2019 COSIA LAND EPA

Mine Research Report

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INTRODUCTION

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

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

COSIA publishes two reports, 2019 COSIA Land EPA – Mine Research Report and 2019 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. Please contact the Industry Champion identified for each research project if any additional information is needed.

2019 COSIA Land EPA – Mine Research Report. Calgary, AB: COSIA Land EPA. REVISION 1. JUNE 2020[1].

*In 2019, Canadian Natural purchased Devon Canada Corporation's assets. All active COSIA Land EPA projects previously supported by Devon Canada Corporation were transferred to Canadian Natural.

[1] Please note this JUNE revised Report has corrected errors on pages 126-129 in the APRIL 2020 publication for COSIA Project: LE0034: NSERC – Industrial Research Chair in Terrestrial Restoration Ecology.

Front cover image courtesy of COSIA

INSTRUMENTED WATERSHED

Aurora Soil Capping Study: Program Overview

COSIA Project Number: LJ0201 (Including LJ0099, LJ0100 and LJ0219 associated with Aurora Soil Capping Study)

Research Providers: University of Alberta, University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural, Imperial, Suncor Energy Inc.

Status: Final Cumulative Summary

PROJECT SUMMARY

The Aurora Soil Capping Study (ASCS) is a multifaceted study to address the following issues for oil sands mine operators in the Athabasca Oil Sands Region: (1) the effect of naturally-occurring petroleum hydrocarbons (PHCs) in soil reclamation materials and overburden on environmental receptors (e.g., plants, surface water and groundwater); (2) the appropriate use of coarse-textured reclamation materials to create soil moisture and nutrient conditions similar to the predevelopment upland forest conditions in the area; and 3) the appropriate tree species and revegetation strategy for quick establishment of a forest stand and promote development of the understory community. The ASCS is designed specifically for the purpose of addressing these issues, consisting of several, replicated soil cover design treatments with vegetation subplots. Learnings from this work are intended to provide guidance on the appropriate soil cover design and capping depth to mitigate risks associated with naturally-occurring PHCs, as well as the appropriate vegetation species and revegetation practices to promote the establishment of key vegetation species and their plant communities. The study is a multi-disciplinary, collaborative field study involving research scientists from the University of Alberta and University of Saskatchewan, with the support of Syncrude Canada Ltd. (Syncrude) personnel and environmental consultants. A list of the research projects, including the primary investigator and their classification within COSIA are provided in the table below.

Project Type	COSIA Project Number	Project Title	Principal Investigator(s)
Joint Industry	LJ0099	Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected Reclamation Soils	Bing Si and Lee Barbour (University of Saskatchewan)
Joint Industry	LJ0219	Hydrocarbon Degradation and Mobility	Ian Fleming (University of Saskatchewan)
Joint Industry	LJ0100	The Roots of Succession: Relations among Plants, Soil and Mycorrhizal Fungi in a Reclaimed Site	Simon Landhäusser and Justine Karst University of Alberta)
Single Industry	LJ0201	Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils	Sylvie Quideau (University of Alberta)
Single Industry	LJ0201	Re-Establishment of Forest Ecosystem Plants, Microbes and Soil Processes in Coarse Textured Reclamation Soils	Derek MacKenzie (University of Alberta)
Single Industry	LJ0201	Water and Carbon Isotope Methods Development	Lee Barbour and Jim Hendry (University of Saskatchewan)

The ASCS is located at Syncrude's Aurora North mine and is situated on the Fort Hills overburden dump. The overburden of the Fort Hills dump consists dominantly of lean oil sand (LOS) which contains petroleum hydrocarbons (PHCs) that generally range from < 1% to 7% oil in the geological formation. LOS is removed in the mine process to expose the oil sand ore body and is disposed in constructed overburden landforms. Soil materials available for reclamation at the Aurora North mine are generally coarse-textured, glaciofluvial surficial geologic materials. They also contain oil sand materials in variable proportions of the soil matrix, in the form of discrete bands (layers) or aggregated particles of PHCs that can range in size from pebbles to boulders. The oil sand materials present in the soil reclamation material have measurable PHC concentrations; however, their total concentration within the entire soil reclamation matrix is significantly lower than the PHC concentration present in LOS.

The ASCS tests a number of soil reclamation cover designs and capping depths on LOS. There are a total of 12 treatments (with one treatment consisting of a split-plot treatment) that are replicated in triplicate in one-hectare (ha) cells, resulting in a total study area of approximately 36 ha. Each cell has been vegetated to a mix of trembling aspen, white spruce and jack pine to a standard density of 1,800 stems/ha. A mix of understory species was also included in the planting. Within each cell there are 25 m by 25 m vegetation subplots. These subplots have individual tree species (trembling aspen, white spruce and jack pine) and a mix of the tree species in a standard density of 2,000 stems/ha, as well as a higher density of 10,000 stems/ha. Within the cells and vegetation subplots, an array of instruments has been installed to measure parameters such as soil moisture, temperature, groundwater presence and water quality. Other individual research programs have also installed a number of instruments to conduct their research within the study area. A meteorological station has been installed at the site to capture local climate data.

Some research programs began in 2010 and the remainder of the projects began when site construction was completed in May 2012. Data collection has taken place each year since construction. Since the study will remain as permanent reclamation, there is an opportunity to continue monitoring and assessment at the site in the future.

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements for the projects that had work remaining in 2019.

The Roots of Succession: Relations among Plants, Soil and Mycorrhizal Fungi in a Reclaimed Site (LJ0100)

Shauna Stack (MSc) completed her thesis examining the effect of fertilization on tree growth at the ASCS. She continued to monitor tree growth from a previous study of the project (Jana Bockstette, MSc) and compared the early establishment (first five years of tree growth) of trembling aspen (*Populus tremuloides* Michx.), jack pine (*Pinus banksiana* Lamb.) and white spruce (*Picea glauca* Moench.) on different reconstructed soil profiles of varying coversoil (salvaged lowland peat and upland surface soil [USS or FFM]), placement depths (10 cm or 30 cm for peat and 10 cm or 20 cm for FFM) and subsoil material types determined by salvage depth (Bm, BC and C). Tree seedling growth was generally greater in soil treatments with FFM coversoil versus peat. Subsoil material influenced growth in the later years of assessment, with trembling aspen greater on subsoil that was shallow salvaged (Bm horizon). Although some of the variability in tree growth may be due to nutrient deficiencies, soil physical properties may also be limiting tree growth. Peat and FFM coversoil have different water holding capacities and thermal conductivity, which can be affecting growth. The marginal increase in silt fraction of the Bm horizon may also have increased the water holding capacity of the soil profile resulting in the increased growth. White spruce showed the lowest response of the three tree species, likely due to its lower slow-growth rate and tolerance to resource and site limitations (relative to the other tree species).

In order to determine if the differences in tree growth response may be (in part) due to nutrient limitations, a fertilizer trial was established in the vegetation plots. A liquid fertilizer application of Nitrogen (N), phosphorus (P) and potassium (K) was applied in different configurations (NPK, PK, P, K and no addition [Control]) to determine if the variable tree growth response is due to a deficiency in one or more of the applied nutrients. Vegetation growth response (i.e., tree growth metrics, foliar nutrients and understory vegetation cover) was assessed over the following two growing seasons (Years 5 to 7 of the planted seedlings).

In general, the fertilizer trial did not find a dramatic increase in tree growth two years after fertilizer application. However, the targeted fertilizer trial did result in a tree growth response in a few instances, particularly in trembling aspen. Soil nutrient analysis found low K and P in the peat and subsoil materials, suggesting that addition of these nutrients would have the greatest impact on tree growth. The addition of P to a peat over deep salvage subsoil (C horizon) treatment resulted in an increase in the relative height of trembling aspen in the second growing season after fertilizer. However, there was no response in the other peat over shallower subsoil treatment (B/C horizons). There was also little response in the conifer tree species (jack pine and white spruce) with fertilizer addition. The greater response in trembling aspen compared to the conifer species may be due to the different growth characteristics of the tree species. Trembling aspen are a fast-growing species relative to the conifer species (especially white spruce), which allowed the aspen to take advantage of the nutrient addition in the soil, whereas the conifer species were limited in their ability to develop a root network to acquire the additional nutrients.

Even though there was a wide range in tree growth across the treatments, the fertilizer addition had little effect on improving tree growth. The following reasons were given to explain the lack of response with fertilizer addition:

- ***Other variables may be affecting tree growth at the site:*** Soil physical properties such as thermal conductivity and hydraulic conductivity may be affecting soil temperature and soil-water content which also play an important role in vegetation growth.
- ***The fertilization rate may have been too low:*** The soil reclamation materials of the study (in particular the peat coversoil) contain a relatively high amount of calcium carbonate, which can result in the sorption of phosphate. Therefore, some of the P addition may have been sorbed and not have been available for plant uptake. In addition, the nitrogen application rate was intentionally lower than normal to focus on the response of P and K addition (which were identified to be low). It's possible that the N application rate was too low to trigger a response.
- ***Uptake of nutrients by other vegetation species:*** There was an immediate increase in understory development in the first year of fertilizer application. *Salsola pestifer* (Russian thistle), which was already present prior to fertilization, significantly increased after the addition of fertilizer. The fertilizer was applied to the surface as a water solution; a minimal amount of water was applied which meant the solution remained near the soil surface. This meant precipitation was required to leach the fertilizer further into the soil profile. However, there was minimal rain after the application meaning the fertilizer application remained near the surface. Therefore, a large proportion of the fertilizer may have been taken up by shallow rooting species like Russian thistle and not reached the intended tree species.

Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected, Reclamation Soils (LJ0099)

Ivanna Hamilton (Faucher) completed her MSc which investigated natural “a1” ecosites to better understand how jack pine trees utilize internal water storage on a diurnal scale under normal and drought-induced conditions. The study also demonstrated that jack pines at a sandy site, under drought conditions, facilitate hydraulic redistribution of soil water. The site for this study was located in the Narrow Hills Provincial Park in Saskatchewan, Canada.

For the utilization of water storage phase of the study, sap flow movement within jack pine tree trunks was measured using heat pulse probes and circumference dendrometers. To interpret water movement under normal and drought conditions sap flow within the trunk was compared with the environmental parameters of soil volumetric water content (VWC), air temperature, air humidity, net radiation, wind speed and water storage within the trunk. A drought condition was induced by covering the soil surface area around the tree with tarps to shed all precipitation away from the tree’s root zone.

Under normal conditions the VWC was higher than under the drought induced condition. Sap flow measurements were found to be higher during normal conditions than during the drought-induced condition. All other measured environmental parameters were consistent in both conditions, indicating that VWC controls the volume of sap flow. Under normal conditions as sap flow increased in the morning there was a moderate negative correlation between sap flow and tree trunk circumference, indicating that the trees acquired water from internal storage as well as from the soil for transpiration. Under drought conditions there was a strong negative correlation between sap flow and tree trunk circumference, suggesting more of the water used by the tree is coming from internal water storage. The diurnal amplitude of change in the tree circumference was similar during normal and drought conditions. However, the daily median minimum tree circumference under normal conditions was significantly greater than under drought conditions, suggesting the tree experienced growth during normal conditions and contraction during drought conditions due to internal water stress.

Further study was undertaken to understand the mechanisms controlling sap flow. Sap flow was found to have hysteric relationships with all measured environmental parameters except VWC and tree trunk circumference fluctuations. Sap flow increases in the morning were generally found to be strongly positively correlated with air temperature, air humidity and net radiation under normal and drought conditions. However, the correlation of sap flow decreases with environmental parameters in the afternoon was variable. There were moderate positive correlations with afternoon sap flow and air temperature and a strong positive correlation with net radiation. However, net radiation began to increase prior to sap flow increases and continued to increase in the afternoon after sap flow began to increase.

The second phase of the study determined if jack pine trees have the ability to perform hydraulic redistribution under drought conditions. Hydraulic redistribution is the process of acquiring and moving soil water moves from areas of low matric potential and releasing the water in the soil profile which has a high matric potential. Jack pine have a taproot that is able to access water from soil depths greater than 1 m, which provides them an opportunity to acquire additional water at depth (low matric potential) and release the water upwards in the soil profile (high matric potential), for later use by the tree and other vegetation present (e.g., understory vegetation). The study injected a deuterium (^{2}H) isotope labelled solution 100 cm below the soil surface in a grid of installed access tubes surrounding jack pines tree and the $\delta^{2}H$ and $\delta^{18}O$ signatures were monitored in soil water and tree sap flow over a period of 35 days.

Injection of the solution at 100 cm soil depth resulted in the soil-water collected from 80 cm to 120 cm to be enriched in ^2H throughout the study period. Eleven days after introducing the isotope solution the δ^2H values increased in xylem water collected tree branches and at breast height confirming the uptake of the isotope solution. There was also an enrichment of ^2H within 0 cm to 20 cm of the soil profile, but no change in the 20 cm to 40 cm, and 40 cm to 80 cm depth intervals. The enrichment of ^2H from 0 cm to 20 cm, but not between 20 cm to 80 cm indicated that the jack pine trees are likely responsible for hydraulic redistribution of soil water.

LESSONS LEARNED

The lessons learned for the Aurora Soil Capping Study research program are summarized by project. Some of the project learnings overlap with each other and may be repeated in different sections.

The Roots of Succession: Relations among Plants, Soil and Mycorrhizal Fungi in a Reclaimed Site (LJ0100)

- Coversoil material type was the key factor influencing early tree growth (five years after planting) at the study site, with seedlings performing better when growing on upland surface soil than peat coversoil. There are nutrient differences such as phosphorus availability (which is low in the peat coversoil), which could be affecting the tree growth. However, the soil temperature in peat coversoil is significantly lower than upland surface soil which may be the main reason for the growth differences.
- There was no improvement in tree growth found for all tree species with an increase in peat or upland surface soil capping depth (i.e., 10 cm versus 30 cm peat, and 10 cm versus 20 cm upland surface soil).
- There may be a risk of placing too much (too thick) peat coversoil when there is minimal to no mineral component contained in the peat material. The lower soil temperature in peat coversoil treatments is the result of its thermal conductivity properties (See summary for LJ0099 below for more details). Peat coversoil with little to no mineral component has a low thermal conductivity, resulting in a delayed warming of the soil and fewer total growing season days. Above- and below-ground growth is restricted due to the reduced growing season.
- Subsoil material type has an effect on tree growth, but to a lesser degree than coversoil type. Subsoil material type influenced trembling aspen growth at the end of the five year assessment period, where the aspen had the greatest growth with Bm horizon subsoil. This study also found jack pine growth with soil treatments with deep subsoil C salvage material was greater than the growth on B/C horizon treatments. There is no conclusive evidence to suggest the reason for the growth differences with different subsoil materials, but the Bm horizon does contain significantly more P than the other subsoils (which is also limiting in peat coversoil). However, there are also relatively small differences in soil texture which could also have an effect on plant available water for growth.
- Subsoil capping depth had no effect on early tree growth. Comparison of treatments with peat (30 cm depth) over B/C horizon subsoil at thicknesses of 30 cm, 60 cm and 120 cm found no differences in tree growth for all species. However, the growth of all these treatments was significantly greater for all tree species when compared to a treatment with no subsoil (i.e., 30 cm peat alone). It should be noted that as the trees mature and develop a more extensive root system in the subsoil, tree growth differences may emerge with the different subsoil material types and capping depths.

- Growth differences across treatments were more evident in trembling aspen than jack pine and white spruce. Aspen has a higher growth rate, which requires them to access a larger area of the soil environment and acquire more resources for growth. Therefore, differences in soil conditions for each treatment may have had a greater influence on aspen growth. Potential responses of the other tree species may be delayed until their root systems expand laterally and vertically in the soil profile.
- Coversoil high in organic matter such as peat can result in low soil temperatures during bud flush of trembling aspen seedlings, resulting in decreased growth.
- Early tree growth performance of trembling aspen is more responsive to surface and sub-surface soil conditions than conifers such as white spruce and jack pine. This is likely due to their faster growing potential; allowing them an opportunity to seek resources and be influenced by the soil environmental conditions.
- Below-ground root development (i.e., root mass and length) in peat and upland surface soil materials was similar with above-ground growth. There was a decrease in root development within peat than upland surface soil coversoil.
- A mixture of tree species (i.e., trembling aspen, jack pine and white spruce), rather than one tree species, resulted in below-ground over-yielding (i.e., more root biomass in mixed stand than a single species at the same age and density) in the upland surface soil treatment. This effect was likely due to trees species having different phonological root depths, resulting in reduced belowground competition. Over-yielding was not observed in the peat coversoil treatment, perhaps due to unfavourable growth conditions such as the low soil temperature which was previously mentioned.
- Targeted fertilizer addition of nitrogen, phosphorus and/or potassium generally did not result in a significant increase in tree growth. A marginal increase in trembling aspen growth was found with phosphorus addition on one of the subsoil treatments. The lack of response may due to a number of factors such as low application rate and application method.
- The fertilizer application method had an impact on vegetation response. The fertilizer was applied as a solution on the soil surface. The site did not experience a significant precipitation event for an extended period of time after application, so the fertilizer remained near the surface. Additionally, the tree roots may have been dormant as the soil temperatures may have been low due to the insulative properties of the peat (mentioned previously). However, Russian thistle (competitive weed species) significantly increased in abundance with the fertilizer addition, indicating that some portion of the fertilizer did not reach the intended roots of the trees that were targeted for growth.
- The main driver of early vegetation colonization is the propagule bank contained within the coversoil materials. Vegetation in treatments with upland surface coversoil had much higher species richness, plant cover and species present in upland forests, than in treatments with peat coversoil and no coversoil (subsoil only).
- During the initial years following reclamation, the type of tree seedling species and their planting density had little to no effect on vegetation re-establishment and development from the propagule bank.
- Coversoil that are rich in vegetation propagules can be used as a tool for nucleation. Upland surface soil, which contains a rich diversity and abundance of propagules can be used as nucleation locations for the spread of plant species to the surrounding reclamation areas that have reduced propagule diversity and abundance.
- Ectomycorrhizal fungi development in the early years post-reclamation have a strong preference for tree species, rather than coversoil material type.

- Coversoil reclamation materials such as peat and upland surface soil (or forest floor material) retain propagules of ectomycorrhizal fungi and can be sources when used in reclamation. Upland surface soil retains some of the ectomycorrhizal fungal community that was present before salvage. Conversely, peat which is derived from a non-upland environment (e.g., water-saturated bogs and fens) does not contain ectomycorrhizal fungi that is associated with an upland soil environment.
- Planting a range of tree species has an additive effect of greater species richness and diversity of the ectomycorrhizal community in early-successional stands. However, when planting a diversity of tree species there were no synergistic effects found in early-successional stands.

