2024 COSIA LAND EPA

Mine & In Situ Research Report

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cosia
with Pathways Alliance

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INTRODUCTION

Canada's Oil Sands Innovation Alliance (COSIA) is the innovation arm of Pathways Alliance. Pathways Alliance is made up of Canadian Natural, Cenovus, ConocoPhillips Canada, Imperial, MEG Energy and Suncor representing about 95% of Canada's oil sands production.

Formed in 2012, COSIA is focused on collaborative action and innovation in four key environmental priority areas: tailings, water, land and greenhouse gases. For more than 10 years, COSIA has brought together innovative thinkers in industry, government, academia and the public to drive oil sands environmental technology.

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

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 2024 COSIA published a combined research report, 2024 COSIA Land EPA — 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. More information about the Land Environmental Priority Area is available on the Pathways Alliance website: www.pathwaysalliance.ca

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

2024 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: COSIA Fall Field Tour 2024, Imperial's Cold Lake Operations, Borrow Y East, Alberta. Image courtesy of Nakita Rubuliak, Fuse Consulting.

WETLANDS

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

Status: Year 5 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, transforming 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, 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 (2020-2024), and Dr. Peter Dunfield (2025).

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 transformation 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 transform land and promote wetland persistence and biodiversity as systems undergo succession. Upon Dr. Ciborowski's retirement in 2024, Dr. Peter Dunfield was approved by COSIA to lead the project in its final year.

BWRAP is addressing the following questions:

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

COSIA members require an assessment of the effectiveness or ‘functionality’ of constructed wetlands. Several attributes are recognized as either modulators or indicators of a wetland’s successional state or its environmental or biological condition. This program has measured a suite of environmental and biological characteristics of newly formed and maturing wetlands and their surroundings, 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. 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 and designed wetlands have been hypothesized to need at least a two-to-one ratio of catchment 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 disrupt 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 end of life planning 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 developed 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-transformed (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, 117 wetlands (minerotrophic fens, swamps, and marsh-like areas) approximately three, eight, 20- and 40-years post-formation, and 'mature' (age-indeterminate), were sampled. 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 entailed compiling and harmonizing existing data — a 20-year record of research conducted on natural and developed wetlands in and around the Fort McMurray oil sands leases. As well, remote sensing imagery of 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 wetlands. A representative set of wetlands varying in age, size, permanence, disturbance history, and water quality were selected for field studies over the next three years (Phase 2). To date, 47 students, research assistants and technical staff have been recruited and trained to participate in the three phases of the project.

Phase 2 — Field Investigations: Each year between 2021 and 2023, teams of fieldworkers assessed a suite of approximately 40 wetlands (minerotrophic fens and swamps and marsh-like areas) using a combination of 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 were 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 are being 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 are being used to identify benchmarks of biological characteristics (bioindicators) of each wetland age class, and 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 end of life planning protocols and ultimately provide objective criteria by which to anticipate the longer-term persistence of developed wetlands.

PROGRESS AND ACHIEVEMENTS

Phase 1 – Recruitment and Database Creation

In 2024, five undergraduate students joined BWRAP, and three completed safety and field training that would qualify them to conduct research in mine lease areas. All students were trained in field sampling and laboratory methods, and assisted in processing samples that had been collected during previous field seasons.

Working in collaboration with the Boreal Ecosystem Recovery and Assessment (BERA) NSERC Alliance-funded project, project researchers completed the development and beta-testing of a georeferenced, relational database that is accessible to both on-campus and off-campus collaborators. The database is designed to be inter-operable with information of the Alberta Biodiversity Monitoring Institute, with whom project researchers will ultimately share data. BWRAP and BERA researchers, collaborators and students have been compiling a common database management plan and relevant standards to maximize inter-operability and comparability of datasets, aligning with data record conventions used by the ABMI database where feasible. Several mapping, search, and synthesis tools have been developed to facilitate database uploads and simplify queries and data summaries. Detailed imagery provided by Syncrude and Suncor have been compiled from which various mapping products are being derived by team members.

Unmanned Aerial Vehicle (UAV) surveys of the 117 wetlands sampled between 2021 and 2023 were compiled and used to create digital elevation models from which open water, riparian and catchment areas were determined. Time trend records of variation in the areas of wetlands since their formation were gathered from analyses of aerial photos (provided by Syncrude and Suncor). Estimates of intra-annual variation for each wetland were derived from Sentinel-1 and Sentinel-2 satellite imagery and are being validated with reference to near-continuous in situ records of water level.

Phase 2 – Field-Collected Data

No additional fieldwork was conducted in 2024. In all, environmental and biological data had been collected from 117 of a target goal of 120 wetlands originally proposed. Laboratory-based sample processing, compilation, analysis and interpretation were the focus of the current year, to summarize the hydrological, and physicochemical water characteristics, soils, aquatic invertebrates, vegetation and microbial genomes of each wetland. The suite of wetlands surveyed encompassed a broad range of ages (two years to > 40 years), hydroperiods (ranging from ephemeral to permanent), salinities (specific conductance ranging from < 500 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, reflecting the inherent differences in characteristics between intact-but-disturbed landscapes and landscapes reclaimed following surface mining. In particular, the most saline wetlands were more prevalent in areas considered reclaimed than in reference areas. Similarly, a greater proportion of wetlands in areas considered reclaimed had shorter hydroperiods than were found in reference areas.

Preliminary summaries of biological trends broadly corroborate interpretations of archival data collected over a 15-year period, beginning in late 1990s. Plant community richness and biomass of dominant species appear to increase modestly with age, whereas community composition shows no clear pattern of change. Soil and water salinity have 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 of mature vegetation 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 (specific conductance > 2,200 uS/cm) but were abundant in older, less saline wetlands. Nevertheless, embryos of a lab culture of a locally-occurring snail species developed and hatched in water collected from one of the most saline young wetlands sampled.

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, and this is reflected in the intra-annual variation of area of wetlands' surface water. 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 transformed areas, similar to the hydrodynamics observed in Alberta's prairie pothole region (Wendlandt 2023). The specific relationships between these indirect measures of wetland dynamics are being determined by comparison with the remote-sensed estimates of variation in wetland area (describe above).

Surveys of vegetation provided estimates of community composition, biomass, and relative cover of the wetland vegetation zones. In all, over 160 species were identified across the 117 wetlands. Processing and enumeration of benthic invertebrates and zooplankton are still in progress.

Phase 3 – *Data Compilation, Analysis and Synthesis:* State-and-Transition modelling to synthesize and interpret wetland development and persistence.

Work on the synthesis phase of BWRAP accelerated in Fall 2023 and winter 2024 with creation of a state-and-transition model designed to document time-trend changes in features of wetlands of transformed landscapes (Bilski et al., 2024). The model built and expanded on a proof-of-concept wetland state-and-transition model design proposed by Frid and Rooney (2015). This part of the project was developed as a course presented to a Community of Practice composed of interested key stakeholders and wetland specialists. The course was developed utilizing the ST-Sim package (ApexRMS 2015, Daniel et al. 2016), within the SyncroSim platform, and presented the key concepts involved in creating an STSM, interpreting model results, adding variability and uncertainty into the models, and demonstrating how to expand the model to incorporate data as it becomes available. This initial formulation of the model explored the occurrence and properties of opportunistic and designed wetlands at the Suncor Base Mine and Syncrude Mildred Lake areas. The model was designed to accommodate and assess three strata – wetland type (primary stratum; anticipated to change over time), landform (secondary stratum; unchanging) and soil prescription (tertiary stratum; unchanging). Wetland classes and subclasses were also defined by criteria of permanence and salinity, following the characteristic attributes outlined according to the Alberta Wetland Classification System (ESRD 2015).

The following tasks/objectives are in progress or planned for 2025:

- Populating the database with archival and BWRAP-collected field data. The three field seasons of invertebrate and vegetation data, and one field season of avian data are being quality-checked before uploading to the database. Archival data are also being quality-checked to meet contemporary metadata standards.
- 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.
- Populating the state-and-transition models of wetland development for each biological attribute.
- Convening synthesis review workshops to corroborate the putative biological classes and their relationship to environmental gradients.

LESSONS LEARNED

With the completion of fieldwork, this program is in the data summary and synthesis stage. Investigations have 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 transformed landscapes. These same environmental stressors also exert major effects on wetland plant community composition. Features of surficial geology and soil placement characteristics are important indirect determinants of hydroperiod and water quality features, suggesting the potential for designing closure landscapes especially conducive to the formation of opportunistic, permanent minerotrophic 'biologically successful' wetlands.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

Patzer, M. 2024. Predictive modeling of time trends in water quantity in opportunistic and constructed wetlands using weather data. M.Sc. Thesis, Royal Roads University.

Jackson, H. 2024. The influence of soil nutrients and wetland age on riparian plant community composition in natural and reclaimed landscapes within the Athabasca Oil Sands region. Hon. B.Sc. Thesis, University of Calgary

van't Riet, L. 2024. Ramshorn snail (*Planorbella pilsbryi*) embryos as biological indicators of wetland environmental pollution in the Alberta Oil Sands region near Fort McMurray. Hon. B.Sc. Thesis, University of Calgary.

Yu, A. 2024. Gastropods as an indicator species: Assessing the diversity and abundance of freshwater snails in boreal landscapes reclaimed post oil sands mining. Hon. B.Sc. Thesis, University of Calgary.

Conference Presentations/Posters

Ciborowski, J.J.H., M. Wendlandt, A. Mombourquette, E. Gillis, H. Porter, M. Rahman, S. Leng, E. Bishko, H. Jackson, M. Fong, M. McLeod, A. Ogilvey, G. Rodrigues, S. Trimming, V. Dvorak, A. Yu, J. Birks, C. Weisener, J. Tomal, I. Vander Meulen, J. Headley. 2024. Defining and quantifying stress/disturbance gradients for young wetlands forming in reclaimed oil sands landscapes. Invited Presentation, World Wetlands Day Research Symposium, Mount Royal University, Calgary, AB, Feb 2, 2024.

Ciborowski, J.J.H. 2024. Formalizing the Reclamation Assessment Approach (RAA) to evaluate wetland condition in reclaimed oil sands watersheds. Guest presentation to Univ. Calgary Environmental Science Capstone Course students, University of Calgary, Calgary, AB, March 22, 2024.

Ciborowski, J.J.H. 2024. Assessing wetland reclamation success in the Alberta Oil Sands Region. Invited presentation, Alberta Innovates 2024 Water Innovation Forum, May 27-28, 2024, Calgary, AB

Ciborowski, J.J.H., M. Wendlandt, A. Mombourquette, E. Gillis, H. Porter, M.M. Rahman, J. Birks, I. Vander Meulen, J. Headley. 2024. Defining and quantifying stress/disturbance gradients for young wetlands forming in reclaimed oil sands landscapes. Society for Freshwater Science Annual Meeting, 4-8 June 2024, Philadelphia, PA, USA.

Gillis, E., A, Mombourquette, M. Villegas Torres, H. Porter, M. Corcoran, H. Jackson P.F. Dunfield, J.J.H. Ciborowski. 2024. Plant community development and the role of root-associated fungi in young wetlands on reclaimed and reference landscapes of the Athabasca Oil Sands Region. Society for Freshwater Science Annual Meeting, 4-8 June 2024, Philadelphia, PA, USA.

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Reports & Other Publications

Bilski, D., L. Frid., G. Donald and J. J. H. Ciborowski. 2024. State-and-transition simulation models for wetland reclamation. Prepared for the Boreal Wetland Reclamation Assessment Program, University of Calgary by ApexRMS. 13 p. Distributed June 6, 2024.

Zeng, R. 2024. Geospatial Portal User Guide. BWRAP and BERA Project. Version 1.0. Prepared for Boreal Wetland Reclamation Assessment Program (BWRAP) and Boreal Ecosystem Recovery and Assessment project (BERA), University of Calgary, Calgary, AB. 15 p. Available at https://wetland.ucalgary.ca

Zeng, R. 2024. BERA/BWRAP Geospatial Portal Development. Prepared for Boreal Wetland Reclamation Assessment Program (BWRAP) and Boreal Ecosystem Recovery and Assessment project (BERA), University of Calgary, Calgary, AB. 31 p.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Calgary

Principal Investigator: Dr. Jan J. H. Ciborowski and Peter F. Dunfield

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)		
Genevieve Rodrigues	University of Calgary	Research Assistant		
Erik Biederstadt	University of Calgary	MSc	2021	2025
Amanda Luzardo	University of Calgary	BSc	2017	2022
Abisola Allison	Mount Royal University	BSc	2018	2022
Nika Tovchyrhechko	University of Calgary	Hon. BSc	2018	2024
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
Michael Wendlandt	University of Calgary	MSc	2020	2023
Steven Blair	University of Calgary	BSc	2015	2020
Elizabeth Gillis	University of Calgary	Hon. BSc (thesis)	2016	2021
Liam Mebesius	University of Calgary	Hon. BSc (thesis)	2016	2021
Emily Moore	University of Calgary	Hon. BSc (thesis)	2016	2021
Manveet Waraich	Mount Royal University	BSc	2018	2022
Matthew Ellis	University of Calgary	BSc	2018	2022
Genevieve Rodrigues	University of Calgary	BSc (thesis)	2019	2023
Maeve Corcoran	University of Calgary	BSc (thesis)	2019	2023
Kyle Filyk	Mount Royal University	BSc	2020	2022
Sean Leng	University of Windsor	BSc	2019	2023
Elizabeth Gillis	University of Calgary	MSc	2021	2025
Hannah Porter	University of Calgary	MSc	2022	2025
Sean Leng	University of Windsor	MSc	2023	2025

Evan Bishko	University of Calgary	MSc	2023	2024
Andy Yu	University of Calgary	BSc (thesis)	2021	2024
Hunter Jackson	University of Calgary	BSc (thesis)	2020	2024
Malcolm McLeod	University of Calgary	BSc	2019	2024
Veronica Dvorak	University of Calgary	BSc (thesis)	2021	2025
Arden Ogilvie	Mount Royal University	BSc	2023	2024
Laura Van't Reit	University of Calgary	BSc (thesis)	2023	2024
Mark Patzer	Royal Roads University	MSc	2022	2024
Matthew King	University of Calgary	BSc	2022	2025
Mathiew Gauthier	Mount Royal University	BSc	2021	2025
Kiarra Brill	University of Calgary	BSc	2020	2024
Annika Burgel	University of Calgary	BSc	2023	2026
Victoria Tolmacheva		BSc	2022	2026

* 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	Cumulative ecological impacts of human activities on biodiversity
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
John Gibson*	InnoTech, Alberta, Calgary	Isotope techniques to quantify water
Scott Ketcheson*	Athabasca University	Groundwater disruption effects on wetland hydrology
Ian Vander Meulen*	National Hydrology Research Centre (NHRC) Environment and Climate Change Canada	Analytical Chemistry of acid extractable organic compounds
Douglas Meunch*	University of Calgary	Trends in degradation of acid extractable organic compounds in constructed wetlands

Quantifying the Effect of In Situ Oil Sands Development on Wetland Function

COSIA Project Number: LJ0349

In Situ

Research Provider: Athabasca University, University of Waterloo, University of Calgary

Industry Champion: Imperial

Status: Year 2 of 5

PROJECT SUMMARY

Much of the bitumen in Alberta Oil Sands (AOS) is too deep for surface mining and must be extracted using in situ techniques, the latter involves construction of well pads interconnected by roads and pipelines distributed across the landscape. Although the area of any given installation is relatively small (e.g., well pads are generally one to four hectares (ha) in size), knowing the effects on wetland ecosystems beyond the direct footprint of the infrastructure, will contribute to a successful site closure. On average, 30% of Canada's boreal region is covered by peatland (Natural Regions Committee, 2006), with areas in the AOS having between 50% to 100% peatland cover, accounting for the majority of wetlands in the region (Vitt et al., 2000). Therefore, in situ oil sands developments can affect large wetland areas directly, and indirectly through changes in local hydrological and chemical conditions. The overall goal of the research program is to quantify the impact of in situ oil sands infrastructure on wetland ecohydrological and carbon accumulation function and evaluate activities that can help mitigate this impact.

The **main objectives** of this research project are to:

1. Determine the effect of in situ infrastructure (roads, well pads) on wetland hydrology, and how this varies among wetland types.
2. Relate the observed hydrological changes to wetland carbon (C) dynamics and plant community composition, productivity and peat accumulation rates.
3. Evaluate the timing of the ecohydrological response to infrastructure construction.
4. Determine best management practices for stockpiled peat and the effect of different stockpiling practices on greenhouse gas (GHG) emissions.

To address these objectives, project researchers have instrumented a peatland complex bisected by a mineral access road at the primary research site (Imperial's Aspen Lease). These ongoing, intensive measurements from this site are complemented by eight additional 'synoptic' wetland study sites impacted by infrastructure to capture the range in variation of ecohydrological response. These additional sites (four established in 2024; four more planned for 2025) allow for the inclusion of a range of wetland types, across a larger geographical area (i.e., within the Athabasca Oil Sands region but beyond the Aspen Lease) to encompass a broader range of ecosites, hydrogeological settings and responses. The synoptic sites have been instrumented with logging measurements and are visited less frequently than the primary site.

The general approaches used to address the project objectives are:

1. Infrastructure and wetland hydrology. This project studies the interactions of the components of the water budget (including evapotranspiration using eddy covariance; EC), in two main wetland types bisected by the road at the primary site (wooded coniferous fen and shrubby fen). Parallel measurements on the up and down-gradient sides of the road will be used to evaluate the magnitude and distribution of hydrological changes.

2. Wetland plant communities and carbon. This involves evaluating shifts in plant community composition, productivity and carbon exchange at the Aspen Lease site. As described in (**1**) the EC towers measure CO_2 exchange at ecosystem scale, and fluxes on both sides of the road will be compared and supplemented by chamber measurements. At the synoptic wetland sites, vegetation surveys and allometric equations will be used to determine biomass and productivity following road construction among wetland types.

3. Timing of wetland response. Researchers will use geospatial datasets (e.g., LiDAR, drone imaging) to evaluate ecosystem structural changes and evaluate its timing along a space-for-time continuum.

4. Stockpiled peat. Stockpile management and planting practice treatments are underway, alongside complementary chamber-based carbon flux measurements to evaluate the effect of environmental conditions (e.g., soil moisture, temperature and plant cover) on stockpiled peat decomposition rates.

The **anticipated key outcomes** of this research project will inform industry development decisions and reclamation practices to help minimize and mitigate impacts to wetlands (avoid sensitive wetland types) and contribute to successful land closure. This includes advancing geospatial capacity to evaluate impacts during in situ oil sands operations and adjusting infrastructure designs based on ecosystem monitoring. Data collection for this project is taking place at Imperial's in-situ sites in Northern Alberta.

PROGRESS AND ACHIEVEMENTS

Comprehensive fieldwork for this project began in 2023. During the summer of both 2023 and 2024, field-based measurements included water table level (see below) and chamber-based carbon flux measurements in two wooded coniferous fen wetlands and two shrubby fen wetlands, on both the up- and down-gradient sides of the main access road at the Aspen Lease site. Chamber measurements were recorded only in the shrubby fen wetland sites.

Water table measurements for this project began via logging pressure transducers. These transducers were installed in August 2021 along transects of wells oriented perpendicular to the main access road at the Aspen Lease area, across two wooded coniferous fen wetlands and two shrubby fen wetlands. These measurements continued throughout the summer months of 2024, and included additional measurements from piezometers (summer 2023 and 2024) to calculate the vertical hydraulic gradient.

Two five-metre-tall eddy covariance towers were installed to quantify water and carbon fluxes on the up- and down-gradient sides of the main access road at the primary site (August 2024).

Vegetation surveys were conducted at locations both near to and far from the road to assess shifts in wetland plant community composition.

Soil samples were collected to assess the impact of roads on wetland soil hydrophysical properties and their relationship to hydrologic function.

Geospatial datasets have been collected to analyze the effects of the timing of the ecohydrologic response at the main site (Aspen Lease) and surrounding 'synoptic' sites, expanding the spatial extent of the research.

LESSONS LEARNED

This research project is still in the early stages. Accordingly, the lessons learned based on research outcomes are limited. However, preliminary water table data show that the water table is closest to the surface of the wetland in the near-road area on the up-gradient side of the road. The extent of water impoundment caused by the road is limited to less than approximately 150 metres at this site.

The observation of water impoundment and its possible impacts was the impetus for investigating potential changes to the wetland soil hydrophysical properties in 2024. Project researchers are also working to relate these hydrological observations to potential ecosystem responses via vegetation community composition and carbon dynamics.

LITERATURE CITED

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Vitt D. H., Halsey L. A., Bauer I. E. and Campbell C. 2000. Spatial and temporal trends in carbon storage of peatlands of continental western Canada through the Holocene. Canadian Journal of Earth Sciences, 37(5): 683-693.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Weiland L., Ketcheson S. J. and Tuffner J. (2024). Assessing the Impact of In Situ Infrastructure on Wetland Connectivity. AU Research Forum, Athabasca, Canada. 28-April-2024.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Scott Ketcheson

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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 4 of 15

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 Surmont Boreal Forest Relamation).

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 and white spruce 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 field outplanting (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 Surmont Boreal Forest Relamation), 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 evaluated two common deciduous tree species (birch [*Betula papyrifera*] or poplar [*Populus balsamifera*]), each representing different propagation methods (seed or hardwood cutting, respectively), in combination with one of three native forbs (aster [*Eurybia conspicua*], dogbane [*Apocynum androesaefolium*], or goldenrod [*Solidago canadensis*]) that vary in their growth morphology as well as their rates of spread and egress. These multi-species plugs were established in three contrasting condition types to evaluate the utility of these stock types across a range of topsoil capping depths. In this study, researchers aimed to answer the following questions:

1. For each tree-forb combination, which stock types favoured comparable survival and growth of both species, and is there any evidence to suggest that hitchhiking native forbs with trees created a growth disadvantage when compared to singly grown plants?
2. What are the impacts of topsoil capping depth on the:
   a. Survival and growth of the planted woody species?
   b. Survival and growth of the planted forb species?
   c. Does topsoil capping depth affect recommendations as described in (1) above?

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., enables the use of 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

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

This update will focus on the findings relating to Trial 3 as the final data and analyses for that trial are now complete. Key elements with respect to the study design employed in Trial 3:

- Seedlings for Trial 3 were produced in 2020 at the Center for Boreal Research greenhouse, overwintered in frozen cold storage, and planted in early June 2021.
- Two deciduous species were tested with contrasting starting conditions: birch was established from seed, while poplar was established from unrooted stem cuttings (one-year-old stems).
- Each tree species was co-grown (hitchhiked) with one of three native forbs: showy aster, creeping dogbane or goldenrod — each of these forbs was sown from seed into the same cavity as the tree species. Hitchhiked stock types were grown in 615A styroblocks (340 mL cavity size, BeaverPlastics™). In parallel, singly grown stock of all five species were grown in 512A styroblocks (220 mL cavity size, BeaverPlastics™).
- The key stock type variable for each hitchhiking pair was the timing of forb seed introduction. For forbs sown with paper birch, the forb seeds were sown at the same time (zero weeks), or two or four weeks **AFTER** sowing the birch seeds. This approach builds on earlier hitchhiking trial work, which indicated that the forb species would grow quickly, potentially outcompeting the birch if it was sown too early. For the forbs sown with poplar, the forbs were sown at the same time (zero weeks), or two or four weeks **PRIOR** to establishing the cuttings. This differing approach was used because the poplar cutting would create intensive shading and compete faster than seed-based growth, this necessitated that the forbs were sown earlier to ensure they could also grow into viable plants.
- Plots with all stock type combinations (12 plants per stock type) were established within the topsoil depth study experiment in four block replicates in the no-topsoil, shallow, and standard topsoil depth treatments (Figure 1). Birch stock types were also planted in the standard + herbicide topsoil depth treatment, though results from this treatment are not presented in this summary.

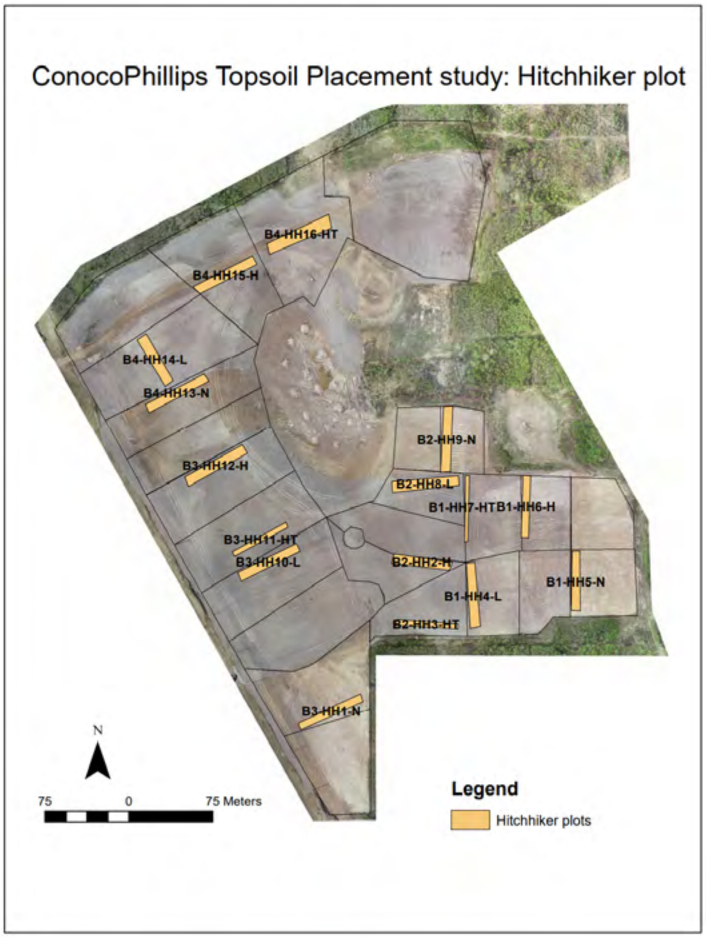


Figure 1: Overview of treatment plot layout showing the topsoil placement and pre-emergent herbicide treatments with hitchhiker plots nested inside main trial replicate plots. Treatment notations are as follows: B1-B4 refer to replicate blocks, HH1-HH16 refer to unique plot IDs associated with replicate plots, H/L/C refer to the standard (H), shallow (L) or no-topsoil treatment (N) and T/C refers to treatment with pre-emergent herbicide (T) or untreated (C).

Growth and survival findings were based on the Year 3 assessment completed in August 2023. Two types of analyses were completed for each tree species (Table 1), the first compares survival and growth amongst hitchhiked stock types while the second compares growth and survival of one hitchhiked stock type (from each forb pairing where the stock type chosen was similar to the single grown stock type at the time of lifting, Table 2) to singly grown trees. This approach allows us to answer questions related to growing the 'best' hitchhiker stock types as well as in addressing questions on whether hitchhiked stock types create disadvantages for either species upon out planting. The findings are presented with reference to the original study questions.

Table 1: Formulae used to run the generalized linear mixed-effects models of the effect of topsoil depth treatment, sow date, forb species, and the interactions between these effects on the survival and growth of paper birch, balsam poplar, and the hitchhiked native forbs after three growing seasons.

Response variable	Fixed effects	Random effects	Distribution	Link function
Forb survival with birch	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Binomial	Logit
Forb survival with poplar	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Binomial	Logit
Forb cover with birch	Soil x Sow date x Forb	(1 | Block/Plot.ID/Line)	Log normal	Log
Forb cover with poplar	Soil x Sow date x Forb	(1 | Block/Plot.ID/Line)	Log normal	Log
Comparing hitchhiked stock types				
Birch survival with forbs	Soil x Sow date + Sow date x Forb + Soil x Forb	(1 | Block/Plot.ID)	Binomial	Logit
Birch height	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Log normal	Log
Birch height increment	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Log normal	Log
Poplar survival with forbs	Soil x Sow date x Forb	(1 | Block/Plot.ID)	Binomial	Logit
Poplar height	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Gaussian	Log
Poplar height increment	Soil x Forb x Sow date	(1 | Block/Plot.ID/Line)	Log normal	Log
Comparing singly grown seedlings and the most similar hitchhiked stock type				
Birch height	Soil x Stock type	(1 | Block/Plot.ID/Line)	Gaussian	Log
Birch height increment	Soil x Stock type	(1 | Block/Plot.ID/Line)	Log normal	Log
Poplar height	Soil x Stock type	(1 | Block/Plot.ID/Line)	Gaussian	Log
Poplar height increment	Soil x Stock type	(1 | Block/Plot.ID/Line)	Log normal	Log

Table 2: Sow dates that were most similar to singly grown species of paper birch and balsam poplar for height, root collar diameter (RCD), shoot mass, and root mass at lifting. Forbs were sown concurrently (0 week), or two and four weeks after the paper birch seed was planted, or sown concurrently (0 week) or two (2 week) and four weeks (4 week) before the balsam poplar cutting was planted. These stock types were chosen for paired field comparisons to evaluate relative growth / survival outcomes of similarly sized hitchhiked trees with singly grown tree seedlings.

