2021 COSIA LAND EPA

Mine Research Report

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INTRODUCTION

This report is funded by members of Canada's Oil Sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA):

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

COSIA LAND EPA publishes two reports, 2021 COSIA Land EPA – Mine Research Report and 2021 COSIA Land EPA – In Situ Research Report. This report summarizes progress for projects related to mine site reclamation of the COSIA Land EPA.

The project summaries included in this report do not include all projects completed under the Land EPA. As in 2020, some projects in 2021 were significantly impacted by the COVID-19 pandemic and consequently no summary is provided this year. Please contact the Industry Champion identified for each research project if any additional information is needed.

2021 COSIA Land EPA – Mine Research Report. Calgary, AB: COSIA Land EPA.

*In 2020, Cenovus acquired Husky Energy Inc. All COSIA Land EPA projects previously supported by Husky Energy Inc. were transferred to Cenovus.

Front cover image of beaver lodge at Golden Pond courtesy of Syncrude Canada Ltd.

WETLANDS

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

COSIA Project Number: LE0037

Research Provider: University of Calgary

Industry Champion: Suncor

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

Status: Year 2 of 5

PROJECT SUMMARY

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

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

BWRAP intends to answer the following questions:

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

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

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

Water quality Influences: Water quality constrains the abundance and composition of wetland biota. Most undisturbed wetlands in the AOS have low conductivity, but natural seeps increase salinity and contain halophilic communities. Wetlands forming in saline sodic overburden storage areas on oil sands leases are also saline enough to influence community composition. Some biota may tolerate higher salinity from natural or runoff sources, possibly due to interactions of the latter with 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 AOS, emphasizing the need to trap and store water during precipitation events. Constructed wetlands have been hypothesized to need at least a two to one ratio of watershed to wetted area for precipitation to sustain fen habitat in the AOS (Price et al., 2009). Land disturbance (altered forest cover, soil, or drainage pattern) is also a key stressor. For example, roads and culverts alter both hydrology and habitat use by biota. Wetland geometry (e.g., slope, emergent zone width, microtopography) influences abundance, richness, and distribution of aquatic communities.

Permanence: Marsh-like wetlands are a focus of AOS reclamation because they are persistent and relatively easy to construct. However, seeps and naturally-forming minerotrophic wetlands wet 10% to 17% 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 Area [RCA]) 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 in the RCA focus on 'climax', stable state, or a mosaic of successional states, recovering or newly reclaimed areas require a different frame of reference. The BWRAP is compiling data from suites of wetlands at early time-points since their formation or creation. These data, essential as a frame of reference for assessing developing landscapes, are being collected and summarized to document the range of natural variation in indicator variables for opportunistically-forming and reclaimed wetlands. Such information will inform guidelines that will determine whether adaptive management may be needed to achieve closure outcomes (maximize the likelihood of a wetland becoming functional and exhibiting the desirable ecological properties of natural systems).

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

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

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

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

PROGRESS AND ACHIEVEMENTS

Phase 1 - Recruiting and Database Creation

Database architectural design and security protocols were approved by the University of Calgary, allowing hardware purchase, data compilation, and database development to begin. Water quality and selected biological data collected from a suite of natural and reclaimed wetlands between 2000 and 2015 were compiled and interpreted by three honours undergraduate thesis students. As well, remote sensing imagery of reclaimed lease areas and reference areas was shared by Syncrude and Suncor partners, which facilitated the search for suitable wetlands to sample during the 2021 field season. The success in locating suitable study sites was greatly aided by recommendations from Syncrude and Suncor field staff and other local experts.

Phase 2 - Field Investigations

In 2021, four graduate students, four undergraduate students and several summer research assistants joined BWRAP and completed the field training necessary to begin their research in mine lease areas. Lab members located and sampled the open water, emergent vegetation, and wet meadow zones of 40 young wetlands, ranging in age from two to 40 years, with open water area between 0.05 ha and 13.5 ha, and with specific conductance ranging from 250 uS/cm to over 7,000 uS/cm. Soil texture composition ranged from sandy soils to a sandy loam, with a few silty loam sites. The specific conductance of water in the wet meadows was consistently around 20% higher than measurements taken in the open water zone. Young, ephemeral wetlands situated in reclaimed areas had considerably higher specific conductance than semi-permanent marshes or shallow open water wetlands.

Preliminary analyses of surface and groundwater radon concentration and stable isotopes of oxygen and deuterium are in progress. Together, these data will be used to infer the proportion of water in each wetland derived from surface water (precipitation, overland, and stream flow) versus groundwater sources. This information will contribute to an assessment of each wetland's resilience to interannual and seasonal variation in precipitation.

Data from field loggers (recording light intensity, temperature, conductivity, dissolved oxygen concentration and water level at 30-min intervals) are presently being analyzed to document day/night and seasonal trends within and among wetlands of each class. Logger records were consistent with spot readings taken at the time of biological sampling. Arial drones and an autonomous water vessel were successfully deployed to provide imagery of topography and surface features, and bathymetry, respectively.

Surveys of vegetation provided estimates of community composition, biomass, and relative cover of the three zones. In all, 140 species were identified in the wet meadow and emergent zones across the 40 wetlands (submergent vegetation data are still being compiled). The dominant species (those with consistently greatest cover) were Blue Joint Grass (*Calamagrostis canadensis*), three sedge species (*Carex aquatilis*, *C. atherodes*, and *C. utriculata*), Softstem Bulrush (*Schoenoplectus tabernaemontani*), and Cattail (*Typha latifolia*). Over 200 benthic macroinvertebrate samples were collected and preserved over the course of the summer and are awaiting processing and enumeration. Avian surveys were not conducted in 2021.

Preliminary results of two sets of benthic macroinvertebrate data analyses provided an intriguing contrast in the composition of communities sampled from young constructed and opportunistic wetlands versus a suite of pools in a naturally saline fen complex. Threshold Indicator Taxon analysis (Titan, King and Baker 2010) was performed on data from 39 ponds and opportunistic wetlands sampled between 1998 and 2012 (Kovalenko et al., 2013). Threshold values above which multiple (sensitive) taxa were absent were evident for two parameters: conductivity (1,200 µS/cm) and pH (8.1; Moore 2021). Similar thresholds were observed following analysis of published data of Preston et al. (2018) on benthic macroinvertebrates collected from brine-contaminated prairie pothole wetlands adjacent to oil and gas wells. In contrast, Vercruysse and Ciborowski (2021) who sampled macroinvertebrates from 52 pools in a naturally saline fen complex (conductivity range 3,757 µS/cm to 20,170 µS/cm) observed greatest richness (24 families) at 9500 µS/cm. In this case, Titan identified 21 indicator taxa, 12 of which decreased in relative abundance along the conductivity gradient and nine of which increased. Community composition changed at an at an estimated threshold of 9,000 µS/cm to 11,000 µS/cm.

LESSONS LEARNED

This program is still in early stages, with only the first field season completed. Therefore, few conclusive statements can be made. One learning is that site selection is difficult because although recently collected imagery has excellent resolution, ground-truthing is still required to confirm the presence and status of each site. Current field work has also found that many aquatic invertebrate taxa can occupy local natural wetlands with much greater salinity ranges than previously thought.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

Gillis, E. 2021. Wet meadow community succession in constructed and opportunistic wetlands of the Alberta Oil Sands region. Hon. BSc Thesis, Biological Sciences, University of Calgary, Calgary, AB.*

Mebesius, L. 2021. Variation in wetland submerged plant community composition in relation to water salinity in boreal wetlands of the Alberta Oil Sands region. Hon. BSc Thesis. Biological Sciences, University of Calgary, Calgary, AB.*

Moore, E. 2021. Successional and disturbance controls on macroinvertebrate community composition in young boreal wetlands. Hon. BSc Thesis, Biological Sciences, University of Calgary, Calgary, AB.*

*Available upon request.

Conference Presentations/Posters

Ciborowski, J. J. H. 2021. Formalizing the Reclamation Assessment Approach (RAA) to evaluate wetland condition in reclaimed oil sands watersheds. COSIA Wetland Technical Sharing Session, Calgary, AB, November 5, 2021 (Virtual).

Ciborowski, J. J. H. 2021. Formalizing the Reclamation Assessment Approach (RAA) to evaluate wetland condition in reclaimed oil sands watersheds. Canadian Ecotoxicity Conference, Halifax, NS, October 2-5, 2021 (In person and virtual).

Ciborowski, J. J. H. 2021. Raising the bar on sustainable wetlands. Invited Presentation for World Water Day Lunchtime Symposium, University of Calgary, AB, March 25, 2021 (Virtual).

Moore, E. and J. J. H. Ciborowski. 2021. Successional and disturbance controls on macroinvertebrate community composition in young boreal wetlands. Entomological Society of Alberta Annual General Meeting, Calgary, AB, October 15-16, 2021, (Virtual).

Vercruysse, B. and J. J. H. Ciborowski. 2021. Variation of Aquatic Macroinvertebrate Community composition along a gradient of salinity in a boreal saline fen. Entomological Society of Alberta Annual General Meeting, Calgary, AB, October 15-16, 2021, (Virtual).

Vercruysse, B. and J. J. H. Ciborowski. 2021. Variation of aquatic macroinvertebrate community composition along a gradient of salinity in a boreal saline fen. Canadian Ecotoxicity Conference, Halifax, NS, October 2-5, 2021 (In person and virtual).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Calgary

Principal Investigator: Dr. Jan J. H. Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Camille Sinanan	University of Calgary	BWRAP Admin Manager		
Mir Mustafizur Rahman	University of Calgary	Post-Doctoral Fellow/ Research Scientist		
Jeremy Hartsock*	Southern Illinois University	Post-Doctoral Fellow		
Zach Wang	University of Calgary	Research Assistant (Drones)		
Ian Perry	University of Calgary	Research Assistant (Drone pilot)		
Erik Biederstadt	University of Calgary	MSc	2021	2023
Amanda Luzardo	University of Calgary	BSc	2017	2022
Abisola Allison	Mount Royal University	BSc	2018	2022
Nika Tovchyrhechko	University of Calgary	Hon. BSc	2018	2023
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	2023
Ashlee Mombourquette	University of Calgary	MSc	2020	2022
Brenten Vercruysse	University of Calgary	MSc	2019	2022
Michael Wendlandt	University of Calgary	MSc	2020	2022
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

* 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.

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
Jabed Tomal	Thompson Rivers University	Statistical modelling

Evaluating the Success of Fen Creation (Phase II)

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor

Industry Collaborators: Imperial, Teck

Status: Year 4 of 5 years

PROJECT SUMMARY

The overall goals of Phase II of the Evaluating the Success of Fen Creation Project are i) to evaluate the longer-term trajectory of the constructed Nikanotee Fen (NF) watershed; and ii) to develop alternate wetland watershed designs and strategies suitable for a closure landscape. This project will provide an ongoing assessment of ecosystem function and development, using empirical manipulation experiments as well as develop conceptual and numerical models of the system performance under the constraints of the current design for various climate cycles and trends. These conceptual and numerical models will be used to test and recommend new fen wetland designs for integration with other constructed landscape units at the scale of closure landscapes.

The Phase II Project has three objectives:

1. Ongoing assessment of NF ecosystems functions: Under a range of climatic conditions, evaluate the NF performance relative to natural reference ecosystems, and provide a database to demonstrate its suitability for reclamation certification.
2. Assess how changes to soil and vegetation form and function affect system trajectory: To project the trajectory of the NF it is important to understand how placed materials have evolved over the first five to 10 years (per the above objective). The rates and processes observed over time are needed to parameterize the numerical modelling of hydrology and solute transport, the output of which is needed to apply conceptual models of biogeochemical and ecological functions including carbon dynamics and plant community development.
3. Use numerical and conceptual models to evaluate alternative design applicability to closure landscape scales. Numerical models of NF hydrology and solute transport validated using field data will be used to understand how design modifications to the closure landscape can improve system function and performance. Design optimization will involve consideration of improvements to contaminant management and water use by different landscape elements.

PROGRESS AND ACHIEVEMENTS

Soil and plant community development, and their role on recharge/runoff relations

Salinity of ponded surface water was responsive to rain-dilution and evapoconcentration. Sodium (Na^+) in the fen rooting zone is highly spatially variable but temporally stable. Highest recorded values of Na^+ exceeded known salinity-stress thresholds for mosses. Time for total aqueously mobile Na^+ export from the NF system is estimated at 36 years post-construction completion.

Controls on water use efficiency and biogeochemical cycling of dominant vegetation in fen and how this varies through the range of wetland succession trajectories

Total gross ecosystem productivity (GEP) in the fen has increased significantly since the NF was completed in 2013, with total growing season carbon (C) values increasing from 24 g C m^{-2} in 2013, to 279 g C m^{-2} in 2019, and now 393 g C m^{-2} in 2021. The highest seasonal total GEP occurred in 2015 at 512 g C m^{-2}. This measurement coincided with the first year that vegetation had robustly established and where the vegetation had yet to be stressed by significant Na^+ upwelling into the rooting zone. Average daily seasonal GEP for the years 2013 to 2021 (2020 excluded) measured in g C m^{-2} day^{-1} was 0.5, 4, 4.3, 5.2, 3.1, 3.3, 2.3 and 4.6.

