2020 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)
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Husky Energy Inc. (Husky)
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Syncrude Canada Ltd. (Syncrude)
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COSIA publishes two reports, 2020 COSIA Land EPA – Mine Research Report and 2020 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. In 2020 some projects 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.

2020 COSIA Land EPA - Mine Research Report. Calgary, AB: COSIA Land EPA.

Front cover image of reclaimed areas adjacent to Base Mine Lake courtesy of Syncrude Canada Ltd.

WETLANDS

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 3 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 Nikanotee Fen 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

Progress in 2020 was significantly hampered by the COVID-19 pandemic. Federal and provincial COVID-19 guidance and direction meant significant travel and operating restrictions were implemented that directly impacted field data collection for the project. Researchers were unable to access the constructed fen during the 2020 calendar year; however some access to reference sites was possible. A local third-party contractor, Hatfield Consultants, was contracted by the University of Waterloo to ensure that data could be recovered from eddy covariance systems and for the initial startup, maintenance and takedown of the eddy covariance systems.

Objective 2: Assess how changes to soil and vegetation form and function affect system trajectory

An evaluation of the evolution of salvaged upland forest floor soil (known as LFH for the soil horizons it comprises) adulterated with underlying mineral soils (herein referred to as LFH) was completed and results published in a thesis (Irving, H. 2020). This study included six locations across the mine lease where LFH had been utilized as a reclamation cover, four to eleven years post-placement, including the NF upland (NF LFH thickness approximately 30.8 cm ± 15.2 cm). The performance of LFH being used as a reclamation cover, where generating barriers to percolation such as for over-burden dumps (Meiers et al., 2011) is understood. However, understanding cover soil performance in terms of its hydrological functions in a constructed landscape — where hydrological connectivity between its units (upland surface, aquifer, fen) is crucial to its success — is novel. Assessment of the reclamation cover performance is key to understanding the long-term trajectory and hydrological function of the landscape units as they relate to the success of the NF's long-term viability. Irving found that initial quality in LFH supersedes temporal effects on the development of some hydrophysical properties (e.g., bulk density and soil organic matter). In addition, higher quality LFH (that is LFH that reflects the definition most closely, as opposed to closer to an LFH mineral mix) contributed to faster canopy development (greater tree density) regardless of initial planting density. However, sites that displayed evidence of receiving lesser quality LFH did not see a decrease in their hydrological upland function.

Water samples collected from the surface and subsurface of the fen in 2019 but processed over into 2020, showed the average Na^+ (sodium) concentration was 302 mg/L and 353 mg/L, respectively. Electrical conductivity (EC) measured at time of sampling was 2,647 microsiemens per centimeter (µS/cm) for fen surface and 3,813 µS/cm for fen sub-surface, respectively. The highest concentrations of field monitored (surface and subsurface) electrical conductivity were found in the wettest part of the fen (southwest corner; average water table 16 cm above ground surface), with EC of 3,662 ± 905 µS/cm and 5,796 ± 361 µS/cm, respectively. Dionex High Performance Liquid Chromatography (HPLC) analysis results for Na^+ concentration of 432 ± 184 mg/L, and 700 ± 285 mg/L, respectively. The lowest field-measured EC (1,529 ± 392 µS/cm, and 2,576 ± 135 µS/cm, respectively) and Na^+ concentration (70 mg/L, and 242 ± 46 mg/L, respectively) were found in the relatively dry (average water table 1.5 cm below ground surface) north-east corner near the fen spillbox that outflows to the over-flow pond. The sodium mass found in the near surface water and soil was stable over the season with an average of 2,961 kg and net change of -565.6 kg from June 3rd to August 19th, 2019. Precipitation-driven discharge controlled the export flux of Na^+ from the fen watershed with an average Na^+ concentration of 229 mg/L.

To determine controls on methane emissions, gas fluxes are been sampled among dominant vegetation communities using the static chamber technique. Associated environmental variables including water table depth, soil temperature, water chemistry and vegetation parameters (height, cover and biomass), as well as sulfate (SO_4^{2-}) concentration at the collars, have been sampled. Methane emissions from the Nikanotee Fen have increased over seven years of ecosystem development, although these are still lower than natural reference fens. Analysis of methane (CH_4) emissions found them to be low due to the presence of high SO_4^{2-} concentrations, which suppresses CH_4^- production. This is despite environmental conditions preferable to methane production such as a high-water table and dominance of aerenchymatous vegetation, such as sedges. NF construction materials have elevated legacy sulfate concentrations as a result of discontinued processing practices such as the use of gypsum. As such, it is likely that SO_4^{2-} porewater concentrations will remain high in the future, leading to a continued suppression of CH_4 emissions. Peat placed within the NF was previously found to be high in sulfate as a result of the type of fen system the peat was salvaged from (moderate-rich).

In the absence of a 2020 field season due to COVID-19 restrictions, progress was directed towards quantifying plant development in both the fen and upland. The enhanced vegetation index (EVI) was applied to field-based measurements collected since construction was completed (leaf area index [LAI], biomass, vegetation surveys). EVI was calculated using satellite-derived 30-m resolution Landsat-8 data. EVI was then post-processed to remove cloud cover, shading and aerosol interference (dust from the surrounding mine and/or forest fire haze) effects. Growing season EVI values are presented as the mean of a pixel grid (90 m x 90 m) located at the centre of eddy covariance tower footprints. This offers a consistent, quantifiable metric of plant development (in the absence of physical site access due to COVID-19) and provides insight into plant inter-seasonal variability from which the determining drivers such as water availability and/or biogeochemistry (soil/water pH, salinity, nutrient availability) can be determined. Annual fen peak season (July) EVI from 2013 to 2019 was: 0.248, 0.281, 0.439, 0.524, 0.588, 0.499, 0.418, respectively. An EVI greater than 0.2 is representative of photosynthetically active vegetation, with 0.4 to 0.6 being among literature values for healthy to lush vegetation in comparable restored and natural peatland systems (Nugent et al., 2018). Annual upland peak season (July) EVI from 2013 to 2019 was: 0.175, 0.219, 0.279, 0.331, 0.445, 0.488, 0.54 respectively. These values fit very well in comparing the EVI signal to comparable natural EVI signals for needleleaf/deciduous uplands in the boreal plains in time since wildfire burns (comparable in that it is new growth starting on bare LFH mineral mix). EVI signal values for burned natural forests five to eight years post-fire averaged 0.51 (Jin et al., 2012), demonstrating the fen upland to be on a healthy trajectory.

To explain these EVI trends, the fen vegetation development since planting was examined. The fen vegetation (dominated by sedges) becomes well developed by 2015, with subsequent inter-annual fluctuations in EVI correlated to environmental drivers (salt/water stress) such as dry or wet years. The 2018 influx of sodium to the fen resulted in a decrease in biomass (and subsequently decrease in plant greenness and productivity) which was captured in the EVI signal. In contrast, the treed species dominant in the upland develop at a much slower rate than the sedges in the fen. The upland vegetation becomes robust from 2017 onwards with no sodium pulse to stress development given that most of the vegetation in the upland draws moisture from LFH cover soil rather than the sand aquifer.

Upland evapotranspiration (ET), water-use efficiency (WUE) and energy fluxes have been quantified from 2013 to 2019 using eddy covariance output. The analysis for 2020 includes linear regressions and mixed effect models to evaluate drivers of water flux trends. Results show average growing season midday friction velocity (u*) reflects the development of vegetation. Friction velocity follows an increasing trend during early years of development from 0.16 m s^{-1} in 2013 (year of planting) to 0.24 m s^{-1} in the seventh year (2019). The Bowen ratio for the upland is greater than 1.0 for all years but exhibits a decreasing trend from 2017 onwards. This means that latent heat flux is becoming a more dominant term in the energy budget as a result of expansion and growth of treed vegetation species. This resulted in an increase in latent heat flux (Q_e), so a larger portion of the energy balance is partitioned to drive evapotranspiration. Energy partitioning therefore appears to reflect inter-annual variations in precipitation and water availability. In years where precipitation rates exceed 230 mm/growing season, latent heat flux (Q_e) is greater than sensible heat (Q_h). Inversely, during drier growing seasons (< 200 mm precipitation/growing season) sensible heat flux is greater than latent heat. This demonstrates a coupled relationship between vegetation, soil moisture (water availability) and energy partitioning. Ground heat flux (Q_g) decreased over time as vegetation developed and bare-ground exposure decreased with litter accumulation.

Cumulative growing season evapotranspiration exceeded precipitation in 2015 (188 mm/growing season) and 2017 (206 mm/growing season) which were drier than average years (less than 200 mm precipitation). Overall, trends depict a slight increase in ET that coincides with the expansion and development of vegetation, from a seasonal mean of 1.4 mm day^{-1} (2014) to 2.4 mm day^{-1} (2019). Highest ET rates occur during peak season and culminate with peak LAI for broadleaf species (ranging from 2.8 mm/day to 3.2 mm/day in early seasons [2013-2016] to 3.9 mm/day to 4.6 mm/day from 2017 onwards).

An examination of the variability in tree water use across the upland was undertaken in 2018 to 2019 and vegetation surveys were completed. Species transpiration (T) rates were measured through stem heat balance sap flow sensors installed in tree trunks. To determine the plant available water, rainfall was partitioned into interception, throughfall and stemflow alongside monitoring soil moisture dynamics and soil water potential. Data indicates that tree transpiration is the dominant control on water use at the site, averaging 51% of total evapotranspiration and is controlled by soil water availability. *Populus balsamifera* and *Pinus banksiana* were most sensitive to variations in vapor pressure deficit (VPD) emphasizing their abilities to close stomata in response to high evaporative demand and to conserve water. VPD appeared to have stronger controls on T rates of coniferous trees, while net radiation has greater influence on broadleaf trees. Vegetation structure and rainfall event characteristics were found to explain most of the variability in rainfall partitioning, which lead to interspecific and intraspecific differences in partitioning abilities among species. Canopy interception of broadleaf tree species, *Populus balsamifera* and *Populus tremuloides*, averaged 25.7% and 28.5%, respectively. Coniferous tree species, *Picea mariana* and *Pinus banksiana,* averaged 34.5% and 31.5%, respectively. While vegetation is in the early stages of development, rainfall partitioning may become an important factor when selecting tree communities in reclamation projects when considering climate canopy effects on groundwater recharge and during canopy development.

Broadleaf species had the highest rates of productivity during peak season due to their maximum LAI occurring in July and August. However, May and September values were lower (due to the timing of foliation and senescence). Plots with coniferous species showed more consistent rates of carbon uptake throughout the growing season. This is consistent with more “growing season” days available for coniferous species, as no foliation or senescence occurs. Edaphic conditions (soil moisture), variable root architecture and leaf physiology between species are likely responsible for species specific trends pertaining to ET and WUE. The broadleaf species (*P. balsamifera, P. tremuloides)* have extensive lateral roots coupled with deep sinker roots which likely extend beyond the LFH layer allowing them to access aquifer held water when soil moisture within the upland LFH cover soil significantly decreases. This allows plant productivity to remain high, even if ET rates fluctuate, resulting in stable or increasing WUE. Coniferous species (*Picea mariana, Pinus banksiana)* have a much shallower rooting system and as a result are more prone to be affected by water-stress. As a result, WUE of these coniferous species was found to be more variable throughout the season and closely linked to the rate and timing of precipitation events.

Dissolved organic carbon (DOC) dynamics at the Nikanotee Fen in response to chemical, structural and successional changes have been investigated, specifically the role of salinity - sodium (Na). Rooting zone porewater samples (10 cm and 30 cm depths) show that DOC composition reflects its vegetation input, exhibiting low molecular weight and low aromaticity. At 10 cm depth, spatial variability and temperature were the largest predictors of DOC quantity and quality. At 30 cm depth, higher Na concentrations corresponded with high concentrations of labile DOC. This strongly suggests that as pore water sodium concentrations increase in the rooting zone (as more of the sodium mass moves from the sand aquifer to below the fen), there will be increased inputs of microbially active DOC – leading to higher quantities of carbon being lost from the fen via hydrological export through the spillbox outflow.

Currently, a greenhouse experiment is underway examining the effects of sodium concentration on the DOC contribution of the dominant fen plant species by means of rhizodeposition (i.e., deposited by the roots). Results to date show that both *J. balticus* and *C. aquatilis* have higher molecular weight contributions to DOC than described in the literature. Both species have exhibited potential tolerance mechanisms to sodium accumulation through suspected Na/H "antiporter activity" (confirmation is in process), with increases in rhizodeposition of aromatic compounds, which may stabilize the root membrane. This has been demonstrated through a significant shift in the rhizodeposits of the species from higher to lower molecular weight, and to a more aromatic character (greater number of polycyclic aromatic compounds).

Nutrient deposition was assessed through a variety of methods (ion-exchange collectors; suction lysimeters; soil mineralization; destructive plant tissue sampling; tree leachate; precipitation inputs) to determine nutrient availability from external sources for vegetation at the Nikanotee watershed.

Nitrogen deposition concentrations across Nikanotee watershed site are high for a wetland, especially for dry deposition — which was observed to be six times higher than wet deposition. NH_4-N and NO_3-N concentrations at the constructed fen are higher than normal due to adjacent industrial activities including a heavy hauler haul road. Comparatively, N deposition across the reference sites decreases with distance from the oil sands upgrader facilities. Within the constructed fen watershed, average dry NH_4-N and NO_3-N deposition were 62.13 (± 12.5) mg/L and 12.15 (± 1.14) mg/L, respectively, and average wet NH_4-N and NO_3-N deposition were 5.28 (± 0.34) mg/L and 1.95 (± 0.08) mg/L, respectively, over the 2019 growing season. However, N deposited onto the fen and upland in both wet and dry forms does not reflect N concentrations in either surface leachate, porewater, stemflow or soil extractable N (all < 0.5 mg/L avg.). There is a sharp decrease in both NH_4-N and NO_3-N content as we move from atmospheric inputs and down into soil and water content.

Results processed in 2020 from 2019 litter decomposition samples found decay rate constants (*k*) are significantly slower in the winter (0.0009 to 0.0012) versus growing season rates (0.004 to 0.006). Reference site litter samples are still under analysis. Environmental variables such as soil moisture, ice-lens persistence and temperature were found to significantly affect decay rate, with drier plots showing a greater decay rate than those ponded or still frozen during the month of May. Within the fen, above-ground litter decomposed faster than below-ground fine root biomass in both the fen and the upland. However, upland below ground biomass exhibited higher rates of decay than that of the fen (0.002 vs. 0.0008) likely due to the difference in litter composition and persistently drier soil conditions in the upland. Above ground biomass decay rates for upland species showed a clear correlation between deciduous and coniferous plant types. Broadleaf species decayed at average constants of 0.048, whereas coniferous needle decay constants were 0.012. Litter layer in the upland is dominated by broadleaf species and is approximately 3 cm deep. In the fen, *C. aquatalis* and *T. latifolia* produce large amounts of litter seasonally and average litter layer thickness is 21 cm.

ICP-MS analysis for phosphorous (P) shows fen plant species P content ranges from 3.1 mg/L to 3.9 mg/L. Average leaf P content found by species found was: *T. latifolia*: 3.9mg/L; *C. aquatilis*: 3.5 mg/L; and *J. balticus*: 3.2 mg/L. In the upland, coniferous species range from 2.2 mg/L to 3.2 mg/L for P (species mean: *Picea mariana*: 2.9 mg/L; *Pinus banksiana*: 2.4 mg/L) and deciduous species range from 4.0 mg/L to 4.6 mg/L for P (species mean: *Populus balsamifera*: 4.4 mg/L; *Populus tremuloides*: 4.1 mg/L). Differences in leaf P concentrations is attributed to physiological difference in respective species leaf size.

Objective 3: Use numerical and conceptual models to evaluate alternative design applicability to closure landscape scales

Hydrogeochemical numerical modelling at the NFW, which projected groundwater flow and solute transport into the future using Monte Carlo realizations of climate, indicates that sodium concentrations in the near-surface of the fen will continue to rise for approximately 15 years post-construction (2028). However, this estimate should be placed in the context of the considerable climatic variability of the region, which could cause surface concentrations to rise for as few as nine years, or as many as 20 years. This climatic variability also influences the future peak spatially-averaged Na concentration of the fen, which varies between 450 mg/L and 850 mg/L, with an ensemble mean of 600 mg/L. This would suggest that the fen will remain inhospitable to many representative moss species, due to the exceedance of salinity-stress thresholds (Pouliot et al., 2013) for many decades post-construction. In contrast, within the range of normal climatic variability, the majority of the fen will not exceed salinity-stress thresholds for *Carex aquatilis* (Vitt, et al., 2020). Comparatively, the elution of sodium from the uplands sand will occur rapidly, with the more distal and peripheral areas of the upland flushing in the first four to six years, the central upland flushing in eight to 12 years, and the fen flushing over much longer time periods (> 40 years). Spatial variability in groundwater recharge in the upland, and proximity to the discharge point in the fen, resulted in clear east-west differences at the site. Large volumes of surface overland flow contributed by the hillslopes to the southeast corner of the upland resulted in considerably faster salt flushing. Similarly, the location of the spillbox in the northeastern portion of the fen caused a salinity gradient, with the northwest corner maintaining much higher salinity for a longer period of time.

LESSONS LEARNED

- Nitrogen (N) deposition analysis has shown the Nikanotee Fen watershed to have plant productivity controlled, in part, by a requirement for nitrogen despite very large atmospheric N-inputs. This is reflected in very low soil extractable N concentrations. Reasoning for the low soil extractable N is being explored.
- Utilizing LFH of greater quality (more reflective of the soil categories definition) will lead to the faster establishment of denser canopy covers.

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PRESENTATIONS AND PUBLICATIONS

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Cameron, R. M., Petrone, R. M., Nwaishi, F. C. 2020. Atmospheric nitrogen deposition loads on a constructed fen-upland and reference fens in the Athabasca Oil Sands Region, Alberta. University of Waterloo World Wetlands Day 2020, February 3, 2020, Federation Hall, Waterloo, ON. Poster Presentation.

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Dube, G., Price, J. S. 2020. Unsaturated flow fingering in a constructed peatland. Water Week Research Showcase, McMaster University, November 1, 2019. Poster Presentation.

Dube, G., Price, J. S. 2020. Unsaturated flow fingering in a constructed peatland. University of Waterloo World Wetlands Day 2020, February 3, 2020, Federation Hall, Waterloo, ON. Oral Presentation.

Fettah, S., Petrone, R. M. 2020. Quantify water use and rainfall partitioning of dominant tree species in a post-mined landscape in the Athabasca Oil Sands Region, Alberta. Online Poster Presentation. Global Water Futures Annual Conference, June 15, 2020.

Fettah, S., Petrone, R. M. 2020. Quantify water use and rainfall partitioning of dominant tree species in a post-mined landscape in the Athabasca Oil Sands Region, Alberta. University of Waterloo World Wetlands Day 2020, February 3, 2020, Federation Hall, Waterloo, ON. Poster Presentation.

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Popovic, N., Petrone, R. M. 2020. The influence of vegetative development on nutrient cycling in a reclaimed, post-oil sands landscape. University of Waterloo World Wetlands Day 2020, February 3, 2020, Federation Hall, Waterloo, ON. Poster Presentation.

Prystupa, E. 2020. Response of dissolved organic carbon dynamics to salinity in a constructed fen peatland in the Athabasca Oil Sands Region. University of Waterloo World Wetlands Day 2020, February 3, 2020, Federation Hall, Waterloo, ON. Oral Presentation.

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RESEARCH TEAM AND COLLABORATORS

Institution: University of Waterloo; Colorado State University

Principal Investigator: Dr. Jonathan Price

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Dr. David Cooper	Colorado State University	Co-Investigator		
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Dr. John Hribljan	Colorado State University	Post-Doctoral Fellow		Completed 2020
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Owen Sutton	University of Waterloo	PhD	2015	2020
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Christine Van Beest	University of Waterloo	MSc	2016	Completed 2018
Emily Prystupa	University of Waterloo	MSc	2018	Completed 2020
Gabriel Dube	University of Waterloo	MSc	2018	2020
Hilary Irving	University of Waterloo	MSc	2017	Completed 2020
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Research Collaborators: Colorado State University

Sandhill Fen Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multi researchers and institutions

Industry Champion: Syncrude

Status: Final Cumulative Summary

PROJECT SUMMARY

The Sandhill Fen Watershed is located on the northwest corner of the East-In-Pit (EIP) Composite Tailings (CT) deposit at Syncrude's Mildred Lake operation, north of Fort McMurray, Alberta. Sandhill Fen was designed, constructed, reclaimed, and revegetated as an instrumented watershed between late 2007 and 2012, and has had an active research and monitoring program since then. The goals of the project were to design and establish the initial conditions necessary to allow for development of a fen wetland and its watershed over time, and to develop techniques for reclamation of CT deposits. A fen is a peat-accumulating wetland with a water table at or near the ground surface, and consisting of mineral-rich water primarily from groundwater.

The Sandhill Fen Watershed (SFW) design included a primary wetland (the fen) surrounded by an upland area with hummocks constructed from tailings sand, perched wetlands, and supporting infrastructure. The Sandhill Fen Watershed represents the first reclamation of an in-pit tailings deposit in the oil sands industry, and was specifically designed to address research hypotheses. It is also the first attempt to create peatland structure and function on the reclaimed mining landscape. This work is important because a large portion of in-pit tailings deposits are expected to be wetlands.

The overarching objectives that drove all activities from design, construction, reclamation, and operation were to:

1. create an instrumented watershed on sand capped soft tailings;
2. to test the viability of practical techniques for soft tailings reclamation and peatland development; and
3. to develop soft tailings reclamation technology to implement operationally. Many of these objectives are transferable to other soft tailings applications.

LESSONS LEARNED

Although the SFW is a newly reclaimed system, there is much that Syncrude has learned through the entire process, from concept, to design, to construction, to reclamation, to research and monitoring. Results from the research and monitoring indicate that successful ecological outcomes were achieved. The SFW project has demonstrated success with respect to establishing a range of natural fen vegetation in the wetland area. There are a variety of important outcomes from the design, construction, and research program on the Sandhill Fen Watershed to validate Syncrude's capability to reclaim in-pit CT landforms.

The following is a high-level summary of key learnings:

- Construction activities, reclamation material placement, and revegetation are possible on a sand-capped CT deposit.
- Even with significant investment in infrastructure to manage the water table at the Sandhill Fen Research Watershed, it was difficult to control the water table at a fine scale of resolution.
- Constructed hummocks formed local-scale groundwater flow systems as predicted.
- Hummock water balance is influenced by hummock size, shape and soil texture.
- Evapotranspiration is an important driver of the water balance, run-off is not.
- CT deposits will provide groundwater to support wetland development.
- Oil Sand Process-affected Water (OSPW) will be present in some wetlands.
- Thresholds of water electrical conductivity for ecological development in wetlands can be as high as 3,000 µS/cm to 4,000 µS/cm.
- Sandhill Fen demonstrates key peatland structural and functional characteristics: typical fen plants, evidence of peat formation, and carbon accumulation.
- It is unlikely that within the timeframes of closure that any reclaimed wetland will accumulate enough peat (> 40 cm) to be classified as a peatland according to the Alberta Wetland Classification system.
- Wetland plant communities are dynamic and respond rapidly to changes in water chemistry and water table fluctuations.
- Many biotic (e.g., leaf area) and abiotic factors (e.g., climate and weather) influence water availability in reclaimed wetlands and therefore designing wetland types that require tight water table control is unreasonable. Instead, an approach that ensures the water quality will be acceptable to a range of outcomes is required.

Knowledge and understanding gained through the instrumented Sandhill Fen Watershed will continue to inform the design, construction and reclamation of other CT deposits, including EIP. Key learnings from each research project are summarized in the following. Continued performance monitoring of Sandhill Fen Watershed will support understanding and prediction of other in-pit CT deposit reclamation. The work done on Sandhill Fen Watershed is a key component of the adaptive management of EIP and is supporting the design, construction, and reclamation of other CT deposits at Syncrude. A complete summary of the entire program from design, construction and ecological performance can be found here: https://doi.org/10.7939/r3-n048-ex41.

Hydrogeologic Investigations of Sandhill Fen Watershed and Perched Analogues: Dr. Carl Mendoza and Dr. Kevin Devito, University of Alberta

Key Learnings

- A shallow groundwater flow system developed in the watershed. These systems can be designed for post-mining landscapes and provide freshwater to downgradient wetlands.
- Horizontal groundwater flow often results in discharge to the lowlands through seepage faces.
- Groundwater within 1.8 m of the water table has a higher proportion of freshwater, indicating groundwater recharge and the development of a freshwater lens.

- Groundwater deeper than approximately 1.8 m below the water table is primarily comprised of oil sands process-affected water (OSPW).
- Water discharging through seepage faces may be subject to evapo-concentration during dry periods, leading to a shallow accumulation of water with elevated solute concentrations. Since shallow water tables are highly responsive to inputs of water, areas with shallow water tables and gentle slopes are prone to discharging water with elevated solute concentrations following precipitation events.
- Water table configurations respond dynamically to variable recharge rates influenced by depth to the water table, and reclamation prescriptions for soil covers and vegetation.
- Recharge varies with soil cover texture (higher recharge in coarser-textured materials) and associated soil hydraulic parameters.
- Finer-textured soil covers tend to retain water which is then lost to the atmosphere through evapotranspiration.
- Simulation results demonstrate a threshold-like relationship between recharge and upland hummock height, where upland hummocks that are not tall enough to limit root water uptake from the saturated zone exhibit decreased recharge or net upflux.
- Recharge is influenced by maximum rooting depths, forest floor placement thicknesses, and leaf area indices on recharge — increased forest development will lead to decreased recharge rates to underlying groundwater systems.
- Inter-annual climatic variability is as influential as variation in soil cover texture in determining recharge.
- Average recharge rates applied to upland areas ranged from 40 mm/year for wetter ecosites to 88 mm/year for drier ecosites.
- Average volumetric groundwater flow through the SFW system was calculated to be 108 m^3/d.

Water and Carbon Balance in the Constructed Fen: Dr. Sean K. Carey, McMaster University; and Dr. Elyn. R. Humphreys, Carleton University

Water Balance Key Learnings

- The precipitation climate of Sandhill Fen Watershed during 2013 to 2018 was drier than the climate normal.
- In the uplands, ET increases in most months as Leaf Area increases.
- ET does not increase in the same way in the wetland — changes to vegetation and boundary layer properties are modest. ET is driven largely by atmospheric demand.
- Water inflows via pumping occurred only in 2013 and 2014.
- Water outflow management since 2013 has been used intermittently to prevent critical infrastructure damage.
- Hummocks can generate freshwater runoff during spring freshet — earlier on south-facing than on north-facing slopes.
- In summer, surface runoff from hillslopes will not respond to most rain events, but in cases where high intensity rainfall exceeds infiltration capacity, overland flow will occur.

- The water table was always highest in spring, and then declined gradually throughout the summer as evapotranspiration increased. Large rainfall events rapidly increased water table.
- There is considerable yearly variability in most components of the water balance, related both to management and to climate variability.