Tree Species	Forb Species	Most similar hitchhiked type to singly grown seedling	Height (cm)	RCD (mm)	Shoot Mass (g)	Root Mass (g)
Birch	Aster	2 week	2 week	2 week	2 week	2 week
	Dogbane	2 week	2 week	0 week	2 week	2 week
	Goldenrod	2 week	2 week	2 week	2 week	2 week
Poplar	Aster	0 week	0 week	0 week	0 week	2 week
	Dogbane	2 week	2 week	4 week	0 week = 2 week	0 week = 2 week
	Goldenrod	0 week	0 week	0 week = 2 week	0 week	0 week

Question 1: For each tree-forb combination, which stock types favour comparable survival and growth of both species, and is there any evidence to suggest that hitchhiking native forbs with trees creates a growth disadvantage when compared to singly grown plants?

Hitchhiking forbs with paper birch:

Showy aster had similar rates of survival across hitchhiked (all sow dates) and singly grown plants (Figure 2). However, there was a clear trade-off for dogbane, as only the zero-week hitchhiked stock type had a similar rate of survival to singly grown seedlings; both the two- and four-week sow dates had progressively lower rates of survival after three years (Figure 2, Table 5). Goldenrod did show a modest decline in survival (approximately 0.80) with the four-week sow date; nevertheless, the survival of this stock type was relatively high (Figure 2). **The differences in survival rates among the forbs hitchhiked with paper birch reinforces the importance of testing hitchhiked stock type combinations prior to scaling up to operational propagation programs.**

While there was no difference in survival for paper birch hitchhiked with aster (Table 3, Figure 2a), there were some subtle trends with respect to soil treatment that influenced the magnitude of the height differences among sow dates after three years. While the four-week sow date birch was taller, on average, compared with the zero- and two-week sow dates, there was no difference in annual height increment which suggests the total height differences may not be long-lasting (Figure 3a,d). Overall, the main differences in height among birch stock types hitchhiked with aster were generally shorter seedlings in the no-topsoil treatment compared with the shallow, and standard treatments (Figure 4). The aster hitchhiked stock type (two-week sow date) showed similar survival (Table 4), total height, and annual height increment to singly grown seedlings (Figure 5a,c), further suggesting that the presence of the aster was not negatively influencing the growth of birch seedlings. **Survival and vegetation cover of aster hitchhiked with birch were similar among stock types and singly grown plants (Figure 2d, Figure 6a). Taken together, these findings indicate that while any of the sow dates tested could be utilized successfully with this species combination, it is recommended that showy aster be sown two or four weeks after sowing paper birch in order to ensure consistent growth of birch seedlings under varying soil conditions.**

When hitchhiked with dogbane, birch seedlings showed similar survival (Figure 2b), total height, and annual height increment across all sow dates (Figure 3b,e). In addition, hitchhiked birch with dogbane grew similarly to singly grown seedlings (Figure 5). Provided dogbane was sown with birch concurrently or up to two weeks following paper birch sowing, there was no statistical difference in dogbane vegetation cover among single grown and hitchhiked stock types after three years (Figure 6b). In contrast, the four-week sow date produced percent cover significantly lower than the singly grown plants, at 10% versus 20% cover on average (Figure 6b); this was also coupled with significantly lower survival at 0.30 compared with 0.60 for the zero-week sow date and 0.70 for singly grown plants (Figure 2e). For this species mixture, it appears that the survival and growth trade-offs were expressed only on the part of dogbane, as birch was very tolerant of the presence of dogbane regardless of sow date. **Based on the field results, hitchhiking birch and dogbane may be best accomplished by sowing dogbane concurrently with birch seeds in order to maximize growth and survival of both species.**

There was a progressive increase in total height and annual height increment with later sow dates when birch was hitchhiked with goldenrod (Figure 3c,f). While there was no statistical difference in survival, there was high variance in survival rate of paper birch in the zero-week sow date (Figure 2c). Unlike the birch hitchhiked types with showy aster and dogbane, there was strong evidence to suggest that the presence of goldenrod created a growth inhibition effect as the hitchhiker stock type (two-week sow date) of similar initial size to singly grown birch was significantly smaller in terms of height and annual height increment after three years (Figure 5a,c). While the four-week sow date created the largest birch seedlings of the three hitchhiked stock types, it was also the stock type with the lowest cover of goldenrod (Figure 6c). Nevertheless, it should be emphasized that the coverage rate of goldenrod for the four-week sow date stock type was still relatively high at 25% on average. This later sow-date also resulted in a slight reduction in survival. Goldenrod did show a modest decline in survival approximately 0.80), which was lower than other hitchhiked stock types, though not significantly different from singly grown plants (Figure 2f). For this species mixture, these results strongly suggest there were growth trade-offs with respect to species development without a clear stock type mixture that balanced both. **Given the strong growth suppression observed in paper birch across all hitchhiked stock types, it is not recommended to hitchhike goldenrod with birch under the conditions tested in this investigation.**

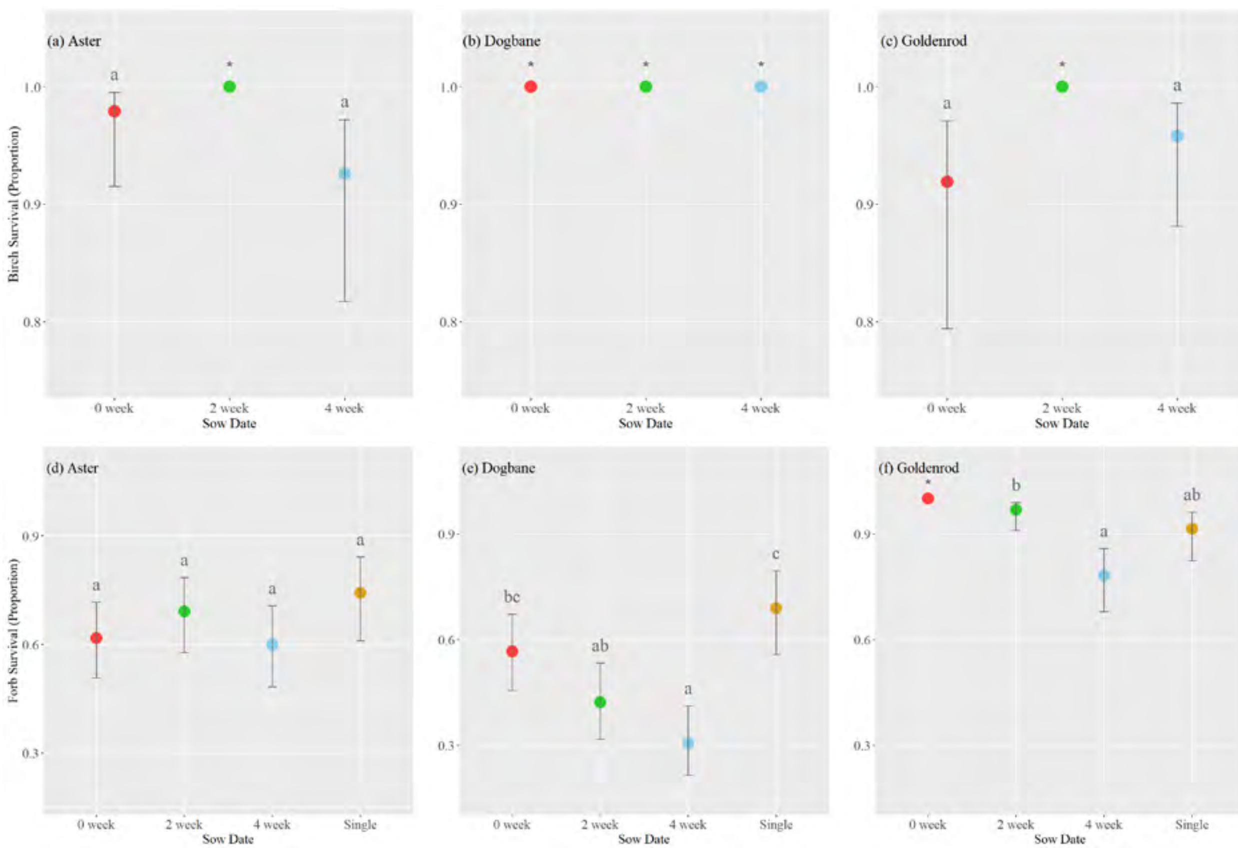


Figure 2: Estimated marginal mean survival of (a-c) paper birch and (d-f) hitchhiked forbs grown with paper birch or grown singly, in year three of the study expressed as a proportion. Treatment means were expressed as a two-way interaction between hitchhiked forb x sow date. Forbs were sown concurrently (0 week) or two and four weeks **after** the paper birch seed was sown. Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments means indicate a significant (α < 0.05) difference in means. Note that * indicates mean values that could not be directly compared with the other treatment levels due to a lack of variability in the data set (all plants survived).

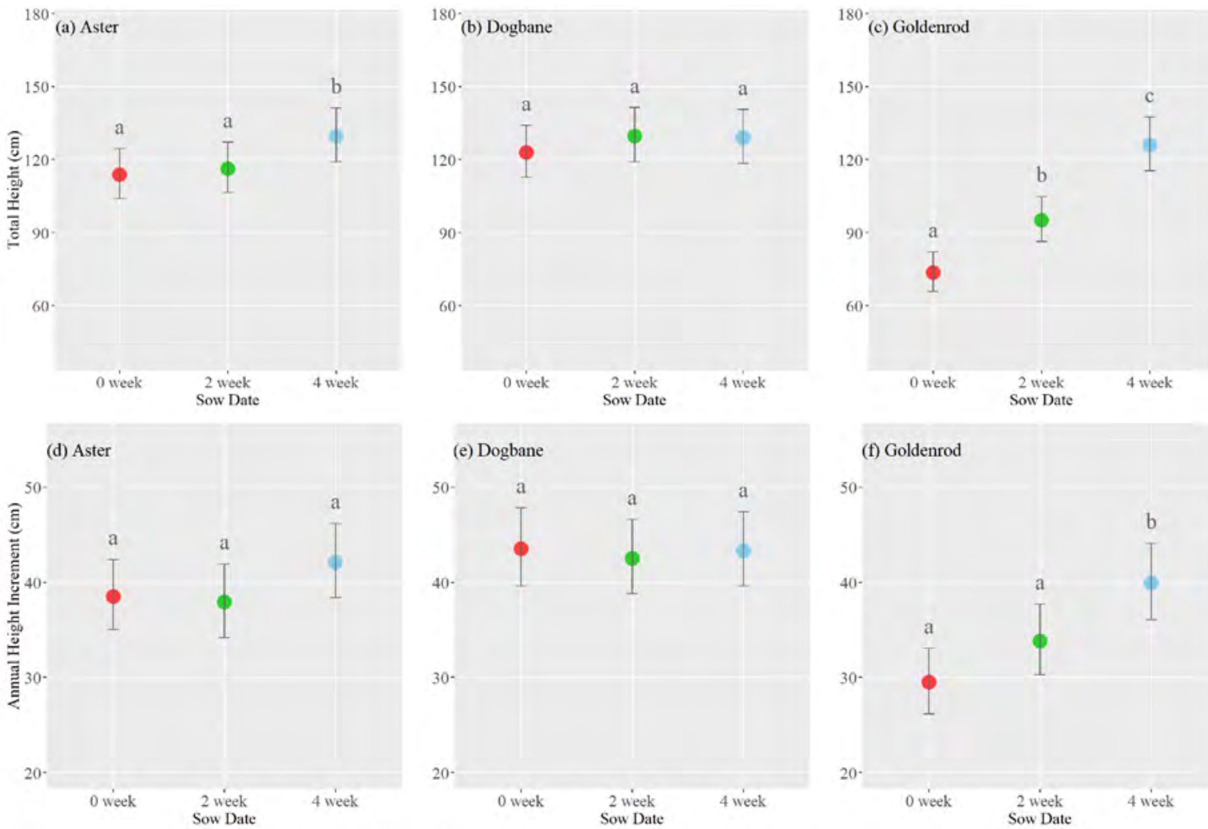


Figure 3: Estimated marginal mean (a-c) total height and (d-f) height increment of paper birch grown with hitchhiked forbs in year three of the study. Treatment means were expressed as two-way interactions between hitchhiked forb x sow date. Forbs were sown concurrently (0 week) or two and four weeks **after** the paper birch seed was planted. Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments indicate a significant (α < 0.05) difference in means.

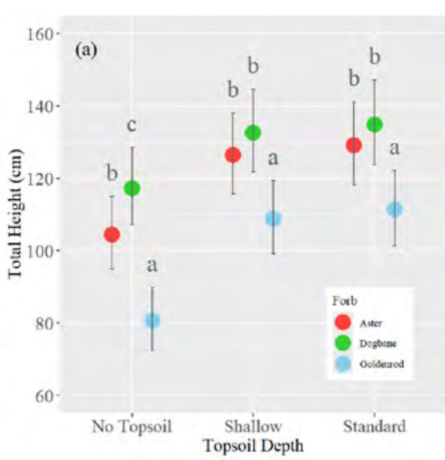


Figure 4: Estimated marginal mean (a) total height of paper birch grown with hitchhiked forbs in year three of the study. Treatment means were expressed as two-way interactions between hitchhiked forb x topsoil depth. Three topsoil treatments were applied, no topsoil (0 cm), shallow topsoil (5 cm), and standard topsoil (15 cm). Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments indicate a significant (α < 0.05) difference in means.

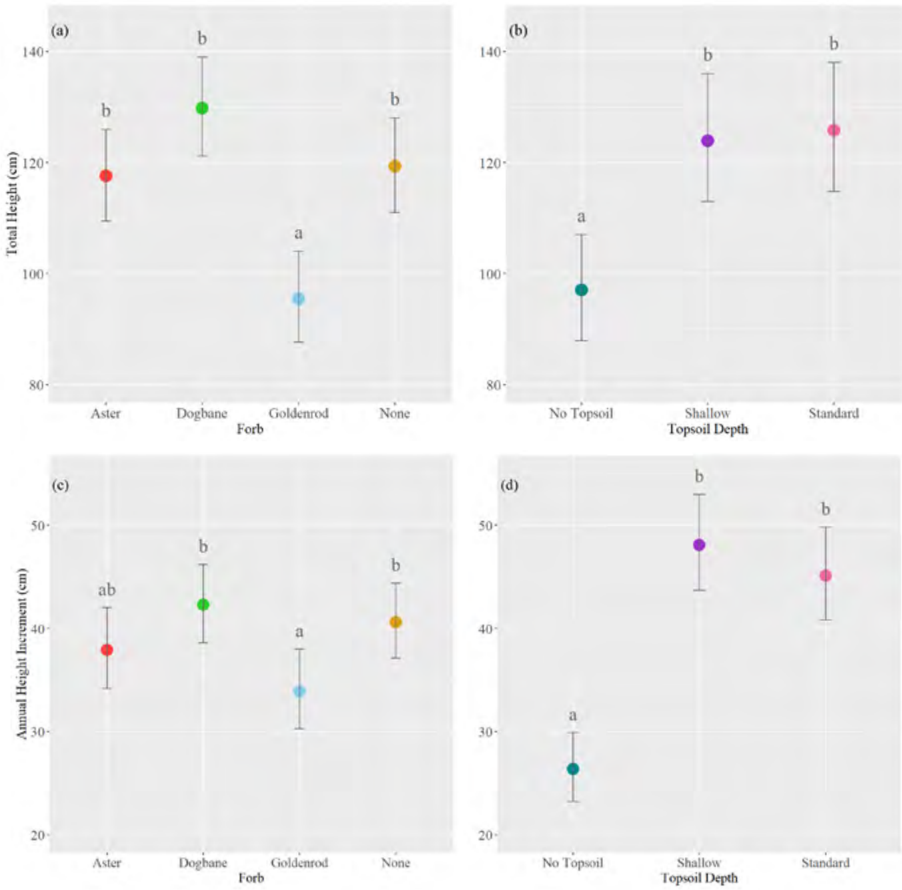


Figure 5: Estimated marginal mean (a-b) total height and (c-d) annual height increment of paper birch grown singly (None) or with the sow date that produced the most similar seedling to the singly grown seedlings for each hitchhiked forb in year three of the study. Treatment means were expressed as the effects of stock type (hitchhiked forb/sow date combination) and topsoil depth treatment on growth. All forbs were sown two weeks **after** the paper birch seed was planted. Three topsoil treatments were applied, no topsoil (0 cm), shallow topsoil (5 cm), and standard topsoil (15 cm). Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments indicate a significant ($\alpha < 0.05$) difference in means.

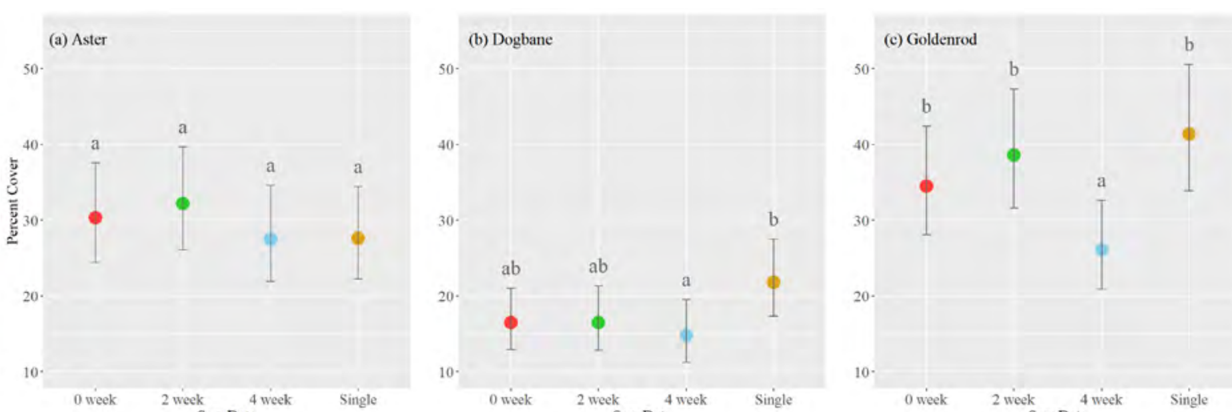


Figure 6. Estimated marginal mean percent cover of hitchhiked native forbs grown with paper birch after three years. Treatments were expressed as the two-way interaction between hitchhiked forb x sow date. Forbs were sown concurrently (0 week) or two and four weeks after the paper birch seed was planted. Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments indicate a significant ($\alpha < 0.05$) difference in means.

Hitchhiking forbs with balsam poplar:

Of the poplar hitchhiker stock types grown with aster, the two-week sow date had the highest average survival at 0.85 (Figure 7a) and notably, there was no observed mortality in singly grown poplars (Table 4). Survival of aster was similar (approximately 0.60) among the two- and four-week sow dates and singly grown stock type with the only reduction observed in the zero-week sow date at 0.35 (Figure 7d). For poplar, there were no significant differences in total height or annual height increment between sow dates of the hitchhiker stock types after three growing seasons (Figure 8a,e). In the comparison of poplar grown with and without a hitchhiked aster (zero-week sow date), the hitchhiked poplar grown with aster showed similar height to singly grown poplar, with the exception of those plants grown in the shallow topsoil treatment, which were significantly shorter (Figure 9a). Annual height increment was also similar between the aster-hitchhiked and singly grown poplar stock type after three years (Figure 9b). Showy aster seedlings sown four-weeks prior to sowing poplar cuttings did show an improvement in vegetation cover at 35% relative to the other hitchhiker stock types (approximately 25%) (Figure 10a). Despite this difference amongst hitchhiker types, both the zero- and two-week sow dates were similar to singly grown seedlings in terms of plant cover averaging 25% to 30% among these treatments (Figure 10a). Together **these results suggest that sowing showy aster seeds two weeks prior to sowing poplar cuttings into the same nursery container is a suitable approach to producing a viable hitchhiker stock type of this species mixture.**

When hitchhiked with dogbane, poplar had the highest rate of survival with the concurrent planting (zero-week sow date) and declined progressively with each of the earlier sow dates where the dogbane was sowed first (Figure 7b). Dogbane sown with poplar two or four weeks prior to sowing poplar showed similar rates of survival to singly grown plants (approximately 0.70); conversely, it was only for the concurrent sowing date (zero week) where survival was reduced at approximately 0.50 (Figure 7e). After three growing seasons, poplar grown with dogbane was tallest when the forb was planted concurrently and shortest when the forb was sown four weeks prior (Figure 8b). Despite differences in total height, annual height increment was similar amongst all dogbane-hitchhiked poplar sow dates (Figure 8e). Given the same starting size, poplar hitchhiked with dogbane (two-week sow date) was comparable to the singly grown poplar regardless of topsoil capping depth (Figure 9a,b). Concurrent sowing of dogbane resulted in significantly lower vegetation cover (approximately 15%) compared with sowing prior to establishing the poplar cuttings as well as singly grown plants, all of which had cover values of approximately 20%, on average (Figure 10b). **Similar to the recommendation made with aster and poplar, it appears that sowing dogbane seeds two weeks prior to establishing the poplar cutting will lead to reasonable growth and survival outcomes for both species**.

For hitchhiked stock types where poplar was grown with goldenrod, poplar survival, total height, and annual height increment were the highest when goldenrod was planted at the same time as the poplar cutting (Figure 7c, 8c, 8f). Even though the zero-week hitchhiked stock type of poplar was similar in initial characteristics to singly grown poplar, by the end of the third growing season, the hitchhiked stock type was shorter (Figure 9a) and growing at a somewhat slower rate than the singly grown plants (Figure 9b). Interestingly, goldenrod survival and percent cover were similar amongst sow dates of hitchhiked stock types or the singly grown stock type (Figure 7f, 10c). **Similar to the result observed in paper birch and goldenrod, these results suggest that goldenrod is a highly competitive species that can negatively influence growth rates of its hitchhiked partner, even three years post-planting. From this viewpoint, this particular species mix may not be suitable for hitchhiking, particularly if tree development is a higher priority goal of the reclamation effort.**

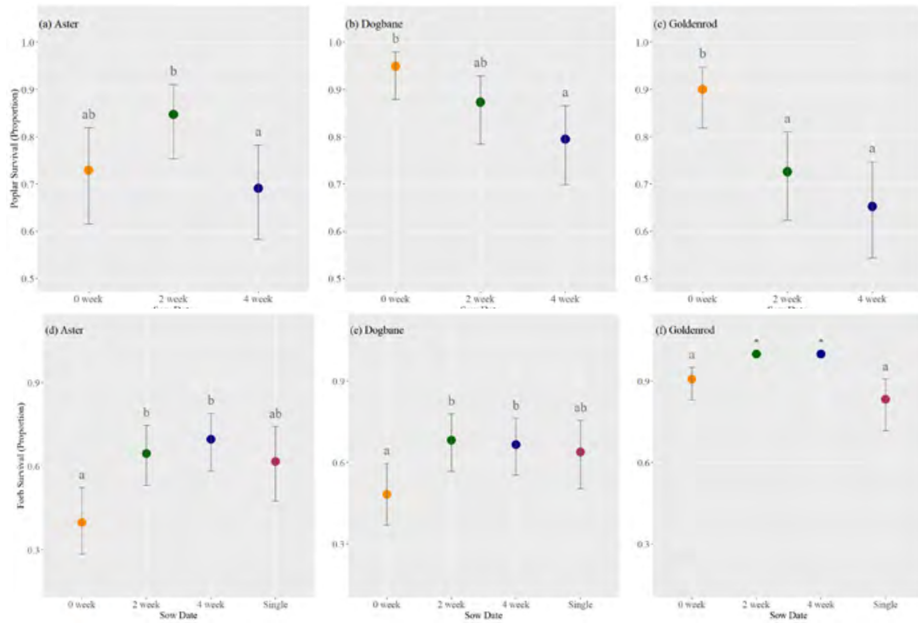


Figure 7: Estimated marginal mean survival of (a-c) balsam poplar and (d-f) hitchhiked forbs grown with balsam poplar or grown singly, in year three of the study expressed as a proportion. Treatment means were expressed as a two-way interaction between hitchhiked forb x sow date. Error bars represent the 95% confidence interval (n=4). Differing letters between treatments means indicate a significant (α < 0.05) difference in means. Note that * indicates mean values that could not be directly compared with the other treatment levels due to a lack of variability in the data set (all plants survived)

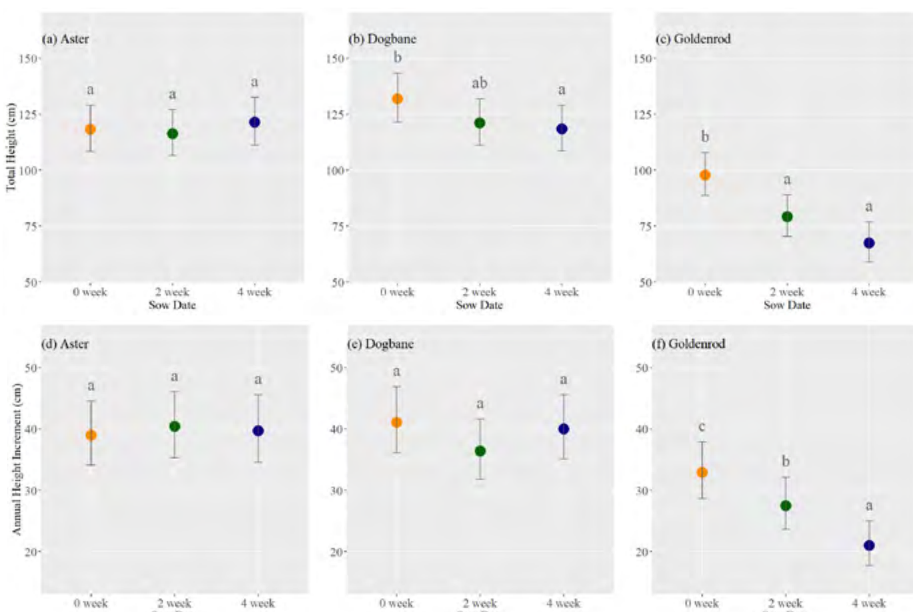


Figure 8: Estimated marginal mean total height and height increment of balsam poplar grown with hitchhiked forbs in year three of the study. Treatment means were expressed as two-way interactions between hitchhiked forb X sow date. Forbs were sown concurrently (0 week) or two and four weeks **before** the balsam poplar cutting was planted. Error bars represent the 95% confidence interval (n =4). Differing letters between treatments indicate a significant (α < 0.05) difference in means.

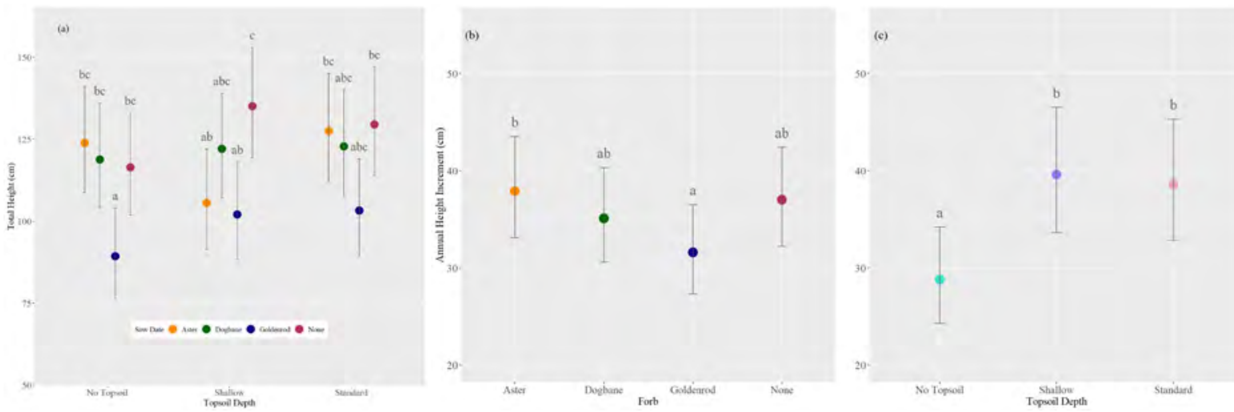


Figure 9: Estimated marginal mean (a) total height and (c-d) annual height increment of balsam poplar grown singly (None) or with the sow date that produced the most similar seedling to the singly grown seedlings for each hitchhiked forb in year three of the study. Treatment means were expressed as two-way interaction between stock type x topsoil depth treatment, and the effects of (b) stock type (hitchhiked forb/sow date combination) and (c) topsoil depth treatment on growth. Goldenrod, and aster were sown concurrently, and dogbane was sown two weeks **before** the balsam poplar cutting was planted. Three topsoil treatments were applied, no topsoil (0 cm), shallow topsoil (5 cm), and standard topsoil (15 cm). Error bars represent the 95% confidence interval (n = 4). Differing letters between treatments indicate a significant (α < 0.05) difference in means.

