteau 2018). For this reason, there are many regional and country-wide control programs for JD. Although the study of JD in domestic ruminants (primarily cattle) provides some guidance, the disease transmission, pathophysiology and environmental persistence of Map strains present in wood bison (*Bison bison athabascae*) is unknown (Forde et al., 2013). The presence of *Map* has implications for the health of bison populations, both farmed and wild. Syncrude's current JD management strategy includes sampling, optimized testing for JD and culling confirmed test positive animals. The information from this research program will provide guiding information to support the long-term viability of managed bison and wood bison species in general.

The overall objective of this project is to understand the current dynamics of Map infection in the bison herd, the impact on the health of the animals, with a focus on co-morbidities and to develop a herd health strategy to reduce the prevalence and transmission of *Map*.

Specifically, project researchers will:

Objective 1: Refine diagnostic tools for *Map* detection in bison. Current efforts to refine diagnostic tools include optimizing real-time polymerase chain reaction (qPCR) — a test for the presence of genetic material — and culture of *Map* bacteria from bison. Culture will allow for genetic characterization of the strain infecting bison and comparison to existing *Map* strains.

Objective 2: Investigate the pathogen's epidemiology (prevalence, transmission, maintenance, environmental persistence) within the herd.

Objective 3: Describe the course of disease (pathophysiology) in clinically affected bison.

Objective 4: Investigate comorbidities, such as worm burden and viral diseases. Successful herd management must consider the diverse array of pathogens that a herd is exposed to for two reasons. First, co-infections can alter the susceptibility of an animal to other pathogens, positively or negatively, and thus influence the epidemiology and impacts at the herd level. Understanding these interactions is critical. Second, many pathogens have a similar transmission route, thus controlling one pathogen through improved management may improve control of another one.

PROGRESS AND ACHIEVEMENTS

The focus of progress in 2023 was on complementing information for Objectives 2 and 3. Details of the progress for each objective are described below.

Objective 1: Refine diagnostic tools for *Map* detection in bison.

Refinement of qPCR for the IS900 and F57 target genes took place in 2022. In 2023, after obtaining *Map* isolates from fecal culture and tissue culture from six clinically affected bison, strain typing was performed using previously described techniques in the literature: IS1311 PCR-Restriction Enzyme Analysis (REA) (Marsh et al., 1999; Sevilla et al., 2005) and Single Nucleotide Polymorphisms (SNP-PCR) (Ahlstrom et al., 2016).

Objective 2: Investigate the pathogen's epidemiology (prevalence, transmission, maintenance, environmental persistence)

Although *Map* has been detected in wood bison, there is no documented information regarding its epidemiology. Therefore, obtaining the within-herd prevalence, evaluating the impact of control strategies, and identifying risk factors of JD in captive wood bison can be beneficial to control the disease.

1. Within-herd prevalence using IS900 and F57 qPCR with culture confirmation: Two samplings from the whole herd including young stock were performed during October 2021 and 2022. Furthermore, two opportunistic samplings were performed during February 2022 and September 2022. These results and comparisons mentioned in Table 1 became available in 2023.

Table 1: Description of the within-herd prevalence and sampling prevalence using IS900 and F57 qPCR results and IS900 with culture confirmation.

Date	IS900/F57 qPCR %	number samples IS900/F57 qPCR	IS900 qPCR with culture %	number of samples IS900 qPCR with culture
Oct-21	4.7	11/234	6.8	16/234
Feb-22*	28.8	17/59	28.8	17/59
Sep-22*	5.2	4/77	13	10/77
Oct-22	4.2	8/191	9.9	19/191

*Opportunistic samplings

Testing continues: Samples were collected from yearlings in October 2023 (n = 65) and none of them tested positive**.** A female (E496) was euthanized and testing of the fecal sample targeting the IS900 and F57 gene confirmed a positive result (culture is in progress). In November 2023 samples were received (n = 7), and one tested positive.

Additional samples from adult animals were sent to the university lab in December 2023 (n = 63). They are currently being processed and will be reported in 2024.

2. Assess the impact of one year of strategic culling of positive animals: At the start of the project, animals were culled based on commercial lab results and clinical confirmation (animal losing body weight and showing diarrhea). Retrospectively, it was found that 56.3 percent of the animals culled within a year (2021-2022) also tested positive with the University of Calgary's Faculty of Veterinary Medicine's (UCVM) diagnostics qPCR test targeting IS900 and F57 gene. The results are noted in the form of quantification cycle (Cq) values, which measure the amount of target DNA in the sample. Lower Cq values indicating higher initial amounts of the target. However, when comparing the Cq values of existing test positive animals, no significant differences were reported when comparing IS900 Cq values between October 2021 and October 2022. This is relevant, as often animals progressing through the later stage of the disease typically will exhibit a steady decline in Cq values, indicating a higher bacterial load.

Examine potential risk factors (e.g., age, sex, pregnancy diagnosis and *Map* infection status of the dam[1]) which may be associated with *Map* positivity in this bison herd: A full epidemiological evaluation of available data was executed in fall 2023. To identify potential risk factors, the study evaluated three different scenarios based on the target regions IS900 and F57 for qPCR.

a. **Base Scenario:** Positive result by fecal IS900 qPCR with culture confirmation of IS900/F57 qPCR. This is the current standard for identification of test positive animals.
b. **Scenario 1:** Positive result by fecal IS900 qPCR with culture confirmation of IS900 qPCR. This scenario has the risk of falsely identifying animals as *Map* positive since IS900 isn't highly specific.
c. **Scenario 2:** Positive result by fecal F57 qPCR with culture confirmation of F57 qPCR was the most conservative scenario. This scenario, featuring a highly specific target gene, is less sensitive, thereby increasing the risk of falsely identifying sick animals as test-negative.

[1] dam is the parent / mother of calf

Using logistic regression analysis, the study identified the following associations. Animals in the age group ≥ 6 to 9 years were more likely to be *Map* positive in all scenarios. Females were more likely to be positive in Base Scenario and Scenario 1. Finally, animals located in Main Ranch were significantly associated with being *Map* positive in Base Scenario and Scenario 1. No significant association was reported with *Map* status and pregnancy diagnosis during 2021 and previous *Map* infection status of the dam.

Objective 3: Describe the course of disease (pathophysiology) in clinically affected bison.

Clinical signs such as diarrhea and weight loss as reported in domestic ruminants have also been reported in wild ruminants (Manning and Collins, 2001). However, there are some exceptions. For example, in cervids *Map* infection is different from that observed in other ruminant species. Clinical evidence of disease appears earlier in cervids than in other ruminants and is more focused on the loss of body condition than the presence of diarrhea (Mackintosh and Koets, 2006).

Although pathologists can easily characterize microscopic changes related to advanced clinical JD in domestic ruminants, these morphological changes and target tissues can differ with wild ruminants. Specifically in wood bison, where only anecdotal information exists regarding JD's clinical presentation and macroscopic pathological findings. Therefore, one of the main objectives of this study is to describe the clinical and pathological findings of JD in wood bison.

Six clinically affected bison were evaluated (Table 2), and necropsies were performed within 48 hours after euthanasia. A total of 24 samples were collected from each bison, as described in detail (Mortier et al., 2013). Intestinal tissues collected included the following: duodenum; mid and distal jejunum; proximal, mid, and distal ileum; ileocecal valve; cecum; spiral colon; transverse colon; and rectum. Furthermore, lymph nodes (LNs) were sampled at locations corresponding with intestinal segments, except for the spiral colon, transverse colon, and rectum. Additionally, the hepatic LN, tonsil, retropharyngeal LN (RP LN), and superficial inguinal LN were also sampled.

At necropsy, no evidence of thickening or corrugation of the intestinal mucosa was observed in any bison. However, granulomatous lesions were more frequent in mid-jejunum LN and distal jejunum LN, followed by ileal LN. In general, tissue culture had the highest rate of positive samples, with 62.5 percent of positive samples, followed by F57/IS900 qPCR with 43.1 percent and histopathology with 29 percent. Based on this study, the researchers concluded that distal jejunum and its associated lymph nodes were the most reliable tissue samples for detecting *Map*, regardless of tissue autolysis or the absence of visible lesions.

With the isolates obtained through tissue culture, strain typing using IS1311 REA and SNP-PCR was performed. This analysis identified a Type II stain (cattle), which represented the second clade within the tissue samples.

Table 2: Description of each bison euthanized and presented for necropsy to UCVM and fecal qPCR results prior to euthanasia due to anticipated *Map* infection

Bison ID*	Age	Date of euthanasia	JD compatible signs at external examination	Fecal qPCR results			
				Oct 2021	Feb 2022	Sept 2022	Oct 2022
1	2	Oct 2021	Diarrhea, weight loss and dehydration				
2	7	Sept 2022	Diarrhea, weight loss and dehydration.	positive IS900 (moderate[1])	positive (moderate[1])	positive (high[1])	
3	8	Dec 2022	Weight loss	positive IS900 (low[1])		positive (low[1])	positive (moderate[1])
4	5	Dec 2022	Weight loss	positive IS900 (low[1])	positive (moderate[1])		positive (moderate[1])
5	3	Dec 2022	Weight loss	negative		positive (moderate[1])	positive (high[1])
6	10	Dec 2022	Diarrhea, weight loss and dehydration	negative		positive (moderate[1])	positive (high[1])

JD = Johne's disease; positive = positive by both genes IS900 and F57. *All bison were female.
[1] Fecal qPCR results were classified according to the Cq value of the IS900 gene as low (Cq > 35), moderate (Cq 26-35), and high shedders (Cq < 26) based on (Russo et al., 2022).
Samples not collected shown as ▭ (diagonally struck cell)
Sampling events were subsamples from the herd shown as ▭ (grey cell)

In June 2023, five yearling animals that tested positive for IS900 but were not confirmed cases of JD, were euthanized and sent to the university for necropsy. Samples were collected during the necropsies. After the culture, all five animals tested negative for *Map*. However, four of them were diagnosed with intestinal cestodiasis, and one of those four tested positive for both cestodiasis and coccidiosis.

Objective 4: Investigate comorbidities.

The fecal sample collection strategy was adjusted from previous years due to very low fecal egg counts. Consequently, fecal samples were collected from the field in October 2023 from three groups: yearlings (k-series), Main herd, and South Herd. These samples were processed to provide information at the group level. Fecal Egg Counts were performed to assess eggs per gram in the feces and coproculture was done to collect larvae.

Parasites were microscopically identified and classified into three distinct egg morphologies: Strongyle-type, Nematodirus, and Moneiza (tapeworm). Finally, protozoa, such as Eimeria, were counted. The larvae are stored and will be processed in the future to determine the species composition using molecular techniques.

The animals have been regularly dewormed and the researchers are looking into the current parasite infection intensities. Moreover, they are working to investigate the anthelmintic resistance in these parasites.

The fecal egg counts and larvae counts in fall 2023 are as follows:

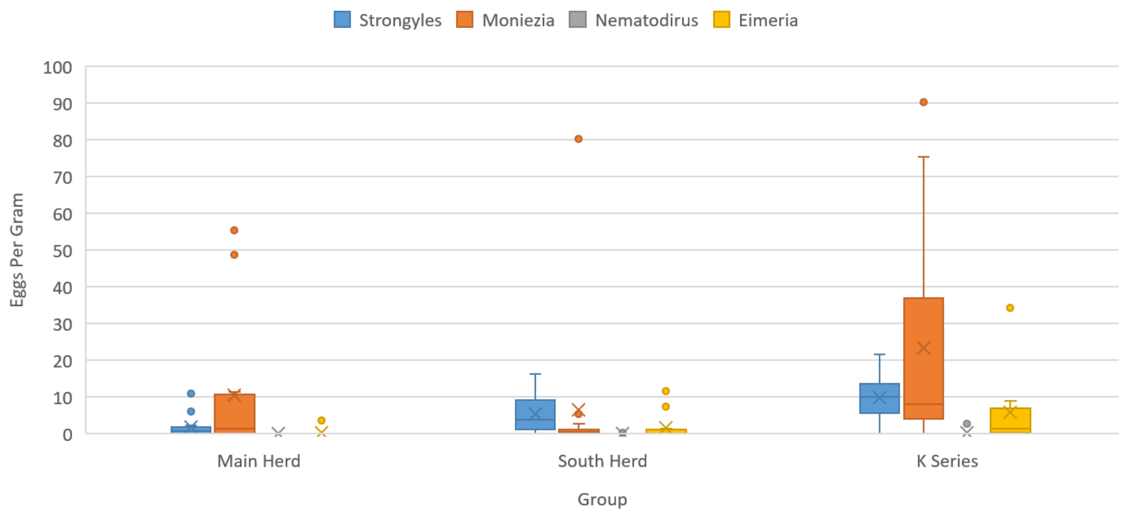

Figure 1: Boxplot showing the eggs per gram (EPG) count per group during 2023.

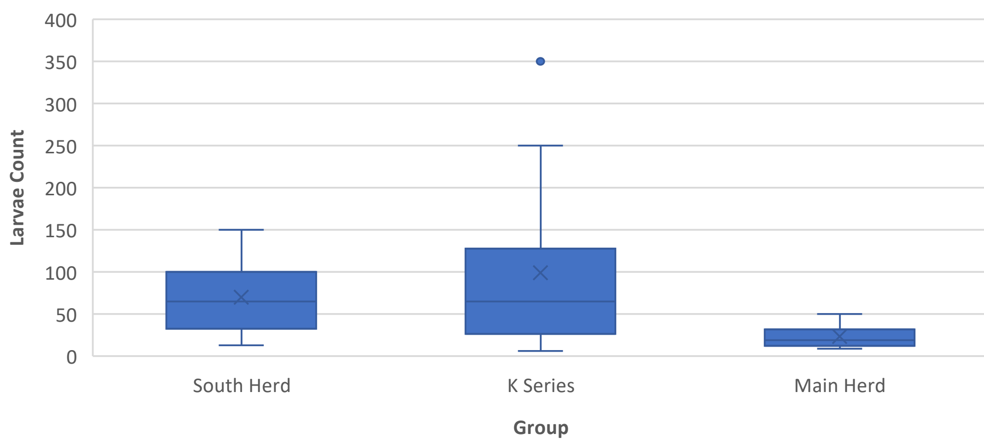

Figure 2: Boxplot showing the larvae count per herd. The y-axis shows the larvae count number and the x-axis shows the herd group.

To support additional parasite analysis, blood samples are anticipated in early 2024. Therefore, no progress has been made towards this part of the project.

LESSONS LEARNED

Objective 1: Refine diagnostic tools for *Map* detection in bison.

Current efforts to refine diagnostic tools include optimizing real-time polymerase chain reaction (qPCR) — a test for the presence of genetic material — and culture of *Map* bacteria from bison. Culture will allow for genetic characterization of the strain infecting bison and comparison to existing *Map* strains.

1. qPCR has been validated and used with both the F57 and IS900 gene. Also, routine culture techniques for Map bacteria have proven effective, allowing for strain typing in this herd. The identified strain is known but not commonly seen in dairy cattle in Canada.

Objective 2: Investigate the pathogen's epidemiology (prevalence, transmission, maintenance, environmental persistence) within the herd.

1. The prevalence of JD in this captive wood bison herd, as reported using the currently optimized diagnostic tests at the UCVM, falls with the range described in the dairy and beef cattle industries. However, management practices in this bison herd align more closely with beef cattle. Calves are grazed with their dams and not weaned until later, allowing the maintenance of fecal-oral transmission from infectious to susceptible animals (calves).

   Due to slow disease progression, and despite the removal of test positive animals from the herd, no decline in herd prevalence was anticipated nor detected at this point in time. Additionally, Cq values were not significantly different in both sample years. Only management changes will prevent new infections from occurring. Therefore, a reduction in herd prevalence reduction can only be anticipated over a five-to-ten-year management strategy adjustment period.

2. To reduce the prevalence and subsequent clinical cases of JD, it is necessary to continue implementing and evaluating herd testing and control strategies. New cases may emerge for up to two years after the last test positive animal has been removed from the herd.
3. There has been no progress on the work to understand environmental persistence at this time.

Objective 3: Describe the course of disease (pathophysiology) in clinically affected bison.

1. Based on full necropsy of clinically affected animals, a better understanding of tissues affected by *Map*-infection will allow for more targeted tissue sampling if full necropsy and workup isn't feasible.

Objective 4: Investigate comorbidities, such as worm burden and viral diseases.

1. Despite low fecal egg counts, UCVM recommends that parasite control must stay on the radar of herd management. The low counts make the herd susceptible to the development of anthelmintic resistance, which has already been described in the commercial bison industry as a significant threat to bison health.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

Dr. Ana Hernandez has successfully defended her Master thesis in December 2023. Her approved thesis will be shared with Syncrude for permission to publicize late January 2024.

Journal Publications, Conference Presentations/Posters

No public presentations were released in 2023.

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Canadian Toad (*Anaxyrus hemiophrys*) Monitoring on Canadian Natural's Horizon Oil Sands

COSIA Project Number: LJ0325

Mine

Research Provider: LGL Limited environmental research associates (LGL Limited)

Industry Champion: Canadian Natural

Status: Year 5 of 5

PROJECT SUMMARY

The Canadian Toad (*Anaxyrus hemiophrys*) is known to occur in the Athabasca Oil Sands Region (AOSR), including in ponds and wetlands on Canadian Natural's Horizon Oil Sands. They have been documented by both Canadian Natural and LGL Limited staff, and during work associated with the Early Successional Wildlife Dynamics Program (Cosia Project LJ0013). Their current status in Alberta is "May be at Risk," though robust data are lacking. Despite the confirmed presence of this species on the Horizon lease, there remains considerable uncertainty regarding (1) annual variation in wetland occupancy; (2) the occurrence and characterization of suitable overwintering habitat; and (3) whether Canadian Toads can be safely relocated from areas likely to be impacted by mine development into suitable receptor ponds.