Carbon Balance Key Learnings

- The carbon balance of the fen is dynamic: In the beginning, the lowland was a large source of CO_2 to the atmosphere and Gross Ecosystem Productivity (GEP) was low due to limited photosynthesis. Following vegetation establishment, GEP and Net Ecosystem Productivity (NEP) increased rapidly. By 2016 the wetland was a carbon sink. In 2017, CO_2 uptake declined and the fen became a carbon source again.
- Ecosystem respiration at the upland site has increased with time, in part offsetting some of the photosynthetic gains in a net balance. This is a function of increased soil biomass and decomposition of fresh litter.
- The lowland had suppressed respiration in all temperatures and years due to saturated conditions.
- CH_4 emissions in the present study unexpectedly remained very low over the three years despite the establishment of a high water table in the lowland areas of the Sandhill Fen Watershed.
- Vegetation community composition (*Typha* versus *Carex*) has an influence on the carbon dynamics (both NEP, and CH_4 flux)
- Dissolved organic carbon (DOC) varied widely throughout the fen and is exhibiting an increase year-over-year from 2013 to 2018.

Wetland Ecological Performance: Wetland Plant Establishment, Community Stabilization and Ecosystem Development: Dr. Dale Vitt, Southern Illinois University

Wetland Plant Performance Key Learnings

- Soil moisture, water table elevation and stability are the key abiotic drivers of plant diversity and abundance.
- Water with sodium concentrations below 600 mg/L Na^+ would allow for a range of wetland plants. Electrical conductivity from a 600mg/L Na solution is approximately 4,000 µS/cm.
- Conditions (wet versus dry) at time of planting are important for the overall success of plant species.
- *Scirpus microcarpus*, *Scirpus atrocinctus*, *Carex aquatilis*, and *Carex hystericina* are particularly recommended for reclamation: high survival in wet and dry areas, spread quickly and produce considerable biomass.
- *Beckmannia syzigachne* survives well and is a good candidate for a cover crop to reduce weed invasion.
- *Triglochin maritima* survives well regardless of moisture levels, but does not spread as much as other species.
- *Betula glandulifera* performs well in drier wetland areas.
- *Carex bebbii* and *Larix laricina* survive well in drier sites, *Eriophorum angustifolium* does better in wetter areas.
- Some species are not recommended: *Carex limosa*, *Carex paupercula*, *Triglochin palustris*, and *Dasiphora fruticosa*.
- Fluctuating water tables while plants are establishing may affect survival during early establishment.
- *Ptychostomum pseudotriquetrum* was the most common bryophyte species.

- Bryophytes are sensitive to water table. Bryophytes are absent from areas with standing water.
- Initial planting of a monoculture allows for higher plant abundance and just as much recruitment of new desirable species as an initial diverse assemblage.
- While the peat likely contributed to the development of a soil microbial community similar to established peatlands, the peat likely does not need to be 50 cm deep. A few centimeters of peat may be enough.
- If wetland soils become dry, decomposition increases releasing carbon.

Wetland Ecological Performance: Development and Controls on Zoobenthic Community Composition and Abundance: Dr. Jan Ciborowski, University of Windsor/University of Calgary

Invertebrate Community Development Key Learnings

- Threshold of Electrical Conductivity (EC) for invertebrate communities is at least as high as 3,000 µS/cm.
- Below the salinity threshold, community composition was variable but quickly accumulated a broad diversity of taxa.
- At age three years, diversity was reduced at sites where conductivity exceeded 3,000 µS/cm. These sites were dominated by larvae of the most tolerant taxa: midges (Diptera: *Chironomidae*) and biting midges (Diptera: *Ceratopogonidae*).

Upland Ecological Performance: Early Tree Establishment and Vegetation Colonization of Upland Areas: Dr. Simon Landhäusser, University of Alberta

Early Tree Establishment Key Learnings

- Tree seedlings planted on fine-textured cover soils grow taller than those on coarse-textured cover soils.
- In dry years, soil moisture loss was greater on fine-textured hummocks, this is likely due to the higher Leaf Area development.
- Tree survival was high across all cover soil types.
- Reduced survival was evident in trembling aspen, likely associated with stock quality.
- Early canopy closure achieved through higher density planting was only achieved on the fine textured cover soils.
- There was no difference in seedling performance and understory development between high (10,000 stems/ha) and medium (5,000 stems/ha) density plantings.
- Spatial variability and complexity is achieved through topography, cover soils, tree density and composition, and coarse woody debris placement.
- The cover soils salvaged from two very different forest types resulted in the development of two very different plant communities early in site development.
- The early response of the colonizing vegetation was most strongly driven by cover soil characteristics and the propagule bank contained within.
- Upland areas with cover soil salvaged from a poor-xeric forest site had vegetation communities with a greater proportion of native species, graminoids and shrubs.

- Upland areas capped with cover soil salvaged from a rich-mesic forest site had vegetation communities that were composed of proportionally more introduced species and forbs.
- In both cover soils, metrics of diversity were highest in areas with north facing aspects and higher tree density.
- In areas capped with the coarse cover soil from the poor-xeric forest site, the effect of aspect on diversity was modified by coarse woody debris.
- Over the whole site, 196 different plant species were detected in the upland areas.

Assessing the Sodium Buffering Capacity of Reclamation Materials in Sandhill Fen: Matt Lindsay, University of Saskatchewan

Buffering Capacity of the Clay Layer Key Learnings

- Sodium attenuation in the clay layer is likely limited and short-lived.
- It is unlikely that calcium concentrations in the surface water are derived from ion exchange with sodium as OSPW migrates through the clay layer.
- Calcium concentrations may be associated with background shallow groundwater.
- There is a mixing trend between OSPW-influenced groundwater to the south of the watershed, and background shallow groundwater within the wetland footprint.
- The apparent absence of a vertical Na breakthrough curve within soil pore water vertical trends in pore water composition (i.e., increasing dissolved Na concentrations with depth) at individual sampling locations suggests that ion exchange reactions have limited impact on Na migration.
- Sodium attenuation was controlled by ion exchange reactions, whereas dissolved Ca (calcium) and Mg (magnesium) concentrations were likely influenced by mineral precipitation-dissolution reactions.
- Results of the field study and column experiments indicated that ion exchange reactions will not effectively limit Na transport over time.

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AWARDS

2014: Mining Association of Canada Towards Sustainable Mining Award for Environmental Excellence
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Note: Principal Investigator(s) are indicated in bold.

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Hydrogeologic Investigations of Sandhill Fen and Perched Analogues				
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Water and Carbon Balance of the Constructed Fen				
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Early Community Development of Invertebrates in Sandhill and Reference Fens — Local Effects of Vegetation, Substrate, and Water Quality				
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The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development				
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Geospatial Metadata System				
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Influence of Peat Depth, Hydrology and Planting Material on Reclamation Success Within a Created Fen-Like Setting				
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Mallory Hazell	University of Alberta	MSc	2013	~2017
Marie-Claire Roy	University of Alberta	Research Associate		

Peatland Reclamation Markers of Success

COSIA Project Number: LJ0273

Research Provider: Southern Illinois University

Industry Champion: Syncrude

Status: Year 5 of 5

PROJECT SUMMARY

This work was undertaken to develop fen indicators to assess the constructed fen wetland. It is important to recognize that there are a range of acceptable wetland reclamation outcomes including ponds, marshes and swamps.

The Sandhill Wetland vegetation community changed considerably in its early development, from having an open unvegetated surface to one richly covered with a variety of plant species. An understanding of early development in Sandhill Wetland, and how benchmark sites may be used to provide a framework for evaluating the progress and success of the wetland as a fen wetland and in comparison to other natural wetland analogues. This program is a set of projects building on the current understanding of the vegetation response in the fen to demonstrate how a suite of specific measurements can be developed into markers of success for oil sands reclamation.

Project 1: Tracking key ecosystem variables. Four important variables have been identified that are dynamic or unpredictable: (1) water chemistry of the peat profile (top 50 cm); (2) plant community development; (3) source-sink carbon flux for monocultures of planted sedges; and (4) diversity and status of indigenous volunteer plant species in the areas of the sandhill fen outside of existing wetland research plots. Each of these variables plays a key role in the success of the wetland, and continued monitoring of these factors will supply valuable information for understanding wetland performance and function.

Project 2: Plant response to sodium concentration. Areas of increased sodicity at Sandhill Wetland have been identified, and it is important to understand how dominant plant species respond to these high sodium concentrations. A series of new research plots that cover a range of sodium concentrations will be identified and monitored for plant health and performance through a variety of eco-physiological measures.

Project 3: Development of peatland markers of success. Fundamental to understanding wetland reclamation performance is the establishment and quantification of markers of success based on comparative benchmark sites. This project endeavours to identify a small number of markers that include parameters that compare structure, function and species diversity for 10 benchmark peatlands.

PROGRESS AND ACHIEVEMENTS

The summer 2020 field program was suspended due to access restrictions related to the COVID-19 pandemic. However, progress was made on the following:

1. A paper (Hartsock *et.*al) summarizing the water quality analysis for Sandhill Wetland was published. Sandhill Wetland has water chemistry most comparable to saline fens in the region. Near surface water in Sandhill Wetland exceeded Alberta Surface Water Quality Protection of Aquatic Life (PAL) guidelines for three substances/properties (dissolved chloride, iron, and total alkalinity) in the most recent year of monitoring. Natural saline fen sites also exceeded these water quality parameters which suggests that guideline exceedances are a norm for some natural wetland types regionally. Dissolved organic compounds assessed in sub- and near- surface water of Sandhill Wetland are below detection limits.
2. Results from greenhouse trials of *Carex aquatilis* responses to Na^+ (sodium ion) were published (Vitt et al., 2020). *Carex aquatilis* survived all treatment concentrations of sodium including the highest treatment of 2,354 mg L^{-1}. In general, both structural and functional attributes of *C. aquatilis* did not differ between the 17 mg L^{-1} and 1,079 mg L^{-1} treatments; however, performances of all attributes were reduced in the 2,354 mg L^{-1} treatment. Belowground biomass had greater decreases compared to aboveground components, including both biomass and photosynthesis. The aboveground decreases in performance were associated with exclusion of sodium from the aboveground components by the belowground components. Reduction in photosynthesis was strongly correlated with reduced stomatal conductance and lower transpiration. Although *C. aquatilis* demonstrated a wide tolerance to sodium concentrations, a clear threshold was present between 1,079 mg L^{-1} and 2,354 mg L^{-1}.
3. Greenhouse trials to determine the responses of *Carex atherodes* to increasing Na^+ are nearing completion. This trial is coupled to an additional trial for *C. aquatilis* in order to better refine its salinity thresholds, and will allow the determination of species responses along the brackish-saline water gradient present at Sandhill Wetland. Completion is expected in March 2021 and results will be published in a journal article (Glaeser, L., M. House, and D. H. Vitt. 2021. Differential responses to increasing sodium concentrations for *Carex aquatilus* and *C. atherodes*: Significance for wetland reclamation in the Alberta oil sands area).
4. An assessment of the eight-year data set on hydrochemistry, water level changes, and vegetation for Sandhill Wetland is underway. Completion expected April 2021, and will be the basis of a journal article (House, M., D. H. Vitt, and J. Hartsock. 2021. Eight years of changing hydrochemistry at Sandhill Wetland: Effects on plant distributions and abundance).
5. Jeremy Hartsock is completing his analysis of environmental factors and vegetation, comparing Sandhill Wetland with reference sites, with completion expected in February 2021.

LESSONS LEARNED

There are a range of expected water qualities for reclaimed wetlands including those on reclaimed tailings deposits, some with elevated water quality constituents. Some of these water quality parameters may also exceed Alberta Surface Water Quality Protection of Aquatic Life (PAL) Guidelines. An assessment of native wetlands in the region indicates that some of these parameters are naturally elevated, and in exceedance of PAL guidelines. Salinity is a key driver of vegetation community composition, and understanding thresholds for plant performance can guide operational wetland reclamation decisions, and end land use target development.

LITERATURE CITED

Hartsock, J. A., J. Piercey, M. House, and D. H. Vitt. 2021. An evaluation of water quality at Sandhill Wetland: Implications for reclaiming wetlands above soft tailings deposits in northern Alberta, Canada. Wetland Ecology and Management 29: 1-17, doi: 10.1007/s11273-020-09771-8

Vitt, D. H., L. C. Glaeser, M. House, and S. Kitchen. 2020. Structural and functional responses of *Carex aquatilis* to increasing sodium concentrations. Wetland Ecology and Management 28: 753-763, doi.org/10.1007/s11273-020-09746-9

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Hartsock, J. A., J. Piercey, M. House, and D. H. Vitt. 2021. An evaluation of water quality at Sandhill Wetland: Implications for reclaiming wetlands above soft tailings deposits in northern Alberta, Canada. Wetland Ecology and Management 29: 1-17, doi: 10.1007/s11273-020-09771-8

Vitt, D. H., L. C. Glaeser, M. House, and S. Kitchen. 2020. Structural and functional responses of *Carex aquatilis* to increasing sodium concentrations. Wetland Ecology and Management 28: 753-763, doi.org/10.1007/s11273-020-09746-9

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University Carbondale

Principal Investigator: Dr. Dale Vitt

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Melissa House	Southern Illinois University	Research Scientist		
Jeremy Hartsock	Southern Illinois University	Researcher / PhD Student	2015	2019

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, Husky, Imperial, Syncrude, Teck

Status: Year 1 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 new knowledge and techniques to develop operational best practices for reconstructing forests and wetlands to achieve equivalent land capability. While industry is currently creating new wetlands in the reclaimed landscape, there is currently no clear guidance against which 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 new Industrial Research Chair (IRC) program — the *Boreal Wetland Reclamation Assessment Program* (BWRAP), led by Dr. Jan Ciborowski.

Dr. Ciborowski's Senior NSERC/COSIA Industrial Research Chair in Oil Sands Wetland Reclamation was established on April 1, 2020, with support from NSERC, eight COSIA 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?

Currently, there are no accepted methods of assessing wetland construction effectiveness or 'functionality' of a wetland reclamation target. However, several attributes are recognized as either modulators or indicators of a wetland's successional state or its environmental or biological condition. This project's Scope of Work is to measure 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 mitigation 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, 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 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 than from tailings waters, 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 wet 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 will compile 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, will be 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 marshlike areas) using; in situ instrumentation; field sampling; 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 thresholds 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

Although the original start date proposed for this IRC program was October 2019, the actual start date was offset by six months to April 1, 2020. Many planned activities were deferred further due to restrictions on research imposed by the need to observe COVID-19 protocols. Consequently, some milestones described in the Activity Schedule of the original IRC proposal have become misaligned with actual timing of individual research activities. Nevertheless, significant initial progress was achieved on several objectives during 2020. Details of progress related to the research objectives are described below, in relation to specific research activities outlined in the original IRC proposal.

The principal activities carried out in Year 1 (Phase 1) of this IRC program were directed to four key themes:

1. Recruiting and training an initial team of Highly Qualified Personnel (HQP)
2. Developing the configuration and design of the BWRAP database to house existing and anticipated data
3. Compiling existing point source data and acquiring remote sense imagery
4. Planning and executing initial field studies and associated laboratory analyses

Objective 1: Recruiting and training an initial team of Highly Qualified Personnel (HQP)

The BWRAP study was configured to engage an administrative manager and two database programmers (supported by start-up and supplemental funds), nine graduate students (five MSc, four PhD), eight Post-Doctoral Fellows and at least 13 undergraduate thesis and/or field assistants. By June 2020, an administrative manager , two Post-Doctoral Fellows, three MSc, and five undergraduate thesis students had joined the program. Three of the undergraduate students have applied to University of Calgary graduate studies in 2021. From June through August, lab members received daily online training in wetland ecology and study design through Zoom presentations, lectures and discussions led by the Principal Investigator and Post-Doctoral Fellows.

COVID-19 safety restrictions eased in late summer permitting students to work in the laboratory and receive introductory instruction in wetland sample processing and aquatic invertebrate identification.

Objectives 2 and 3: Database configuration and design and data acquisition

Funds to purchase computer hardware and to engage programmers to build and populate the geospatial relational database were acquired through a grant from the John R. Evans Leadership fund of the Canadian Foundation for Innovation and Alberta Economic Development and Trade, awarded in November. The system will be configured and tested over the winter by a programmer (recruitment in progress) with the assistance of University of Calgary IT services.

BWRAP has had successful discussions with global information system (GIS) and database researchers at Suncor, Syncrude, and with representatives of Alberta Biodiversity Monitoring Institute and Alberta Environment and Parks to review existing database frameworks and opportunities to maximize the interoperability and compatibility of data collection approaches. BRWAP is also working closely with the COSIA-funded *Boreal Ecological Recovery and Assessment II* project to maximize database compatibility.

Data sharing agreements with Suncor and Syncrude have been developed, providing access to the high resolution remote sensing data from which to inventory the location and age of opportunistic wetlands forming on reclaimed landforms. Post-Doctoral Fellow/Research Scientist Mir Mustafiz Rahman is the chief liaison between BWRAP and the partner organizations.

Objective 4: Planning and executing initial field studies and associated laboratory analyses

Opportunities to conduct pilot-scale fieldwork were limited by travel restrictions through most of the 2020 field season. However, permission was received from the University of Calgary to conduct a one-week field trip in September 2020. A field crew of three graduate students and four undergraduate assistants visited several mature fen sites and conducted extensive sampling from pools in a saline fen complex south of Fort McMurray (Wells and Price, 2015).

Over a five day period, the team measured the conductivity, temperature and dissolved oxygen concentration of 72 pools and swales along a north-south gradient. Conductivity ranged from 3,750 µS to 21,000 µS. A subset of 50 waterbodies was stratified-randomly selected to span the conductivity gradient. At each of these wetlands the team sampled the benthic invertebrate fauna by collecting sweep net samples. Water samples were also collected for later analysis of cations, anions and stable isotopes.

The benthic invertebrate community exhibited marked differences in composition across the conductivity gradient. Wetlands with relatively low conductivity had an abundant and diverse fauna. In contrast, swales and ponds exhibiting the highest conductivity were dominated by high numbers of Diptera, especially mosquito larvae, and a few beetles and water boatmen. These samples and data, which form the basis of Brenten Vercruysse's MSc, will be used to develop a bioindicator of salinity against which the biota of reclaimed wetlands can ultimately be assessed.

LESSONS LEARNED

This project is in early stages so there are few emerging outcomes or lessons learned for 2020. One provisionally significant finding is that a broad diversity of aquatic invertebrate taxa appear to be able to develop in a naturally saline fen with conductivity values that match or exceed the readings typically observed in landscapes reclaimed with sodic overburden.

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Devito, K. J., Hokanson, K. J., P. A. Moore P. A. et al. 2017. Landscape controls on long-term runoff in subhumid heterogeneous Boreal Plains catchments. Hydrological Processes 31:2737–2751.

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Moreno-Mateos, D., Power, M. E., Comy, F. A., Yockteng, R. 2012. Structural and functional loss in restored wetland ecosystems PLoS Biology 10(1):1-8.

Price, J. S., McLaren, R. G., Rudolph, D. L. 2010. Landscape restoration after oil sands mining: conceptual design and hydrological modelling for fen reconstruction. International Journal of Mining, Reclamation and Environment 24:109-123.

Wells, C. M., Price, J. S. 2015. A hydrologic assessment of a saline-spring fen in the Athabasca oil sands region, Alberta, Canada – a potential analogue for oil sands reclamation Hydrological Processes 29:4533-4548.

PRESENTATIONS AND PUBLICATIONS

Ciborowski, J. J. H. 2020. The Reclamation Assessment Approach - calibrating bioindicators of environmental condition to monitor boreal wetland reclamation. Invited Presentation, Alberta Environment and Parks, Chief Science Officer Seminar series. May 5, 2020 (virtual presentation).

Ciborowski, J. J. H. 2020. Evaluating Biodiversity in Reclaimed Wetland Landscapes – New Tools for New Systems. Keynote Address, World Wetlands Day Research Symposium, Mount Royal University, Calgary, AB, Feb 4, 2020.

Ciborowski, J. J. H. 2020. Calibrating Bioindicators of Environmental Condition and Recovery from Degradation. Invited Seminar, University of Lethbridge, Lethbridge, AB, Jan 31, 2020

Ciborowski, J. J. H. 2019. Calibrating Bioindicators of Environmental Condition and Recovery from Degradation. Invited Seminar, Thompson Rivers University, Kamloops, BC. Nov 14, 2019.

Conference Presentations/Posters

Tomal, J., Ciborowski, J. J. H. 2020. Detection of environmental thresholds by assessing discontinuities in slopes and variances via a Bayesian regression model. Annual meeting of Canadian Mathematical Society, December 3-8 2020. (virtual meeting).

Ciborowski, J. J. H., J. J. H., Menard, J. A. Dings-Avery, C., Wiseman. H., Barr, L. 2020. Early development and controls on aquatic and semiaquatic invertebrate community composition in the Sandhill Constructed Watershed, (Alberta, Canada). Geoconvention 2020, September 21 to 23, 2020 (virtual meeting).

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		
Ashlee Mombourquette	University of Calgary	MSc	2020	2022
Brenten Vercruysse	University of Calgary	MSc	2019	2021
Michael Wendlandt	University of Calgary	MSc	2020	2022
Steven Blair	University of Calgary	BSc	2015	2020
Elizabeth Gillis	University of Calgary	BSc (thesis)	2016	2021
Liam Mebesius	University of Calgary	BSc (thesis)	2016	2021
Emily Moore	University of Calgary	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.

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	Alberta Innovates, Calgary	Isotope techniques to quantify water balance
Christopher Weisener	Earth Sciences, 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
Lee Foote	Renewable Resources, University of Alberta	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

COSIA Swamp and Bog Reclamation Workshop: Investigating Innovation Opportunities for Reclaiming In Situ and Mining Developments in the Alberta Oil Sands Region

COSIA Project Number: LE0062

Workshop Facilitator: Vertex Professional Services Ltd.

Industry Champion: Suncor

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

Status: Complete

PROJECT SUMMARY

The *COSIA Swamp and Bog Reclamation Workshop: Investigating Innovation Opportunities for Reclaiming In Situ and Mining Developments in the Alberta Oil Sands Region* was held on February 3 and 4, 2020, in Calgary, Alberta, and was attended by invited guests from industry, academia, government and consulting. The overall goal of the workshop was to engage wetland and reclamation experts in a review of the current state of knowledge around swamps and bogs on reclaimed landscapes.

Specific workshop objectives were to:

1. Establish the current state of knowledge regarding swamps and bogs on reclaimed landscapes;
2. Identify potential learnings from natural and constructed systems regarding re-establishment of swamps and bogs in the Alberta Oil Sands Region (OSR); and
3. Share perspectives and proposed strategies relating to wetland establishment on closure mining or in situ landscapes.

PROGRESS AND ACHIEVEMENTS

Key speakers, Dr. Dale Vitt (Southern Illinois University), Dr. Kevin Devito (University of Alberta), Dr. Jonathan Price (University of Waterloo), and Dr. Maria Strack (University of Waterloo) were invited to present on current knowledge regarding wetland reclamation of mining and in situ oil sands developments, and the abundance and characteristics of swamps and bogs in the Alberta OSR. Industry representatives, Lisa Bridges (Suncor) and Carla Wytrykush (Syncrude), also presented, providing context regarding reclamation of mining and in situ operations in Alberta. Discussions during the key speaker presentations and subsequent panel discussion generally focused on the functions of each wetland type within the wider landscape and whether reclamation goals should target specific wetland types or wetland functions, regardless of wetland classification.

The key speakers agreed that the main drivers of wetland development in reclaimed landscapes include landscape position and hydrologic regime. As hydrologic conditions on reclaimed sites cannot be precisely controlled, they recommended that wetland reclamation goals should focus on creating functioning wetland complexes rather than specific planned wetland types within the reclaimed landscape.

Through facilitated activities, workshop participants identified numerous key questions related to bog and swamp reclamation in post-mining and in situ environments. The questions were consolidated and can be summarized as follows:

1. What are the best indicators of successful wetland reclamation trajectories?
2. How can landscapes be designed/created in a way that encourages wetland reclamation success?
3. What are the functional roles of bogs and swamps in natural and reclaimed landscapes?
4. What is the acceptable range of water quality and quantity that will allow specific wetland types to develop?
5. What are the expected ranges of surface and groundwater quality on reclaimed landscapes?
6. Should bog and swamp attributes be included as specific reclamation goals, or is it desirable to create wetlands that provide particular functions and which may develop attributes divergent from swamps and bogs?
7. How should target vegetation communities be considered in wetland reclamation planning?

On the second day, the COSIA Land Environmental Priority Area Wetlands Working Group member company representatives held a discussion with the key speakers regarding the key questions identified on Day 1, and the overall feasibility of the approaches proposed to address these gaps.

LESSONS LEARNED

COSIA industry member company representatives and key speakers considered the knowledge gaps and approaches proposed by all participants during the first day of the workshop and arrived at the following conclusions:

- Swamp identification is inconsistent due to the variety of historical classification systems applied within Alberta, and the difficulty in remotely sensing this wetland type. As a result, the abundance of swamps within the Alberta OSR is unclear.
- Given that swamps are forming opportunistically in reclaimed post-mined landscapes in the Alberta OSR, swamp reclamation for in situ sites is technically possible. Future work could assess water chemistry, vegetation communities and thresholds of change in natural and opportunistic swamps in the Alberta OSR.
- Future work could include exploring how a study of natural and opportunistic swamps would help to address the knowledge gaps. The study could include using natural saline and/or sodic wetlands as natural analogues to vegetation communities that might develop opportunistically in discharge areas in reclaimed mining environments.
- Reclaiming linear features such as roads associated with in situ developments to bogs is likely technically possible and methods could be further explored. Existing guidance could be reviewed to determine if additional decision support is required.

- Creating bogs on reclaimed mine substrates with inherently high pH levels and limited peat source for live transfer was thought to be unfeasible. The term '*Sphagnum*-dominated wetlands' was generally agreed upon as a potentially achievable reclamation target.

PRESENTATIONS AND PUBLICATIONS

Workshop

2020 COSIA Swamp and Bog Reclamation Workshop – Executive Summary. Available at: https://cosia.ca/sites/default/files/attachments/Executive%20Summary%20-%20Final_Light.pdf

WORKSHOP FACILITATION TEAM AND KEY SPEAKERS

Facilitators: Vertex Professional Services Ltd.

Key Speakers:

Name	Institution or Company	Job Title
Dr. Dale Vitt	Southern Illinois University	Professor Emeritus
Dr. Kevin Devito	University of Alberta	Professor
Dr. Jonathan Price	University of Waterloo	Professor
Dr. Maria Strack	University of Waterloo	Professor
Dr. Bin Xu*	NAIT Centre for Boreal Research	Program Lead - Centre for Boreal Research
Lisa Bridges	Suncor	Reclamation Specialist - Biodiversity
Carla Wytrykush	Syncrude	Ecologist – Mine Closure Research

* Dr. Bin Xu co-authored the presentation given by Dr. Maria Strack. He was scheduled to present but was unable to attend due to restrictions brought about by the COVID-19 pandemic.