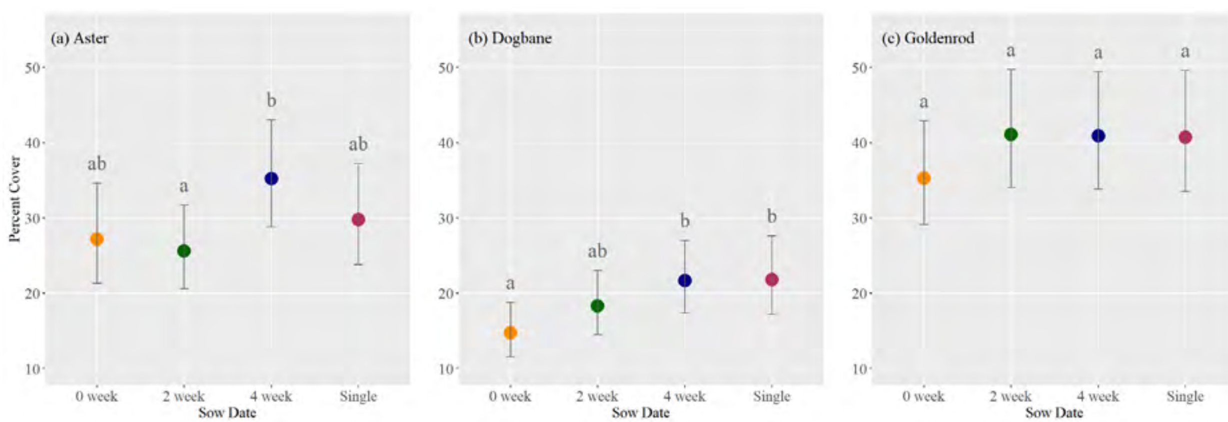


Figure 10: Estimated marginal mean percent cover of hitchhiked native forbs grown with balsam poplar after three years. Treatments were expressed as the two-way interaction between hitchhiked forb x sow date. Forbs were sown concurrently (0 week) or two and four weeks **before** the balsam poplar cutting was planted. Error bars represent the standard error (n = 4). Differing letters between treatments indicate a significant (α < 0.05) difference in means.

Question 2a: What are the impacts of topsoil capping depth on the survival and growth of the planted woody species?

This question will be answered by focusing on the results of birch and poplar single stock versus hitchhiker stock comparisons (Figure 5, 9). The topsoil capping depth did not have a significant impact on the survival of birch or poplar (Tables 3, 6). For paper birch, total height and annual height increment in Year 3 showed substantial gains in the presence of topsoil (shallow or standard treatments) relative to no topsoil placement, with a 20% increase in total height (Figure 5b), and nearly double the height increment (Figure 5d). Similar to birch, annual height increment of poplar was substantially higher, on average, in shallow and standard topsoil capping depth treatments compared with no topsoil (Figure 9c). This was an interesting finding as project researchers did not observe a consistent improvement in total height associated with soil treatment within any particular stock type for poplar (Figure 9a).

These findings suggest that the presence of even a small quantity of topsoil (shallow depth treatment) can have positive growth effects on these tree species. However, the similar rates of survival and strong patterns of growth experiment-wide in both species also lends support to the potential suitability of birch and poplar across a wide range of soil conditions.

Question 2b: What are the impacts of topsoil capping depth on the survival and growth of the planted forb species?

The survival of the forbs hitchhiked with either birch or poplar were not significantly affected by the topsoil capping depth in the third year of the study (Table 5). The percent cover of aster, dogbane, and goldenrod hitchhiked with either birch or poplar did not differ significantly between the topsoil depth treatments (Table 5). **The lack of significant differences in the results indicates that topsoil capping depth was not an important driver of early survival and growth for these species.**

Question 2c: Does topsoil capping depth affect recommendations as described in (1) above?

While there were some subtle distinctions in the growth observed for the tree species under different soil treatments, the broader patterns and recommendations remain the same, as generally the tree species responded to the soil treatments in a similar way across single-grown and hitchhiked stock types. Interestingly, there was no indication that the native forbs were strongly influenced by soil treatment as this effect was largely non-significant with respect to survival or vegetation cover development.

Table 3: Summary of generalized linear mixed-effects models of the effect of soil treatment, forb, sow date, and the interactions between them on survival, total height, and annual height increment of paper birch after three growing seasons. Fixed effects in bold are shown graphically (Figures 3, 7 and 8).

Response	Fixed effects	Df	Chi-square Value	p-value
Comparing hitchhiked stock types				
Birch survival	Soil	2	4.54	0.1032
	Sow date	2	2.99	0.2238
	Forb	2	3.13	0.2093
	Soil x Sow date	4	6.72	0.1516
	Forb x Sow date	**4**	**9.22**	**0.0559**
	Soil x Forb	4	0.23	0.9941
Birch height	Soil	2	14.53	0.0007
	Forb	2	89.73	< 0.0001
	Sow date	2	73.08	< 0.0001
	Soil x Forb	**4**	**17.05**	**0.0019**
	Soil x Sow date	**4**	**10.09**	**0.0390**
	Forb x Sow date	4	74.36	< 0.0001
	Soil x Forb x Sow date	8	6.94	0.5427

Birch height increment	Soil	2	74.03	< 0.0001
	Forb	2	42.56	< 0.0001
	Sow date	2	11.30	0.0035
	Soil x Forb	4	2.07	0.7227
	Soil x Sow date	4	3.58	0.4663
	Forb x Sow date	**4**	**16.53**	**0.0024**
	Soil x Forb x Sow date	**8**	**8.15**	**0.4188**
Comparing singly grown seedlings and the most similar hitchhiked stock type				
Birch height	**Soil**	**2**	**15.36**	**0.0005**
	Stock type	**3**	**46.00**	**< 0.0001**
	Soil x Stock type	6	4.37	0.6269
Birch height increment	**Soil**	**2**	**63.14**	**< 0.0001**
	Stock type	**3**	**15.67**	**0.0013**
	Soil x Stock type	6	4.47	0.6140

Table 4: Arithmetic mean survival (expressed as a proportion) of paper birch seedlings grown singly or with the hitchhiker stock type and estimated marginal mean survival and 95% confidence interval (CI) of balsam poplar cuttings grown singly or with the hitchhiker stock type after three growing seasons. Refer to Table 2 for details on the selection process used to choose the hitchhiked seedling. Forbs were sown concurrently (0 week) or two (2 week) and four weeks (4 week) after the paper birch seed was planted or sown concurrently or two and four weeks before the balsam poplar cutting was planted. Differing letters between treatments indicate a significant ($\alpha < 0.05$) difference in means. Modelling birch survival was not possible due to a lack of mortality, therefore only arithmetic means are shown.

Tree Species	Forb Species	Mean Survival	95% CI
Birch	Single	0.98	
	Aster	0.97	
	Dogbane	0.96	
	Goldenrod	0.94	
Poplar	Single	1.00	No variation
	Aster	0.73a	0.61-0.82
	Dogbane	0.87ab	0.78-0.93
	Goldenrod	0.90b	0.82-0.95

Table 5: Summary of general linear mixed effects models of the effect of soil treatment, forb, sow date, and the interactions between them on the survival and percent cover of the hitchhiking forbs after three growing seasons. Fixed effects in bold are shown graphically (Figures 3, 7 and 8).

Response	Fixed effects	Df	Chi-square Value	p-value
Forb survival with birch	Soil	5	10.72	0.0573
	Forb	5	95	<0.0001
	Sow date	5	29.08	<0.0001
	Soil x Forb	6	3.69	0.7181
	Soil x Sow date	8	6.29	0.6151
	Forb x Sow date	**8**	**17.38**	**0.0264**
	Soil x Forb x Sow date	12	13.68	0.3215
Forb percent cover with birch	Soil	2	0.85	0.6533
	Sow date	3	25.09	<0.0001
	Forb	2	165.48	<0.0001
	Soil x Sow Date	6	8.60	0.1971
	Soil x Forb	4	7.77	0.1005
	Forb x Sow date	**6**	**17.82**	**0.0067**
	Soil x Sow date x Forb	12	13.74	0.3173
Forb survival with poplar	Soil	4	2.72	0.6056
	Forb	6	77.72	<0.0001
	Sow date	7	25.94	0.0005
	Soil x Forb	6	3.66	0.7228
	Soil x Sow date	8	11.15	0.1932
	Forb x Sow date	**8**	**12.11**	**0.1464**
	Soil x Forb x Sow date	12	10.45	0.5768
Forb percent cover with poplar	Soil	2	2.24	0.3270
	Sow date	3	17.85	0.0005
	Forb	2	207.54	<0.0001
	Soil x Sow date	6	10.84	0.0936
	Soil x Forb	4	5.83	0.2124
	Forb x Sow date	**6**	**12.49**	**0.0519**
	Soil x Sow date x Forb	12	11.36	0.4980

Table 6: Summary of generalized linear mixed-effects models of the effect of soil treatment, forb, sow date, and the interactions between them on survival, total height, and annual height increment of balsam poplar after three growing seasons. Fixed effects in bold are shown graphically (Figures 3, 7 and 8).

Response	Fixed effects	Df	Chi-square Value	p-value
Comparing hitchhiked stock types				
Poplar survival	Soil	2	4.54	0.1035
	Sow date	2	14.92	0.0006
	Forb	2	13.87	0.0010
	Soil x Sow date	4	2.48	0.6485
	Soil x Forb	4	6.16	0.1879
	Forb x Sow date	**4**	**13.3**	**0.0099**
	Soil x Sow date x Forb	8	14.57	0.0681
Poplar height	Soil	2	1.51	0.4696
	Forb	2	144.56	<0.0001
	Sow date	2	15.60	0.0004
	Soil x Forb	4	4.39	0.3560
	Soil x Sow date	4	2.31	0.6782
	Forb x Sow date	**4**	**21.41**	**0.0003**
	Soil x Forb x Sow date	8	8.21	0.4131
Poplar height increment	**Soil**	**2**	**8.56**	**0.0139**
	Forb	2	86.65	<0.0001
	Sow date	**2**	**7.91**	**0.0192**
	Soil x Forb	4	1.68	0.7948
	Soil x Sow date	4	0.72	0.9490
	Forb x Sow date	**4**	**29.08**	**<0.0001**
	Soil x Forb x Sow date	8	7.40	0.4942
Comparing singly grown seedlings and the most similar hitchhiked stock type				
Poplar survival	Soil	3	0.98	0.8059
	Stock type	**4**	**16.61**	**0.0023**
	Soil x Stock type	6	10.00	0.1249
Poplar height	Soil	2	0.83	0.6588
	Stock type	**3**	**41.77**	**<0.0001**
	Soil x Stock type	**6**	**13.49**	**0.0359**
Poplar height increment	**Soil**	**2**	**10.66**	**0.0048**
	Stock type	**3**	**9.05**	**0.0287**
	Soil x Stock type	6	8.41	0.2093

(a)

(b)

(a)

(d)

(e)

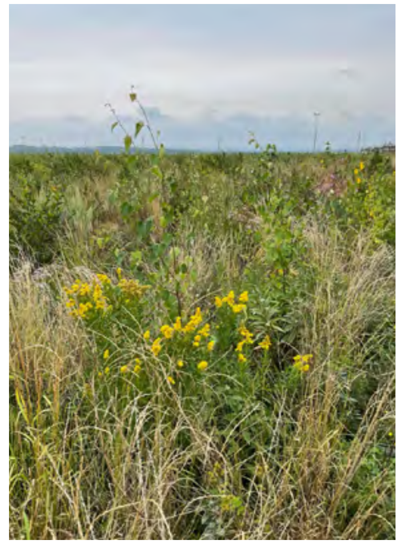
Figure 11: Paper birch hitchhiked with showy aster where the showy aster was sown at **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks after sowing paper birch and singly grown **(d)** paper birch and **(e)** showy aster in August 2023.

Figure 12: Paper birch hitchhiked with creeping dogbane where the creeping dogbane was sown **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks after sowing paper birch and singly grown **(d)** paper birch and **(e)** creeping dogbane in August 2023.

(a)

(b)

(c)



(d)

(e)

Figure 13: Paper birch hitchhiked with goldenrod where the goldenrod was sown at **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks after sowing paper birch and singly grown **(d)** paper birch and **(e)** goldenrod in August 2023.

Figure 14: Balsam poplar hitchhiked with showy aster where the showy aster was sown at **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks before planting a poplar hardwood cutting and singly grown **(d)** balsam poplar and **(e)** showy aster in August 2023.

Figure 15: Balsam poplar hitchhiked with creeping dogbane where the creeping dogbane was sown at **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks before planting a poplar hardwood cutting and singly grown **(d)** balsam poplar and **(e)** creeping dogbane in August 2023.

Figure 16: Balsam poplar hitchhiked with goldenrod, where the goldenrod was sown at **(a)** zero weeks, **(b)** two weeks, or **(c)** four weeks before planting a poplar hardwood cutting and singly grown **(d)** balsam poplar and **(e)** goldenrod in August 2023.

LESSONS LEARNED

The results of this study indicate that sowing the hitchhiked forbs two weeks after the birch seed for aster and dogbane would strike a reasonable balance between tree growth and forb cover. The recommended sow date ultimately depends on the priority of the reclamation project when hitchhiking aster or dogbane with birch. If creating a taller birch seedling is the priority, then using the two-week sow date would be most sensible; however, if creating native forb cover is more critical, then utilizing the zero-week sow date is recommended. When considering the poplar hitchhiker stock types, aster was the most versatile of the forbs evaluated, as all stock types tested resulted in similar growth of poplar and aster. For poplar hitchhiked with dogbane, sowing the dogbane two weeks prior to establishing the unrooted cutting worked best, though sowing the dogbane four weeks earlier may be more appropriate if the desired outcome is to produce greater native plant cover. Considering the high competition potential in goldenrod and observed growth suppression of both birch and poplar, goldenrod is not recommended in a hitchhiking mixture, though it most certainly can provide valuable understory plant cover in a land reclamation context. From this viewpoint, it may be better suited to be planted as a single plug seedling.

The differences in woody plant and native forb survival and growth between topsoil depth treatments were modest; with most differences associated with reductions in height and height increment of paper birch in the no-topsoil treatment. This study suggests there is no measurable growth or survival reduction with placing a minimal quantity of topsoil, given similar survival and growth results between the shallow and standard treatments experiment-wide, across all tree and forb species in the present investigation. The ability to vary topsoil capping depths has implications for optimizing the placement of available topsoil to achieve the best reclamation outcomes across multiple sites, as some sites may have limited available topsoil.

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PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Schoonmaker A.L., Baah-Acheamfour M., Degenhardt D., Albricht R. Topsoil replacement depth impacts on forest reclamation outcomes. Canadian Land Reclamation Conference, March 2024. https://www.nait.ca/getmedia/992f2cf5-a47b-451a-be2a-ed550c08aba6/CLRA-topsoil-depth-study-v3_small.pdf.aspx

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REVEGETATION

Restoration of Native Tree and Shrub Species on Reclaimed Grassy Sites

COSIA Project Number: LJ0291

In Situ

Research Provider: Natural Resources Canada, Canadian Forest Service

Industry Champion: Imperial

Status: Final Cumulative Summary

PROJECT SUMMARY

The objective of the study is to determine the most effective site treatment to establish trees and shrubs on oil sands legacy sites (20 to 30 years old) in the boreal forest that were reclaimed using non-native grass and herbaceous species. These sites were reclaimed to the standards of the day (standards in place at the time the reclamation was completed) and have grass as the only or predominant vegetation growing on the site. The intent is to establish desirable boreal tree and shrub species so that these sites can be placed on trajectory to becoming fully functioning forest ecosystems. Restoration of forest ecosystems on these sites will reduce the area of disturbed forest and forest fragmentation impacting woodland caribou and other wildlife species.

In the spring of 2016, a field study was established to test a range of mechanical and chemical site preparation treatments on the establishment and growth of tree and shrub seedlings. The field study was established at D63 Borrow which is located at Imperial's Cold Lake Operations. The soil at this study area is a compacted sandy clay loam with a 2 cm to 5 cm thick LFH layer. Soil pH ranged between 6.4 and 7.8 and sodium adsorption ratio (SAR) between 0.5 and 1.1. Soil nutrient concentration was approximately 4 ppm of nitrogen, less than 4 ppm of phosphorus and 77 ppm to 110 ppm of potassium. The site was divided into forty, 9 m x 30 m plots in two rows of twenty and oriented north/ south along the short axis of the site. Given the poor nutrient availability, fertilizer tablets (Scotts Agriform™ Fertilizer Tablets, 20-10-5, 21 gram) were placed by each seedling/cutting in half of the plots (randomly selected). Four replications of each treatment by fertilizer combination were randomly assigned to each plot on the site.

The treatments (four site preparation techniques and an untreated control) being tested are:

1. Non-selective herbicide (glyphosate) 1 m x 2 m spot spray followed by planting the next year, installation of a 40 cm tall biodegradable waxed paper tree shelter supported by a wooden stake after planting, and an additional application of a non-selective herbicide (glyphosate) around the tree shelter the following spring after planting;
2. Excavator mounding of soil (mounds 30 cm wide x 25 cm long), followed by planting;
3. Excavator mounding of soil followed by the application of a non-selective herbicide (glyphosate) only over the mound area in the late summer of treatment, followed by herbicide before planting;

4. High-speed soil mixing (160 cm wide x 140 cm long patches) followed by the application of a non-selective herbicide (glyphosate) only over the mixed area in the late summer of treatment, followed by herbicide before planting; and,
5. Untreated control.

Eighteen seedlings of white spruce (*Picea glauca* Moench Voss.) and green alder (*Alnus viridis* [Chaix] DC.), and eighteen 20 cm long balsam poplar cuttings (*Populus balsamifera* L.) were planted in June of 2017 in each of the treatments. Seedlings/cuttings were planted on the top of the mounds or in the middle of the mixed bed. The planting spot was randomly assigned to each seedling. Total shoot height and stem diameter at the soil interface were measured at the end of each growing season, with the last measurement occurring in the fall of 2023 — seven growing seasons after planting. Seedling condition and any damage were also recorded.

In 2018, two additional study sites were developed at Cold Lake Operations (J10, P3). Soil sampling and analysis was not performed at these study areas. Treatments at these sites incorporated learnings from the D63 Borrow. In J10 and P3, the pre-emergent herbicide Torpedo™ (NuFarm Canada) was added to the tank mix with glyphosate in the treatments where herbicides were used to control the alsike clover (*Trifolium hybridum*) seedbank. Given the damage and mortality observed in D63, the fertilizer application protocol was modified. The fertilizer tablets were placed at least 10 cm away from the stem of each seedling or cutting. The experimental design followed that of D63, consisting of four treatments plus a control, each applied with and without fertilizer, and replicated four times across randomly assigned 9 m × 30 m plots. The two sites were prepared in 2018 and planted in spring 2019. Total shoot height and stem diameter at the soil interface were measured at the end of each growing season, with the final measurement taken in fall 2023, five growing seasons after planting. Seedling condition and any observed damage were also recorded.

An ANOVA was conducted on the data by species. Dunnett's test was used to compare treatment results to the controls. Statistical significance was assessed at a probability level of $\alpha = 0.05$ for all tests of means.

PROGRESS AND ACHIEVEMENTS

The final measurements of the D63, J10 and P3 were completed in the early fall of 2023 and the sites were decommissioned (pin markers for each planted seedling removed). The D63 site was monitored for seven years and the J10 and P3 sites were monitored for five years.

At D63, seven growing seasons after planting, survival significantly differed between fertilizer treatments for alder ($P = 0.0386$) and poplar ($P = 0.0012$). Across all site treatments, survival was higher without fertilizer for both species: 74% versus 59% for alder and 68% versus 47% for poplar. This difference was attributed to fertilizer tablets being placed too close to the seedlings, leading to damage and mortality. In contrast, no significant difference in survival was observed between fertilizer treatments for white spruce ($P = 0.6702$).

Treatments were compared to the controls (untreated sites) by species and fertilizer application to assess whether site treatments provided a survival benefit over direct planting into grass (control). For poplar, survival in the herbicide with shelters, with (HSY) and without fertilizer (HSN), and in mounding without fertilizer (MN) was significantly greater compared to the control ($P = 0.0267$, $P = 0.0013$, and $P = 0.0211$, respectively). Survival rates were 40%, 62%, and 47% for the HSY, HSN, and MN treatments, respectively, compared to 6% (CN, no fertilizer) and 0% (CY, with fertilizer) in the control (Figure 1). Interestingly, mounding with herbicide and no fertilizer also had a relatively high survival rate of 38% but it was not significantly different from the control with no fertilizer ($P = 0.0998$).

For alder and white spruce, no significant differences in survival were observed between treatments and the control within the fertilizer and no-fertilizer groups. White spruce survival ranged from 80% to 93% (Figure 1). For alder, survival without fertilizer ranged from 11% to 36% across treatments, compared to 22% in the control (Figure 1). With fertilizer, alder survival ranged from 0% to 24% across treatments, compared to 8% in the control (Figure 1).

The damage and mortality caused by fertilizer tablets being placed too close to plant stems, along with the massive germination and intense competition from alsike clover in D63, necessitated repeating the experiment. The results from J10 and P3 reflect the effects of adding pre-emergent herbicide to the treatments and ensuring fertilizer tablets were placed at least 10 cm away from the plant stems. Data from the two blocks were combined for analysis, as no significant differences in seedling survival were observed between blocks for alder (P = 0.3097), poplar (P = 0.1156), or white spruce (P = 0.6044).

For the J10 and P3 sites combined, there was no significant difference in survival for all treatments combined with or without fertilizer for alder (P = 0.6939), poplar (P = 0.8174) and white spruce (P = 0.4383), five growing seasons after planting. Additionally, the fertilizer by treatment interaction was not significant for alder (P = 0.3942), poplar (P = 0.9672) and white spruce (P = 0.1040) indicating that the addition of fertilizer did not significantly affect survival in any treatment.

For poplar with no fertilizer, survival in the mounding with herbicide (MHN)) and mixing with herbicide (XHN) treatment was significantly greater than the control (P = 0.0004 and P = 0.0118 respectively). Survival after five years was 30% for MHN and 22% for XHN, compared to 2% for the control. This represents a 1,400% improvement for MHN and 1,000% improvement for XHN (Figure 2). For poplar with fertilizer, survival was significantly greater for the, mounding with herbicide (MHY) (P = 0.0009) and mixing with herbicide (XHY) (P = 0.0344) treatments. Survival for MHY and XHY was 29% and 20% respectively, compared to 3% for the control (Figure 2). This represents an improvement of 867% for the MHY treatment and 567% for the XHY treatment, respectively, compared to the control.

For alder, there was no significant difference between treatments and the controls, both without and with fertilizer. Survival in the control was 1% without and 2% with fertilizer, respectively (Figure 2). Survival ranged from 4% to 11% without fertilizer (Figure 2), with the highest survival occurring in the mounding treatment (MN). It was just barely not significant compared to the control with P = 0.0631. Although total survival is low for MN, this is still an improvement of 1,000% compared to the control. With fertilizer, survival ranged between 5% and 10% (Figure 2), with the highest survival occurring in the mounding with herbicide treatment (MHY). This is a 400% improvement in survival when compared to the control. Although the absolute seedlings survival numbers are low, using mechanical site preparation improved seedling survival as a percentage change compared to the control. The low alder survival could be partially due to high levels of rodent damage to the seedlings. Stem girdling was observed during all five years of the study.

For white spruce, survival in the herbicide with shelter treatment was significantly less than the control (P = 0.0053) when no fertilizer was applied (HSN). Survival was 49% for HSN and 74% for the control with no fertilizer (CN) (Figure 2). When fertilizer was used, survival was significantly greater for the mounding (MY) (P = 0.0290) and mounding with herbicides (MHY) (P = 0.0087) treatment when compared to the control (CY). Survival was 88%, 91% and 67% for the MY, MHY and CY treatments, respectively (Figure 2). The percentage increase in survival for MY and MHY compared to CY was 30% and 35%, respectively.

The herbicide treatment was modified in J10 and P3 after observing that alsike clover rapidly dominated the mechanical site treatments in D63 during the planting year. The addition of Torpedo™ pre-emergent herbicide provided effective clover control in J10 and P3 for 1.5 years after application.

In the mounding treatment, the inclusion of pre-emergent herbicide significantly improved poplar survival compared to the control, both with and without fertilizer. Without fertilizer, poplar survival was 30% with herbicide and 11% without herbicide (Figure 2), representing a 172% improvement. With fertilizer, survival was 29% with herbicide and 8% without herbicide (Figure 2), reflecting a 262% improvement. Survival in the control plots was 2% without fertilizer and 3% with fertilizer.

For alder, using herbicides with mounding appears to provide less of a benefit (Figure 2). Without fertilizer, alder survival was 10% with herbicide and 11% without herbicide, representing a 10% decrease in survival with herbicide. With fertilizer, alder survival was 10% with herbicide and 6% without herbicide, reflecting a 67% survival improvement with herbicide. Survival in the control group was 1% without fertilizer and 2% with fertilizer. As noted earlier, this may be a function of damage and mortality caused by rodents.

White spruce benefits less from the use of herbicides compared to the two deciduous species, alder and poplar (Figure 2). Without fertilizer, white spruce survival was 89% with herbicide (MHN) and 91% without herbicide (MN), showing a very similar outcome. With fertilizer, white spruce survival was 91% with herbicide (MHY) and 88% without herbicide (MY). Again, a very similar outcome. Survival in the control group was 74% without fertilizer and 67% with fertilizer.

LESSONS LEARNED

The use of fertilizer tabs did not improve survival of alder and poplar. In D63 project researchers learned that if the fertilizer tabs are placed too close to the seedling, they cause damage to the plants and increase mortality. Care must be taken with the placement of fertilizer tablets like those used in this study. Tablets must be placed at least 10 cm away from the stem. Alternative spot fertilizer methods, such as tea bags, may prove more effective and be more forgiving, though they were not tested in this study.

Mechanical site preparation treatments that disturb the soil, such as mounding, improved alder and poplar survival when compared to planting directly into the grass (control). Mechanical treatments combined with a tank mix of pre- and post-emergent herbicide to control both established and seedbank weed species are essential for ensuring higher survival rates of alder and poplar. A pre-emergent herbicide is especially important if clover was included as part of the initial reclamation revegetation treatment. The tank mix of herbicides reduced perennial weed development and inhibited alsike clover germination and growth for approximately 1.5 years after application. Planting after the application of the herbicide mix did not result in seedling damage or mortality. For optimum control, perennial weeds such as grass and Canada thistle should be emerged and actively growing before spraying.

White spruce survival also improved with mechanical site preparation (mounding and mounding with herbicides), though not to the same extent as the two deciduous species. White spruce copes better with grass competition than the two deciduous species. This provides options for site rehabilitation treatments where the entire site is not treated (e.g., mounding) and it is desirable to establish tree species on the undisturbed grassy areas. White spruce could be planted in undisturbed portions to increase tree/shrub species density and break up any patterns associated with the site preparation treatment.

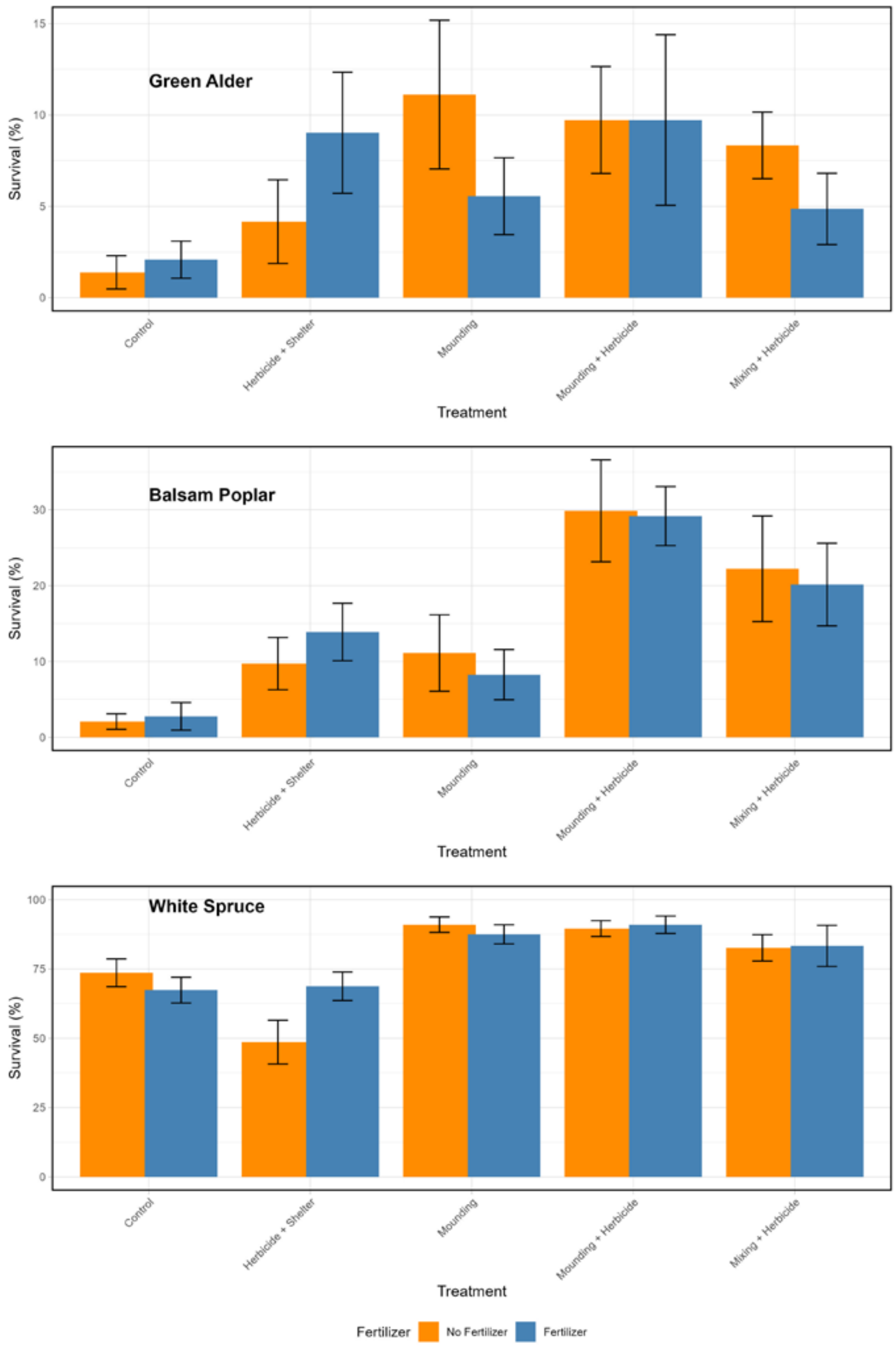

Figure 1: Survival of green alder, balsam poplar and white spruce, with and without fertilizer, seven years after planting for site D63.