To address the above uncertainties, and to reduce impact on Canadian Toads during mine expansion, a Canadian Toad monitoring and mitigation plan was developed in 2017 and implemented in 2018. The primary objective of this work is to relocate toads from wetlands within the mine footprint to mitigate the effects of habitat loss on toads. In pursuit of this objective, the following tasks were identified:

Task 1: Determine wetland occupancy of breeding Canadian Toads and other amphibians on Canadian Natural leases.

Task 2: Test Canadian Toads for chytridiomycosis (*Bd* infection) and ranavirus at collection and receiving sites prior to relocation.

Task 3: Translocate toads and/or egg masses with subsequent monitoring to determine success of relocations.

Task 4: Identify, characterize, and monitor suitable overwintering habitat on Canadian Natural leases.

Task 5: Validate (and, if needed, refine) the updated Canadian Toad habitat suitability index model (see Cosia study LJ0326).

In previous years, the main study area consisted of Horizon and Horizon South, with some opportunistic autonomous recording units (ARUs) monitoring at Canadian Natural's Albian Sands lease (Albian). In 2023 the Albian lease was fully incorporated into this project; all research methods employed at Horizon, including mitigation translocations, were expanded to include Albian.

Tasks 1 to 3 have been an ongoing effort since the project's inception in 2018. Task 1 requires conducting nocturnal calling surveys, performed in person or via ARUs, and daytime visual encounter surveys. (Task 1 also involved the development of a Canadian Toad eDNA assay in 2019 under COSIA project LJ0327).

To determine wetland occupancy, acoustic data are collected from ARUs and analyzed using pattern-recognition software to detect species-specific vocalizations. Hits identified by the software are validated by a trained biologist who then targets those sites with recent calling activity for follow-up visual encounter surveys. This improves survey efficiency by focusing on sites with confirmed calling activity. During the follow-up field surveys, Canadian Toads are captured, measured, weighed, and photographed. Dermal swabs are also collected at this time, pursuant to Task 2, for testing for ranavirus and *Batrachochytrium dendrobatidis* (*Bd*), the causative fungal pathogen of chytridiomycosis. Because *Bd* is readily transmissible and can persist in the environment between hosts, testing toads prior to translocation is essential to avoid introducing *Bd* into uninfected ponds or watersheds (Carey et al., 2006). Mitigation translocations (Task 3) can then be carried out, while ensuring toads are moved only between wetlands with *Bd* infection statuses that are alike (i.e., collection and receiving sites are either both positive or both negative). Translocations alleviate the immediate threat of habitat loss due to encroaching mine activities, but further study is needed to determine their long-term efficacy (Randall et al., 2018). Receiving sites will remain a monitoring focus to evaluate translocation outcomes. Success is measured in the near-term as initial translocation survivorship then over subsequent years as annual recruitment with the ultimate goal of establishing or augmenting self-sustaining populations.

As a frost-intolerant amphibian species near the northern end of their range, Canadian Toads in the AOSR have adapted life-history traits to help them endure the harsh winters. They spend much of the year underground in upland areas, beneath the frostline but above the water table, to insulate themselves from freezing temperatures (Hamilton et al., 1998; Russell et al., 2000). Thus, their overwintering habitats must possess specific thermal and hydrological properties while being accessible to a low-vagility species with a limited capacity for digging. Recent declines in Canadian Toad populations are believed to be caused in part by a lack of habitats on the landscape with this particular confluence of biophysical properties (Eaton et al., 2005; Browne 2009). For this reason, identifying and characterizing overwintering habitat has become a priority for Canadian Toad ecologists. LGL has made efforts to integrate new knowledge of Canadian Toad habitat requirements into the current project by: (1) analyzing soil sensor data from a putative Canadian Toad hibernaculum on Horizon South, (2) revising a Canadian Toad habitat suitability index (HSI) model to consider both breeding and wintering habitat along with the distance between them, (3) field-validating the new model, and (4) preparing initial plans for a Canadian Toad habitat creation project.

This work will assist in determining the efficacy of translocations as a strategy to mitigate the effects of habitat loss on Canadian Toads. If deemed effective, it will provide a template for similar projects to be carried out elsewhere in the AOSR. It will also contribute to an increased understanding of behaviour, population trends, and habitat use of Canadian Toads that will be applicable to other developments in the AOSR.

PROGRESS AND ACHIEVEMENTS

All five tasks listed above were addressed in 2023. To assess occupancy (Task 1), wetlands at Horizon Oil Sands, Horizon South, and Albian Sands were monitored by 39 ARUs which recorded acoustic activity nightly for the duration of the active season (roughly May to August; Figure 1). The ARU data were used to guide a survey effort of 194 surveyor-hours. Surveys were conducted nocturnally and during the day to target different stages of Canadian

Toad breeding phenology. Calling activity generally occurs at night in late May and early June, while juveniles and recent metamorphs are more likely to be encountered during daylight hours in July and August (Breckenridge and Tester 1961; Eaton et al., 2005).

Task 2, testing toads for fungal and viral pathogens, was completed as a precaution prior to relocating animals. Dermal swabs were collected from 118 amphibians including 16 Canadian Toads, 95 Wood Frogs (*Lithobates sylvaticus*), and seven Boreal Chorus Frogs (*Pseudacris maculata*) from Canadian Natural's three leases. To avoid spreading pathogens between watersheds, animals were only moved between wetlands with disease testing results that were alike (i.e., both positive or both negative).

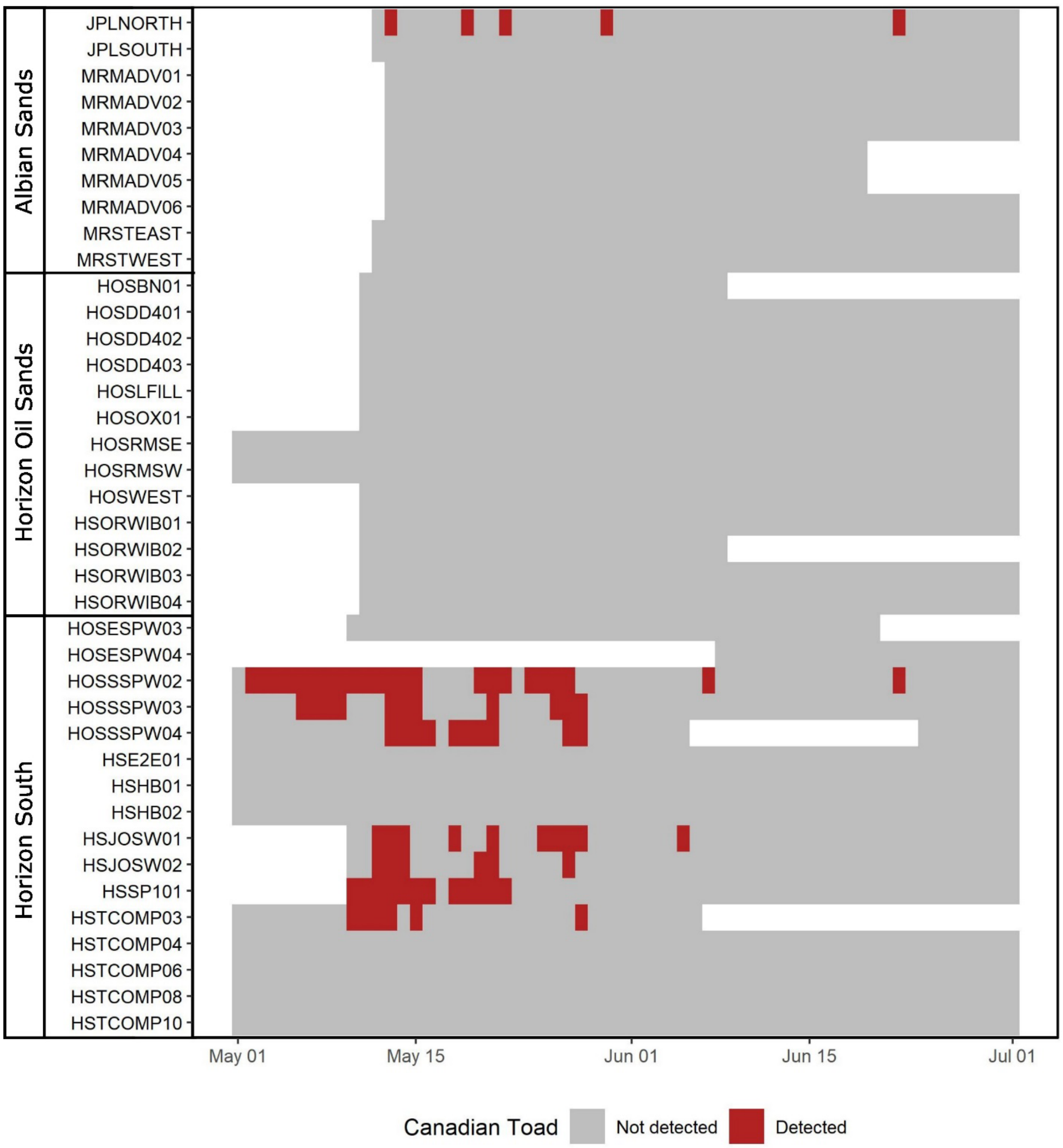

Figure 1: Timeseries of detections by ARUs stationed on Canadian Natural leases. Positive detections were made at Horizon sites Sandpit South (HOSSSPW02, 03, 04), Joslyn West (HSJOSW01, 02), SP1 (HSSP101), and Toad Complex; and at Jackpine Lake (JPLNORTH) at Albian. Non-detections outside of May 1 to July 1 have been truncated for scale.

Mitigation translocations (Task 3) were conducted at both Horizon and Albian (Figure 2). 2023 marks the third year where translocations have taken place at Horizon and the first at Albian. A total of 265 Canadian Toads were relocated away from the path of imminent mine advance: 112 at Horizon South and 153 at Albian. All toads were recovered from opportunistic wetlands (i.e., not naturally occurring) near mine hazards such as open pit excavations and active haul roads. They all survived the initial move and appeared active and healthy upon release. Receiving sites will continue to be monitored in 2024 to assess survivorship of translocation cohorts.

Figure 2: Releasing Canadian Toads at the Horizon South translocation receiving site.
Toads were weighed, measured, and photographed before being released on a sandy berm with vegetation cover nearby.

Tasks 4 and 5 address the importance of developing the body of knowledge surrounding Canadian Toad seasonal habitats for use in applied ecological studies such as this. Researchers documented new habitat at both Horizon and Albian (Task 4), including occupied breeding wetlands and potentially suitable overwintering habitat. The Albian Sands lease received a greater survey effort than it had in previous years as part of its incorporation into this Canadian Toad mitigation project, which resulted in the discovery of several new sites of interest. The most active breeding site was situated between upland forest and tall berms of loose sand, both of which are habitats relevant to overwintering toads. Task 5, validation of the updated HSI model (Hawkes and Papini 2020a, b), saw significant progress and is scheduled for completion in 2024. Validation involves conducting field-based surveys to ground-truth model predictions and to confirm the accuracy of environmental datasets (Brooks 1997; Muir et al. 2011). In other words, assessing whether the underlying data used by the model (inputs) and predictions generated by the model (outputs) accurately reflect the environment in its present condition. To accomplish this, researchers evaluated soil substrates in terms of their ability to support overwintering toads by inspecting soil texture, consistency, accessibility, drainage, and other attributes. Further information on this project is provided in the summary report for COSIA study LJ0326.

LESSONS LEARNED

Several lessons related to Canadian Toad monitoring and relocation can be shared at this point:

1. This project has produced resources that may be valuable to Canadian Toad studies in the AOSR and elsewhere:
    a. The updated HSI model will be a useful resource for predicting the occurrence of valuable habitat on the landscape, e.g., to locate extant populations and candidate relocation sites.
    b. During the course of this project, researchers have documented many active breeding sites and taken comprehensive accounts of biophysical factors, individual animal profiles, and behaviours. Taken together, the qualitative data compiled here represents a significant addition to the body of literature describing Canadian Toads and their seasonal habitats. This knowledge can be applied to a variety of conservation projects — among them, the prescription and design of compensation habitat.
    c. The methods described in this project can be replicated in future conservation efforts to detect breeding activity, test animals for pathogens, safely capture and handle animals in the field, and identify suitable habitats.
2. Annual variation in wetland occupancy has been evident throughout this project. Each year, some sites with previously robust breeding populations go quiet, while others are newly occupied or reoccupied. Breeding site fidelity seems to be low in Canadian Toads in the AOSR, perhaps partly due to the transient nature of habitats in the natural resource industry. More research is needed to determine fidelity to overwintering sites.
3. Active breeding populations continue to be found in recently disturbed areas. In fact, some of the most productive habitats in the AOSR have been ephemeral, opportunistic, mineral wetlands, which is to say temporary standing water accumulated in areas stripped of organic materials (e.g., unused lots, drainage ditches, roadsides, etc.). Canadian Toads also do not appear to be deterred by exposure to mine-related noise.
4. Evaluating the success of translocations will present its own research challenges. Determining the fates of relocated toads is made difficult by the fact that non-detections during follow-up monitoring do not necessarily indicate a failed translocation. Acoustic monitoring targets breeding male toads only. Considering males take one to three years to reach maturity and that most relocated toads were younger than a year, some in the translocation cohorts may have to survive multiple winters before they begin vocalizing and thus become detectable. Some may simply move to different habitat (Breckenridge and tester 1961; Eaton et al., 2005). Toads face high attrition rates during their first winter, even in ideal conditions; low recruitment may also be due to environmental factors unrelated to the translocation.

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PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2023.

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Canadian Toad (*Anaxyrus hemiophrys*) Habitat Suitability Index Model Update and Validation

COSIA Project Number: LJ0326

Mine

Research Provider: LGL Limited environmental research associates

Industry Champion: Canadian Natural

Industry Collaborators: Suncor

Status: Ongoing

PROJECT SUMMARY

In 2019, the Canadian Toad (*Anaxyrus hemiophrys*) habitat suitability index (HSI) model was updated to address regulatory requirements associated with Canadian Natural's *Environmental Protection and Enhancement Act* (EPEA) approvals (Horizon Lease: 149968-01-00; Albian Sands Lease: 20809-02-00 [Muskeg River Mine] and 00153125-01-00 [Jackpine Mine]) and to inform recent initiatives regarding Canadian Toad relocations on Canadian Natural's Horizon Oil Sands (Hawkes and Papini 2020a, b). HSI models use a rubric to score environmental and biophysical traits on their suitability as habitat for a taxon of interest. Mapping the model output produces a prediction of the occurrence of suitable habitat on the landscape (Figure 1).

The updated HSI model considered habitat attributes used in previous models (i.e., 1999, 2005 and 2007) but placed increased weight on overwintering habitat, while reducing the relative importance of breeding habitat. The update emphasizes the relationship between suitable overwintering habitat (friable soils up to 1.25 m in depth in the a and b ecosites), breeding habitat (certain shallow water ponds and wetland habitats), and, importantly, the distance between them. To sustain populations year-round, wintering and breeding habitats must co-occur within the range of Canadian Toad seasonal movements. As a frost-intolerant amphibian species near the northern end of their range, Canadian Toads in the Athabasca Oil Sands Region (AOSR) have adapted life-history traits to help them endure the harsh winters. They spend much of the year underground in upland areas, beneath the frostline but above the water table, to insulate themselves from freezing temperatures (Hamilton et al., 1998; Russell et al., 2000). Thus, their overwintering habitats must possess specific thermal and hydrological properties while being accessible to a low-vagility species with a limited capacity for digging.

A base layer comprised of the derived ecosite phase (DEP) dataset, which is based on Alberta Vegetation Inventory (AVI) and LiDAR-derived datasets, was used to display the results of the model. Maps were produced for Canadian Natural's Horizon Oil Sands, Horizon South, and Albian Sands leases. A comparison between updated HSI mapping and the original model produced for the mine expansion environmental impact assessments (EIAs) from 1999, 2005, and 2007 suggests that the current distribution of highly and moderately suitable habitat on Canadian Natural leases is significantly less than previously thought. The updated suitability maps are based on more recent information regarding Canadian Toad ecology and are a better representation of the occurrence and distribution of Canadian

Toad habitat on each lease. They also align with recent observations of Canadian Toads on the Horizon and Albian leases. For model specifics see Hawkes and Papini (2020a, b) or [Cosia project LJ0326] in the 2019 edition of this report.

Habitat models require several internal and external validation measures to confirm model assumptions are reasonably met (Muir et al., 2011). Assumptions are inherent in the design of every model; validation procedures are used to ensure the assumptions being made accurately reflect reality. Internal validation involves reviewing model outputs, sensitivity testing, and calibrating variable weightings and model equations (see Van Horne and Wiens 1991). External validation is concerned with comparing model predictions to data collected in the field, i.e., ground-truthing. Ideally, model developers will have access to a test variable that is indicative of habitat quality. For example, species abundance/density or a measure of population success such as body condition or annual recruitment. In the absence of a convenient test variable, or for species that are difficult to survey, an alternate method may be used whereby habitat quality is independently assessed by expert opinion (Brooks 1997). Due to delays caused by the COVID-19 pandemic, field validation of the updated model was postponed in 2020 and 2021.