COMPENSATION LAKES AND AQUATICS

Horizon Lake Monitoring Program

COSIA Project Number: LJ0011

Research Provider: Canadian Natural, Golder Associates

Industry Champion: Canadian Natural

Status: Year 12 – Ongoing

PROJECT SUMMARY

Canadian Natural Horizon Oil Sands (Horizon) contains a compensation lake (Wāpan Sākahikan) to permanently offset areas of fish habitat affected by Horizon developments. The primary purpose of the compensation lake, hereafter referred to as Horizon Lake, is the establishment of habitat that will support self-sustaining resident fish populations. Horizon Lake is located approximately 80 km north of Fort McMurray within the Tar River watershed. The lake has a surface area of 76.7 ha and a maximum depth of approximately 20 m.

The measure of success for Horizon Lake is based on satisfying conditions identified in Canadian Natural's Fisheries Act Authorization for Horizon. The condition states that the compensation habitat must "achieve permanent fish habitat productive capacity gains that offset fish habitat productive capacity losses to meet a compensation ratio of 2:1 based on fish biomass productivity."

Canadian Natural designed and began the implementation of a monitoring program in 2008, to track the establishment and development of the lake. Monitoring includes documentation of the existing fish populations, water and sediment quality, plankton and benthic invertebrate communities, and growth of macrophytes and shoreline vegetation.

PROGRESS AND ACHIEVEMENTS

Note: Results of the 2019 monitoring program became available in 2020 after the publication of the 2019 COSIA Land EPA Mine Site Reclamation Research Report, and are therefore presented in this report.

In 2019, the Horizon Lake Monitoring Program completed its eleventh year of monitoring. Findings have demonstrated that Horizon Lake continues to provide functional food sources and habitats that are suitable to resident fish populations. The chemical and physical environment are well suited to the establishment and proliferation of aquatic life.

Fish Populations

A total of 10 species have been documented in Horizon Lake over the 11 years of the monitoring program. This includes Arctic grayling, brook stickleback, burbot, fathead minnow, finescale dace, lake chub, longnose sucker, slimy sculpin, trout-perch and white sucker.

Sampling in 2019 processed 7,969 fish, of which three were recaptures including one longnose sucker during the spring, and a white sucker and Arctic grayling during the fall. The recaptures were initially tagged in 2016, 2015, and 2017 respectively. Sampling techniques included fyke netting, gill netting, minnow trapping, electrofishing, snorkel surveys and Adaptive Resolution Imaging Sonar (ARIS). In the spring program 6,941 fish were captured and 1,028 in the fall. The spring catch consisted of six species, mostly forage fish, consisting of trout-perch, fathead minnow, lake chub, slimy sculpin, brook stickleback, white sucker and longnose sucker. The fall capture consisted of 89% forage fish species, 10% sucker species and 0.4% sportfish, with eight species captured.

Two Passive Integrated Transponder (PIT) antennae have been deployed in the upper Tar River to track fish movement in and out of Horizon Lake to the Tar River. In 2019, PIT tags were implanted in 74 large-bodied fish throughout the year, with two Arctic grayling, 34 longnose sucker and 38 white sucker tagged. A total of 233 unique tags were detected in 2019, with tags from all monitoring years with the exception of 2009, demonstrating fish from the lake are using the upper Tar River and providing clear evidence of population connectivity and recruitment.

Fish tissue sampling for total metals and organic compounds in Horizon Lake, and background reference samples from Calumet watershed and Tar Lake, were taken. 2019 was the first year fish were sampled in Tar Lake as part of the Horizon Lake Monitoring Program. Concentrations in Horizon Lake continue to be below human health consumption guidelines, with the exception of arsenic and aluminum. These two metals had concentrations that exceeded the consumption guidelines in Horizon Lake, Tar Lake and the Calumet watershed. Horizon Lake total and methyl mercury in juvenile white sucker were within historical ranges, and were lower than Calumet watershed samples. Median adult white sucker tissue plugs taken for total and methyl mercury concentrations in 2019 were lower than in all previous years. As was initially predicted, mercury peaked in 2011 and 2012, shortly after the creation of Horizon Lake, followed by the subsequent reductions, which have been observed in recent years.

A seventh hydroacoustic survey was completed in 2019. The survey estimates productivity and abundance of fish in the lake. The resultant production estimates were below the total production requirement of 2,543 kg/year that is stipulated in the DFO (Fisheries and Oceans Canada) Authorization with an estimated production of 1,880 kg/year. Seven of the 10 species in the lake are used in the estimates. The remainder of the offsetting production is expected to be provided by the diversion channel that will connect the lake with the Athabasca River when the mine approaches its closure phase in 2044.

Benthic Invertebrates

Benthic invertebrate sampling in 2019 generally followed historical trends, with moderate variability in density, taxonomic richness and percent ETO in Horizon Lake. Diptera (true flies, midges and mosquitoes) were the most dominant taxon. Pelecypoda (fingernail clams) were found for the first time in 2019. Density and pooled species richness were highest near the shore. Sensitive ETO (Ephemeroptera, Trichoptera and Ordonata) species were present at the near-shore sites, with the percent ETO less than one percent. This could be due to the habitat ETO taxa use for predator avoidance, and the lower amounts of effective sampling in these sheltered habitat types. Benthic communities were dominated by collector-gatherers, consistent with all years except 2009 and 2017. Generally, the near-shore areas contain a higher number of functional feeding groups, indicating a greater number of food sources closer to shore.

Water Quality

Variability in key water analytes has been relatively low since monitoring began in 2008. Most variability observed is due to the regularly occurring natural events such as turnover and freshet. No substantial increases in metal concentrations were seen compared to previous years. The majority of the analytes sampled in the bi-annual sampling remained within the range of water quality guidelines for protection of aquatic life. In 2019, dissolved silicon and total tin concentrations exceeded historical levels in September and February respectively. Water quality has remained similar since 1998, when RAMP (Regional Aquatics Monitoring Program) initiated the Tar River watershed monitoring.

Continuous data from the thermistor string in Horizon Lake shows spring turnover in mid-May, with an establishment of a thermocline until early October. Seasonal surface temperatures in 2019 were near or below historical observations. Temperatures in May being slightly higher than historical data, while all temperatures in July were below historical range. Dissolved Oxygen (DO) patterns on the thermistor string were similar to all previous years of monitoring. Concentrations decreased from January until April, until increasing during spring turnover. DO concentrations decreased throughout the summer with an annual minimum of 2.5 mg/L at 5 m in early August, and 0.4 mg/L at 10 m in mid-August, and then increased in the fall during lake turnover in October.

Seasonal in-situ water quality samples from Horizon Lake showed conditions similar to historical data. The pH profiles remained within the historical range during the February, May and September sampling events, ranging between 7.3 to 8.5. Discrete DO sampling identified concentrations falling below 5.5 mg/L (lowest acceptable concentration to support all life stages of all species of fish; CCME 1999) below 12 meters, reaching a minimum concentration in February. DO in profundal areas declined between July and September, with sharply decreasing concentrations below the thermocline. However, fish would be expected to stay in the vast areas of oxygen-rich water until lake turnover occurred. Winter sampling continues to confirm that suitable oxygen levels are available to support overwintering of all fish species in Horizon Lake.

The trophic status of Horizon Lake is determined using the production-based Trophic State Index (TSI) presented in Wetzel 2001. TSI was 56 in the fall and 42 in the winter, suggesting a eutrophic system in the fall and mesotrophic system in the winter.

Plankton

In 2019, average phytoplankton density and biomass were lowest in the spring and highest in the summer. Summer 2019 has had the highest abundance of phytoplankton. Mean species richness ranged from 16 species in spring to 31 species in fall in 2019. Mean Simpson's diversity and evenness were similar through the year, with evenness ranging from 0.21 to 0.29 and diversity from 0.64 to 0.69. Community composition was dominated by diatoms in the spring, cyanobacteria in the summer and dinoflagellates in the fall. Generally, Horizon Lake has supported a moderately to highly diverse (≥ 0.5) phytoplankton community since monitoring began.

Zooplankton density and biomass in 2019 was observed to be the highest biomass and abundance in summer compared to historical data. Recent annual trends of lowest abundance in spring, and highest in summer were observed in the monitoring year. The zooplankton community's highest contributors to density and biomass were rotifers in spring and ciliates in summer and fall. Mean species richness was highest in the summer (15) and lowest in the spring (12). Historically, higher variability has been observed in the spring and summer, while the fall has been relatively stable. Diversity was highest in the spring, decreasing through the season and was lowest in the fall. Mean evenness was highest in spring and lowest in fall. The Horizon Lake's zooplankton community is dominated by few taxa which has produced low evenness scores since monitoring began (< 0.25), with the exception of summer 2019 when it was moderate (0.29). Phytoplankton and zooplankton communities in Horizon Lake are dominated by few taxa, and range in diversity, evenness, abundance and biomass depending on the season.

LESSONS LEARNED

1. Through eleven years of monitoring, it has been documented that Horizon Lake provides suitable habitat for all resident fish species.

   Hydroacoustic surveys have indicated overall abundance and distribution of fish sizes have remained self-sufficient. Age distributions of both large- and small-bodied fish indicate that there is consistent recruitment and age-dependent mortality occurring. Production values have fluctuated mainly based on the relative abundance during capture events — thought to be caused by the degree of capture success. This is likely caused by poor success electrofishing, size selection bias, and high capture rates in minnow traps. The uncertainties from this success are reflected in calculated abundance per species and subsequently biomass and productivity.

   Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both seasonally and temporally (Findlay and Kling 1979; Paterson 2002). This natural variability has been observed in phytoplankton and zooplankton taxonomic richness, biomass, abundance and community composition in Horizon Lake. Zooplankton graze on phytoplankton; therefore, they respond directly to changes in the phytoplankton community. In turn, zooplankton can influence phytoplankton biomass, abundance and community composition through top-down control (Carpenter and Kitchell 1984).

   Overall, the benthic invertebrate community assessments for Horizon Lake suggest that habitat quality has improved over time, which may be a result of more diversity in primary production and food sources for invertebrates, and more available habitat niches.

   The lake is stabilizing to an upper mesotrophic to slightly eutrophic system, and will continue to provide nutrients for the primary producers and sustain the aquatic food web.

2. Future monitoring will be important to determine whether the large-bodied fish species in Horizon Lake are stabilizing or declining, or whether there is simply high annual variability in these populations.
3. The lack of connectivity of Horizon Lake to the lower Tar River and the current species composition (e.g., no piscivorous fish) may affect the lake's ability to meet the prescribed production target.

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PRESENTATIONS AND PUBLICATIONS

Reports and Other Publications

Golder Associates. 2020. Horizon Lake Monitoring Program – 2019 Technical Report. Prepared for Canadian Natural. Calgary, Alberta. P. 590.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates

Principal Investigator: Michael Day

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Joanne Hogg	Canadian Natural	Lead, Research		
Devon Versnick-Brown	Canadian Natural	Coordinator, Environment		
Jason Lewis	Golder Associates	Fish Biologist		
Alyssa Thompson	Golder Associates	Water Quality Specialist		
Kate Sinclair	Golder Associates	Senior Water Quality Specialist		
Kent Nuspl	Golder Associates	Aquatic Biologist		
Kelly Hille	Golder Associates	Aquatic Biologist		
Michael Terry	Golder Associates	Biologist		
Kasey Clipperton	Golder Associates	Principal, Senior Fisheries Biologist		
Zsolt Kovats	Golder Associates	Associate, Senior Aquatic Ecologist		
Cameron Stevens	Golder Associates	Associate, Senior Fisheries Biologist		
Jason Inkster	Golder Associates	Biologist		
Emma King	Golder Associates	Biologist		
Meghan Isaacs	Hatfield Consultants	Environmental Specialist		
Daniel Moats	Hatfield Consultants	Program Manager		
Alex Fraser	Hatfield Consultants	Environmental Technician		
Curtis Higson	Hatfield Consultants	Environmental Technician		

SOILS AND RECLAMATION MATERIALS

cosia

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Infinity

Industry Champion: Imperial

Status: Year 5 of 6

PROJECT SUMMARY

An important part of mine site reclamation is the salvage and storage of upland surface and subsurface soils. Salvaged soils need to be 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, there may be some limitations to this approach. Research suggests that viability of plant propagules significantly diminishes with depth in soils that are stockpiled for long periods of time (MacKenzie 2013). Also, storing different textured soils separately requires more space and associated land disturbance than if combined in one stockpile.

The purpose of this research project is to determine whether coarse textured soils (surface soils from a/b ecosites [Beckingham and Archibald, 1996]) can be co-mixed with moderate/fine textured soils (d/other surface soil) in the same pile without negatively affecting soil chemical and physical properties or potential vegetation community establishment.

The following treatments are being evaluated:

- Treatment 1 – Stockpiled ABSS (coarse textured soils)
- Treatment 2 – Stockpiled OSS (moderate-fine textured soils)
- Treatment 3 – Stockpiled ABSS + OSS (also referred to as MIXED)

In 2016, six stockpiles were constructed (two ABSS, two OSS and two MIXED) at the Kearl Oil Sands Operation. Each stockpile is approximately 3,000 m^3 in volume, with a maximum height of 5 m and a footprint of approximately 38 m x 38 m. The average grade for all slopes on each stockpile is 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 rough-textured to reduce erosion.

Soil quality parameters as well as vegetation will be monitored for a minimum of six years. The data will be compiled and statistically analyzed.

PROGRESS AND ACHIEVEMENTS

Soil monitoring in 2020 (Year 5) was conducted in October and November for the six stockpiles. Vegetation monitoring was completed in July.

Soil Parameters

Similar to 2019, soil parameters in 2020 were assessed at four sampling depths for each stockpile including:

1. Physical parameters – bulk density, percent saturation, percent sand, percent silt, percent clay;
2. Salinity parameters – pH, electrical conductivity (EC), sodium adsorption ration (SAR);
3. Soluble ions – calcium (Ca), magnesium (Mg), potassium (K), sodium (Na); and
4. Nutrients – Total Organic Carbon (TOC), Total Kjeldahl Nitrogen (TKN) and available nitrogen (N), phosphorus (P), potassium (K), sulphur (S).

Values for key parameters in 2020 are presented in Figure 1 below.

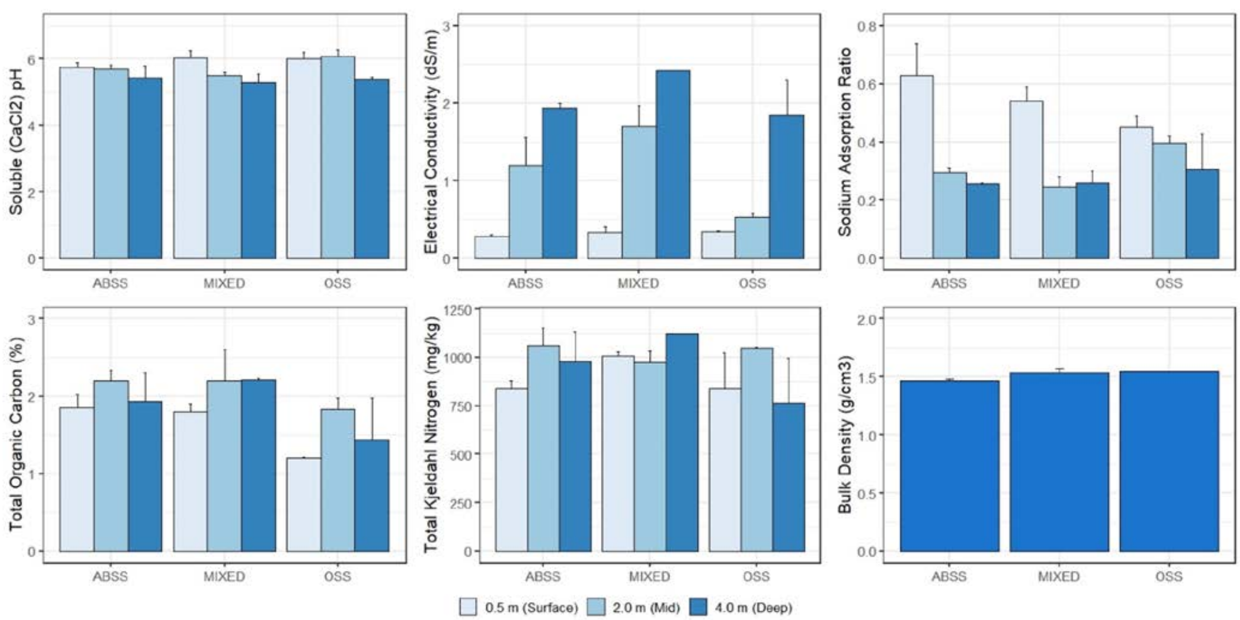

Figure 1: pH, salinity, nutrients and bulk density by soil type in 2020.

Changes in these key parameters over the years (2016 to 2020) for surface, mid and deep sampling depths are illustrated in Figures 2 to 4.

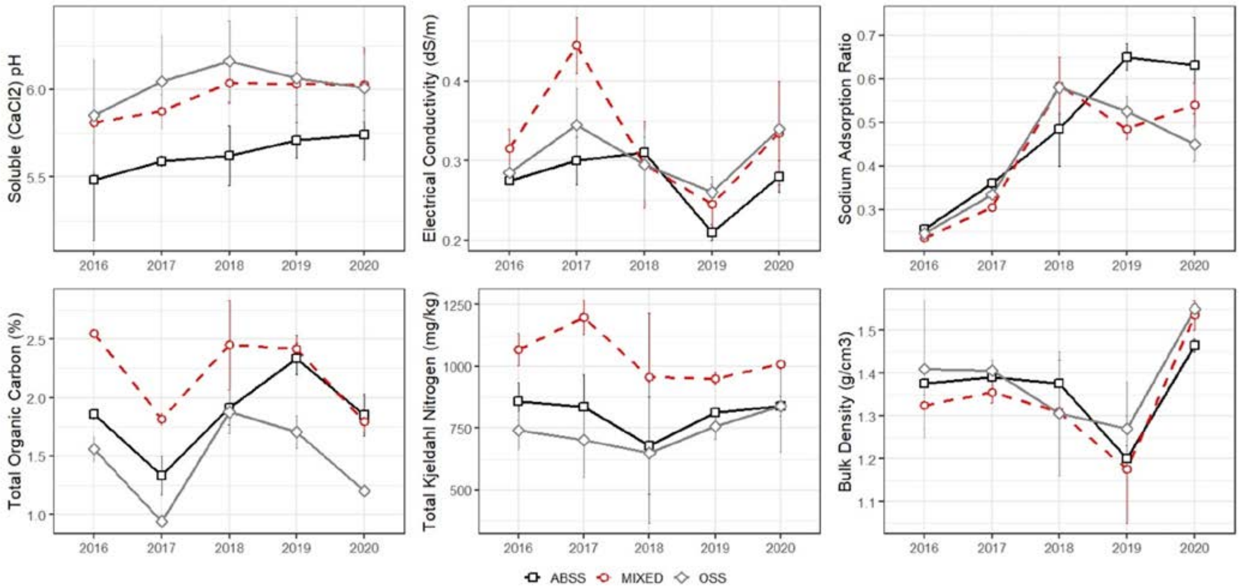

Figure 2: Surface (0.5 m) measurements for salinity, nutrients and bulk density for surface soil types (2016 to 2020).

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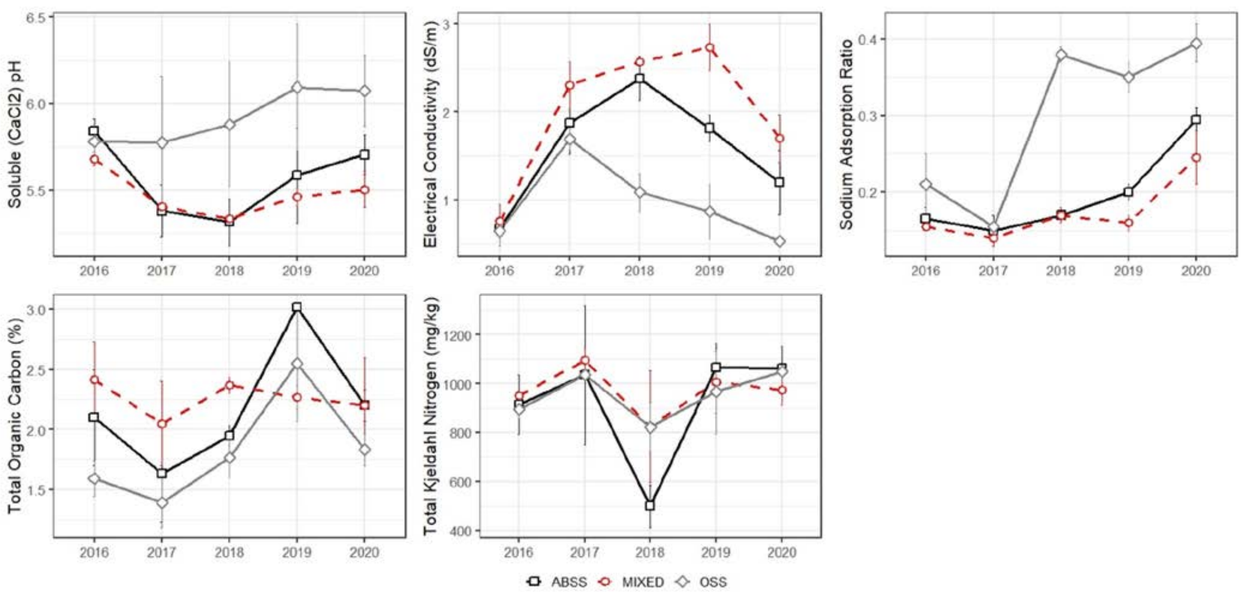

Figure 3: Mid-depth (2.0 m) measurements for pH, salinity, and nutrients by soil types (2016 to 2020).

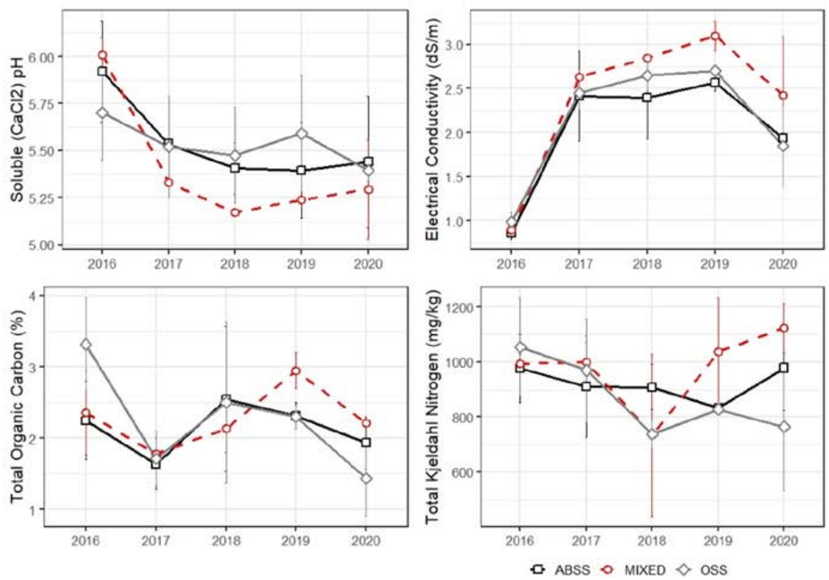

Figure 4: Deep-depth (4.0 m) measurements for pH, salinity, and nutrients by soil types (2016 to 2020).

The results can be summarized as follows:

- Bulk density (measured at the surface of the stockpiles) was significantly affected by assessment year. There were no significant effects of soil type on bulk density.
- Percent saturation was significantly affected by assessment year but was not dependent on soil type or sampling depth.
- Percent sand was significantly different among soil types, assessment year, and sampling depth. Percent silt was significantly different among soil types, but that difference was dependent on assessment year. There was no significant effect of sampling depth on percent silt. Percent clay was not significantly affected by assessment year but was significantly different among soil types.
- Soil pH was significantly affected by soil type, irrespective of assessment year. There was no significant effect of assessment year on soil pH.
- Soil electrical conductivity (EC) was significantly affected by soil type, assessment year, and sampling depth. EC also increased significantly with sampling depth in all assessment years, with lower EC values at surface sampling depths compared to mid and deep sampling depths.
- The sodium adsorption ratio (SAR) was dependent on soil type, assessment year, and sampling. SAR was significantly higher in OSS and ABSS stockpiles than MIXED stockpiles. No significant differences in SAR were observed between OSS and ABSS stockpiles.
- With the exclusion of K^+ ions, all the other soluble cations (Ca^{2+}, Mg^{2+}, Na^+) were all significantly higher in MIXED soil types than in ABSS and OSS, though trends amongst years were not always clear. Soluble cations all had significantly higher concentrations with depth.

- Total Organic Carbon (TOC) was significantly affected by soil type, assessment year, and sampling depth. While significantly affected by assessment year, TOC contents did not increase or decrease consistently over time. Higher TOC contents were observed in mid and deep sampling depths when compared to surface sampling depths.
- Total Kjeldahl Nitrogen was also significantly affected by assessment year, although, as with TOC, values did not consistently increase or decrease over time.
- Available phosphorus (P), potassium (K) and SO_4-S (sulphate) were significantly affected by soil type, assessment year, and sampling depth.

Vegetation Parameters

Similar to previous years, vegetation performance parameters calculated for the stockpiles included total vegetative cover, species richness per plot, species richness per stockpile, evenness and diversity (Shannon Diversity Index).

The results are summarized below and illustrated in Figure 5.

- Diversity and species richness per plot were dependent on soil type, with ABSS stockpiles supporting 12% lower diversity and 18% lower richness per plot than OSS. Species richness per plot for MIXED stockpiles was also 9% lower than for OSS stockpiles, though this difference was not statistically significant. Diversity values for MIXED stockpiles were statistically similar to both ABSS and OSS stockpiles.
- All vegetation performance metrics were dependent on assessment year. Total vegetative cover increased 6%, species richness per plot increased 14%, species richness per stockpile increased 27%, diversity increased 28%, and evenness increased 22% between 2019 and 2020. Evenness was also dependent on aspect, with higher values calculated for southern slopes (average evenness = 0.88) compared to northern slopes (average evenness = 0.85).