Hydrocarbon Degradation and Mobility (LJ0219)

- Gas flux rates in the field from exposed lean oil sand (LOS) overburden, which is an indication of petroleum hydrocarbon degradation (PHC), varied spatially and temporally. However, a correlation with gas flux and PHC concentration was identified. High levels of soil moisture caused by rainfall events resulted in a temporary decrease in gas flux rates by reducing the air space available for CO_2 to travel in the soil and the dissolution of CO_2 in the soil-water phase.
- Soil temperature has a significant (positive) effect on gas flux rates, consistent with literature.
- Methane (CH_4) concentrations were generally higher in the subsurface and decreased towards the ground surface as a result of oxidation. Occasionally, elevated concentrations of CO_2 and CH_4 were detected in LOS overburden, possibly caused by the presence of low permeability layers in the overburden inhibiting free flow of gas to the surface. Eventual release of these of gases could have a temporary negative impact on plant growth.
- LOS overburden in the study is predominantly composed of PHC F3 and F4 fractions (i.e., heavy molecular fraction hydrocarbons). Degradation rates of PHCs in LOS overburden from the column study were relatively slow, indicating these hydrocarbons are relatively stable and not readily degradable. Biodegradation rates are correlated with soil temperature, measured to be approximately 60 g/yr at 22°C and 15 g/yr from 2°C to 14°C (mean average approximately 6°C). In relation to the total PHCs that were present in the LOS of the column (2.8 kg), the degradation rate measured for 2°C to 14°C (representative of field conditions) is < 1% of the total hydrocarbons.
- LOS overburden should have a low environmental impact on surface or groundwater quality. Benzene, toluene, ethylbenzene, xylenes (BTEX) and PHC F1 fraction were detected in column leachate. PHC F2 fraction leachate slightly exceeded screening level guidelines only in cases where the column temperatures were raised to ≥ 22°C, which is not reflective of general field conditions.
- Differences in reclamation soil cover design in the surface 0.1 m to 0.3 m did not alter the O_2 pore-gas concentration in the underlying subsoil layer of reclamation subsoil or LOS overburden at a depth of 0.5 m below ground surface.
- Bulk density of the LOS overburden is correlated with O_2 and CO_2 pore-gas, which is an indication of CH_4 oxidation. CH_4 oxidation rates were elevated at lower LOS bulk densities based on reduced pore-gas concentrations of O_2 and elevated pore-gas concentrations of CO_2. Conversely, rates of CH_4 oxidation appear to have been restricted at higher LOS bulk densities based on elevated pore-gas concentrations of O_2 and reduced pore-gas concentrations of CO_2.

- Soil water content also plays an important role in the oxidation of pore-gas CH_4. The capability of LOS to oxidize pore-gas CH_4 may be limited when the soil volumetric water content of the LOS is approximately < 15% and > 24%.
- Based on the reclamation soil materials and LOS overburden of the study, the results suggest a thicker reclamation soil cap (> 1 m) may require a LOS overburden bulk density < 1.5 Mg/m^3 in order to maintain sufficient pore-gas O_2 concentrations in the plant-rooting zone of the soil reclamation cover, while allowing sufficient oxidation of CH_4 in the uppermost horizon of the LOS. If a thinner soil reclamation cover (< 1 m) is placed, a bulk density > 1.5 Mg/m^3 may be necessary to maintain sufficient pore-gas O_2 concentrations in the plant-rooting zone of the soil covers, while allowing sufficient oxidation of CH_4 in the uppermost horizon of the LOS.
- Based on the study findings, the reclamation soil cover design (i.e., material type and thickness) appears to be less impactful to pore-gas dynamics than the physical characteristics (i.e., bulk density) of the LOS overburden.

Water and Carbon Isotope Methods Development (LJ0201)

- Methods were developed and standardized for the collection of stable isotopes of pore water collected from soil or vapour sampling.
- Methods were developed to use analytical equipment in the field for in-situ measurements of stable isotope composition of pore water through vapour sampling.
- Verification of the ability to simulate advective/diffusive transport of the stable isotopes of water in combined aqueous/vapour phases of an unsaturated soil.

Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected, Reclamation Soils (LJ0099)

- Increases in lean oil sands (LOS) overburden bulk density reduces the volume of macropores, while higher PHC concentrations fill micropores and reduces the connectivity of macropores. This reduces the pore space and saturated hydraulic conductivity of LOS, which has the potential to contribute to the retention of more water and nutrients in the overlying soil reclamation cover (i.e., soil water perching above the LOS).
- Aggregated oil sand materials (AOSM) in reclamation subsoil material, at the range of concentrations and forms (e.g., bands, layers, balls) found in a reclamation profile, has no significant effect on water infiltration rate and nutrient retention. AOSM had no significant effect on soil water retention curves and saturated hydraulic conductivity of reclamation subsoil. Even though AOSM is water repellent and does not contribute to soil water storage, its presence in the soil may impede and retain gravity-water flow in the subsoil. This effect appears to offset the loss of soil water storage of AOSM.
- There was significantly less preferential flow and penetration depth in reclamation soil profiles at the study than a similar textured natural soil in the region. This is likely the result of loss of macropores from soil salvage and placement (i.e., due to the creation of a massive soil structure) and/or a lack of a well-defined root system acting as channels for water flow. Peat coversoil also was able to retain a significantly greater volume of water which reduces the infiltration depth of gravity-water flow.
- Coversoil with a high proportion of organic matter (i.e., peat) substantially delays the warming and cooling of the soil profile, relative to a coversoil with a higher mineral content. Tests of peat coversoil from the study with variable proportions of sand mixing found that the thermal conductivity of peat alone was about

one-fifth of that of the study's coarse textured subsoil. Modelling was able to accurately predict the soil thermal conductivity and thermal capacity of peat-mineral mixes under both frozen and unfrozen conditions.

- AOSM collected from subsoil materials at the study site and the Aurora North Mine was found to be water repellent (hydrophobic). Measured times for water droplet penetration for AOSM were generally within 60 seconds, but at reduced infiltration rates compared to the surrounding soil. It's unlikely that AOSM will create preferential water flow. However, they may have the ability to increase the water retention time in the subsoil for plant-water uptake.
- LOS overburden field saturated hydraulic conductivity (Ks) and peat have the greatest influence on transpiration (T) and net percolation (NP). Changes in T and NP based on subsoil thicknesses ranging from 50 cm to 150 cm were relatively small (when coarse textured like the study). LOS with a low Ks can restrict drainage sufficiently to increase the water availability to plants in the reclamation cover following a large infiltration event. Conversely, higher Ks LOS allows for drainage of water from the subsoil, which reduces the available water stored in the subsoil and decreases transpiration. Peat coversoil has a higher water storage capacity than coarse textured upland surface soil and subsoil. This increases the water storage capacity and potential for plant growth. The low water storage capacity of coarse textured subsoil results in minimal increases in plant-available water with increases in thickness (e.g., 50 mm of additional water available with a 100 cm increase in subsoil thickness).
- Soil physical properties (e.g., soil texture, bulk density, hydraulic conductivity, restricting layers) play a critical role in soil-water availability for tree and understory vegetation establishment in reclaimed and natural coarse textured soil profiles. However, water availability should also consider the importance of hydraulic redistribution. Jack pine were found to be able to acquire water at depth and to redistribute it near the soil surface. Trees (and other vegetation species) that are able to perform hydraulic redistribution may play an important role in the ability of vegetation to survive in moisture limited environments (e.g., a ecosites) through acquiring water deep in the soil profile and redistributing it near the surface where most roots are present.
- The cosmic-ray soil moisture (COSMOS or CRP) probe was able to provide comparable large-scale measurements of stored water that were collected from direct sampling of the instruments installed at the study site, despite the wide range of soil organic matter contents and cover designs present at the study. The results proved the COSMOS probe is suitable for monitoring watershed scale soil water content and has the potential to be down-scaled with modelling, to estimate soil–water content for a range of soil material types within the footprint. The COSMOS probe also was able to provide accurate real-time wide-area snow water equivalent (SWE) measurements over an area of approximately 40 ha.

Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils (LJ0201)

- Relatively small changes in soil profile texture, (e.g., sandy loam versus loamy sand, or loamy sand versus sand) and/or textural discontinuities in the subsoil, can result in a wide range of vegetation community characteristics. Textures of the upper soil profile of lower productivity pine forest stands contained a mean sand content of 94%, while higher productivity aspen forest stands had a mean of 88% sand. This corresponded with an increase in silt and clay content of ≤ 8%.
- Soil texture of the upper soil horizons (e.g., B horizon) or texture discontinuities at lower depths create a feedback loop with vegetation productivity and community development. The aspen forest stands had higher total nutrient stocks and quality (e.g., lower C:N and higher C, N, P, S, Ca, Mg and K) in the forest floor material

than the pine forest stands. This is likely due to a finer textured soil profiles or textural discontinuities providing more plant-available water for increased growth—in turn this provides greater quantity and quality of litter that provides nutrients, which is also critical for plant growth. This has an effect on site vegetation productivity and the type of vegetation species that are able to establish.