Total seasonal GEP for the NF upland increased from 65 g C m^{-2} in 2013, to 439 g C m^{-2} in 2019. Measurements totaled 284 g C m^{-2} in 2021, for the 84 days recorded. Lowest average daily upland GEP was in 2013 at 0.5 ± 0.3 g C m^{-2} day^{-1}, followed by an increase in 2014 to 2 ± 1.3 g C m^{-2} day^{-1}, likely due to the emergence of sparse understory vegetation. Moreover, there was a substantial increase in upland daily GEP in 2018 and 2019 (3.7 ± 1.7 g C m^{-2} day^{-1} and 3.7 ± 1.4 g C m^{-2} day^{-1}), when tree and understory vegetation became more established. In 2021, upland daily GEP had decreased slightly to 3.4 g C m^{-2} day^{-1}.

The fen quickly developed from a carbon source in 2013 (70 g C m^{-2}), to a sink by 2015 (-243 g C m^{-2}), after which NEE (Net Ecosystem Exchange) remained a relatively stable sink of carbon dioxide (CO_2) (-178 g C m^{-2}, -214 g C m^{-2}, -185 g C m^{-2}, -123 g C m^{-2}). This has artificially decreased to -75.9 g C m^{-2} in 2021 due to a shorter measurement period, using Eddy Covariance equipment, because of pandemic travel restrictions. Average daily NEE ranged from 1.5 ± 0.4 g C m^{-2} day^{-1} in 2013, to -3.3 ± 1.4 g C m^{-2} day^{-1} in 2015 — with highest NEE rates typically occurring in early July. Daily peak season uptake from 2015 to 2019 ranged between -1 ± 1 g C m^{-2} day^{-1} in 2019, to -3.3 ± 1.4 g C m^{-2} day^{-1} in 2016. In 2021, daily NEE was -0.9 g C m^{-2} day^{-1}. As upland vegetation established and GEP increased, carbon sink capacity and daily C uptake have both increased. Highest upland C emissions occurred during 2013, with 519 g C m^{-2} released. This subsequently decreased to an annual source of only 63 g C m^{-2} in 2021.

Fen water use efficiency (WUE) increased from 0.6 ± 1.0 g C kg H_2O^{-1} day^{-1} in 2013 (year one) to 1.5 ± 1.65 g C kg H_2O^{-1} day^{-1} in 2014, the first full growing season. This was followed by a relative stabilization in WUE across later years (2015 onwards) at mean rates measured in g C kg H_2O^{-1} day^{-1} of 1.8 ± 1.3, 2.1 ± 1.7, 1.7 ± 1.3, 1.8 ± 1.3, 1.5 ± 1.1 g for 2015 to 2019, respectively. WUE reached 1.9 g C kg H_2O^{-1} day^{-1} in 2021.

Following the development of vegetation, even in drier years (2015, 2017) rates have remained stable. Upland WUE has been steadily increasing as vegetation continues to mature from 1.0 g C kg H_2O^{-1} day^{-1} in 2013, to 2.5 g C kg H_2O^{-1} day^{-1} in 2021.

The results above demonstrate the functionality of the constructed ecosystem, namely carbon and water fluxes are being controlled by plant growth and establishment. The fen evolved from a carbon source in 2013 to a stable carbon sink by 2015 (total seasonal NEE of 70 g C m^{-2} to -243 g C m^{-2}). In contrast, the slower growth rate of trees coupled with dry soil conditions of the upland, has resulted in net carbon losses during the study period (NEE of 519 g C m^{-2} in 2013, to 63 g C m^{-2} in 2021). Once vegetation established, WUE rates in both the fen and upland showed a marked increase.

Multi-year analyses of upland CO_2 fluxes completed in 2021, found trends linked to tree type. Understory plots had the lowest overall seasonal NEE (1.1 ± 3 g C m^{-2} day^{-1} in 2018, and -0.2 ± 2 g C m^{-2} day^{-1} in 2019), due to low Gross Primary Productivity (GPP) (13 ± 5, 9 ± 2 g C m^{-2} day^{-1}) rates, and relatively high respiration rates (14 ± 3, 9 ± 4 – essentially cancelling out GEP) due to the bare ground, dry brush composition of these plots. Coniferous (*Pinus banksiana and Picea mariana*) plot NEE ranged between -10 g C m^{-2} day^{-1} to -30 g C m^{-2} day^{-1} while broadleaf species (*Populus tremuloides* and *P. balsamifera)* NEE ranged between -28 g C m^{-2} day^{-1} to -94 g C m^{-2} day^{-1}. Upland rates of NEE, GEP and ER were less in 2019 due to the overall wetter, overcast conditions of the season. Moreover, leaf physiology, photosynthetically active radiation (PAR) and seasonality differ significantly between the two tree types in GEP trends. Coniferous plots typically display only a small increase in GEP (approximately 5 C m^{-2} day^{-1} to 10 g C m^{-2} day^{-1}) between May and July, whereas broadleaf plots exhibit a much larger increase in GEP (approximately 10 C m^{-2} day^{-1} to 30 g C m^{-2} day^{-1}) following full leaf out and green up (i.e., during peak season, July) followed by a slight decrease again in August (e.g., 2019 *Populus balsamifera* May GEP: 64 C m^{-2} day^{-1} ± 6 g C m^{-2} day^{-1}; July GEP: 92 C m^{-2} day^{-1} ± 11 g C m^{-2} day^{-1}; August GEP: 71 C m^{-2} day^{-1} ± 8 g C m^{-2} day^{-1} versus 2019 *Pinus banksiana* May GEP: 44 C m^{-2} day^{-1} ± 4 g C m^{-2} day^{-1}; July GEP: 53 C m^{-2} day^{-1} ± 11 g C m^{-2} day^{-1}; August GEP: 41 C m^{-2} day^{-1} ± 8 g C m^{-2} day^{-1}).

Analyses of soil, leaf and root material from the fen and upland were finalized in 2021 for carbon 13 (^{13}C) and nitrogen 15 (^{15}N) isotope compositions, and for elemental carbon-to-nitrogen ratios (C:N), to determine what biogeochemical processes were occurring; e.g., carbon deposition/accumulation or losses, and available N for growth processes. Mean peat elemental percent C and percent N (% per g) in the fen was 31 ± 6.2 and 1.2 ± 0.1 with a C/N ratio of 26. These values are an increase from those reported by Nwaishi (2016) from an initial assessment of the constructed fen (%C: 29 ± 3.5, %N: 1.3 ± 0.16, C/N: 22.5) and reflective of reference sites in the region (%C: 33 ± 16, %N:1.25 ± 0.64, C/N: 26). Upland mean soil elemental percent C and percent N were 3.6 ± 2.8 and 0.15 ± 0.1. Despite having low elemental percentages, mean upland C/N is 24.

Elemental analysis of above and below-ground plant biomass of dominant species was also analyzed. In the fen, leaf percent C was similar between the three dominant species (*Carex aquatilis:* 44 ± 1.2, *Juncus balticus:* 44 ± 0.8, *Typha latifolia*: 43 ± 1.8) however there was slight variability in percent N (*C. aquatilis*: 2.1 ± 1.9, *J. balticus*: 1.3 ± 0.6, *T. latifolia*: 1.9 ± 1.1). Elemental composition differences extend to root biomass make-up, likely due to variability in species root architecture. For example, *T. latifolia* had a mean percent C and percent N of 47 ± 2.5 and 0.65 ± 0.3 vs. *J. balticus* 38 ± 3.7, 0.84 ± 0.9, respectively. Greater percent C in *T. latifolia* is likely due to the large tap root and abundant rooting system. However, *T. latifolia* thrives in wet, ponded conditions typically resulting in less available nitrogen, and overall lower root percent N. Comparatively, *J. balticus* possesses finer rooting system and typically occurs in drier areas of the fen, suggesting more available N. *Carex aquatilis* root biomass values sit between the other two species at 41 ± 1.6 and 0.7 ± 0.3 percent, C and N, respectively.

Elemental upland leaf composition is correlated to tree type, with broadleaf species *(Populus tremuloides* and *P. balsamifera)* demonstrating elemental compositions of percent C: 47 ± 2.4 and 47 ± 1.8 and percent N: 1.85 ± 0.3 and 1.57 ± 0.12. Coniferous species (*Pinus banksiana and Picea mariana*) exhibit a larger range of percent C (45 ± 4.5 and 51 ± 3.8) but similar percent N compositions (0.97 ± 0.3 and 0.82 ± 0.5).

DOC dynamics of fen in response to chemical, structural and successional changes

Examination of the inputs, outputs and production of dissolved organic carbon (DOC) in the constructed fen watershed found that while a small amount of DOC was added to the fen annually through surface runoff from the upland and surrounding slopes (for example during periods of snowmelt), increases in fen pore water DOC primarily originate from internal production through increased vegetation productivity as opposed to losses from decomposition of the salvage peat deposit that forms the basis of the fen. DOC concentrations within the fen have increased since construction and now reflect levels seen at natural reference sites. NF pore water DOC concentration increased from 30.4 mg L^{-1} in 2013, to 44.6 mg L^{-1} by 2016 within the measured vadose zone (i.e., within 50 cm of the fen surface).

Determine the role of nutrient deposition for plant productivity, net CO2 uptake and N2O (nitrous oxide) emissions

The nutrient enriching impacts from nitrogen (N) deposition align with the spatial pattern of deposition, making the reclaimed site the most susceptible to the influence of increased N inputs. NF receives 4.1 kg N ha^{-1} over a four-month growing season from aerial deposition. In comparison, Poplar, a rich fen reference site 10 km away, receives only 2.6 kg N ha^{-1}; and Saline, located 40 km from the constructed fen receives 2.5 kg N ha^{-1}. Acidifying impacts of N deposition are of little concern to sites close to dirt roads (e.g., NF, Poplar) as the aerial dust contains base cations that buffer the effects of N-induced acidification.

In the fen, N deposition is fueling growth of vascular vegetation, while also developing an environment unsuitable for bryophytes to be sustained — a critical load of 3 kg N ha^{-1} $year^{-1}$ is recommended for poor fens in Alberta.

The NF site has received greater-than-background levels of N deposition for the Athabasca Oil Sands Region (AOSR) (background is 1 kg N ha^{-1} yr^{-1}), however despite this, the reclaimed site is still a low N environment based off various ecosystem indicators (i.e., N solution chemistry profile, NH_4-N:NO_3-N, soil and foliar (leaf or needle) total nitrogen, C:N ratio and soil net mineralization processes).

- Fen: 2.1 kg N ha^{-1} (growing season 2019 values) or scaled up to approximately 8.5 kg N ha^{-1} $year^{-1}$
- Upland: 1.5 kg N ha^{-1} (growing season 2019 values) or scaled up to approximately 6.2 kg N ha^{-1} $year^{-1}$

Since N is a limiting nutrient in this environment, N deposition is acting as a fertilization process, boosting growth and productivity within the reclaimed system. For increased ecosystem N to occur, vegetation demand for N must be satisfied before soil demands. In both the reclaimed fen and upland, extractable N was much greater in vegetation than soil ($p < 0.05$), reflecting the concentration of N in vegetation — no differences were observed between species. Within the upland, N deposition is likely beneficial to tree development since soil N concentrations are very low. As the upland canopy develops, N deposition will accumulate within the canopy, which may increase stemflow (and throughfall) N fluxes to the soil.

Numerical modelling of NF watershed hydrology and solute transport

Integration of seven years of hydrologic and geochemical data from the NF in combination with previous modelling efforts has projected spatiotemporal patterns of Na^+ as it is flushed from the tailings sand aquifer into the fen. To accomplish this, a three-dimensional groundwater flow and solute transport model was developed in MODFLOW SURFACT. The model used stochastically generated climate data to simulate a variety of climate “realizations”. This work has shown that even under very dry climatic conditions the fen will maintain high enough water tables that are thought necessary to sustain wetland ecohydrological processes. Furthermore, thresholds associated with the onset of salinity stress in the dominant vegetation species (*Carex aquatilis*; 1,100 mg/L) will likely not be exceeded. However, such Na^+ concentrations will limit moss establishment across much of the fen for several decades post-construction.

Hydrogeochemical influences on vegetation composition, production, and carbon dynamics

A greenhouse experiment carried out on vegetation core samples from the NF found that Na^+ concentrations within NF peat cores were significantly affected by water table fluctuations. Cores subjected to lower water table treatments saw faster increases in surface Na^+ concentrations, except for one *C. aquatilis* core with a water table treatment of 15 cm bgs (below ground surface). Plant stress responses —as measured by light stress indicators to Na^+ concentrations — were mixed. However, a *Carex* core with a water table treatment of 30 cm bgs saw significant decrease in both Phi PSII (a metric for actual initial light energy capture efficiency of the plants) and actual efficiency of PSII, as Na^+ concentrations increased. Reduction in photosystem efficiency occurred between 1,000 and 1,500 parts per million (ppm) Na^+ concentrations.

Simulated precipitation flushing on the peat cores resulted in decreased Na^+ concentrations in the upper 10 cm of the peat profile. However, Na^+ concentrations would recover to pre-flushing values within seven days post-flushing. This greenhouse work suggests that to achieve a sustained long-term decrease in near-surface NF peat Na^+ concentrations, precipitation events greater than 50 mm would be required across the growing season, which is not representative of precipitation events observed at the constructed fen site.