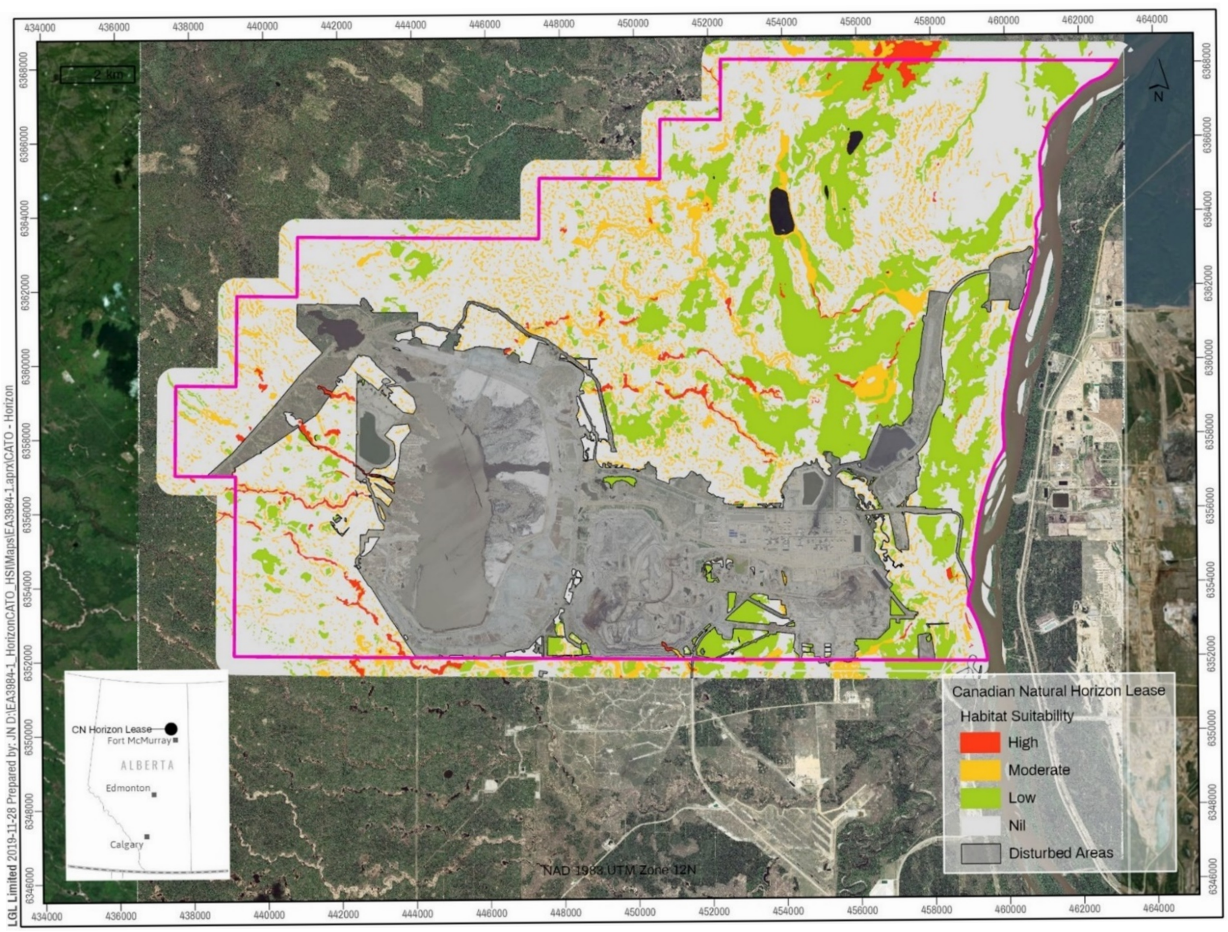

Figure 1: Distribution of high, moderate, low, and nil suitability Canadian Toad habitat on Canadian Natural's Horizon Oil Sands.
A 500 m buffer was added to the lease boundary to indicate that suitable toad habitat occurs in habitats adjacent to the lease.

External model validation began in earnest in 2022. Polygons were sampled using a generalized random-tessellation stratified (GRTS) design, a spatially balanced sampling method that can accommodate variable inclusion probabilities (Stevens and Olsen 2004). At each site LGL biologists conducted qualitative assessments of the habitat features relevant to overwintering Canadian Toads, focusing on soil characteristics. This involved digging pits to appraise soils in terms of their ability to support effective hibernacula (Figure 2). Researchers focused on the texture, consistency, and accessibility of mineral soils — all key components of overwintering habitat. To support toad hibernacula over the winter, soils should be loose, friable, well-drained, and accessible to a depth of 1 m to 1.5 m (Hamilton et al., 1998).

Recent declines in Canadian Toad populations are believed to be caused in part by a lack of habitats on the landscape with the hydrological and thermal properties required to sustain overwintering toads (Eaton et al., 2005; Browne 2009). For this reason, locating and characterizing winter habitat has become a priority for Canadian Toad ecologists. The updated habitat model described herein is an important resource for identifying and conserving suitable Canadian Toad habitat throughout the AOSR, including at Suncor's Base Plant and Fort Hills oil sands leases where a similar program is being implemented.

Figure 2: Soil sampling during model validation.
External validation involves ground-truthing model predictions to confirm that assumptions inherent to the model are being met. One such assumption is that environmental datasets accurately depict conditions as they currently exist.

PROGRESS AND ACHIEVEMENTS

The scope of Canadian Toad conservation efforts in the AOSR grew significantly in 2023, with the application of the updated HSI model expanded to include Suncor's Base Plant and Fort Hills Operations. Geographic Information System (GIS) analysts are currently fitting the model to Suncor leases. LGL and Suncor are working together to compile and implement the necessary spatial datasets. The next step, sampling points on the landscape for external validation, is scheduled for 2024.

Progress was also made at Canadian Natural's Horizon, Horizon South, and Albian Sands leases, where the model is at a later stage of development. The Canadian Natural leases have assembled the spatial datasets needed to run the model and are now in the process of externally validating model predictions. Field validation began at Horizon in 2022 (discussed above; Figure 2) and was nearly completed in 2023. Less than 10 sites remain for soil assessments in 2024. At Albian, validation field sites were sampled this year, and about half of them were visited for soil assessments, with the remainder scheduled for 2024.

LESSONS LEARNED

Multiple regional data sets (e.g., soil parent material, Alberta Vegetation Inventory, ecosite mapping data, and the derived ecosystem phase dataset) were combined with lease-specific data to update and validate the habitat suitability index (HIS) model for Canadian Toad. The results of this work address regulatory requirements and apply to other initiatives undertaken by Canadian Natural. The outputs of the updated suitability map provide improved guidance (compared to historical maps) with respect to the occurrence and distribution of suitable seasonal habitats. The updated maps offer important information relevant to future translocations and habitat reclamation.

Canadian Toads have a proclivity for recently disturbed habitats in the AOSR (Russell and Hawkes 2023). In fact, some of the most productive breeding habitats project researchers have encountered are ephemeral, opportunistic, mineral wetlands, which is to say temporary standing water accumulated in areas stripped of organic materials (e.g., unused lots, drainage ditches, roadsides, etc.). This presents two conservation challenges: (a) toads may colonize an area before disturbance to the land has concluded and (b) it is difficult to model habitat that is continuously modified. In the AOSR, translocations are used to partially mitigate the direct hazards associated with cyclic creation and destruction of habitat, but issues arise when attempting to predict the occurrence of suitable habitat within the industrial footprint.

HSI model validation work continued in 2023, and while it is still too early to draw significant conclusions, researchers noticed some habitats rated as highly suitable were compromised by past industrial activity. For example, where suitable substrates are present but have been compacted by heavy machinery — this reduces their penetrability and prevents toads from accessing depths required to escape freezing winter temperatures. Ongoing changes to the landscape are difficult to capture in an algorithm but still need to be considered when interpreting model outputs. That is to say, the model is still expected to be efficacious in its main purpose — to predict the occurrence of suitable habitat — but its predictions should be considered in the context of recent mine activity.

In conclusion, the updated HSI model will be a key resource for Canadian Toad conservation in the AOSR by predicting the distribution of suitable habitat on the landscape. Those areas where the various seasonal habitats co-occur can then be targeted for further exploration as potential hotspots. Compared to previous iterations of the model, the updated version has indicated that suitable habitat exists in relatively small patches. Identifying these areas allows field researchers to concentrate their search effort, an important step when studying cryptic species such as Canadian Toads. The model is currently in the process of being fitted to four oil sands leases owned by Canadian Natural and Suncor.

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PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2023.

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Principal Investigator: Virgil Hawkes

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Wildlife Monitoring – Horizon Oil Sands

COSIA Project Number: LJ0186

Mine

Research Provider: LGL Limited environmental research associates

Industry Champion: Canadian Natural

Status: Year 17 — Ongoing

PROJECT SUMMARY

Wildlife cameras are useful for assessing and monitoring various aspects of terrestrial wildlife, especially their return to and use of anthropogenically altered habitats. Their proper implementation increases the likelihood of detecting the use and distribution of certain wildlife species across specific areas and habitats (Burton et al., 2015). Wildlife cameras have been used throughout the Athabasca Oil Sands Region to photograph wildlife in riparian corridors and their natural habitat and have recently been incorporated into reclamation monitoring (Hawkes et al., 2021; Hawkes et al., 2019). They provide a cost-efficient way to monitor wildlife's use of reclaimed habitats over time and assess the effectiveness of reclamation approaches for meeting specific wildlife objectives.

Wildlife cameras have been deployed on Canadian Natural's Horizon Oil Sands Lease since 2006, and an extensive network is currently active across the lease. Remote cameras used in the COSIA Project LJ0186 contribute important data on the occurrence and distribution of wildlife and the time of year certain species occupy and utilize various habitats. Wildlife cameras were operated and maintained in three treatment types on Canadian Natural's Horizon Oil Sands Lease: (1) the riparian corridor along the Athabasca River, (2) the habitats surrounding Horizon Lake, a compensation lake, and (3) on two reclamation areas (Reclamation Area 1 and the North Toe Berm). Although the cameras have been operated since 2006, this report summarizes the results associated with wildlife camera data collected in 2021 and 2022. Wildlife camera data from 2006 to 2020 is presented in the 2020 COSIA Land EPA Mine Research Report (pages 92 to 100). Figure 1 shows the distribution of cameras by year and treatment area, and maps of the camera arrays are provided in Figures 2 through 4.

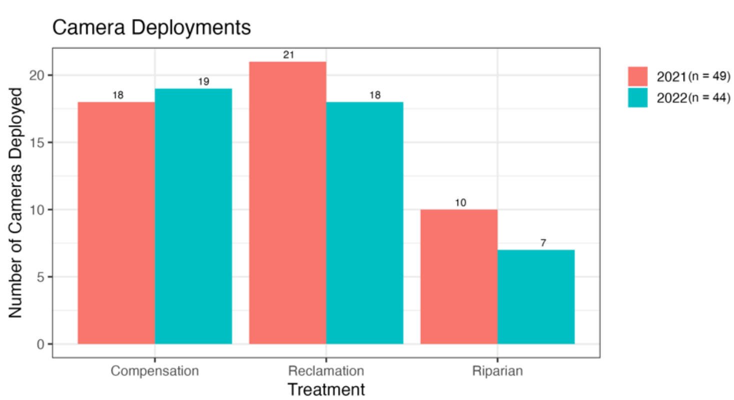
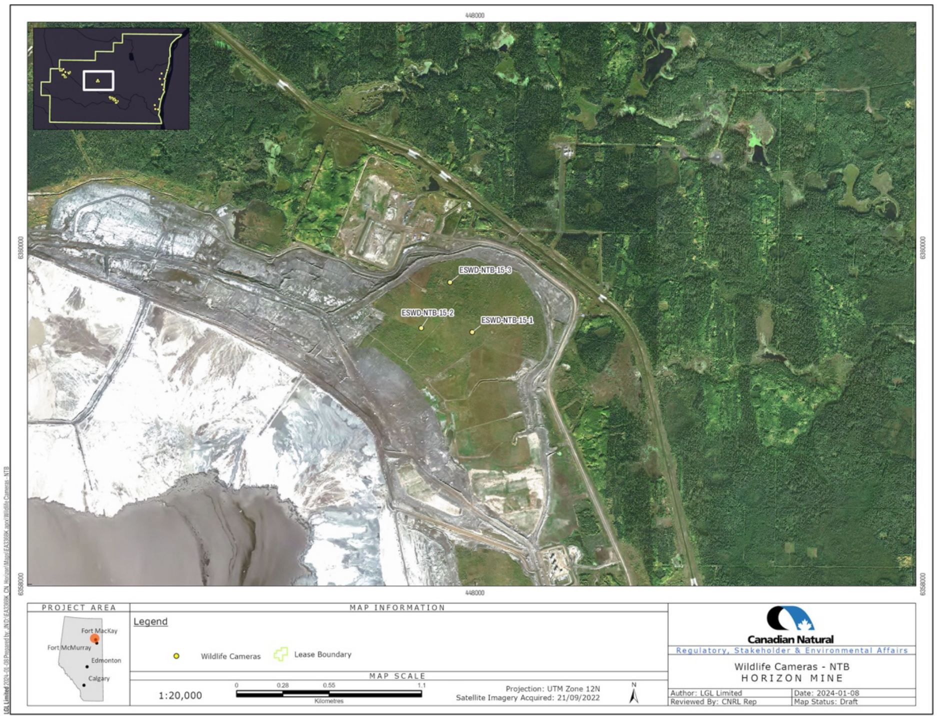


Figure 1: The number and distribution of wildlife cameras by treatment and year in the Canadian Natural Horizon Lease.



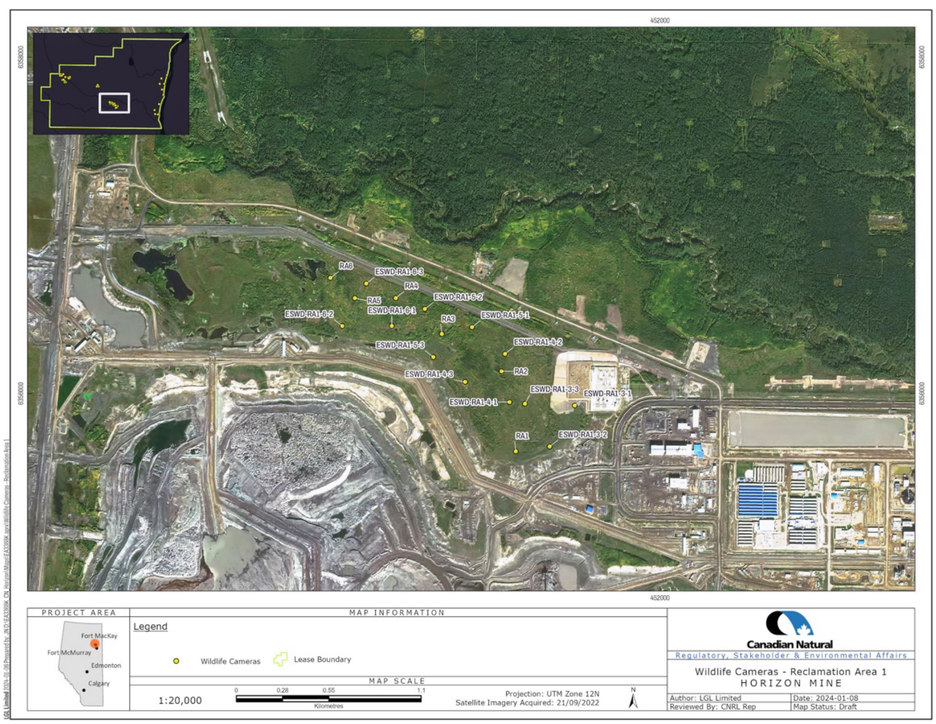


Figure 2: Location of the camera arrays in the Reclamation Areas within the Canadian Natural Horizon Lease. The upper image shows the camera array at North Toe Berm, and the lower image shows the camera array at the Reclamation Area 1.

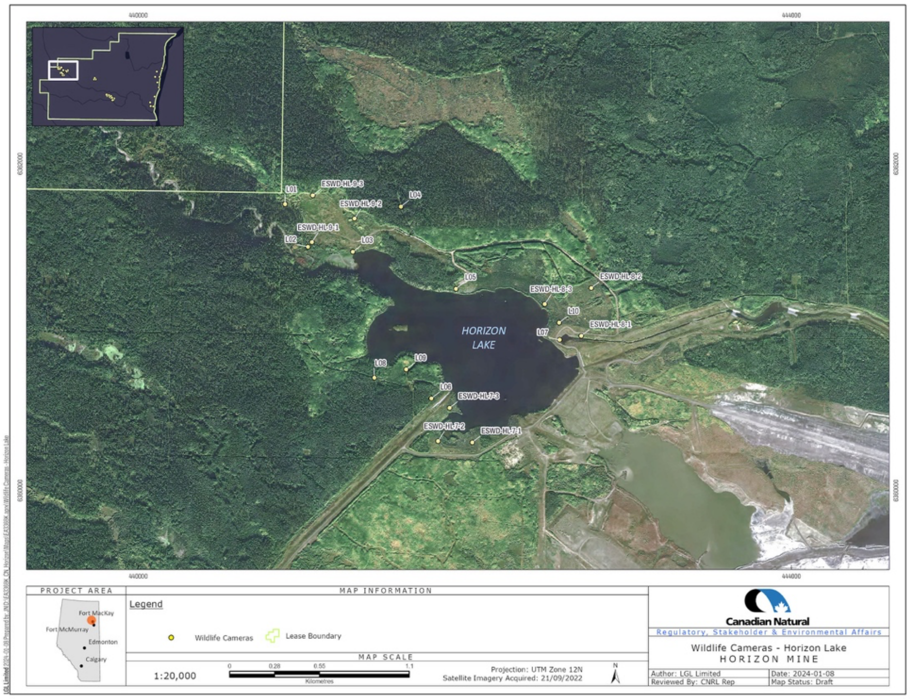


Figure 3: Location of the camera arrays around the Horizon Lake within the Canadian Natural Horizon Lease.

Figure 4: Location of the camera array in the Athabasca River Corridor within the Canadian Natural Horizon Lease.

PROGRESS AND ACHIEVEMENTS

Between 2021 and 2022, 50 cameras were deployed in the three habitat types: Athabasca River corridor, n = 10 cameras; Horizon Lake, n = 19 cameras; reclamation areas, n = 21 cameras (Figures 1 through 4). A total of 149,120 camera-triggering events were recorded, including 96,378 false triggers (i.e., mainly vegetation). Of the remaining 52,742 wildlife events (detections), 48,693 were duplicate photos of the same event where detections occurring within 15 minutes for a given species were classified as duplicates. Similar criteria for filtering out duplicate photos have been used elsewhere (e.g., Keim et al., 2019).