- Landform substrates that have a textural discontinuity and/or restricting layer—like those of the study which contains a coarse textured subsoil over lean oil sands—may be more suitable for an aspen type community. Conversely, a jack pine type community may be more suitable with a coarse textured soil cover and substrate similar to ones found in natural stands in the region. Jack pine forest stands in the study typically had textures with 94% to 99% sand and had very little variation in soil texture to depth of at least 2 m. On the other hand, the aspen forest stands typically had texture of sandy loam or finer (< 85% sand) and/or textural discontinuities within the upper and lower soil profiles (i.e., within 2 m of the surface).
- Glucose addition (priming) in peat and FFM coversoils triggered soil organic matter mineralization, confirming that the organic carbon component in peat is primarily unavailable to the soil microbial community. The observed priming effect resulted in a shift in the overall microbial community structure, although there was minimal movement towards the two compared natural soil forest floor materials.
- Upland surface soil coversoil did not show any enhanced soil organic matter mineralization linked to glucose addition, similar to the two forest floor materials sampled from natural soils. Nonetheless, the overall microbial community structure in the FFM became more similar to that of the natural soil forest floor material following glucose addition.
- Most of the plant-available N in the reclaimed soil profiles is concentrated in the coversoil material (upland surface soil or peat); subsoil or underlying substrates (i.e., lean oil sand overburden or tailings sand) provide minimal available N.
- Upland surface soil (or forest floor material) and peat coversoils release comparable amounts of N on a per kilogram of soil basis. However, when N release rates are normalized based on each material's organic C content, the release of N is six times greater for upland surface soil than for peat. Overall C mineralization and P release rates were over one magnitude higher with upland surface soil than peat.
- In the early stages after soil reclamation placement, upland surface soil releases more N and P than peat. However, this will result in the material degrading faster than peat, while peat may provide a smaller but more stable release of N. The ratio of N to P release rates of the study was 15 for upland surface soil versus > 250 for peat. Such a wide N/P ratio for the peat material may result in plant P deficiency in the early years post-reclamation, in the absence of some other form of nutrient addition either by land management (e.g., fertilization) or normal soil processes (e.g., lowering of pH through weathering and leaching of base cations, or release of organic acids in root exudates).
- Peat coversoil is better able to retain inorganic N addition than upland surface soil. Laboratory soil columns tests with nutrient additions that underwent simulated intense rainfall found the peat coversoil was able to retain 44% of its initial inorganic N, while 84% of the inorganic N present in the upland surface soil was leached down the soil profile. There is little risk of losing fertilizer-P from the coversoil by leaching. However, the addition of P to peat coversoil may have little impact on plant growth in the short term (considering its low extractability and fast immobilization of P).

- Nutrient leaching in reclaimed soils can be significant in soil cover designs comprised of coarse textured upland surface soil and subsoil during an intense rainfall coinciding with a high concentration of nitrate-N in the coversoil.
- Textural discontinuities and restricting layers (e.g., lean oil sand overburden) may be able to restrict gravity-water flow from the soil profile, and thus, retain more nutrients in the root zone for plant growth. The leaching of N was slower and partly restricted in the soil columns that contained a base of lean oil sand, compared to reclamation subsoil material and tailings sand.

Re-establishment of Forest Ecosystem Plants, Microbes, and Soil Processes in Coarse Textured Reclamation Soils (LJ0201)

- Soil macro-nutrients are available in similar proportions between upland surface soil and the forest floor material (LFH and surface mineral horizon(s)) of a natural, tree-harvested analogue. Conversely, peat coversoil has greater nitrogen, sulfur, and calcium availability, but lower phosphorus and potassium availability.
- Microbial community structure and function in early reclamation at the study site vary more across different coversoil types (e.g., peat vs upland surface soil) than by application depth. Upland surface soil was more similar in microbial community structure and function than with the surface soil horizons of a natural, tree-harvested analogue than peat coversoil.
- Shallower peat and upland surface soil application depths (i.e., 10 cm), rather than deeper applications (i.e., 20 cm for upland surface soil and 30 cm for peat) had more similar soil microbial function of a natural, tree-harvested analogue.
- Principal component analysis of soil and foliar nutrients found peat coversoil was dissimilar to upland surface soil and forest floor material of natural sites. Peat coversoil has greater soil N, K, S, Ca and foliar Ca (aspen only), as a well as lower foliar P, Mg and Mn.
- Admixing peat from the study with subsoil improves tree growth. Greenhouse studies evaluating tree growth with different proportions of peat and mineral subsoil from the study showed improved tree growth with the addition of subsoil with peat. Higher P and K concentrations were found with the addition of subsoil.
- The addition of peat biochar in the greenhouse trial affected nutrient availability of the peat-mineral mix trial, but there was no response in tree growth.
- Soil microbial gene sequencing of peat-mineral mix coversoil found the microbial community assemblage is more similar in diversity and phylogeny to pure peat. However, a peat-mineral mix of 50:50 did display some functional similarity with the upland surface soil in terms of nutrients.
- Some below-ground function remains after soil reclamation salvage and placement activities. Soil respiration in the first two years after soil placement at the study found seasonal patterns similar to natural reference sites on upland surface soil treatments. However, soil respiration in peat treatments did not have a similar seasonal patterns like those of natural reference sites. Soil microbial biomass and heterogeneity increased with time since disturbance, potentially indicating stages of site recovery for coarse textured sites (e.g., a/b ecosites).

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Published Theses

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Hankin S. L. 2015 Native tree seedling interactions with variations in edaphic properties in upland boreal forest restoration. MSc Thesis, 142 pages, Department of Renewable Resources, University of Alberta.

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RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta (UofA) and University of Saskatchewan (UofS).

Principal Investigators:

LJ0099 – Bing Si, Co-investigator Lee Bar (UofS)

LJ0100 – Simon Landhäusser and Justine Karst (UofA)

LJ0201 – Lee Barbour and Jim Hendry (UofS); Sylvie Quideau, Co-investigators Miles Dyck and Simon Landhäusser (UofA); M. Derek MacKenzie (UofA)

LJ0219 – Ian Fleming (UofS)

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
LJ0099 - Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected, Reclamation Soils				
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LJ0100 - The Roots of Succession: Relations Among Plants, Soils and Mycorrhizal Fungi in a Reclaimed Site				
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Caren Jones	University of Alberta	Field Technician		
Pak Chow	University of Alberta	Lab Technician		
LJ0201 – Water and Carbon Isotope Methods Development				
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Mingbin Huang	University of Saskatchewan	Research Scientist		
LJ0201 –Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils				
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Sylyanne Foo	University of Alberta	Assistant		
Shelby Buckley	University of Alberta	Assistant		
Justine Lejoly	University of Alberta	Technician		
LJ0201 – Re-Establishment of Forest Ecosystem Plants, Microbes, and Soil Processes in Coarse Textured Reclamation Soils				
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Jeff Battigelli	University of Alberta	Research Associate		
LJ0219 – Hydrocarbon Degradation and Mobility				
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Research Collaborators: LJ0201 – Brad Pinno and Brian Lanoil, University of Alberta

Evaluating The Success of Fen Creation (Phase II)

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial, Teck Resources Ltd.

Status: Year 2 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 Nikanotee Fen Watershed (NFW) and ii) to develop alternate 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 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 NFW 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 NFW it is important to understand how placed materials have evolved over the first five to 10 years (per the above objective), and how they have developed over longer time-frames (10 to 30 years) at other reclaimed sites. 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 NFW 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

Objective 1: Assessment of Nikanotee Fen ecosystem functions

Research conducted summarized six year datasets for hydrological and geochemical variables and provided information to inform boundary conditions for future design modelling efforts. In 2018, methane emissions at NWF were higher when compared with 2013 to 2017. Nikanotee Fen continues to experience a larger growing season water deficit, when compared with the Poplar reference fen, however, both Nikanotee and Poplar Fen have higher water tables than two other reference sites examined.

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

NFW is strongly influenced by groundwater input, relying on recharge through upland soil cover. Since construction, upland cover soil hydraulic properties have continued to improve. Thin cover soil promotes groundwater recharge, and a thicker cover soil promotes evapotranspiration. Vegetation promotes evapotranspiration, and root water uptake reduces frequency of recharge events to the underlying aquifer. The LFH cover soil and tailings sand exhibited limited spatial heterogeneity and could be adequately described with a single set of soil hydraulic properties. In the tailings sand, the total area wetted by finger flow was found to be low. A capillary barrier was found to exist between the LFH and underlying tailings sand, consistent with existing literature.

Total dissolved solids at NFW are elevated compared with reference fens, due to the presence of oil sands process water from the tailings sand aquifer, and high SO_4^{2-}, Ca^{2+} and Mg^{+} originating in source peat [1,2]. Salts are precipitating out of porewater within the fen peat and subsequently precipitating on the surface of the peat due to evapoconcentration. When precipitation increases, these salts return to solution and subsequently increase, and drive water of higher EC (electrical conductivity) down into the near surface rooting zone. DOC (dissolved organic carbon) concentration and quality at the constructed fen are more closely resembling that of reference fens sites. Although DOC concentration was not found to be controlled by salinity, DOC lability increased with increasing salinity. The more labile DOC is, the more easily it can be converted into carbon dioxide by microbial activity. Additionally, more labile DOC can more readily bind to contaminants, potentially increasing their mobility into downstream environments.

Trends during early ecosystem development appear directly linked to the development of vegetation, which in turn influences the system's ability to assimilate carbon. Since 2014 the fen has been sequestering CO_2, whereas the upland has remained a source of CO_2 with a trajectory towards functioning as a CO_2 sink (once upland vegetation is more established) likely within the next five years. Ecosystem productivity and water use efficiency remain stable throughout seasonal and annual fluctuations in water availability.