Flushing of the peat cores did not alleviate salt stress in plants, with no measured stress parameters showing any improvement post flushing. Mature *C. aquatilis* plants do not indicate any benefit from flushing. However, the effect of flushing on establishing young *C. aquatilis* culms is unknown.

Plants in each core were destructively sampled for tissue analysis of Na^+ post-greenhouse experiment. *C. aquatilis* cores all showed high Na^+ concentrations in the 0 cm to 10 cm core sections. The *C. aquatilis* core at water table treatment 0 cm (WT 0) had an initial Na^+ concentration of 32,000 ppm at 0 cm to 10 cm and decreased to 26,000 ppm at 20 cm to 30 cm depth, before increasing again to 31,000 ppm at 50 cm to 60 cm depth. The *C. aquatilis* core at water table treatment -15 cm (WT 15) had a maximum Na^+ concentration of; 13,000 ppm in the 0 cm to 10 cm interval; to a minimum of 4,700 ppm in the 30 cm to 40 cm interval; and then increasing to 6,700 ppm in the 50 cm to 60 cm interval. The *C. aquatilis* core at water table treatment -30 cm (WT 30) had a similar trend to the other cores with a maximum Na^+ concentration of; 12,000 ppm at the 0 cm to 10 cm interval; to a minimum of 7,300 ppm in the 20 cm to 30 cm interval; and increasing substantially to 26,000 ppm in the 50 cm to 60 cm interval. Sodium concentration in the *C. aquatilis* core at WT 30 was 33,000 ppm Na^+ in the 60 cm to 70 cm interval — the highest Na^+ concentration observed in all the *C. aquatilis* biomass samples.

In contrast to the *C. aquatilis* cores, a constant decrease of Na^+ concentrations were observed in *J. balticus* 0 cm to 10 cm to 40 cm to 50 cm core sections. The *J. balticus* core at WT 0 initially had the highest Na^+ concentration of 81,000 ppm at 0 cm to 10 cm but this decreased rapidly to 2,000 ppm in the 40 cm to 50 cm section. The *J. balticus* core at WT 15 had a Na^+ concentration of 49,000 ppm in the 0 cm to 10 cm section, decreasing to 6,200 ppm in the 40 cm to 50 cm section. The *J. balticus* core at WT 15 maintained the highest Na^+ concentrations in each section from 20 cm to 50 cm. *J. balticus* core at WT 30 had the lowest Na^+ concentration of 21,000 ppm in the 0 cm to 10 cm interval and decreased to 2,800 in the 40 cm to 50 cm interval.

Since NF construction was completed in 2013, methane (CH_4) emissions remained low. Methane emissions rose in 2014 to an average 6.7 ± 22.3 mg CH_4 m^{-2} d^{-1} between July and August and then fell to almost 0 mg CH_4 m^{-2} d^{-1} the following year. However, in recent years, there has been a significant increase in CH_4 emissions (mean CH_4 flux in 2019: 14.4 ± 45.0 mg CH_4 m^{-2} d^{-1}). Although mean fluxes have been low in most years, occasional high fluxes (i.e., > 50 mg CH_4 m^{-2} d^{-1}) have been observed in 2014, 2018 and 2019 indicating that CH_4 is being produced at hot spots within the NF when conditions allow.

In 2019, sulfate (SO_4^{2-}) concentrations in *C. aquatilis*, Mixed *Juncus-Carex* and *T. latifolia* plots ranged from 320 mg L^{-1} and 2,480 mg L^{-1}. However, *J. balticus* plots possessed higher SO_4^{2-} concentrations, with values between 1,240 mg L^{-1} and 3,800 mg L^{-1}. Although this site maintains a consistently high-water table and is heavily dominated by aerenchymatous species such as *C. aquatilis* — conditions conducive to high CH_4 production and emission rates — the low CH_4 emissions are likely due to the high SO_4^{2-} concentrations present. The fen will maintain high SO_4^{2-} concentration and therefore, future CH_4 emissions are likely to remain low.

LESSONS LEARNED

- Results obtained from the Hydrus 3-D modelling have strengthened the case for constructing connected upland-fen systems as drought resilient cover systems in the post-mined landscape of the Athabasca Oil Sands — despite the sodium-rich construction materials utilized in construction.
- Appropriate cover vegetation choices have tolerated high Na^+ pore water concentrations, allowed for carbon accumulation and reflect a surface cover vegetation assemblage reflective of natural fen systems which is able to facilitate ecosystem processes previously observed in natural reference fen systems.
- This work has identified the need for landscape-scale planning that can integrate constructed fen-upland cover systems within a wider planned hydrological network to avoid exporting sodium rich outflow into other cover systems such as end-pit lakes, marshes, or cover upland tributaries that may be especially vulnerable to increases in Na^+ within the soil porewater or water body.
- Salvaged peat used in the construction of the NF possesses a high sulphur content, which has meant significantly lower methane production than observed in natural reference systems. As a result, there is the prospect of low-methane producing fen systems to be constructed, with sulphur byproduct (as a result of the upgrading process) enriched peat suppressing methane greenhouse gas emissions from saturated cover systems comprised of organic material such as peat deposits or peat mineral mix cover soils where the soils remain saturated and subject to high-methane potential environmental conditions.

- Plant function and carbon uptake were able to persist throughout dry years indicating sufficient hydrological connectivity between upland and fen and thus ecosystem resilience to intervals of periodic water stress. Interannual variability of fluxes suggested that plant communities are exhibiting typical responses to environmental changes, as these responses mirror those of natural sites in the surrounding area experiencing similar conditions. Barring a successional shift caused by prolonged saline or dry conditions, water and carbon fluxes of both landscapes are expected to stabilize, and future fluctuations in the noted values above are predicted to be largely controlled by meteorological influences.

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RESEARCH TEAM AND COLLABORATORS

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SOILS AND RECLAMATION MATERIALS

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Infinity General Partnership

Industry Champion: Imperial

Status: Final Cumulative Summary

PROJECT SUMMARY

An important part of mine site reclamation is the salvage and storage of upland surface and subsurface soils. Salvaged soils are often stockpiled for long periods of time until final placement in the reclaimed landscape occurs. During this storage time biogeochemical transformations can alter physical, chemical, and biological properties of the soils relative to the pre-disturbance conditions or undisturbed forest ecosystems.

Mine operators are required to minimize mixing of markedly different soil textures, and in some cases may be required to segregate upland surface soil by ecosite (Alberta Environment and Water 2012) to preserve soil texture and other soil qualities, and to maintain separate and distinct seed banks. However, storing different textured soils separately requires more space and associated land disturbance than if combined in one stockpile.

This Trial was designed to assess soil quality and natural vegetation establishment on three surface soil stockpile treatments. When the mixing of surface soils was approved at the Kearl Oil Sands Mine (Kearl), the focus of the Trial shifted towards capturing temporal changes in soil biogeochemistry and soil physical characteristics, as well as associated reclamation suitability ratings and potential effects on the establishment of vegetation and native plant communities.

Stockpiled soil dynamics are of critical importance to future reclamation work, particularly given the scale of soil salvage operations, the inherent variability of soil within Kearl, and how widely changes in the aeration status of soil can alter soil chemical parameters in stockpiles.

The following treatments were evaluated:

- Treatment 1 – Stockpiled *a/b* coarse-textured surface soils (ABSS)
- Treatment 2 – Stockpiled *d/*Other moderate to fine-textured surface soils (OSS)
- Treatment 3 – Stockpiled ABSS + OSS (MIXED)

In 2016, six stockpiles were constructed at Kearl. These included two replicates each of ABSS, OSS and MIXED treatments. Each stockpile was approximately 3,000 cubic metres (m^3) in volume, with a maximum height of five metres (m) and a footprint of approximately 38 m x 38 m. The average grade for all slopes on each stockpile was 3H:1V (Horizontal:Vertical). To mimic operational procedures as closely as possible, mixing of the ABSS + OSS stockpiles was not perfectly homogenous. Mixing was accomplished by dumping alternating loads of ABSS and OSS; a support dozer was used to achieve further mixing. Stockpile surfaces were coarse textured to reduce erosion.

Soil quality parameters were monitored from 2016 to 2021. Vegetation performance parameters were monitored from 2018 to 2021.

PROGRESS AND ACHIEVEMENTS

Soil Monitoring

Soil monitoring was conducted annually for the duration of the Trial (2016 to 2021). Soils were sampled in late fall at nine random locations on the stockpile plateaus at 0.5 metre (m) (surface), 2.0 m (mid), and 4.0 m (deep) depths. Samples were composited by depth to yield three bulk samples per depth, per stockpile. Composite samples were used to minimize the error associated with non-homogenous mixing of the stockpiles, and to reduce the number of samples that were analyzed. Three pairs of bulk density samples were also collected from each stockpile plateau. All samples were submitted to Bureau Veritas Laboratories™ and tested for parameters listed in Table 1.

Table 1: Species harvested

Sampling Protocol Requirements	Annual Monitoring
Number of sample sites per stockpile	Nine
Depths sampled at each site	Surface = 0.5 m, mid = 2.0 m, deep = 4.0 m
Number of composite samples per depth, per stockpile (e.g., replicates)	Three
Total number of composite samples	54 samples, plus 18 pairs of bulk density samples
Soil parameters	• pH • Salinity (electrical conductivity [EC]) • Sodicity (sodium adsorption ratio [SAR]) • Soluble Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^{+}), and Sodium (Na^{+}) • Available Nitrogen (N), Phosphorus (P), Potassium (K), and Sulphate (SO_4-S) • Total Organic Carbon (TOC) • Total Kjeldahl Nitrogen (TKN) • Texture • Bulk Density

Statistical analyses were completed on all soil quality parameters, including those related to physical properties, salinity and pH, soluble ions, and fertility. Average changes in select parameters over time are presented in Figure 1 (surface), Figure 2 (mid), and Figure 3 (deep).

Figure 1: Select Surface (0.5 m) Soil Parameters by Soil Type (2016 to 2021)

Figure 2: Select Mid Depth (2.0 m) Soil Parameters by Soil Type (2016 to 2021)

Figure 3: Select Deep Depth (4.0 m) Soil Parameters by Soil Type (2016 to 2021)

All soil parameters were significantly affected by assessment year, with the exception of percent clay content, which was unchanged; however, the influence of time was mostly through annual fluctuations rather than consistent increases or decreases over time. These fluctuations may have been the result of laboratory error, and/or the heterogeneous nature of the stockpile matrices. The effect of sampling depth was a stronger determinant of soil parameters. All soluble cations increased with sampling depth. Salinity, sodicity, pH, some soil nutrients (TOC, available N, available P, available sulphate), percent sand, and percent clay also had consistent trends of either increasing or decreasing with depth. Percent sand, SAR, and available K were the only parameters that were dependent on soil type. In all three cases, values in MIXED stockpiles were significantly lower than in other stockpiles.

Reclamation suitability ratings for each soil type and sampling depth were determined through sample laboratory analyses (Table 2) according to the *Soil Quality Criteria Relative to Disturbance and Reclamation* (AAFRD 2004). The 2021 annual monitoring results indicate that all material types are rated as “Good” or “Fair” for reclamation. Limitations were due to EC values equal to or above 2.0 dS/m at mid- (ABSS and MIXED) and deep- (MIXED and OSS) sampling depths and saturation percent equal to or below 30% at deep-sampling depths (ABSS and MIXED). In 2021, EC values ranged from 0.2 dS/m to 3.4 dS/m and percent saturation ranged from 25.3% to 36.3%.

Table 2: Reclamation Suitability Rating by Surface Soil Type and Sampling Depth (2016-2021)

Year	Sampling Depth[w]	Reclamation Suitability Rating by Soil Type[x,y,z]		
		ABSS	MIXED	OSS
2016	Surface	Good	Good	Good
	Mid	Good	Good	Good
	Deep	Good	Good	Good
2017	Surface	Good	Good	Fair (pH)
	Mid	Good	Fair (EC)	Good
	Deep	Fair (EC)	Fair (EC)	Fair (EC)
2018	Surface	Good	Good	Good
	Mid	Fair (EC)	Fair (EC)	Good
	Deep	Fair (EC)	Fair (EC)	Fair (EC)
2019	Surface	Good	Good	Good
	Mid	Good	Fair (EC)	Good
	Deep	Fair (EC)	Fair (EC)	Fair (EC)
2020	Surface	Good	Good	Good
	Mid	Good	Good	Good
	Deep	Fair (EC)	Fair (EC)	Fair (EC)
2021	Surface	Good	Good	Good
	Mid	Fair (EC)	Fair (EC)	Good
	Deep	Fair (saturation)	Fair (EC)	Fair (EC, saturation)

NOTES:
[w] Sampling depths are surface (0.5 m), mid (2.0 m) and deep (4.0 m)
[x] Suitability ratings determined according to Table 8 of the *Soil Quality Criteria Relative to Disturbance and Reclamation* (AAFRD 2004)
[y] Limiting factors for "Fair" Reclamation Suitability Ratings are indicated in brackets
[z] "Good" suitability ratings are shaded green; "Fair" suitability ratings are shaded yellow

Vegetation Monitoring

Annual vegetation monitoring was initiated in 2018. In July of each year (2018 through 2021) three 1.0 m x 0.5 m plots were established on each of the north and south slopes of the six stockpiles (lower, mid, and upper slope). Percent cover of all species within the 0.5 m x 1.0 m plots was recorded. Data collected were used to calculate the following parameters:

- Species abundance (percent cover): the relative representation of each species in a sample plot
- Species richness: the number of species present in a sample plot
- Evenness: the relative abundance of individual species in a sample plot
- Diversity: species richness weighted by measured species abundance (percent vegetative cover)
- Characteristic species: those species typically found in the undisturbed, native plant communities of a particular ecosite (AENV 2010).