Of the 4,049 unique wildlife sighting events, 3,837 could be identified to species level. A total of 48 species of wildlife (31 species of bird; 17 species of mammal; Table 1) were recorded on cameras with detections of 10 species accounting for 93.1% of the sample: white-tailed deer (*Odocoileus virginianus*, n = 2,346 detections, 61.1%), American black bear (*Ursus americanus*, n = 465 detections, 12.1%), American moose (*Alces americanus*, n = 288 detections, 7.5%), coyote (*Canis latrans*, n = 131 detections, 3.4%), red fox (*Vulpes vulpes*, n = 78 detections, 2%), grey wolf (*Canis lupus*, n = 68 detections, 1.8%), Canada lynx (*Lynx canadensis*, n = 60 detections, 1.6%), deer mouse *(Peromyscus maniculatus*, n = 53, 1.4%*);* snowshoe hare (*Lepus americanus*, n = 43 detections, 1.1%), and Green-Winged-Teal (*Anas carolinensis*, n = 40, 1.0%). Of the three habitats assessed, more detections and species were associated with the compensation lake habitat (n = 1,946 detections of 39 species: 24 birds and 15 mammals), followed by habitats reclaimed to an upland forest type (n = 1,292 detections of 19 species: 8 birds and 11 mammals) and riparian corridors (n = 599 detections of 20 species: 9 birds and 111 mammals).

Table 1: Species of wildlife (birds and mammals) detected on cameras in each of the three treatment types samples. Species associated with bold text and highlighting used in subsequent analyses. Comp = Compensation Lake, REC = Reclamation Areas, and RIPC = Riparian Corridor.

		2021			2022			
	Species	**COMP**	**REC**	**RIPC**	**COMP**	**REC**	**RIPC**	**Total**
Birds	American Coot				20			20
	American Robin			2		2	1	5
	American White Pelican	8						8
	American Wigeon				22			22
	Belted Kingfisher				4			4
	Black-Billed Magpie	1		1				2
	Blue-Winged Teal				2			2
	Canada Goose	2			26			28
	Canada Jay	1			1			2
	Cedar Waxwing					1		1
	Common Goldeneye				9			9
	Common Merganser				3			3
	Common Raven	7	4		3		2	16
	Common Redpoll				1			1
	Dark-Eyed Junco		3					3
	Eared Grebe				1			1
	Great Blue Heron	3						3
	Green-Winged Teal				40			40
	Lesser Scaup				2			2
	Mallard	1			22			23
	Northern Flicker	1		2	6			9
	Northern Harrier	1	1	3		1	1	7
	Northern Shoveler	6			17			23
	Redhead				2			2
	Ruffed Grouse	1	1	1			2	5
	Sandhill Crane					1	2	3
	Savannah Sparrow	1						1
	Sharp-Tailed Grouse			1				1
	Short-Eared Owl			3				3
	Swainson's Thrush	1						1
	White-Throated Sparrow					2		2

	Species	2021 COMP	2021 REC	2021 RIPC	2022 COMP	2022 REC	2022 RIPC	Total
Mammals	**American black bear**					**2**		**2**
	American marten	141	46	56	100	55	67	465
	American moose	**3**	**1**	**2**				**6**
	American red squirrel	99	2	75	84	7	21	288
	Canada lynx	**2**			**1**			**3**
	Coyote	**38**		**2**	**19**		**1**	**60**
	Deer mouse	2	38			**12**		52
	Fisher			1				1
	Gray wolf	**16**	**7**	**17**	**23**	**1**	**4**	**68**
	Least chipmunk	2	3			**4**		9
	Mule deer	2	24	1				27
	North American river otter	1			**5**			6
	Red fox	**35**	**3**	**31**	**8**		**1**	**78**
	Snowshoe hare	**21**	**2**		**20**			**43**
	White-tailed deer	**733**	**531**	**216**	**302**	**505**	**59**	**2,346**
	Wolverine				**1**			1
	Woodchuck			1				1
	Detections per Treatment	1169	684	433	777	608	166	3,837
	Species per Treatment	27	15	18	28	12	12	48
	Bird Species	34	9	13	181	7	8	252
	Mammal Species	1135	675	420	596	601	158	3585

For standardization, detection rates (detections per camera) were calculated to control for changes in the number of cameras deployed in the treatment area and year (Figure 5). Overall, the total number of detections and detection rates were higher in 2021 than in 2022, which can largely be accounted for by the greater number of detections of white-tailed deer in the compensation and riparian treatments in 2021 (Table 1). Figure 6 shows the annual and seasonal (monthly) variation in detection rates for the eight most common species detected in each habitat. Detection rates for these eight species were highest for the compensation (Horizon) lake area, followed by the riparian corridor and reclamation areas. Detection rates for 2021 and 2022 were moderate to high at the compensation lake for all eight species, except for Canada lynx and snowshoe hare, which were moderate to high in the riparian corridor but low in the reclamation and compensation areas. Detection rates were low for all species except for American black bear, coyote, and white-tailed deer in the reclamation areas, consistent with detection rates observed in previous years (2006 to 2020; Canadian Natural and LGL Limited, 2021a).

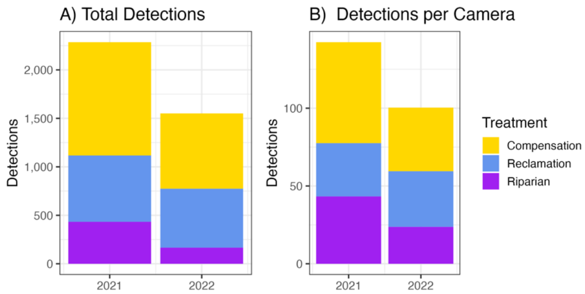


Figure 5: Comparison of the total number of detections and the detection rates (detections per camera) within three treatment types at Canadian Natural's Horizon Oil Sands in 2021 and 2022. Detection rates are the number of detections adjusted for the number of available cameras per array.

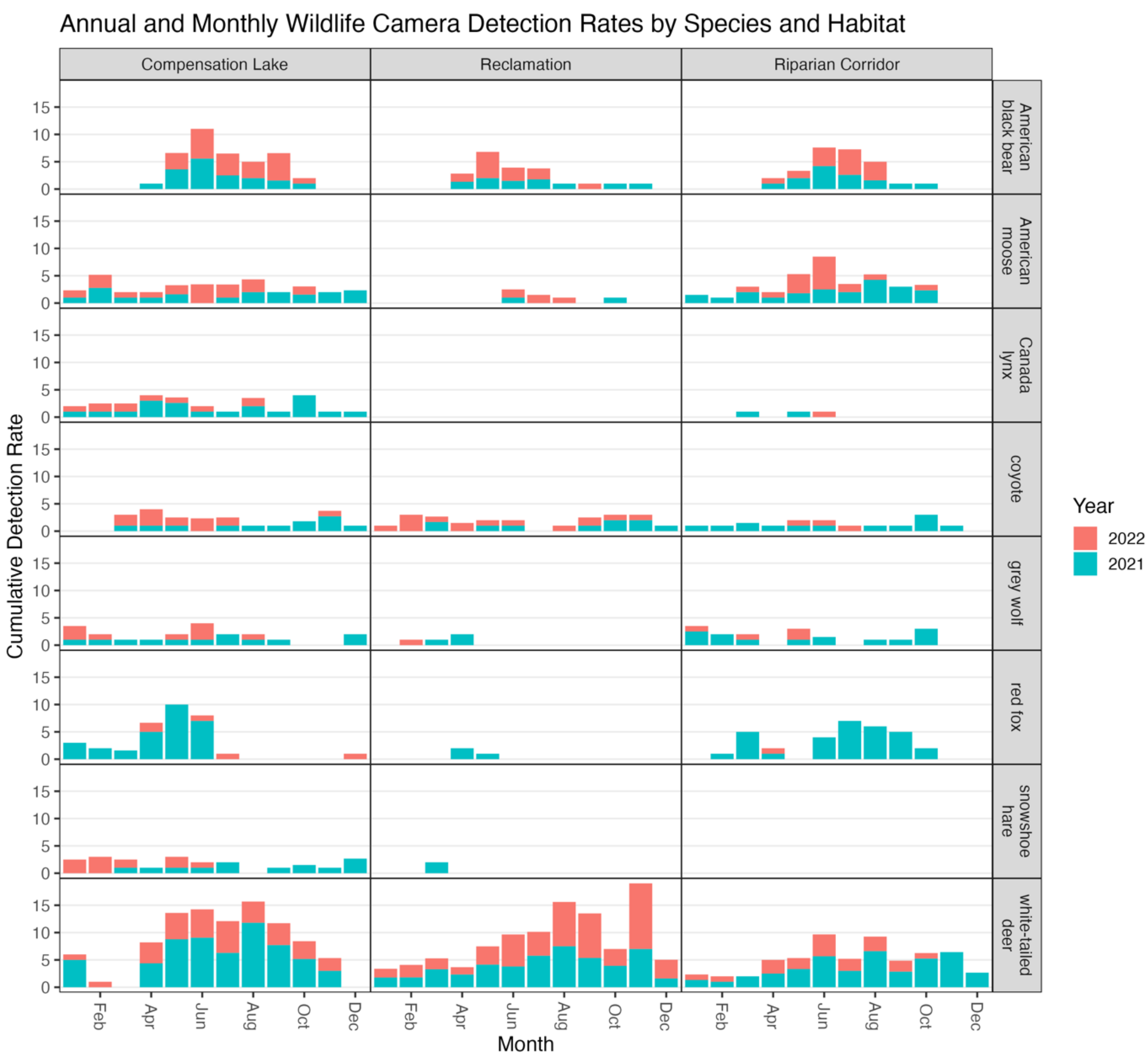


Figure 6: Annual and monthly detection rates of eight species of the most common species detected on and adjacent to Canadian Natural's Horizon Oil Sands.

The disparity in detection rates for species other than coyote, white-tailed deer, and American black bear in the compensation and reclamation areas is noteworthy as the ages of terrestrial habitats surrounding Horizon Lake and Reclamation Area 1 are similar (circa 2011). The habitat diversity and complexity are greater at Horizon Lake. The compensation area includes habitats such as lakes, shorelines, streams, and well-developed wetland habitats that are absent from the reclamation area, and the compensation area is closer to mature forests. Further, wildlife utilizing the Horizon Lake area experience less human disturbance as it is further away from mining activity and bitumen processing than the reclamation areas. These factors compound direct comparisons of wildlife utilization of the treatment areas and must be considered when evaluating treatment approaches.

Dynamic occupancy models (MacKenzie et al., 2003; MacKenzie et al., 2006) were fit to the camera data to generate occupancy estimates for species frequently captured during detection events (Canadian Natural and LGL, 2021a). Monthly occupancy estimates were estimated using a hierarchal Bayesian state-space model implemented in JAGS (Just Another Gibbs Sampler), a program for analysis of Bayesian models using Markov Chain Monte Carlo (MCMC) simulation (Plummer 2003). The results of the occupancy/usage models indicate seasonal, annual, and temporal trends for each of the eight species considered. For each species, there was considerable season-to-season variability in usage among the three habitats sampled between 2021 and 2022. An example of this is provided for American moose and white-tailed deer in Figure 7; however, in contrast to the results presented in Canadian Natural and LGL (2021a), no apparent trends are discernable. Access to longer-term datasets affords a greater opportunity to assess habitat use patterns by attenuating yearly variability.

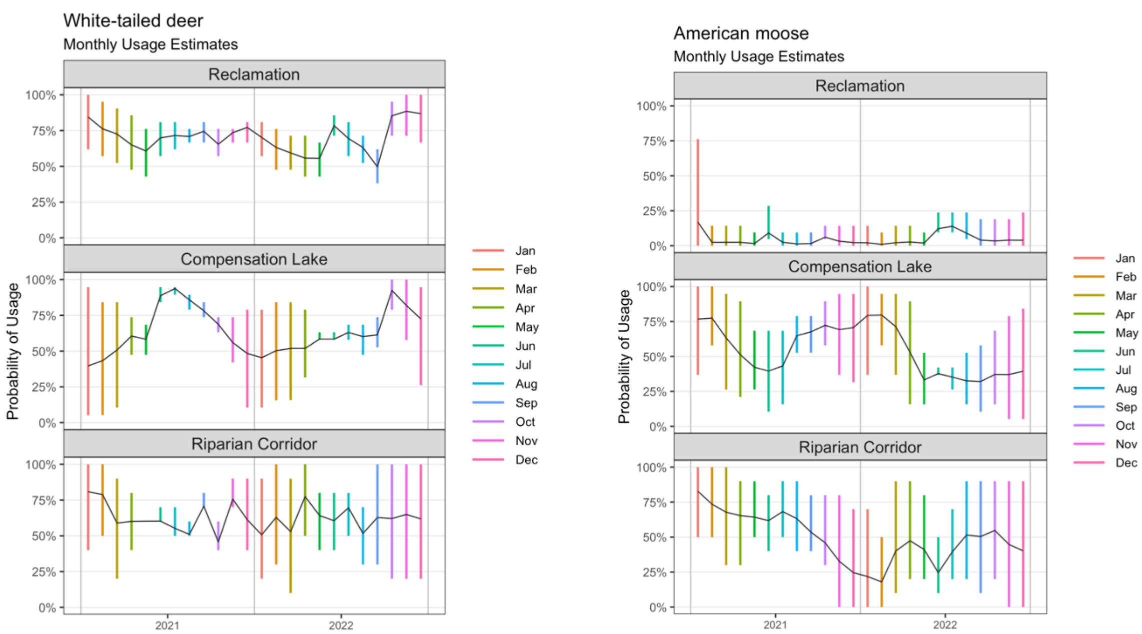


Figure 7: Monthly usage estimates from 2021 to 2022 generated from the monthly time-step occupancy model for moose (Alces americanus) and white-tailed deer (Odocoileus virginianus). Error bars indicate 95% credible intervals, with colour indicating month. Vertical lines indicate the boundary between assessment years.   Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct).

Seasonal usage averages were determined for each habitat area by averaging the sequential monthly estimates for each year of sampling. This provided a way to assess whether there was a systematic difference in seasonal usage relative to the treatment area over the assessment period. Figure 8 shows the average usage of the four most common wildlife species captured on wildlife cameras by area over the assessment period.

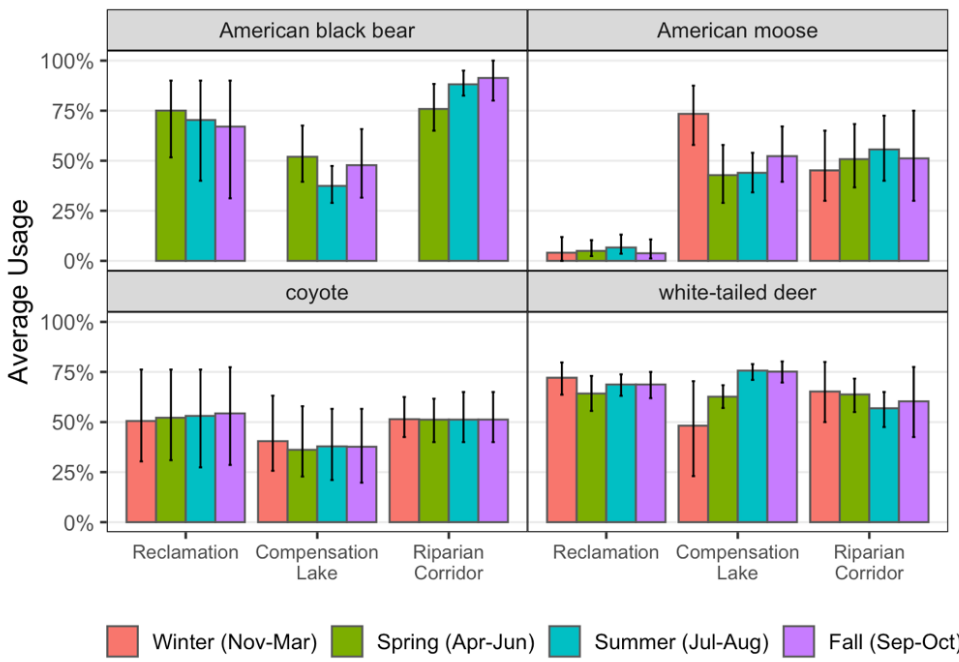


Figure 8: Average seasonal usage for the four most common wildlife species captured on wildlife cameras over the assessment period by area. There was insufficient data for the four other species plotted in Figure 6. Error bars indicate the 95% credible intervals for a given seasonal estimate. Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct).

Remotely triggered wildlife cameras, deployed on and adjacent to Canadian Natural's Horizon Oil Sands, provide a cost-effective way of collecting data on wildlife occurrence and distribution. With advances in occupancy modelling, these long-term datasets provide valuable data on usage patterns and trends for wildlife species common to the area. Although occupancy models were not applied to all species captured on wildlife cameras because the data were too sparse, assessing lease-specific patterns of wildlife occurrence and distribution is possible where data is sufficiently abundant. Although the results from 2021 and 2022 are inconclusive, the long-term data set provides the means to assess longer-term trends in usage patterns for select wildlife (Canadian Natural and LGL Limited, 2021a). These data also contribute to broader regional programs such as the Early Successional Wildlife Dynamics (ESWD) Program (COSIA project #LJ0013). The ESWD program (Canadian Natural and LGL Limited, 2021b; Hawkes and Gerwing, 2019) assesses the return to and use of reclaimed habitats by wildlife. The lease-specific camera data support assessments of reclamation effectiveness and the regional importance of long-term datasets associated with wildlife camera arrays, and their relevance to achieving biodiversity and reclamation goals in the region cannot be overstated.

LESSONS LEARNED

1. Wildlife camera data collected on and adjacent to Canadian Natural's Horizon Oil Sands contributes important data to lease-specific and regional biodiversity and reclamation objectives.
2. Most wildlife species are not likely to be detected frequently enough by wildlife cameras to assess temporal trends in usage. However, camera data can still be used to assess variation in the distribution and occurrence of wildlife species at a local and regional scale (depending on the distribution of the camera arrays)
3.` Long-standing wildlife camera arrays provide important data that can be modelled to assess seasonal and annual trends in occupancy (usage) using emerging modelling techniques. The examples provided here summarize data collected in two years. Longer-term data sets are required to assess seasonal and annual trends in occupancy. See Canadian Natural and LGL Limited (2021a) for examples.
4. When considering differences in wildlife use on reclamation habitats, factors such as topographical heterogeneity, habitat diversity, and proximity to the aquatic ecosystems (e.g., lake, wetlands, and stream) must be considered. Additionally, the juxtaposition and diversity of adjacent habitats, along with human disturbance from mining and other activities, must also be considered.