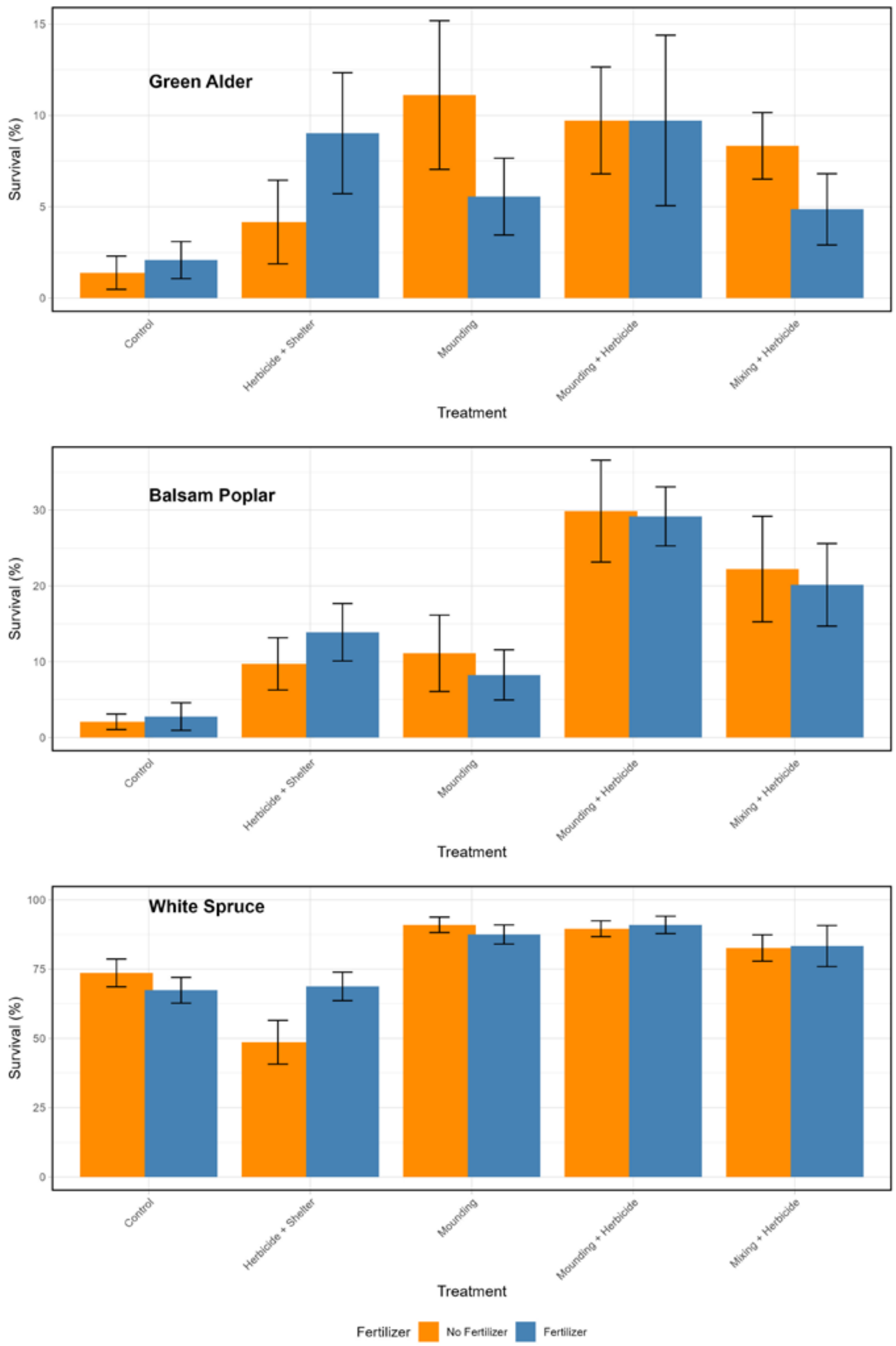

Figure 2: Survival of green alder, balsam poplar and white spruce, with and without fertilizer, five years after planting for sites J10 and P3 combined.

PRESENTATIONS AND PUBLICATIONS

Presentation at the COSIA Land EPA - In Situ Research Fall Field Tour. 2024. Reclamation Key Learnings and Opportunities. Held at Imperial Oil Cold Lake Operations, September 11th-12th 2024.

RESEARCH TEAM AND COLLABORATORS

Institution: Natural Resources Canada, Canadian Forest Service, Canadian Wood Fibre Centre, Edmonton

Principal Investigator: Richard Krygier

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Martin Blank	Canadian Wood Fibre Centre	Research Technician		
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Surmont Boreal Forest Reclamation

COSIA Project Number: LJ0226

Mine and In Situ

Research Provider: NAIT Centre for Boreal Research

Industry Champion: ConocoPhillips

Status: Year 10 of 20

PROJECT SUMMARY

For the past 10 years this research project has focused on reclamation practices specific to upland boreal forests. The title “Interim Reclamation” is rooted in the fact that the main research site is comprised of two soil stockpiles that will be re-disturbed during the final reclamation of the adjacent facilities. With the renewal of the research agreement between NAIT and ConocoPhillips the project title has been updated to “Surmont Boreal Forest Reclamation” to reflect the fact that the studies at this site all support boreal forest reclamation irrespective of whether the outcome is final reclamation or temporary 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 when 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 practice, though not widely used, 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 location 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 also 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 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 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 is 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 1b, 1f, and objectives 3-4. Much of the results described below relate to indirect effects of slope position (top versus bottom slope) and the presence or absence of coarse woody materials (CWM) that were applied throughout the study site. Some caution is needed with interpretation of these variables, particularly CWM, as it was strategically applied to areas that were operationally deemed at highest risk for erosion, where slope grades were steepest, and soil texture was coarsest.

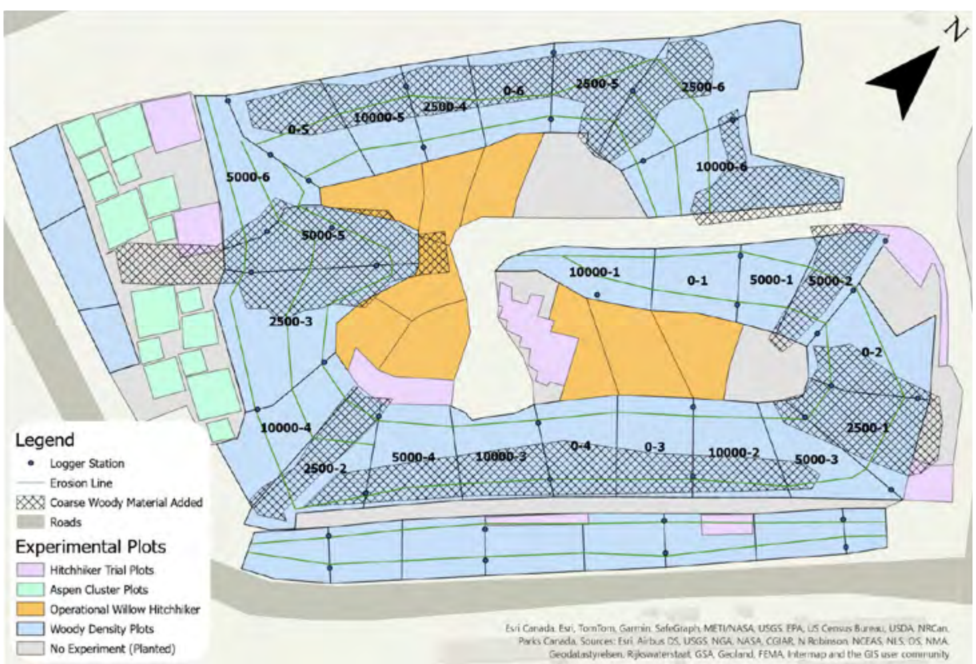

Figure 1: Plot treatment layout for projects within the soil stockpile site. Text within green blocks indicate the woody species planting density treatments followed by the replicate block number. Red circles indicate the location of standalone HOBO loggers (Onset). Transect lines where erosion assessments were conducted are shown by grey lines that circle the stockpile site.

Objective 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). The following sub-questions will be addressed in this objective: (b) Which species are best suited to different combinations of slope position on reclamation soils? (f) Does slope position interact with plant establishment through these methods?

Slope position was not an important explanatory variable with respect to predicting differences in stem counts (**Table 2**) and was only a significant predictor for height in *P. balsamifera* and *A. viridis* where it interacted with the CWM factor (**Table 1**). *P. balsamifera* had significantly greater mean heights in the upper (top) slope position but only when CWM was present (**Figure 2**). Similarly, for *A. viridis*, mean height increased in the top slope position but only when CWM was present; in the absence of CWM, heights were similar between the top and bottom slope positions (**Figure 2**). For most of species planted (*B. papyrifera, P. tremuloides, P. glauca, P. banksiana* and *Salix* spp.), the lack of difference in growth does suggest that these species had similar growth potential within the top and bottom slope positions; recognizing of course that there were absolute differences in growth amongst the species. Since there was no difference in stem count due to slope position for any of the planted species, this further suggests within-species survival was also similar between slope positions. To answer question (f), it was found that slope position did not interact with density treatment for any of the seven species in terms of height growth (**Table 1**) or stem counts (**Table 2**). In all cases, soil type (topsoil versus subsoil) had a much stronger growth effect in this study (**Figure 2, COSIA report 2023).**

Table 1: Generalized linear mixed-effects model (GLMM) outputs associated with woody species heights and woody debris site preparation in year eight of the survey. Factors tested included: whether woody debris was present (WD), soil type (ST), and planting density (DY) treated as an ordinal factor. Random effects included the replicate block nested within density treatment. All models were fitted with GLMM in R (R core team, 2024), using the package glmmTMB. The distribution selected for individual GLMMs are noted in the table (Model).

Response	Factor	Chisq	DF	p-value	Model
Betula papyrifera height	WD	8.734	1	0.003	Gamma
	SL	1.929	1	0.165	
	ST	17.774	1	< 0.001	
	DY	0.023	2	0.989	
	WD x SL	0.921	1	0.337	
	WD x ST	0.773	1	0.379	
Populus balsamifera height	WD	0.254	1	0.614	Gaussian
	SL	4.848	1	0.028	
	ST	19.024	1	< 0.001	
	DY	5.273	2	0.072	
	WD x SL	6.966	1	0.008	
	WD x ST	0.933	1	0.334	
Populus tremuloides height	WD	0.004	1	0.947	Gamma
	SL	0.029	1	0.865	
	ST	14.281	1	< 0.001	
	DY	3.714	2	0.156	
	WD x SL	2.737	1	0.098	
	WD x ST	1.169	1	0.280	

Picea glauca height	WD	23.220	1	< 0.001	Gaussian
	SL	4.125	1	0.042	
	ST	2.968	1	0.085	
	DY	6.840	2	0.033	
	WD x SL	0.699	1	0.403	
	WD x ST	12.288	1	< 0.001	
Pinus banksiana height	WD	1.080	1	0.299	Gaussian
	SL	0.001	1	0.974	
	ST	2.835	1	0.092	
	DY	1.921	2	0.383	
	WD x SL	0.325	1	0.569	
	WD x ST	2.012	1	0.156	
Alnus viridis height	WD	0.316	1	0.574	Gaussian
	SL	3.218	1	0.073	
	ST	7.106	1	0.008	
	DY	3.108	2	0.211	
	WD x SL	8.751	1	0.003	
	WD x ST	0.074	1	0.786	
Salix sp. height	WD	1.184	1	0.277	Gamma
	SL	0.084	1	0.772	
	ST	14.707	1	< 0.001	
	DY	1.805	2	0.406	
	WD x SL	0.205	1	0.650	
	WD x ST	0.166	1	0.684	

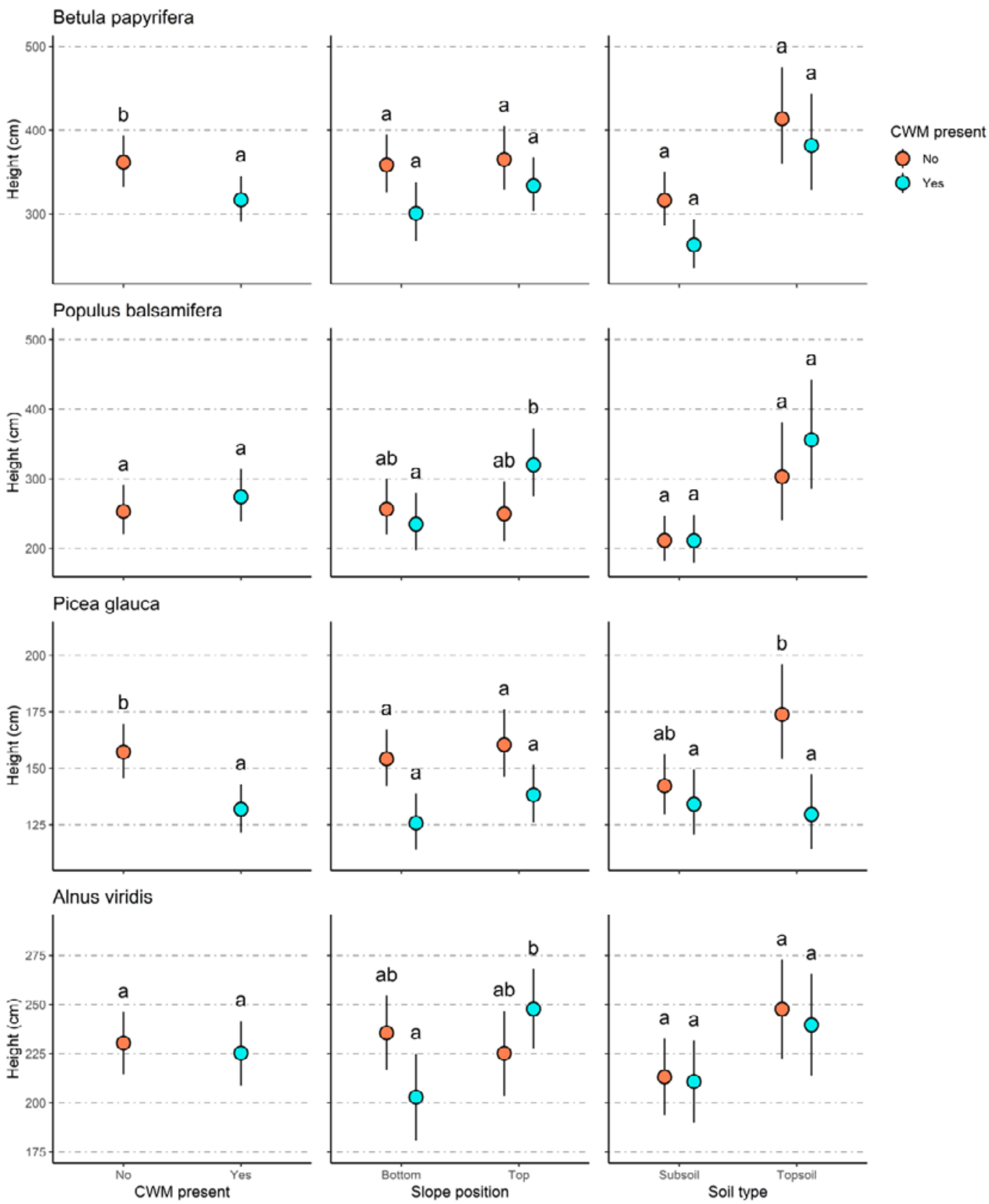

Figure 2: Estimated marginal mean heights of species with significant differences between coarse woody material application (CWM: present or absent) and interactions between CWM with slope position (top or bottom) and soil type (see **Table 1**). Unique letters indicate significant differences between treatments based on generalized linear mixed-effects model outputs.

Table 2: Generalized linear mixed-effects model (GLMM) outputs associated with woody species stem counts and coarse woody materials (CWM) in year eight of the survey. Factors tested included: whether CWM was present (WD), soil type (ST), and planting density (DY) treated as an ordinal factor. Random effects included the replicate block nested within density treatment. All models were fitted with GLMM in R (R core team, 2024), using the package glmmTMB. The distribution selected for individual GLMMs are noted in the table (Model).

Response	Factor	Chisq	DF	p-value	Model
Betula papyrifera stem count	WD	1.019	1	0.313	Poisson
	SL	0.937	1	0.333	
	ST	8.341	1	0.004	
	DY	38.572	2	<0.001	
	WD x SL	0.370	1	0.543	
	WD x ST	0.549	1	0.459	
Populus balsamifera stem count	WD	2.849	1	0.091	Lognormal
	SL	0.754	1	0.385	
	ST	31.152	1	<0.001	
	DY	6.671	2	0.036	
	WD x SL	3.614	1	0.057	
	WD x ST	0.660	1	0.416	
Populus tremuloides stem count	WD	0.576	1	0.448	Gaussian
	SL	0.012	1	0.912	
	ST	5.895	1	0.015	
	DY	7.788	2	0.020	
	WD x SL	0.303	1	0.582	
	WD x ST	0.076	1	0.783	
Picea glauca stem count	WD	0.127	1	0.722	Lognormal
	SL	2.061	1	0.151	
	ST	52.900	1	<0.001	
	DY	29.902	2	<0.001	
	WD x SL	0.022	1	0.882	
	WD x ST	0.938	1	0.333	
Pinus banksiana stem count	WD	0.127	1	0.722	Lognormal
	SL	2.061	1	0.151	
	ST	52.900	1	<0.001	
	DY	29.902	2	<0.001	
	WD x SL	0.022	1	0.882	
	WD x ST	0.938	1	0.333	

Alnus viridis stem count	WD	0.115	1	0.735	Lognormal
	SL	0.246	1	0.620	
	ST	11.572	1	0.001	
	DY	4.314	2	0.116	
	WD x SL	0.628	1	0.428	
	WD x ST	0.492	1	0.483	
Salix sp. stem count	WD	4.116	1	0.042	Poisson
	SL	0.159	1	0.690	
	ST	0.001	1	0.970	
	DY	8.439	2	0.015	
	WD x SL	0.644	1	0.422	
	WD x ST	0.643	1	0.423	

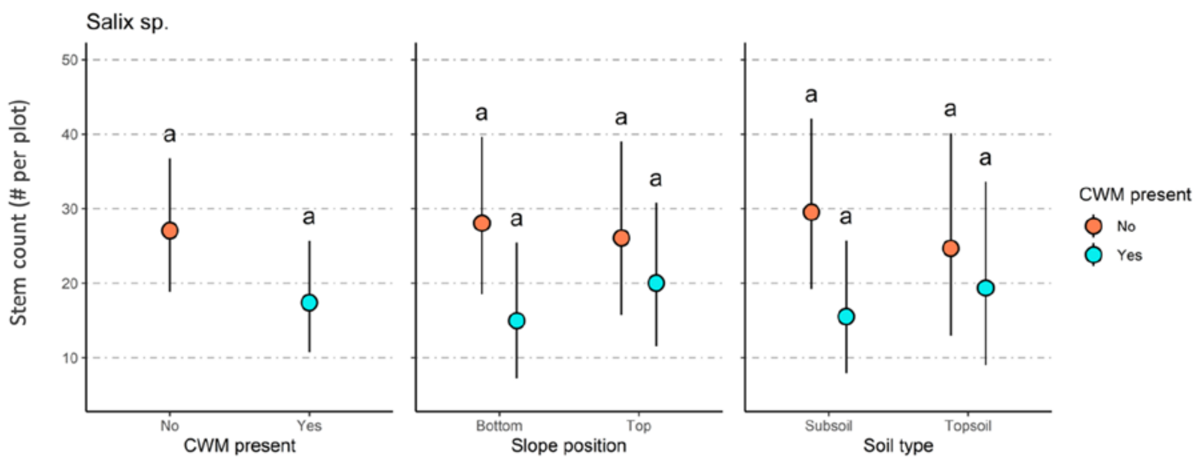

Figure 3: Estimated marginal mean stem counts of *Salix* sp. between coarse woody material application (CWM: present or absent) and interactions between CWM with slope position (top or bottom) and soil type (note: *Salix* sp. stem counts were the only response where CWM was a significant predictor; see **Table 1**). Unique letters indicate significant differences between treatments based on generalized linear mixed-effects model outputs.

Objective 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?

Individual species responses to CWM were highly variable with P. tremuloides, P. banksiana and Salix spp. showing no detectable growth response to the presence or absence of CWM (Table 1-2). B. papyrifera was taller on average within plots where CWM was absent (Table 1, Figure 2) while P. balsamifera was taller in areas with CWM applied but only in upper slope positions (Table 1, Figure 2). P. glauca showed a significant CWM by soil type effect where heights were greater in topsoil without CWM application while this effect was not detectable in subsoil (Table 1, Figure 2). For A. viridis, CWM also interacted with slope position where plants were taller without CWM in the bottom slope position while plants tended to be taller in the top (upper slope) position with CWM (Table 1, Figure 2). Neither slope position nor CWM application resulted in significant changes in tree species stem counts (Table 2), though Salix spp. had higher stem counts on average in the absence of CWM (Figure 3). In contrast, soil type and initial plant density were often highly significant predictors (Table 2, refer also to COSIA report 2023 for detailed discussion of these effects). Given the inconsistent and varied growth responses of individual species to CWM coupled with lack of response in terms of stem counts, it is unclear if CWM is consistently beneficial to tree and shrub survival or growth. It is likely that the mixed responses observed in the present investigation may be a result of the strategic placement of CWM. For example, a substantial portion of CWM was placed along the southwest side of the stockpile, an area that also contained the coarsest textured soils. Similarly, CWM tended to be placed in areas with the steepest slopes in order to mitigate for soil erosion. Together, these underlying environmental conditions associated with the types of conditions CWM was placed are invariably interacting with plant growth responses.

CWM did not substantively change the quantity of ground area or depth of individual erosion gulleys in the first four years of the trial (**Table 3**). Mechanical site preparation did act to reduce the total ground area with surface erosion across subsoil and topsoil averaging 3.4% to 4.2% after the first year, and only 0.6% in subsoil by the fourth year with topsoil areas having no observable erosion present. Across the same time, untreated areas had 6.9% to 11.4% of the ground surface with erosion present. As the untreated area reflected only a portion of the site (subsoil, southern aspect, **Figure 1**), some caution should be taken with extrapolation of these findings. As noted above, CWM was strategically applied to areas that were expected to be at greatest risk of erosion; therefore, the lack of difference in erosion between CWM and no-CWM areas may reflect some bias with how these treatments were placed across the site.

Table 3: Results of erosion surveys collected between the first and fourth years of the study. Results represent the mean (a) percentage of ground area where erosion was observed and (d) depth of individual erosion gulleys. Values in brackets represent one standard deviation of the mean (n = 4-6 replicate treatment plots).

(a) ground area (based on % of transect where erosion was observed)

Soil treatment	Soil type	CWM	Fall year 1	Spring year 3	Spring year 4
No MSP	Subsoil	None	11.4 (12.2)	8.4 (6.9)	6.9 (7.4)
With MSP	Subsoil	Average	4.2 (1.9)	1.2 (0.7)	0.6 (1.5)
		None	5.0 (2.0)	1.1 (0.9)	0.0 (0.1)
		Yes	3.6 (1.7)	1.3 (0.5)	0.9 (1.9)
	Topsoil	Average	3.4 (1.2)	0.1 (0.2)	0.0 (0)
		None	3.6 (1.3)	0.2 (0.3)	0.0 (0)
		Yes	3.3 (1.2)	0.0 (0.1)	0.0 (0)

(b) depth (cm) of individual erosion gulleys

Soil treatment	Soil type	CWM	Fall year 1	Spring year 3	Spring year 4
No MSP	Subsoil	None	4.6 (1.3)	4.4 (2.3)	8.4 (4.5)
With MSP	Subsoil	Average	4.7 (2.0)	8.9 (5.7)	10.6 (4.6)
		None	3.6 (0.5)	8.9 (5.6)	8.5 (NV)
		Yes	5.4 (2.4)	8.9 (6.2)	11.0 (5.1)
	Topsoil	Average	4.6 (1.1)	19.5 (9.2)	-
		None	5.0 (1.3)	13.0 (NV)	-
		Yes	4.4 (1.1)	25.0 (NV)	-

NV = no variation observed, single data point.

Objective 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?

P. tremuloides was the only species where researchers observed periodic ungulate browsing at this study site. No evidence was found that wildlife was actively browsing coniferous trees (*P. glauca* and *P. banksiana*), other hardwood trees (*P. balsamifera* and *B. papyrifera*) or planted shrubs (*A. viridis* and *Salix sp.*). The intensity of browsing for *P. tremuloides* was tracked over the first five years in plots on the south-west side of the research site to further relate browsing pressure to growth responses in *P. tremuloides* (Aspen cluster trial, **Figure 1**).

Height of *P. tremuloides* increased steadily over the first four years of monitoring despite periodic browsing **(Figure 4a)**. Browsing was highly variable with no damage observed in years one and four, and, on average, 2% to 10% of trees affected in years two and three (**Figure 4b**). Height development appeared to slow between year 4 and 5, perhaps due to somewhat higher browsing pressure, which was observed in approximately 15% of trees (**Figure 4b**). However, it is more likely that between year four and five, *P. tremuloides* simply grew more laterally, as it had, on average, reached sufficient height to clear the herbaceous plant canopy by year four (**Figure 5**), which was generally less than 1.5 m in height.

Given the lack of browsing observed across planted species and the relatively steady height development of *P. tremuloides*, despite browsing, there does not appear to be strong evidence to suggest that browsing was impactful to canopy development in the present investigation. Moreover, there was no relationship between tree height and the percentage of trees browsed for individual plots (**Figure 4c**), further supporting that the browsing observed in this study was not sufficiently damaging to general tree growth.

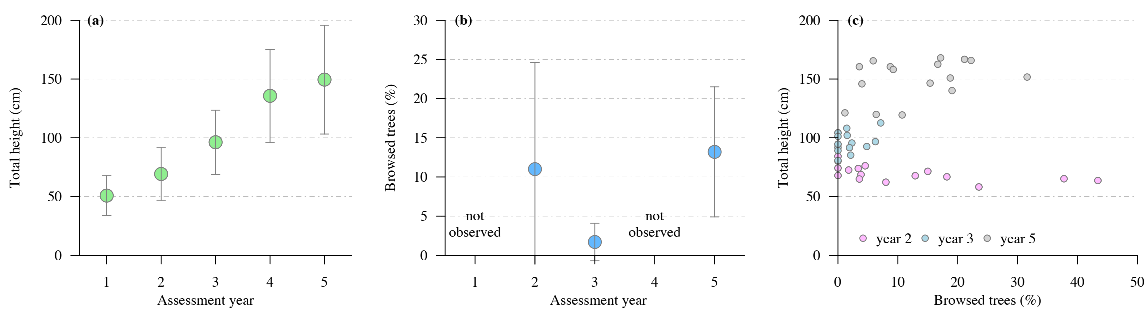

Figure 4: Means of total height and percentage of aspen seedlings with evidence of ungulate browsing within the aspen cluster trial plots (see Figure 1). Brackets indicate one standard deviation from the mean. In panel (b), no browsing was observed in year one and four.

(A)

(C)

(B)

(D)

Figure 5: Examples of aspen after (a-b) four growing seasons and (c-d) five growing seasons, with images taken in the same locations for comparative effect.