In addition to the assessment plots, a larger survey of each stockpile was also completed annually; plant species observed on the six stockpiles that were not captured in the vegetation plots were recorded. Statistical analyses were performed on all vegetation parameters collected apart from characteristic species, which were used to assess shifts in community composition over time. Data are presented in Figure 4.

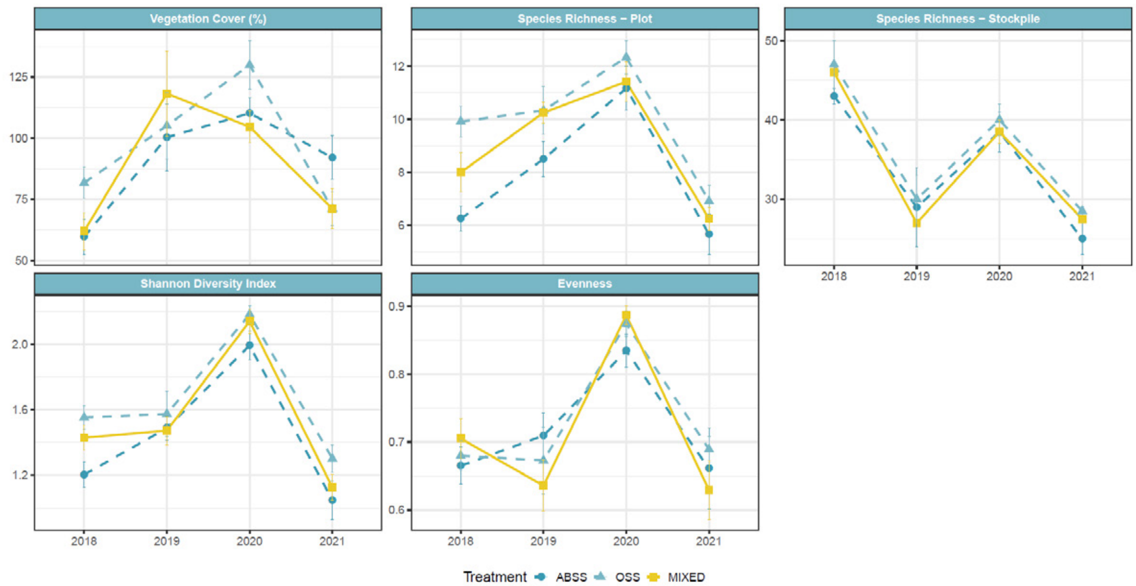

Figure 4: Vegetation Performance Parameters by Surface Soil Types from 2018 to 2021

Between 2018 and 2020, vegetation establishment and total cover on the stockpiles increased, though a significant decrease was observed between 2020 and 2021. 2021 was an uncharacteristically hot and dry year at the study site. Decreases in species richness (plot and stockpile level) and species diversity were also observed. In 2020 species diversity was considered to be within the ideal range (1.5 < SDI < 3.5) for all stockpiles in the Trial. With the decrease in species diversity observed in 2021, all stockpiles moved below this ideal range.

Neither the ABSS nor the OSS stockpiles differed from the MIXED stockpiles in percent cover, diversity, evenness, or species richness (stockpile level). The only parameter to be influenced by soil type was plot-level species richness. As would be expected when comparing *d/*Other surface soil to *a/b* surface soil, plot-level species richness was significantly higher on OSS stockpiles than on ABSS stockpiles, but again, neither OSS nor ABSS stockpiles differed from MIXED stockpiles.

In the final year of the Trial (2021), there was considerable overlap among characteristic species observed on stockpiles of each soil type. ABSS stockpiles supported seven species characteristic of dry site types, OSS stockpiles supported 12 species characteristic of moist-rich site types, and MIXED stockpiles supported 13 species characteristic of dry and/or moist-rich site types. At the culmination of the trial, all stockpiles, regardless of soil type, met the minimum thresholds for characteristic species for their associated site type as per the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (AENV 2010). The threshold for characteristic species for dry site types (sub-class aspen [Aw], white spruce [Sw], Mix) is four, the threshold for moist-rich site types is seven. While thresholds were met, the number of characteristic species was lower in 2021 than in 2020 for all stockpiles; characteristic species richness was highest in 2019 and 2020.

LESSONS LEARNED

With the culmination of the Trial, the following conclusions were made regarding trends in soil biogeochemistry, soil physical characteristics, reclamation suitability ratings, and effects on the establishment of vegetation when ABSS and OSS are stockpiled together.

Temporal trends: All parameters changed over the course of the Trial with the exception of percent clay content, but most changes were fluctuations from year to year rather than explicable trends over time.

- Changes in soil physical parameters were not expected over time — the minor fluctuations observed, while statistically significant, were generally not considered practically important.
- Soil pH and salinity parameters generally increased, but these increases did not affect reclamation suitability ratings.
- Soluble cations increased during the early years of the Trial and remained high for the rest of its duration.
- Some nutrients (available N, available sulphate) decreased over time.
- All vegetation performance parameters decreased between 2020 and 2021 suggesting that vegetation is entering into early successional stages, with reductions in percent cover, richness, and diversity of early competitive species — high temperatures and dry conditions in the summer of 2021 may have also contributed to the changes observed in vegetation between 2020 and 2021.

Trends with soil depth: The strongest trends observed were those associated with sampling depth.

- Percent sand and percent clay were negatively correlated with one another; percent sand decreased with depth while percent clay increased with depth.
- Soil pH and SAR both decreased with sampling depth while EC increased with sampling depth.
- All soluble cations increased with sampling depth, but concentrations remained relatively low.
- All nutrient parameters increased with sampling depth with the exceptions of available P, which decreased with sampling depth, and TKN, which did not change.

Trends with soil type: Nearly all parameters were unaffected by soil type — stockpiles of MIXED surface soils were generally not different from ABSS or OSS stockpiles.

- Both percent sand content and available K were highest in ABSS stockpiles, followed by OSS stockpiles, and MIXED stockpiles.
- SAR was higher in ABSS and OSS stockpiles than MIXED stockpiles.
- Vegetation communities developing on MIXED stockpiles were similar to both ABSS and OSS stockpiles.

Reclamation Suitability: Reclamation suitability ratings ranged from Fair to Good, with limitations on EC and percent saturation.

- Surface soil from MIXED stockpiles is not less suitable for reclamation than either ABSS or OSS stockpiles after six years of storage.
- Thresholds for number of characteristic species were met for all stockpiles, however, all of the observed characteristic species for dry site types (ABSS) are also characteristic species for moist-rich site types (OSS).

After six years of surface soil storage, there was little difference in soil quality and chemistry between stockpile types. In most cases, soil parameters fluctuated over time but ultimately remained within a relatively narrow range of values. MIXED surface soil stockpiles were similar to ABSS and OSS stockpiles in most cases.

As there are currently no MIXED soils used for reclamation at Kearl, the next step in determining if mixing ABSS and OSS has any impact on reclamation success would be a reclamation field trial. While stockpiled soils in this Trial appear to be relatively stable, placement and reclamation may show differences among soil types as re-aeration and increased exposure to the environment of stockpiled soils during these activities may catalyze changes in soil parameters. Changes to reclamation soil conditions towards conditions more representative of natural, undisturbed soils could improve soil growing conditions not only for *d* ecosite species, but potentially *a* and *b* ecosite species as well.

LITERATURE CITED

Alberta Agriculture, Food, and Rural Development (AAFRD). 2004. Soil Quality Criteria Relative to Disturbance and Reclamation (Revised). Prepared by Macyk, T. M., L. K. Brocke, J. Fujikawa, J. C. Hermans, and D. McCoy. for AAFRD. Edmonton, AB.

Alberta Environment (AENV) 2010. Guidelines for Reclamation to *Forest Vegetation in the Athabasca Oil Sands Region.* CEMA: Cumulative Effects Monitoring Association Terrestrial Subgroup. Fort McMurray, Alberta.

Alberta Environment and Water. 2012. *Best Management Practices for Conservation of Reclamation Materials in the Mineable Oil Sands Region of Alberta*. Prepared by MacKenzie, D. for the Terrestrial Subgroup, Best Management Practices Task Group of the Reclamation Working Group of the Cumulative Environmental Management Association, Fort McMurray, AB. March 2011.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications have been released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Infinity General Partnership

Principal Investigator: Paragon Infinity General Partnership

Shrub and Perennial Outplanting Study

COSIA Project Number: LJ0332

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Suncor, Imperial

Status: Year 3 of 4

PROJECT SUMMARY

The rationale for this study stems from historic uncertainties around outplanting success for a number of boreal forest understory species. Successful deployment of these species in oil sands reclamation areas may be required to meet stakeholder and regulatory expectations related to achieving locally common boreal forest ecosystems (i.e., the characteristic target species for forest land reclamation and specific species utilized by First Nations communities as listed in *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oils Sands Region* Alberta Environment 2010).

For some species there is insufficient operational experience to gauge outplanting success, while for others the existing anecdotal evidence suggests that survival rates are poor or inconsistent. Overall, there is a substantial lack of quantitative and observational evidence on the magnitude of the problem and on the potential causes of poor establishment success such as seedling quality, environmental conditions, and their interactions.

A key step to achieving establishment is access to good seedlings with good early growth potential. Generally, defining seedling quality is difficult, as it is species and site specific. There are many research studies and reviews related to how to assess quality in tree seedlings, but little information is available for boreal shrubs and perennials.

While height, root collar diameter and root system size (plug size) are seedling characteristics useful to evaluate seedling quality in tree species, shrubs and perennials will likely require additional measures such as number of branches, number and size of buds, leaf area in the case of evergreen species, and below ground measures such as rhizome development. Other characteristics that might also be considered include measures such as root volume and root mass, root to shoot ratio (RSR; root mass/shoot mass), state of dormancy, root growth potential (RGP), carbohydrate reserves, and other physiological measurements. The relevancy of these indicators is often species specific and not yet clarified for the species of interest here.

The objectives of this study are to:

1. Characterize early outplanting success (growth and mortality) of shrub and perennial forb species for which oil sands operators have experienced low historical survivorship or have limited experience.
2. Develop hypotheses on potential influential factors related to outplanting success for each species that could guide subsequent controlled experiments.

As suggested in Objective 2, there is poor ecological understanding of these species and how they perform in field settings. Therefore, this study is primarily inductive rather than deductive, as the intention is to develop meaningful and testable hypotheses that can be explored further. Seedling performance will be observed under a wide range of growing environments, such as; newly reclaimed sites with minimal early competition from ruderals; relatively young reclamation sites with a well-established ruderal community; older reclamation with an established canopy; agronomic fields with controlled competition; a mid to late seral stage natural forest; and well controlled potted studies in growth chambers and greenhouses.

Based on the performance of each species, potential causes for the observed variations in performance can then be narrowed down. For example, if seedlings of a particular species perform poorly under all conditions, it would strongly suggest that the seedlings are generally of poor quality and that the problem is related to nursery production or cold storage of the seedlings stock. If seedling performance is markedly different for a species among sites, this might suggest different strategies are required for the timing of seedling deployment (e.g., waiting for canopy development), or for site conditions that are tailored for a particular species. Overall, the results of this project are expected to contribute to a better fundamental understanding of planting stock quality for a range of boreal shrub species regardless of reclamation context (i.e., mining versus in situ). Operating in parallel with a new proposed operational monitoring protocol for understory species, this project is a first step toward fully identifying the magnitude of the challenge in propagating each species, for generating hypotheses, and for guiding future research.

PROGRESS AND ACHIEVEMENTS

Background progress information:

- A first batch of seedlings consisting of four species (bunchberry, honeysuckle, blueberry, and Labrador tea) was outplanted on a wide range of reclaimed mine sites near Fort McMurray and reference sites (an agronomic field setting [competition control] and a natural forest mixedwood site which contains almost all these species) closer to Edmonton, and in controlled conditions in a growth chamber in 2019.
- All seedlings planted in 2019 were assessed for survival and vigour in the fall of that year, while in 2020 only the agronomic field and natural forest site were remeasured.
- A second set of nine species (Labrador tea, lowbush cranberry, snowberry, crowberry, blueberry, lingonberry, bunchberry, twinflower, and honeysuckle) was outplanted in 2020 on a similar range of reclamation sites with two new variants added.
- Seedlings of the nine species were also planted in the agronomic field, the natural forest, and in controlled potted conditions. The potted seedlings and the seedlings planted in the agronomic field and natural forest were measured before and after the growing season.
- None of the planted seedlings on the reclamation sites were measured in 2020 due to access restrictions related to the COVID-19 pandemic.