Sapflow sensors, installed at the start of the 2019 growing season, indicate transpiration peaking during the growing season for all species, and decreasing as senescence begins, as expected. *Populus tremuloides* and *P. balsamifera* transpire at the highest daily rates during peak growing season, this is due to low leaf area. Throughfall and stemflow collectors installed in 2019 showed *Picea mariana* trees intercepted the largest quantity of precipitation due to having highest leaf area.

Vegetation cover and above-ground biomass in the fen (dominantly *Carex aquatilis, Juncus balticus, Typha spp.*) peaked in ~2016, which coincided with the arrival of sodium in the rooting zone[1]. *Typha* and some *Carex* mortality were observed in 2018/2019, reducing above-ground biomass. Below-ground biomass has been steadily increasing since 2013[5].

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

Net Ecosystem Exchange, a measure of the net exchange of carbon between an ecosystem and the atmosphere, and a primary gauge of ecosystem carbon sink strength[4], shows that the Nikanotee Fen is a CO_2 sink, within the range of reference fens.

Pre-fire (2013 to 2015) and post-fire (2016 to 2018) conditions at Poplar Creek Reference Fen were compared. Methane emissions indicated a switch in the typical understanding of boreal peatland, methane emissions. Methane emissions were significantly lower in the burned hollows in both years compared to unburned hollows. Methane emissions were higher at the unburned site than prior to the fire, where the water table was close to the surface. At burned sites, no relationship was found between methane emissions and water table, even under similar hydrological conditions to the unburned site. There was also significantly higher methane production potential from the unburned site than the burned sites. The reduction in methane emissions and production in the hollows at burned sites highlights the sensitivity of hollows to fire. Fire consumes and removes labile organic material for potential methanogenesis, lowering the overall greenhouse gas contribution. The resistance of hummocks to fire also results in reduced impact on methane emissions and likely faster recovery to pre-fire methane emission rates.

No significant change to DOC concentrations were observed post-fire; DOC is instead controlled by local hydrogeological factors rather than fire, a finding supported by the literature. Fall hydrological conditions and subsequent winter storage processes impose a strong control on DOC concentrations in the following year, rather than assuming vegetative or natural disturbances as the dominant drivers, an important consideration for future DOC trend modelling.

An examination of ecohydrological role of seasonal ground ice at a reference poor fen, Pauciflora, revealed that melting seasonal ground ice reduces the energy available for evaporation, which reduces potential evapotranspiration, creating feedback that reduces water loss in the spring. This work outlines a feedback process that may be useful in future fen designs. Controls on the spatial variation in seasonal ground ice thickness are a consequence of hillslope shading and proximity to mature trees. Spatial variability in observed melt rates were low, meaning even lower spatial variability with the reduction of potential evapotranspiration. This indicates that potential evapotranspiration measurements can be scaled up from a reference plot scale to reference site scale, such that they can be used for future alternate design modelling for different fen designs.

LESSONS LEARNED

The numerical modelling of NFW hydrology and solute transport has produced recommendations for future reclaimed upland watersheds above fens, specifically the carrying capacity for maximum leaf area index. This may inform future planting prescriptions previously developed by informing industry as to specific species and densities for planting prescriptions that will allow for successful reclamation under modelled climate regime changes expected for the region.

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PRESENTATIONS AND PUBLICATIONS

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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)
Dr. Richard Petrone	University of Waterloo	Co-Investigator		
Dr. Maria Strack	University of Waterloo	Co-Investigator and NSERC CRC		
Dr. David Cooper	Colorado State University	Co-Investigator		
Scott Davidson	University of Waterloo	Post-Doctoral Fellow		
John Hribljan	Colorado State University	Post-Doctoral Fellow		
Natasa Popovic	University of Waterloo	PhD	2017	2021
Owen Sutton	University of Waterloo	PhD	2015	2020
Brandon Van Huizen	University of Waterloo	PhD	2015	2020
Hilary Irving	University of Waterloo	MSc	2017	2019
Sarah Fettah	University of Waterloo	MSc	2018	2020
Tyler Prentice	University of Waterloo	MSc	2017	2020
Gabriel Dube	University of Waterloo	MSc	2018	2020
Suyuan Yang	University of Waterloo	MSc	2018	2020
Rebecca Cameron	University of Waterloo	MSc	2018	2020
Emily Prystupa	University of Waterloo	MSc	2018	2020
Karisa Tyler	University of Waterloo	MSc	2018	2020
Jacob Whitehouse	University of Waterloo	MSc	2019	2021
Matthew Elmes	University of Waterloo	PhD	2014	Completed 2018
Christine Van Beest	University of Waterloo	MSc	2016	Completed 2018
Lewis Messner	Colorado State University	MSc	2015	Completed 2019
Adam Green	University of Waterloo	Technician		
Eric Kessel	University of Waterloo	Data Manager		
James Sherwood	University of Waterloo	Project Manager		

Research Collaborators: Colorado State University

Sandhill Fen Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multi researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

Syncrude Canada Ltd. (SCL) has undertaken over 30 years of research and monitoring to understand and develop best practices for out of pit landforms and structures (i.e., upland landscapes conducive to the development of upland forests) such as overburden disposal areas, tailings dyke beaches, and slopes of tailings storage areas. The closure landscape will also contain in-pit 'soft tailings' landforms. Soft tailings are generally defined as tailings that do not possess sufficient shear strength to support the earth moving equipment utilized for closure and reclamation operations. Soft tailings include un-amended fluid fine tailings (FFT), densified FFT, FFT centrifuge cake (FFTC) and composite tailings (CT). CT (a mixture of coarse and fine tailings with gypsum) is one of the tailings treatment technologies first developed and commercialized in the industry.

The objectives of the Sandhill Fen Research Watershed (SFRW) are to:

1. Develop technology and practices for reclamation of sand capped soft tailings; and
2. Test the ability to re-establish fen wetlands.

The SFRW is located in the northwest corner of Syncrude's East in Pit (EIP). EIP is a former mine which has been hydraulically filled with approximately 50 m of CT and a portion of EIP is capped with varying amounts of tailings sand. The design intent of the SFRW was to create a pilot watershed with the necessary initial conditions to support a wetland with the potential to develop into a fen over time. Sandhill Fen was designed, constructed, reclaimed and revegetated as an instrumented watershed between 2008 and 2012, and has been operational since June 2013. SFRW is approximately 55 ha, and includes a nearly 17 ha primary wetland surrounded by an upland area with seven hummocks, two perched fens, and associated infrastructure (roads, research centre, boardwalks). The hummocks were constructed with mechanically placed tailings sand directly on top of the tailings sand cap.

The SFRW program utilizes the Instrumented Watershed Research approach to address the objectives. Watershed Research is a scientific approach that involves intensive monitoring of constructed landforms which enable the execution of concurrent, integrated, multi-disciplinary research programs. Central to the watershed approach are the determination of:

- Water and energy balances (location, quantity, quality and movement of water in a landscape);
- Mass balances (including inorganics, organics, ions, nutrients, metals); and
- Plant and ecological responses.

The SFRW was designed to enable the integrated study of watershed performance and the opportunity for discrete comparisons between hummocks. Each of the seven hummocks vary in height, shape and orientation. Five of the seven hummocks were reclaimed with a ‘dry’ target moisture regime (a/b-ecosite), and two of the seven hummocks were reclaimed with a ‘moist’ target regime (d-ecosite). The ‘moist’ hummocks were reclaimed with 30 cm of clay till subsoil and 20 cm of upland surface soil salvaged from a d ecosite source location. The ‘dry’ hummocks were reclaimed with 40 cm of coarse sand and 15 cm of upland surface soil from an a/b ecosite source location. Each hummock has areas with coarse woody materials. The SFRW uplands and hummocks were revegetated with the standards tree species mix (Table 1).

Table 1: Planting prescriptions for upland areas of Sandhill Fen Research Watershed

Prescription Type (Density)	Tree species
No planting (0 stems/ha)	No trees planted
A/B ecosite (5,000 or 10,000 stems/ha)	10% Aspen (*Populus tremuloides*) 10% White spruce (*Picea glauca*) 80% Jackpine (*Pinus banksiana*)
D ecosite (5,000 or 10,000 stems/ha)	80% Aspen (*Populus tremuloides*) 10% White spruce (*Picea glauca*) 10% Jackpine (*Pinus banksiana*)
Standard (2,000 stems/ha)	20% Aspen (*Populus tremuloides*) 20% White spruce (*Picea glauca*) 20% Jackpine (*Pinus banksiana*) 20% White birch (*Betula papyrifera*) 20% Black spruce (*Picea mariana*)

Plots of varying tree density and species composition (Table 1) were established on different aspects (north-facing, plateau, south facing) of each hummock. Control plots (no trees planted) were also established.

In the central wetland, a 50 cm clay till layer was placed and overlaid with 50 cm of freshly salvaged peat. A native seed mix (6 dominant and 15 subdominant wetland species) was broadcast to the wetland area in the winter of 2011 and summer of 2012. Twenty-two experimental wetland vegetation plots (9 m x 9 m) were planted with native wetland seedlings in summer of 2012.

The SFRW is instrumented with a large number (> 175) of piezometers, two eddy-covariance monitoring stations, a weather station, a freshwater pond, a leaky berm, four underdrains and an outlet weir.