LESSONS LEARNED

Emerging lessons:

The species planted in this trial (*P. glauca, P. banksiana, P. tremuloides, P. balsamifera, B. papyrifera*) have generally responded similarly to planting on upper and lower slope positions, suggesting that a simple planting strategy of mixing all species together may be appropriate for similarly sized reclamation sites (8-10 hectares).

Differences in growth, observed for *B. papyrifera, P. glauca* and *P. balsamifera*, as a response to presence or absence of CWM may warrant further investigation as it is possible these differences are confounded by other conditions associated with areas where CWM was strategically placed (it was not randomly placed on the site).

While ungulate browsing was observed, it was largely confined to a single species, *P. tremuloides*; interestingly the percentage of trees browsed varied substantially from year to year and researchers did not find strong evidence that the browsing pressure inhibited growth of *P. tremuloides* over the five-year period it was assessed.

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PRESENTATIONS AND PUBLICATIONS

No public presentations or publications in 2024.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Amanda Schoonmaker

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Kristine Ladislao	NAIT Centre for Boreal Research	Research Assistant		

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

COSIA Vegetation Research Committee (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

Fifteen 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. In 2024, to better reflect this initiative, the OSVC rebranded to the COSIA Vegetation Research Committee (CVRC).

The CVRC's strategic objectives are twofold:

- To identify knowledge gaps related to vegetation used for oil sands reclamation revegetation; and
- To support research programs aimed at optimizing seed harvest, storage, propagation, and final field establishment.

The scope of work for this project includes providing resources to assist in effective seed harvest, such as monitoring annual seed harvests, managing records for CVRC seed inventories in the provincial seed bank (Alberta Tree Improvement and Seed Centre - ATISC), and providing technical expertise on identification, collection, storage and deployment of native seed. The committee also provides technical guidance regarding research needs, coordinates research project development, prepares support documents such as literature reviews and data summaries, and produces a bi-annual newsletter.

PROGRESS AND ACHIEVEMENTS

Seed Banking

In 2024 (15th season) the CVRC did not conduct a cooperative harvest as had been done in previous years. Instead, CVRC member companies commissioned their harvests internally or by contracting harvesters. Seed was registered and, in early 2025, will be tested for viability following a minimum of a month in storage.

Thirty-three seedlots were harvested in 2023 with 22 tested for viability in early 2024 following registration. The remaining lots were direct sown before testing could be completed as they were either too small or were non-woody species. These last lots are not registered with ATISC.

Progress on Strategic Objectives

- CVRC members held nine meetings in 2024 to discuss knowledge gaps and propose research.
- In 2024, a literature review was published for four species deemed a priority by members: green alder, Labrador tea, dwarf blueberry and lowbush cranberry (see summary below).
- Work on the Operational Monitoring Program (initiated in 2018) to determine survival of outplanted shrubs over the oil sands area continued. This program examines survival of outplants by species on various reclamation materials. Thirty-eight plots were monitored in 2024 and included the first observations from seven plots established between 2022 and 2024. A summary report of information in the database was prepared.
- In 2021 a trial (in cooperation with Smoky Lake Forest Nursery) was initiated to improve operational production methods for lowbush cranberry (*Viburnum edule)*, a particularly difficult species to produce. In 2024/25, in cooperation with NAIT Centre for Boreal Research, this work will be expanded and focus on temperature and light exposure differences during stratification and emergence period. Increasing stratification duration has been included to determine if emergence can be further synchronized.
- Following a literature review, a protocol was developed to assess the supply chain for one priority species, green alder (*Alnus alnobetula*). This included harvesting from three stands at three different times over the ripening period in 2024. A sample of catkins were assessed for size, maturity (based on colour), and seed per catkin. Following this, seed was divided between two extractors for processing, then registered and banked with ATISC. The quality of the seed (amount, germination, and tetrazolium staining) will be assessed in early 2025 and then provided to two or more producers to grow seedlings for outplanting in 2026. Establishment success will then be monitored in subsequent years. Following this effort, an adapted protocol is expected to be applied to other priority species in the future.

Communications

- Two editions of the newsletter (May and November 2024) were published.[1, 2]

LESSONS LEARNED

A literature review on four priority species, previously identified by CVRC members, was completed. For each species, collection method and time, handling practices, ideal storage conditions, germination pretreatments and conditions, production knowledge, and field establishment success were explored. Based on the literature review:

- Green alder should be harvested in late summer or early fall. Once extracted and dried, seeds should be stored frozen. Quality can be determined using quick germination tests. Seed may be sown in April and seedlings stored frozen for outplanting the following spring/early summer. Establishment success is widely variable.
- Labrador tea should be harvested in late summer and autumn. Once extracted and dried, seeds should be stored frozen. Quality can be determined using quick germination tests. Seedling production is complicated by

small seed size. It may be sown into seeding trays and then pricked out into styroblocks or other containment system. There remains little data regarding survival and establishment.

- Dwarf blueberry should be harvested over the summer into plastic containers and kept cool until delivered for extraction. Once extracted and dried, seeds should be stored frozen. Quality can be determined either by germination testing or tetrazolium staining (viability). Reports on establishment success vary.
- Lowbush cranberry should be harvested in late summer into plastic containers and kept cool until delivered for extraction. Once extracted and dried, seeds should be stored frozen. Germinability is difficult to assess due to complicated stratification requirements, but viability can be assessed using tetrazolium staining. Once grown, seedlings can be stored frozen for spring/early summer planting. Reports on establishment success vary. An alternative establishment method could be vegetative propagation by outplanting rooted softwood cuttings. Although a method for rooting cuttings is available, outplanting success has not been adequately assessed.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

[1]Wild Rose Consulting, Inc. 2024. Oil Sands Vegetation Cooperative Newsletter. May 9(1). 4 pages.

[2]Wild Rose Consulting, Inc. 2024. COSIA Vegetation Research Committee Newsletter. November 9(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: Jean-Marie Sobze, NAIT Centre for Boreal Research

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

Status: Year 5 of 5

PROJECT SUMMARY

The goal of this project is to develop an affordable (approximately CAN $1.00 per test), 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 could 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 because it is 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 single 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 have been contacted by representatives from the Canadian, Mexican and South African governments as well as Interpol and Europol, interested in the potential for using these tools to detect illegal trade of wildlife parts.

The first field trials for the technology were conducted in mid-January 2024 in far Northeast British Columbia (BC) with the Provincial Caribou Recovery Program in full partnership with Fort Nelson First Nation. Further work in 2024 with an engineering company is close to producing a first-level prototype which will then be tested among a variety of non-experts to ensure it can be implemented in the real world. The feedback from these end-users will guide the optimization and automation of the technology to ensure its effectiveness in a multitude of wildlife monitoring applications.

A company, WildTechDNA Inc. was formed in 2024 to aid in scaling the technology beyond caribou to many different species and applications globally, as well as a diversity of stakeholders including government, NGOs, academia and Indigenous communities.

PROGRESS AND ACHIEVEMENTS

The focus of 2024 was primarily on field-testing and engineering the technology. This is the final year of the joint industry project.

In 2024, researchers completed lab-based development of the methods behind the technology (i.e., Aims 1-4), conducted initial field-trials (Aim 5), built a first-level prototype for testing with a variety of end-users, and began work on designing a blue-print that would allow for the easy expansion of the technology to other species and applications. Specifically:

- The method behind the technology has been developed for the targeted detection of caribou and other Canadian cervids and provides results for fecal and tissue samples with 100% specificity, high sensitivity (5-10 DNA copies/mm^3 of sample), and all in under 30 minutes. Researchers have also developed a test, using the same methods, to identify the **sex** of caribou from a genetic sample. Careful consideration of sex-specific differences and needs is critical to effective conservation and management of caribou and other species.

  The method consists of sample preparation and DNA extraction using gravity filtration (2 minutes), followed by advanced DNA amplification that is simple, rapid, highly specific and sensitive (15 minutes) and concludes with lateral flow visualization (5-10 minutes). The amplification method is more tolerant to inhibitors present in fecal samples compared to the conventional Polymerase Chain Reaction (PCR) technique, is orders of magnitude more sensitive, is more effective in dealing with degraded, fragmented DNA, requires no expensive heating devices, and is particularly useful in situations where access to laboratories and expertise are limited.

With this methodology, the technology solves many problems faced by other portable DNA technologies used in the detection and identification of genetic samples. A summary of the technology highlights is included in Table 1.

Table 1: Highlights of the Project technology compared to a current portable wildlife detection technology (portable quantitative polymerase chain detection [qPCR] test).

	Portable qPCR Test	Project Technology
Cost per unit	~$10,000	$50
Cost per reaction	~$1	~$1-5
Sensitivity	1 DNA copy	5-10 DNA copies
Amplification impacted by inhibitors	Yes	No
Total run time/sample	~110 Minutes	~30 Minutes
Expertise needed	Medium	Low
Sample preparation/DNA extraction	30-45 Minutes	5 Minutes
Works well with crude lysates	No	Yes

- Researchers conducted first field trials of their methods in January 2024 on boreal woodland caribou as part of non-invasive fecal DNA capture-recapture surveys, which took place from December 2023 to February 2024, to provide population abundance estimates (Figure 1). The surveys were run by British Columbia's Caribou Recovery Program in collaboration with Fort Nelson First Nation, Prophet River First Nation, Doig River First Nation, Blueberry River First Nation, and the University of Calgary, covering the Snake-Sahtaneh and Maxhamish regions in far northeastern British Columbia.

  They also collected over 100 pellets of variable age and from different individuals of both caribou and moose, with older samples found buried in the snow compared to fresh samples found at the surface. These samples were used for further testing in the lab.

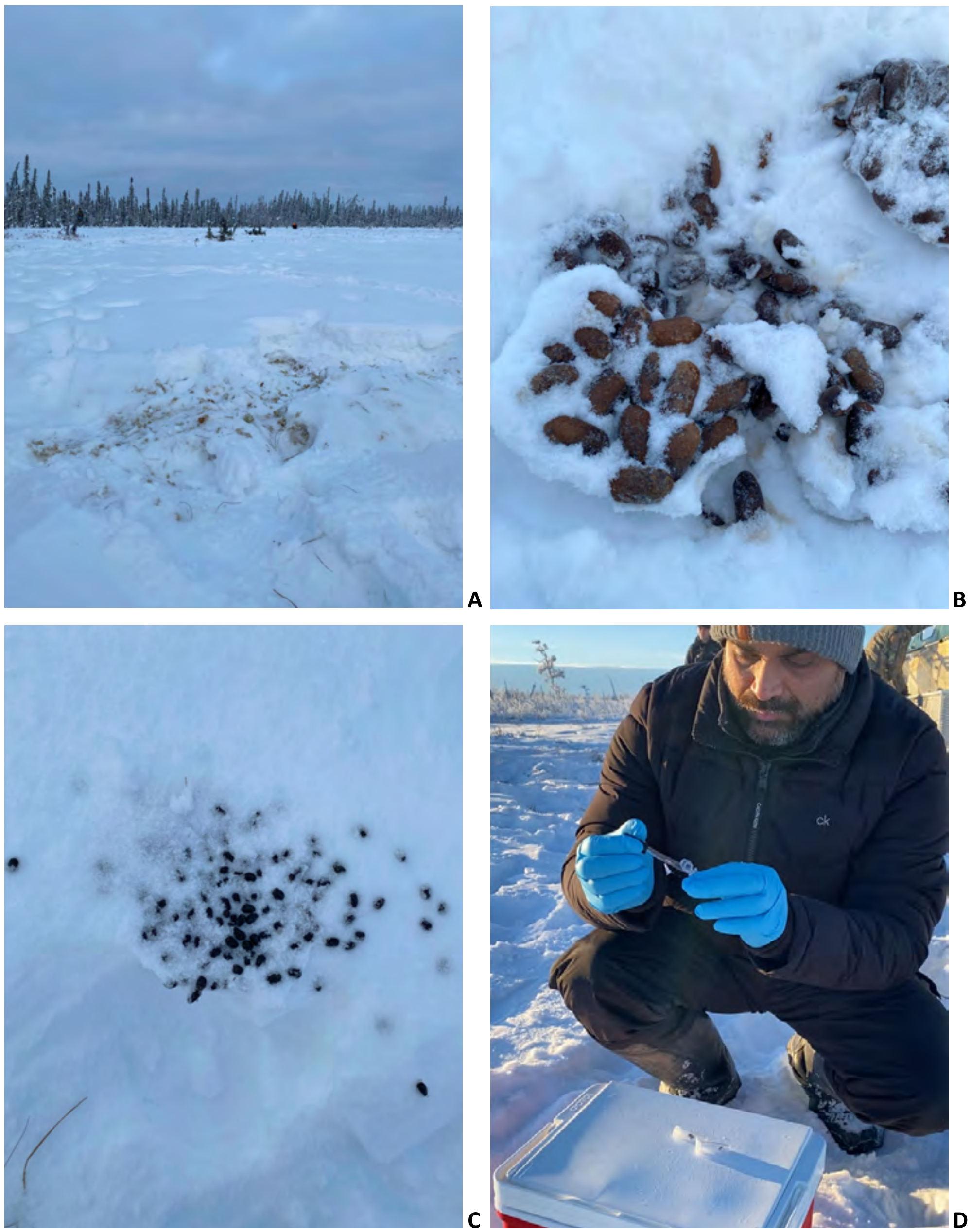

Figure 1: First field trials on boreal woodland caribou and moose in far northeastern British Columbia, January 2024. Photos: **A)** Craters left by caribou digging for lichen, **B)** Moose pellets, **C)** Caribou pellets, and **D)** Project researcher Rahul Chaudhari (Post-Doctoral Fellow) conducting DNA extraction on site (at -35°C).

- The researchers have engaged the services of an engineering company in Ontario to build a first-level prototype, with completion anticipated before the end of 2025 (Figure 2). The prototype will include all three components of the methodology in a simplified form (DNA extraction, amplification and lateral flow signal). The goal of this prototype is to have a minimum viable product that can be trialed with a variety of end-users that will then guide further optimization, consolidation and automation of the technology. Although the prototype will be an effective product in and of itself, with further funding, researchers plan to continue engineering development to create a final technology that further maximizes simplicity, minimizes cost and reduces the potential for human error.

Figure 2: First-level prototype design for initial trials with a variety of end-users involved in the monitoring of caribou.

- Beyond caribou, designing DNA primers for every new target species of interest can be difficult and time-consuming, as conserved species-specific regions need to be identified with little homology to potential background DNA and primer sets need to be tested to ensure they don't cross-react with genetically similar species. To overcome this problem the researchers are partnering with a bioinformatician to build a python-based software to automate the creation and filtering of primers and probe sets for the DNA amplification method used in this technology. The software uses an AI approach, learning as it aligns thousands of sequences to identify conserved targets, and filters regions that cross-react with possible background species. This blueprint will enable any research group globally to quickly and easily identify the best primers for their target species of interest that can be incorporated into this methodology and technology.

Outside the development and testing of the technology there have also been some exciting new initiatives and advances to new species and applications:

- The researchers formed a company around the technology to scale its use globally – WildTechDNA Inc.
- The Wildlife Enforcement Directorate of the Canadian Government has contracted the research team to develop tests to detect European eel (*Anguilla anguilla*), a critically endangered species listed in CITES Appendix II that has been heavily trafficked in Europe and North America. The researchers will be developing primers for the species to be used with the prototype and testing them at the University of Potsdam in Germany this January 2025. Law enforcement officers will be issued with hundreds of units and will receive personalized training from the researchers on how to use the technology. The feedback from officers will be critical in guiding future iterations of the technology.
- The research team will be presenting the technology at a side event of the CITES Standing Committee meeting (CITES SC78) in Geneva from February 3-8,2025. CITES is a multilateral treaty to protect endangered plants and animals from the threats of international trade. The Standing Committee provides policy guidance to the secretariat and overseas compliance. Supporting the team at this side event will be the head of the Mexican delegation who will discuss the application of the technology to the monitoring of big cats in trade, and a representative of Interpol and Europol who will talk of the application to CITES-listed fish species. The meeting provides a unique opportunity to showcase the technology to government and NGO delegates globally as a simple, effective, and inexpensive solution to monitor wildlife trade, especially for low-resource countries.
- The research team has developed primers for all the big cat (Panthera) species in collaboration with the Toronto Zoo, Zoo de Granby, and the Greater Vancouver Zoo. The *Panthera* species range from near-threatened to endangered according to the IUCN Red List and are all decreasing rapidly. They are considered high priority species that drive the structure and function of biological communities in diverse ecosystems around the world. Because *Panthera* require large territories and plentiful prey populations to survive, conservation efforts aimed at preserving these species have the potential to produce significant biodiversity gains across multiple taxa. The conservation monitoring of these species is extensive, and scat samples are difficult to distinguish from other apex predators in the field. Many of the key countries that are home to the big cats do not have access or funding for detailed laboratory analyses of samples for identification. The technology could greatly assist in monitoring of these species in the wild, and the team plans to test the prototype in the field with researchers focused on snow leopards and jaguars in 2025.

- In winter 2023-24, PhD student Letizia Dondi developed a simple to use, portable and non-toxic DNA extraction kit for the extraction of DNA from ungulate scat. The developed test can be completed in only four simple steps with very limited consumables, making it suitable for field use by biologists to extract scat DNA. The team has summarized the invention in a manuscript which is being finalized for submission in early 2025. They compared the DNA extraction efficiency of the method to the gold-standard Qiagen kits and found that the method resulted in a higher yield of DNA which was stable at 23°C for seven days. The extracted DNA can then be used directly for PCR analysis. The team envision this kit to be incorporated into a lab-in-a-box setup for conservation field work.
- The team has been invited by the Wood Buffalo Regional Innovation Network (RIN) to propose a project to engage local Indigenous communities to learn whether the species detection technology would benefit their current monitoring efforts of culturally important wildlife species (i.e., a technology complementing their traditional knowledge). There is also the potential to co-design and optimize the prototype of the technology with community members, if they wish to proceed, to ensure it works well for their specific needs. The project proposal has been submitted and is currently waiting on a decision by the RIN.

LESSONS LEARNED

What might be very straight-forward for experienced scientists using the technology in the lab is quite different when dealing with a variety of different end-users and diverse environmental conditions where it could be deployed. Field work carried out in -40°C conditions in British Columbia taught the team that there will be limitations in the conditions where the technology will be optimal. Currently, the prototype functions best between 10°C and 35°C and is best tested at a field camp or indoors to minimize potential error from contamination, wind etc. It is the researchers' hope that with further engineering optimization, they can build a version of the technology capable of withstanding a greater range of environmental conditions.

The prototype of this technology has been tested successfully by the 10-year-old daughter of the team's post-doctoral fellow, Rahul Chaudhari, thus proving that the test is easy to use for non-experts.

Further testing and refining with a variety of end-users is needed to ensure the technology is robust in different monitoring scenarios (including tests to assess the limitations of the technology under certain environmental conditions and sample degradation). The present technology works effectively with both fecal samples and fresh tissue and thus would be a valuable tool for industry or consultants in the monitoring of species at risk or as part of Environmental Impact Assessments. The tool eliminates the need for samples to be sent to an external lab for analysis, saving considerable time and money, allowing for on-the-spot management decisions.

One of the project goals has been to engage local Indigenous communities who may lead or contribute to caribou conservation monitoring to seek their guidance on whether the device would complement and benefit their efforts. Researchers received conflicting information on when in the development process that engagement should take place. Ultimately, some Indigenous groups were engaged in the field trial in 2024. In hindsight, it would have been more beneficial to have engaged these and other Indigenous communities from the beginning of the project, to gauge their interest and establish regular discussions on what was important to them through the project phases. The researchers are hopeful that the proposed project in front of the Wood Buffalo RIN, if approved, will allow for further Indigenous community guidance through the engineering and end-user testing phases.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Dondi, L., Chaudhari, R., Schmitt, N., Poissant, J., Musiani, M., Filipe, C., Li, Y. (In Preparation). Rapid and field applicable scat DNA extraction method for animal conservation.

Chaudhari, R., Dondi, L., Schmitt, N., Deakin, S., Poissant, J., Musiani, M., Filipe, C., Li, Y. (In Preparation). A novel, point-of-care and integrated test for nucleic acid detection in 30 minutes.

Conference Presentations/Posters

Schmitt, N., Chaudhari, R., Dondi, L., Deakin, S., Poissant, J., Musiani, M., Filipe, C., Li, Y. (2024). A portable, affordable, rapid DNA technology for wildlife detection. COSIA-PTAC Ecological Forum.

Schmitt, N. (2024). Rooted resilience: Empowering grassroots conservation in a globalized world. Embassy of Nature Conference, Paris.

Reports & Other Publications

Barrette S., Deakin S., Pelletier A., Priadka P., Schwantje H., Thacker C., Neufeld L., Rogers S., Musiani M., and Poissant J. (2024). A comparison of protocols for isolating and quantifying host DNA from caribou fecal pellets (poster). Annual Meeting of the Canadian Society for Ecology and Evolution (CSEE), Vancouver, Canada.

Bourbon, C., Deakin, S., Michalak, A., Hughes, M., Cavedon, M., Neufeld, L., Pelletier, A., Polfus, J., Schwantje, H., Thacker, C., Musiani, M., and Poissant, J. (2024). A genomic assessment of inbreeding and effective population size in Western Canada's woodland caribou (Rangifer tarandus caribou). *Plant and Animal Genome Conference*, San Diego, CA. Poster.

Bourbon C., Deakin S., Michalak A., Hughes M., Cavedon M., Neufeld L., Pelletier A., Polfus J., Schwantje H., Thacker C., Musiani M., and Poissant J. (2024). Inferring contemporary and historical effective population size (Ne) of woodland caribou in Western Canada. *Canadian Society of Ecology and Evolution Annual Meeting*, Vancouver. Talk.

Deakin S., Poissant J., Ruckstuhl K., and Musiani M. (2024). Endangered hybrid swarms of caribou: glacial, interglacial climates, adaptation and current threats. European Congress of Conservation Biology (ECCB), Bologna, Italy.

Hughes M. M., Bourbon C., Milanesi P., Veitch J. S. M., Deakin S., Schwantje H., Thacker C., Pelletier A., Polfus J., Neuhaus P., Ruckstuhl K. E., Poissant J., and Musiani M. (2024). Integrating movement behaviours for intra-specific conservation: The caribou case. Annual Meting of the Canadian Society for Ecology and Evolution (CSEE), Vancouver, Canada.

Michalak A., Deakin S., Cavedon M., Hughes M., Neufeld L., Pelletier A., Polfus J., Schwantje H., Steenwig R., Thacker C., Musiani M., and Poissant J. (2024). A Hierarchical Assessment of Genomic Diversity in Caribou (Rangifer tarandus) to Aid Designation of Conservation Units in Western Canada. Plant and Animal Genomics conference (PAG), San Diego, USA.

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 4 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

In 2024, the focus was on finalizing and publishing the prevalence data for Objective 2, summarizing the findings of Objective 3 so far, and continuing data collection for the remaining components of Objective 2 (environmental persistence) and Objective 4 (co-morbidities).

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

As was reported in 2023, the 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).

This PCR approach is now routinely used in the research laboratory in Calgary to process the *Map*-related samples from the bison herd.

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

The most important findings of 2022-2023 were captured in the thesis of Dr Ana Hernandez-Reyes (defended December 2023 and submitted). Results for this objective are also summarized and accepted for publication (final acceptance in November 2024) in the Canadian Veterinary Journal under the title 'Risk factors associated with Johne's disease in a captive wood bison herd.' The abstract of the manuscript is as follows:

Mycobacterium avium subsp. paratuberculosis (Map) has been identified in a wide range of domestic and wild ruminants. Captive wildlife, including bison spp can experience Johne's disease (JD)-related epidemiological scenarios similar to those seen in cattle. To date, there is no epidemiological information about Map in captive wood bison (Bison bison athabascae) herds. The objective of this study was to examine age, sex, and location specific density as potential risk factors which may be associated with Map positivity in a captive wood bison herd, located in Alberta, *Canada. Fecal samplings were obtained from October 2021 to October 2022, DNA was extracted and qPCR targeting IS900 and F57 followed by liquid culture confirmation was performed. Within-herd prevalence of IS900/F57 qPCR in October 2021 was 4.7%; prevalence of IS900 qPCR with culture confirmation was 6.8%. Regression analysis using 3 different outcomes based on different diagnostic approaches was employed. Base scenario (positive result by fecal IS900 qPCR with culture confirmation of IS900/F57 qPCR), Scenario 1 (positive result by fecal IS900 qPCR with culture confirmation of IS900 qPCR) and Scenario 2 (positive result by fecal F57 qPCR with culture confirmation of F57 qPCR). Wood bison in the age group ≥ 6-9 y were more likely to be Map positive in all scenarios. Animals in location B (higher animal density) were significantly associated with being Map positive in base scenario and scenario 1. This study identifies risk factors related with JD in a captive wood bison herd and can be used to initiate more studies in both the commercial as well as wild wood bison herds.*

Understanding the within-herd prevalence supports the management of the disease. Additional sampling events were performed and these results and comparisons mentioned in Table 1.

Fall 2024: Herd level sampling

During the fall roundup in November 2024, a total of 138 samples were collected, including 11 previously identified by qPCR and five samples from clinically suspected or fecal-confirmed cases that were humanely euthanized on site. Of the 122 routine samples processed in pools of four to five samples, six pools showed a signal in IS*900*. However, when those 30 samples were processed individually, none of the samples came back positive for F57. Fifteen animals testing positive for IS*900* qPCR.

Table 1: Description of the within-herd prevalence and sampling prevalence using IS*900* and F57 qPCR results

Date	IS900 positives %	IS900/F57 qPCR %	Number Samples IS900/F57 qPCR
Oct-21	6.8	4.7	11/234
Feb-22*	28.8	28.8	17/59
Sep-22*	13	5.2	4/77
Oct-22	9.9	4.2	8/191
Dec-23*	7.9	3.2	2/63
Feb-24*	8.8	2.9	3/102
Nov-24	10.9	2.9	4/138

*Opportunistic samplings

Resampling strategy

Throughout 2024, a more proactive field sampling strategy was chosen to quickly identify animals that are shedding *Map*-bacteria. Animals with a signal for IS900 in the qPCR fecal sample, but not confirmed as *Map*-positive with F57, were listed for resampling, ideally every three to six months.

Environmental persistence:

Understanding where and how long *Map* survives in the environment will support managing the health of the bison herd. This study will assess impacts of controlled freeze thaw on viability of *Map* and examine water sources for the presence of *Map*. To mimic variation in environmental temperature and exposure time, a study was designed for laboratory experimentation using negative feces from the bison herd (collected in November 2024) and the *Map*-strain from the same herd, cultured in known quantities at the UCVM lab.

Currently, fecal samples have been spiked with a known quantity of *Map* bacteria, frozen, and will be thawed for quantification to assess the decline in viability over time.

Table 2: Study design for environment persistence as started in Late 2024:

Temperature	Time	Replications
-20°C	2 weeks	10
	4 weeks	10
	8 weeks	10
	12 weeks	10
-10°C	2 weeks	10
	4 weeks	10
	8 weeks	10
	12 weeks	10
0°C	2 weeks	10
	4 weeks	10
	8 weeks	10
	12 weeks	10
10°C	2 weeks	10
	4 weeks	10
	8 weeks	10
	12 weeks	10
20°C	2 weeks	10
	4 weeks	10
	8 weeks	10
	12 weeks	10

For presence of *Map*-bacteria in the surface water that can be a source for drinking water for the animals, three water samples have been received from one time point and those samples have been stored until sufficient sample numbers have been received for laboratory processing.

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

The most important findings of year 2022-2023 were captured in the thesis of Dr Ana Hernandez-Reyes who defended her thesis in December 2023. Two chapters are now submitted and accepted for publication in peer reviewed journals. In August 2024 the Journal of Wildlife Diseases accepted the manuscript under the title "Diagnostic strategies and strain typing for Johne's disease in wood bison (*Bison bison athabascae*). The manuscript is awaiting publication. The abstract of the manuscript is as follows:

Cattle diseases are considered a major threat to wood bison (Bison bison athabascae) conservation. Johne's disease (JD) is a chronic infectious enteritis caused by Mycobacterium avium subspecies paratuberculosis (Map), that affects domestic and wild ruminants globally and could have a negative impact on wood bison health. Currently, there is no documented clinical manifestation of JD in free-ranging or captive wood bison. We conducted this study in a captive wood bison herd, located in Alberta, Canada. Our objectives were to: 1) detect Map in bison clinically suspected of Johne's disease, by histopathology, qPCR, and isolation by culture; 2) identify optimal tissue samples for Map detection; and 3) identify the strain(s) of Map isolated. Six wood bison were evaluated with clinical signs suggestive of JD. We performed necropsies within 24-48 hours after euthanasia, and collected a total of 24 tissue samples from each bison. At necropsy, no evidence of thickening or corrugation of the intestinal mucosa was observed in any bison. However, on histopathology granulomatous lesions with acid-fast bacilli were more frequent in the paracortex of the mid-jejunal lymph node (LN) and distal jejunal LN, followed by ileal LN in comparison to the rest of the tissue samples evaluated. In general, tissue culture had the highest proportion of positive samples, with 62.5% (90/144) of positive samples, followed by F57/IS900 qPCR with 43.1% (56/130), and histopathology with 29.0% (38/131). Based on this study, we 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 gross lesions. Finally, using IS1311 PCR-Restriction Enzyme Analysis (REA) and Single Nucleotide Polymorphisms (SNP-PCR), we identified a type II (cattle) strain, secondary clade in tissue samples. These findings have practical relevance for field necropsies as they provide evidence to direct selection of preferred sampling sites to detect Map in wood bison and to choose appropriate diagnostic techniques.