Progress in 2021:

- All sites (reclamation and control sites) were visited in spring 2021 and in late summer 2021 and final measurements were taken on all seedlings.
- In the summer some seedlings from the 2019 outplanting were excavated on the agronomic field site to assess variables including root system expansion and field root to shoot ratios of seedlings.
- Soil samples and other site variables were collected at all sites with the goal of quantifying site differences.
- In the fall, collected samples were analyzed and data entered. The process of compiling and summarizing these data for a final report in 2022 is underway.

LESSONS LEARNED

There are no formal results available for 2021 as not all analyses have been completed. However, it appears that seedling quality is the dominant influence on establishment and growth performance for some shrub species, while site and particularly soil conditions have a greater impact on others. In both cases, analyses using covariates will attempt to identify specific factors that are associated with reduced performance and can be further investigated in subsequent studies as potential causal mechanisms.

LITERATURE CITED

Alberta Environment, 2010. Guidelines for reclamation to forest vegetation in the Athabasca oil sands region. Prepared by the Terrestrial Subgroup of the Reclamation Working Group of the Cumulative Environmental Management Association, Fort McMurray AB, December 2009. Available at: https://open.alberta.ca/publications/9780778588252

PRESENTATIONS AND PUBLICATIONS

No reports or publications available for 2021.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Brittany Hynes	University of Alberta	MSc	2019	2022
Serena Farrugia	University of Alberta	Research Assistant		
Rachelle Renauld	University of Alberta	Research Assistant		
Emmily MacDonald	University of Alberta	Research Assistant		
Nicklas Baran	MacEwan University	Research Assistant		
Caren Jones	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

Industry collaborator: Robert Nemeth, Smoky Lake Forest Nursery

REVEGETATION

Hitchhiker Field Trial at Kearl Operations

COSIA Project Number: LJ0324

Research Provider: Paragon Infinity General Partnership

Industry Champion: Imperial

Status: Year 4 of 5

PROJECT SUMMARY

Hitchhiker planting has been proposed as a means to introduce early successional herbaceous species and facilitate the growth and survival of planted woody species simultaneously (Dosite et al., 2016). This method involves sowing two species in the same plug — a shade tolerant, slower growing woody plant along with an early-successional pioneer herbaceous plant. Co-planting in this way provides later successional species with important shade and protection, potentially increasing growth and survival while promoting early herbaceous cover. Alternatively, separate plugs for the woody and herbaceous plants can be planted at the same planting site (companion planting), to achieve the same effect.

A Hitchhiker Planting Trial (the Trial) was established at Imperial's Kearl Oil Sands Mine (Kearl) in July 2018 along an east-facing temporary reclamation area on the East Tailings Area (ETA). The Trial was set up with species (shrub species [green alder and willow] and partner forb species [common fireweed and bunchberry]) and planting methods (Hitchhiker planting and Companion planting) as treatments in a modified split-plot design. Control plots where only green alder (Alder Control) or willow shrubs (Willow Control) were planted (no partner forb) were included. The soil prescription was consistent across treatments and fertilizer was not applied.

The main objectives of the Trial are to determine whether:

1. Survival and growth of woody shrubs (green alder [*Alnus viridis*] and willow [*Salix* spp.]) are facilitated by co-planting with locally common forb species (common fireweed [*Chamerion angustifolium*] and bunchberry [*Cornus canadensis*]).
2. Similar survival and growth rates can be achieved by co-planting two plugs in one planting site (Companion planting) as opposed to true Hitchhiker co-planting (i.e., two plants in one plug).
3. Co-planting methods provide additional vegetative cover in plots planted with woody shrubs and herbaceous species compared to sites planted with woody shrub seedlings only, providing additional erosion control in newly reclaimed areas

PROGRESS AND ACHIEVEMENTS

As in previous years, the 2021 trial plots were monitored in September at the end of the growing season. Performance metrics including seedling survivorship, height, health, and percent vegetative cover were measured.

Objective 1: Co-planting with Forb Species

Based on the results from Year 4, green alder and willow appear to respond differently when co-planted with locally common forb species. The effects observed are likely driven by the different site conditions each species needs to thrive.

Green alder seedling growth was not affected by the presence of partner forbs; all shrub:forb combinations had similar heights by the end of the fourth growing season, when planting method was excluded (Figure 1). In terms of shrub health, green alder seedlings that were Hitchhiker-planted with common fireweed fared the worst ($P < 0.0001$; Figure 2). Conversely, willow seedlings planted with common fireweed were taller ($P < 0.0001$) and healthier ($P < 0.0001$) than those planted with bunchberry, and both treatments were generally taller than willow that were planted alone (Figure 2). Notably, both green alder and willow seedlings were taller in the Hitchhiker-planted Control plots than in the Companion-planted Control plots ($P < 0.0001$), where partner forbs were not planted (Figure 1). Seedling heights would be expected to be similar in the Control plots under consistent site conditions.

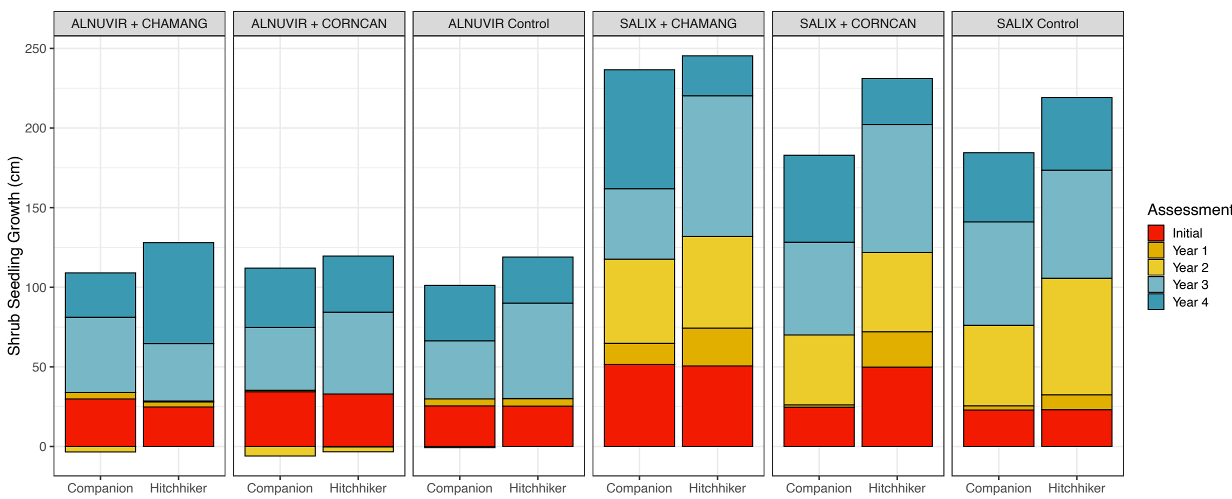

Figure 1: Average Growth of Shrub Seedlings During the First Four Growing Seasons.
Notes:
[1] ALNUVIR = green alder (*Alnus viridis*), CHAMANG = common fire weed (*Chamarion angustifolium*), CORNCAN = bunchberry (*Cornus canadensis*), and SALIX = willow spp. (*Salix* spp).
[2] Average height of green alder decreased in some treatments in Year 1 – depicted as negative average growth

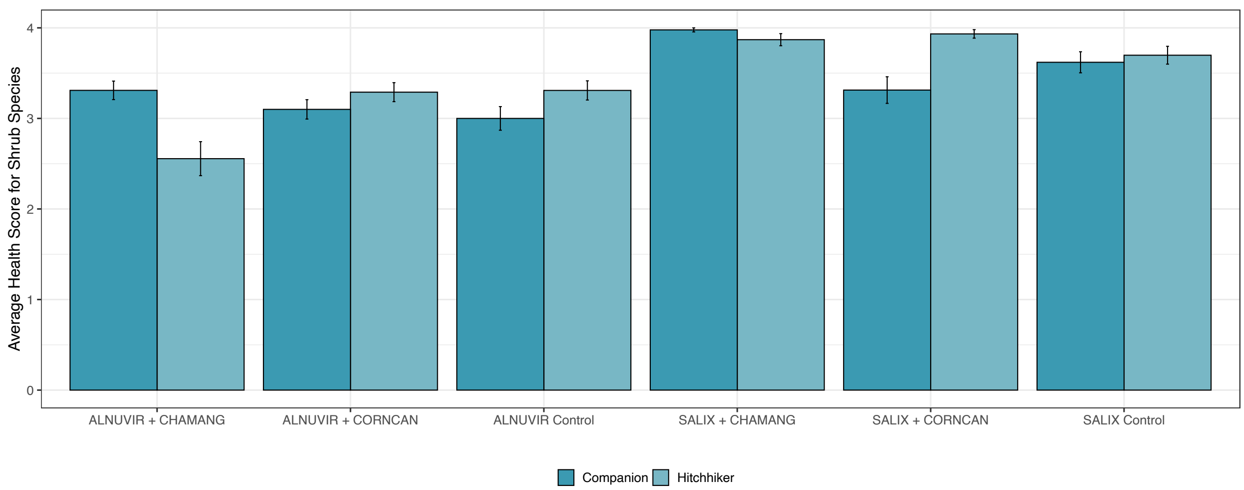

Figure 2: Average Health of Shrub Seedlings after Four Growing Seasons.
Note:
Health Score was measured on a scale of 0 to 4, where 0 = missing, 1 = dead, 2 = poor, 3 = good, and 4 = excellent.

Co-planting with partner forbs also affected the percent cover of planted shrub species differently (Figure 3). Green alder percent cover was maximized when planted alone ($P < 0.0001$), whereas willow percent cover was maximized when planted with common fireweed ($P < 0.0001$; Figure 3). Generally, trends observed in green alder performance were more pronounced in Hitchhiker-planted plots than in Companion-planted plots ($P = 0.0004$).

Decreases in the percent cover and health of shrubs in Year 4 may have been a result of a relatively hot and dry summer, which caused necrosis and early leaf drop, particularly in green alder shrubs.

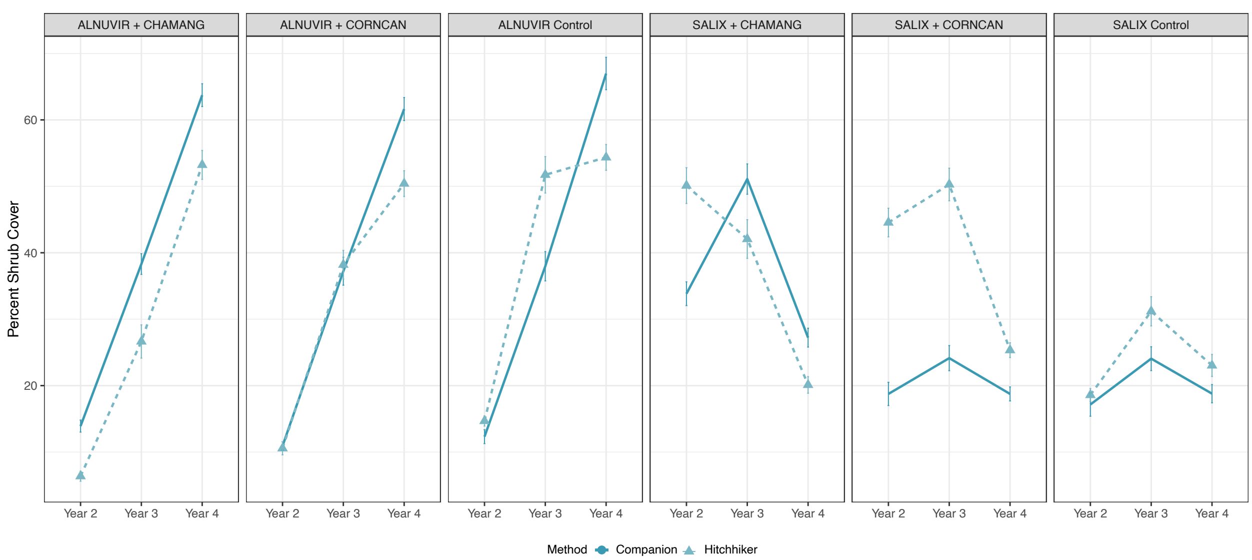

Figure 3: Average Percent Cover of Planted Shrubs after Four Growing Seasons.

Objective 2: Planting Method

Planting method generally had a stronger effect on shrub performance than the species of partner forb planted. For green alder, growth was highest in the Hitchhiker-planted plots (P < 0.0001; Figure 1), but shrub survival (Figure 4) and percent cover (P = 0.0004; Figure 3) was maximized in the Companion-planted plots. Growth, health, and percent cover of willow shrubs were maximized in the Hitchhiker-planted plots (P < 0.0001 for all contrasts).