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PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2023.

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Gregg Hamilton	Canadian Natural	Coordinator, Environment		
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Caribou Detection in Boreal Forest Environments

COSIA Project Number: LE0075

In Situ

Research Provider: University of Saskatchewan

Industry Champion: Suncor

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Imperial, Syncrude

Status: Year 2 of 5

PROJECT SUMMARY

This project revolves around the integration of innovation and interdisciplinary research to tackle the complex challenges associated with wildlife conservation in the boreal forests of Alberta, Saskatchewan, Manitoba, and the Northwest Territories. Organized around a set of Research Milestones, the goal is to advance an innovative and interdisciplinary program that can substantially contribute to bridging the significant knowledge gaps currently hindering the ability to flatten the pace of environmental change in the Boreal Plains and buffer its impacts. The project brings together a multi-sectoral partnership of Indigenous groups, the Saskatchewan, Alberta, and federal governments, a non-governmental organization, engaged industrial partners both private and public, and a diverse team of academics from three universities.

Ultimately, the program is about providing the tools, knowledge, practical options, and inclusive capacity necessary for conserving the changing Boreal Plains ecosystem while safeguarding core socioecological needs and values. The outcomes of this work will be both partner-specific and common, including the long-term evolution of the diverse and growing Program Advisory Committee into a knowledge-sharing consortium known as the Boreal Network. This consortium is designed to advance the understanding of the causes and mitigate the consequences of change in the western boreal.

The goals of the project and partnership are to:

1. Advance an innovative and interdisciplinary program to address the most significant knowledge gaps limiting the understanding of the causes of change in the western boreal forest; and
2. Increase the social and institutional/academic abilities to mitigate the consequences of those changes and minimize risks of accelerating unintentional change to species, food systems, and economies.

Research Milestone 1: *New Approaches to Wildlife Detection (M1)* tackles the fundamental yet intractable problem of how to more cost-effectively obtain accurate, precise, and simultaneous data on multiple wildlife populations at the scale of the Boreal Plains and Shield ecozones to monitor complex population dynamics and test ecological theory. While data on relative species abundances at a local scale can be obtained from both traditional ecological knowledge (TEK) and science (e.g., surveys, mark-recapture analysis), when scaled-up to the extent of an ecozone, data equivalencies fall apart.

The project is positioned to provide the food-web dynamics modelling that has been beyond the reach of ecologists due to a lack of data on densities of interacting species, especially for species that are costly to monitor like large mammals in forested environments. M1 pairs a multi-spectral, high resolution but scalable TK-7 imaging payload to remotely census large mammals using artificial intelligence and deep learning to optimize manual identification and counting in complex environments.

Research Milestone 2: *Modelling Species Abundances (M2)* will apply M1 innovations across the Boreal Plains to explore theoretical and data-intensive problems of modelling densities of identifiable species and habitat features from a standardized set of study blocks. These study blocks extend from western Manitoba through to Prince Albert National Park (Saskatchewan), to east-central Alberta, to Sundre (Alberta), and to the southern Northwest Territories, where project partners are currently collaring target moose, boreal caribou, wolves, black bears and bison; and where contemporary abundance surveys for moose and bison will be available.

By Year 5, the aim is for the dataset to become the world's largest of its kind for evaluating higher-trophic level, boreal food-web assembly rules. Using these data points of relative multi-species density (substituting space-for-time), ground-truthed with partner support from large-scale camera trapping, the aim is to test hypotheses of coexistence, exclusion, and apparent competitive exclusion in varying environments as they might emerge at the scale of an ecozone.

PROGRESS AND ACHIEVEMENTS

- Using the TK-7 payload mounted onto a Cessna 182 plane, with wiring also completed for a Cessna 172 (Mitchinson Flight Center, Saskatoon), flight missions were carried out in late April and September 2023.
- A setback was encountered when all planned flights through May to June were grounded due to extensive wildfire smoke within the study area. Flights were grounded both for safety reasons and because good visibility is required for colour sensors.
- The focus for the successful flight missions was to continue work on optimizing and testing the system under various scenarios related to acquiring colour and thermal imagery of wildlife in zoo situations and in the wild within caribou range (spring missions flown prior to the wildfire setbacks in northern Saskatchewan).
- Early results were presented at the Canadian Society for Ecology and Evolution (CSEE) meeting in Winnipeg in June 2023 and at the North American Moose Conference in Grand Portage, Minnesota, in May 2023.

LESSONS LEARNED

No lessons learned are available for 2023.

Initial data are being annotated for the application of computer science with the ultimate goal of streamlining a pipeline of data acquisition (transects of imagery) for computer-aided identification of targets of significance (large mammals bearing signatures of colour and thermal gradients), which will lead to human-assisted identification and counting.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

McLoughlin, P. D., B. Neufeld, A. Arnyek, E. Lyimo, P. Chandramouli, and I. Stavness. 2023. Scaling up drone-resolution remote sensing to practical extents for wildlife and wildland conservation. Invited talks: Welcome to the Future: How Technology Can Help Us Characterize Habitat and Ecological Relationships: Canadian Society for Ecology and Evolution Annual Meeting, Winnipeg, MB 11—14 June 2023.

Neufeld, B., A. Arnyek, and P. D. McLoughlin. 2023. New approaches to wildlife detection for Boreal Plains large mammals: drone-level resolution with aircraft-level coverage. 55th North American Moose Conference and Workshop. Grand Portage, Minnesota. 22–26 May 2023. Poster presentation.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Dr. Philip McLoughlin

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Alexa Arnyek	University of Saskatchewan	BSc (Thesis)	2019	2023
Pranav Chandramouli	University of Saskatchewan	MSc Student	2022	2024
Emmanuel Lyimo	African College of Wildlife Management	PhD Student	2023	2027
Branden Neufeld	University of Saskatchewan	Professional Research Associate		
Ian Stavness	University of Saskatchewan	Professor, Computer Science		

ENVIRONMENTAL RESEARCH AND MONITORING

Boreal Ecosystem Recovery and Assessment — Phase 2

COSIA Project Number: LJ0220

In Situ

Research Provider: University of Calgary

Industry Champion: ConocoPhillips

Industry Collaborators: Cenovus, Canadian Natural, Imperial, Alberta-Pacific Forest Industries Ltd.

Status: Year 3 of 5

PROJECT SUMMARY

The Boreal Ecosystem Recovery and Assessment (BERA) program (www.bera-project.org) is a multi-sectoral partnership of academic researchers and partners from industry, government, and non-government organizations.

The central goal of BERA is to understand the effects of industrial disturbance on natural ecosystem dynamics, and to develop strategies for restoring disturbed landscapes. BERA's research supports four strategic management goals associated with industrial disturbance:

1. Promoting a return to forest cover
2. Restoring natural carbon dynamics
3. Maintaining wildlife habitat
4. Enhancing woodland caribou habitat

Practitioners involved in boreal restoration are interested in maximizing effectiveness and efficiency. BERA conducts research on every phase of restoration — planning, implementation, and monitoring — to provide practitioners with the key knowledge, tools, and techniques they need to enhance understanding and improve outcomes of restoration activities.

PROGRESS AND ACHIEVEMENTS

Passive recovery trajectories of seismic lines in North American Boreal Forests
Colleen Sutheimer, Department of Renewable Resources, University of Alberta

Previous BERA research identified that at the stand level passive tree regeneration on seismic lines was lower in peatlands, increased with fire, increased on wider lines with more light, and in many cases met height and density recovery targets. However, decision makers and resource managers need recovery trajectories across space and time to identify when and where passive regeneration of trees on seismic will meet reforestation standards. Researchers modelled passive recovery trajectories considering regeneration lag, which has not been previously considered, on conventional seismic lines at stand, landscape, and regional scales to provide insights on where and when passive recovery may be sufficient to meet reforestation targets and where active treatment may be needed.

Between 2016 and 2022, researchers sampled dominant trees on 344 sites without repeated human disturbance across the eastern half of the Athabasca oil sands region, a study area of approximately 42,400 km^2. Sites were sampled proportionally to percent area of boreal forest type within the study area and included conventional seismic lines in xeric uplands forests, mesic upland forests, transitional forests, and peatland forests. The height and diameter of dominant trees were measured at each site and then trees were destructively sampled to obtain establishment ages. Field sampling and geospatial data were then used to build statistical and spatial models to predict recovery status in 2023 at stand, landscape, and regional scales considering regeneration lag and height.

Observed median regeneration lags on seismic lines were longest in transitional forests (12 years) and shortest in xeric upland forests (three years), with observed average heights of trees on seismic lines tallest in mesic upland forests (3.8 m) and shortest in peatland forests (1.0 m). Median establishment ages were similar across all boreal forest types in 2023, ranging from 21 to 22 years. Over half of seismic lines in xeric upland forests and mesic upland forests had regeneration lags predicted to be less than five years indicating trees began regenerating before the establishment survey period. However, seismic lines in transitional and peatland forests were predicted to have regeneration lags longer than eight years, indicating trees may not start regenerating until after the establishment survey period. Except for peatland forests, predicted average heights on seismic lines were between 1.3 m and 5 m in 2023 indicating trajectories toward recovery.

Assessing solar irradiance availability on seismic lines based on site characteristics and LiDAR (Light Detection and Ranging) data

Marlis Hegels, Department of Geography, Ludwig-Maximilians-University Munich

Aiming to promote the return of forest cover on seismic lines as well as efficient and effective restoration management, it is beneficial for restoration assessment to know the site-limiting factors constraining tree growth. The goal of this research project is to measure and model photosynthetically active radiation (PAR) in Alberta's treed wetlands using in-situ measurements and remote sensing, since there is a lack of tools designed to help characterize microclimatic effects (e.g., light availability) for management purposes.

Maps of solar irradiance were created using a model that validated LiDAR data against a network of in-situ measurements. Maps of understory vegetation structure were created using a combination of field and LiDAR observations for five understory structural attributes: understory mean height, percent understory cover, understory density, understory complexity, and understory volume. This research project reveals that:

1. North-South lines were predominantly influenced by above-canopy radiation, while East-West lines additionally showed seasonal variability by the changing path length through the canopy;
2. Canopy transmittance on seismic lines was predominantly influenced by the surrounding canopy density (effective leaf area index) in contrast to line characteristics; and
3. The applied modelling approach based on LiDAR data, the laser penetration index, and principles of Beer's law for daily canopy transmittance and PAR estimates, achieved high performance compared to the in-situ measurements.

Seismic line effects on peatlands carbon cycling

Percy Korsah, Department of Geography, University of Waterloo

Researchers measured in-situ and in-vitro soil respiration, net primary production (NPP), and litter decomposition, as well as methane (CH_4) emissions on eight seismic lines across one fen and two bog peatland sites affected by seismic exploration in northern Alberta. Results were then compared to adjacent natural areas. Soil respiration was slightly lower on seismic lines than from natural peatlands, likely due to minimal contributions of tree root respiration on the lines. Ground layer NPP was higher on the lines, but this did not offset the loss of overstory NPP. The litter decomposition rate was similar on and off the seismic line, but a shift in plant community composition towards species with more easily decomposable litter, particularly at the fen site, resulted in greater loss of litter overall. The potential peat accumulation rate, calculated as the difference between NPP and litter loss to decomposition over two years, was therefore lower on the seismic lines. This implies that recovery of an overstory in these wooded peatlands is necessary to achieve pre-disturbance carbon (C) accumulation rates. Methane emissions were significantly higher on the seismic lines, increasing by 176% in fens and 261% to 308% in bogs compared to the adjacent natural peatland. Higher CH_4 emissions on the seismic lines were associated with warmer, wetter conditions, and at the fen site, higher sedge cover.

Seismic lines are creating browse subsidies in certain ecosites

Spencer Quayle, Department of Renewable Resources, University of Alberta

Seismic lines, which remove overstory woody vegetation, may provide a forage subsidy in the form of winter browse for ungulates by promoting shrub growth. This browse subsidy hypothesis was tested by comparing preferred winter browse (shrubs and saplings) at 18 replicate sites (144 plots) on lines to the adjacent reference forest. The comparison covered a moisture gradient from upland to peatland forest ecosites, including the transitional ecotone between upland and lowland forests. Generally, both browse availability and use were higher on seismic lines. Although moose and deer seemed to select seismic lines more often for browsing, the increase in browse use remained proportional to the increase in abundance. In addition, average browse abundance (both forest and lines) increased as ecosite elevation increased and moisture levels decreased.

Forest harvesting promotes seismic line regeneration in mesic upland forest

Leonardo Viliani, Department of Renewable Resources, University of Alberta

Seismic lines are a key conservation concern in Canada boreal forests. [Seismic Regeneration: On the Edge – Boreal Ecosystem Recovery and Assessment (beraproject.org)](beraproject.org)) In some cases, other resource extraction, including forest harvesting, overlaps with seismic line disturbances. A key question is whether forest harvesting 'erases' seismic lines during regeneration of the harvest block. This project examines whether cut-blocks in mesic upland forests enhance the regeneration of seismic lines, thus 'erasing' them and eliminating the need for subsequent restoration actions.

This project studied tree regeneration for legacy (2D) seismic lines in 15 upland mesic sites, each represented by two 20 m^2 plots inside the cut-blocks (seismic line and adjacent recently harvested forest), and two 20 m^2 plots in the mature forest (seismic line and adjacent forest). In each plot, the researcher counted all acceptable, non-germinant, and alive tree and shrubs stems by species and height category.

Overall, it was found that 95% of seismic lines within cut-blocks reached the density target of the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta, while 65% of seismic lines in the mature uncut forest reached the same benchmark standards. Moreover, regeneration density inside the line within harvests was 65% higher than in the mature forest. However, the species assemblage inside the harvest blocks, for both seismic lines and adjacent forest, differed from the nearby mature forest reference stand, being more dominated by deciduous species ('un-mixing the mixedwood').

These results suggest that harvesting does provide the conditions for the structural regeneration of seismic lines, even when natural regeneration does not occur in adjacent unharvested seismic lines. This suggests that harvesting practices are facilitative (e.g., increase of sunlight, scarification of the soil and reduction of competition) and thus effectively 'erase' seismic lines, while factors such as soil compaction do not appear to be limiting.

Although forest harvesting is not an immediate solution for sensitive species like caribou, these results suggest that areas with forest harvesting will contribute in the long-term towards landscape-level structural restoration of linear features without the need more directed active restoration for these sites.

Inverted mounds hasten seedling growth on seismic disturbances in boreal treed fens
Colette Shellian, Department of Geography, University of Calgary

Seismic lines in western Canada's boreal region are linear disturbances that affect the habitat of threatened woodland caribou (*Rangifer tarandus caribou*). To hasten the return of forest cover and ultimately to restore caribou habitat, restoration managers use silviculture treatments in wet areas that involve the mechanical mounding of seismic lines to create artificial hummocks. Tree planting then takes place on top of these hummocks. However, the effectiveness of this silviculture technique for restoring seismic lines in peatlands is largely untested.

In this project, researchers sampled incremental height growth of coniferous seedlings at 41 seismic line plots in poor and rich treed fens in northeast Alberta, Canada. They compared lines that had been treated with inverted mounding (a type of mechanical mounding) and subsequent tree planting, to nearby lines that were left untreated for natural recovery. Generalized linear mixed models were used to test the effect of silviculture treatments on five-year growth increments of black spruce (*Picea mariana*) and tamarack (*Larix laricina*).

Overall, it was found that mounding and tree planting improved seedling growth compared to seismic lines regenerating naturally. However, growth responses were found to vary by species, ecosite, initial seedling size, and light availability.

Are restored seismic lines heading in the right direction? Comparing taxonomic, phylogenetic, and functional plant diversity in boreal peatlands
Ellie Goud, Department of Biology, Saint Mary's University

Human activities related to petroleum development in boreal Alberta have resulted in highly fragmented landscapes, in part due to the creation of seismic exploration lines that remove surface vegetation and microtopography. Although forest cover on seismic lines in some uplands appear to recover over time, peatlands do not seem to recover, and impacts on wildlife and carbon dynamics remain even decades after seismic line construction.

Recent restoration efforts apply inverted mounding to recreate microtopography and promote tree seedling growth. However, whether inverted mounds are successful in recovering plant diversity in boreal peatlands remains a critical knowledge gap.

In this project, researchers compared multiple biodiversity metrics, including taxonomic, phylogenetic, and functional diversity, of ground layer plant communities in treed bogs and fens across treated and untreated seismic lines, as well as reference sites. They measured the relative abundance and evolutionary relationships among species and obtained functional trait data for plant height (H), leaf dry matter content (LDMC), and foliar nitrogen (N) and phosphorus (P) contents.

Consistent evidence was not found to support the idea that inverted mounding encourages plant succession towards target reference conditions within the observed time scale (within the first decade post-restoration). However, researchers did observe a positive impact of mounding on black spruce tree seedling cover, potentially at the expense of the larger understory plant community.

Treated lines differed from untreated lines and reference sites, showing shifts towards higher community-weighted means for all four traits. In bogs, all diversity metrics on treated lines were further from the target reference conditions, driven by increases in horsetails, forbs, and graminoids with larger leaf nutrient contents (N, P) and decreases in non-vascular (e.g., moss) diversity. In fens, taxonomic and phylogenetic diversity of treated lines also differed from reference sites, while functional diversity was similar to reference conditions.

The results reveal that bog and fen communities respond differently to seismic line disturbance and restoration, which needs to be considered during management and restoration planning. Changes in plant diversity have implications for ecosystem recovery and function, especially carbon storage and nutrient cycling.