For a complete understanding of the course of disease, it is important to understand the clinical, pathological and laboratory outcomes of animals that are affected by *Map*-infections before showing clinical signs. To aid in this understanding, four categories were defined to indicate the stage of *Map*-infection, and the animals matching these categories were identified (Table 3).

Table 3: Category definition for animals in different stages of Map-infection

Category	Clinical Signs	IS9OO	F57	Number of Animals	Comments
1	+	+	+	6	Reported (2023)
2	-	+	+	2	
3	-	+	-	4	
4 (healthy)	-	-	-	1	

Two animals, H757 and 758, were identified in Category 2; as *Map*-positive fecal samples with IS900/F57, however, those animals did not show clinical signs yet. They were humanely euthanized and shipped to Calgary for full necropsy work up. The macroscopic evaluation of the pathologist confirmed the diagnosis Johne's disease, and either five or six out of 26 tissue samples per animal that were processed for direct qPCR, were PCR test positive.

The histopathology results and tissue cultures from the two animals in Category 2, as compared to those from the animals from Category 1, are shown in Tables 4, 5 and 6.

Table 4: Direct qPCR test results on tissues from animals in Category 2

No.	Tissue Samples	H757	H758
1.	Tonsil		
2.	Retropharyngeal LN		
3.	Inguinal LN		
4.	Hepatic LN		
5.	Liver		
6.	Kidney		
7.	Spleen		
8.	Duodenum		
9.	Duodenal LN		
10.	Mid-jejunum		
11.	Mid-jejunum LN		
12.	Distal jejunum		
13.	Distal jejunum LN		
14.	Proximal Ileum		
15.	Mid-ileum		
16.	Distal ileum		
17.	Ileal LN		
18.	Ileocecal valve		
19.	Ileocecal LN		
20.	Caecum		
21.	Cecal LN		
22.	Spiral colon		
23.	Transverse colon		
24.	Rectum		
25.	Tracheal LN		
26.	Lung		
	Positive Samples/Total Samples	06/26	05/26

Red cells indicate a qPCR positive test result for IS900 and F57

Table 5: Tissue histopathology test results for animals in Category 1 and 2

		Category 2		Category 1					
No.	**Tissue Samples**	**H757**	**H758**	**G671**	**C282**	**B170**	**E505**	**G684**	**Z009**
1.	Tonsil								
2.	Retropharyngeal LN								
3.	Inguinal LN								
4.	Hepatic LN								
5.	Liver								
6.	Kidney								
7.	Spleen								
8.	Duodenum								
9.	Duodenal LN								
10.	Mid-jejunum								
11.	Mid-jejunum LN								
12.	Distal jejunum								
13.	Distal jejunum LN								
14.	Proximal Ileum								
15.	Mid-ileum								
16.	Distal ileum								
17.	Ileal LN								
18.	Ileocecal valve								
19.	Ileocecal LN								
20.	Caecum								
21.	Cecal LN								
22.	Spiral colon								
23.	Transverse colon								
24.	Rectum								
	Positive Samples/ Total Samples	03/24	04/24	10/24	4/11	3/24	8/24	7/24	6/24
	Percentage of Positive Samples	13%	17%	42%	36%	23%	33%	29%	25%

Red and orange cells indicate IS900 and F57 positive test results

Table 6: Tissue culture test results for animals in Categories 1 and 2

		Category 2		Category 1					
No.	**Tissue Samples**	**H757**	**H758**	**G671**	**C282**	**B170**	**E505**	**G684**	**Z009**
1.	Tonsil								
2.	Retropharyngeal LN								
3.	Inguinal LN								
4.	Hepatic LN								
5.	Liver								
6.	Kidney								
7.	Spleen								
8.	Duodenum								
9.	Duodenal LN								
10.	Mid-jejunum								
11.	Mid-jejunum LN								
12.	Distal jejunum								
13.	Distal jejunum LN								
14.	Proximal Ileum								
15.	Mid-ileum								
16.	Distal ileum								
17.	Ileal LN								
18.	Ileocecal valve								
19.	Ileocecal LN								
20.	Caecum								
21.	Cecal LN								
22.	Spiral colon								
23.	Transverse colon								
24.	Rectum								
	Positive Samples/ Total Samples	6/24	5/24	17/24	18/24	11/24	15/24	13/24	16/24
	Percentage of Positive Samples	25%	21%	71%	75%	46%	63%	54%	67%

Red and orange cells indicate IS900 and F57 positive test results

The last data collection opportunity was during the fall round-up, when five animals were humanely euthanized on-site. Fecal samples from these animals were processed, and four out of five animals tested positive for IS900/F57. No opportunity was identified to send these animals to Calgary for full necropsy and workup.

Objective 4: Investigate comorbidities

The fecal sample collection strategy is now focused on group sampling mainly, due to very low fecal egg counts. Consequently, fecal samples that were collected from the field in October 2023 were 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.

In January 2024, again a sample was taken to get a group representation. A total of 37 samples collected by bison management team were processed: 18 from the main herd, 18 from East Toe Berm, and one from the South Herd. Egg counts were extremely low or not detected and not presented in table or figure.

Another 60 samples were received from the same three groups, as well as from yearlings and processed in February 2024. Parasite eggs were microscopically identified and classified into three distinct egg morphologies: Strongyle-type, Nematodirus, and Monieiza (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.

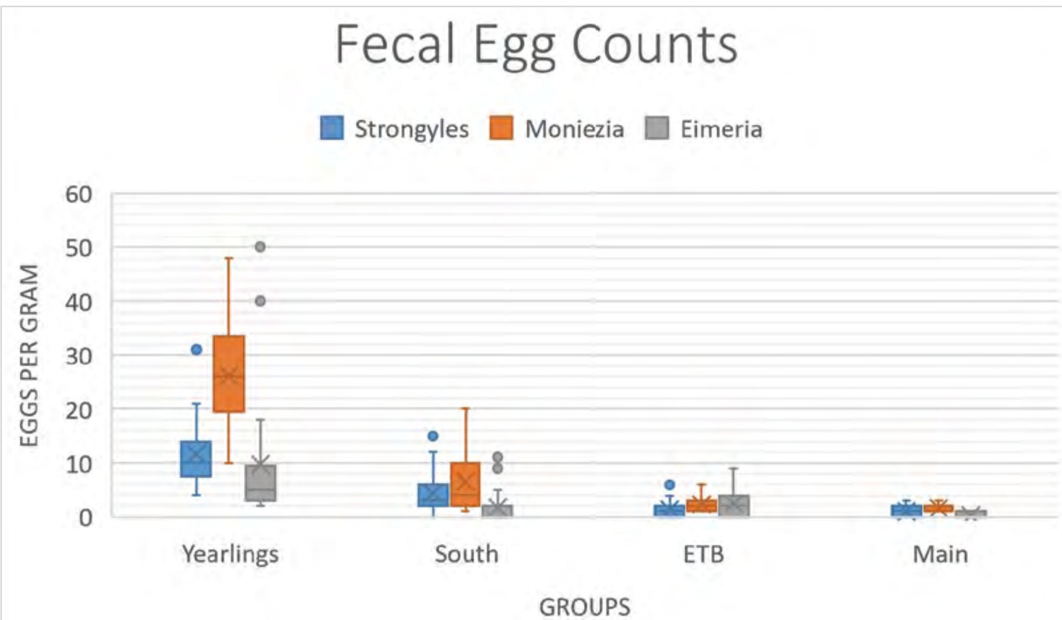

Figure 1: Fecal egg count results of 60 samples processed in February 2024

Another sampling opportunity was identified during the fall 2024 roundup. A total of 54 samples were collected. (Table 7)

Once again, extremely low egg counts were identified, along with unusual findings of zero to low egg counts. Only one of a total of 54 samples had a higher egg count. This sample was from a calf and is a relatively normal finding.

Table 7: Egg count results for 54 fecal samples collected during fall round up 2024

Egg counts	Number of samples	Comments
Zero (not detectable)	31	Extremely rare finding
Low egg counts (1-10 eggs/gram)	22	
High egg counts (> 25 eggs/gram for strongyle or > 50 eggs/gram for moniezia)	1	Calf M123 from the Main Herd

LESSONS LEARNED

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

The refined diagnostic tools, including qPCR and culture of *Map* bacteria from bison, are now routinely used in the research laboratory for diagnostics in bison samples. Culture has allowed for genetic characterization of the strain infecting bison as a strain of second clade as described in dairy cattle before.

1. qPCR has been validated and used with both the F57 and IS900 gene. Also, routine culture techniques for *Map* bacteria have proven effective and have allowed for strain typing in this herd. The identified strain has previously been described in domestic cattle. However, it is not a commonly identified strain.

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 within 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).

   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 that includes an adequate culling strategy based on fecal test positively.

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. Therefore, the following test strategy has been proposed:
   - Annual testing of all animals in the herd
   - Retesting every three months of animals that are solely qPCR-positive for IS900, to allow for early diagnostics when animals start testing positive for F57
   - Immediate culling of IS900/F57-positive animals from the herd

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

1. Based on the results from full necropsies of clinically affected animals, a better understanding of the tissues affected by *Map* infection was developed. This enables a more targeted approach to tissue sampling when a full necropsy and workup isn't feasible.
2. Through the categorization of different stages of the disease, project researchers have the impression (based on two animals) that distal jejunal lymph nodes are the most likely tissue to have a test-positive laboratory result. However, more observations are needed to confirm this statement.

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

1. Due to zero and low fecal egg counts, UCVM recommends that parasite control should be re-evaluated and treatment stopped, or significantly reduced, as the risk of development of anthelmintic resistance is very high. The low counts make the herd highly susceptible to the development of anthelmintic resistance, which has already been described in the commercial bison industry as a significant threat to bison health. The finding of "zero" egg counts in November when the last reported treatment was in July 2024 is extremely rare.

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Ahlstrom C., Barkema H. W., De Buck J. 2016. Relative frequency of 4 major strain types of Mycobacterium avium ssp. paratuberculosis in Canadian dairy herds using a novel single nucleotide polymorphism-based polymerase chain reaction. Elsevier. J Dairy Sci 99:8297–8303

PRESENTATIONS AND PUBLICATIONS

Published Theses

Dr. Ana Hernandez successfully defended her Master thesis in December 2023. Her approved thesis has been shared with Syncrude. Permission to publicize is expected spring 2025, when the two publications will be published in the peer-reviewed journals.

Journal Publications, Conference Presentations/Posters

No public presentations were released in 2024.

Journal Publications

Hernandez-Reyes A., De Buck J., Davies J. L., Eshraghisamani R., Martins L., Orsel K. Diagnostic strategies and strain typing for Johne's Disease in wood bison (*Bison bison athabascae*). Accepted for publication in Journal of Wildlife Diseases Aug 2024

Hernandez-Reyes A., De Buck J., Orsel K. Risk factors and impact of test and cull strategy on within-herd prevalence for Johne's disease in a captive wood bison herd. Accepted for publication in Can Vet J. Nov 2024.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Calgary

Principal Investigator: Dr. Karin Orsel

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ana Hernandez Reyes	University of Calgary	MSc	2021	2024
Muhammad Jehangir Asghar	University of Calgary	MSc	2023	
Jeroen De Buck	University of Calgary	Professor		
John Gilleard	University of Calgary	Professor		
Susan Kutz	University of Calgary	Professor		
Frank van der Meer	University of Calgary	Professor		

Canadian Toad (*Anaxyrus hemiophyrs*) Mitigation, Monitoring, and Habitat Suitability Index Modeling

COSIA Project Number: LJ0325 and LJ0326

Mine

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

Industry Champion: Canadian Natural

Industry Collaborators: Suncor

Status: Ongoing

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 and Albian Oil Sands, as well as Suncor's Base Plant and Fort Hills mine operations. Canadian Toads have been documented by staff from Canadian Natural, Suncor, and LGL Limited,, as well as 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 these leases, 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 the 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.

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.

Task 5: Apply, validate and, if needed, refine the updated Canadian Toad habitat suitability index model for each lease.

Task 6: Develop a radio telemetry study to track Canadian Toad movement and locate overwintering sites.

In previous years the main study area consisted of Horizon and Horizon South with some opportunistic Automatic Recording Unit (ARU) monitoring at Albian. In 2023 the Albian Sands lease was fully incorporated into this project; all research methods employed at Horizon, including mitigation translocations, were expanded to include Albian.

In 2023, Suncor (Suncor Base Plant and Fort Hills Operations) joined the Canadian Toad Monitoring Joint Industry Partnership.

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 environmental DNA 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: 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.

In 2019, the Canadian Toad 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). In 2024, the Canadian Toad HSI model was updated and applied to Suncor's Base Plant (EPEA 94-03-00) and Fort Hills Operations (EPEA 151469-01-00). The updated HSI model will support this program by identifying habitat on Suncor Base Plant and Fort Hills that could be involved in mitigation translocations, either as donor sites within the mine footprint or receiving sites away from mine disturbance. 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. Future field work including soil sampling, ground-truthing datasets that have been referenced, and identifying Canadian Toad breeding habitats will allow for the validation of this habitat suitability model and contribute to mitigation related to habitat loss associated with mine expansion on Suncor's Base Plant and Fort Hills leases.

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 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.

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).

For Canadian Natural, 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. 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 in Alberta 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 here will be 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. The updated HSI model will support this program by identifying habitat on Suncor leases that could be involved in mitigation translocations, either as donor sites within the mine footprint or receiving sites away from mine disturbance.

Though progress was made on several other aspects of the toad mitigation program at Canadian Natural, more work remains to assess translocation success, characterize overwintering habitat where it occurs, and pursue new and innovative ways to conserve Canadian Toad habitat in the future. Future research directions will continue to support mitigation of impacts to Canadian Toads and their habitat, utilizing translocations where necessary.

PROGRESS AND ACHIEVEMENTS

In 2024, LGL made progress on four of six main tasks. They (1) assessed wetland occupancy using ARU arrays and in-person surveys, (2) tested for *Bd* and ranavirus infection prior to relocating toads, (3) relocated 13,121 Canadian Toads away from the impact of mine operations, and (4) completed fieldwork to validate the updated habitat suitability index model. In 2024, the radio telemetry component (task 6) was not addressed because no toads large enough to support the weight of the transmitter were encountered and no new overwintering hibernacula were confirmed.

Tasks 1-5 listed in the Project Summary were addressed in 2024 on Canadian Natural's Oil Sands leases. LGL investigated Canadian Toad presence (Task 1) at Canadian Natural's leases using autonomous acoustic recording units (ARUs) and field-based surveys. Ponds and wetlands at Horizon Oil Sands, Horizon South, and Albian Sands were monitored by 20 ARUs that recorded acoustic activity nightly for the duration of the active season (roughly May to September; Figure 1). The ARU data were used along with habitat features, future mine development land use plans, historical amphibian occurrence, and observations from other contractors on site to guide a survey effort of 375 worker-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). Total detections decreased compared to 2023, but several newly active wetlands were also discovered. Canadian Toads were also present at the designated receiving sites at both leases.

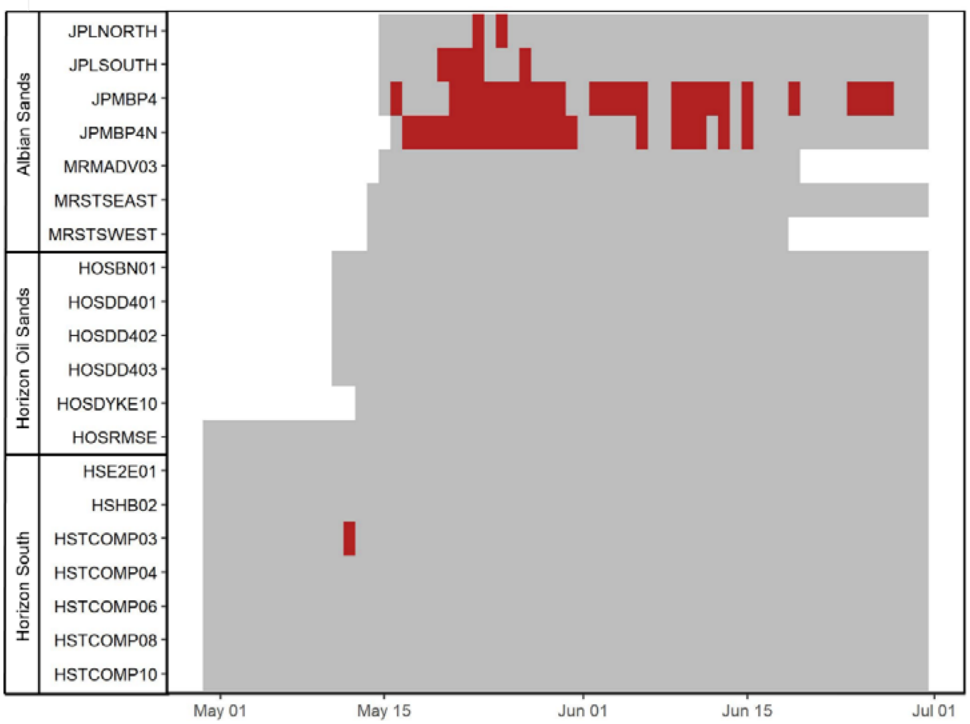

Figure 1: Timeseries of detections by ARUs stationed on Canadian Natural leases. Positive detections were made at Toad Complex on Horizon South (HSTCOMP03) and at Jackpine Lake (JPLNORTH and JPLSOUTH) and JPMBP4 (JPMBP4 and JPMBP4N) at Albian Sands. Non-detections outside of May 1 to July 1 have been truncated for scale.

Task 2, testing toads for fungal and viral pathogens, was completed as a precaution prior to relocating animals. Dermal swabs were collected from 84 amphibians including 31 Canadian Toads, 35 Wood Frogs (*Lithobates sylvaticus*), and 18 Boreal Chorus Frogs (*Pseudacris maculata*) from Albian Sands and Horizon South. To avoid potentially spreading pathogens between watersheds, animals were only moved between wetlands with disease testing results that were alike (i.e., both positive or both negative).

Task 3 was addressed at Horizon South and Albian Sands. Forty-six toads were captured at Horizon South in August and relocated to the receiving site at Toad Complex and all were recent metamorphs. At Albian Sands, 13,075 Canadian Toads were translocated: 10,774 were tadpoles (larval stage) and the remaining 2,301 were newly metamorphosed toads. No adult toads or eggs were translocated from the site in 2024. Follow up surveys confirmed that translocated larvae successfully developed at the Albian Sands receiving sites, with metamorphs observed at each location.

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. LGL 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.

Field validation of the updated habitat suitability model was completed for all Canadian Natural leases in 2024. Validation involves assessing habitat features and components at a subset of polygons and comparing them to model predictions. This ensures that spatial datasets used to run the model accurately reflect conditions on the ground and confirms assumptions that model variables are relevant components of habitat suitability. Generally, model predictions correlated well with habitat as appraised during field visits. The limited area rated as highly suitable has generally been found to contain features thought to be conducive to overwintering survival. Habitat in polygons free from mechanical disturbance have been especially well-predicted by the model. Some inconsistencies have arisen in areas that have been reclaimed or otherwise affected by industrial activities, because those processes affect the landscape and the substrates but are not necessarily captured by spatial datasets. For example, where suitable substrates are present but have been compacted by heavy machinery – this detracts from soil penetrability, preventing toads from accessing depths required to escape freezing 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 appears to be effectively predicting the occurrence of suitable habitat but its predictions should be considered in the context of recent and historical mine activity.

In 2024, the update and application of the Canadian Toad HSI model (Task 5) was conducted for Suncor Base Plant and Fort Hills Operations (Hawkes and Conlin, *in review*). LGL identified over 6,797 ha and 3,910 ha of Canadian Toad habitat in the currently undisturbed portions of Suncor's Base Lease and Fort Hills Operations, respectively (Figure 2: Distribution of high, moderate, low, and nil suitability Canadian Toad habitat at A) Suncor Base (left) and B) Fort Hills Operations (right).). Only approximately 568 ha for Suncor and approximately 706 ha for Fort Hills were identified as highly suitable while most were identified as having low suitability (approximately 6,220 ha for Suncor and approximately 3,166 for Fort Hills). This is not to suggest that Canadian Toad habitat does not occur on Suncor Base Plant or Fort Hills Operations. The results are simply a reflection of the relationship between what is considered suitable overwintering habitat, suitable breeding habitat, and the distance between those two important and limiting habitat features. The outputs of HSI models can be thought of as hypotheses of species habitat relationships that aim to be biologically valid and operationally robust; however, they are derived from expert opinion and literature review. As such, the model outputs presented here should be considered relative to the somewhat limited knowledge available regarding Canadian Toad overwintering habitat in the Athabasca Oil Sands Region. Field validation for the HSI model applied to Suncor's Oil Sands leases will be scheduled for 2025.

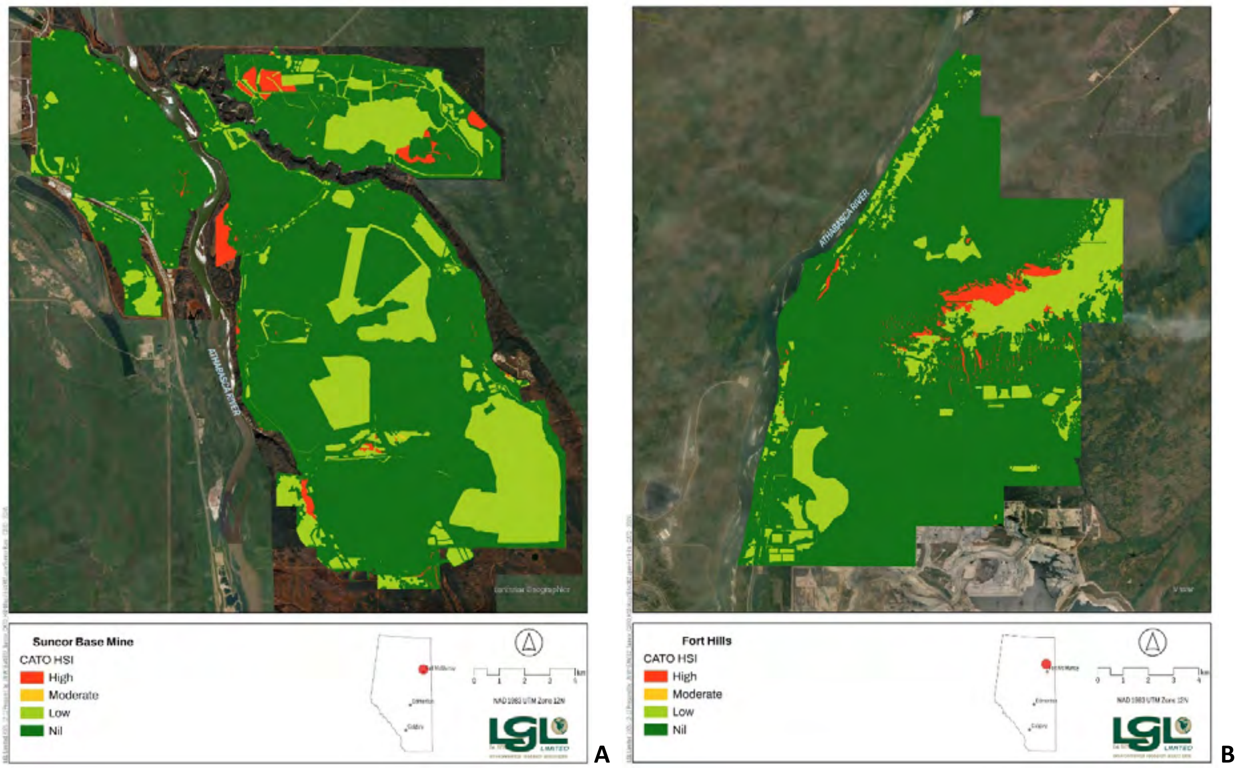

Figure 2: Distribution of high, moderate, low, and nil suitability Canadian Toad habitat at A) Suncor Base (*left*) and B) Fort Hills Operations (*right*).

Based on the available literature it is reasonable to assume that loose or very friable (e.g., sandy) soils of 1 m to 1.2 m in depth will provide highly suitable overwintering habitat for Canadian Toad. However, it is unknown if other potential overwintering habitats such as old squirrel middens, small mammal burrows, or even American beaver (*Castor canadensis*) lodges could provide suitable overwintering habitat. Furthermore, the suitability of various wetland types has not been adequately assessed and the current model is based on toad ecology in general and on the characterization of known and suspected breeding habitat. Future field work including soil sampling, ground-truthing datasets that have been referenced, and identifying Canadian Toad breeding habitats will allow for the validation of this habitat suitability model and contribute to mitigation related to habitat loss associated with mine expansion. LGL proposes sampling at Suncor Base Plant and Fort Hills Operations to inform validation of the Canadian Toad HSI model. As with all habitat suitability index models, further adjustments and subsequent validation processes may be required as more information regarding Canadian Toad ecology becomes available.

LESSONS LEARNED

Several lessons related to Canadian Toad monitoring and relocation at the Canadian Natural Oil Sands leases 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 documented many active breeding sites and collected 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 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. The biggest obstacle to translocations was to obtain enough swab samples for disease testing prior to translocating amphibians from the sites within the mine impact area. By the time a robust profile of disease testing is obtained, adult toads are less likely to be encountered. Unfortunately, this process reduces the chance that adult toads will be translocated, as they are most conspicuous for a short period of time at the start of the season, and thus are at risk of impact from the mine activities. Over successive years of disease testing at these sites, researchers have concluded that *Batrachochytrium dendrobatidis*, the causal agent of chytrid disease, is prevalent at all sites, despite inconsistent results between individuals and years. While *Bd* is ubiquitous, no amphibians were observed with the deleterious signs of this disease. A re-evaluation of disease testing requirements would improve mitigation translocations, and the best outcome would be to move adult toads and eggs during the breeding season rather than missing this important timing window.
5. 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 young-of-the-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 2024.

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Principal Investigator: Virgil Hawkes

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Early Successional Wildlife Dynamics Program

COSIA Project Number: LJ0013

Mine

Tour Facilitator: LGL Limited environmental research associates

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Canadian Natural Upgrading Limited, Suncor Energy Oil Sands Limited Partnership (Suncor and Fort Hill Operations), Imperial, ConocoPhillips

Status: Supplemental Year 2

PROJECT SUMMARY

The Early Successional Wildlife Dynamics (ESWD) program is a long-term, multi-taxa wildlife monitoring program designed to assess the efficacy of upland reclamation to provide habitat for wildlife in the mineable and in situ portions of the Athabasca Oil Sands Region (AOSR). Sampling for the ESWD program occurs on seven different types of sites: (1) reclaimed (REC); (2) reclaimed habitat adjacent to compensation lake (COMP); (3) mature forest (MF); (4) cleared habitats (CLR); (5) logged (LOG); (6) burned (BRN) habitats; and (7) fragmented mature forest (FMF). Although the primary contrast of interest is between REC and MF sites, sampling from COMP, LOG, BRN, FMF and CLR habitats provide an indication of whether wildlife usage patterns on reclaimed landforms are consistent with those associated with sites recovering from stand replacing fire, logging, or site clearing. Since the ESWD program began in 2012 much has been learned about wildlife use of the different habitat types, however, more remains to be learned about year-round use by species other than mammalian wildlife.

The ESWD program has transitioned to a combination of Phase 1 (baseline data collection) and Phase 2, with an emphasis on the productivity and function of habitats reclaimed to an upland landform. The ESWD Phase 1 program was initially implemented on surface mines in the Athabasca Oil Sands Region but now includes in situ operations. Phase 1 was a baseline data collection program to understand the occurrence and distribution of wildlife using habitats reclaimed to an upland landform. A summary of the ESWD Phase 1 work is provided by Hawkes et al. (2021) and several papers have been published in the peer-reviewed literature (Hawkes and Gerwing, 2019; Hawkes et al., 2021; Hawkes et al., in review). Phase 2 aims to assist operators in creating more effective habitats during reclamation activities while also meeting various other environmental approval clauses. Some of this work will involve collecting new data, such as attempting to measure songbird productivity; however, much of the analysis can be conducted using data that has already been collected for the ESWD program. Phase 2 will also aid in establishing the expected criteria and performance measures in EPEA approvals for wildlife habitat, ecosystem function, sustainability, and biodiversity.

Work associated with Phase 2 began in 2023 and was expanded in 2024. This report briefly summarizes the status of Phase 1 data collection and summarizes data collected under the ESWD Phase 2 program in 2024.