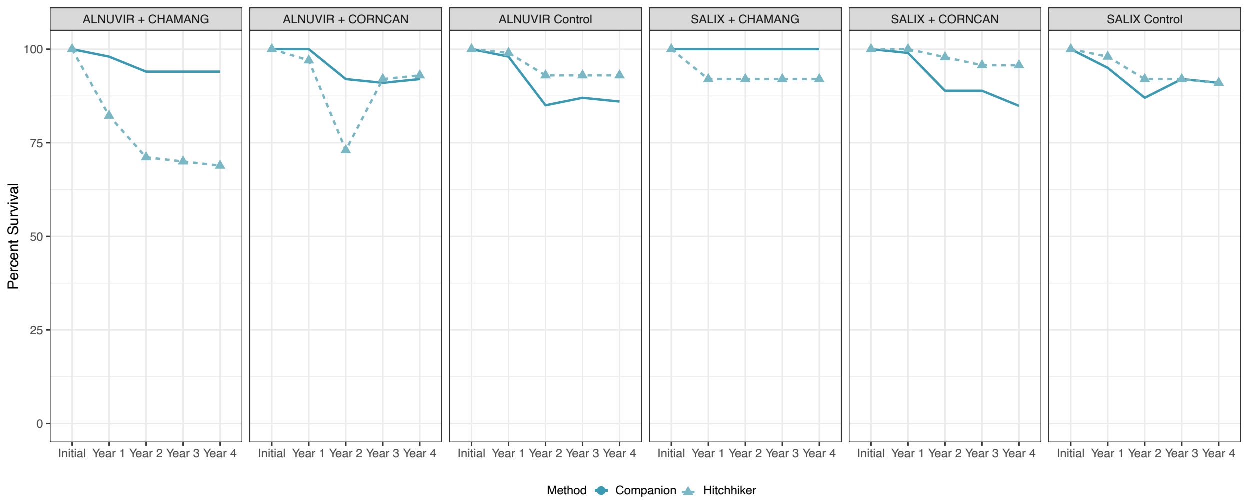

Figure 4: Percent Survival for Shrub Seedlings During the First Four Growing Seasons.

Objective 3: Vegetative Cover and Erosion Control

By the end of the fourth growing season, no obvious signs of erosion were observed at the Trial site. Shrub and herbaceous cover appear to be stabilizing the substrate adequately in all plots. However, herbaceous cover in green alder plots was greater when co-planted with partner forbs, particularly using the Hitchhiker planting method (P < 0.0001; Figure 5). Herbaceous cover in willow plots was maximized when bunchberry was included as the partner forb species (P < 0.0001).

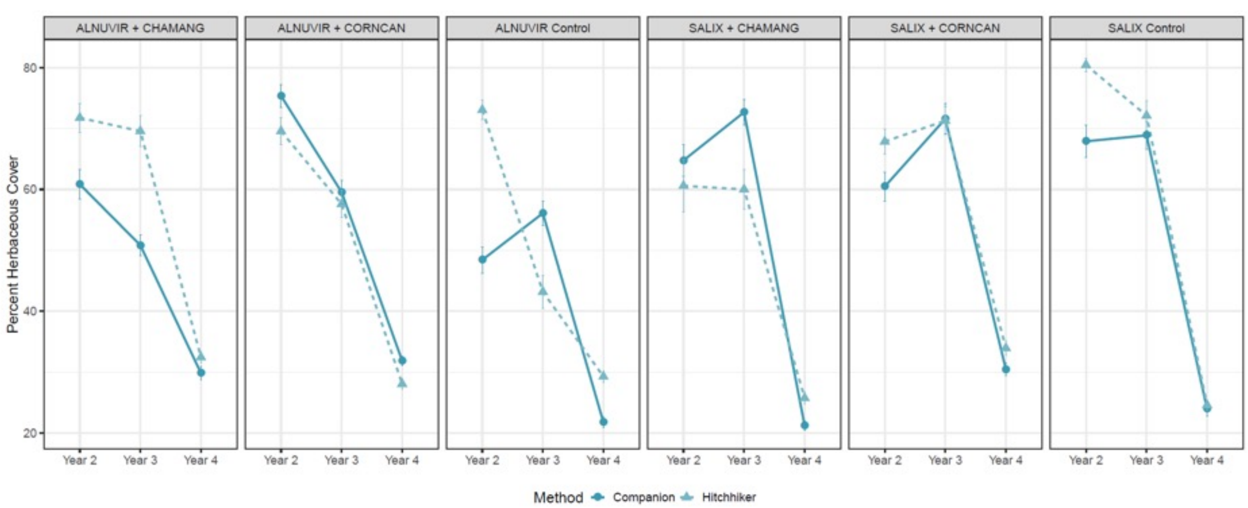

Figure 5: Average Percent Cover of Herbaceous Species after Four Growing Seasons

LESSONS LEARNED

Lessons learned will be summarized after the final year of the program (2022).

LITERATURE CITED

Dosite, J., Floreani, T., and Schoonmaker, A. 2016. Hitchhiker planting: *Development of combination container stock of target woody and herbaceous plants*. NAIT Boreal Research Institute. Oral Presentation ASSW.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2021.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Infinity General Partnership

Principal Investigator: Paragon Infinity General Partnership

Effects of Non-Segregated Tailings (NST) on Growth on Oil Sands Reclamation Plants

COSIA Project Number: LJ0303

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 6 of 6

PROJECT SUMMARY

Non-Segregating Tailings (NST) are a by-product of oil sands bitumen processing in northeastern Alberta. NST deposits at the Canadian Natural Horizon lease must be reclaimed: capped with tailings sand, subsoils, coversoils and revegetated. However, there are significant knowledge gaps as to the potential success of NST reclamation, such as how vegetation will tolerate the potentially elevated salt concentrations, high pH, limited nutrient supply, or the presence of phytotoxic substances such as fluoride and naphthenic acids that are present in the NST substrate and may migrate into the root zone. These factors can adversely affect water and nutrient uptake of the plants used for reclamation, as well as microbial activities and community structures, particularly of mycorrhizae, in the reconstructed soils. It is therefore crucial to understand how plant species that are commonly used in the revegetation of tailings-affected sites would respond if in contact with the NST or any of its components.

Several plant species that are used for oil sands reclamation are of special significance to the Aboriginal communities in the area. Therefore, an important part of the investigation of NST reclamation is also to understand if potential contaminants derived from the NST beneath the reconstructed soil profiles could significantly reduce the growth and the quality of these plants for potential medicinal uses. Mycorrhizal associations have been identified in many boreal forest plants (Calvo-Polanco et al., 2009; Dimitriu et al., 2010), but there is little understanding of how mycorrhizal fungi may improve the performance of reclamation plants that could produce deep roots extending beyond the reconstructed soil profile and into the NST. These associations are essential to provide plants with sufficient nitrogen and phosphorus nutrition, and to protect them from abiotic and biotic stresses. In addition, elemental sulfur is an important by-product of the oil sands mining industry, and it is commonly used to lower soil pH in agricultural practices. Therefore, elemental sulfur has potential benefits to be used for mitigating high pH stress of reclamation soil on vegetation.

The objectives of the project are:

1. To examine growth and physiological parameters in 20 native boreal forest plant species growing in six types of growth media containing a combination of NST and/or coke, capped with reclamation coversoils.
2. To examine the effects of NST on the uptake and tissue distribution of trace elements in three selected species of plants of special significance to Aboriginal communities.
3. To examine the effects of NST and enhanced NST on the growth and physiological responses and rhizosphere microbial communities of reclamation plants.
4. To examine the effects of different nitrogen, phosphorus and sulfur supplies on plants growing in NST-amended soil.

The project consists of seven studies that include both field and environmentally controlled experimental conditions:

Study 1. Effects of NST deposit on growth, survival and physiology of reclamation plants.

Study 2. Effects of NST tailings water chemistry and hypoxia on growth, survival and physiology of reclamation plants.

Study 3. Effects of tailings release water chemistry on aspen (*Populus tremuloides*) seedlings.

Study 4. (revised) Effects of NST and enhanced NST (eNST) on the growth and physiological responses of paper birch, Labrador tea, lingonberry, and blueberry seedlings.

Study 5. Nitrogen and phosphorus nutrition of plants growing in NST-amended soil.

Study 6. Effects of NST on plant uptake and distribution of heavy metals and other trace elements.

Study 7. Effects of elemental sulfur on growth of reclamation plants.

PROGRESS AND ACHIEVEMENTS

Studies 1, 5, 6 and 7 were completed in prior years.

All the sample and data analyses of Studies 2 and 3 were completed in 2021. The growth chamber experiment of revised Study 4 was conducted in 2021, and most of the sample and data analyses were completed.

Study 2. Effects of NST tailings water chemistry and hypoxia on growth, survival and physiology of boreal trees

The interaction between aeration level and solution elemental concentration (aeration-elements interaction) was significant for balsam poplar, jack pine, and tamarack ($P < 0.001$, 0.01, and < 0.05, respectively) but not for aspen, black spruce and lodgepole pine. The interaction between the media type and solution elemental concentration (Media-Elements) was highly significant for all treatments ($P < 0.001$). Aeration-Media-Elements interaction was significant for aspen, balsam poplar, black spruce, and tamarack ($P < 0.05$, < 0.01, < 0.05, and < 0.001, respectively).

Study 3. Effects of tailings release water chemistry on aspen (*Populus tremuloides*) seedlings

Analyses demonstrated that plant mortality was highest in the synthetic complete NST (solutions simulating NST water chemistry) treatment. This was followed by the synthetic NST – sodium, naphthenate positive control, synthetic CT (solutions simulating chemistry of complete composite tailings), and NST release water treatments. There was no mortality in the control, sodium positive control, and Synthetic NST – naphthenates treatments.

Foliar sodium concentrations were the highest in the synthetic CT treatment followed by the synthetic complete NST, NST release water, sodium positive control, and synthetic NST – sodium treatments.

Boron concentrations were the highest in the NST treatment compared with other treatments.

As shown in the multiple factorial analysis cluster dendrogram, growth parameters such as height and root collar diameter were strongly negatively correlated with the presence of naphthenates, mortality, and a high root to shoot ratio. High concentrations of sodium and boron were negatively correlated with transpiration and photosynthesis.

Due to the strong initial effect of naphthenates, synthetic NST, synthetic NST without sodium, and the control with naphthenates treatments showed similar responses throughout the experiment (as evidenced in the cluster dendrogram). In contrast the Synthetic NST without naphthenates, and the control with sodium treatments showed the responses closest to the control treatment.

Study 4. Effects of NST on the growth and physiological responses of paper birch, Labrador tea, lingonberry, and blueberry seedlings

In 2020, seedlings of white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*), lingonberry (*Vaccinium vitis-idaea* var. minus Lodd.) and Labrador tea (*Ledum groenlandicum*) were grown from seeds. However, after several months of growth the white spruce seedlings became dormant and could not be used for the study. Due to the interruptions caused by the COVID-19 pandemic and the unexpected slow growth rate of the mycorrhizal fungi media, enough fungal samples were not available on time to inoculate the seedlings for the originally proposed study. However, since enhanced NST (eNST) materials from Canadian Natural for a different project were available, this study was revised and aimed at comparing the effects of NST and eNST on the survival, growth, and physiological parameters of paper birch, lingonberry, Labrador tea, and blueberry (*Vaccinium myrtilloides*).

One-year-old seedlings were grown for a period of 12 weeks in three growth media including topsoil (collected from Canadian Natural's Horizon Mine Dyke 10 site), mixture of non-segregating tailings (NST) and topsoil (1:1, v/v), and mixture of enhanced NST (eNST) and topsoil (1:1, v/v). There were ten replicates of seedlings per species in each treatment. The plants were watered every second day and fertilized weekly with the Miracle-Gro water soluble Evergreen & Acid-Loving Plant Food (28N-10P-10K) fertilizer. At the end of the treatment period, the plants were harvested and measured for: the leaf, stem, and root dry weights; net photosynthesis and transpiration rates; leaf chlorophyll concentration; and leaf elemental concentrations. Fresh root samples were flash-frozen in liquid nitrogen and stored in the ultra-low temperature freezer to determine the effects of NST and eNST on the structure and composition of rhizosphere microbial communities.

It was found that the pH of topsoil was similar to eNST and NST mixtures and all ranged between 7.5 to 8, which could be due to a higher concentration of sodium in topsoil. However, the electrical conductivity (EC) of all growth media ranged between 0.5 mS cm^{-1} to 0.6 mS cm^{-1}, which is within the acceptable range (0 mS cm^{-1} to 2 mS cm^{-1}) for growth of boreal woody plant species (Alberta Environment 2010). Therefore, the plants in this experiment were mainly affected by the high root zone pH stress, while the stress caused by elevated salinity was minimal.

After three weeks of growth, the blueberry seedlings grown in eNST mixtures showed approximately 60% mortality, while the seedlings grown in the NST mixtures had about 20% mortality. Therefore, all blueberry seedlings were harvested at that time. After 12 weeks of treatment, lingonberry seedlings grown in both eNST and NST mixtures had 50% to 60% mortality, while there was no mortality for plants grown in the topsoil. Labrador tea's mortality was 10% in the NST mixtures, while the mortality of paper birch was 10% in eNST mixtures. At the end of the experiment, paper birch and lingonberry had greater leaf, stem, and root dry weights, as well as higher shoot to root dry weight ratios when grown in the topsoil compared with either NST or eNST mixtures.

Paper birch, Labrador tea and blueberry showed drastic reductions in leaf chlorophyll concentrations for seedlings grown in eNST and NST mixtures compared with those grown in the topsoil. Blueberry seedlings grown in the eNST and NST mixtures had significantly lower net photosynthesis rates compared with the plants grown in the topsoil.

Labrador tea seedlings grown in the NST mixtures had lower photosynthesis rates compared with the plants grown in the topsoil and eNST mixtures. Lingonberry and paper birch seedlings had similar photosynthesis rates when grown in the different media.