Response of boreal songbird communities to linear features of varying width
Tharindu Kalukapuge, Department of Biological Sciences, University of Alberta

Alberta's boreal forest is heavily dissected by linear features, including seismic lines, pipelines, transmission lines, and roads. In provincial bird models used for regulatory decision-making, all linear features are treated as having the same width. Consequently, there is a considerable ambiguity regarding how various linear features of varying widths impact bird communities in the boreal forest. These impacts can be either positive or negative for certain species depending on their life history traits. Moreover, there may be threshold widths at which species begin to experience benefits or detrimental effects.

Therefore, it is important to determine which linear feature widths are wide enough to influence associated bird communities and whether these impacts are positive or negative. This knowledge will help the energy sector, government, and other stakeholders in determining the least harmful line width for boreal songbirds when creating new developments. Additionally, it will aid in identifying which lines require immediate restoration to minimize the impacts associated with their width, while allowing others to undergo natural regeneration.

From 2021 to 2023, autonomous recording units were used to monitor bird communities in over 2,000 linear features, primarily consisting of seismic lines, pipelines, and transmission lines. These features span various ecosites, including upland mixedwood, deciduous, coniferous, as well as lowland and wetlands. Researchers are on the verge of completing a first manuscript, which focuses on how songbird communities respond to the width of linear features in upland forest habitats.

There are several key findings from this study:

1. Bird communities undergo changes in species richness, diversity, and composition as the width of linear features increases.
2. Wider linear features are associated with higher species richness and diversity. They tend to attract more shrub-associated and early seral birds, thereby altering the species composition of the original bird community.

Small mammal use of linear features

Alessandro Franceschini, Department of Biological Sciences, University of Alberta

Small mammals are key components of terrestrial environments. Numerous studies suggest they can negatively impact forest regeneration in temperate and boreal habitats due to their seed and seedling predation activity. Nonetheless, little is known about their response and potential to affect forest regeneration trajectory on seismic lines, and their effect is often neglected. Being able to account for their response is the first step to understanding how they can ultimately affect regeneration outcomes.

For this project, the researcher deployed 528 camera traps for four consecutive nights, stratifying the study area by habitat type (upland deciduous, mixed wood, and lowland coniferous) and linear feature width (transmission lines, pipelines, conventional seismic, and low-impact seismic), collecting a minimum of 15 replicates per stratum. The researcher visited crown land and lease sites (ConocoPhillips, Kirby South, Canadian Natural Jackfish, Canadian Natural Wolf Lake) from Cold Lake to Anzac.

Preliminary analyses found that as linear features get wider, the community of small mammals changes. Wider linear features are progressively abandoned by species that are adapted to forest habitats (e.g., the Southern red-backed vole or the Red squirrel), which can still 'tolerate' narrower linear features (up to 10 metres) but are almost entirely absent in linear features that are more than 100 metres wide. On the contrary, wide linear features create habitat for species adapted to more open habitats, such as the Eastern meadow vole and the Western jumping mouse, which become predominant at linear features wider than 80 metres. This method also proved capable of collecting data on species rarely detected with other methods, like shrews, and recorded a variety of intra- and interspecific interactions between rodents, opening up possibilities for behavioural analyses.

Automated detection of coniferous seedlings on seismic lines using deep learning

Irina Terenteva, Department of Geography, University of Calgary

To plan treatments and assess further reforestation, there is a need for simple and affordable ways to count regenerating seedlings on seismic lines. Manual counting of seedlings, whether using high-resolution imagery or conducting field surveys, is highly accurate but labour-intense and difficult to scale. The integration of drones and deep learning (DL) offers new opportunities for cost effective assessment of restoration success. However, there is limited understanding of how technical and environmental controls affect detection accuracy. Addressing these questions could optimize vegetation surveys, resulting in cost savings and improved restoration outcomes.

Using field-collected information on seedlings, the researchers developed and evaluated a deep learning algorithm for 10 seismic lines in Kirby South. Model performance was assessed depending on phenology, seedling height, image resolution and number of training data using 2,500 field-measured seedling locations and crown sizes.

Several DL models and their ensembles were developed to automatically detect coniferous seedlings within seismic lines in Northern Alberta. While visual interpretation exhibits superior precision compared to DL, its recall accuracy serves as a valuable benchmark for DL's performance: the researchers attained a recall rate of over 90% for visible seedlings, irrespective of their height.

Seedling detection accuracy varied across different lines due to multiple influencing factors. Specifically, seedlings taller than 90 cm showed a 90% detection rate, whereas those ranging from 60 cm to 90 cm were detected at a 75%

rate compared to in situ data. Notably, Tamarack seedlings had a consistently lower detection rate, attributable to their smaller crown size.

The leaf-off season enhances conifer detection compared to the leaf-on season. This enhancement is attributed to reduced overlap between crowns and less heterogeneous ground vegetation.

LESSONS LEARNED

1. A better understanding of passive recovery trajectories will help guide restoration planning

Understanding when and where forests will recover on their own is key to planning restoration initiatives. Two key variables for understanding passive recovery — the time it takes for trees to start growing after a disturbance (regeneration lag) and how quickly trees grow once established — are related to ecosite and tree species. Sites with both short regeneration lags and tree species that grow quickly will likely be good candidates for passive recovery.

Why is it important?

Many different variables including initial conditions of the disturbance, the status of recovery, the ecosite the disturbance is in, and tree species all affect patterns of passive recovery. Actively treating seismic lines is a huge effort. Restoration strategies that consider how different variables affect passive recovery trajectories will help practitioners better manage limited restoration resources.

2. LiDAR is a powerful planning tool

LiDAR is a versatile three-dimensional data source that can be used by practitioners for a variety of applications. The power of LiDAR-based tools comes from their ability to reduce the need for costly and labour-intensive field surveys. Recent BERA research shows the utility of LiDAR to create maps of understory vegetation structure and solar irradiance (light availability).

Why is it important?

Accurate information is essential for forest management and restoration. While many forest maps are readily available, information on understory vegetation and solar irradiance is rarely included. Understory vegetation plays a key role in forest ecological processes including nutrient cycling, forest succession/regeneration, fire regimes, wildlife movement, and carbon dynamics. Light availability constrains tree growth and can be used to identify if seismic lines have suitable light conditions for specific species. Irradiance maps could help practitioners make restoration plans with a higher probability of seedling survival.

3. Seismic lines alter carbon dynamics in boreal peatlands

In some boreal peatlands, seismic line disturbances encourage saturated soil conditions, limit tree recovery, shift vegetation communities, and alter microclimatic conditions. These changes increase CH_4 emissions, alter peat accumulation rates, and influence long-term carbon storage.

Why is it important?

Although the proportion of the landscape disturbed by oil sands activity is very small, peatlands are important and store about one third of the world's soil carbon and play a key role in the regulation of greenhouse gasses. Peatlands also account for 5% to 10% of global methane emissions — which are produced when organic matter decomposes without oxygen. The management of peatlands has been highlighted as an important nature-based climate solution.

4. Seismic lines create browse subsidies for ungulates in certain ecosites

Seismic lines can create browse subsidies (increased food abundance) for moose and deer in some ecosites. BERA researchers showed that the amount of browse on seismic lines in peatland and transitional sites was double that of undisturbed forest (on upland sites, browse did not differ between seismic lines and interior forest). On seismic lines, researchers found evidence for browse subsidies in peatland interior, peatland transition, and upland transition sites, with 139%, 127%, and 118% increases in browse abundance, respectively.

Why is it important?

Forest disturbances like seismic lines remove mature trees and promote the growth of deciduous shrubs. Moose and deer rely on shrub species (browse vegetation) for food, particularly in the winter. High populations of deer and moose, indirectly, negatively affect at-risk woodland caribou populations. Therefore, it is important to understand if seismic lines are changing the amount of food available for moose and deer and whether this leading to increased populations.

5. Additional disturbances can 'erase' seismic lines in some ecosite types

Seismic lines are one of the largest contributors to forest fragmentation in the boreal and negatively affect caribou populations. When wildfire and forest harvest blocks are layered on top of seismic lines, the initial disturbances are largely 'erased', being replaced by the most recent disturbance.

Why is it important?

Understanding that disturbances tend to 'erase' each other in some ecosite types rather than accumulate is important. Different disturbance types have different landscape effects, and some types are easier to restore than others. For example, trees regenerate more quickly within cut-blocks or burned areas than they do on seismic lines. Moreover, controlling recreational access can become easier in these other disturbance types, further accelerating restoration.

6. Context matters: fragmentation analysis can greatly increase restoration efficiency

Not all seismic line restoration efforts influence recovering caribou habitat to the same extent. Prioritizing the right sites for restoration can maximize positive effects for caribou and other wildlife while also maximizing cost-effectiveness.

Why is it important?

Fragmented habitats are indirectly negatively impacting caribou populations. Seismic line restoration can help restore these habitats but is expensive and time intensive. A restoration-planning approach that prioritizes restoring seismic lines where caribou habitat will be most efficiently defragmented can help ensure that resources have the greatest positive effect.

7. Inverted mounds promote tree growth, but emerging techniques provide opportunities for continual improvement

Selecting which mounding techniques work best in peatlands depends on the goals of restoration. Currently, inverted mounding treatments are supported by the most comprehensive research regarding tree growth, but emerging research into other novel mounding techniques may provide opportunities for continual improvement that better preserve natural peatland functions.

Why is it important?

There are many different mounding techniques that can be used to create the microsites trees need to grow but not all these methods have been rigorously tested. A key BERA study has now tested the effectiveness of inverted mounding on seedling growth — which is essential for habitat restoration and caribou recovery. However, it is important to keep in mind that inverted mounds have both positive and negative effects, and influence complex ecosystem components like plant communities, soil function, and hydrology. Our understanding of the effects of different mounding techniques on these components, as well as the associated trade-offs, is still evolving.

8. Species communities shift as linear feature widths increase

The width of linear features is a key variable that alters communities of birds and small mammals. Many species are tolerant of linear disturbances up to a certain width threshold. Above this threshold, species communities start to shift, attracting birds who prefer shrub-based and early seral habitats.

Why is it important?

This knowledge will help practitioners determine which line widths have the lowest effect on wildlife communities and better predict the response curves of animal communities across space. It will also help identify which line widths should be prioritized for restoration and which could be left to regenerate naturally. In addition, small mammals can alter forest regeneration patterns through seed and seedling predation. Knowing the conditions these species prefer can help practitioners anticipate risks and plan accordingly.

9. Some birds adapt their vocalization patterns to deal with industrial noise

Some birds, like the Lincoln's Sparrow prefer the more open habitats created by industrial activities. To live in these noisy areas, however, they need to change the ways they communicate.

Why is it important?

Industry disturbances alter vegetation communities, which are known to shift bird-species compositions. However, many industrial disturbances involve other components such as light or noise pollution that should be investigated as well. It is important to consider the full range of habitat requirements of a species when determining how they are affected.

10. LiDAR and Landsat data together provide a better way to predict bird responses to harvest

Using a combination of LiDAR and Landsat data rather than relying only on traditional forest inventory data helps improve predictions of bird responses to forest harvest.

Why is it important?

To conserve federally listed species, wildlife managers need to understand when habitat conditions are contributing to species declines. Although the most accurate methods of predicting bird response to harvest involve detailed ground-based surveys, these are difficult and costly to implement over large areas. Using remote sensing technology makes it easier to get this information, but often comes at the cost of accuracy. Traditional forest inventory data obtained through aerial photography does not capture all the habitat features that are important for determining bird responses to harvest.

11. Artificial Intelligence (AI) is changing the way we detect and measure seedlings

AI interpretation of LiDAR and optical imagery obtained from drones is transforming the way we detect and monitor seedlings on industrial disturbances. Preliminary results from a variety of studies are showing promising initial results that may pave the way for remote sensing-based establishment surveys.

Why is it important?

Boots-on-the-ground field surveys to count seedlings and perform stocking assessments are costly and labour intensive. Many different tools and technologies are being tested to determine the best way to detect and measure seedlings remotely. BERA researchers are prioritizing accuracy, feasibility, and affordability in their exploration of new tools to bring to practitioners.

PRESENTATIONS AND PUBLICATIONS

Published Theses

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Conference Presentations/Posters

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Bao, J., Dabros, A., Goud, E., Strack, M. 2023. Evaluating the effects of seismic line disturbance on the function of peatland plant communities. Canadian Geophysical Union Annual Meeting, Banff, AB. May 9. https://www.meet-here.ca/CGU2023/Presenters?page=1&per-page=30

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Davies, M., Davison, S. J., Kleinke, K., Schmidt, M., Strack, M. 2023. Synthesis of soil properties on seismic lines in northern Alberta, Canada. RE3 2023 Conference: Reclaim, Restore, Rewild, Quebec, QC. June 12.

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Hillson, S., McDermid, G., Linke, J., and F. Wiemer. 2023. Assessing the Hydrological and Pedological Impacts of Mechanical Mounding Techniques on Wetland Ecosystems in Northeastern Alberta: Implications for Successful Restoration Efforts. AGU 23 – Wide. Open. Science. San Francisco, CA. December 15. https://agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1413804

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Kalukapuge, T., Martínez-Lanfranco, J. A., Leston, L., and Bayne, E. 2023. Response of boreal songbird communities to linear features of varying width. Pacific Ecology and Evolution Conference 2023, Vancouver, British Columbia.

Kalukapuge, T., and Bayne, E. 2023. Effects of linear feature width on boreal songbird Communities: How much does width matter? The Alberta Chapter of The Wildlife Society Conference 2023, Calgary, Alberta.

Ketcheson, S. J., Weiland, L., McDermid, G., and Strack, M. (2023) The Influence of Seismic Lines on Local Hydrology in the Boreal Region of Alberta, Canada. Restore, Reclaim, Rewild (RE3) Conference (International level), Quebec City, QC. June. 15.

Kleinke, K., Davidson, S. J., Schmidt, M., Xu, B., Strack, M. 2023. How mounds are made matters: implications for seismic line restoration in peatlands. RE3 2023 Conference: Reclaim, Restore, Rewild, Quebec, QC. June 15.

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Principal Investigator: Dr. Greg McDermid

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Edge Effects of Seismic Footprint in the Lowland Boreal Ecosystems of Alberta

COSIA Project Number: LE0081

In Situ

Research Provider: Canadian Forest Service — Natural Resources Canada

Industry Champion: Imperial

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Suncor, Syncrude, Teck

Status: Year 2 of 3

PROJECT SUMMARY

This study addresses the extent and nature of edge effects (Murcia, 1995) of seismic lines in lowland ecosystems of the northern Alberta landscape. Oil and gas development has resulted in a dense (up to $40km/km^2$ [Filicetti et al., 2019]) network of seismic lines, combined with other industrial disturbances (e.g., roads, well pads, pipelines), leading to extensive landscape fragmentation. Persistence of seismic lines and lack of canopy regeneration in boreal ecosystems is particularly notable in boreal treed peatlands (van Rensen et al., 2015). Despite the potential ecological risks associated with edge effects caused by industrial disturbances such as seismic lines (e.g., loss of native biodiversity, establishment of invasive species [Bender et al., 1998; Haddad et al., 2014]), there is little information on their nature or how they might be mitigated in boreal forests and peatlands, nor the potential for restoration efforts to remove edge. This study builds on the research projects on edge effects in boreal ecosystems (including peatlands) already initiated and carried out by the Canadian Forest Service in the department of Natural Resources Canada (Dabros et al., 2017; Dabros et al., 2021; Dabros et al., 2023).

Persistence of ubiquitous seismic lines in Alberta's boreal region, along with their edge effects can lead not only to change in native biodiversity, but also to altered habitat quality for native species of flora and fauna (Bender et al., 1998; Haddad et al., 2014). This in turn may change the resilience and successional trajectories of the disturbed ecosystem. Knowledge of the full extent of influence of industrial linear features such as seismic lines on a range of organisms (plants, lichens, arthropods, soil fungi) is important to inform questions of recolonization during site recovery. Further, characterization of recolonization by native biodiversity, when active treatments (e.g., restoration including silvicultural practices such as site preparation and tree planting) are employed is of value. The study of edge effects is valuable not only to help better understand the impact of seismic lines, but also for continual improvement of restoration practices. The results from this study will contribute to the understanding of whether restoration practices mitigate edge effects, which may help identify important indicators of restoration performance and thereby lead to continual improvement opportunities.

The general objectives of this study are:

1. **To assess edge effects on biotic and abiotic factors. The hypotheses are that edge effects are proportional to line width and degree of ground alteration. The degrees of changes in environmental conditions associated with the disturbances (abiotic factors) will affect responses of biotic factors, e.g., diversity and abundance of various vegetation functional groups, lichens, arthropods, and fungi.**

   In addressing this objective, researchers found synergy with another research project that is a part of the Boreal Ecosystem Recovery Assessment (BERA) phase 2 collaborative research initiative. This allowed this research to address a question regarding potential edge effects on plant functional traits (e.g., do plant species on seismic lines possess traits that allow them to persist or thrive on the lines, and potentially prevent or inhibit other species from establishing? Do plant functional traits vary with proximity to forest edges?), as well as to explore the relationship between plant functional traits, their environment, and remotely sensed variables (and ultimately, to test the application of remote sensing as a cost-saving tool to detect edge effects and optimize restoration practices of seismic lines).

   Research sites were set up in poor bogs of the Peace River region in NW Alberta (conventional seismic lines dating as far back as 1950s, Fig. 1); moderate-rich fens in the Conklin region near Christina and Clyde Lakes in NE Alberta (conventional seismic lines dating back to 1990s, Fig. 1 and Fig. 2a,b); and for the BERA project, in moderately rich fens in the Conklin region at Canadian Natural's Kirby South site (Fig. 1). In addition, researchers have one upland site in the Swan Hills region of NW Alberta, with Low Impact Seismic (LIS) lines that were cut in 2011 (Fig. 1).

2. **To assess biotic and abiotic responses to edge over time. The hypotheses are that edge effects will diminish over time if the site is on the trajectory towards recovery. However, if succession is arrested, edge effects will persist or increase over time.**

   To address this objective, in summer 2022 researchers resampled the research sites in Peace River that were initially sampled in 2015 to 2016 (Dabros et al., 2021). Additionally, in summer 2024, resampling will occur at the upland research site in the Swan Hills region, which were sampled in 2014 and 2019 (Fig. 1) (Dabros et al., 2017, 2023). Potentially, in Peace River, where the seismic lines vary in ages, researchers will also be able to determine the ages of seismic lines in the same area and assess if the age of the line is correlated to line recovery, or the extent and magnitude of edge effects.