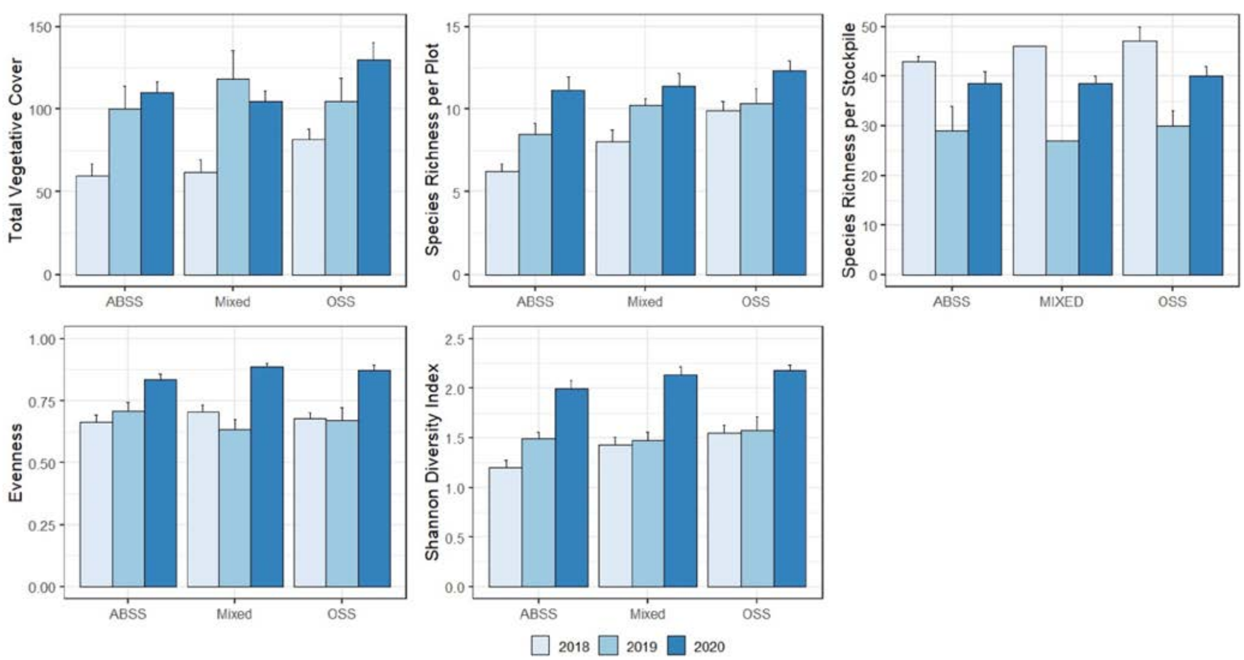

Figure 5: Vegetation performance parameters by surface soil types from 2018 to 2020.

LESSONS LEARNED

Lessons learned will be summarized after the final year of the program (2021).

LITERATURE CITED

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PRESENTATIONS AND PUBLICATIONS

No public presentations were released in 2020.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Infinity

Principal Investigator: Paragon Infinity

Shrub and Perennial Outplanting Study

COSIA Project Number: LJ0332

Research Provider: University of Alberta

Industry Champion: Syncrude

Industry Collaborators: Suncor, Imperial

Status: Year 2 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, this study is primarily inductive rather than deductive as researchers are developing rather than testing meaningful hypotheses, where those hypotheses can be further explored in subsequent studies. This is being done by observing seedling performance under a wide range of growing environments with more or less controlled conditions (e.g., 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 natural forest; and pot studies in growth chambers and greenhouses). Depending on the performance of each species on each site, researchers can intuitively narrow down the potential causes for any meaningful variations. For example, if seedlings of a particular species perform poorly under all conditions, it would strongly suggest that seedlings are generally of poor quality and that problems may lie primarily in nursery practices. If seedling performance for any species is markedly different by site, this might suggest different strategies either for timing of deployment (e.g., waiting for canopy development prior to planting to provide a protected growing environment) or more careful matching of that species to particular field conditions. Overall, 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 of propagating each species, for generating hypotheses and for guiding future research.

PROGRESS AND ACHIEVEMENTS

- 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, an agronomic field setting, a natural forest site and in controlled conditions in a growth chamber in 2019.
- All of the 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 site types added.
- Seedlings of the nine species were also planted in the agronomic field, the natural forest, and in controlled potted conditions. These potted seedlings and those planted seedling 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.

LESSONS LEARNED

No lessons learned available for 2020 as data analyses have not been completed.

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. https://open.alberta.ca/publications/9780778588252

PRESENTATIONS AND PUBLICATIONS

No reports or publications available for 2020.

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	
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

NSERC - Industrial Research Chair in Forest Land Reclamation

COSIA Project Number: LE0012

Research Provider: University of Alberta

Industry Champion: Syncrude

Industry Collaborators: Canadian Natural, Cenovus, ConocoPhillips, Husky, Imperial, Suncor, Teck, TransAlta Corporation

Status: Final Cumulative Summary

PROJECT SUMMARY

Oil sands extraction is a major component of the Alberta and Canadian economy, and the associated surface mining temporarily disrupts forest ecosystems. A pressing objective of land reclamation in the boreal forest region is to return disturbed sites to functioning and self-sustaining ecosystems. Early in the recovery of forests, the main challenge is rapid redevelopment of a tree canopy to create conditions that initiate and sustain abiotic and biotic processes characteristic of functioning forest ecosystems. The first Industrial Research Chair (IRC) program dealt with the use of trembling aspen, a tree species native to the boreal forest, to quickly develop a forest canopy. During that program great progress was made in developing better aspen planting stock and increasing the establishment success of aspen on stressed sites that hastened the development of a closed tree canopy. Building on this, the IRC program was renewed to examine critical issues related to constraints of tree growth and the maintenance of understory species diversity during stand initiation and early development on forest reclamation sites.

The Chair addressed three general topic areas and associated detailed research questions:

Accelerating Forest Establishment

- How does the application of organic amendments (e.g., salvaged peat or forest floor material) influence tree and vegetation establishment on undeveloped subsoil mineral surface substrates?
- What is the impact of specific fertilization prescriptions on newly planted trees across different capping materials and what is its effect on understory vegetation and competition?
- What is the impact of increased surface roughness on environmental gradients and microsite variability and how do these gradients affect the establishment of tree and understory species and community development in reclamation sites?

Influencing Forest Stand Trajectories

- Can aspen stem density and performance be increased in older reclamation sites by cutting to promote vegetative reproduction (suckering), coupled with reducing competition?

- Can tall aspen stock with high root to stem ratios be developed? How feasible is it to use tall aspen seedling stock on high competition sites? And is infill planting of seedlings on low density forest reclamation sites a viable option for forest canopy development and competition control?

Assessing Trajectories of Forest Reclamation

- What role does rooting space play in root water uptake, leaf area, and stand productivity for aspen, jack pine and white spruce in reclaimed oil sands sites and how do confining soil layers (chemical or physical) affect root growth behaviour and rooting space?
- How does the relationship between leaf area/Leaf Area Index (LAI) and water use/availability vary on reclaimed sites as a result of stand composition, canopy development, and age and what is its impact on productivity?

PROGRESS AND ACHIEVEMENTS

As this program is drawing to a close, 2020 was mainly spent completing and finalizing students ongoing graduate programs, as well as synthesizing the learnings from their research projects. Details on the activities and associated results in 2020 are listed below, while the findings and implications of the projects are summarized by topic area in the next section.

Accelerating Forest Establishment

To study questions related to the feasibility of enhancing micro- and meso-topography for natural establishment of vegetation and trees early vegetation establishment and tree performance were monitored on an operational-scale study site on the Canadian Natural Albian Sands lease. Sophie Aasberg (MSc candidate) continued work on her MSc thesis analyzing and synthesizing her data and writing her thesis and producing publications that include the data collected earlier by Kate Melnik (MSc 2017) and Trevor de Zeeuw (MSc 2019). All field measurements for the vegetation work were completed in 2019 and no new results were obtained in this reporting period.

Influencing Forest Stand Trajectories

In a controlled study, the feasibility of cutting juvenile aspen (eight to 12 years) of seedling origin to increase stem density through root suckering was explored. Building on earlier work by Carolyn King (MSc 2017), Caren Jones (Research Technician) selected operational reclamation sites in the SAGD (steam-assisted gravity drainage) and mining region in 2017 which were subsequently disturbed (manually felled) to promote suckering in 2018 and measured in the late summer of 2018. In 2019 data was summarized and analyzed, but the decision was made to add additional site information (soil data) from the SAGD site. No additional results were obtained for this project in this reporting period.

Assessing Trajectories of Forest Reclamation

There has been over 30 years of forest land reclamation in the mineable oil sands area. Assessment of stand trajectories as a result of past reclamation strategies will provide insights into tree growth, leaf area development, forest structure, soil development and soil-water availability of these reclaimed forests. Soil water availability and water-use as main drivers of forest stand performance on reclamation sites are being explored and the accuracy and applicability of sap flow measurements to estimate tree water-use has been tested.

Morgane Merlin (PhD candidate) has analyzed and summarized a very complex data set that explores how leaf area, rooting depth, and climatic and edaphic variables can be linked to water-use, and how those linkages change with different tree species. Morgane successfully defended her thesis early in the spring of 2020. No new results have been obtained from that project in the reporting period.

LESSONS LEARNED

Accelerating Forest Establishment

1. *Impact of coversoil type on early tree and vegetation establishment*

As part of this project researchers explored how the coversoil type (salvaged peat versus forest floor) and the application thickness (10 cm versus 30 cm) placed on subsoil substrates impacts early tree and colonizing vegetation establishment. This study was executed on the Aurora Soil Capping study site as part of an extension of the *Roots of Succession* project. As expected, capping material type had significant effects on tree growth, where all seedlings planted in the forest floor material performed significantly better than seedlings planted in a salvaged peat coversoil, particularly when the peat was applied at a thickness of 30 cm. The magnitude of the tree response was modulated by tree species, where aspen was more sensitive to coversoil differences than pine, which in turn was more sensitive than spruce.

Potential drivers of these responses were differences in nutritional conditions of these materials (see also project 3 below), with the less mobile nutrients such as phosphorus being of particular concern, as well as differences in the physical attributes of the coversoils (i.e., soil temperature conditions and water holding capacity). Both drivers interacted and affected resource availability (i.e., nutrients and water) and subsequently growth responses.

The application thickness of the coversoil materials was also very important, particularly for peat where the insulative properties and high spring water content in the peat layer significantly delayed (up to three weeks) soil warming in the root zone, shortening the belowground growing season. Based on post-hoc observations, these effects may have been exacerbated on this site for those treatments where the thick peat coversoils were placed over compacted lean oil sand on a flat terrain, potentially creating a seasonally perched water table.

However, there is a potential trade-off between soil temperature limitations and soil water availability, with increased peat placement depth. Under climatic or edaphic conditions during which summer or late season moisture availability is low (low precipitation and/or coarse textured soils), a higher total organic content in the reclaimed soil could provide additional water storage capacity particularly for sites that have a high forest productivity end land use.

Characteristics of subsoils (texture and nutrient availability) placed below the coversoil also had a measurable effect on early seedling establishment and growth. It was found that differences in nutrient availability (in this case phosphorous) and small changes in clay content in coarse textured subsoils may play a much larger role in tree growth on forest reclamation sites than previously thought. It is suspected that these effects may become more pronounced as trees get older and their root systems occupy a larger rooting space.

Mixing different salvaged materials for subsoil and/or coversoils might be an option to balance nutrient availability with greater water holding capacity for establishing vegetation, particularly on sites where it is desirable to mitigate drought or other growth limitations.

More details on the objectives, treatments, and experimental design can be found in Stack 2019; Bockstette 2018; Stack et al. 2020; Jones and Landhäusser 2018, and in the outcomes from the Aurora Capping Study Report 2018.

2. *Impact of organic amendments on early tree establishment*

Here a novel and innovative site preparation technique was tested that utilized the inversion of a mixed organic layer consisting of co-composted municipal compost and biosolids (organic mix). The organic mix was obtained from the Edmonton Composting Facility, City of Edmonton and placed on a 6 ha reclamation site on the Highvale coal mine lease of TransAlta. Treatments included: i) uncapped subsoil; ii) subsoil capped with 20 cm of native topsoil; iii) a 20 cm layer of organic mix incorporated into the subsoil; iv) the same organic mix incorporated into the subsoil and capped with an additional 20 cm of clay loam subsoil; and (v) the same organic mix incorporated into the subsoil and capped with an additional 20 cm of sandy subsoil. The effect of these covers and material on early tree establishment was explored.

All soil treatments that contained compost had poor seedling survival after the first growing season. It is suspected that the source of compost, its application rate, and the degree of incorporation into the subsoil were important factors that negatively impacted seedling survival. These factors all need to be considered when using these types of materials as they created unsuitable growing conditions for tree seedlings in the first growing season. The most likely explanation for the mortality was the unexpectedly high salt content in this material, likely from the co-composting of concentrated biosolids. A lower application rate, as is more typical in agricultural applications, may reduce the adverse effects observed here. However, this material had an additional side effect as it allowed a salinity-tolerant, aggressive and competitive annual *(Kochia scoparia*), whose propagules were likely present in the stockpiled soil materials, to take advantage of these conditions to the detriment of the planted seedlings.

It was also found that the placement method and the textural composition of the mineral soil cap influenced the physical and chemical characteristics of the compost. Evidence was found that the fine and coarse mineral soil cap created conditions of low oxygen availability in the compost layer, and increased soil temperatures — likely from the decomposition in the compost. This appeared to cause elevated CO_2 (carbon dioxide) emissions and increased water holding capacity in the underlying compost, leading to denitrification and elevated N_2O (nitrous oxide) emissions.

Based on the above findings, a thorough understanding of the detailed chemistry and composition of the organic amendment is necessary to ensure its effectiveness and understand its environmental impact. In our study the municipal (Grade B) compost was categorized as a mature and stable Agriculture Grade material; however, it still contained small fragments of waste materials (e.g., glass and plastic) which might be undesirable.

Despite high mortality in the first growing season, seedlings that survived grew taller in the inverted treatment (i.e., mineral soil cap over compost) than in the other treatments with and without compost. These observations reinforce observations from inverted mounding in forestry that highlight the benefits of a buried organic layer under a mineral soil cap — where tree roots often follow the interface between organic and mineral soil constituents. Based on variation in mineral cap thickness and the rooting depth of *Kochia scoparia*, it appears that a mineral soil cap over the compost/biosolid mix, of 50 cm or greater is effective in limiting the growth of this deeply tap-rooted species, reducing its competitive effects on planted trees.

More details on the objectives, treatments, and experimental design can be found in Valek 2018.

3. *Impact of specific (targeted) fertilization prescriptions on planted trees and effects on vegetation competition*

Targeted fertilization of forest reclamation sites several years after tree planting (as opposed to at the time of soil placement and/or planting) was investigated as an option to improve fertilizer uptake efficacy and for potential cost savings. The underlying hypothesis was that because older established trees have larger and more extensive root systems than newly planted seedlings, they can better access the applied nutrients. Further, the intent of the targeted fertilization in a forest reclamation setting was not only to address specific nutrient deficiencies in the coversoil to improve growth of the planted species but also to avoid excess nutrients being available for undesirable competitive species and/or being leached from the root zone to other parts of the landscape. This study was executed in specific treatments on the Aurora Soil Capping Study that had shown poor seedling growth responses (i.e., thick peat coversoil, see project 1).

The tree responses to the fertilizer application appear to be strongly influenced by the nutritional requirements of the targeted species, the chemistry of the peat layer, and the environmental conditions of a growing season. In this study aspen responded the strongest to fertilization, particularly when the fertilizer prescription contained phosphorous (P). After two growing seasons, aspen treated with P alone had growth rates similar to those measured on other capping treatments in project 1 with the greatest aspen growth. Pine and spruce on the other hand, showed a limited response potentially indicating that either, i) nitrogen, phosphorous and potassium were not necessarily limiting for these species, ii) there were other nutritional imbalances that were not addressed in the fertilizer formulation, or iii) other soil and site conditions that may have been more limiting. Competing vegetation responded positively to fertilization, but only in treatments that included nitrogen. These results suggest that fertilizer formulations can be tailored to particular forest species and to potentially minimize adverse competition effects.

Targeted fertilization of forest reclamation sites several years after establishment could be an option to improve efficacy of nutrient uptake while generating cost savings; however, prior to application other factors such as the nutritional requirements of species, potential nutrient imbalances due to soil pH, precipitation, and soil water availability need to be carefully considered and will likely require further, more detailed examination.

More details on the objectives, treatments, and experimental design can be found in Stack 2019 and Stack et al. 2020.

4. *Impact of increased surface roughness on environmental gradients, microsite variability, tree establishment, and plant community development*

An operational scale study site was installed at the Canadian Natural oil sands mine lease to test the impact of microtopographical variation on early forest reclamation. Increasing microtopographic variation and maximizing the variety of microsite types through mechanical site preparation was very beneficial to forest reclamation efforts.

Greater microtopographic variation, ranging from 0.3 m to 1.5 m vertically and from 0.5 m to 6 m horizontally, resulted in increased diversity of microsites and associated conditions; particularly with respect to soil temperature and moisture gradients, and providing shelter from unfavourable abiotic conditions (wind, high sun exposure etc.). Using different coversoil materials (mineral versus organic) further increased diversity of microsite conditions.

Increased microsite diversity had a positive influence on native plant species establishment and growth, providing establishment niches for a greater range of native species across a wider environmental amplitude than typically observed for more uniform surface treatments. Increased species recruitment was observed both for propagules that were contained in the coversoil and via immigration through wind dispersal of seeds. Of particular note was the higher colonization of aspen and shrubs species from seed. Additional benefits included an overall improved productivity of the planted tree seedlings.

Potential mechanisms include increased niche diversity (varying combinations of moisture and soil temperature regimes) required for germination and/or sprouting of a variety of species and an increased surface roughness that allows for a greater seed capture and provides protection from extreme climatic conditions and seed predation. Creating loosely piled mounds (resembling moguls on a ski hill) was most beneficial for both planted aspen and jack pine, as well as for the recruitment of naturally regenerating aspen and shrubs.

The topographic position and coversoil characteristics of the reclamation area are important considerations when applying microtopographic treatments at an operational scale. It was found that there were greater benefits to tree and vegetation establishment and growth on sites that are more likely to experience stress conditions (i.e., south-facing slope and/or coarse soil texture of soil materials) compared to sites with more moderate conditions. These differences might become even more apparent later in stand development, when the root system of individual trees have expanded and roots can access a range of microsite conditions, which inherently increase the resistance and resilience of these trees to stress and disturbance.

Creating increased topographical variation on a reclamation site does not necessarily add to the operational cost of site establishment. In this study making mounds was the most economical treatment as it required significantly fewer machine passes to lay down the same amount of material — decreasing operational costs while reducing the risk of soil compaction during site establishment.

More details on the objectives, treatments, and experimental design can be found in Melnik 2017, de Zeeuw. 2019, Melnik et al. 2018, Merlin et al. 2019; and Landhäusser et al. 2019.

Influencing Forest Stand Trajectories

1. *Exploring vegetative regeneration of planted aspen and its resilience to aboveground disturbance*

This research explored the impact of cutting seedling origin aspen to induce a suckering response. The rationale for executing these studies were to i) demonstrate that aspen stands originated from planted seedlings have the capability to successfully reproduce vegetatively after disturbance through root suckering, and ii) test what effect stand conditions of plantations such as aspen stocking, age and/or density and the existing vegetation have on sucker regeneration and future stand canopy development. These questions were explored in two research settings, one being eight to 12 year old aspen plantations in an agronomic setting near Edmonton, and the other being 15 to 24 year old plantations on two operational reclamation sites (Syncrude near Ft McMurray and Imperial at Cold Lake). Research on the sites near Edmonton was more detailed and included root system excavations.

Cutting trees close to the soil surface produced more root suckers than leaving a higher (25 cm) stump. There was a large variability in the regeneration potential of the planted aspen trees, with about 25% of the trees not producing any suckers. This could have significant implications for the regeneration dynamics of planted aspen stands, in comparison to natural sucker-origin stands where phenotypes that produce few new suckers have already been eliminated via natural selection.

Cutting planted aspen of seedlings origin (aged 15 to 26 years) on reclaimed sites resulted in sucker regeneration densities ranging from 600 stems per ha to 21,000 stems per ha (five to eight times higher than pre-treatment stand density). Sucker vigour was comparable to naturally regenerating stands, with first year height growth averaging 1 m. Sucker density was dependent on pre-treatment stand conditions dominated by factors such as stand density and basal area, but not by root system size (biomass). In some sites the high sucker numbers were sufficient to create new higher density stands that could ultimately achieve a closed canopy; however, when initial stocking was too low, overall sucker densities continued to be insufficient to create closed canopy conditions.

Vegetation community composition and competition has been demonstrated to affect aspen suckering in other studies, but any such effects appeared to be limited on the studied reclamation sites. This may be a result of relatively low vegetation cover levels or the type of plant community needed to trigger adverse impacts. Careful attempts to control vegetation using a glyphosate herbicide and isolating the trees from its application, resulted in negative effects on suckering and sucker growth, indicating that practical vegetation management options using herbicides in conjunction with aspen cutting are likely very limited.

Browsing pressure by ungulates was another factor that could adversely impact sucker performance — however the impact of browsing appears to be highly variable and dependent on the location of reclamation sites within a landscape.

Overall, these trials have provided convincing evidence that planted seedling-origin aspen on reclaimed sites have the capability to reproduce vegetatively following aboveground disturbance in a manner that is similar to natural aspen. However at the stand level, the regeneration density and its vigour is largely driven by the initial condition of the aspen (e.g., density, age, and vigour) prior to disturbance.

More details on the objectives, treatments, and experimental design can be found in King 2017, King and Landhäusser 2018, Jones et al. 2018, Wiley et al. 2019.

2. *Production, establishment and growth of tall aspen seedlings for planting on high competition sites and for infill planting of low density forest reclamation sites to promote closed forest canopy development*

Site conditions often play a large role in determining what seedling stock type characteristics are needed for improved seedling establishment. When competing vegetation is nominal or controlled and soil resources (moisture and nutrients) are not limiting, the need for a seedling with tailored morphological characteristics becomes less important, as most stock types will typically be able to grow unimpeded. For sites where seedlings are expected to experience high levels of vegetative competition, it is believed that relatively tall seedlings with high root to stem ratios could provide superior results. It is well known that aspen planting stock with high root to stem ratios can be produced, but production of tall seedling stock with high root to stem ratios is limited by lack of operational experience and the higher costs associated with the larger seedling container sizes.

Earlier research has shown that high initial root to stem ratios provide a very useful general indicator of aspen seedling quality. In this study researchers produced and field tested different aspen stock types that had overall higher root to stem ratios than seedlings typical of current commercial nursery practice.

This study shows that tall seedlings with a high root to stem ratio can be recommended for sites with tall competing vegetation. While in this study all sizes of seedlings with a high root to stem ratio had similar total height growth, the taller seedlings maintained their height advantage after two growing seasons when planted with competition.

On dry sites which had generally have low competition, enhancing early root growth after outplanting is a priority and therefore medium sized stock types with a large root mass (high root to stem ratio) are recommended. Seedlings with a higher initial root to stem ratio also store a greater amount of carbon and nutrient reserves prior to planting and performed best when outplanted on dry sites. However on these sites, tall seedlings with high root to stem ratios are not recommended, as they produce more leaf area than is desirable during early establishment. Alternately, very small seedlings with high root to stem ratios may also not be beneficial, as they have a relatively small total root mass and may not store enough reserves to withstand even low competition levels.

Controlling and reducing competing vegetation on moderate to rich sites before outplanting improved height growth, particularly in seedlings with high root to stem ratios. For aspen in such cases, planting short to medium sized seedlings with high root to stem ratios offers a reasonable balance between cost and production of stress-tolerant seedlings.

More details on the objectives, treatments, and experimental design can be found in Le 2017; Le at al. 2020; Howe et al. 2020a, b; Bockstette et al. 2018; Schott et al. 2016; Kelly et al. 2015.

Assessing Trajectories of Forest Reclamation

1. *Measuring and extrapolating water-use in trees: Exploring the role of rooting space in root water uptake, leaf area, and stand productivity for aspen and white spruce in reclaimed oil sands sites*

The research was executed at the South Bison Hills study site on the Syncrude mine lease, a landform that was constructed using saline sodic clay shale overburden material and capped with different depths of salvaged subsoil and topsoil materials. The shallow cap (35 cm) was composed of 20 cm subsoil and 15 cm topsoil, and the thick cap (100 cm) included 80 cm subsoil and 20 cm topsoil. Planted aspen and spruce trees were 12 years old when measured.

Rooting characteristics appear to play a role in the response of trees to rooting space, with the deep-rooted aspen being more sensitive to coversoil thickness. Over two growing seasons, the shallow rooting space was the main factor limiting leaf area and cumulative sap flux for aspen, with commensurate effects on growth based on four-year radial increments. Spruce, which is shallow rooted, appeared to be more limited by topographical position (upper slope versus lower slope). While there was a clear link between capping thickness and tree response to water availability in aspen, the contrasting response with white spruce might also relate to differences in physiological characteristics between the two species, such as water uptake and water use dynamics in response to soil water availability and climate. Generally, sap and transpiration fluxes decreased with season in both species; however, white spruce was able to respond positively to a large stochastic precipitation event, while in aspen this recovery response was much more muted.

While both species appear to adapt to the edaphic site conditions under current climates, there are still open questions that relate to leaf area development and the future resistance to stress conditions such as drought and the associated resiliency of these stands under less favourable climatic conditions. In light of a drier, but more variable climate, the differing responses of aspen and spruce to seasonal variability and stochastic precipitation events will most likely have profound effects on water cycling and how it is associated with forest composition and canopy cover at the stand and landscape level.

To test some of these assumptions, researchers combined the above measurements with other available soil and hydrological data for this site in a modelling study investigating the usefulness of a process-based terrestrial ecosystem model (*ecosys*) to explore an optimization of soil cover design and depth for the study site. Modelled transpiration increased nonlinearly with increasing cover depth, indicating a threshold depth above which additional gains in transpiration and hence productivity would be limited. The modelling exercise found that ecosystem productivity was negatively affected by a 35 cm cover depth, likely due to limited soil water holding capacity that can buffer against significant water stress during dry years. This study highlights the importance of sufficient cover depth where end land use objectives necessitate maximizing forest productivity, but conversely also introduces the possibility of intentionally varying cover depths to mimic the natural range of variability for forest productivity on the surrounding undisturbed landscape. The study also demonstrated that a terrestrial ecosystem model such as *ecosys* can be a useful tool in forecasting land capability for reclamation soil covers of different depths and properties under diverse climates.

More details on the objectives, treatments, and experimental design can be found in Merlin 2020; Merlin and Landhäusser 2019; Merlin et al. 2020; Welegedara et al. 2019.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Morgane Merlin. 2020. Using sap flow sensors to measure water uptake in trees: Challenges and opportunities. PhD thesis, Department of Renewable Resources, University of Alberta, 195 pages.

Shauna Stack. 2019. The influence of soil reconstruction materials and targeted fertilization on the regeneration dynamics in boreal upland forest reclamation. MSc thesis, Department of Renewable Resources, University of Alberta, Edmonton, Canada.

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Carolyn King. 2017. Regeneration dynamics of seedling-origin aspen: implications for forest reclamation. MSc thesis, Department of Renewable Resources, University of Alberta, 87 pages.

Katherine Melnik. 2017 The role of microtopography in the expression of soil propagule banks on reclamation sites. MSc thesis, Department of Renewable Resources, University of Alberta, 117 pages.

Kyle Le. 2017. Evaluating trembling aspen seedling stock characteristics in response to outplanting and competition. MSc thesis, Department of Renewable Resources, University of Alberta, 95 pages.

Published theses supported by the chair position, with research funding from other sources

Robert Bidner. 2020. Digging Deep: Methods to Improve Our Understanding of Aspen Regeneration and Aspen Distribution Across the Intermountain West. MSc thesis, Quinney College of Natural Resources, Wildland Resources Department, Utah State University, USA.