LESSONS LEARNED

Study 2. Effects of NST tailings water chemistry and hypoxia on growth, survival and physiology of reclamation plants

Statistical analysis of foliar elements showed that hypoxia and NST tailings water had significant levels of interaction in aspen, balsam poplar, black spruce, and tamarack seedlings. Combined with the observations of leaf elemental concentrations (including sodium and boron), the results demonstrated that hypoxia aggravated the effects of NST water in these plant species.

Study 3. Effects of tailings release water chemistry on aspen (*Populus tremuloides*) seedlings

Plants treated with naphthenic acids at pH 5.5 suffered from relatively high mortality, which was aggravated by the NaCl treatments. This response was interpreted to be due to surfactant properties of naphthenates that made the plants more sensitive to NaCl treatments at the lower pH compared with the pH of 8.5 measured in the NST water samples. These results demonstrate that a high pH may offset the effects of naphthenates on seedling roots. This observation merits further study since lowering the pH of tailings water to improve plant growth could potentially come at the expense of elevated naphthenate phytotoxicity, which may need to be addressed.

Study 4. Effects of NST on the growth and physiological responses of paper birch, Labrador tea, lingonberry and blueberry seedlings

The unusually high pH of topsoil collected from Canadian Natural's Horizon Dyke 10 site shows that there can be large variations of soil pH at reclamations sites. The reasons for the high pH of naturally occurring topsoil need further investigation. The results showed that eNST caused higher mortality of blueberry seedlings compared with NST, while for Labrador tea, the impact of eNST on photosynthesis was milder compared with NST. This demonstrates that different plant species may respond differently to the factors associated with NST and eNST. Overall, both NST and eNST impaired shoot growth of studied plants, particularly in lingonberry and paper birch, and Labrador tea and paper birch showed higher resistance to the stress caused by the presence of tailings.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

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Journal Publications

Sun, X., Zhang, W. Q., Vassov, R., Sherr, I., Du, N., and Zwiazek, J. J. 2021. Effects of elemental sulfur on soil pH and growth of Saskatoon berry (*Amelanchier alnifolia*) and beaked hazelnut (*Corylus cornuta*) seedlings. Journal of Environment Quality (submitted).

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta, Department of Renewable Resources

Principal Investigator: Janusz Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Wenqing Zhang	University of Alberta	Research Associate		
Killian Fleurial	University of Alberta	PhD	2017	2022
Xuehui (Chris) Sun	University of Alberta	MSc	2018	2020
Michelle Moawad	University of Alberta	PhD	2021	2025

Oil Sands Vegetation Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting, Inc.

Industry Champion: Canadian Natural

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

Status: Ongoing

PROJECT SUMMARY

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

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

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

PROGRESS AND ACHIEVEMENTS

Seed Banking

In 2020 and 2021 (12th season) the OSVC harvested 225 litres (L) and 116 litres (L) of fruit respectively. Seeds were harvested from two seed zones in northeastern Alberta for the NAOS division. Harvest was based on requests from member companies. The following were extracted and registered:

Table 1: Species harvested

Alnus alnobetula (green alder) 2020 and 2021	*Dasiphora floribunda* (shrubby cinquefoil) 2021
Alnus incana (river alder) 2021	*Populus tremuloides* (trembling aspen) 2020
Betula pumila (dwarf birch) 2020	*Populus balsamifera* (balsam poplar) 2021
Betula papyrifera (paper birch) 2020	*Prunus pensylvanica* (pin cherry) 2021
Calamagrostis canadensis (Canada reed grass) 2020	*Shepherdia canadensis* (buffaloberry) 2021
Carex aquatilis (water sedge) 2020	*Vaccinium vitis-idaea* (lingonberry) 2020
Cornus sericea (red-osier dogwood) 2020 and 2021	*Viburnum edule* (lowbush cranberry) 2020 and 2021

In 2020 and 2021, activities supporting the OSVC seed collection initiatives included:

- In 2020, following a quick review of production effectiveness, routine seed testing was initiated to provide qualitative information regarding purity and viability of each stored seed lot.
- In 2020, a business case and cost analysis of seed orchards for individual shrub species was completed.
- Annual updates to the cross-company record keeping system and administration of the cooperative bank continued in 2020 and 2021.
- In 2021, a harvest site audit was undertaken to ensure healthy populations and to maintain an active inventory of suitable harvest sites in each seed zone for individual species.
- The 10-year seed requirement projections were completed in 2020 and will be used to plan future harvests.

Progress on Strategic Objectives

- OSVC members held eight meetings in 2020 and 11 in 2021 to discuss knowledge gaps and propose research.
- A Knowledge Gap Context document was initiated in 2020 to further identify specific gaps and propose hypotheses and research questions to address these concerns. Refinements to this document continued in 2021.
- A review of viability, germination and production gaps was prepared for priority species as a starting point for continued research (2020).
- In 2020, an initial meeting was held with representatives of the Wetland Working Group to determine if the OSVC could assist with accessing required seed.
- In 2020, the OSVC members were included in discussions with nursery producers to improve communication and streamline plant production methods.
- The pilot vegetative propagation trial with *Corylus cornuta* (beaked hazelnut) and *Viburnum edule* (lowbush cranberry) was completed and a report submitted.
- Work on the Operational Monitoring program (initiated in 2018) to determine survival of outplanted shrubs over the oil sands area continued. This monitoring program examines survival by species on various reclamation materials, and information may be used to begin to assess stock quality.
- In 2021 a trial (in cooperation with Smoky Lake Forest Nursery) was initiated to improve operational production methods for *Viburnum edule* (lowbush cranberry), a particularly difficult species to produce.

Communications

- Three editions of the Oil Sands Vegetation Cooperative Newsletter (May 2020, May and November 2021) were published.
- An overview of the OSVC was presented at the World Conference on Ecological Restoration in June 2021 and was well received and generated much interest.
- A meeting between Wild Rose Consulting and Federal MP James Cummings to discuss the overall state of revegetation in Alberta, provided an opportunity to introduce and explain the effectiveness of the COSIA-OSVC seed banking system.

LESSONS LEARNED

- The vegetative propagation pilot project completed by OSVC and NAIT Centre for Boreal Research in 2020 determined stem cuttings of both *Corylus cornuta* (beaked hazelnut) and *Viburnum edule* (lowbush cranberry) could be rooted, but additional work was needed to refine rooting methods. This led to further investigation into the production of both species by Canadian Forest Service.
- Researchers are moving towards filling the numerous identified knowledge gaps. Particularly in the areas of; seed handling practices, shrub mortality, vegetative and seed propagation of shrubs, and the potential for establishment of seed orchards and stooling beds for specific species. Collaboration with growers continues.
- For the seed bank to be successful, it is important that the banked seeds are of the highest quality possible. The harvest and handling of native seed is expensive and labour intensive. Boreal shrub species exhibit strong dormancies and require excessive time periods for germination testing. Moreover, standard protocols for testing do not exist. Therefore, the OSVC is having all seedlots assessed by a third-party, accredited seed testing laboratory using a standard TZ viability test. Seed quality testing will be invaluable in determining seeding rates, will assist in improving seed harvest and handling operations, and be useful for evaluating longevity.

PRESENTATIONS AND PUBLICATIONS

Wild Rose Consulting, Inc. 2020. Vegetative Propagation of *Corylus cornuta* and *Viburnum edule* from softwood stem cuttings. In cooperation with NAIT Centre for Boreal Research. Prepared for the Oil Sands Vegetation Cooperative and Canadian Oil Sands Innovation Alliance.

Newsletters

Wild Rose Consulting Inc. 2019. Oil Sands Vegetation Cooperative Newsletter. May 4(1). 3 pages. https://www.cosia.ca/sites/default/files/attachments/OSVC%204%281%29.pdf

Wild Rose Consulting Inc. 2019. Oil Sands Vegetation Cooperative Newsletter. November 4(2). 3 pages. https://www.cosia.ca/sites/default/files/attachments/OSVC%20Newsletter%204%282%29.pdf

Wild Rose Consulting, Inc, 2021. Oil Sands Vegetation Cooperative Newsletter. November 6(2). 4 pages. https://cosia.ca/sites/default/files/attachments/Oil%20Sands%20Vegetation%20Cooperative%20November%202021%20Newsletter.pdf

Conference Presentations/Posters

COSIA 2021. A Collaborative Initiative for Sustainable Plant Community Establishment. Society for Ecological Restoration – A New Global Trajectory, 9th World Conference on Ecological Restoration. June 23, 2021.

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu

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Kimberly Gould	Wild Rose Consulting, Inc.	Field Ecologist		

Research Collaborators: Jean-Marie Sobze, NAIT Centre for Boreal Research; Dani Dagenhardt, Canadian Forest Service, Natural Resources Canada; Peggy Popel, Smoky Lake Forest Nursery

The Use of Carbon Nanomaterials to Improve Seed Germination, Seedling Vigour and Growth

COSIA Project Number: LE0067

Research Provider: NAIT Centre for Boreal Research

Industry Champion: Canadian Natural

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

Status: Year 1 of 2

PROJECT SUMMARY

Seed priming techniques are applied to enhance seed germination and seedling vigour and are especially useful in treating seed to become more resistant to abiotic stresses. Nanopriming is a technique based on the combination of seed priming and nanoparticle treatment. Nanopriming methods have been used extensively on agricultural crops but have not been widely tested on native boreal forest species, particularly in the context of improving seed germination and growth performance. Recent work using nanopriming with multi-walled carbon nanotubes (MWCNTs) and functionalized with carboxylic acid (MWCNT-COOH) or functionalized with hydroxyl (MWCNT-OH), combined with cold stratification techniques, was successful at improving the seed germination and seedling vigour for two dormant boreal forest species, green alder (*Alnus viridis*) and buffaloberry (*Shepherdia canadensis*) (Ali et al., 2020). However, the need remains to investigate the potential of using nanopriming with carbon nanoparticles to improve the germination of key native boreal species used in the reclamation of industrially disturbed sites.

The primary objective of this project is to evaluate the effects of MWCNTs in improving seed germination, seedling vigour and growth in select native boreal plant species ideally suited for forest reclamation following oil sands mining and in-situ development.

To achieve this objective, NAIT and COSIA members have identified key reclamation species to evaluate in this study, including chokecherry (*Prunus virginiana*), bearberry (*Arctostaphylos uva-ursi* [L.]), common blueberry (*Vaccinium myrtilloides*), low-bush cranberry (*Viburnum edule*), and redcurrant (*Ribes triste*).

Seed scarification involved using 5% sulfuric acid to soften the seed coat to facilitate water imbibition. Seed stratification consisted of breaking seed dormancy through a moist and chill treatment to promote the germination. The effect of stratification, scarification, and carbon nanotubes on the germination of three native seeds (chokecherry, low-bush cranberry, and redcurrant) is being investigated. The tested stratification times were for zero, two, four, eight and 12 weeks. For scarification, 5% sulfuric acid was used. Three carbon-based nanotube types (MWCNT, COOH, and OH) were used at concentrations of 10 µg/L, 20 µg/L, and 30 µg/L.

Chokecherry was the only species that germinated during the observation period (50 days), while the germination of low-bush cranberry was completed in 130 days. No germination of redcurrant was observed.

Germination was monitored every two days for a period of 50 days and recorded when the radicles grew to approximately 3 mm. For chokecherry, the germination rate (%), mean germination time (MGT), and synchronization index (SYN), which measures asynchrony associated with the distribution of the relative frequency of germination, were estimated through observation. The germination rate is the percentage of seeds that complete the germination process. MGT indicates the mean average time required to germinate one seed from a seed lot. The germination synchrony (SYN) was initially proposed to evaluate the degree of overlap of flowering individuals in a population (Primack, 1985). When SYN is equal to one, seed germination occurs simultaneously — whereas a SYN closer to zero indicates that at least two seeds complete the germination process at different times. For low-bush cranberry, only seeds stratified for 12 weeks had estimated germination rates.

In 2021, the membrane integrity test was conducted on three species, chokecherry (*Prunus virginiana*), low-bush cranberry (*Viburnum edule*), and bearberry (*Arctostaphylos uva-uris*). The membrane integrity test has been determined to be the most promising method for the assessment of seed vigour (Ramos et al., 2012).

PROGRESS AND ACHIEVEMENTS

Chokecherry (*Prunus virginiana*) - Seed germination test

Cold stratification time significantly increased the seed germination rate in chokecherry. For the seed germination rate, there was an interactive effect of cold stratification time, scarification, and carbon nanotube (CNT) type. The seed germination rate increased with increasing cold stratification time in all CNT types with the exception of seeds scarified and treated with MWCNT. The scarified seeds that were treated with MWCNT showed no improvement in germination rate after 12 weeks of cold stratification. The highest germination rates were observed in scarified seeds, treated with COOH, and cold stratified for 12 weeks.

MGT was significantly affected by the interactive effect of cold stratification time, scarification, and CNT concentration.

Overall, MGT was significantly shortened through the use of eight and 12 weeks of cold stratification, whereas further treatment by scarification and CNT type did not significantly affect MGT when combined with the eight- and 12-week stratification treatments. Significant differences were observed between the scarification and CNT type treatments under the four weeks of cold stratification treatment. However, this difference is likely due to the low germination rate preventing the MGT from being measured.