To support collaboration and integration among the multi-disciplinary SFRW studies, an online metadata and mapping tool system was developed by the University of Windsor. The tool system allows researchers access to information being collected by others, thereby assisting in collaboration and integrated interpretation.

RESEARCH TEAM AND COLLABORATORS

The SFRW team includes a number of research disciplines for each research study. A list of research projects, including the primary investigator and their classification within COSIA are provided in the table below. A more detailed description of "Hydrogeologic Investigation of Sandhill Fen and Perched Analogues" can be found in the accompanying project updates in this document. Completed projects (see earlier annual reports for descriptions):

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)
LJ0204	Water and Carbon Balance in the Constructed Fen	Dr. Sean Carey Dr. Elyn Humphreys (McMaster University and Carleton University)	Complete in 2018
LJ0204	Forest reconstruction on upland sites in the Sandhill Fen Watershed	Dr. Simon Landhäusser Dr. Brad Pinno (University of Alberta)	Complete in 2018
LJ0204	The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development	Dr. Dale Vitt Dr. Stephen Ebbs Dr. Kelman Wieder (Southern Illinois University and Villanova University)	Complete in 2016
LJ0204	Hydrogeologic Investigation of Sandhill Fen and Perched Analogues	Dr. Carl Mendoza Dr. Kevin Devito (University of Alberta)	Underway
LJ0204	Influence of peat depth, hydrology and planting material on reclamation success within a created fen-like setting	Dr. Lee Foote (University of Alberta)	Complete in 2016
LJ0204	Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality	Dr. Jan Ciborowski (University of Windsor)	Complete in 2016
LJ0204	Sandhill Fen Geospatial Metadata System	Alice Grgicak (University of Windsor)	Complete in 2016
LJ0204	Assessing the Sodium Buffering Capacity of Reclamation Materials in Sandhill Fen	Matt Lindsay (University of Saskatchewan)	Complete in 2016

Sandhill Fen: Hydrogeologic Investigations of Sandhill Fen and Perched Analogues

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 8 of 8 (awaiting final report)

PROJECT SUMMARY

This program investigated integrated hydrologic studies to quantify and generalize landscape and transition zone hydrologic interactions within the Sandhill Fen Research Watershed (SFRW) at a number of scales. These range from determining the hydrologic role of basin-scale hummocks, to the contributing influence of transition areas and ephemeral draws, to the hydrologic functioning of two isolated perched fens. The field studies will help develop and refine models that can be used to generalize hydrologic and salt dilution requirements for future landscape construction.

This work is tightly integrated with other programs on the Sandhill Fen Watershed, including Simon Landhäusser's work on vegetation succession and very shallow moisture regimes on hummocks, and Sean Carey's work on atmospheric interactions. Additional work within this program looks at monitoring the hydrologic behaviour of a perched fen complex at the Utikuma Region Study Area (URSA). This is valuable in providing background conditions for natural peatlands and to assess the relative role of climatic variability on initiation and maintenance of the constructed fen.

This program addressed the following objectives:

Objective 1: Test the configuration, height and size of coarse grained hummocks required to maintain wetland and forest ecosystems on reconstructed landscapes

Objective 2: Test soil layering in perched fens and the role of storage in layers of different types and thicknesses on generating moisture surplus for wetland and adjacent forestland water demands

Objective 3: Determine the role of ephemeral draws on generating moisture surplus and delivering water to wetland and adjacent forests

Objective 4: Use reference perched fens (burned and unburned) to quantify the hydrological behavior of a perched fen overlying coarse-grained substrates

PROGRESS AND ACHIEVEMENTS

This past year was devoted to the processing and interpretation of data.

This program examined the hydrogeologic characteristics of the Sandhill Fen Watershed, and the resulting groundwater flow systems following construction. The hydrogeology of the watershed was evaluated using field measurements over several years from 230 shallow piezometers including groundwater measurements (water level, temperature, and electrical conductivity), analysis of water samples, and interpretation of soil saturation maps. Elemental chemistry and stable isotopes of water were used to resolve mechanisms leading to observed solute distributions. A three-dimensional steady state numerical groundwater flow model was calibrated from field observations.

Activities during the reporting period involved interpretation of past data and integration of field results into conceptual models. No field work was performed.

LESSONS LEARNED

General results from this program are summarized as follows:

- Geochemical, electrical conductivity and stable water isotope data indicate that deeper groundwater (deeper than 1.8 m below the water table) is predominantly composed of oil sands process-affected water (OSPW).
    - In areas where the water table is regularly found at depth (> 1.8 m below ground surface),the chemistry of the 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.
- A shallow groundwater system dominated by lateral flow has developed in the Sandhill Fen Watershed.
- The flow system is influenced by hydraulic conductivity and has little inputs from deeper groundwater.
- Most recharge originates from a laterally extensive berm that coincides with the groundwater divide.
- Shallow water tables, and standing water in the wetland/lowland areas are most sensitive to precipitation.
- In general, solute concentrations increase with depth in the watershed. However, areas with shallow water tables and shallow slopes exhibit elevated solute concentrations after precipitation events. Sloped areas with shallower water tables that fluctuate within the rooting zone tend to have elevated solute concentrations near the water table, especially after precipitation events because of lateral groundwater seepage, groundwater ridging and evapoconcentration.
- Fresh shallow groundwater systems can develop for wetland reclamation.
    - The Sandhill Fen Watershed landform design (hummocks) enabled a freshwater lens to develop at the water table beneath hummocks where groundwater was approximately 2 m below ground surface.
- When Tailings Sand, which contains residual OSPW, is used in landform construction, it is possible to promote groundwater recharge in upland areas by building hummocks that are broader in areal extent and more moderate in height (relative to the anticipated water table) than those in the Sandhill Fen Watershed, in order to support water tables approximately 2 m below ground surface.

- Wetlands should occupy most, if not all, of the lowland area exposed to shallow fluctuating water tables to reduce movement of OSPW.
- Landform design and construction should create abrupt interfaces between upland hummocks and lowlands to limit the extent of seepage faces.
- These recommendations will allow better management of recharge and solutes so that the shallow groundwater system can remain fresh, while sourcing water to down gradient environments.
- Detailed soil-moisture data and corresponding numerical modelling results indicate that the degree of recharge and subsequent mounding beneath hummocks is largely controlled by vegetation and reclamation material texture and thickness.
- It is too early to tell which direction water will eventually flow between the uplands and lowlands (e.g., forest to wetland versus wetland to forest, or frequent water reversals). Vegetation and reclamation material texture and thickness influence recharge rates below hummocks; however, overall recharge is more areally extensive than simply the contribution from the hummocks constructed in the Sandhill Fen Watershed
- The electrical conductivity (EC) at depth (within 10 m of the ground surface) is 2,000 to 3,000+ µS/cm. However, it tends to be lower, yet highly variable, in shallow piezometers and wells. At depth, higher EC is correlated to elevated sodium concentrations. Elevated electrical conductivities are observed along the toe of the SE swale following precipitation events.
- Results suggest the potential ability of small topographic changes to provide water table separation and surface water recharge.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Twerdy, Pamela. 2019. Hydrogeological Considerations for Landscape Reconstruction and Wetland Reclamation in the Sub-humid Climate of Northeastern Alberta, Canada. University of Alberta, MSc thesis. 78 pp.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Carl Mendoza

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Carl Mendoza	University of Alberta	Principal Investigator		
Kevin Devito	University of Alberta	Principal Investigator		
Maxwell Lukenbach	University of Alberta	Postdoctoral Fellow		
Mika Little-Devito	University of Alberta	Research Technician		
Pamela Twerdy	University of Alberta	MSc	2016	2019
Jordan Pearson	University of Alberta	Research Assistant		
Hayley Hedstrom	University of Alberta	Research Assistant		
Brittany Onysyk	University of Alberta	Research Assistant		

Research Collaborators: Our hydrogeological work is closely tied to a number research programs including:

Forest reconstruction on upland sites in the Sandhill Fen Watershed
Collaborator: Simon Landhäusser, University of Alberta

Water and Carbon Balance in the Constructed Fen
Collaborator: Sean Carey, McMaster University

Applying natural analogues to constructing and assessing long-term hydrologic response of Oil Sands reclaimed Landscapes
Collaborator: Kevin Devito, University of Alberta

NSERC – Syncrude Industrial Research Chair in Mine Closure Geochemistry

COSIA Project Number: LJ0292

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Final Cumulative Summary

PROJECT SUMMARY

Dr. Lindsay's Associate NSERC/Syncrude Industrial Research Chair (IRC) in Mine Closure Geochemistry started on April 1, 2014 with support from NSERC, Syncrude Canada Ltd. (Syncrude), and the University of Saskatchewan (U of S). The overall goal of this IRC program has been to develop geochemical and conceptual models to inform oil sands mine closure planning. Achieving this goal required that a comprehensive understanding be developed of the geochemical characteristics and evolution of oil sands mine materials within closure landscapes. The specific research objectives and activities defined for this IRC therefore focus on developing this geochemical understanding.

Interdisciplinary field and laboratory studies of chemical, biological, and physical processes have examined controls on the release, transport, and attenuation of contaminants in oil sands mine closure landscapes. This research examined relationships between geochemical and hydrogeological processes, and assessed the influence of geochemical variability on contaminant mobility across a range of measurement scales. Emphasis was on processes occurring at environmental interfaces, including mineral grain margins and material boundaries. This research addressed four principal objectives:

Objective 1: Define the geochemical characteristics of existing waste deposits.

Objective 2: Identify processes and conditions controlling water quality.