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Brown, S. M., Petrone, R. M., Chasmer, L., Mendoza, C. A., Lazerjan, M. S., Landhäusser, S. M., Silins, U., Leach, J., and Devito, K. J. 2014. Atmospheric and soil moisture controls on evapotranspiration from above and within a Western Boreal Plain aspen forest. Hydrological Processes 28: 4449-4462. (Imp Fact: 2.696).

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Conference Presentations/Posters

Combined, my students and I gave more than 65 oral and 35 poster presentations at local, national and international workshops and conferences between 2014 and 2020.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jana Bockstette	University of Alberta	MSc	2013	2018
Caren Jones	University of Alberta	MSc	2013	2016
Kyle Le	University of Alberta	MSc	2014	2017
Katherine Melnik	University of Alberta	MSc	2014	2017
Jeff Kelly+	University of Alberta	Post-Doctoral Fellow	2013	2017
Simon Bockstette	University of Alberta	PhD	2011	2017
Morgane Merlin	University of Alberta	PhD	2015	2020
Carolyn King	University of Alberta	MSc	2015	2017
Erika Valek	University of Alberta	MSc	2015	2018
Shauna Stack	University of Alberta	MSc	2016	2019
Trevor de Zeeuw	University of Alberta	MSc	2016	2019
Ashley Hart	University of Alberta	MSc	2016	2021
Kevin Solarik	University of Alberta	Post-Doctoral Fellow	2017	2019
Erin Wiley	University of Alberta	Post-Doctoral Fellow	2013	2018
Sophie Aasberg	University of Alberta	MSc	2018	2021
Coral Fermaniuk	University of Alberta	MSc	2018	2021
Brittany Hynes	University of Alberta	MSc	2020	2023
Rachel Hillabrand	University of Alberta	Post-Doctoral Fellow	2019	2021
Shauna Stack	University of Alberta	Research Assistant		
Trevor de Zeeuw	University of Alberta	Research Assistant		
Ashley Hart	University of Alberta	Research Assistant		
Robert Hetmanski	University of Alberta	Research Assistant		
Alana Benoit	WISEST	Research Assistant		
Jasmin Danzberger	Visiting Student TU Munich	Research Assistant		
Robert Hetmanski	University of Alberta	Research Assistant		
Angeline Letourneau	University of Alberta	Research Assistant		
Mika Little-Devito	University of Alberta	Research Assistant		
Jeff Kelly	University of Alberta	Post-Doctoral Fellow		
Nichole Moen	University of Alberta	Research Assistant		
Andi Fitzsimmons	University of Alberta	Research Assistant		
Emily Reich	University of Alberta	Research Assistant		

Brittany Hynes	University of Alberta	Research Assistant		
Daniel Doyon	University of Alberta	Research Assistant		
Johannes Mueller	Visiting student Germany	Research Assistant		
Alana Beniot	University of Alberta	Research Assistant		
Caren Jones	University of Alberta	Technician		
Fran Leishman	University of Alberta	Technician		
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Industry Collaborators: Bob Nemeth, Smoky Lake Forest Nursery; Jeff Hoyem, Woodmere Nursery

Government Collaborators: Cameron Stevens, Crop Development Centre North, Alberta Agriculture and Forestry

NSERC – Industrial Research Chair in Terrestrial Restoration Ecology

COSIA Project Number: LE0034

Research Provider: University of Alberta

Industry Champion: Syncrude

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

Status: Year 5 of 6

PROJECT SUMMARY

After mining, some landforms are reconstructed with oil sands that do not meet the criteria for processing yet contain petroleum hydrocarbons. As a result, this lean oil sand (LOS) may be in contact with the rooting zone of forests. However, in this region of boreal forest, oil sand outcrops naturally occur and forests have developed on these deposits over thousands of years post-glaciation. Lean oil sand differs from oil sand outcrops in that it has not undergone weathering. As such, there are concerns that the disruption and placement of LOS in a new environment may pose an environmental risk and impair growth of vegetation on reclaimed lands. Specifically, LOS may act as a barrier to root growth with subsequent effects on the aboveground functioning of trees, shrubs and herbaceous plants establishing on sites reconstructed with this material. Currently there is a lack of science-based evidence guiding reclamation involving LOS and the approvals framework for how these activities are regulated.

The focus of the research program is to build knowledge on belowground features that support self-sustaining forests. The overarching research question is whether LOS acts as a barrier or medium to root growth of plants comprising typical boreal forest. Several lines of inquiry will be followed through the research to answer the overarching question:

1. What are natural dimensions and mechanisms underlying rooting zones of boreal plants?
2. What are the effects of oil sand on root structure and function?
3. Do root microbial symbionts mediate tree survival on oil sand?

PROGRESS AND ACHIEVEMENTS

Progress made towards the stated objectives in 2020 is as follows.

Objective 3: Do root microbial symbionts mediate tree performance on oil sand?

Some historical evidence has suggested that vegetation performance may be affected by soil hydrocarbons and it is hypothesized that soil microbial communities may mitigate the impacts. Some species or populations of root microbes may be abundant in sites with oil sand present, while others may be absent. Such patterns would suggest species specialization and are the premise for screening plants and microbes as candidates for phytoremediation of substrates containing hydrocarbons. PhD student James Franklin continues his research on this particular focus.

In a parallel study, Nicholas Brown (MSc student) investigated whether we can adopt current tree species used in revegetation to degrade hydrocarbons present in LOS. Specifically, his research assessed the capacity of roots of aspen and jack pine to degrade hydrocarbons through their exudates. He found that the degradation of hydrocarbons was not increased in the presence of seedlings of these two tree species. However, the addition of nutrients and water to the system may have acted as a biostimulant and enabled naturally occurring soil microbes to degrade groups of hydrocarbons generally considered to be recalcitrant. Furthermore, analysis of phospholipid fatty acids showed that increased concentrations of hydrocarbons corresponded to increased microbial phospholipid fatty acids concentrations regardless of functional group — potentially indicating that the local microbial community can use hydrocarbons to produce additional biomass.

LESSONS LEARNED

At low concentrations (> 5% by volume), the native microbial community may be stimulated in the presence of hydrocarbons to degrade these compounds and immobilize them via incorporation into new biomass. At the seedling stage, the presence of aspen and jack pine do not enhance hydrocarbon degradation under controlled conditions.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Brown, Nicholas. 2020. Biodegradation of hydrocarbons in bitumen: exploring plant-assisted and microbial stimulation techniques. MSc thesis, Department of Renewable Resources, University of Alberta

Journal Publications

La Flèche M., Cuss C. W., Noernberg T., Shotyk W., Karst J. Trace metals as indicators of tree rooting behaviour in natural bituminous soils. Accepted by Land Degradation and Development, November 2020

Wasyliw J., Karst J. 2020. Shifts in ectomycorrhizal exploration types do not offset fine root abundance in mature pine stands. *Journal of Ecology* https://doi.org/10.1111/1365-2745.13484

AWARDS

James Franklin, Alberta Graduate Excellence Scholarship

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Justine Karst

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Paul Metzler	University of Alberta	MSc	2016	2018
James Franklin	University of Alberta	PhD	2017	2021
Marc La Fleche	University of Alberta	MSc	2017	2019
Josh Wasyliw	University of Alberta	MSc	2017	2019
Ariel Brown	University of Alberta	MSc	2017	2019
Nicholas Brown	University of Alberta	MSc	2018	2020
Brea Burton	University of Alberta	Summer Undergraduate Technician		
Andrea Simeon	University of Alberta	Summer Undergraduate Technician		
Jason Eerkes	University of Alberta	Summer Undergraduate Technician		
Christine Simard	University of Alberta	Lab Technician		
Serena Farrugia	University of Alberta	Summer Undergraduate Technician		
Pak Chow	University of Alberta	Lab Technician		

Research Collaborators: Pedro Antunes, Algoma University; William Shotyk, University of Alberta; Brian Lanoil, University of Alberta; Sylvie Quideau, University of Alberta

Native Balsam Poplar Clones for Use in Reclamation of Salt-Impacted Sites

COSIA Project Number: LJ0202

Research Provider: Alberta-Pacific Forest Industries Inc.

Industry Champion: Syncrude

Status: Final Cumulative Summary

PROJECT SUMMARY

The main objective of this research is to, identify and select balsam poplar (*Populus balsamifera*) clones from the Alberta-Pacific (Al-Pac) Controlled Parentage Program Plan (CPP-PB1) for balsam poplar that are well adapted to, and are appropriate for planting on, growing sites challenged with elevated dissolved salt concentrations on reclaimed oil sands mine sites.

It is hypothesized that balsam poplar clones exhibiting tolerance to salts in greenhouse trials (identified by exposure to varying concentrations of oil sands process-affected water [OSPW]) will have higher survival and increased growth (e.g., height and diameter) on reclamation sites than either; i) poplar clones tested with OSPW that did not exhibit tolerance to elevated salt concentrations; or ii) a local Stream I Syncrude Canada Ltd. balsam poplar cutting collection (Syncrude control). The null hypothesis is that no such differences exist.

Two years of greenhouse screening (2012 and 2013) of several hundred balsam poplar clones from Al-Pac's program, using OSPW from Syncrude's processing facility in Ft. McMurray, has provided the information to guide the selection of material for field testing. A total of 35 clones selected from Al-Pac's CPP-PB1 registered clonal population were included in this field study based on the results from previously completed greenhouse salt screening. Twenty-five of these clones were the top performing clones in the 50% OSPW treatment (high salt treatment) and were chosen as the 'salt tolerant treatment group' (Treatment 1), and 10 of the remaining clones that did not exhibit salt tolerance in the 50% process affected water treatment were chosen as a control group (Treatment 2). The Syncrude Stream I cuttings (local seed zone wild collection) (Treatment 3) were included as a second control to compare the Al-Pac CPP clones to a local unscreened (Stream I) population.

Three discrete trials were established on the Syncrude oil sands lease in the fall of 2014: trial one was established on the south shore of Base Mine Lake, trial two was established on a Transitional Wetland site in the southeast corner of the Sandhill Fen Watershed and trial three was established on Sand Islands "A" and "B" within the Sandhill Fen Watershed. All three trials were laid out as a randomized block design with single tree plots. Trials one and two were established with four ramets of each of 35 Al-Pac clones and 60 Syncrude control trees planted in three blocks (for a total of 200 trees in each block). Trial three consists of one tree of each of the 35 Al-Pac clones and 25 Syncrude control trees planted in each of six blocks. Each block had a total of 60 trees (10 trees x 6 trees) with three blocks planted on each of the two sand islands (180 trees per island).

Soils on the Sand Island "A" and "B" sites were bare tailings sand with a 10 cm to 30 cm elevation above the local water table. Soils on the Transitional Wetland site are comprised of a 50 cm cover of peat over a 50 cm clay loam subsoil, with a local water table within 0 cm to 15 cm of the soil surface for much of the growing season. On the Base Mine Lake site, reclamation soils are a 10 cm placement of peat cover soil over 90 cm of clay loam subsoil.

PROGRESS AND ACHIEVEMENTS

Work completed in 2020 included final analysis and the reporting of project outcomes.

Of the three trial sites, only the Base Mine Lake location experienced acceptable rates of tree performance expected for operational planting of trees.

One of the two Sand Island sites (Island B) experienced severe flooding and high mortality. The other (Island A) experienced poor growth: < 30 cm mean cumulative height increment over three years regardless of treatment. Treatment 1 (tolerant clones) grew significantly more in height (but not in root collar diameter) than Treatments 2 and 3, but the overall growth rate at this location was very low, such that treatment gains are of minimal practical application. While not directly evaluated, it is hypothesized that poor nutrition in the tailings sand in which the seedlings were planted was the cause of the poor growth. It was initially hoped that water flow within the sand would provide adequate nutrition much like on a fluvial sand bar or in a hydroponic-type agronomic environment, but this did not appear to be the case.

Growth of planted poplar was even poorer on the Transitional Wetland site, with cumulative height growth averaging 20 cm or less over three years. Similar to the Sand Island A site, statistically significant growth improvements were observed for Treatment 1, but again the results were so small as to be of limited practical significance. While a relatively high soil salinity in this location may have been a factor, the primary limitation to growth is suspected to be a high, stagnant water table (and associated negative effects on aerated rooting volume and soil temperatures), resulting in an estimated hygric moisture regime and poor to very poor nutrient regime (equivalent to a 'g' ecosite). Note that the selected site was not typical of the entire Sandhill Fen Watershed, but was instead a discrete area purposely selected based on an expectation of having relatively poor growing conditions related to high salinity.

Growth observations were terminated on the Sand Island A and Transitional Wetland sites after three growing seasons. While the results for both sites are generally supportive of the hypothesis that the Treatment 1 clones will exhibit greater salt tolerance in the field than either the Treatment 2 or Stream 1 clones, the growing conditions for these trials were subsequently deemed unsuitable for any planting of poplar such that the results have limited practical applicability.

In contrast to the trail sites within the Sandhill Fen Watershed , growth at the Base Mine Lake site was very good. After five years, total heights for Treatments 1, 2 and 3 were 3.8 m, 3.6 m and 3.6 m respectively, and diameters were 2.8 cm, 2.7 cm and 2.6 cm respectively. There were no statistically significant differences between treatments. The lack of a treatment response possibly reflects that: i) balsam poplar in general is noted for its salt tolerance; ii) the selected high tolerance clones (Treatment 1) were not necessarily the tallest trees overall in the initial screening experiment, some of the clones performed well in all three treatments while others were selected because they performed better in the 50% process water treatment than the 25% process water and control treatments; and (iii) the salinity of Base Mine Lake water (2.7 mS cm^{-1} to 3.0 mS cm^{-1}) (White and Liber, 2018), even undiluted with meteoric water in adjacent shoreline soils, is less saline that the experimental conditions used to separate salinity tolerance in the initial screening trials (3.0 mS cm^{-1} to 3.6 mS cm^{-1}).

While there was no treatment effect noted at the Base Mine Lake site, there was a blocking effect wherein trees 10 m to 20 m from the lakeshore grew better than trees either closer to the lakeshore or trees 20 m to 30 m from the shore. While not actually tested and confirmed in the trial, it is hypothesized that this was a soil edaphic effect related: i) to a reduced aerated rooting volume close to the lake shore (related to a relatively shallow saturated zone); and ii) potentially to reduced late season moisture availability at the furthest distance from the lake.

LESSONS LEARNED

Overall learnings include:

1. Barring the presence of any localized effects that concentrate salinity in soils to levels well above those observed at the Base Mine Lake site, balsam poplar will be an acceptable species for planting on the shores of end pit lakes regardless of the presence or absence of selection for salinity tolerance;
2. Balsam poplar is not an acceptable species for planting in growing conditions reflecting the Sand Island sites (bare tailings sand) and the very wet (hygric) and physiologically nutrient limited Transitional Wetland site;
3. The possibility remains that selected clones (Stream 2) may be suitable for achieving improved tolerance on sites experiencing higher salinity than those observed on the Base Mine Lake site and not experiencing the severity of other limiting factors as were observed on the Sand Island A and Transitional Wetland sites; and
4. Access to the Stream 2 (Treatment 1 and Treatment 2) clones from stoolbeds and/or existing trees could simplify collections while also ensuring the material can be planted over a much wider area (i.e., no seed zone restrictions) associated with the CPP region.

LITERATURE CITED

White, K. B., Liber, K. 2018. Early chemical and toxicological risk characterization of inorganic constituents in surface water from the Canadian oil sands first large-scale end pit lake. Chemosphere 211: 745-757.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Hu, Y., Kamelchuk, D., Thomas, B. R. 2021. Field testing of selected salt tolerant screened balsam poplar (*Populus balsamifera*) clones for use in reclamation around end-pit lakes associated with bitumen extraction in northern Alberta. Forests Special Issue. “Growth and Development of Short Rotation Woody Crops for Rural and Urban Applications” (*In Preparation*).

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta-Pacific Forest Industries Inc.

Principal Investigator: Dr. Barb Thomas, Professor, University of Alberta

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
David Kamelchuk	Alberta Pacific Forest Industries Inc.	Management Forester		
Yue Hu	University of Alberta	PhD Candidate	2015	2021

cosia

Jack Pine Establishment

COSIA Project Number: LJ0263

Research Provider: Paragon Infinity

Industry Champion: Imperial

Status: Year 5 of 5

PROJECT SUMMARY

Following surface mining, oil sands operators are required to reclaim the disturbed land such that reclaimed soils and landforms are capable of supporting a self-sustaining, locally common boreal forest regardless of the end land use, and to ensure that the reclaimed land is integrated with the surrounding areas. Establishment of jack pine (*Pinus banksiana* Lamb.) stands on sandy materials (*a*1 ecosite phase) is often challenging.

During a 2013 site visit to the Kearl River Water Intake (RWI), it was noticed that dense stands of jack pine were establishing along the RWI Right-of-Way (RoW) south of the RWI access road. At the time, it was assumed that the establishment was due to the Richardson Fire that burned the area in May 2011. Prior to the fire, the RoW appeared to be colonized by grasses and early successional herbaceous species through natural regeneration and/or ingress; jack pine seedlings were not planted.

The Jack Pine Revegetation Trial (Trial) was initiated as a "proof-of-concept" trial to mimic the effect of fire and revegetate two former construction laydown areas (Bouchier and Willbros) at the Kearl site with jack pine seed through three separate cone heating and seeding treatments, and compare the results to plots located in nearby natural burned areas. Soils at the two laydown areas were similar, but pH was higher and moisture percent, sodium adsorption ratio, available potassium, available nitrite and available nitrite/nitrate were lower at the Willbros laydown. The Willbros laydown was also seeded with grasses, while the Bouchier laydown was left to revegetate naturally. The three treatments were: Treatment 1 – broadcast seeding of jack pine seed; Treatment 2 – scattering of untreated, intact jack pine cones; and Treatment 3 – scattering intact jack pines cones, and then applying a heat treatment on site using black polyethylene covering for 24 hours. The black polyethylene tarps were in place during June 21-22, 2016. Temperatures under the tarps were not measured during this time, but prior preliminary field experiments indicated a temperature increase of at least 5^{o}C to 10^{o}C relative to ambient air temperature. The temperature under the tarps might have reached 33^{o}C to 38^{o}C as the air temperature was 28^{o}C at the time.

Specific objectives of the trial include: evaluating jack pine revegetation success (via seeding) based on establishment of desired plant communities and trajectory towards the target *a*1 ecosite phase, comparing results of the three treatments to jack pine establishment and height in natural burned areas at "Year 5 post-treatment" (2020) to the revegetation results at "Year 5 post-fire" (2016), to make generalizations about stand trajectory and the efficacy of the seeding treatments in relation to regeneration following a fire.

The data and observations made as part of the trial may provide early indications that alternative revegetation strategies (e.g., other than via seedling planting) are possible, and aid in adaptive management of revegetation programs.

PROGRESS AND ACHIEVEMENTS

Year 5 (2020) of vegetation monitoring for the Trial took place in mid-July 2020. The plots at the Willbros site were not assessed as part of the Year 4 (2019) and Year 5 (2020) monitoring because of dense graminoid cover and the absence of jack pine seedlings at the site. Year 5 monitoring at the Bouchier site captures the fifth growing season for the treatment plots, and Year 9 post-fire for the natural burned area. Year 8 and 9 data are not required for the natural burned area as part of the Trial. As in previous years, each subplot was assessed for percent cover of trees, shrubs, forbs, graminoids, bryophytes and lichens, leaf litter and bare ground. Vegetation species were identified with reference to the Flora of Alberta (Moss 1983) and Plants of the Western Boreal Forest and Aspen Parkland (Johnson et al., 1995).

As recommended in the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (the Revegetation Guidelines, AENV 2010), information collected from the vegetation quadrats was used to calculate species abundance, richness, evenness and diversity, using the Shannon Diversity Index (SDI). These vegetation metrics from the five years were compared using analysis of variance. The number of established seedlings in each height class (100 cm) was too low to perform statistical analysis.

Unlike previous years, jack pine seedlings at the natural burned sites (N1 and N2) in 2016 (Year 5) were only present in higher abundances than two of the three treatment plots in 2020 (Year 5) (Figure 1). While statistical analyses were not possible, by Year 5 the number of emerged seedlings in the broadcast seeding treatment at the Bouchier laydown now exceeds the number of emerged seedlings in the natural burned sites. Seedlings have continued to emerge from the heated cones treatment at the Bouchier laydown, to the extent that the total number of seedlings in this treatment by Year 5 is approaching the number observed in Year 5 for the natural burn sites. Some additional seedlings have also emerged in the untreated cones treatment, although the total number of emerged seedlings remains low when compared to natural sites. These results demonstrate that there are viable options other than tree planting that can be used to re-establish jack pine on dry reclaimed sites in quantities that meet or exceed those present in natural sites.

Seedling growth in the treatment plots has improved over 2019 values, although it is still slower than in the natural burned area. By Year 5 (2016) in the natural burned area, most seedlings were taller than 1.0 m. By Year 5 (2020) in the broadcast seeding treatment, all seedlings were taller than 10 cm, with approximately 25% over 30 cm in height. In the heated cones treatment, over 90% of seedlings were above 10 cm in height, with approximately 35% over 30 cm by Year 5. While the total number of seedlings was low in the untreated cone treatment, all seedlings were above 10 cm in height by Year 5, with nearly half being over 30 cm.

Community performance metrics were generally similar when treatment plots in 2020 (five years since reclamation) were compared to natural burned plots in 2016 (five years since fire). Similarities between all three treatment plots and natural sites, for all community performance metrics other than SDI, suggests that treatment plots have developed along a trajectory to better emulate natural vegetation conditions post-burn. However, this recovery of community performance metrics seems to be independent of jack pine stem densities. Some differences do still exist between natural and treatment plots, largely in relation to higher abundances of early successional graminoids and forbs present in treatment plots by Year 5 (2020). These differences are likely to continue to persist until established jack pine seedlings are large enough to begin shade-excluding understory vegetation species. All treatment sites now surpass the minimum threshold of two species for the Dry site type (including the *a*1 ecosite phase, pure jack pine dominated) as presented in the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (AENV 2010).

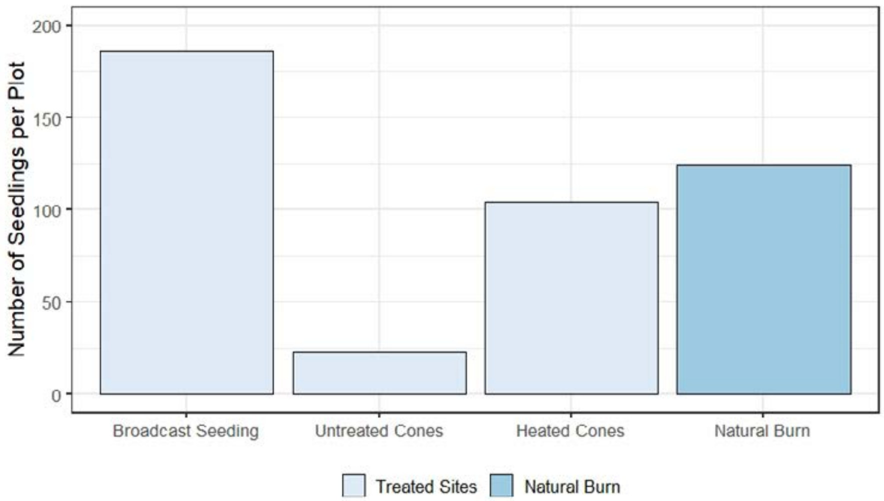

Figure 1: Average number of jack pine seedlings in Year 5 Treatment plots (2020) compared to Year 5 (2016) Natural Burn plots.

LESSONS LEARNED

After Year 5 (2020) of this Trial, broadcast seeding appears to still be the most effective treatment for establishing jack pine from seed, with more seedlings having established five years post-reclamation than were present five years post-burn. The heated cones treatment, while not as effective, was also able to produce similar numbers of seedlings when compared to natural burned sites, suggesting that both treatment options may be effective at establishing jack pine seedlings on dry sites. However, as evidenced by the lack of germination, establishment, and survival at the Willbros laydown, these treatments are ineffective if there is a high abundance of graminoid species present (i.e., if the site has been heavily seeded to grass). Seedling growth across all treatment plots continued to be lower by the end of Year 5 (2020) than observed in Year 5 post-burn (2016), suggesting that graminoid species and early successional species are still exerting negative competitive influences on established jack pine seedlings, thereby suppressing tree growth.

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Johnson, D., L. Kershaw, A. MacKinnon and J. Pojar. 1995. Plants of the Western Boreal Forest and Aspen Parkland. Lone Pine Publishing, Edmonton, Alberta. 392 pp.

Moss, E. H. 1983. Flora of Alberta Second Edition (revised by J. G. Packer). University of Toronto Press. Toronto, Ontario.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Infinity

Principal Investigator: Paragon Infinity

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

COSIA Project Number: LJ0303

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 5 of 5

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 on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in reconstructed soils and the roots 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. Effects of NST on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in soil and roots of reclamation plants.

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, 2, 5, 6 and 7 were completed in prior years.

Studies 3 and 4 were to be conducted in 2020 but due to restrictions related to the COVID-19 pandemic, Study 4 was delayed and will be completed in 2021.

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

This study was conducted with one-year-old aspen seedlings (*Populus tremuloides*). Non-segregated tailings water (NSTW) was obtained from Canadian Natural's Horizon oil sands mine near Fort McMurray. The study was conducted in a controlled-environment growth room using a hydroponic setup. Following the chemical analysis of NSTW, the chemical compositions for all treatments were designed, and then prepared in 50% Hoagland's mineral solution with a pH adjusted to 8.0 (commonly measured in oil sands tailings and reclamation sites).

Eight treatments were applied to the seedlings:

1. Control (50% Hoagland's mineral solution);
2. Synthetic complete NST;
3. Synthetic CT: Synthetic complete composite tailings (CT);
4. Synthetic NST – Na^+ (sodium);
5. 50% Hoagland's solution + Na^+ (Na positive control);
6. Synthetic NST – naphthenates;
7. 50% Hoagland's solution + NST levels of naphthenates (naphthenate positive control); and
8. NST release water (tailings water control).

The mortality rate, root collar diameter, shoot height, total plant fresh and dry weights, electrolyte leakage, net photosynthesis, transpiration rates, and leaf elemental concentrations (including total nitrogen) were measured at the start of the experiment and after six weeks of treatment.

Preliminary analyses demonstrated that plant mortality was highest in the synthetic complete NST treatment. This was followed by the synthetic NST – Na^+, naphthenate positive control, synthetic CT, and NST release water treatments. There was no mortality in the control, Na positive control, and Synthetic NST – naphthenates treatments.

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

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

Further statistical analysis and modelling of the results is currently in progress.

Study 4. Effects of NST on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in soil and roots of reclamation plants.

Seeds of two ecomycorrhizal plant species, white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*), and two ericoid mycorrhizal (ERM) plants, lingonberry (*Vaccinium vitis-idaea* var. *minus* Lodd.) and Labrador tea (*Ledum groenlandicum*], were sown in autoclaved soil in mid-May of 2020. The germination rates of the seeds and the growth rates of white spruce, lingonberry and Labrador tea were low. Therefore, seeds were sowed again in September. In November, the University of Alberta was closed due to the COVID-19 pandemic which prevented the preparation of fungal cultures and the inoculation of the plants with mycorrhizae. The seedlings will be inoculated with the ECM and ERM fungal cultures in early 2021. The seedlings will be then transferred to the NST containing substrates and their growth and physiological parameters will be monitored.