PROGRESS AND ACHIEVEMENTS

Phase 1:

Data collected under the ESWD program provides a good understanding of the occurrence and distribution of wildlife relative to reclaimed, mature forest, burned, logged, cleared, and compensation lake habitats (Hawkes and Gerwing 2019; Hawkes et al., 2021); however, data gaps remain. Sample sizes are limited for some habitats and mature forests, and logged, burned, and cleared habitats and compensation lake sites continue to be difficult to locate in areas where sampling is feasible. Reclamation in the AOSR has been ongoing for over 50 years but reclaimed areas older than 38 years have not been sampled, limiting the ability to evaluate the trajectory of wildlife populations. Older reclaimed sites exist and efforts to gain access to those sites are ongoing. Further, some recently added sites do not have a full five-year dataset at the end of 2024, and data collection will continue at these sites until this is achieved. These sites include all the sites at Horizon South, two at Albian Sands, two at Kearl Oil Sands, and one at Fort Hills.

The ESWD program began collecting data at ConocoPhillips Surmont lease in 2023, an in situ extraction project located south of Fort McMurray. Five years of baseline data will be collected at mature forest and various types of reclaimed sites. Researchers will continue to add more in situ sites to the program in future years.

Summaries of Phase 1 results have been provided in past COSIA progress reports and are not included in this report.

Phase 2:

Phase 2 of the ESWD program is being conducted on all sites, including those that are undergoing data collection for Phase 1. Under Phase 2, three components of the program have been initiated, including:

- Food sources for Birds, Bats, Small Mammals and Amphibians
- Food sources for carnivores and raptors
- Winter bird use of reclaimed lands

Of the components listed above, the first two are currently in preliminary stages. This includes the “food source” programs that will evaluate habitat productivity and quality for a variety of animal groups and they are described briefly below. A more thorough summary is provided for winter bird use of reclaimed lands.

Food sources for Birds, Bats, Small Mammals and Amphibians.

Arthropods (insects, spiders, etc.) are an exceedingly abundant and diverse component of virtually all terrestrial and freshwater ecosystems and are the basis for many of the ecological communities that inhabit these environments. These organisms are prey for a wide variety of higher organisms (fish, amphibians, reptiles, birds, mammals), pollinate flowering plants, aid in the dispersal of seeds and fungal spores, and provide many other valuable ecological functions, all of which correlated with functional habitat. Project researchers are examining habitat use of both ground-dwelling and aerial insectivores as they relate to abundance of their prey to examine how reclaimed sites in the oil sands region are contributing to the habitat base for these species. Aerial insect biomass sampling using Malaise traps began in 2023 and was expanded in 2024 (Table 1: Number of plots sampled with Malaise traps in 2023 and 2024 for the ESWD program.); however, these data have not been analyzed. Pitfall trap data for ground dwelling insects and spiders, will contribute to analyses in future years.

Table 1: Number of plots sampled with Malaise traps in 2023 and 2024 for the ESWD program.

	Albian	Horizon	Horizon South	Fort Hills	Suncor Base Plant	Kearl	Surmont
2023	0	0	0	3	0	3	7
2024	7	7	3	3	12	4	10

Food sources for carnivores and raptors

The abundance and distribution of small mammals influences many other animals that use them as a primary food source. This includes coyotes, wolves, fisher, marten and several owl and hawk species. Reliable food sources are required to ensure the return of these species to reclaimed areas so determining reclamation practices that may influence the return of their prey species to reclaimed areas would be beneficial. To assess which reclamation practices are creating conditions for healthy small mammal populations, researchers are proposing a study that looks at their distribution as it relates to a number of habitat features that can be influenced by reclamation practices. This includes the placement of coarse woody debris, the placement of snags as perches for birds of prey, the placement of litter, and site-specific (landform for mature forest) topography of the site. The analysis will be a desktop exercise that attempts to model the influence of these habitat features that can be manipulated by reclamation practices. Re-population of reclaimed sites by small mammals can also be strongly influenced by the proximity to other habitat types, in this case proximity to mature forest or an opportunistic/constructed wetland. Proximity to features such as this will also be included in the model. The collection of abundance and distribution data for prey and predator species began in 2023; however, these data have not been analyzed.

Winter Birds:

Phase 1 of the ESWD program focuses primarily on the snow-free period (except for wildlife cameras, which are active year-round). To better understand year-round use of reclaimed habitats by species other than mammalian wildlife, a winter program to document the occurrence and distribution of winter-resident birds was implemented as of January 2024. Resident birds in the boreal forest require security and thermal habitat (roosting sites) along with a predictable food source to survive the winter months. An evaluation of the occurrence and distribution of reclaimed sites by resident birds and those that migrate to the AOSR from arctic breeding sites is an important measure of the ability of reclaimed habitat to provide for wildlife – including birds – on a year-round basis. Existing vegetation data can be reviewed relative to food availability (fruits and seeds) that may be used as winter forage for resident birds.

The program was initiated at the start of 2024, so visits to sites to document the presence and activities of birds were conducted in late winter (February-March) of 2024 only. In future, two visits will occur each year, with early winter surveys occurring in December and January and late winter surveys in February and March. Early winter surveys (2024-2025) were underway at time of writing, with sampling occurring in the Athabasca Oil Sands Regions on Albian Sands, Fort Hills, Horizon Oil Sands, Suncor Base plant and Surmont leases (Figure 1: Overview map of sampling points for February/March 2024 winter bird surveys, colour-coded by ESWD habitat type.). Some preliminary results are presented below.

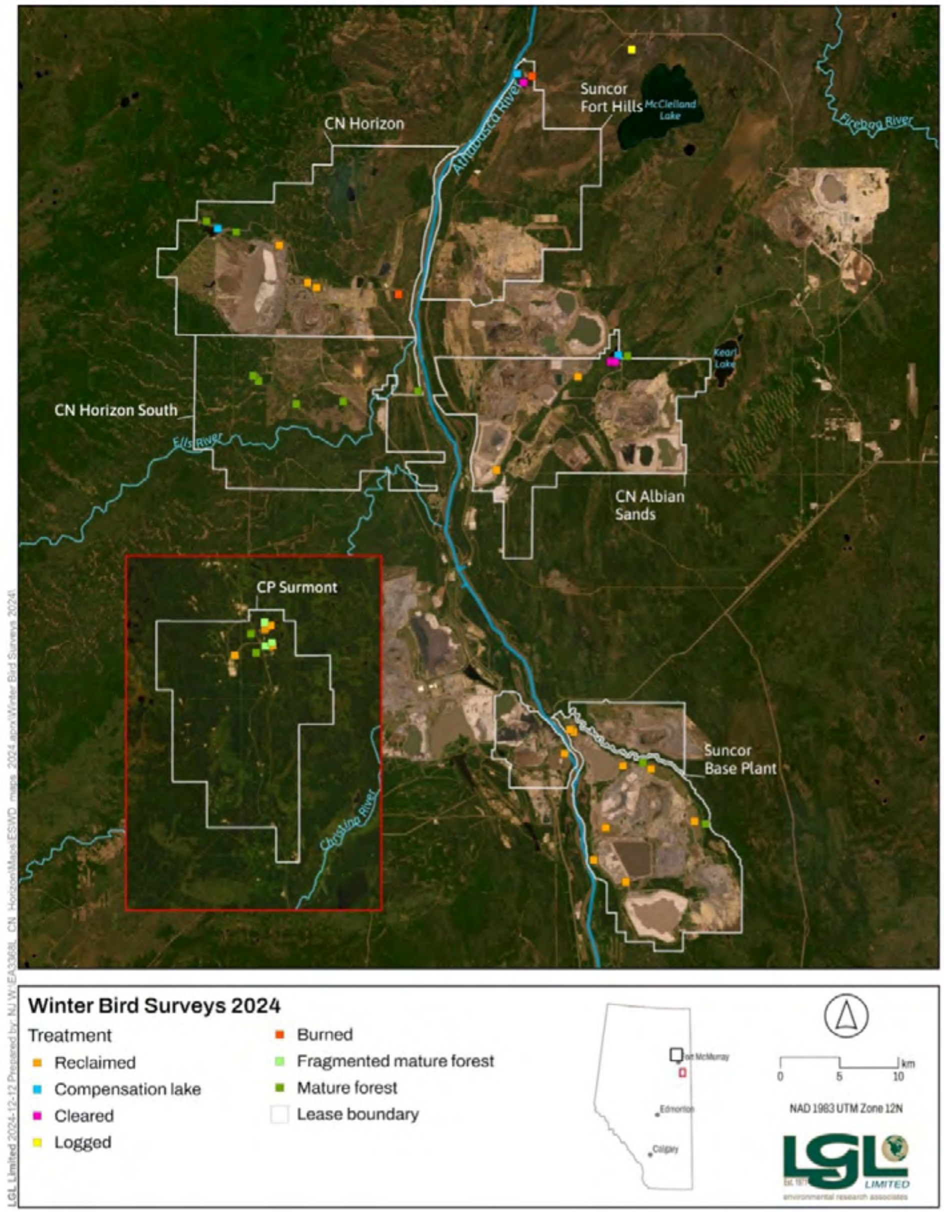

Figure 1: Overview map of sampling points for February/March 2024 winter bird surveys, colour-coded by ESWD habitat type.

Bird surveys were conducted on BRN (n = 2), CLR (n = 3), COMP (n = 3), FMF (n = 3), LOG (n = 1), MF (n = 12) and REC (n = 21) sites across five oil sands leases: Albian Sands, Fort Hills, Horizon Oil Sands, Suncor Base Plant and Surmont. A total of 235 birds (17 species) were recorded during the surveys (Table 2: Species observed and total number counted across habitat types for all surveys for February/March 2024 winter bird surveys, shown per lease. Habitat types are: Burned Forest (BRN); Cleared (CLR); Compensation Lake (COMP); Fragmented Mature Forest (FMF); Mature Forest (MF); Logged (LOG); and Reclaimed (REC). *Denotes a Provincially Sensitive Species. Blanks indicate no detections of that species on a given lease.). There was one species in BRN, six in CLR, nine in COMP, four in FMF, two in LOG, 15 in MF, and 12 in REC. There were also 16 unknown grouse, four unknown woodpecker and nine unknown bird observations. Eighty-six birds (36.6% of observations) were Common Redpoll, mostly from Fort Hills COMP site (57 Common Redpoll). Often the observations were of birds feeding or moving between feeding areas, often as a single species or mixed flock. In decreasing order, 19.1% of observations were Common Raven, 6.8 % were unknown grouse, 6.4% Canada Jay, 6.0 % Sharp-tailed Grouse and 6.0 % Black-billed Magpie. Common Raven was the only species in all seven habitat types, while White-winged Crossbill, Red Crossbill, Downy Woodpecker, Boreal Chickadee and Black-backed Woodpecker were only in MF; Spruce Grouse occurred only in LOG; Hoary Redpoll was only in REC; and Northern Saw-whet Owl was only in COMP.

Table 2: Species observed and total number counted across habitat types for all surveys for February/March 2024 winter bird surveys, shown per lease. Habitat types are: Burned Forest (BRN); Cleared (CLR); Compensation Lake (COMP); Fragmented Mature Forest (FMF); Mature Forest (MF); Logged (LOG); and Reclaimed (REC). *Denotes a Provincially Sensitive Species. Blanks indicate no detections of that species on a given lease.

Row Labels	BRN	CLR	COMP	FMF	LOG	MF	REC	Total
Albian Sands		**10**	**3**		**2**	**5**	**8**	**28**
Black-billed Magpie		2					1	3
Black-capped Chickadee		1						1
Canada Jay						2		2
Common Raven		4	2		1		3	10
*Sharp-tailed Grouse		3	1					4
Spruce Grouse					1			1
Unknown Grouse Species						1	4	5
White-winged Crossbill						2		2
Fort Hills	**1**	**13**	**62**					**76**
Canada Jay		1						1
Common Raven	1	1	1					3
Common Redpoll			57					57
*Pileated Woodpecker			2					2
*Sharp-tailed Grouse		7						7
Unknown Bird Species		4						4
Unknown Grouse Species			1					1
Unknown Woodpecker Species			1					1
Horizon Oil Sands	**2**		**9**			**27**	**31**	**69**
Black-billed Magpie						1	5	6
Black-capped Chickadee						1	5	6
Bohemian Waxwing						3	1	4
Canada Jay			1			4	2	7
Common Raven	2		3			12	9	26
Common Redpoll			2				3	5
Downy Woodpecker						2		2
Hoary Redpoll							1	1
Northern Saw-whet Owl			2					2

Row Labels	BRN	CLR	COMP	FMF	LOG	MF	REC	Total
Pine Grosbeak			1				1	2
Red Crossbill						2		2
*Sharp-tailed Grouse							3	3
Unknown Bird Species							1	1
Unknown Grouse Species						1		1
Unknown Woodpecker Species						1		1
Suncor Base plant						**11**	**28**	**39**
*Black-backed Woodpecker						1		1
Black-billed Magpie							5	5
Black-capped Chickadee							2	2
Boreal Chickadee						1		1
Canada Jay						1	1	2
Common Raven							1	1
Common Redpoll						6	11	17
*Pileated Woodpecker						1		1
Unknown Bird Species							1	1
Unknown Grouse Species						1	6	7
Unknown Woodpecker Species							1	1
Surmont				**6**		**2**	**15**	**23**
Canada Jay				2		1		3
Common Raven				1			4	5
Common Redpoll							7	7
*Pileated Woodpecker				2				2
Unknown Bird Species				1		1	1	3
Unknown Grouse Species							2	2
Unknown Woodpecker Species							1	1
Grand Total	**3**	**23**	**74**	**6**	**2**	**45**	**82**	**235**

LESSONS LEARNED

- Achieving adequate sample sizes to establish a baseline of the ecological diversity and heterogeneity across the different habitat types included in the ESWD program is essential for a robust analysis of reclamation effectiveness in the AOSR. However, achieving adequate sample sizes in some habitats (e.g., logged, burned, mature forest) is challenging due to logistical difficulties and time required to collect sufficient data from multiple, often remote, habitats.
- Under Phase 2 of the ESWD program, winter bird data are being collected using a moving transect within a one-hectare area in each of the ESWD sites. The precise methods are evolving as project researchers are learning to deal with the noise created when moving in a snow-covered environment. Observers are now spending more time standing still and listening for birds, then moving quickly to another stopping point.

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RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Virgil C. Hawkes

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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 3 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 forest.

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, mounted on a Cessna 182 aircraft, to remotely census large mammals using artificial intelligence and deep learning to optimize manual identification and counting in complex environments. Originally designed to detect fire hotspots, the TK-7 payload uses a high resolution camera to obtain imagery in strips by piecing together photographs of co-boresighted colour and thermal sensors.

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

For Research Milestones 1 and 2 in 2024 surveys were flown to collect data using the TK-7 imaging payload, from study areas across Alberta (including Athabasca caribou ranges and Sundre), Saskatchewan, and the Northwest Territories. The goal was to collect actionable data on multi-species occurrences, while also collecting data for continued research and development to advance the multi-spectral imaging payload for Identifying and counting wildlife in remote regions.

Areas surveyed during the spring imaging season (April-May) include:

Study area	Ungulates of Interest	Province	Number of Blocks	Number of Transects	Survey Boundary (km2)
Athabasca	Caribou, deer, moose	Alberta	9	98	63,361
Sundre	Feral horse, moose, elk, deer	Alberta	3	106	6,400
NE Sask	Moose, deer, elk	Saskatchewan	4	64	18,319
Foran	Caribou, moose	Saskatchewan	1	42	1,453
Orano	Caribou, moose	Saskatchewan	2	30	93
Great Slave Lake	Moose, bison, caribou	NWT	9	117	22,660

To enable multi-species detections and advance artificial intelligence (AI) solutions for identification and counting, collected data are being used to calibrate the system to optimize technical aspects of aerial surveys. In 2024, the project made specific improvements to the annotation workflow to develop training datasets, including developments in:

- Batch image conversions (methods acquire hundreds of terabytes (TB) a season of high-resolution imagery);
- Image alignment;
- Hotspot animal prediction; and
- Training and testing of a preliminary model (YOLOv7) to determine the viability and areas of improvement of the current dataset.

Also in 2024, the research team presented a paper addressing one of the AI solutions to counting and identifying rare animals on the landscape at the International Conference on Learning Representations (ICLR) in Vienna, one of the premier conferences in the field of machine learning and AI. This interdisciplinary work arose out of Pranav Chandramouli's MSc project with Ian Stavness in Computer Science. Branden Neufeld is a Professional Research Associate under Dr. Phil McLoughlin who, with Ian Staveness, holds a Canada Foundation for Innovation Grant which saw to the purchase of a first-for-Canada multi-spectral camera for attachment to an aircraft, with the objective of censusing wild mammals in remote areas with colour and thermal imaging.

LESSONS LEARNED

While application of the TK-7 payload is advancing towards the remote-sensing of large ungulates, indications are that the system is likely to be most useful in relatively open areas and where species being surveyed are large in mass. This may include open bogs and fens, taiga, shield, and tundra habitats. In areas of forest, the training sets needed for AI solutions to identify and count wildlife will require greater manpower to assemble. This is one of the current foci, having annotators working approximately 40 hours a week to develop the training set for machine learning with a particular focus on boreal caribou.

The work has additional promise for censusing beaver populations, as beaver dams including their thermal hotspots were easily identified in the imagery. The project team has also assisted industry partners in using the imaging payload to provide ultra-high-resolution (three cm colour) imagery for environmental monitoring in project areas.

PRESENTATIONS AND PUBLICATIONS

Chandramouli, P., I. Stavness, B. Neufeld, and P. D. McLoughlin. 2024. Composite augmentations for semantic segmentation in aerial images with few samples. International Conference on Learning Representations (ICLR) 2024 Machine Learning for Remote Sensing (ML4RS) Workshop. Published as part of the Proceedings, May 11, 2024, Vienna. 6 ms pages.

NOTE: Authors of primary research in computer science favour conference proceedings over journals because the format helps disseminate work out to the global community faster. The peer-reviewed proceedings contribution is openly available on GitHub and the conference's website.

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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)
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Aaryan Patel	University of Saskatchewan	BSc Student, Computer Science	2022	2026
Emmanuel Lyimo	University of Saskatchewan and African College of Wildlife Management	PhD Student, Biology	2023	2027
Branden Neufeld	University of Saskatchewan	Professional Research Associate, Biology		
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 4 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 helping maximizing effectiveness and efficiency of restoration activities. 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

A seismic line is a cleared corridor through vegetation, such as forests, created to facilitate seismic surveys for subsurface geological exploration. These clearings allow for the placement of seismic sensors or charges and provide access routes for equipment. Over time, seismic line construction methods have evolved, leading to two primary classifications: legacy seismic lines and low-impact seismic (LIS) lines.

Legacy seismic lines, constructed predominantly from the late 1940s until the late 1990s, are typically 5 m to 10 m wide. Built using heavy machinery like bulldozers, these lines are straight and wide, resulting in significant disturbance to the soil and vegetation. The straight paths were designed for optical surveys, necessitating clear, unobstructed routes. Low-impact seismic (LIS) lines emerged in the mid-1990s as a method to minimize environmental impact. These lines are narrower, ranging from approximately 1.75 m to 3 m in width. LIS lines employ mulchers to remove aboveground vegetation while preserving root structures, resulting in meandering paths that reduce visual and ecological disruption. The use of advanced GPS technology allows for precise navigation, eliminating the need for straight lines. The transition from legacy to low-impact seismic lines reflects the industry's commitment to reducing environmental footprints and promoting faster ecological recovery in exploration areas.

Mapping Trails and Tracks in the Boreal Forest Using LiDAR and Convolutional Neural Networks
Irina Terenteva, Department of Geography, University of Calgary

Trails and tracks are the detectable signs of passage of wildlife and off-highway vehicles in natural landscapes. They record valuable information on the presence and movement of animals and humans. The latest technologies currently used to track wildlife and biodiversity include global navigation satellite systems, camera traps, or environmental genomics. All these efforts could benefit tremendously from complementary information on trails and tracks. Maps of human trails and tracks can also enhance our understanding and mitigation of anthropogenic disturbances on ecosystems.

We compared maps developed with LiDAR from a drone platform (10 cm digital terrain model) with those from a piloted-aircraft platform (50 cm digital terrain model). We developed two U-Net models: one for the piloted-aircraft data and a second for the drone data. We assessed the accuracy of the two models using a census of all the trails and tracks located within eleven 50 m x 50 m test polygons distributed randomly across a physically separate test area.

There was no significant difference in the accuracy of the two maps. In fact, the piloted-aircraft map (F1 score of 77 ± 9%) performed nominally better than the drone map (F1 score of 74 ± 6%) and demonstrated better balance among error types.

Our maps reveal a 2,829 km network coverage of trails and tracks across our 59 km^2 study area. These features are especially abundant in peatlands, where the density of detected trails and tracks was 68 km/km^2. We found a particular tendency for wildlife and off-highway vehicles to adopt linear industrial disturbances like seismic lines into their movement networks. While seismic lines covered just 7% of our study area, they contained 27% of all detected trails and tracks. The observation supports the notion that humans and wildlife both use seismic lines as preferential travel corridors through the boreal forest, which may further impede forest recovery.

Our research demonstrates an emerging ability to map trails and tracks across large areas with remote sensing and convolutional neural networks — a capacity that can benefit a broad variety of research and management communities.

Linear Feature Edge Effects on Songbird Communities in the Boreal Forest of Alberta
Tharindu Kalukapuge, Department of Biological Sciences, University of Alberta

Alberta's boreal forest is extensively dissected by energy sector linear features (LFs). Dissection is considered an early stage of fragmentation. Studies have shown that gap width influences whether birds perceive LFs as creating edges or as boundaries for their territories. However, given the substantial variation in LF widths (approximately 4 m to 120 m) how wide a LF must be to cause habitat loss beyond fragmentation and edge effects for birds in the boreal forest of Alberta is poorly understood. Past research has shown positive, negative, or neutral effects of LFs width on forest bird communities. However, currently in Alberta, most wildlife models used for regulatory decision-making treat LFs being the same width, or in broad categories such as soft and hard LFs or narrow, intermediate and wide categories. Such categories have also been used inconsistently across studies, which makes it difficult to generalize results.

As a result, although the impacts of linear features on birds have been reported, there is not alignment on how linear width per se influences birds in the boreal forest.

Over the past four years from 2021 to 2024, we surveyed nearly 3,000 linear features, including legacy 2D seismic lines, pipelines, and transmission lines, ranging in widths from 4 m to 120 m. These linear features represent different vegetation recovery stages and were located across different ecosite types. This project has now been published in the journal Avian Conservation and Ecology, presenting our analysis of how boreal songbirds and communities in upland deciduous and mixedwood forests respond to linear features of varying widths.

Our results show that boreal songbirds and communities respond to linear feature width. Forest specialists decline at widths greater than those typical of seismic lines, while early seral and shrub-associated species increase. Species show specific threshold responses to line width. We recommend moving away from traditional grouping of linear features in impact assessments and provincial bird models and instead using specific widths to understand wildlife responses to improve management and restoration efforts.

Remote Sensing Tree Species Detection for Seismic Line Restoration Planning
Nicole Byford, Department of Geography, University of Calgary

Assessing seismic line regeneration status is a key part of seismic line restoration planning. This relies on accurate assessments of the existing regeneration, including tree species composition, density, coverage, and growth rate. High-resolution remote sensing data and its analysis (e.g., deep learning) show promise for conducting these assessments over extensive areas; however, the achievable accuracies of these methods require further investigation. In this study, we set out to document the effect of data modality (i.e., conventional red-green-blue, multispectral, LiDAR) and spatial resolution on seedling detection accuracies in boreal wetlands.

Conventional red-green-blue (RGB) (1 cm/pixel), multispectral (5 cm/pixel), and LiDAR (200 pts/m^2) data were collected using a drone for ten regenerating seismic line segments in treed wetlands within the Surmont lease area. Deep learning models were developed for each data source to detect black spruce (*Picea mariana*) and tamarack (*Larix laricina*) seedlings.

Conventional RGB imagery with ultra-fine spatial resolution (1 cm/pixel) was more effective than coarser-resolution multispectral imagery (5 cm/pixel) for deep learning-based seedling mapping, indicating that spatial resolution should be prioritized over spectral resolution in this context. This is particularly important for seedlings with crown diameters smaller than 60 cm (approximately 1 m height). We found, however, that larger seedlings (taller than approximately 1 m) can be reliably detected from both data sources. This is promising for operational scalability of remote-sensing workflows for seismic line restoration planning, since multispectral imagery with the specifications used in this study (5 band, 16-bit, 5 cm/pixel) can be acquired over extensive areas using manned aircraft.

When spatial resolution cannot be improved, acquiring imagery in additional spectral bands (e.g., near infrared, red-edge) can improve seedling detection accuracies. However, combining LiDAR with conventional RGB or multispectral imagery did not substantively or consistently improve seedling detectability in this instance, even in shadowed areas that are problematic for the optical data sources. As such, we found that LiDAR provides limited value to the workflow used in this study and may not be worth the additional acquisition cost.

Assessing Changes in Peatland Plant Community Functions Following Seismic Line Disturbance of Different Ages
Christina Bao, Department of Geography and Environmental Management, University of Waterloo

The study in a rich fen, initiated in 2022 at Canadian Natural's Kirby South, assessed plant community composition and functional traits across four site types with varying disturbance histories (undisturbed, old - disturbed once 30 years ago, re-disturbed – disturbed once 30 years ago and again in the winter before the study, new – disturbed the winter before the study). Measurements included plant community composition, plant height, leaf chemistry, and environmental variables like depth to water table, water pH and soil nutrients to evaluate differences across site types.

Understory plant community composition was not substantially different among the disturbance types, although sites disturbed 30 years ago were most similar to undisturbed sites. This indicates that understory communities in rich fens establish quickly after disturbance and that passive recovery of the understory plant community occurs on decadal time scales.

New and re-disturbed sites were characterized by plant traits that favour rapid growth and resource acquisition and these competitive strategies could compromise re-establishment of resource conservative species, like black spruce. However, species like *Betula gladulosa*, through their rapid growth, help to recreate some of the pre-disturbance environmental conditions, like ground layer shading, that help support plant communities similar to adjacent undisturbed areas.

We found that the extent of intraspecific trait variation (ITV) differed among species. While ITV played a role in shaping plant traits following disturbance, community weighted mean of traits varied more among disturbance types than did mean traits values; this illustrates that shifts in species composition played a more important role in community level functional changes in response to disturbance than ITV alone.

Local Hydrologic Conditions and Seismic Lines in the Boreal Forest of Northern Alberta
Lelia Weiland, Department of Geography, University of Calgary

Much research has been completed on vegetation regrowth on seismic lines; however, little is known about the underlying mechanisms which control this. Previous work has identified changes to soil properties, where soils on seismic lines can have a higher compaction than in the adjacent area. By investigating the summer and winter hydrology of low impact and legacy seismic lines, we hope to answer the question: how do seismic lines affect water movement?

Soil and hydrology data was collected from seismic lines on Stony Mountain and at Kirby South in the Boreal region of Northern Alberta in 2021-22. Snow data was collected in the winter of 2022.

The core findings from this work are that seismic lines do affect both summer and winter hydrological processes, as well as soil hydrophysical properties. The way in which the seismic line will interact with these processes differs depending on seismic line characteristics and surrounding topography. Line wetness – a limiting factor for seedling growth – is influenced by the mesotopographical position of the seismic line. This study also showed that snow accumulates differently on seismic lines than the surrounding matrix, which may lead to increased line wetness.

These results together suggest that seismic lines may result in altered catchment-scale hydrological processes: something that should be examined in future work. The findings from this research may influence where seismic lines should be constructed to maximize restoration potential post-exploration.

A Data Compilation and Synthesis of the Effects of Seismic Surveys on Surface Soil Properties

Marissa Davies, Department of Geography and Environmental Management, University of Waterloo

Planning seismic line restoration requires assessing all abiotic and biotic factors that control forest regeneration. One such factor is soil properties, as they are associated with water and nutrient retention and biogeochemical cycling and affect vegetation growth and subsequent ecosystem recovery. This project aimed to collect new and compile previously published data on three major soil properties at both reference (off-line) and on-line sites across the various ecosites of northern Alberta: (i) dry bulk density, (ii) water content, and (iii) organic matter content. The compiled dataset provides a summarized baseline for land managers to quantitatively evaluate seismic line recovery and the efficacy of restoration techniques.

Surface soil samples were collected across the BERA study region in the summers of 2022/2023. Each study site had soil samples taken on and adjacent to a seismic line (reference sample). Samples from the BERA 2022/2023 field seasons were combined with data from previous studies across northern Alberta for a total of 51 sites and 1,638 individual surface samples.