Due to the low germination rate, SYN was not estimated for the four-week stratification treatment. SYN was significantly affected by the interactive effect of cold stratification length, scarification, and CNT type. However, the difference between the two treatments (cold stratification time and scarification) was marginal with the exception of scarified seeds treated with MWCNT and stratified for eight and 12 weeks.

Low-bush cranberry *(Viburnum edule)* - Seed germination test

Since low-bush cranberry did not germinate during the observation period, the only results acquired were for the germination rate of seeds that were stratified for 12 weeks. The best germination rate came from the seeds treated with 10 µg/L of MWCNT, without prior scarification and stratified for 12 weeks. Whether scarified or not, seeds treated with functionalized CNT (COOH and OH) did not provide significantly higher germination rates when compared to the control.

Membrane integrity test

The membrane integrity test was conducted on three species including chokecherry, low-bush cranberry, and bearberry. The germination test for bearberry is ongoing.

CNT type affected the electrical conductivity measurements for chokecherry. The leakage from the seeds treated with MWCNT was significantly higher compared to the control.

LESSONS LEARNED

Overall, chokecherry and low-bush cranberry reacted differently to treatments with carbon nanotubes. The functionalised CNT treatment improved chokecherry seed germination after a long stratification period, and the non-functionalised (MWCNT) treatment improved the germination of low-bush cranberry after 12 weeks of stratification.

Study results indicate the significant value of cold stratification when using nanoparticles to improve seed germination rate, MGT, and SYN. The highest germination rates were found within the longest cold stratification period (12 weeks). However, depending on the combination of scarification and CNT treatments, germination could be negatively affected by a longer stratification period. In the membrane integrity test, a weakening of cell membranes was found in MWCNT treated seeds. This may be a reason why 12 weeks of cold stratification did not improve the seed germination rate in treatments that combined scarification and longer treatment with MWCNT.

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Ramos, K. M. O., Matos, J. M. M., Martins, R. C. C., and Martins, I. S. (2012). Electrical Conductivity Testing as Applied to the Assessment of Freshly Collected *Kielmeyera coriacea* Mart. Seeds. *ISRN Agronomy*, *2012*, 1–5. https://doi.org/10.5402/2012/378139

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications available for 2021.

RESEARCH TEAM AND COLLABORATORS

Institution: NAIT Centre for Boreal Research

Principal Investigator: Dr. Jean-Marie Sobze

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Sahari Inoue	NAIT Centre for Boreal Research	PhD		
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Katie Bartman	NAIT Centre for Boreal Research	Research Assistant		

WILDLIFE RESEARCH AND MONITORING

Bison Research, Mitigation and Monitoring Program

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck

Industry Collaborators: Canadian Natural

Status: Year 6 of 6

PROJECT SUMMARY

The goal of the *Bison Research, Mitigation and Monitoring Program* is to fill knowledge gaps identified by the Ronald Lake Bison Herd Technical Team[1], specifically those related to the habitat and population ecology of the Ronald Lake wood bison herd located in northeast Alberta[2]. Information from the project is intended to inform herd management and planning by the Ronald Lake Bison Herd Cooperative Management Board[3], as well as strategies to mitigate the potential effects of future industrial activities from exploration, operation, and reclamation activities. Specifically, the project is addressing four over-arching questions, some with sub-questions, through a multi-year project led by the University of Alberta. These questions include:

1. What is the spatial distribution (habitat) of wood bison in relation to season, land cover type, and natural and anthropogenic disturbances?
   a. What are the seasonal patterns in home range size and location?
   b. What are the seasonal patterns in habitat selection for different land cover types?
   c. Do natural and anthropogenic disturbances alter bison behaviour (habitat use)?
2. What bottom-up (forage and habitat supply) or top-down (predation) factors naturally limit the Ronald Lake wood bison herd?
   a. Where is forage supply highest, how does this change with season (availability), and what are the projected changes in forage supply with resource development?
   b. Is access to preferred forage in wetlands in summer limited by insect harassment and ground firmness?
   c. What mechanisms promote selection for upland meadow habitat in early summer, and what influence does this have on recruitment and calf survival?
   d. How do winter conditions and wolf predation risk influence winter habitat use and survival of bison?

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1 The Ronald Lake Bison Herd Technical Team is a multi-stakeholder group (i.e., Indigenous groups, provincial and federal government and industry) with a mandate to identify and address information needs that will inform management decisions.

2 Wood bison (*Bison bison athabascae*) are federally listed as Threatened under Schedule 1 of the Species at Risk Act due to small population sizes, restricted distribution, and threats from disease outbreaks (COSEWIC 2013). The Ronald Lake Bison Herd is a subpopulation of wood bison and is culturally significant for local aboriginal communities (Candler et al., 2015). The formerly proposed Frontier Oil Sands Mine Project intersected a portion of the home range of the Ronald Lake wood bison herd. Teck withdrew the federal regulatory application for the Frontier Oil Sands Mine Project on February 23. 2020.

3 The Cooperative Management Board was formed by the Government of Alberta in 2019 through Ministerial Order. The board's purpose is to advise the Minister on matters related to the long-term sustainability of the Ronald Lake Bison Herd, including sustainability of Indigenous traditional use of and cultural connection to the herd.

3. What is the expected response of the Ronald Lake wood bison herd to resource development?
    a. How do anthropogenic disturbances affect forage availability, habitat selection, and bison movement?
    b. What can be done to manage the expected response of the herd to projected resource development?
4. What mitigation and reclamation strategies can be used to minimize adverse effects of development if it does occur?

Teck Resources Limited and Canadian Natural provide funding for this project that are leveraged with federal grant funds to the University of Alberta from the Natural Sciences and Engineering Research Council (NSERC). The work is technically directed by the Ronald Lake Bison Herd Technical Team.

PROGRESS AND ACHIEVEMENTS

A summary of the results of the 2021 program are as follows:

- Diets of bison were significantly more diverse and of higher quality in spring and summer compared to winter.
- Bison foraged more intensively in wetlands during the winter for one of three species of sedges (e.g., *Carex atherodes*, *C. utriculata*, *C. aquatilis*), while grasses and woody plants were of low importance. Not surprisingly, winter forage sites were inversely related to snow depth.
- Relative to wetland types, preferred forage items from bison in winter were split between mineral and organic substrates with wheat sedge and grasses being observed in mineral-based wetlands (generally east of the esker that runs south-southeast of Ronald Lake for a half-dozen or more kilometers), and beaked sedge and water sedge found in wetlands with organic substrates (generally west of the esker).
- The instantaneous rate of green-up (IRG) in spring and wolf predation pressure play a larger role in habitat selection during egress than ingress for the bison's annual spring migration, suggesting that timing of initial spring migration isn't necessarily associated with green-up.
- During summer (growing period), bison foraging was more likely to occur in sites closer to linear disturbances and in graminoid-rich wetlands — relative to available habitats in the area.
- Bison wallowing/bedding behaviour was more likely for sites closer to linear disturbances with lower shrub/sapling and coarse woody debris densities, drier soils, and less sedge biomass.
- Finally, analyses of the collared wolf population in the area showed that wolves were less likely to overlap the bison range in late winter, but when within the bison range, wolves increased their use of sites where there was more local bison activity.

LESSONS LEARNED

The results of the research completed through this program will provide useful information to inform environmental impact assessments that may be required for any future proposed industrial development in and around the herd's range, as well as support priority research gaps identified by the Technical Team in the habitat, ecology, and population biology of bison. This includes informing habitat needs (vegetation) for reclamation work if needed.

Wood bison in the Ronald Lake herd are largely associated with mineral and organic wetlands surrounding Ronald Lake to the north of the Teck Frontier lease. These wetlands are dominated by three species of sedges with the species found dependent on whether the wetlands are organic or mineral. This drives the foraging behaviour of bison, particularly in winter when forage is limited. Because these wetlands are uncommon over the range of the herd, yet important to bison, avoiding impacts to these wetlands from industry activities (directly through habitat loss or indirectly through hydrology) is a priority. In places with past energy exploration, it is apparent that bison select narrow linear features from seismic assessments for travel, foraging and wallowing. This suggests exploration activities do not substantially impact the long-term behaviour of bison (after the oil sands exploration project), and thus the reclamation of seismic lines would not be as important to bison as it is for other threatened wildlife. Finally, if future mining in this region occurs, reclamation activities with larger footprints should consider the value of adding and promoting cover of *Carex atherodes*, *C. utriculata*, and *C. aquatilis* in wet sites, given how important these three species are for forage productivity and forage selection by bison — especially if the core wetlands at the center of the Ronald Lake herd are impacted.

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PRESENTATIONS AND PUBLICATIONS

Journal Publications

Hecker, L. J., Edwards, M. A. & Nielsen, S. E. 2021. Assessing the nutritional consequences of switching foraging behavior in wood bison. Ecology & Evolution 11:16165–16176.

Sheppard, A. H. C., Hecker, L. J., Edwards, M. A. and Nielsen, S. E. 2021. Determining the influence of snow and temperature on the movement rates of wood bison (*Bison bison athabascae*). Canadian Journal of Zoology 99: 489–496.

Hecker, L. J., Coogan, S.C.P., Nielsen, S. E. & Edwards, M. A. 2021. Latitudinal and seasonal plasticity in American bison *Bison bison* diets. Mammal Review 55: 193-206.

Conference Presentations/Posters

No formal conferences due to COVID-19.

Reports and Other Publications

Rawleigh, G., Hecker, L. J., Dewart, L. T., Epperson, D. M., Edwards, M. A. and Nielsen, S. E. 2021. Ronald Lake Wood Bison Research Program: 2021 Annual Report. Report to the Ronald Lake Bison Herd Science Technical Team, December 15, 2021. University of Alberta, Edmonton, Alberta, Canada T6G 2H1, 30 pp. Available at: https://ace-lab.ca/publications.php#Research%20Reports

Rawleigh, G., Hecker, L. J., Dewart, L. T., Epperson, D. M., Edwards, M. A. & Nielsen, S.E. 2021. Ronald Lake Wood Bison Research Program: Semi-Annual Progress Report 2021. Report to the Ronald Lake Bison Herd Technical Team, May 1, 2021. University of Alberta, Edmonton, Alberta, Canada T6G 2H1. 22 pp. Available at: https://ace-lab.ca/publications.php#Research%20Reports

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott Nielsen

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Mark Edwards	Royal Alberta Museum and University of Alberta	Curator Mammalogy, Adjunct Professor		
Darren Epperson	University of Alberta	Research Technician		
Lee Hecker	University of Alberta	PhD	2017	2022
Lindsey Dewart	University of Alberta	MSc	2018	2022

Research Collaborators: Alberta Environment and Parks, Environment and Climate Change Canada, Parks Canada, Fort Chipewyan Metis, Fort McKay First Nation, Fort McKay Metis, Fort McMurray First Nation, Fort McMurray Metis, Lac La Biche Metis, Mikisew Cree First Nation

Johne's Disease in Bison

COSIA Project Number: LJ0342

Research Provider: University of Calgary

Industry Champion: Syncrude

Status: Year 1 of 4

PROJECT SUMMARY

The Beaver Creek Wood Bison Ranch started operations on February 16, 1993, when a herd of 30 pure wood bison arrived at Syncrude's Mildred Lake site from Elk Island National Park near Edmonton. Those original wood bison have grown into a herd of 300, living on more than 300 hectares of reclaimed grassland on Syncrude's former base mine about 50 kilometers north of Fort McMurray. A joint venture between Syncrude and Fort McKay First Nation manages the herd which has maintained a tuberculosis and brucellosis disease-free status since inception. The herd has been used for research opportunities to support a growing industry.

Mycobacterium avium subspecies *paratuberculosis* (*Map*) is a bacterial pathogen that causes chronic intestinal inflammation and wasting in ruminants known as Johne's Disease (JD). Although the study of JD in domestic ruminants (primarily cattle) provides some guidance, the disease transmission, pathophysiology and environmental persistence of *Map* in bison is unknown. Presence of *Map* has implications for the health of bison populations, both farmed and wild. Syncrude's current JD management strategy includes sampling, testing for JD and culling animals that show signs of the disease. 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, and to develop a herd health strategy to reduce prevalence and transmission of *Map.*

Specifically, project researchers will:

1. Investigate the epidemiology (transmission, maintenance, environmental persistence) of the pathogen within the herd.
2. Describe the course of disease (pathophysiology) in clinically affected bison.
3. Refine diagnostic tools for *Map* detection in bison. Current efforts to refine diagnostic tools include optimizing polymerase chain reaction (PCR, 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.
4. Investigate comorbidities, like 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 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

First sample collection was completed in October of 2021.

Laboratory work is underway to culture *Map*, optimize diagnostic tools, and investigate comorbidities. In addition, available JD testing continues to be utilized to assess disease prevalence. This work will provide key initial information to better understand JD epidemiology and pathophysiology in bison.

LESSONS LEARNED

There are no lessons learned to be reported in 2021 since sample collection and processing has just begun.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications in 2021.

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	2023
Jeroen De Buck	University of Calgary	Professor		
John Gilleard	University of Calgary	Professor		
Susan Kutz	University of Calgary	Professor		
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