LESSONS LEARNED

Lessons learned from previous studies have been provided in earlier COSIA reports.

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 salt treatments. We interpreted this response to be due to surfactant properties of naphthenates which made the plants more sensitive to salt treatments at the lower pH compared with pH 8.5. These results merit further study as they suggest that contrary to the initial hypothesis, lowering the pH of tailings containing naphthenates may not be beneficial to plant growth.

Study 4. Effects of NST on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in soil and roots of reclamation plants.

At first all plants were fertilized with 25% Hoagland's solution. However, the ericaceous plants of Lingonberry and Labrador tea seedlings grew very slowly. Then, we found that to maintain optimum growth of Lingonberry and Labrador tea, the seedlings need to be watered with slightly acidic mineral nutrition of pH 4.5 to 5.5.

LITERATURE CITED

Calvo-Polanco M., Zwiazek J. J., Jones M. D., MacKinnon M. D. 2009. Effects of NaCl on responses of ectomycorrhizal black spruce (*Picea mariana*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) to fluoride. Physiologia plantarum 135:51-61.

Dimitriu P.A., Prescott C. E., Quideau S. A., Grayston S.J. 2010. Impact of reclamation of surface-mined boreal forest soils on microbial community composition and function. Soil Biology and Biochemistry 42:2289-97.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Sun X. 2020. Effects of non-segregated tailings, nitrogen, phosphorus and elemental sulphur on growth of plants in oil sands reclamation soils. MSc Thesis, University of Alberta, Edmonton, Canada, 100pp.

Journal Publications

Zhang W.-Q., Fleurial K., Sherr I., Vassov R., Zwiazek J.J. 2020. Growth and physiological responses of tree seedlings to oil sands non-segregated tailings. Environmental Pollution 259: 113945 (9 pp.).

Conference Presentations/Posters

Fleurial K. Got Aquaporins? Understanding responses and tolerance mechanisms of plants exposed to phytotoxic tailings water and hypoxia. Poster presentation at: Botany 2020 Virtual Conference. July 2020.

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 Assistant		
Killian Fleurial	University of Alberta	PhD	2017	2021
Xuehui (Chris) Sun	University of Alberta	MSc	2018	2020

Hitchhiker Field Trial at Kearl Operations

COSIA Project Number: LJ0324

Research Provider: Paragon Infinity

Industry Champion: Imperial

Status: Year 3 of 5

PROJECT SUMMARY

Hitchhiker planting has recently 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 and partner forb species) and planting methods (hitchhiker planting and companion planting) as treatments in a modified split-plot design. The soil prescription was consistent across treatments and fertilizer was not applied.

The main objectives of the Trial are to determine whether:

- 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*]).
- 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).

PROGRESS AND ACHIEVEMENTS

The 12 trial plots were monitored at the end of the 2020 growing season (September). Performance metrics including survivorship, height and health were monitored.

Survivorship

Survivorship of shrubs over the third growing season (2020) was generally high. Green alder had 85% survival in hitchhiker planting treatment plots, and 90% survival in companion planting treatment plots. Willow had 94% survival in hitchhiker planting treatment plots and 93% survival in companion planting treatment plots. Overall, survivorship of planted shrubs was 90% in the hitchhiker planting treatment plots and 92% in companion treatment plots.

After the third growing season, survivorship of partner forb species was also generally high. In the hitchhiker planting treatment, average survival of common fireweed was 81%, and survival of bunchberry was 94%. Partner forb survival in the companion planted treatment was higher, averaging 97% for common fireweed and 89.5% for bunchberry.

Height

Results of the Year 3 analyses suggest that planting method is having a significant effect on both the height of green alder ($P = 0.007$) and willow seedlings ($P < 0.001$); both green alder and willow shrubs were taller in the hitchhiker treatment than in the companion treatment. Heights for both green alder and willow shrubs increased significantly by the end of the 2020 growing season ($P < 0.001$). By September 2020, green alder shrubs were 78.9 cm tall in the hitchhiker treatment — an average gain of 55.2 cm. And 70.7 cm tall in the companion treatment — an average gain of 43.6 cm. Similarly, willow shrubs were 193.8 cm tall in the hitchhiker treatment — an average gain of 80.4 cm. And 143.1 cm tall in the companion treatment — an average gain of 60.9 cm.

For both planting methods, willow shrubs were significantly taller when planted with common fireweed than when planted alone ($P < 0.001$). Similarly, willow shrubs were taller when planted with bunchberry, though this effect was only significant when using the hitchhiker method ($P < 0.001$).

Health

Average health scores for planted shrubs were generally high and varied between Good and Excellent.

Willow seedling health was dependent on the method of planting ($P < 0.001$) and was significantly higher when using the hitchhiker planting method ($P = 0.02$).

In contrast, green alder health scores were not dependent on the method of planting ($P = 0.964$). The health score of green alder seedlings planted with common fireweed was significantly lower than those planted with a bunchberry partner ($P = 0.009$) or when planted alone ($P = 0.03$), though only for the hitchhiker planting method.

Regardless of planting method, the health scores for willow seedlings planted with common fireweed were significantly higher than those planted with bunchberry or when planted alone ($P < 0.001$).

Planting method had a significant effect on the health score of the forb partner, regardless of whether the forb was planted with green alder or willow seedlings. In both cases, the health score of the partner forb was significantly higher when planted using the companion planting method ($P < 0.001$).

LESSONS LEARNED

This project is in its early stages so there are currently no lessons learned.

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.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Infinity

Principal Investigator: Paragon Infinity

WILDLIFE RESEARCH AND MONITORING

Wildlife Monitoring – Horizon Oil Sands

COSIA Project Number: LJ0186

Research Provider: LGL Limited environmental research associates

Industry Champion: Canadian Natural

Status: Year 15 – Ongoing

PROJECT SUMMARY

Remote wildlife cameras are a useful tool for assessing and monitoring various aspects of terrestrial wildlife, especially their return to and use of anthropogenically altered habitats. Their proper implementation increases the likelihood of detecting the use and distribution of certain species of wildlife across specific areas and habitats (Burton et al., 2015). Wildlife cameras have been used throughout the Athabasca Oil Sands Region to photograph wildlife in riparian corridors and their natural habitat and have recently been incorporated into reclamation monitoring (Hawkes et al., 2017; Hawkes et al., 2019). They provide a cost-efficient way to expand the documentation of species for monitoring programs, especially for large- and medium-sized animals, as well as more inconspicuous species.

Wildlife cameras have been deployed on Canadian Natural's Horizon Oil Sands Lease since 2006 and an extensive network is currently active across the lease. Remote cameras used in the COSIA Project LJ0186 contribute important data on the occurrence and distribution of wildlife, and the time of year that certain species occupy and utilize various habitats. Species sightings that occurred at the same camera within 15 minutes of the previous sighting event were classified as duplicates. Similar criteria for filtering out duplicate photos have been used elsewhere (e.g., Keim et al., 2019).

This report summarizes the results associated with wildlife camera data collected from three arrays of cameras deployed on and adjacent to Canadian Natural's Horizon Oil Sands: (1) Athabasca River corridor, (2) around Horizon Lake, and (3) on Reclamation Area 1 on Horizon Oil Sands, between 2006 and 2020.

PROGRESS AND ACHIEVEMENTS

Between 2006 and 2020 a total of 53 cameras were deployed in the three habitat types (Athabasca Corridor, n = 16 cameras; Horizon Lake, n = 19 cameras; Reclamation Area 1, n = 18 cameras). A total of 201,357 camera triggering events were recorded, with 127,667 events being false triggers (i.e., not wildlife). Of the remaining 73,690 wildlife events, 60,507 were duplicate photos of the same event. Of the 13,183 unique wildlife sighting events, 13,045 could be identified to the species level. A total of 77 species of wildlife (52 species of bird; 25 species of mammal) were recorded on cameras with detections of 10 species dominating the sample: white-tailed deer (*Odocoileus virginianus*, n = 6,289 detections), American black bear (*Ursus americanus*, n = 1,220 detections), red fox (*Vulpes vulpes*, n = 1,196 detections), grey wolf (*Canis lupus*, n = 1,037 detections), American moose (*Alces americanus*, n = 717 detections), coyote (*Canis latrans*, n = 580 detections), snowshoe hare (*Lepus americanus*, n = 365 detections), Canada lynx (*Lynx canadensis*, n = 207 detections), American red squirrel (*Tamiasciurus hudsonicus*, n = 196 detections) and ruffed grouse (*Bonasa umbellus*, n = 103 detections). The seasonal (monthly) and annual detections (2006 to 2020) for eight of these species is shown in Figure 1 to provide an indication of the annual and seasonal variation in sighting events in each habitat.

Most species were detected in all three habitats with two exceptions: American moose and snowshoe hare were not documented on the Reclamation Area 1 cameras. The Athabasca Corridor and Horizon Lake camera arrays are in or adjacent to relatively intact boreal forest which may influence the use of the habitats in which the wildlife cameras were deployed. Wildlife detections at Reclamation Area 1 were lower but still had considerable sightings of white-tailed deer, coyote, and American black bear.

Seasonal usage patterns by American black bear followed a similar pattern in all habitats with a peak in the number of sightings occurring between April and August. Sightings of American moose tended to be greater in spring and summer while coyote and grey wolf were present year-round. Red fox sightings were greatest around Horizon Lake. White-tailed deer were observed year-round with more of an obvious peak in sightability around Horizon lake between May and October (Figure 1). Sandhill Crane sightings were highest on Reclamation Area 1 in June 2020 with lower numbers observed in July and August. The number of sighting events of wildlife on Reclamation Area 1 may be a function of the early seral habitats dominating that area, the proximity of Reclamation Area 1 to active mining, or both. The vegetation communities on Reclamation Area 1 may need to mature before the number of sightings of these species of wildlife is similar to that in the Athabasca Corridor and around Horizon Lake (Hawkes and Gerwing, 2019).

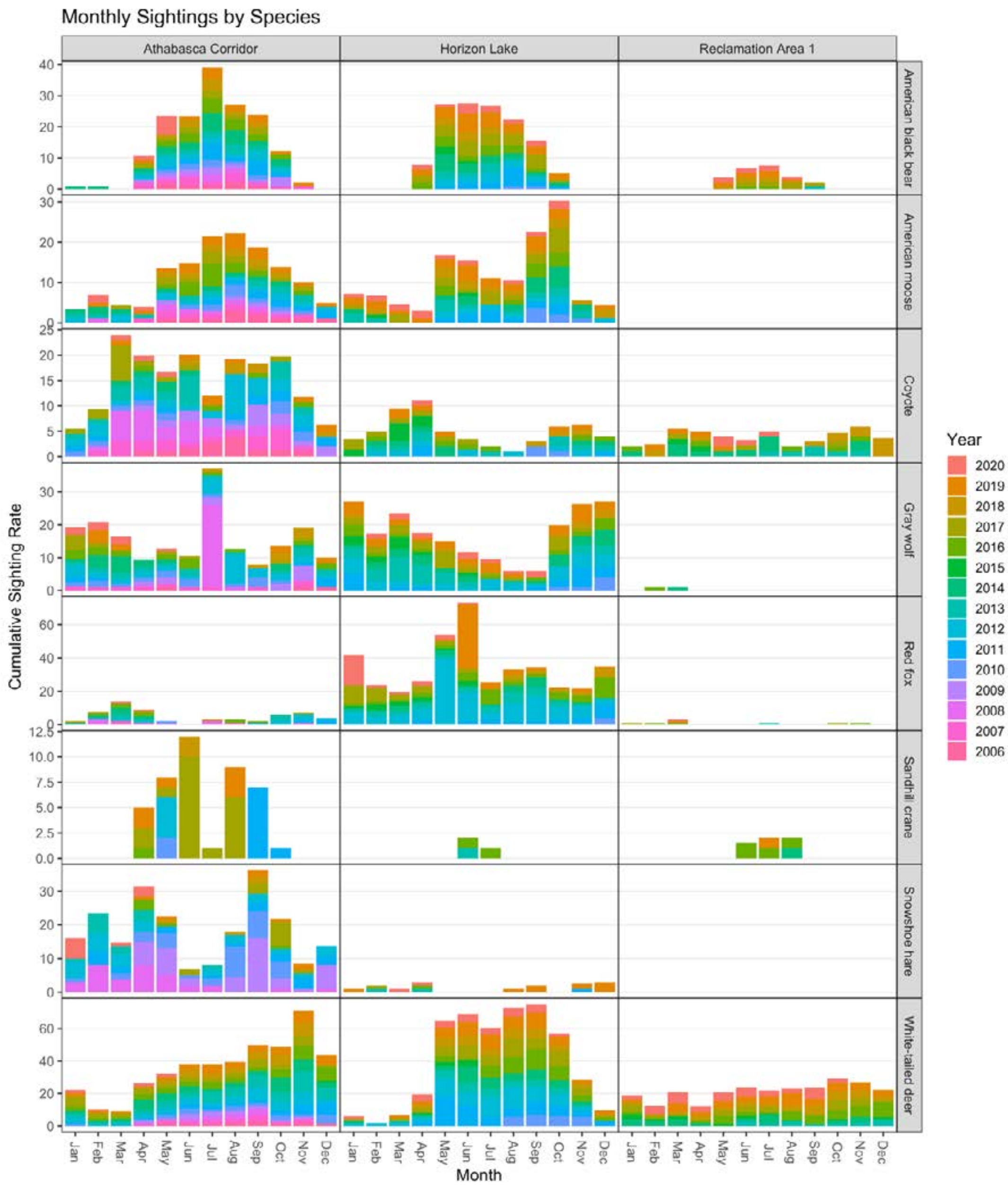

Figure 1: Seasonal (monthly) and annual (2006 to 2020) sightings of the six most frequently photographed species of wildlife in each camera array on and adjacent to Canadian Natural's Horizon Oil Sands. Sighting counts adjusted for number of available cameras per array.

Dynamic occupancy models (MacKenzie et al., 2003; MacKenzie et al., 2006) were fit to the camera data to generate estimates of occupancy for species that were frequently captured during detection events. Occupancy models explicitly handle issues of non-detection (i.e., the animal was in the area, but not photographed), which is a well-known issue affecting camera trap monitoring (Shannon et al., 2014). The occupancy framework divides the assessment area into a grid of cells, with a goal of estimating the proportion of the grid occupied by the species of interest. Issues of non-detection (i.e., species present in a grid cell, but not photographed) are handled using repeat surveys (i.e., measurements) during periods of assumed site closure (i.e., no occupancy changes in the grid of cells). The repeat surveys of the same cell during state closure provides an estimate of the probability of detection (i.e., probability of detecting the species if occupied). The estimates of detection are then used to adjust the naïve estimate of occupancy (i.e., percentage of grid cells with an observation) to account for the possibility of missed detections. Dynamic occupancy models extend this concept further by relaxing the assumption of closure for certain periods where occupancy state of the grid cells is open to change. In the case of the current analysis, each assessment month is considered to be closed, but occupancy changes are allowed to occur between months.

Monthly occupancy estimates were estimated using a hierarchal Bayesian state-space model implemented in JAGS (Just Another Gibbs Sampler), a program for analysis of Bayesian models using Markov Chain Monte Carlo (MCMC) simulation (Plummer 2003). Fundamental model parameters included the initial probability of occupancy (ψ_1), the probability of detection (p_t), probability of colonization (γ_t), and probability of persistence (ϕ_t). Detection, colonization, and persistence are indexed by, which indicated a sequential month number in the assessment period. After the initial occupancy state was defined, each site (camera station) was assumed to go through a series of Markov state transitions alternating between either an occupied or unoccupied state governed by the colonization (γ_t), and persistence (ϕ_t) parameters, where persistence is an alternate occupancy model parameterization representing the compliment of local extinction (i.e., $1 - \varepsilon_t$). Within each sequential month each of the "surveys" shared the same probability of detecting the species of interest on any given survey (i.e., p_t), conditional on the site being occupied. Finally, because detection, colonization, and persistence probabilities were indexed by the sequential assessment month, hierarchical structuring was added to make model fitting more tractable. Structuring included cyclicity to capture regular seasonal changes, as well as random errors at differing temporal scales to represent environmental stochasticity unrelated to the regular seasonal changes.

The results of the occupancy/usage models provide an indication of seasonal, annual, and longer-term temporal trends for each of the six species considered. For each species there was considerable season-to-season variability in usage among the three habitats sampled between 2006 and 2020. An example of this is provided for American moose in Figure 2. In this case monthly usage generally increases through the spring and summer with a peak in August or September and a decline through the fall and winter. This pattern is consistent for each of the habitats sampled.

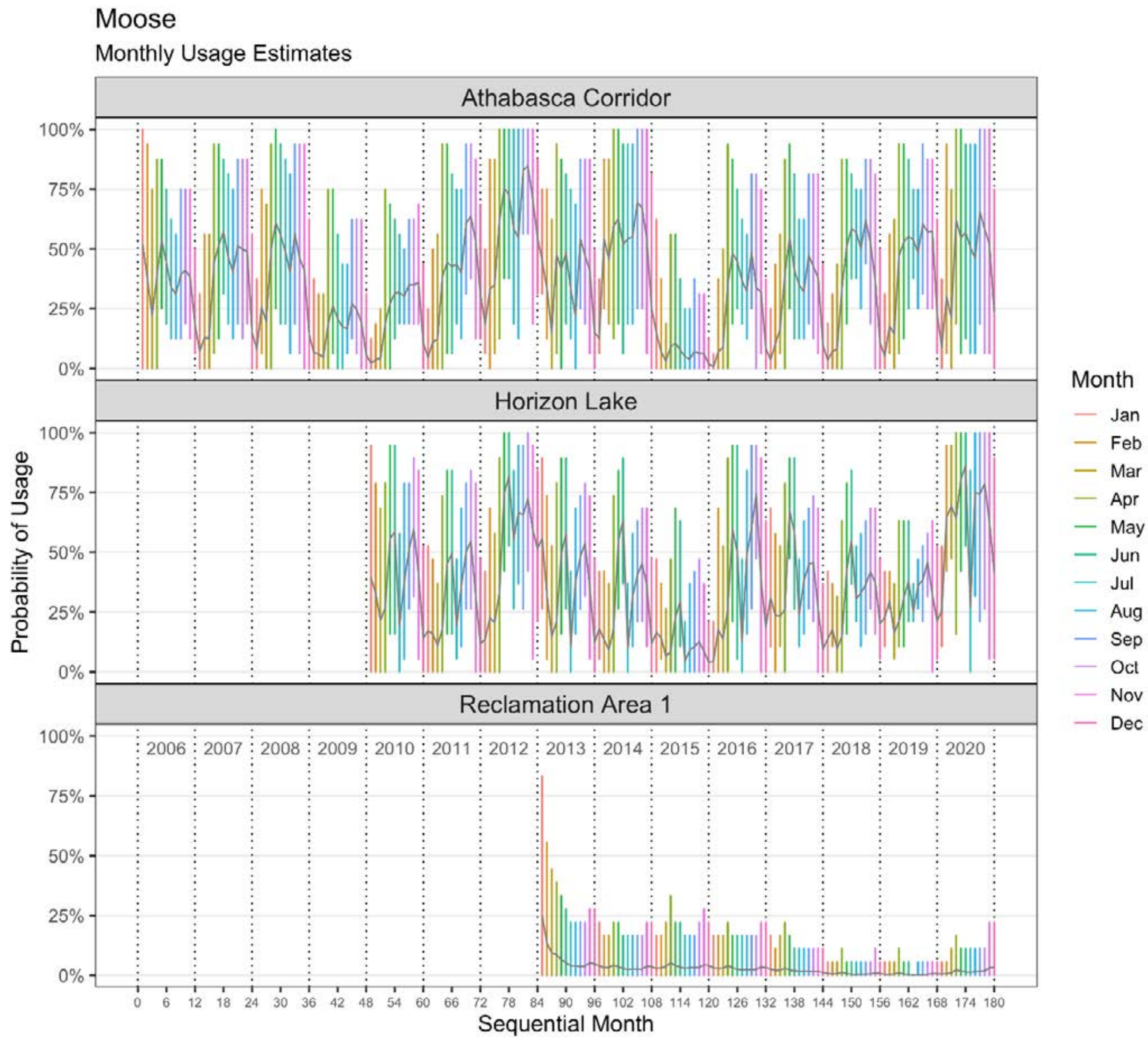

Figure 2: Monthly usage estimates generated from the monthly time-step occupancy model for American moose (*Alces americanus*). Error bars indicates 95% credible intervals, with color indicating month. Vertical dotted lines indicate assessment year. The time series associated with each camera array is: Athabasca Corridor: 2006-2020, Horizon Lake: 2010-2020; Reclamation Area 1: 2015-2020.

Access to longer-term datasets affords the opportunity to assess longer-term trends in wildlife usage. Long-term trends in usage were determined by deriving average monthly usage estimates and then estimating a trend in the yearly usage. Overall, the eight analyzed species showed stable long-term trends in site usage, with an example for white-tailed deer provided in Figure 3. In this example we see evidence of a relatively stable and cyclical patter of usage that tends to be highest in the spring and summer for the Athabasca Corridor and highest in spring, summer, and fall for Horizon lake and Reclamation Area 1. Usage estimates are consistently lowest in the winter for all habitats sampled with a notable decline in usage in summer and fall 2015 (Figure 3).

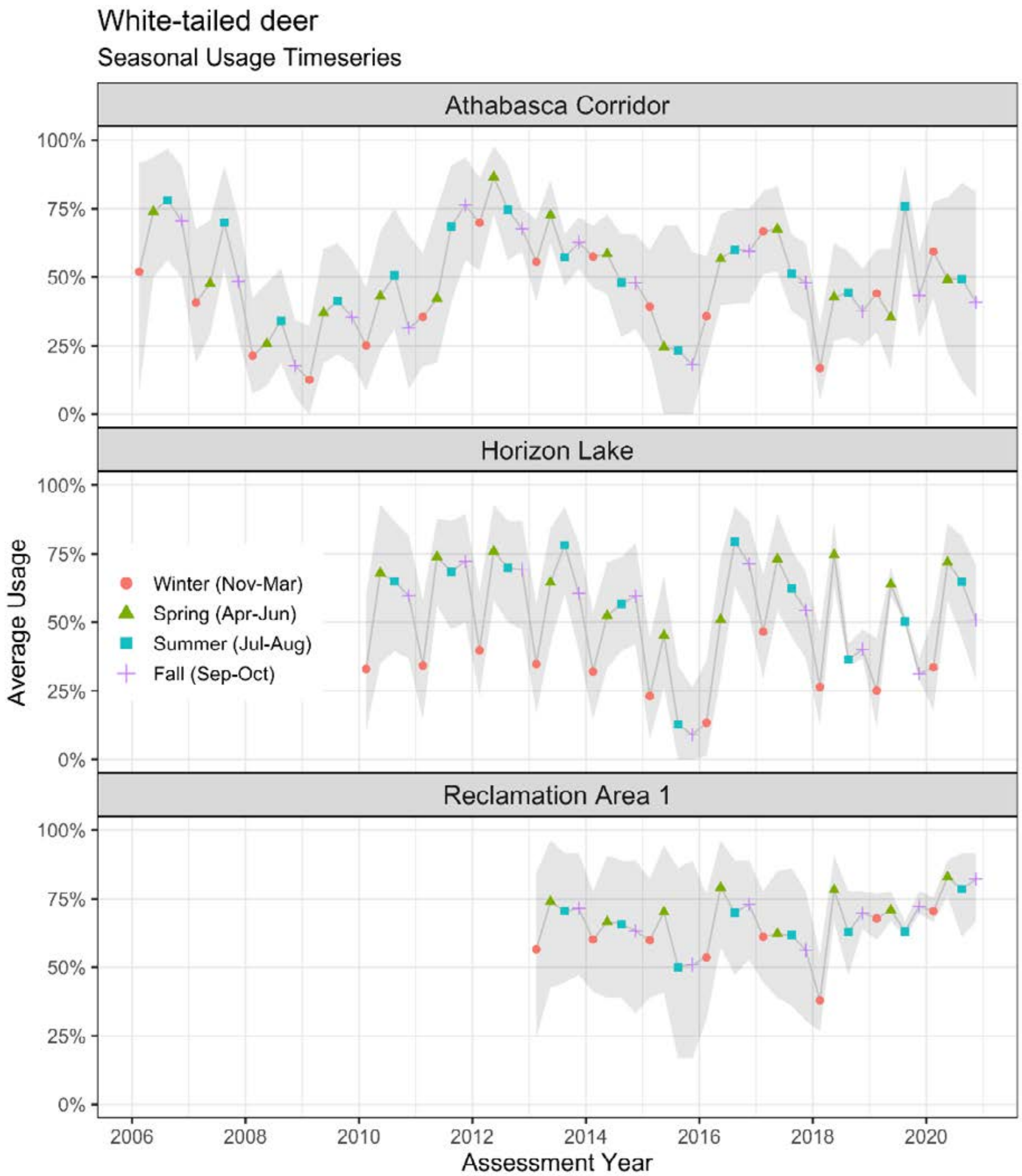

Figure 3: Longer-term seasonal usage estimates derived for White-tailed deer (*Odocoileus virginianus*) by averaging the appropriate monthly estimates. Shading indicates the 95% credible intervals for a given season. Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct).

Seasonal usage averages were determined for each habitat area by averaging the sequential monthly estimates for each year of sampling. This provided a way to assess whether there was a systematic difference in seasonal usage over the assessment period relative to habitat type. For example, three species (red fox, American moose, and grey wolf) showed a systematic seasonal difference in usage with less use of reclaimed habitats compared to other habitats sampled. Coyote and white-tailed deer exhibited the most stable seasonal usage patterns relative to habitat type compared to species such as red fox and American moose (Figure 4).