3. **To assess whether restoration treatment measures mitigate edge effects in adjacent boreal ecosystems, and to assess the interaction of time and treatment on edge effects. The hypothesis is that over time, successful restoration treatments will mitigate edge effects.**

   To address this objective, researchers set up research sites in the summer of 2023 at the Caribou Habitat Recovery Program (CHRP) Area A near Clyde Lake (Fig. 2b), that have received restoration treatment in 2019, and in summer 2024 they are planning to set up sites at the Kirby South, in the moderately rich fens (all in the Conklin region of NE Alberta, Fig. 1), where some lines have also received a mounding restoration treatment in 1996.

   The identification of optimal treatment regimens to restore sites affected by an industrial footprint is one of COSIA's priorities and is also important in the implementation of Alberta's Caribou Habitat Recovery Program. This is especially pertinent in Alberta, where conventional seismic lines are prominent and exist in caribou range (Government of Alberta, 2017). Ultimately, this study will deliver knowledge on the extent of edge effects on baseline ecological components in boreal ecosystems (with a focus on peatland ecosystems), both biotic and abiotic, which may support the ability to model, predict, and plan for successful restoration of seismic line footprint. Science-based evidence about which methods are most effective in reducing the industrial footprint, including edge effects, can increase the effectiveness of restoration and reduce its costs. Furthermore, while most research on edge effects focuses on plants only, in the present study, researchers are collecting data on native assemblages of living organisms (biotic factors: percent cover and species diversity of plants and lichens, and species richness and diversity of arthropods and soil fungi) and their environmental conditions (abiotic factors: soil moisture, temperature, pH, electrical conductivity (EC), and light levels). As such, researchers can focus on the biodiversity of major drivers of ecosystem functioning, as well as their interactions with each other and their environment (i.e., abiotic factors), over time.

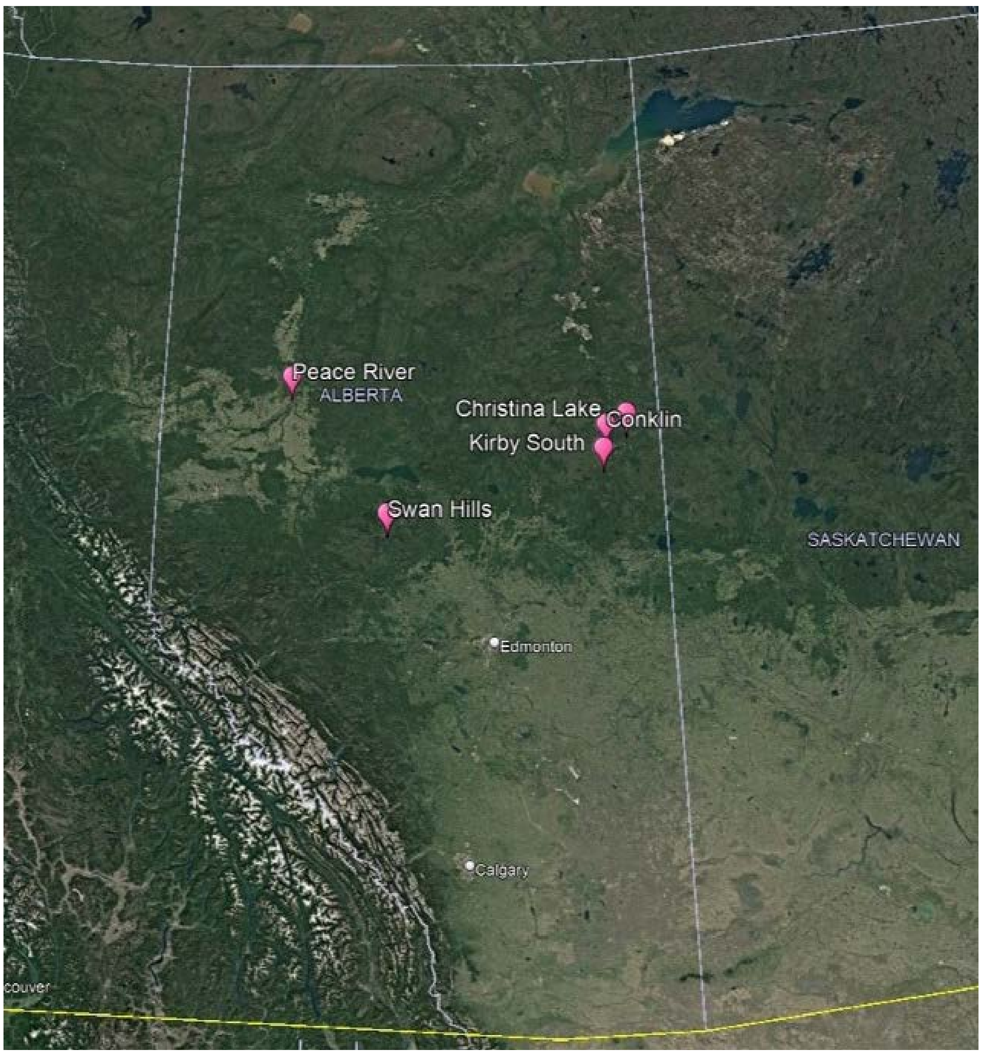

Figure 1: Map of all locations of current research sites in northern Alberta.: in NW Alberta, upland site in Swan Hills, peatland site near Peace, and in NE Alberta, Christina Lake, and Kirby South in the Conklin region. .

Figure 2: Map of two research sites in the Conklin region: A) Caribou Habitat Recovery Program (CHRP) Area A, with some conventional seismic lines treated in 2019 (blue points) and some lines left untreated (pink points); and B), Christina Lake (CH), with untreated convectional seismic lines (pink points). Ten treated transects and six untreated transects were sampled at the CHRP Area A site, and fourteen untreated transects were sampled on untreated lines at CH site.

PROGRESS AND ACHIEVEMENTS

Establishment of Experiments and Sampling

To address the first objective of this research project, in summer 2022, after exploration of the Conklin region, ten new transect locations were established near Christina Lake (CH), in the moderate rich fens, on conventional seismic lines (approximately 8 m wide) (Fig. 2b). Vegetation and environmental variables data were collected there along 75 m long transects, sampling in 1 m x 1 m plots at 11 distances (line, 0 m, 1 m, 2 m, 5 m, 10 m, 15 m, 25 m, 35 m, 50 m, 75 m).

Following preliminary statistical analysis of the data collected in summer 2022 at CH site, in 2023 researchers improved their sampling design to yield more accurate results. This included adding another sub-transect (20 m away from the original transect) at each of the ten transect locations, while reducing the number of plots sampled along each sub-transect (line, 0 m, 1 m, 2 m, 5 m, 10 m, 50 m, 75 m; Fig. 3).

Additionally, in summer 2023, arthropod traps were established at five of the ten CH locations to collect arthropod samples. Researchers chose five east-west (E-W) oriented sites for arthropod sampling at CH site, to be consistent with the five E-W oriented transect locations that were sampled in Peace River peatlands in year 2022 – deliverable from previous year.

Arthropod samples were collected four times, every three weeks over summer 2023. Soil samples were also collected at the same locations as the arthropod traps, and they will be processed in the lab to determine soil fungi community.

To obtain additional environmental data, in 2023 loggers were established at the same five transect locations as the arthropod traps. These loggers were set at five distances (line, 10 m, 25 m, 50 m, 75 m) along the transect (Fig. 3) and were programmed to record soil temperature and light conditions every 15 minutes. The loggers were left at the sites over winter, to provide continuous environmental data over the whole year.

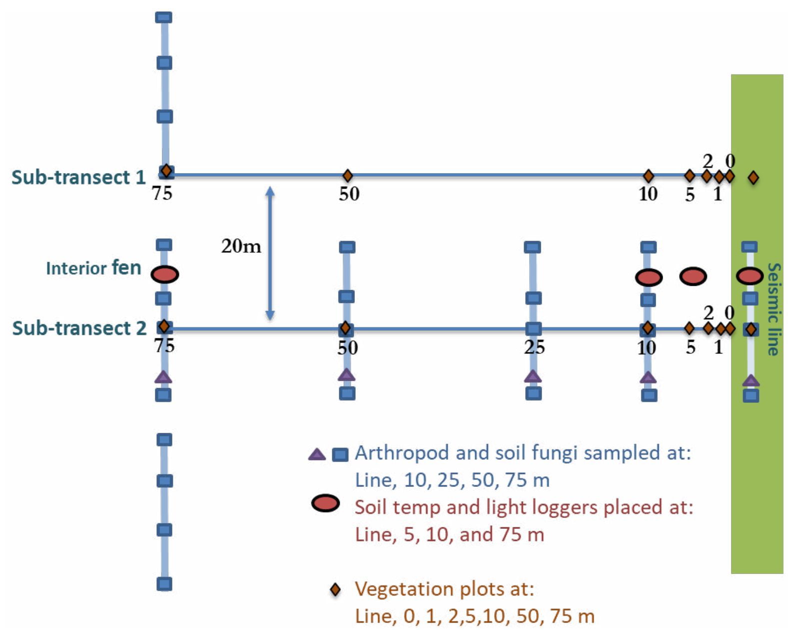

Figure 3: Experimental design used at CH and CHRP research sites: Transects ran perpendicular to the seismic lines. Vegetation was sampled in 1 m x 1 m plots on the line and at seven distances, and arthropod traps were set up on the line, and four distances from the line edge. Soil fungi samples were collected at the same distances as the arthropod traps. Soil and light loggers were set up to log continuous data every 15 minutes, on the line, and at three distances away from the line edge.

To address the second objective of this research project, in spring 2023, the researchers explored the Conklin region to locate treated and untreated seismic lines. Two areas were explored: CHRP Area A and CHRP Winefred Lake. With the latter area not presenting the desired ecosite conditions (which in this case were the moderately rich fens), the researchers chose ten transect locations at CHRP Area A, where mounding treatment was applied on conventional seismic lines in 2019 (Fig. 2b).

In addition, the researchers selected six untreated line transect locations at CHRP Area A and four untreated line transect locations in CH area (for a total of ten untreated line transect locations), which served as controls/references (Fig. 2a,b). Following the same sampling design as at CH site in 2023 (see above), the researchers sampled along 75 m long transects at all 20 transect locations (Fig. 3). Plots (1 m x 1 m) were sampled at various distances along the transect, with plants identified to species level, and percent cover for each species determined. Environmental variables were measured in the same 1 m x 1 m plots. Overstory tree density, tree count, and tree height, and DBH were also assessed, in 5 m x 20 m belts on the seismic lines and at three other distances moving towards the interior fen (Fig. 4).

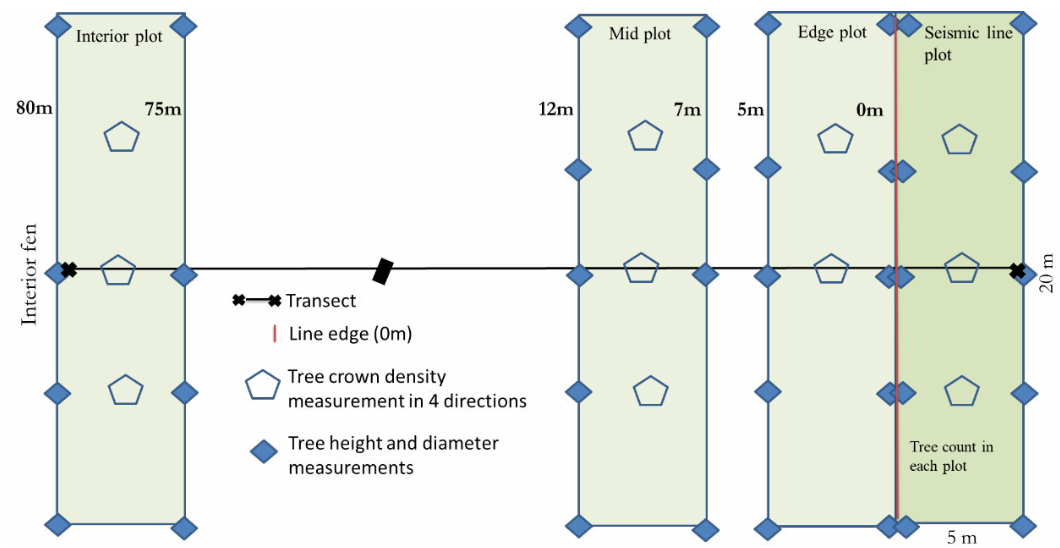

Figure 4: Experimental design for sampling the overstory in Peace River and Christina Lake (CH) research sites in summer 2022, and at CH site and CHRP Area A site in summer 2023. Within each plot, all trees were counted and separated into categories according to their size (seedling, sapling, pole, tree), density was measured in three spots with each measurement made in four directions using a densiometer and tree height and diameter at breast height (DBH) was measured for the eight trees at the corners and along the lengths of the plot (every 5 m).

In addition to sampling of all vegetation types (woody, herbaceous, and bryophyte species) as described above, a more detailed sampling of bryophytes (all moss and liverwort species) in their preferred microhabitats was performed following a different design (Fig. 5). Bryophytes were sampled in 1 m x 10 m belts embedded in the overstory plots (Fig. 5). In each belt, all bryophyte species were identified to species level in 0.5 m x 0.5 m plots: two at the top of the two highest hummocks and two in the water hollows. Microtopography was sampled along the 10 m belt, with two measurements taken at every metre, at the highest and lowest point. Bryophytes play a crucial role in peatland communities, as they often provide growing media for vascular plants. Some bryophyte species are more favourable to tree seedling establishment and growth than others.

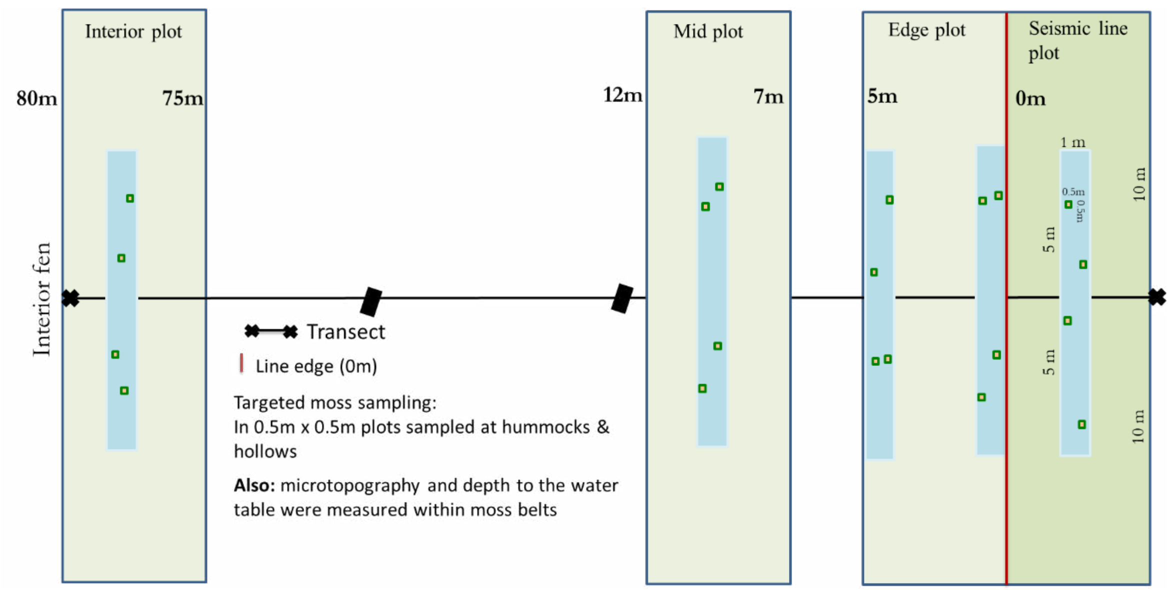

Figure 5: Bryophyte belt plots (1 m x 10 m) were embedded inside the overstory plots, on the line and at four distances away from the line. Bryophyte species were assessed in four 0.5 m x 0.5 m plots inside each belt: two on the hummocks, and two at the hollows. General sweep of the whole belt was performed to assess presence/absence of other bryophyte species not captured in the four plots. Microtopography was measured at 20 spots along the belt, including inside the four 0.5 m x 0.5 m plots.

At the end of August 2023, remote sensing data were collected for sampling locations at the CH site (Fig. 2) by one of the BERA 2 students, Xue Yan Chan. A series of remotely piloted aircraft system (RPAS), i.e., drone missions, were conducted with the goal of supporting research on seismic line edge effects. This data can complement the ground data collected (overstory, microtopography, depth to the water table) and can be used to explain plant and arthropod distribution and patterns.

Summary of Samples and Data Collected as of Fall 2023

Overall, in Conklin region in summer 2023 plant composition and environmental data was collected in 1 m x 1 m plots on 20 transects (with two sub-transects each): 10 on treated seismic lines (CHRP), 10 on untreated seismic lines (6CHRP + 4CH), plus on additional sub-transects for all 10 CH transects that were sampled in 2022. For the project focusing specifically on bryophytes, data were collected on 10 CHRP transects on treated lines and 10 CH transects on untreated lines. Over summer 2022 and 2023, the researchers found a total of 158 taxa (vascular and non-vascular plant species and lichens) during 1 m x 1 m plot sampling: 59 bryophytes, 19 shrubs, 43 forbs, 26 graminoids, seven lichens, and four trees. For the project focusing on bryophytes, 120 taxa were found, including 20 liverworts.

Arthropod and soil fungi samples were collected on five transects in Conklin region (untreated lines in fens at CH site) in 2023, during four collection trips over the summer. As of fall 2023, a total of 12,608 spider individuals were found, representing 144 species. Additionally, 267 carabid beetles, 1,578 rove beetles, and 3,318 ant species were found. Sorting and identification of arthropod specimens is ongoing. For soil fungi samples, all samples have been processed in the lab: dried, broken up and mixed in a sterilized blender, freeze dried, and DNA extracted with a DNeasy plant kit. This will be followed by DNA sequencing, and assessment of the diversity and abundance of the fungi present in the soil.