Dry bulk density and organic matter content on seismic lines are significantly different from reference samples, especially on older, conventional 2D seismic lines. Changes in dry bulk density can in part be explained by the loss of organic matter in the soil, which increases the dry bulk density. Even accounting for organic matter loss, seismic lines still have higher dry bulk densities for a given organic matter content, suggesting that other factors, such as enhanced decomposition, compression, and changes to litter inputs are also needed to explain differences from reference samples. Soil properties in peatland and transitional samples on conventional, 2D lines are not distinguishable by microtopography, suggesting that the simplification of the seismic line surface has remained post-disturbance. In low impact, 3D seismic lines, however, microtopographic patterns of soil properties are similar to reference values, suggesting limited soil disturbance and/or more rapid recovery. Since microtopography appears to remain intact or recover on low impact seismic lines, inverted mounding may not be necessary. Seismic lines in upland areas with additional disturbances, such as forest harvesting and wildfire, have no detectable difference between seismic lines with no additional disturbance. Therefore, the role of additional disturbances on surface soil properties on seismic lines appears to have less of an effect than seismic line creation itself, likely due to post-disturbance processes.

LESSONS LEARNED

1. Remote sensing can help map tracks and trails across large landscapes

LiDAR and deep learning are tools that can be used to map off-highway vehicle tracks and wildlife trails across large landscapes, though we are constrained by data availability and certain environmental conditions. Mapping these features can provide valuable insight into how humans and wildlife are using linear features as movement corridors, which inhibits vegetation recovery. Mapping tracks and trails can support future research and management decisions to mitigate these effects.

2. Songbirds are more affected by line width than line type

Linear feature width is a key driver of songbird diversity and species composition, and different species show different threshold responses to linear feature width. Land managers, researchers, or other stakeholders should consider line width rather than line type when assessing linear feature impacts and making restoration or management decisions.

3. Capturing the state of lines: how remote sensing can support restoration planning

Remote sensing and deep learning are effective tools for assessing seismic line vegetation recovery, but the achievable accuracy depends on data resolution and seedling size. Ultra-high-resolution drone imagery (1 cm/pixel) is essential for reliably mapping small seedlings (< 1 m tall). Larger seedlings, however, can be effectively mapped using coarser imagery (5 cm/pixel), which is more feasible for operational-scale restoration planning.

4. Are peatlands recovering?

Understory plant communities on seismic lines disturbed 30 years prior to the study demonstrated that passive recovery, given enough time, can facilitate the regeneration of key species and ecosystem functions without the need for extensive interventions. However, targeted efforts are still beneficial to accelerate the establishment of the slower-growing species, including peatland trees. Restoration efforts should aim to maintain the functional integrity of these reestablished communities while recognizing that some areas are already progressing toward a pre-disturbance state.

5. Seismic lines alter hydrology through increased snow accumulation and soil compaction

Seismic lines can disrupt local hydrological conditions through soil compaction and vegetation removal. These impacts are largely dependent on the spatial configuration of the seismic line relative to the surrounding ecosystem. Seismic lines accumulate more snow in winter which can have impacts on the local hydrology. Additionally, the compaction of the soil and the proximity of the water table to the surface are affected, hindering vegetation recovery and altering carbon dynamics on seismic lines.

6. A reference dataset for evaluating seismic line recovery and treatment selection

Soils are disturbed during the creation of seismic lines which has impacts on how water, nutrients, and other compounds are stored and cycled throughout the soil. A surface soil-property dataset, combined with linkages to tree growth responses, compiled by BERA can support restoration managers in evaluating seismic line recovery and selecting appropriate restoration techniques.

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Reports & Other Publications

The Edge 2024. Expected publication mid to end February 2025.

RESEARCH TEAM AND COLLABORATORS

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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: Final Cumulative Summary

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 three primary goals of the project were to:

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

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

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

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

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

Table 1: Performance Metrics Summary

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

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.

EcoSeis Phase 2 project results and lessons learned have been published in detail in four journal articles, 37 conference/workshop presentations, 41 other presentations, and four awards. Where an abstract or transcript of recording is available, references and links for these are provided in the next section. Project work was divided into four categories: Geophysics, Environment/Field Operations, Data Analytics, and Software. The following narrative describes the work completed and lessons learned within each of these categories.

Geophysics

EcoSeis Phase 2 Technical Field Trial

The technical field trial provided verification of the EcoSeis method for acquiring high-quality, cost-effective subsurface images with a reduced land footprint and GHG emissions (Naghizadeh & Crook, 2024b). The EcoSeis geometry utilized in the 3D technical field trial compared favourably with the conventional 3D orthogonal geometry typically utilized at the site. Subsurface imaging results were similar for both datasets with good ties to well logs and little difference in steam chamber imaging. Unexpectedly, observations from processing and interpretation indicate that EcoSeis methods are compatible with time-lapse (4D) over legacy surveys. This has significant impact on the acquisition of future 4D seismic surveys since it indicates that if designed and processed correctly, a 4D survey may not need to repeat the exact same source and receiver locations as the original baseline 3D. This has led to a new and exciting area of research into sparse 4D acquisition for cost-effective measurement, monitoring, and verification (MMV) for carbon capture and storage (CCS) projects (Crook, 2024).

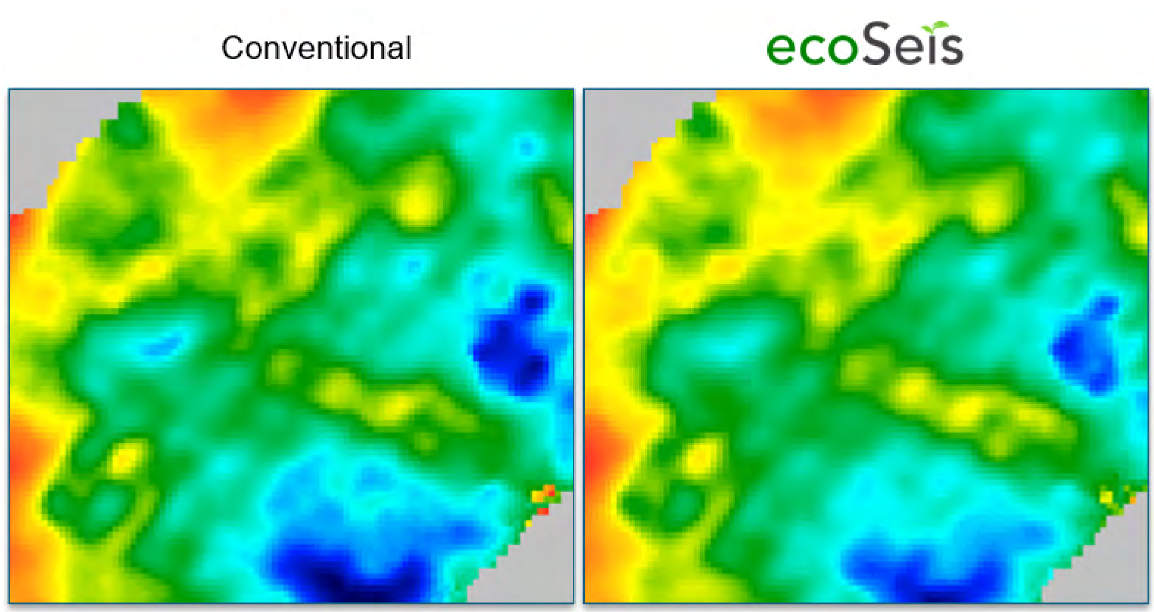

Figure 1: Seismic time slice from the conventional 3D (left) and the EcoSeis 3D (right) showing excellent correlation between the two methods.

Geometry Analyses

Alternative linear geometries, such as EcoSeis, can provide a new way to acquire seismic data with a lower overall land footprint (Crook, 2022). Depending on the method of implementation, reductions in linear kilometers over 50% can be achieved. In non-forested areas, the reduction in linear kilometers can increase operational efficiencies, resulting in cost savings and reduced emissions. Subsurface imaging with EcoSeis geometries is comparable to conventional orthogonal geometries (Figure 2). However, converting a conventional orthogonal geometry to an alternative linear geometry requires careful consideration to ensure adequate imaging at all targets. The distance between lines, amplitude, and frequency of line variations (sinusoidal aspect) and the distribution of stations along the line play a part in determining the ultimate subsurface resolution (Naghizadeh et. al., 2023).

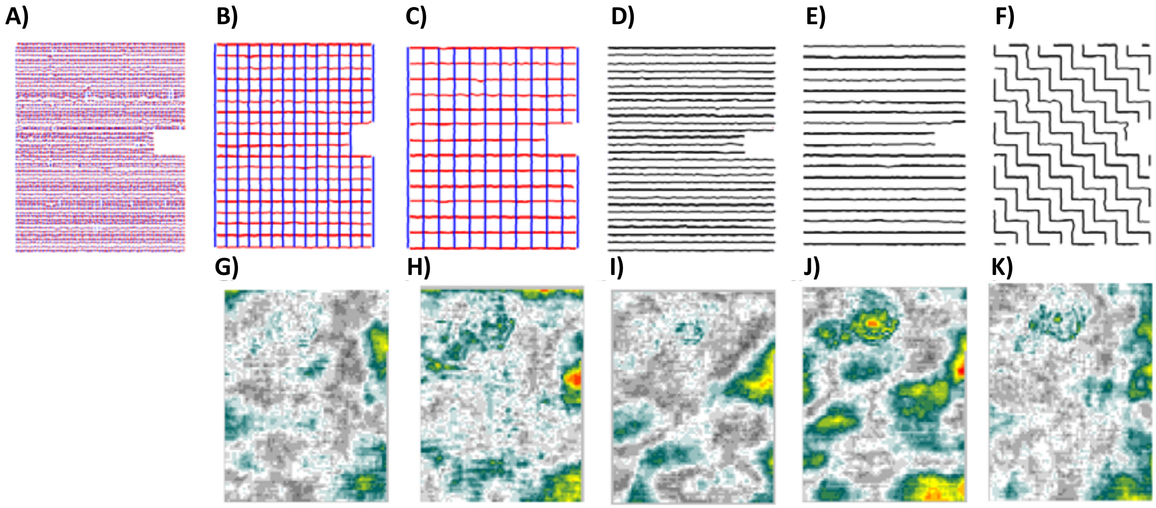

Figure 2: A) Original full grid real seismic dataset (fully sampled). **B)** to **F)** Five decimated geometries from original full grid. **G)** to **K)** NRMS difference plots of target time-slices with respect to the full grid dataset. Grey and white colours indicate a good match to the fully sampled dataset. Greens show some differences, which may or may not be acceptable. Yellows and reds show areas with unacceptable differences.

Seismic Equipment Analyses

All equipment tested during the project performed well with comparable results achieved from all geophone and sensor types. Miniature source tests were limited due to the unavailability of one piece of equipment. However, tests conducted during the project indicate that shallow deployment of a small seismic source can provide sufficient energy and resolution for imaging oil sands seismic targets (Figure 3). By utilizing a shallow, miniaturized source, the width of source cut lines can be decreased to 1.75 m, which will reduce the environmental impact of acquiring seismic data. Furthermore, this may translate to potentially reducing operational time along with cost savings due to less line cutting, surveying, and drilling (Crook et. al., 2023). Although miniature sources generally performed well for shallow targets, deeper targets benefited from incorporating miniature sources with conventional sources in a dispersed source array configurations to achieve broader bandwidth at depth (Naghizadeh and Crook, 2024a).

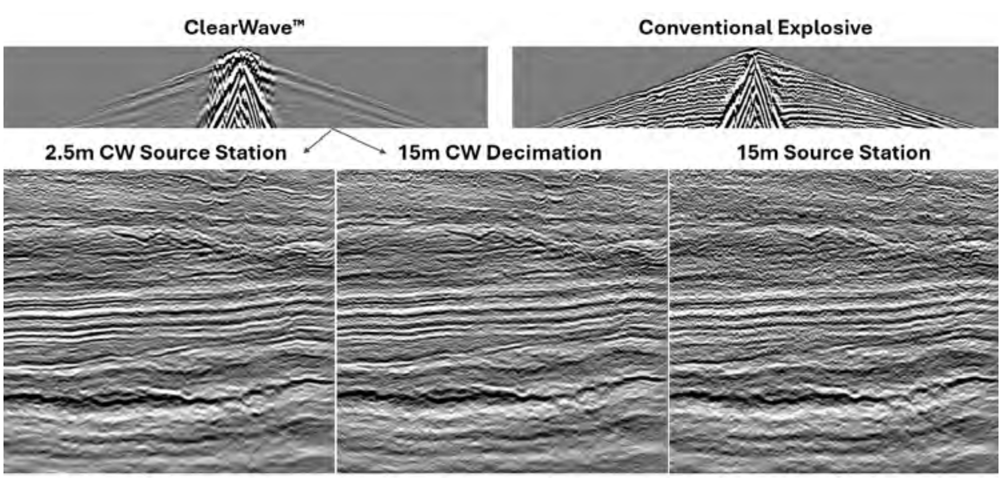

Figure 3: The directional explosive, ClearWave™ by Orica was tested at several locations. This example shows results from a 2D line where it was deployed every 2.5m at depth of 1 m. The conventional explosive was 125 g of dynamite deployed every 15 m at a depth of 6 m. Datasets were processed independently with the ClearWave™ also decimated to the same sampling as the conventional explosive. Despite the small size and shallow depth, excellent imaging was obtained for the target (oil sands).

Environment

Re-growth Study

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

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

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

Ecosite A - Jack Pine - lichen

Ecosite D - Aspen/White Spruce

Figure 4: Seismic line regrowth showing recovery in two different ecosites. In Ecosite A, seismic lines recover fully as avoidance cutting (lines meander around larger trees) results in minimal disturbance. Ecosite D has rapid recovery with nearly full regrowth on previously cut seismic lines.

GHG Emissions Reduction

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

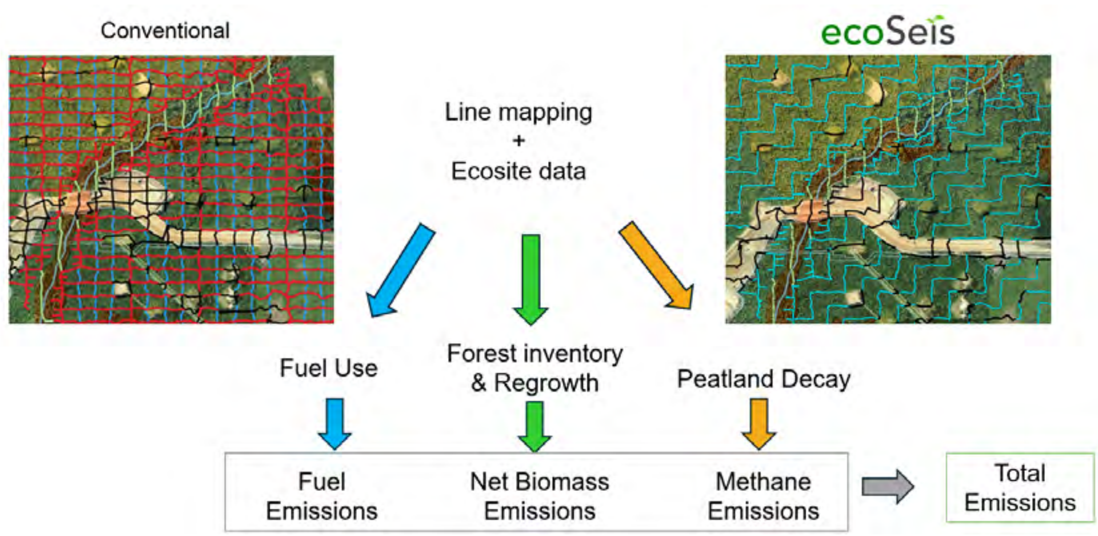

Figure 5: Methodology for determining emissions related to conventional and EcoSeis seismic acquisition.

Software

The osDesign™ software package and associated modules were developed to design and evaluated seismic surveys and generate new seismic geometries that can provide accurate subsurface images while also reducing the environmental impact associated with seismic acquisition. Various seismic acquisition geometry layouts including new alternative and EcoSeis methods were coded and incorporated into the software. New methods for survey evaluation such as Fresnel Fold were developed and incorporated into the software code (Naghizadeh et. al., 2022; Hons et. al., 2023). These enable rapid assessment and comparison between various conventional, alternative, and EcoSeis geometries. Learnings from the technical field trial were also incorporated into the software including algorithms for optimizing field layout for reduced environmental impact and tracking field acquisition activities for calculating GHG emissions associated with seismic acquisition activities. An example of the software analysis and outputs is provided in Figure 6.

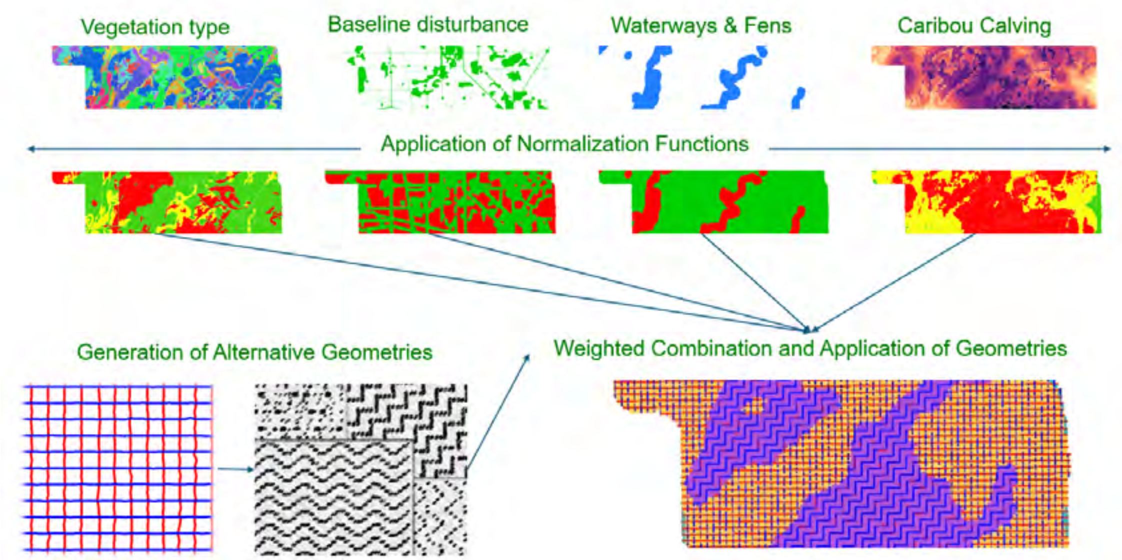

Figure 6: This is a real-world application of a combined EcoSeis and conventional seismic program. Inputs include various constraint maps that are normalized and then weighted based on sensitivity priority. EcoSeis geometries are generated and then applied in the most sensitive areas. Given the success of EcoSeis geometries in imaging the subsurface, combination programs are not required, and EcoSeis-only geometries may be deployed without loss of data quality.

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Naghizadeh, M., and Crook, A. [2024b]. Alternative Linear Land Geometries for Acquiring 3D and 4D Seismic Surveys. *IMAGE 2024 Conference Abstracts.*

PRESENTATIONS AND PUBLICATIONS

Journal and Online Publications

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

2024 (September): IMAGE, Joint AAPG-SEG-SPE conference; Poster Session ACQ P4, Alternative Linear Land Geometries for Acquiring 3D and 4D Seismic Surveys. https://www.imageevent.org/technical-program-/full-schedule

2024 (June): GeoConvention, technical presentation, The Impact of 3D Sampling on McMurray Formation Imaging. https://geoconvention.com/wp-content/uploads/abstracts/2024/104308-the-impact-of-3d-sampling-on-mcmurray-formation-im.pdf

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2023 (May): GeoConvention, Evaluating Innovations in Geophysical Acquisition, https://geoconvention.com/wp-content/uploads/abstracts/2023/11115-sustainable-and-innovative-geophysics-acquisition.pdf

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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/

Other Communications

2024 (October): CRIN Cafe, OptiSeis EcoSeis: Environmental Footprint Reduction for Subsurface Exploration Programs https://www.youtube.com/watch?v=B62DpXWj-E0

2024 (October) – 2025 (March): CSEG Canadian Distinguished Lecture Tour, Sustainability and Innovation in Seismic Data Acquisition. https://cseg.ca/wp-content/uploads/CSEG_CDLTour_AndreaCrook-1.pdf

2024 (June): GeoConvention, Showcase Stage 1: Is exact source and receiver repeatability necessary for timelapse (4D) seismic surveys: Learnings from EcoSeis phase II, https://geoconvention.com/wpcontent/uploads/documentation/2024/2024-showcase-stage.pdf

2024 (June): GeoConvention, Showcase Stage 1: Understanding Linear Seismic Acquisition Geometries, https://geoconvention.com/wp-content/uploads/documentation/2024/2024-showcase-stage.pdf

2023 (November) Platts Capital Crude podcast with S&P, New underground mapping may mean more oil and gas, fewer cut trees. Andrea Crook.

2023 (September): SEG Women's Network, Decarbonizing Subsurface Imaging, https://www.youtube.com/watch?v=fjz5NAtdPAM

2023 (May): CRIN Cafe, OptiSeis EcoSeis Phase 2, https://www.youtube.com/watch?v=48noiwWfrjU

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' 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

2022 (March): CRIN Announcement.

2023 (March): HETI Pitch Competition & Award.

AWARDS

2024 (June): GeoConvention, Calgary, AB: OptiSeis won Best Oral Presentation for the paper highlighting results from the EcoSeis project: *The Impact of 3D Sampling on McMurray Formation Imaging*. https://geoconvention.com/2024-award-recipients/

2024 (June): Global Energy Show, Calgary, AB: The EcoSeis project won the 2024 Collaborative Trendsetter Award. https://www.globalenergyshow.com/special-features/global-energy-show-canada-awards/2024-winners/

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

Institution: OptiSeis Solutions Ltd.

Principal Investigator: Andrea Crook, P.Geoph., CEO

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Cameron Crook	OptiSeis Solutions Ltd.	Advisor		
Mostafa Naghizadeh	OptiSeis Solutions Ltd.	Director of R&D, P.Geo.		
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.		
Carolina Berdugo-Clavijo	Imperial Oil	Environmental Researcher, P.Biol.		
Lori Neufeld	Imperial Oil	Land Use and Biodiversity Lead, P.Biol.		
Kees Sinke	Suncor Energy Inc.	Geophysical Advisor		
Emily Duncan	Suncor Energy Inc.	Manager, Geoscience Firebag and MacKay, P.Geoph.		

COSIA Fall Field Tour 2024

COSIA Project Number: LE0091

In Situ

Tour Facilitator: Fuse Consulting Ltd.

Industry Champion: Imperial

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

Status: Complete

PROJECT SUMMARY

The Land Environmental Priority Area (Land EPA) held a two-day field tour on September 11 and 12, 2024, at Bonnyville, AB. The goal of the tour was to showcase progressive reclamation practices and to discuss practical research findings at multiple in-situ reclamation sites. The tour included site visits to Imperial's Cold Lake Operations (Day 1) and Canadian Natural's Wolf Lake Operations (Day 2). A half day workshop was also hosted on the second day of the field tour, with the goal of synthesizing lessons learned on the field tour and identifying specific actions participants could take back into their organizations. This year's tour included participation from COSIA member companies, the Alberta Energy Regulator, Government of Alberta, Northern Alberta Institute of Technology, Université Laval, Pathways Alliance, Natural Resources Canada, and various consulting agencies.

PROGRESS AND ACHIEVEMENTS

On September 11-12, 2024, 41 individuals from across Alberta came together for the annual COSIA Land EPA fall field tour. The field tour brought together participants from diverse professional backgrounds including individuals from research, industry, consulting, government and regulatory agencies. Over the two days, participants leveraged their unique perspectives and expertise to discuss key challenges, learnings, and opportunities for advancing progressive reclamation practices.

On Day 1 of the tour, participants visited seven sites at Imperial's In-Situ Cold Lake Operation (Figure 1), and covered key topics including:

- Improving seedling establishment and early growth in reclaimed legacy grassy sites;
- Weed control through rapid establishment of tree and shrub cover;
- Wetland reclamation techniques to reclaim peatland function; and
- Considerations for borrow pit reclamation.

Figure 1: Tour participants during Day 1 visiting reclamation sites at Cold Lake Operations, including **A)** a legacy grassy site (drilling sump D62/ D63), **B)** a reclamation certified site (drilling sump H57), and **C)** a borrow pit within the woodland caribou range (borrow Y East).

On Day 2 of the tour, participants visited three sites at Canadian Natural's Wolf Lake In-Situ Operations (Figure 2), and covered the following topics including considerations for:

- Watercourse crossing removal;
- Addressing untreated sites with natural regeneration; and
- Wetland reclamation techniques to reclaim peatland function including comparisons with the wetland reclamation trial at H38 Pad visited on Day 1.

Figure 2: Site visits during Day 2 at Wolf Lake Operations, including **A)** a group of participants standing on top of the large soil pile (9-12 sump; top left), **B)** visiting a well pad removal trial (top right), and **C)** walking around Q1 Pad/Culvert and Road removal site (bottom).

To complement the field tour, a half-day workshop was hosted for participants to debrief what they had learned during the tour. The main objective of the workshop was to identify tangible next steps for advancing progressive reclamation practices and for applying key lessons in practice.

The first portion of the workshop included a presentation from the Alberta Energy Regulator (AER) about the use of remote sensing in reclamation inquiries. The workshop facilitator then hosted an interactive activity to help participants identify the top five topics/learnings they wanted to discuss following the field tour. Breakout groups were then used to identify specific ways in which learnings from the field tour could be actioned within organizations.

The five discussion topics from this exercise were as follows:

1. Longer-term considerations for where to place borrow material during reclamation.
2. The development of a guidebook to capture the variety of available wetland reclamation techniques, and to explain how the surrounding environments impact the success of these techniques.
3. The importance of knowledge sharing, collaboration, and the development of best management practices among companies, researchers, and operators.
4. Comparisons and contrasts between reclamation certificate requirements and caribou habitat restoration.
5. The role of natural regeneration for legacy sites where older reclamation practices (i.e. planting of grass) were applied.

Some of the overall discussion highlights throughout the tour were:

- The evolution from past practices of planting grass and monoculture tree stands to using native species, woody materials, rough and loose soils, etc.
- Emerging techniques for re-establishing forest cover on legacy sites with a high level of grass and clover.
- Opportunities for rapid re-establishment of forest ecosystems on sites with low disturbance and timely reclamation post-disturbance.
- Uncertainty associated with changing expectations of reclamation requirements within woodland caribou ranges, and potential adjustments considering sub-regional planning direction.
- Emerging beneficial practices for the reclamation of wetland sites, including a discussion of the appropriate levels of fill removal and the ideal opportunities for re-establishing wetland communities.
- Challenges and opportunities associated with watercourse crossing removals, as well as practical steps related to the management of fill material, the timing of crossing removals, and opportunities to re-establish fish passage in large portions of a watershed.
- Broader challenges associated with taking sites to closure:
    - The uniqueness of applying for a reclamation certificate under Environmental Protection and Enhancement Act.
    - Navigating the evolving requirements for borrow pits and caribou sub-regional planning considerations.
    - Recognizing that many forms of vegetation control outside of weed spraying can be employed on reclaimed sites.
    - Managing conservation and reclamation data over the life span of an in-situ project footprint to minimize rework.
- Remote and field-based inquiries for reclamation certification.

The field tour participants also discussed a series of challenges to overcome, which included:

- Managing both recent and historical data for sites that have been in operation for long periods of time.
- Identifying opportunities for reclamation certification while also providing long-term company flexibility.
- Documenting current beneficial management practices and ensuring a new generation of reclamation practitioners and equipment operators are aware of, and actively applying, proven practices.

LESSONS LEARNED

Overall, the 2024 COSIA Fall Field Tour generated thoughtful and dynamic conversations among the participants who came from a diverse range of professional backgrounds and expertise. The tour provided an interesting opportunity to visit both older and newer reclamation sites. A key theme was that when good practices are used, they lead to the successful and often rapid recolonization of a site by trees and shrubs.

The tour also helped showcase emerging findings related to wetland reclamation. Although practices may not be fully tested across a wide range of environments, current findings related to the amount of fill material that should be removed, as well as opportunities to encourage the recolonization of wetland vegetation and reformation of peat, were key learnings that emerged over both days.

There was also widespread interest in the existing guidebooks that support reclamation efforts and in the development of new guidebooks to aid in planning, operations, and ultimately successful reclamation practices.

TOUR FACILITATORS AND PRESENTERS

Facilitators: Matthew Pyper, Nakita Rubuliak, and Stephanie McKenzie (Fuse Consulting ltd).

Planning Team: Lori Neufeld (Imperial), Carolina Berdugo-Clavijo (Imperial), Kinzie Gray (Imperial), James Agate (CNRL), Paul Kip (CNRL), Jack O'Neill (Pathways Alliance), and Lindsay Clothier (Pathways Alliance).

Tour Presenters:

Name	Institution or Company	Job Title
Day 1:		
Lori Neufeld	Imperial	Sr. Environmental Advisor
Richard Krygier	Canadian Forestry Service	Principal Investigator
Bin Xu	NAIT	Principal Investigator
Kinzie Gray	Imperial	Environmental and Regulatory Advisor
Day 2:		
Paul Kip	Canadian Natural	Field Operations Coordinator
Bruce Nielsen	Woodlands North Inc	Sr. Researcher
Terry Osko	Circle T Consulting	Sr. Researcher
Nadia Cruikshank	Alberta Energy Regulator	Sr. Reclamation Specialist