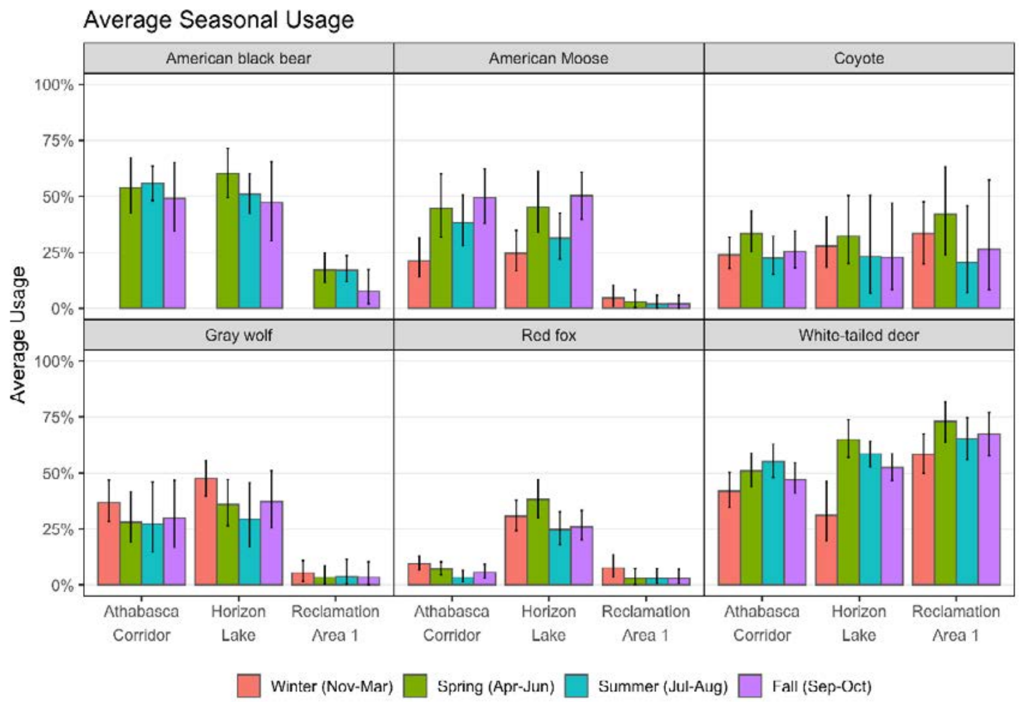

Figure 4: Average estimated seasonal usage for six species captured on wildlife cameras over the assessment period by area. Error bars indicate the 95% credible intervals for a given seasonal estimate. Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct). See Figure 3 for definition of the assessment period for each habitat.

Remotely triggered wildlife cameras deployed on and adjacent to Canadian Natural's Horizon Oil Sands provide a cost-effective way of collecting data on wildlife occurrence and distribution. With advances in occupancy modelling these long-term datasets are providing valuable data on usage patterns and trends for wildlife species common to the area. Between 2006 and 2020, occupancy, which in this case is a proxy for use, changed little over time for each of the six species assessed, although for some species patterns of usage are associated with a high degree of variability as depicted by the width of the credible intervals in Figure 3.

Although occupancy models were not applied to all species captured on wildlife cameras because the data were too sparse, it is possible to assess lease-specific patterns of wildlife occurrence and distribution. Not only does data collection on camera arrays like those in the Athabasca River corridor and those around Horizon Lake result in time-series of data exceeding or approaching a decade, thereby providing the means to assess longer-term trends in usage patterns for select wildlife, but these data also contribute to broader regional programs such as the Early Successional Wildlife Dynamics (ESWD) Program (COSIA project #LJ0013). The ESWD program (see summary sheet and Hawkes and Gerwing, 2019) is assessing the return to and use of reclaimed habitats by wildlife. The lease-specific camera data support assessments of reclamation effectiveness and the regional importance of long-term datasets associated with wildlife camera arrays and their relevance to achieving biodiversity and reclamation goals in the region cannot be overstated.

LESSONS LEARNED

1. Long-standing wildlife camera arrays provide important data that can be modelled to assess seasonal and annual trends in occupancy (usage) using emerging modelling techniques.
2. Most wildlife species are not likely to be detected frequently enough by wildlife cameras to assess temporal trends in usage. However, camera data can still be used to assess variation is the distribution and occurrence of wildlife species at a local and regional scale (depending on the distribution of the camera arrays).
3. Wildlife camera data collected on and adjacent to Canadian Natural's Horizon Oil Sands contributes important data to lease-specific and regional biodiversity and reclamation objectives.

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PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were release in 2020.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Virgil C. Hawkes

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Bison Research, Mitigation and Monitoring Program

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck

Industry Collaborators: Canadian Natural

Status: Year 5 of 5

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

Knowledge gaps, as defined by the Ronald Lake Bison Herd Technical Team's Work and Action Plan and related to those associated with this project in 2020 included:

- What is the relationship between wetland characteristics and bison forage?
- How are wetlands used by bison in the winter?
- How are different habitats used by bison within their range?
- What is the herd's diet and how does it change seasonally?
- How do anthropogenic and natural disturbances affect habitat selection?
- How do winter conditions influence bison movement and habitat selection?
- Where and when are bison at risk of predation by wolves?

Preliminary results are reported to the Ronald Lake Bison Herd Technical Team as an annual report (Dewart et al., 2020) and summarized here in the Lessons Learned section below. It should be noted that field activities were initially reduced between April and mid-June 2020 due to the COVID-19 pandemic, but not for the main winter period for work on bison and wolves and the mid-summer to early-fall period for work on bison. This was accomplished by adhering to University of Alberta COVID-19 restrictions drawn from Alberta Health Services and through communication with representatives of the Fort McKay community. Moreover, some 'field' data were collected remotely through telemetry (bison and wolves), wildlife trail cameras, and snow monitoring gauges/cameras.

LESSONS LEARNED

Although the federal regulatory application for Teck's Frontier Oil Sands Mine Project has been withdrawn, 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.

A summary of the preliminary results of the 2020 program are as follows:

- Bison selected for open habitats with significantly less coarse woody material (> 2 cm diameter), shrubs, and saplings in the spring and summer when visiting recent bison locations and comparing to random locations in the herds range.

- 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.
- Bison movement rates (activity) during winter were inversely related to snow depth and positively related to daily maximum temperatures, as well as their interaction (i.e., colder temperatures — especially when below 15°C during the day — and deeper snows resulted in the lowest movements/activity).
- Two of three collared wolf packs (*Canis lupus*) had bison in their diet during the late winter period of 2020 (March to April), whereas their diet was dominated by white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) throughout the winter period, and the summer diet consisted mostly of beaver (*Castor canadensis*).

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PRESENTATIONS AND PUBLICATIONS

Journal Publications

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Conference Presentations/Posters

Functional macronutrient selection by a large herbivore, the North American bison (Bison bison), American Bison Society October 28 to November 2, 2019.

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Dewart, L. T., Hecker, L.J. Epperson, D. M., Rawleigh, G., Sheppard, A. H. C., Nielsen, S. E. and Edwards, M. A. 2020. Ronald Lake Wood Bison Research Program: 2020 Annual Report. Report to the Ronald Lake Bison Herd Science Technical Team, December 1, 2020. University of Alberta, Edmonton, Alberta, Canada T6G 2H1, 43 pp.

Lee J. Hecker, Lindsey T. Dewart, Robert J. Belanger, Scott E. Nielsen and Mark A. Edwards. 2020, Ronald Lake Wood Bison Research Program: Annual Progress Report 2019.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Scott Nielsen

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Darren Epperson	University of Alberta	Research Technician		
Lee Hecker	University of Alberta	PhD	2017	2021
Lindsey Dewart	University of Alberta	MSc	2018	2021

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.

Early Successional Wildlife Dynamics Program

COSIA Project Number: LJ0013

Research Provider: LGL Limited environmental research associates

Industry Champion: Canadian Natural

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

Status: Year 6 of 6

PROJECT SUMMARY

Wildlife use of naturally occurring upland and wetland habitat in the Athabasca Oil Sands Region is relatively well-understood; however, the ability for reclaimed upland habitats to promote the return to and use of previously disturbed habitats remains under-studied.

To address this deficiency, a five year program was implemented to fulfil various objectives including:

1. Addressing requirements for reclamation certification;
2. Evaluating wildlife use of reclaimed habitats and areas adjacent to the development;
3. Assessing return and re-establishment of wildlife on reclamation areas; and
4. Evaluating effectiveness of practices and principles applied in reclamation areas to improve biodiversity.

Focal taxa representing terrestrial, and avian species were selected for annual monitoring of reclaimed habitats, mature forest, cleared, burned, and logged juvenile stands on leases operated by Canadian Natural Resources Limited (Horizon Oil Sands), Suncor Energy Inc. (Oil Sands Base), Canadian Natural Upgrading Limited (Albian Sands), Fort Hills Operations (Fort Hills), and Imperial (Kearl Oil Sands). Annual sampling was used to generate a baseline dataset that can be used to assess how different species of wildlife are distributed relative to reclaimed habitats, and to assess whether reclaimed habitats are on a developmental trajectory similar to other juvenile stands in the region. Data collected from reclaimed and juvenile stands are compared to data collected from mature forest reference sites that represent the desired endpoint of upland reclamation in the Athabasca Oil Sands Region. Data collected from habitats reclaimed to an upland forest type were also compared to data collected from sites recovering from other human or natural disturbance (logging, clearing, forest fire). Results obtained from the wildlife program will be used to quantify the successful re-establishment of wildlife habitat on each operator's lease and will ultimately demonstrate to stakeholders and regulators that wildlife habitat is being successfully established and maintained within operational footprints. These data will also be used to ensure that oil sands operators comply the terms and conditions of their EPEA approvals. The design of the program is flexible enough to ensure expandability and adaptability over time. Further, wildlife sampling protocols are aligned with other regionally relevant and accepted methods and are part of a "living document" — one that will be updated as new information becomes available or adapted to changing goals and objectives.

Wildlife sampling is occurring in habitats representing several distinct types of sites: (1) reclaimed (REC); (2) reclaimed habitat adjacent to compensation lake (COMP); (3) mature forest (MF); (4) cleared habitats (CLR); (5) logged (LOG); and (6) burned (BRN). A standardized sample unit (Figure 1) is used that includes a small mammal live-trapping grid, songbird point count stations, and remotely triggered cameras. Winter-active animal usage is extracted from the wildlife camera data. Focal taxa include small mammals (deer mouse [*Peromyscus maniculatus*], meadow vole [*Microtus pennsylvanicus*], and southern red-backed vole [*Myodes gapperi*]), bats (with autonomous recording units [ARUs]), winter-active animals (with data collected by remotely triggered wildlife cameras); songbirds; and terrestrial arthropods (spiders and beetles). Other taxa considered for some or all leases include (Canadian toad [*Anaxyrus hemiophrys*]), mammals (Canada lynx [*Felis canadensis*], beaver [*Castor canadensis*], common muskrat [*Ondantra zibethicus*], moose [*Alces alces*], American black bear [*Ursus americanus*], snowshoe hare [*Lepus americanus*]), and various groups of birds (waterfowl, owls, and raptors [diurnal and forest-nesting]), specific species of birds (ruffed grouse [*Bonasa umbellu*], yellow rail [*Coturnicops noveboracensis*], and pileated woodpecker [*Dryocopus melanoleucus*]). All other wildlife observed on each lease that are not the focus of systematic surveys are recorded as incidental observations. These data often provide important insights regarding the use of an area by all wildlife species. In addition to sampling wildlife taxa, vegetation data collected are used to assess species:habitat relationships for the various plot types.

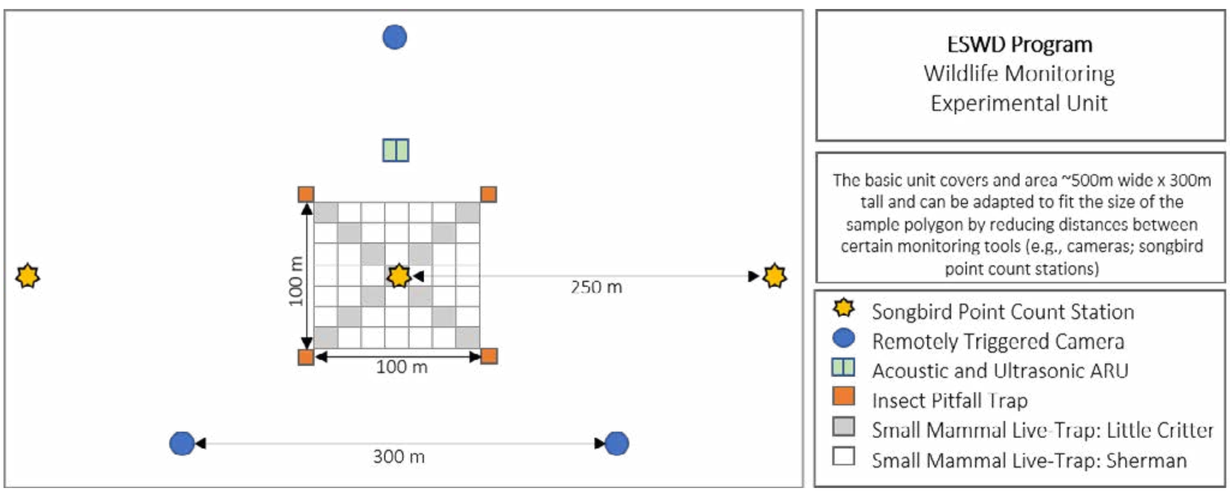

Figure 1: Ideal experimental unit used to sample for various wildlife species and groups targeted by the early successional wildlife dynamics program in the Athabasca Oil Sands Region. The distance between certain monitoring tools (e.g., remote cameras, songbird point counts) and the size of the small mammal trapping grid may be changed to accommodate the size and shape of a plot.

Annual sampling occurs in all months, with most work occurring during the snow-free period. Survey methods include the use of qualified and proficient biologists to; (1) document songbird species occurrence and distribution; (2) capture and identify amphibians; (3) live trap and identify small mammal species; (4) deploy remote sensing equipment (remotely triggered cameras and autonomous recording units); (5) assess vegetation species composition, cover, and height at all sample sites; and (6) make reliable observations of all wildlife species during all seasons of the year. Autonomous passive recording devices such as Wildlife Acoustics Song Meters are being used for bats, amphibians, and some species of birds (yellow rail, owls). Wildlife cameras are deployed throughout each lease to track the presence and distribution of medium- and large-sized mammals. All data are collected in a standardized manner so that appropriate statistical tests can be applied. A comprehensive report (one that pools all data from all operators) was produced in 2016. A report summarizing the results of this program will be available in 2021.

PROGRESS AND ACHIEVEMENTS

Sampling in 2020 was limited due to the COVID-19 pandemic. Continued sampling of select groups of wildlife using remote sensing (remotely triggered cameras [mammals, some birds] and acoustic autonomous recording units [owls, songbirds, amphibians]) and a small mammal live trapping program occurred on four of the five partner leases in fall 2020 (all but Kearl Oil Sands). All data collected in 2020 were combined with previously collected data in advance of the development of a five-year comprehensive report. The comprehensive report is based on data collected between 2016 and 2020, which defines the baseline conditions of wildlife usage of each treatment type, which was one of the main objectives of the Early Successional Wildlife Dynamics (ESWD) program.

The data collected to date were used to developed species profiles for each treatment sampled, one of the key outcomes of the five-year Phase 1 program. For example, of the seven species of bat known to occur, silver-haired bat, little brown myotis, and eastern red bat had the greatest relative proportion of detection rates in most years and treatments (Figure 2). Silver-haired bat had the greatest relative proportion of detection rates in all treatments (excluding mature forest [MF]) each year except for cleared (CLR) habitat in 2016. Little brown bat had the greatest proportion of detection rates in MF habitats each year. Bat species associated with MF (long-eared bat and Northern myotis) had greater proportions of detection rates in MF and burned (BRN) treatments than other treatments. The data collected to date contribute to the development of a 'data profile' for bats using the various treatment types sampled. More importantly, these data provide an indication of bat usage patterns of mature forest types. As habitat reclaimed to an upland forest type mature, the data profile of bats on those sites should start to resemble those of mature forests providing an indication of reclamation success.

Figure 2: Relative proportion of detection rates of each of the seven bat species for each year and treatment sampled in the Athabasca Oil Sands Region. Detection rate is equal to the number of classifications to species in a given treatment. Treatment codes are: MF = mature forest; BRN = burned forest; CLR = cleared; REC = reclaimed; COMP = compensation lake; LOG = logged. EPTFUS: *Eptesicus fuscus* (big brown bat); LASBOR: *Lasiurus borealis* (Eastern red bat); LASCIN: *Lasiurus cinereus* (hoary bat); LASNOC: *Lasionycteris noctivagans* (silver-haired bat); MYOEVO: *Myotis evotis* (long-eared myotis); MYOLUC: *M. lucigugus* (little brown bat); MYOSEP: *M. septentrionalis* (Northern myotis).

Similar results are available for birds. The data collected to date suggest that white-throated sparrow (WTSP) is a good indicator for BRN, though it is also present in a relatively high proportion in MF and logged (LOG) treatments, with a relatively low proportion of detections in early successional habitats such as reclaimed (REC) and CLR (Figure 3). Clay-colored sparrow (CCSP) shows the opposite trend, being an indicator for REC, and found in relatively high proportions in early successional habitats of REC, CLR and compensation lake (COMP), but with few to no observations from BRN and MF (Figure 3). Many species were detected in multiple treatment types, but at varying levels of occupancy. In general, the proportional distribution of certain indicator species of songbirds relative to each other and to all other songbird species provides an indication of the songbird fauna that should be supported by reclaimed plots when they eventually mature (Figure 3).

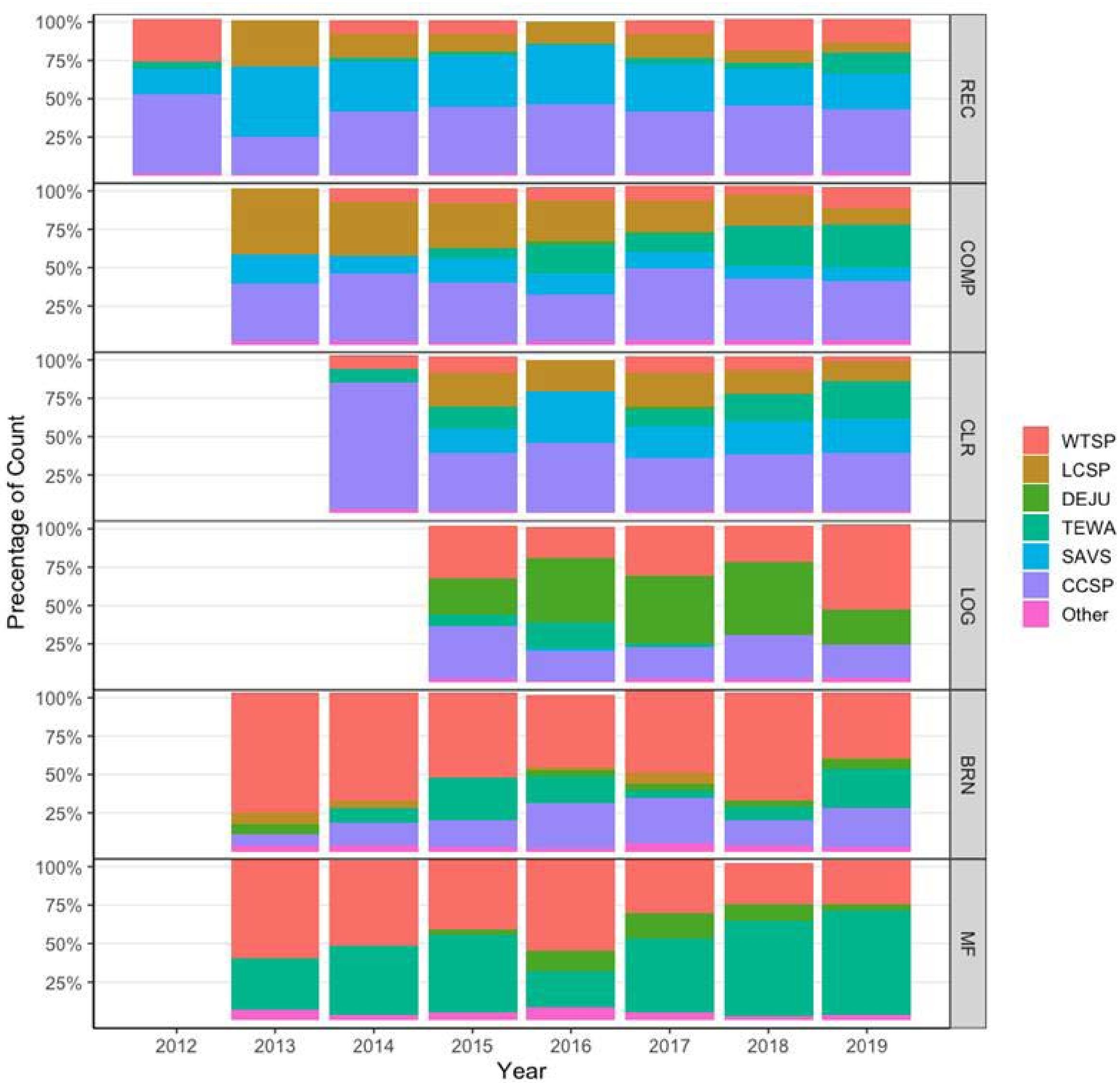

Figure 3: Proportion of songbird species detections within each treatment type sampled in the Athabasca Oil Sands Region, 2012 to 2019. Only select indicator species are specifically shown. BRN = burned reference; CLR = cleared; COMP = compensation lake; LOG = logged; MF = mature forest; REC = reclamation. WTSP = white-throated sparrow; LCSP = LeConte's sparrow; DEJU = dark-eyed junco; TEWA = Tennessee warbler; SAVS = savannah sparrow; CCSP = clay-coloured sparrow.

These data profiles provide guidance with respect to what to expect for each taxonomic group sampled in each treatment and provide an indication of the 'target' wildlife species profiles on landforms reclaimed to an upland forest type should resemble when they have reached mature forest age.

LESSONS LEARNED

Current results indicate that wildlife is returning to and using reclaimed upland habitat with the return being a function of time since reclamation, proximity to intact mature forest, and vegetation composition of the reclaimed habitats. In general, the species of wildlife encountered at each treatment type are expected (based on known habitat associations). The following lessons learned/recommendations for future consideration are provided. Some of the lessons learned affirmed our expectations (e.g., well-established wildlife survey methods are appropriately applied to study wildlife use of upland reclaimed sites) while others (e.g., consideration of habitat function and productivity) have developed as the Early Successional Wildlife Dynamics Program has been implemented.

1. Commonly used wildlife survey methods (small mammal live-trapping, songbird point counts, use of remote-sensing equipment (autonomous recording units and remotely triggered wildlife cameras) provide a standardized dataset upon which appropriate statistical analyses can be performed. The application of these survey methods contributes to the development of a time-series dataset that can be used in trend assessments and community ecology analyses.
2. Insect sampling (pitfall trapping) is providing data by which ecological shift can be assessed. Preliminary results reveal the presence of species-specific habitat associations with some species occurring in only a single habitat type. With time, it should be possible to better characterize the species-habitat associations and use the presence and abundance of a suite of species to discuss reclamation efficacy.
3. The use of remotely triggered wildlife cameras to sample winter-active animal use of reclaimed habitats and other treatments sampled is proving to be more reliable than snow-tracking.
4. The inclusion of incidental data (i.e., data not collected using standardized data collection techniques) provides a more robust understanding of wildlife occurrence and distribution on sites reclaimed to upland habitats when combined with data collected using standardized methods. These incidental observations are an important part of the Early Successional Wildlife Dynamics Program.
5. Preliminary analyses suggest that an indicator species approach could be used to focus surveys on a subset of species in each taxonomic group. More data are required to fully test this hypothesis, and this is currently being investigated through targeted analyses on insect data and bird data.
6. The current focus is on developing a baseline against which future comparisons can be made, which necessitates the collection of species occurrence, distribution, and abundance data relative to each site sampled. Although informative, species presence and abundance data are only telling part of the story. In addition to knowing which species occur on upland reclaimed sites relative to the various analogs (burned, logged, cleared, compensation lake, and mature forest) an understanding of the function and productivity of upland reclaimed habitats is required. It will be necessary to determine if upland reclaimed habitat provides the habitat attributes necessary for wildlife to fulfill their life requisites in a manner consistent with (but not necessarily identical to) existing mature forest in the region. This will ensure a comprehensive assessment and understanding of reclamation efficacy and success.

7. Existing mature forests are being used as the reference point for upland reclamation. These habitats provide one possible outcome of upland reclamation; however, it is unknown if reclaimed habitats will develop into mature forests characterized using existing accepted methodology (e.g., Beckingham and Archibald 1996) or if they will simply resemble a currently described mature forest with a different species assemblage. As such, the utility of mature forest points as desired outcomes of upland reclamation may need to be reconsidered or at the very least, put into the context of one of several to many possible outcomes.

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PRESENTATIONS AND PUBLICATIONS

Journal Publications

Hawkes, C. V., N. T. Hentze, and T. G. Gerwing. Submitted. Avian Usage trends of reclaimed boreal forest habitat in Canada's Oil Sands. Avian Conservation and Ecology.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Limited environmental research associates

Principal Investigator: Virgil C. Hawkes

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

COSIA Project Number: LJ0325

Research Provider: LGL Limited environmental research associates

Industry Champion: Canadian Natural

Status: Year 3 of 3

PROJECT SUMMARY

The Canadian toad (Anaxyrus hemiophrys) is known to occur in the Athabasca Oil Sands Region, including in ponds and wetlands on Canadian Natural's Horizon Oil Sands. This has been documented by both Canadian Natural and LGL Limited staff, and during work associated with the Early Successional Wildlife Dynamics Program (COSIA Project #LJ0013: Early Successional Wildlife Dynamics Program). The current status of this species in Alberta is, "May Be at Risk," and despite the known presence of this species on the Horizon Lease, there remains considerable uncertainty regarding, (1) the distribution of Canadian toads on the lease; (2) the occurrence and characterization of suitable wintering habitat; (3) typical movement patterns (daily and seasonal); and (4) whether Canadian toads can be relocated from areas that are likely to be impacted from mine development into suitable receptor ponds that are consistent with the habitats they are moved from, and yet are within the same watershed.

To reduce the impact on Canadian toad habitat during mine expansion on the Horizon Lease, a toad translocation program was developed and implemented in 2018. The primary objective of this work was to study the efficacy of a toad mitigation translocation program (moving toads that would otherwise be destroyed or negatively affected by mining-related activities) to lessen the effects of habitat loss on this species.

To reach the primary objective the following tasks were assigned:

1. Determine the occurrence and distribution of Canadian toads using eDNA (2019 COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling, pages 181 to 185. Available at COSIA.ca).
2. Determine where Canadian toads and other species of amphibians are breeding (which ponds/wetlands are used) using nocturnal calling surveys (autonomous recording units [ARUs]), visual observations and egg mass counts;
3. Disease test (Chytridiomycosis) Canadian toad individuals at collection and receiving sites prior to relocation;
4. Translocate toads and egg masses with subsequent monitoring to determine the success of the relocations;
5. Develop a radio telemetry study to determine Canadian toad movement and overwintering locations; and
6. Monitor/characterize overwintering sites on the Horizon Lease.

Work completed in 2018 and 2019 focused on the first five of the six tasks. Task 6 (overwintering habitat) was not completed due to an inability to track toads that had been fitted with transmitters to their winter habitat (the transmitters were either shed or removed prior to hibernation). Work related to Task 1 (eDNA) was initiated in 2018 and details on the progress of this specific project can be found under the 2019 COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling, pages 181 to 185. Available at COSIA.ca.

The results obtained from this work will assist in validating whether translocating Canadian toads is an effective mitigation strategy. This work will also contribute to an increased understanding of behaviour and habitat use of Canadian toads on the Horizon Lease that can be applied across the Athabasca Oilsands Region, including other leases where Canadian Natural operates. This Canadian toad research is closely tied to other research programs (2019 COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling, pages 181 to 185 and 2019 COSIA Project #LJ0326: eDNA for Canadian Toad Habitat Suitability Model Update, pages 186 to 193. Available at COSIA.ca).