Objective 3: Constrain geochemical implications of potential closure scenarios.

Objective 4: Develop conceptual models of the geochemical evolution of closure landscapes.

These research objectives and associated activities initially focused on tailings centrifuge cake (cake) and fluid petroleum coke (coke) for the following three reasons: (i) information on their geochemical characteristics and evolution were limited; (ii) large volumes of these materials will be stored in the closure landscape; and (iii) results are immediately applicable to ongoing closure planning.

PROGRESS AND ACHIEVEMENTS

This research was program was completed March 2019. Specific details and cumulative learnings of the program are outlined below.

Objective 1: Define the geochemical characteristics of existing waste deposits

This research objective focused on cake and coke deposits and involved several field-sampling campaigns. Detailed analyses were performed on these samples to determine their geochemical, mineralogical, microbiological, and physical characteristics. Research activities associated with this objective were completed in 2016. However, in 2017 and 2018, additional research was conducted on coke geochemistry.

Activity 1.1 – Characterization of existing centrifuge cake deposits

Centrifuged cake is a thickened tailings material produced by amending fluid fine tailings (FFT) with a coagulant (i.e., gypsum) and flocculent (i.e., polyacrylamide) and then centrifuging. The objective of this research activity was to identify principal controls on water chemistry in existing CFT deposits. This research has examined biogeochemical conditions and processes within two experimental and two full-scale CFT deposits at Mildred Lake. Kaitlyn Heaton completed her MSc in Geological Sciences on this topic between September 2013 and December 2015. Mattea Cowell subsequently conducted a related BSc honours research project between January and April 2016.

Activity 1.2 – Characterization of existing petroleum coke deposits

Petroleum coke is an upgrading by-product, which is produced during thermal cracking of the non-distillable bitumen fraction. Although the initial objectives of this research were achieved in May 2016, additional research was carried out in 2017 and 2018 focused on the molybdenum geochemistry of coke deposits.

The objective of this research activity was to characterize spatial and temporal variability in coke geochemistry, and to examine biogeochemical and physical processes controlling pore-water chemistry. Field sampling was focused on the coke beach (CB), coke watershed (CW), and coke cell 5 (CC5) deposits at Mildred Lake. This research was focused on: (1) pore-water geochemistry of coke deposits (CB, CW); (2) mineralogical, geochemical and physical characteristics of coke deposits (CB, CW, CC5); and (3) vanadium and nickel speciation within particles from coke deposits (CB, CW, CC5). Jake Nesbitt accomplished all objectives for this research activity through his MSc thesis, which he successfully defended in May 2016. This research activity was completed in May 2016 and resulted in two published journal articles (Nesbitt et al., 2017a and 2017b).

The additional research was initiated after elevated dissolved molybdenum concentrations (up to 2 mg L^{-1}) were observed within pore waters of the Coke Beach deposit. Dissolved molybdenum concentrations were found to be highest at elevated electrical conductivities and mildly alkaline pH conditions. There is some evidence that sulfidic conditions, commonly found in fluid fine tailings (FFT), may also promote attenuation of dissolved molybdenum. It was determined that adsorbed molybdenum(VI) complexes at coke particle surfaces are likely the principal source of dissolved molybdenum within these deposits. Although generally a minor phase, the abundance of these molybdenum(VI) complexes generally decreases with depth in the deposits, suggesting that they could form via oxidative weathering of molybdenum(IV)-sulfur phases above the water table.

A paper focused on nickel geochemistry was published in 2018 (Nesbitt et al., 2018), and another manuscript focused on molybdenum geochemistry was submitted and accepted in 2018 (Robertson et al., 2019).

Objective 2: Identify processes and conditions controlling water quality

This objective includes two principal activities that aim to improve the understanding of relationships between biogeochemical and physical processes influencing water quality in cake and coke deposits. This research is dependent upon the findings of the initial field studies outlined above (*Activity 1.1*, *Activity 1.2*) and was initiated in December 2016.

Activity 2.1 – Laboratory investigation of controls on cake pore-water chemistry

This research activity examined interactions among the chemical, biological, and physical processes that influence the geochemical evolution of cake. Field studies (*Activity 1.1*) demonstrated that evaporation and freeze-thaw cycling are important controls on pore-water chemistry in cake deposits. Consequently, two sets of laboratory research experiments were completed: (1) biogeochemical implications of coagulant/flocculent addition during cake production; and (2) freeze-thaw-evaporation induced salt redistribution within cake deposits.

Laboratory batch experiments on coagulant/flocculent addition have demonstrated that gypsum addition has a significant impact on water chemistry in cake deposits. For example, systematic increases in gypsum addition produced corresponding increases in electrical conductivity, sodium concentrations, and sulfate concentrations. Despite the increased sulfate concentrations, hydrogen sulfide production was not linearly proportional to gypsum addition and, therefore, initial sulfate concentration. This finding, based upon longer-term data (i.e., > 6 months) and relevant coagulant additions, differs from what we reported in 2016 for preliminary studies using excessively high gypsum amendment rates. Additionally, detectable methane concentrations were apparent throughout the experiment, but a relationship with gypsum addition was not apparent with these gypsum amendment rates. Final sampling of these experiments (64 weeks) was completed in July 2018.

Laboratory column experiments were conducted in 2018. Six columns (90 cm long by 35 cm diameter) were packed with fresh cake and each column was instrumented with thermocouples (temperature profiles) and load cells (column mass) connected to data loggers. The experiments were conducted over eight months in a freezer/cold room with capacity to accurately control temperature and relative humidity. The columns were subjected to three freeze-thaw-evaporation cycles, and pore-water sampling was performed following each cycle. These experiments concluded in December 2018 and data analysis completed by March 2019.

Activity 2.2 – Laboratory investigation of controls on coke pore-water chemistry

This activity has examined metal release from fresh fluid petroleum coke for the purpose of optimizing the use of coke in the closure landforms at closure. A series of laboratory column experiments were initiated in 2017, based upon initial research findings (*Activity 1.2*), to examine metal leaching capacity under different water chemistries that coke may encounter in closure landscapes. Specifically, metal leaching was examined for various water chemistries potentially encountered in closure landscapes: (1) meteoric water (i.e., precipitation/snow melt); (2) oil sands process-affected water (OSPW); and (3) acid rock drainage (ARD). These experiments included one large (70 cm long) column and six small (15 cm long) columns. The three solutions were pumped through the large column in sequence, whereas each solution was individually pumped through two small columns. Solute transport parameters were determined using conservative tracers for all columns, and also with geophysical methods for the large column.

Results show that metal leaching behaviour varies among elements and solution. In general, metal leaching was greatest at the beginning of the experiment (i.e., initial pore volumes) and declined with time. Leaching of vanadium (V), nickel (Ni) and molybdenum (Mo) was enhanced by ARD, whereas Mo leaching was also enhanced by OSPW. Nevertheless, cumulative metal leaching over 40 to 45 pore volumes represented only a small component of total metal concentrations. The experiments were initiated in July 2017 and both geochemical and geophysical monitoring was completed in October 2018. Data analysis was completed by March 2019.

Objective 3: Constrain geochemical implications of potential closure scenarios

Research focused on this objective started in October 2015 and concluded in 2018. This objective involved interdisciplinary field and laboratory studies designed to improve the understanding of the geochemical implications of proposed closure scenarios for water quality. More specifically, this research examined chemical, biological, and physical processes controlling the evolution of water chemistry under different closure scenarios. Consequently, the study of the mechanisms and implications of salt release from tailings (i.e., cake) and subsequent transport through overlying materials (e.g., coke, reclamation soil covers) was the principal focus.

Activity 3.1 – Field experiments on the geochemical implications of potential closure scenarios

This activity initially included a series of lysimeter experiments, but later expanded to integrate field (i.e., Sandhill Fen) and laboratory (i.e., columns) research.

The lysimeter experiments were constructed and instrumented in October 2015 using mine wastes and reclamation cover materials to emulate three potential closure scenarios:

1. Peat-mineral mix (0.5 m) overlying coke (1.0 m) overlying cake (1.5 m);
2. Coke (1.0 m) overlying cake (2.0 m); and
3. Cake (2.0 m) overlying tailings sand (1.0 m).

These three scenarios were replicated under water saturated and unsaturated conditions to mimic in-pit and out-of-pit closure landscapes. Much of the data collection was completed in 2017, however, data analysis was completed in 2018. Key findings of this research include:

- Upward vertical salt transport initially is advection dominated and proportional to cake dewatering;
- Limited sodium attenuation occurs within the coke layer;
- Evaporation from the surface results in substantial increases in dissolved salt concentrations; and
- Reclamation soil covers suppress evaporation and minimize impacts of evaporation on dissolved salt concentrations.

A complementary laboratory column experiment (1.5 m long, 0.2 m inner diameter) was completed in 2017. One Master's thesis focused on this Objective was completed in 2018 (Swerhone, 2018).

Objective 4: Develop conceptual models of the geochemical evolution of closure landscapes

This objective focused on data synthesis and the development of conceptual models of the geochemical evolution of closure landscapes. Integration of data derived from complementary research activities being conducted under Objectives 1 through 3 is critical for effective knowledge transfer and informing long-term closure planning.