The major products derived from the remote sensing data collected over the CH sites included: 2 cm resolution RGB orthomosaics, approximately 90 pts/m^2 LiDAR point clouds, and 15cm resolution digital terrain models (DTM), digital surface models (DSM), and canopy height models (CHM). This data can complement the ground data collected (overstory, microtopography, depth to the water table) and can be used to explain plant and arthropod distributions and patterns.

Sample Processing, Analyses Progress and Preliminary Results as of Fall 2023

Based on the data collected in the Conklin region over summers 2022 and 2023:

- In assessing the influence of mounding treatment on seismic lines on vegetation communities, treated seismic lines were more dissimilar from the reference sites in the interior fen, than untreated lines, especially for vascular plants. Plant species heterogeneity was higher on untreated lines compared to treated lines for both, vascular and bryophyte species.
- For the focused sampling of bryophytes, the patterns observed revealed that colonizer species were most often found on the mounds of treated lines. Microhabitat and microtopography were important for diversity with pools and hollows having more diversity than hummocks. However, pools created by mounding were much deeper than natural pools and supported fewer species than natural pools and hollows.
- For the untreated sites, there were no mature trees and less shrubs (overall, less woody species) on the seismic lines, but more graminoids on the lines and at the edges, compared to interior fen. Forbs and bryophytes were unaffected based on the percent cover, but species composition likely differed between the lines and the adjacent fen.
- For treated sites, the cover of tree species (mostly seedlings) on the lines and in the adjacent fen was similar, but there were fewer low shrubs on the lines. There were more graminoids on the lines compared to adjacent fen, with the edge being a transition zone. The cover of forbs was unaffected, but species composition was likely different. The cover of bryophytes was lower on the lines compared to adjacent fen, with the edges and 1 m away from the edge being a transition zone.
- For the untreated sites, the canopy was denser near the edges compared to further distances from the edge in the fen; this was not observed for the treated sites. There were more larch seedlings on treated lines compared to adjacent fen and untreated lines, and more black spruce seedlings on treated lines than untreated lines. However, in the adjacent fen, there were more black spruce seedlings for untreated lines than for treated lines, especially within the first 12 m from the edge.
- There were less saplings and no mature trees on both treated and untreated lines, but there were more mature larch trees at the edges of both treated and untreated lines. For black spruce, there were more mature trees at the edges of untreated lines only.
- In terms of environmental conditions, soil moisture was higher on the seismic lines compared to the adjacent fen, especially for untreated sites (not accounting for the pools of water associated with the mounding on treated lines). Other environmental factors measured did not differ significantly based on the distance from the seismic line edge.
- The remote sensing data might be used to provide tree counts along the seismic lines and edges in the adjacent fen to verify and scale up the data collected on the ground (overstory measurements). It can also be utilized

to provide digital terrain models (DTM), digital surface models (DSM), and canopy height models (CHM), which may be used to interpret plant and arthropod species composition and distribution on the seismic lines and in the adjacent fen. Microtopography and depth to the water table can also be assessed.

- For the BERA collaborative project, mapping plant functional types and traits through remote sensing at Kirby South (MSc project of Xue Yan Chan), and analysis comparing plant functional traits on the seismic lines and in the adjacent interior fen on the ground (MSc project of Christina Bao) are currently in progress. There is also collaborative research with BERA 2 members on assessing edge effects of seismic lines on plant functional traits, with preliminary results indicating little evidence of edge effects affecting traits.

LESSONS LEARNED

Key findings based on the preliminary analysis of the data collected on seismic lines in fens in the Conklin region after summer 2023 indicate that **the treated seismic lines are more dissimilar to the interior (reference) fens than the untreated lines, in terms of plant species composition.** The moisture was higher on the untreated seismic lines, compared to the adjacent fen, and it was higher on treated seismic lines compared to interior fen (50 m and 75 m away from the edge). The cover of graminoids was higher for treated lines, with the edges presenting a transitional zone, followed by lower graminoid cover in the adjacent fens; this pattern was less evident for the graminoid cover on untreated lines, which was higher on the lines and near the edges, becoming lower only in the interior fen, 75 m away. Wetter conditions on the lines likely contributed to higher abundance of graminoid species (mostly sedges), which may not be optimal for tree regeneration. **In that respect, mounding treatment may provide drier conditions and better chances of survival for tree seedlings.**

There were more tree seedlings on treated lines compared to untreated lines, likely due to the planting treatment on the mounds in 2019 on the treated lines. There were fewer tree seedlings or trees of any size on the untreated seismic lines compared to the treated lines and the adjacent fen, **indicating that over the past four years since the treatment at CHRP Area A, the seedlings are surviving well on the seismic lines, while they are still not regenerating on their own on the untreated seismic lines.**

For black spruce, the highest number of seedlings for both treated and untreated lines was observed in the interior fen 75 m away from the edge, indicating that less spruce seedlings are present close to the edges of the lines, regardless of the treatment. **This can be interpreted as edge effect, indicating that the conditions close to the edges of seismic lines are less favourable for seedling regeneration and growth.**

Furthermore, when comparing treated to untreated seismic lines, there were generally fewer spruce seedlings at any distance away from the edge for the treated seismic lines. **This can be interpreted as a more pronounced edge effect on spruce seedling regeneration observed for treated versus untreated seismic lines.**

Generally, there were more mature trees on the edges of both treated and untreated seismic lines compared to further away from the edge, **indicating that trees grow well along the edges of the lines regardless of the treatment on the line.** However, canopy density along the edges was higher for the untreated seismic lines compared to the fen further away from edge, while this pattern was not observed for the treated lines. While this may indicate that there might be less light reaching the ground near the edges of untreated lines (edge effects), this was not captured by the light measurements, nor has it affected the cover of understory species, including bryophytes, forbs and graminoids. **Overall, although the observed edge effects of higher tree count within the first 5 m of the edge were observed for both treated and untreated seismic lines, they do not seem to affect understory species cover.** Further analyses need to be performed to assess if plant species composition is different near the edges.

In summary, preliminary analyses of plant data collected on seismic lines in the fens of Conklin region indicate patterns of edge effects on tree seedlings of both treated and untreated seismic lines, with potentially stronger impact observed for treated lines. While there is little evidence of edge effects on understory species cover, the effects on species composition still needs to be assessed. Mounding treatment appears to be successful in terms of tree seedling survival over the last four years, but overall plant species composition on the lines is more dissimilar compared to the interior fen than for the untreated seismic lines.

The next steps of this project will include continuation of the analysis of vegetation patterns and the assessment of arthropod and soil fungi diversity on the treated and untreated seismic lines and in the adjacent fen to determine presence and nature of potential edge effects of seismic lines.

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Dabros A., Higgins K. L., Pinzon J. 2021. Seismic line edge effects on plants, lichens and their environmental conditions in boreal peatlands of northwest Alberta (Canada). Restoration Ecology doi:10.1111/rec.13468

Dabros, A., Higgins, K.L. 2023. Vegetation recovery and edge effects of low impact seismic lines over eight-year period in boreal uplands of northern Alberta. Forest Ecology and Management. doi.org/10.1016/j.foreco.2023.120850

Filicetti A., Cody M., Nielson S. E. 2019. Caribou conservation: restoring trees on seismic lines in Alberta, Canada. Forests 10:185; doi:10.3390/f10020185

Government of Alberta. 2017. Restoration and establishment framework. Prepared for Alberta Environment and Parks, Land and Environment Planning Branch, Edmonton, Alberta, Canada.

Haddad N. M., Brudvig L. A., Damschen E. I., Evans D. M., Johnson B. L., Levey D. J., Orrock J. L., Resasco J., Sullivan L. L., Tewksbury J. J., Wagner S. A., Weldon A. J. 2014. Potential negative ecological effects of corridors. Conservation Biology 28(5):1178–1187

Murcia C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology & Evolution 10(2):58–62

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

PRESENTATIONS AND PUBLICATIONS

Dabros, A., Higgins, K. L., 2023. Vegetation recovery on low impact seismic lines over eight-year period in boreal uplands of northern Alberta. Restore, Reclaim, Rewild (RE3) Ecological Conference (June 11-16) in Quebec City, QC (oral presentation).

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service, Natural Resources Canada

Principal Investigator: Anna Dabros

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jaime Pinzon	Canadian Forest Service	Research Scientist		
David Langor	Canadian Forest Service	Research Scientist		
Tod Ramsfield	Canadian Forest Service	Research Scientist		
Jim Hammond	Canadian Forest Service	Biologist		
Jennifer Buss	Canadian Forest Service	Research Technician		
Philip Hoffman	Canadian Forest Service	Research Technician		
Brooklyn Bolstad	Canadian Forest Service	Field Assistant		
Ashleigh Davidson	Canadian Forest Service	Field Assistant		
Celina Waldron	Canadian Forest Service	Field Assistant/Student		
Madeline Koch	Canadian Forest Service	Field Assistant/Student		

Research Collaborators:

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Xue Yan Chan	University of Calgary	MSc Student/BERA Collaborator	2022	
Irina Terenteva	University of Calgary	Post-Doctoral Fellow/ BERA Collaborator		
Greg McDermid	University of Calgary	Associate Professor/ BERA Collaborator		
Julia Linke	University of Calgary	BERA Science Coordinator/BERA collaborator		
Christina Bao	University of Waterloo	MSc Student/BERA Collaborator	2022	
Maria Strack	University of Waterloo	Professor/BERA Collaborator		
Ellie Goud	University of Mary's University	Professor /BERA Collaborator	2022	
Richard Caners	Royal Alberta Museum (RAM)	RAM Curator		

Collaborators: Boreal Ecosystem Recovery Assessment (BERA) and Royal Alberta Museum (RAM)

EcoSeis Phase 2

COSIA Project Number: LJ0344

In Situ

Research Provider: OptiSeis Solutions Ltd.

Industry Champion: Imperial

Industry Collaborators: Canadian Natural, Cenovus, Conoco, Suncor

Status: Year 1 of 2

PROJECT SUMMARY

Eco-Seis is a methodology to reduce the amount of line clearing on seismic programs. This method utilizes unique geometries in conjunction with conventional or miniature seismic equipment to minimize surface disturbances while also providing high quality seismic data and safe access for field personnel. This method will work with geometry variations and multiple source types, increasing the ability to minimize surface disturbance and making it possible to apply the methodology in many different types of terrains both within Canada and internationally.

The key goal of the project is to complete validation of the EcoSeis methodology through a field trial which will compare an EcoSeis seismic program with a conventional seismic acquisition program. This will involve joint acquisition of the two seismic datasets followed by seismic processing, inversion, environmental assessments, and statistical analyses to evaluate reductions in land footprint, greenhouse gas (GHG) emissions, and costs.

The successful implementation of this technology or use of the knowledge generated could result in:

- Reductions of up to 50% in the amount of tree cutting on seismic programs;
- Reductions in the amount of GHG generated during seismic programs;
- Reduction in habitat disturbance and/or ability to avoid or limit entry into sensitive areas with high biodiversity; and
- Support for development of guidelines for achieving high quality subsurface seismic images while maintaining biodiversity and protecting sensitive habitats.

PROGRESS AND ACHIEVEMENTS

The project began in February 2022 and the first milestone was completed on March 31, 2023.

The primary objective of Milestone 1 was to acquire both the EcoSeis and conventional seismic datasets in the fourth quarter of 2022 and begin the geophysical analyses in the first quarter of 2023. This involved preliminary geophysical and environmental studies, evaluation of potential testing sites, final site selection, and the planning and subsequent acquisition of the combined conventional seismic and EcoSeis 3D programs.

Field operations began in October 2022 and were safely completed in December 2023 on time and on budget. During field operations, statistics such as equipment movement, costs, and fuel use, were tracked to accurately quantify the emissions reduction associated with EcoSeis.

Analysis will be completed in Milestone 2. Processing of the seismic datasets began in January 2023 with interpretation of some initial processing products underway as of the end of Milestone 1.

Additional work in Milestone 1 included ongoing software development to incorporate learnings from the field program into the EcoSeis implementation algorithms.

As of March 31, 2023, there have been 109 communications related to the project. These are listed below and include journal publications, technical and non-technical presentations, courses, workshops, and various online communications on both the OptiSeis website (Optiseis Solutions Ltd. – Geophysical Acquisition Design & Software) and LinkedIn (https://www.linkedin.com/company/optiseis-solutions-ltd/). These communications, which include results from both Phase 1 and Phase 2 work completed to date, are used to raise awareness of EcoSeis in order to facilitate its large-scale adoption.

LESSONS LEARNED

EcoSeis Phase 1 lessons learned were published in the 2022 COSIA Land EPA – In Situ and Mine Research Report under COSIA project Number: LJ0340.

Lessons learned for EcoSeis Phase 2 will be available in the 2025 report once the project analysis is completed.

PRESENTATIONS AND PUBLICATIONS

Journal and Online 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. https://optiseis.com/2023/02/use-of-miniaturised-seismic-sources-for-reduced-environmental-impact/

Conference Presentations/Posters

2023 (March): Oral presentation at AEGC. Designing Seismic Surveys for Reduced Environmental Impact. https://2023.aegc.com.au/cms/wp-content/uploads/AEGC-2023-Detailed-Program-3.3.23.pdf

2023 (March): Poster presentation at AEGC. Using seismic trace density for optimal 3D seismic survey design. https://2023.aegc.com.au/cms/wp-content/uploads/AEGC-2023-Poster-Program.pdf

2023 (February): AAPG workshop in Barranquilla. Sustainable Subsurface Imaging Technology Part 1: Design, Processing, and Interpretation. https://optiseis.com/2023/02/caribbean-2023-geosciences-technology-workshop-february-8-2023/

2023 (January): ACGGP workshop in Bogota. Reducing the environmental impact of acquiring seismic data. https://www.linkedin.com/feed/update/urn:li:activity:7026918017326350336

2022 (November) – GSH 3D Design Symposium. https://www.gshtx.org/SharedContent/Events/Event_Display.aspx?EventKey=2ffd2ae2-32d0-4fd5-9341-6e2bbeb3c3e2&iSearchResult=true&WebsiteKey=955f17e6-46ad-4401-acbd-2af6c393752b

2022 (November) – CHAO/CSEG Symposium. EcoSeis – Reducing the environmental impact of acquiring seismic while maintaining data quality https://optiseis.com/2022/10/cseg-choa-joint-symposium/

2022 (November) – EAGE Near Surface. https://optiseis.com/2022/10/second-eage-conference/

2022 (September) – Carbon Capture Canada: 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/

2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Workshop; Evaluating Acquisition Innovations: A Guide for Accurate Assessments.

2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Technical Presentation; Optimal Infilling of seismic station using Fresnel zone binning analysis. https://library.seg.org/doi/10.1190/image2022-3750648.1

2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Presentation; reducing environmental impact of Acquiring Seismic – The EcoSeis Approach.

2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; Panel Discussion; Imaging Acquisition and Interpretive Technologies: Surface and Subsurface.

2022 (June) – GeoConvention Conference. 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/

2022 (June): GeoConvention. 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/

2022 (April) – ICE AAPG Conference https://cartagena2022.iceevent.org/program/technical-program/on-demand-only

Reports and 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/

2023 (March): Crownsmen Partners's Interview. Optimizing Seismic surveys and the application of seismic methods in carbon capture and storage.

2023 (January): GeoWomen. https://www.linkedin.com/feed/update/urn:li:activity:7022279371965038592

2023 (January): Pathways-COSIA

2022 (November) – CSPC Panel https://optiseis.com/2022/10/canadian-science-policy-conference/

2022 (August): Crowsmen interview. https://optiseis.com/2023/02/building-energy-optiseis-solutions-is-changing-seismic-exploration-landscape/

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

2023 (March): Workshop at AEGC. Advances in Seismic Acquisition: Innovations, Resolution, and Sustainability Applications for Mining. https://2023.aegc.com.au/workshops/

2023 (March): HETI Pitch Competition & Award. https://optiseis.com/2023/03/heti-energy-ventures-pitch-competition-march-8-2023/

2023 (January): Plug and Play. https://www.plugandplaytechcenter.com/startups/our-startups/

2022 (November) – Foresight Demo Day

2022 (November) - Foresight Top50 https://foresightcac.com/foresight-50/

2022 (August): IMAGE '22 Joint AAPG-SEG-SPE conference; U-pitch New Technology Showcase; EcoSeis: A lower Carbon Solution for Seismic Acquisition

2022 (June) – Propel Conference https://propelenergytech.com/

2023 (March): Booth presentations at 3D Seismic Symposium in Denver. https://optiseis.com/2023/02/2023-3d-seismic-symposium-march-2-2023/

2022 (August): Booth presentations at IMAGE '22

75 announcements/updates on OptiSeis linked in and 40 on OptiSeis website since June 2022 when tracking began.

AWARDS

EcoSeis won its category in the HETI Pitch Competition at CeraWeek in Houston, TX in March 2023. https://optiseis.com/2023/03/heti-energy-ventures-pitch-competition-march-8-2023/

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Andrea Crook

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Michael Hons	OptiSeis Solutions Ltd.	Operations Geophysicist, P.Geo		
David Simmons	OptiSeis Solutions Ltd.	Operations Manager		
Mark Nergaard	Canadian Natural Resources Limited	Geophysical Operations Manager		
John Parkin	Cenovus Energy Inc.	Sr. Manager: Geophysical Services, P.Geoph.		
Brad Gerl	ConocoPhillips Canada	Senior Geophysicist, P.Geoph.		
Tyler Colberg	Imperial Oil	Research Advisor, P.Biol.		
Lori Neufeld	Imperial Oil	Land Use and Biodiversity Lead, P.Biol.		
Megan Boutin	Suncor Energy Inc.	Sr. Advisor, Integration, P.Geo.		
Emily Duncan	Suncor Energy Inc.	Manager, Geoscience Firebag and MacKay, P.Geoph.		