In 2020 aspects of the Canadian toad program were expanded to Canadian Natural's Horizon South and Albian Sands Leases. Specifically, autonomous recording units were deployed to assess Canadian toad presence at Horizon Oil Sands, Horizon South and Albian Sands and a putative overwintering location at Horizon South was monitored (as per Task 6, above).

PROGRESS AND ACHIEVEMENTS

Canadian Toad Detections

In 2020, 37 autonomous recording units (ARUs) were deployed at Canadian Natural's Horizon Oil Sands (n = 19), Canadian Natural's Horizon South (n = 12) and Canadian Natural Albian Sands (n = 6) (Figure 1). Most ARUs were operational (i.e., recording) for between 71 and 111 days between April 28 and September 6, 2020 (Table 1). One ARU recorded for three days and failed. Autonomous recording units were scheduled to record for 10 minutes every hour. Recordings associated with peak calling hours (23:00 to 03:00) were extracted and reviewed for Canadian toad calls via SongScope (Wildlife Acoustics, Inc.) in conjunction with the CATO recognizer (http://bioacoustic.abmi.ca), as well as human listening and spectrogram visualization. Canadian toads were detected at 24 of 37 locations (Horizon Oil Sands: 11 of 19 locations; Horizon South: 9 of 12 locations; Albian Sands: 4 of 6 locations). Canadian toads were detected between May 16 and July 10, 2020 (Figure 2). The number of nights of calling with that range varied from 1 to 23 (Table 1).

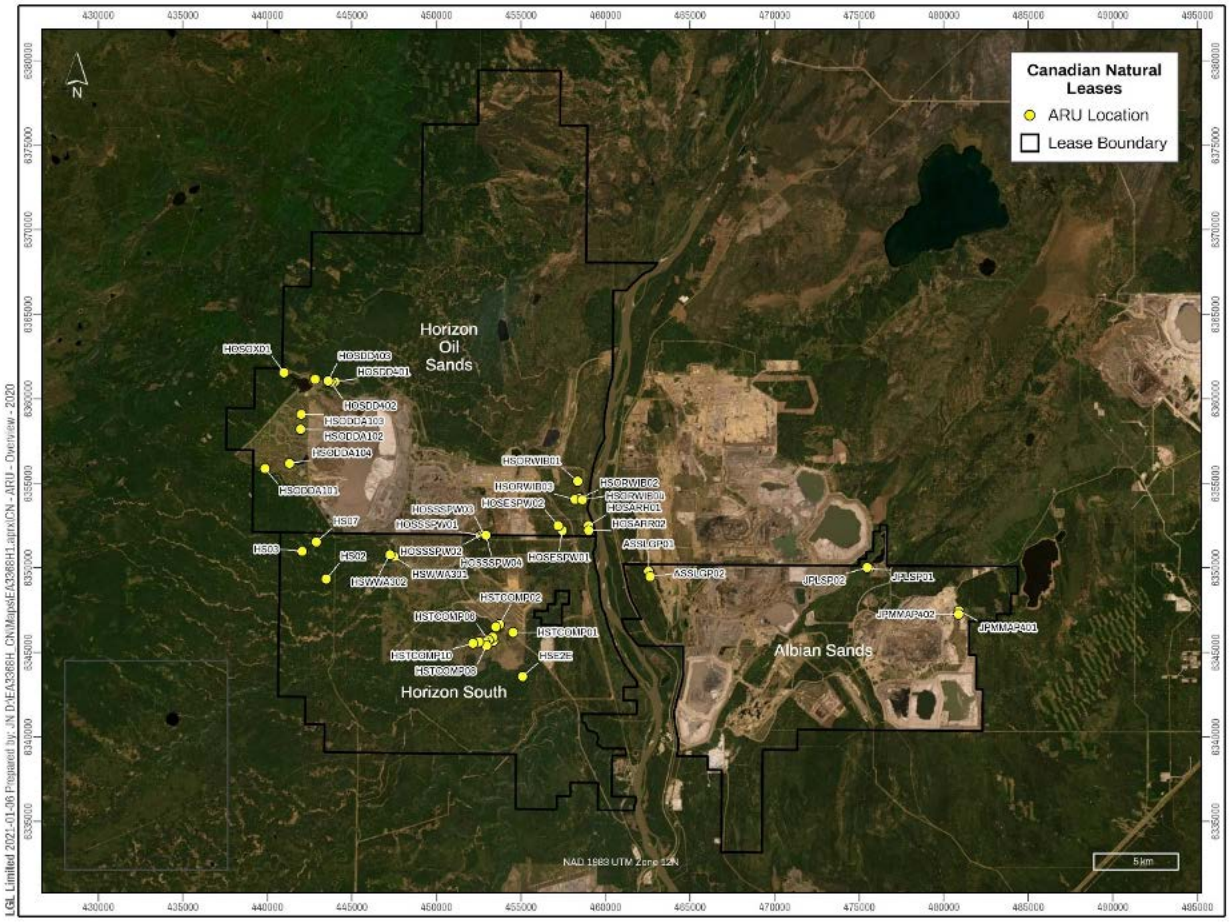

Figure 1: Distribution of autonomous recording units (ARUs) deployed at Canadian Natural's Horizon Oil Sands, Horizon South, and Albian Sands leases in 2020. ARU labels align with those in Table 1.

Table 1: Summary of autonomous recording unit deployment at Canadian Natural's Horizon Oil Sands, Horizon South, and Albian Sands leases in 2020. CATO = Canadian Toad. Deployment dates were late due to restrictions associated with the COVID-19 pandemic.

			Recording			CATO Detections			
Mine	Site Name	ARU Label	Start	End	CATO?	First	Last	Total nights	Comments
Albian Sands	Susan Lake Gravel Pit	ASSLGP01	20-May	17-Aug	No	.		.	
		ASSLGP02	20-May	17-Aug	No	.		.	
	JPM Mine Advance: North of Pond 4	JPMMAP401	26-May	17-Aug	Yes	26-May	04-Jun	4	Late deployment, likely missed calling onset
		JPMMAP402	26-May	17-Aug	Yes	26-May	15-Jun	14	Late deployment, likely missed calling onset
	Pond south of Jackpine Lake	JPLSP01	25-May	04-Aug	Yes	25-May	19-Jun	13	Late deployment, likely missed calling onset
		JPLSP02	25-May	17-Aug	Yes	07-Jun	13-Jun	3	Late deployment
Horizon Oil Sands	Sandpit South Wetland Complex	HOSSSPW01	29-Apr	15-Aug	No	.		.	
		HOSSSPW02	29-Apr	15-Aug	Yes*	12-Jun	12-Jun	1	*faint, calling from nearby ARU
		HOSSSPW03	29-Apr	15-Aug	Yes	21-May	12-Jun	2	
		HOSSSPW04	29-Apr	15-Aug	Yes	21-May	12-Jun	2	
	Athabasca River Translocation Site	HOSESPW03	11-May	19-Aug	Yes*	30-May	30-May	1	*faint
		HOSESPW04	11-May	19-Aug	Yes	02-Jul	03-Jul	1	
	DD4 Wetlands	HOSDD401	08-May	16-Aug	No	.		.	
		HOSDD402	08-May	17-Aug	No	.		.	
		HOSDD403	08-May	16-Aug	No	.		.	
	Bean	HOSBN01	08-May	18-Aug	No	.		.	
	Oxbow	HOSOX01	07-May	10-May	Unknown	.		.	Unit failed 3 days after deployment.
	DDA1	HSODDA101	18-May	06-Sep	Yes	27-May	20-Jun	21	
		HSODDA102	18-May	17-Aug	No	.		.	
		HSODDA103	18-May	13-Aug	Yes	02-Jul	02-Jul	1	
		HSODDA104	18-May	30-Jul	Yes	05-Jun	19-Jun	4	
	RWI road/burn area	HSORWIB01	09-May	18-Aug	No	.		.	
		HSORWIB02	19-May	18-Aug	Yes	20-Jun	30-Jun	4	
		HSORWIB03	19-May	24-Jul	Yes	10-Jun	23-Jun	13	
		HSORWIB04	19-May	18-Aug	Yes	27-Jun	27-Jun	1	
Horizon South	Horizon South Wetland complex	HSTCOMP01	28-Apr	23-Jul	Yes	21-May	16-Jun	23	Chorus
		HSTCOMP02	28-Apr	26-Jul	Yes	16-May	16-Jun	19	Chorus
		HSTCOMP03	28-Apr	14-Aug	Yes	19-May	28-Jun	9	
		HSTCOMP04	28-Apr	14-Aug	Yes	28-Jun	09-Jul	8	
		HSTCOMP05	28-Apr	14-Aug	Yes	28-Jun	10-Jul	8	
		HSTCOMP06	28-Apr	14-Aug	Yes	02-Jun	19-Jun	3	
		HSTCOMP07	28-Apr	14-Aug	Yes	27-May	20-Jun	6	
		HSTCOMP08	28-Apr	28-Jul	Yes	30-May	21-Jun	10	
		HSTCOMP09	28-Apr	14-Aug	No	.		.	
		HSTCOMP10	28-Apr	14-Aug	Yes	03-Jun	28-Jun	15	
	West of WA3	HSWWA301	28-Apr	26-Jul	No	.		.	
		HSWWA302	28-Apr	15-Aug	No	.		.	

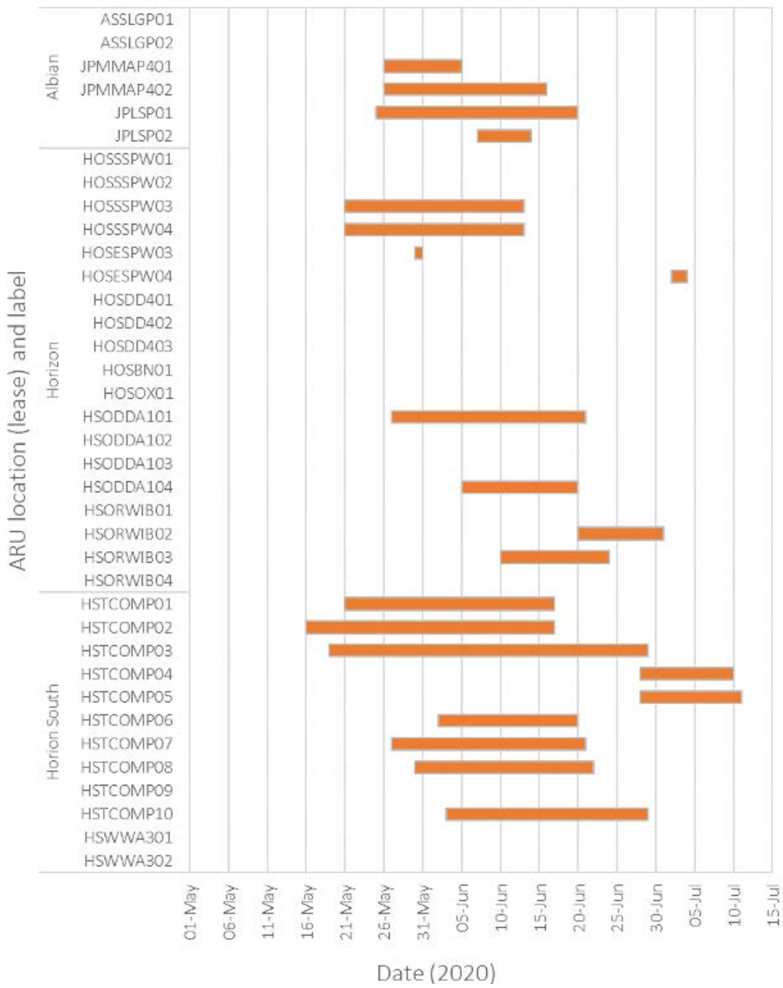

Figure 2: Date range of Canadian toad (*Anaxyrus hemiophrys*) detections from autonomous recording units deployed at Canadian Natural's Horizon Oil Sands, Horizon South, and Albian Sands leases north of Fort McMurray, Alberta.

Canadian toads were documented from locations identified as moderate to high suitability Canadian toad habitat at Horizon Oil Sands, Horizon South, and Albian Sands (as per 2019 COSIA Project #LJ0326: Canadian Toad Habitat Suitability Model Update; Hawkes et al., 2020 a,b), providing some degree of validation of the updated habitat suitability index model and maps updated in 2019 (Hawkes et al., 2020 a, b).

Overwintering Location

A single putative overwintering location was located at Horizon South and monitoring of this location commenced in October 2020. The overwintering location is typical of those described for Canadian toad. Toads typically burrow into the soil profile below the frost line for protection from freezing temperatures and as such, soil substrate is critical for overwintering suitability (Breckenridge and Tester 1961; Hamilton et al., 1998). For ease of burrowing, hibernation sites are usually located in upland areas consisting of coarse-textured, sandy soils as opposed to a fine textured clay or muddy substrate (Breckenridge and Tester 1961; Hamilton et al., 1998). These preferred substrates are also well-drained with lower soil moisture content, which is an important characteristic as Canadian toads are not freeze-resistant (Hamilton et al., 1998; Garcia et al., 2004). Hibernation sites often contain many individuals and aggregations of several hundred have been reported (Kuyt 1991; Hamilton et al., 1998). Throughout their hibernation, toads may burrow deeper into the soil in response to decreasing temperatures (Breckenridge and Tester 1961; Hamilton et al., 1998). Average depths between 50 cm and 60 cm have been reported in mid-September to mid-October, with individual burrows as deep as 117 cm in January and February (Breckenridge and Tester 1961; Tester and Breckenridge 1964; Kuyt 1991; Hamilton et al., 1998). The putative wintering location at Horizon South is shown in Figure 3.

Figure 3: Putative Canadian toad (*Anaxyrus hemiophrys*) wintering habitat on Canadian Natural's Horizon South lease. Yellow arrows indicate location of a Canadian toad relative to a burrow. The photo in the bottom right identifies the location of two Canadian toads: one inside the opening of the burrow and one slightly upslope.

The overwintering location was monitored using a series of soil oxygen (%), moisture (%), and temperature (°C) data loggers (Oxygen: Apogee Instruments SO-400 Series Decagon Devices 5TM Sensor - Moisture and Temperature Sensor) deployed at depths of 24 cm, 50 cm, 75 cm, and 100 cm below the surface. The soil oxygen sensor at 25 cm failed after installation so only data from 50 cm, 75 cm, and 100 cm are reported. Of the three parameters measured, Soil temperature is likely the most important. Data collected between October 15 and December 1, 2020 Indicate that temperature increases with increasing depth with all data loggers returning positive (> 0°C) temperatures for the period assessed (Figure 4). The temperature profiles of the loggers deployed at 25 cm and 50 cm below ground were relatively stables with those deployed at 75 cm to 100 cm decreasing by approximately 2°C to 2.5°C. Average ambient (air) temperature during this period was -7.7°C with minimums approaching -28°C (Figure 5). Although temperatures at depths of 25 cm to 100 cm were < 2°C by January 6, 2021, they did not dip below 0°C suggesting this site could be a suitable wintering location (at least from a temperature perspective).

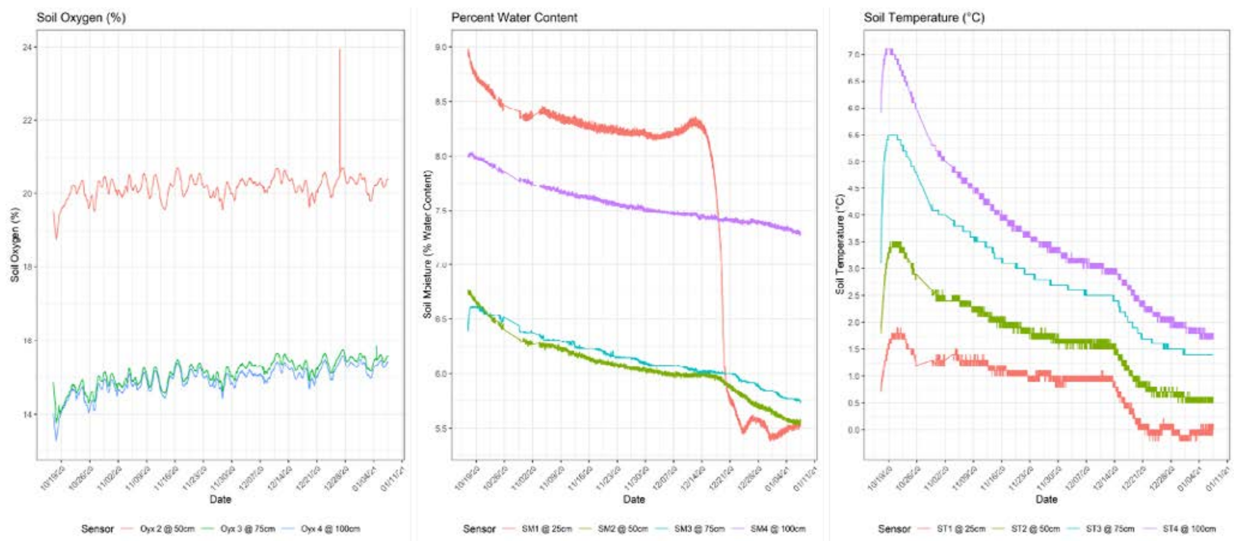

Figure 4: Variation in soil oxygen (%), soil moisture (%), and soil temperature (°C) at the putative Canadian toad (*Anaxyrus hemiophrys*) overwintering location at Horizon South relative to depth below ground (25 cm, 50 cm, 75 cm, and 100 cm) between October 15, 2020 and January 6, 2021.

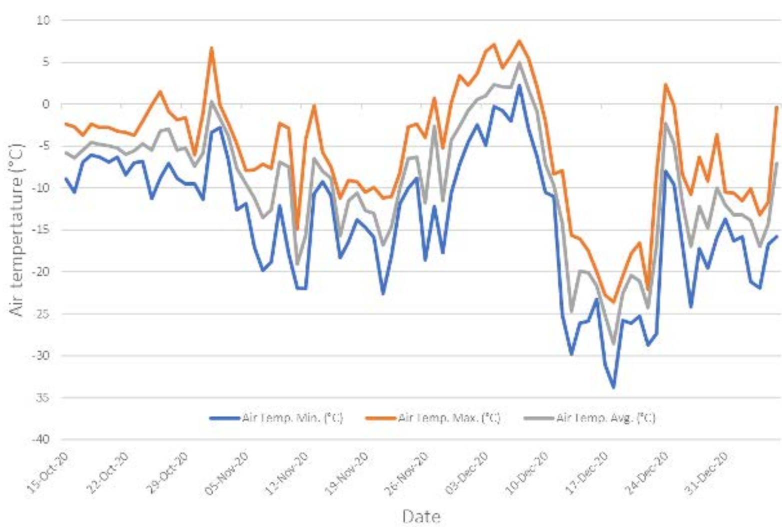

Figure 5: Maximum, minimum, and average air temperature (°C) recorded at Horizon Oil Sands October 15, 2020 and January 6, 2021.

LESSONS LEARNED

Canadian toads were detected at all three leases in 2020 with some locations consistent with previous years (e.g., Sandpit South Wetlands at the border of Horizon Oil Sands and Horizon South). With additional sampling (i.e., more ARUs) Canadian toad was detected at additional locations on all three leases sampled. Of note was the lack of detection in the vicinity of Horizon Lake which served as the primary release location for translocated toads in 2018 (Hawkes and Papini 2018). Given the relative lack of suitable Canadian toad winter habitat in this area (Figure 4), it is not overly surprising that no toads were recorded despite having previously recorded either single- to few-calling males in ponds adjacent to DD4 and encountering immature Canadian Toads around Horizon Lake.

Overall, 65% of the locations sampled had Canadian Toad detection even though the timing of deployment was later than desired due to various constraints related to the COVID-19 pandemic (refer to Table 1). At Horizon Oil Sands, toads were detected at 58% of locations sampled; Horizon South, 75% of locations; and Albian Sands, 67% of locations. The locations at which toads were located align with habitats rated as moderate to high, providing some degree of validation of the updated Canadian Toad HSI model and the associated outputs. The predictive power of the updated Canadian Toad HSI model has relevance across the Athabasca Oil Sands Region. The revised model outputs could inform future Canadian toad relocation efforts and serve as the basis for future possible investigations regarding Canadian toad habitat use and distribution.

The observation of a putative wintering site at Horizon South provided the opportunity to study various abiotic parameters (soil oxygen, moisture, and temperature) during winter 2020/2021 (work is ongoing). If this site proves to be used by Canadian toad to overwinter the future characterization of the habitat at this location (in terms of soil texture, depth, area etc.) can inform the creation of wintering habitat for Canadian toad on active oil sands leases. The results could also inform future reclamation efforts to mitigate for the impacts to Canadian toads and their habitats. For example, reclamation efforts could consider the placement of deep (1 m to 1.25 m) friable soils adjacent to suitable breeding habitats that would enable toads to burrow below the frost line to survive the winter.

LITERATURE CITED

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Hamilton, I. M., J. L. Skilnick, H. Troughton, A. P. Russell, and G. L. Powell. 1998. Status of the Canadian Toad (*Bufo hemiophrys*) in Alberta. Alberta Environmental Protection, Wildlife Management Division, and the Alberta Conservation Association, Wildlife Status Report No. 12, Edmonton, AB. 30 pp.

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Hawkes, V. C. F. Papini, J. Novoa. 2020a. Canadian Toad (*Anaxyrus hemiophrys*) Habitat Suitability Index Model Update for Canadian Natural’s Albian Sands. LGL Report EA3984. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources, Fort McMurray, AB. 32 pp + appendices.

Hawkes, V. C. F. Papini, J. Novoa. 2020b. Canadian Toad (*Anaxyrus hemiophrys*) Habitat Suitability Index Model Update for Canadian Natural’s Horizon Oil Sands. LGL Report EA3984. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources, Fort McMurray, AB. 34 pp + appendices.

Kuyt, E. 1991. A Communal Overwintering Site for the Canadian Toad, *Bufo americanus hemiophrys*, in the Northwest Territories. Canadian Field Naturalist, 105: 119–121.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications available for 2020.

RESEARCH TEAM AND COLLABORATORS

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Devon Versnick-Brown	Canadian Natural	Coordinator, Environment		
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Angela Stefura	Canadian Natural	Coordinator, Environment		
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Bianca Unrau	Canadian Natural	Student BSc Environment	2017	2021

Genomics and eDNA Workshop

COSIA Project Number: LE0069

Workshop Facilitator: Hemmera

Industry Champion: Imperial

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

Status: Complete

PROJECT SUMMARY

With the rapid advances in sequencing technologies and data analysis, environmental genomics can offer a variety of tools that can be used to obtain comprehensive biological information. These tools include the collection of environmental DNA (eDNA) for use in species and community assessment. This is emerging as a promising method for biodiversity monitoring and is expected to help improve environmental performance and management in the oil sands industry.

In November 2020, the COSIA Genomics and eDNA Workshop was held with the goal of exploring more sustainable and cost effective monitoring methods for the assessment of biodiversity and reclamation trajectories within the oil sands industry.

The main objectives of the workshop were to:

- Share current research and to gain knowledge about leading edge research in environmental genomics and its applications in reclamation.
- Identify specific applications, limitations, and knowledge gaps of genomics and eDNA tools as they relate to oil sands reclamation and biodiversity monitoring.
- Encourage new research collaborations among industry, academia and consultants.

PROGRESS AND ACHIEVEMENTS

Due to COVID-19 restrictions, the Genomics and eDNA Workshop was held online using Microsoft Teams on November 4th and 5th, 2020. Up to 66 attendees from across North America participated in the workshops each day. They included respresentatives from environmental government organizations, consulting agencies, the oil and gas industry, and academia.

The workshop was organized into two main sessions; eDNA for Species Monitoring (day one); and Genomics for Community Assessment (day two). Each session consisted of a keynote presentation followed by various presentations from speakers in academia, consulting, industry, and government. The keynote speakers were Dr. Caren Helbing from the University of Victoria (day one) and Dr. Merhdad Hajibabaei from the University of Guelph (day two). At the end of each day, a discussion session was carried out to debate prepared themes, as well as emerging questions from the participants. In addition, participation was encouraged through the use of survey questions that were sent to attendees (via POPin platform).

After the completion of the workshop, a report was prepared by Hemmera to summarize the main highlights and any emerging themes.

LESSONS LEARNED

The main topics and highlights discussed during the workshop are summarized below:

- There is an increasing amount of eDNA research and pilot project work being conducted in the oil sands region related to environmental monitoring – much of this is conducted through the collaborative efforts of academic researchers, industry managers and consulting scientists.
- In general, eDNA assessment surveys have been compared with traditional sampling methods for a variety of targeted species and broader ecosystem characterization studies. A strong alignment between the methods has been observed.
- The general consensus is that eDNA analysis has great potential as an additional tool in the environmental assessment toolbox.
- Identified advantages of using eDNA methods compared to traditional methods include: reduced cost, ability to assess ecosystem taxa and community-level ecosystem health more comprehensively, potential reduction of sampling frequency, and less destructive sampling methods.
- Current challenges with using eDNA methods include: the limited availability of adequately validated assays for some species and taxonomic groups, and issues in some studies with false positives and/or false negatives, the current lack of standardized testing methods contributes to end users having reduced confidence in the results, and there is limited eDNA lab capacity beyond academic research institutions.
- Next steps needed to advance these methods were recognized. These included the standardization of sampling design, analytical methodology, and quality assurance/control protocols. A national working group that includes academics, researchers, government bodies and consulting firms has been formed to advance standardization through the Canadian Standards Association.

PRESENTATIONS AND PUBLICATIONS

Workshop

2020 COSIA Genomics and eDNA Virtual Workshop Summary Report. Availabe at: https://cosia.ca/sites/default/files/attachments/Genomics_eDNAworkshop_Report_FINAL_Mar9.pdf

WORKSHOP FACILITATION TEAM AND KEY SPEAKERS

Facilitators: Hemmera

Workshop Facilitation and Report Preparation: Kate Witte, Doug Bright, and Desiree Hartshorn

Workshop Speakers:

Name	Institution or Company	Job Title
Keynote Speakers		
Dr. Caren Helbing	University of Victoria	Professor
Dr. Merhdad Hajibabaei	University of Guelph	Associate Professor
Invited Speakers		
Dr. Natalie Schmitt	McMaster University	Post-Doctoral Fellow
Dr. Brian Lanoil	University of Alberta	Associate Professor
Dr. Christine Martineau	Canadian Forest Services	Research Scientist
Sherry Walker	Fisheries and Oceans Canada	National Manager of Biotechnology and Genomics Program
Dr. Ryan Mercer	Genome Alberta	Manager of Program and Business development
Dr. Jordan Angle	ExxonMobil	Environ. Genomics Lead
Dr. Mary Murdoch	Stantec and Canadian Natural	Senior Aquatic Biologist
Dr. Steve Crookes and Dr. Mario Thomas	Precision Biomonitoring	Co-founders
Dr. Brian Eaton and Susan Koziel	InnoTech Alberta and Canadian Natural	Manager of Environ. Impacts Team and Research Technologist
Kenneth Clogg-Wright	Canadian Standards Association	Project Manager