Activity 4.1 – Synthesis of data from field and laboratory research activities

This final research activity was initiated in July 2016; however, all research included in Objectives 1 through 3 will support this final activity. This study integrates field measurements, laboratory observations, and modelling by PhD, MSc, and BSc students into a guidance document that will support ongoing mine closure planning. This data synthesis will be written up as a chapter for an upcoming book co-edited by Lindsay (IRC). The chapter will include key information on geochemical characteristics and behaviour of materials examined through this IRC, plus additional oil sands mine materials research conducted by Lindsay or published by others.

LESSONS LEARNED

Research conducted over the course of the IRC has provided valuable insight into: (1) the biogeochemical characteristics of centrifuged fine tailings; (2) metal mobility within coke deposits; (3) salt and metal transport within layered waste systems; and (4) salt transport within reclamation soil covers.

Centrifuge Cake: Gypsum amendment corresponds to increased sodium and sulfate concentrations within cake deposits. Although dissolved hydrogen sulfide concentrations are elevated in cake deposits, there does not appear to be a direct relationship between gypsum amendment (i.e., sulfate addition) and hydrogen sulfide concentrations when using relevant amendment rates.

Fluid Petroleum Coke: Leaching of vanadium, nickel and molybdenum can lead to elevated dissolved concentrations within coke deposits. Although solid-phase molybdenum concentrations are up to two orders of magnitude lower than vanadium, dissolved concentrations are similar within coke deposits. Molybdenum mobility increases under oxic and alkaline conditions but decreases under sulfidic conditions commonly found in FFT deposits. Metal leaching is also enhanced under acidic conditions characteristic of ARD. Unlike vanadium and nickel, molybdenum does not appear to be associated with porphyrin complexes, which may explain the enhanced leaching behaviour.

Layered Waste Materials: Initial dewatering of gypsum-amended cake drives upward advective transport of sodium-rich pore-waters. Advective fluxes decline with time and, eventually, diffusion will become the dominant solute transport process. Coke layers provided limited to no capacity for sodium attenuation (i.e., via ion exchange) during dewatering of underlying cake. Reclamation soil covers suppressed evaporation and limited evaporative concentrations of dissolved salts within coke layers. However, salt transport and accumulation within the soil covers was observed when water-saturated conditions extended to the ground surface.

PRESENTATIONS AND PUBLICATIONS (CUMULATIVE 2014-2019)

Published Theses

Vessey, C. J., 2019. Impacts of mineral surface reactions on aqueous vanadate attenuation. MSc Thesis, University of Saskatchewan, Saskatoon, Canada, 82 pp. https://harvest.usask.ca/handle/10388/12496

Swerhone, L. A., 2018. Trace element mobility in layered oil sands mine wastes. MSc Thesis, University of Saskatchewan, Saskatoon, Canada, 109 pp. https://harvest.usask.ca/handle/10388/9657

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RESEARCH TEAM AND COLLABORATORS

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Applying Natural Analogues to Constructing and Assessing Long-Term Hydrologic Response of Oil Sands Reclaimed Landscapes

COSIA Project Number: LJ0215

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural

Status: Final Cumulative Summary

PROJECT SUMMARY

The Utikuma Region Study Area (URSA) research sites, in the Boreal Plain (BP) region, have been the focus of ecohydrological and hydrogeological research for over 19 years (e.g. TROLS, HEAD, HEAD2, SFMN projects, etc.) that are informing the oil-sands mining industry on the natural functioning of aquatic, peatland and forestland systems with heterogeneity in vegetation and geology representative of the Ft. McMurray region (Devito et al., 2012). The wildfire burn in May 2011 of the Utikuma region encompassed much of the URSA transect, providing a natural analogue for a range of future reclaimed oil-sands landscapes in the initial years post construction, when the risk of landscape failure is greatest (Devito et al., 2016). Knowledge gained from this research will direct future management, and catchment design and planning, by providing the foundation for the development of resilient catchments and self-sustaining ecosystems in the next generation of reclaimed oil-sands environments.

Limits on water use and distribution on constructed oil-sands landscapes are key issues in initial and final closure plan developments. Consequently, we hypothesize that:

- On any landscape, water use, actual evapotranspiration (AET) and availability is proportional to the spatial weighting and interaction (perimeter–area) of hydrologic units (HU - wetland-forestlands) and the vegetation successional state; and
- The storage and connectivity (release of water for other systems) is proportional to the spatial weighting of hydrologic response area (HRA - landform material), temporally modulated by climate cycles.

The large-scale and range in degree of disturbance at URSA will test the role of soil type, soil depth, vegetation (wetland-forestlands, HUs) and geology (equivalent material storage – hydrologic response areas, HRAs) interactions with climate cycles on the timing and location of water and chemical storage and connectivity at the landscape scale in the BP.

Developing equivalent ecosystems and ensuring water needs on reconstructed oil-sands landscapes requires investigating:

- Whether BP ecosystems (wetlands-forestlands) develop and interact to minimize overall water use or develop to maximize productivity;
- How water use versus productivity varies with the succession (or development) of wetland vs. forestland ecosystems; and
- The role of organic (peat) depth versus local (mineral soils) and regional geology (HRA-connectivity) on the successional trajectory of natural and constructed wetlands and forestlands. By testing this on natural ecosystems following watershed burning, we determine the controls that maintain ecosystem function in response to disturbance.

These findings can be used directly in the development of landscape design criteria at both the local and lease scale to ensure long-term resilience of constructed ecosystems.

The overall objective of the research is to determine the distribution and limits of water use within reconstructed landscapes by examining the hydrological processes controlling the fluxes and stores of water within natural analogue landscapes (Devito et al., 2012). The research examines small-scale ecohydrological interactions (Scope 1), large-scale landscape interactions (Scope 2), and landscape evolution in early succession (burned) and mature (unburned) watersheds, in order to develop accurate conceptual models of how water moves through the BP landscape (Scope 3), and determines how this affects the trade-offs between catchment runoff and ecosystem productivity.

Specific objectives to address the hypotheses and questions are addressed in three scopes of research and nine objectives listed below.

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

Objective 1: ***Peatland substrate and ice layering.*** Determine the role of soil layering and ice formation in peatlands and mineral margin swamps on water storage, evapotranspiration rates and moisture conservation.

Objective 2: ***Peatland vegetation succession and moisture conservation.*** Determine the recovery rate following wildfire and the role of succession on ET and water conservation of wetlands / peatlands.

Objective 3: ***Modelling hydrological trajectories and peatland sustainability.*** Determine the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession to model and assess peatland sustainability.

Objective 4: ***Ephemeral draws***. Determine the controls on ephemeral draw wetland formation and role in generating moisture surplus and delivering water to downstream wetlands and adjacent forests.

Objective 5: ***Forestland hummocks and landscape water balance***. Determine the influence of the configuration, height, substrate type and size of forestland hummocks on sheltering and water use in sustaining forest and wetland ecosystems.

Objective 6: ***Wetland-forestland interface (WFI) and riparian areas.*** Determine the role of landform and riparian vegetation and root distribution on the dynamics of water and chemical movement to or from the hummocks and adjacent wetland or aquatic systems.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

Objective 7: ***Influence of HU and HRA landscape distribution on runoff.*** Determine the role of HRA (coarse- and fine-textured landforms) and HU (wetland and forestland ecosystems) proportion and connectivity on landscape scale AET, storage type and long-term runoff response of BP catchments during different climate cycles?

Objective 8: ***HRA connectivity and temporal and spatial background hydro-chemistry and forest biomass.***

a) Determine how surface and groundwater flow and hydro-chemistry vary across the landscape in response to seasonal and climate forcing and succession (post-wildfire); and

b) Determine how forest biomass relates to the spatial weighting and configuration of wetland-forestland interfaces on different HRAs and during early succession (post-wildfire).

III. Scope 3: Integrated Modelling for Catchment Design and Application

Objective 9: ***Catchment design and application.*** Integrate the research questions and results from the larger catchment runoff responses and process field studies to parameterizing "fuzzy box models" for different landform and landscape configurations to determine the initial configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems that are more sustainable and resilient.

PROGRESS AND ACHIEVEMENTS

This research program is complete. Answers to specific research questions of the program are outlined below supported by published references associated with the particular research.

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

Objective 1: ***Peatland substrate and ice layering***

Q1.1a, What is the role of wetland succession (vegetation, peat thickness) in peat and mineral soil layering, and subsequent promotion of frost formation in storage and conservation of moisture in peatlands and how does it vary across HRAs?

Shallow storage (< 0.4 m; composed of either peat and/or organics within either fine grained or perched systems) induces low system memory (Dixon et al., 2017). This induces frequent periods of both saturation and low water availability, the latter restricting ET. Small measured reductions in ET were observed under dry conditions in shallow wetland soils (0.60 m of storage; Hurley et al., in prep), although severity of drying during measurement periods was low.

Q1.1b, Can layering soils in wetlands (including hydrophobicity and frost formation) be used to reduce ET to behave as an effective capping material and generate surplus fresh water and surface runoff in various Athabasca Oil Sands (AOS) landscapes?

ET is extremely low from dry hydrophobic peat that is formed post fire (Kettridge et al., 2014). Hydrophobicity persists in peat for many years post fire maintaining the dry low evaporating peat even after periods of intense rainfall. While frozen soils supply melt water during the growing season (James, 2017), they also restrict access to deep water stores where ice persists into the growing season (Dixon et al., in prep).

Objective 2: ***Peatland vegetation succession and moisture conservation***

Q1.2a, What are the expected recovery rates and succession of wetlands (peatlands) with large-scale wildfire disturbance?

Peatland margin canopy composition consists of mixed coniferous and broadleaf deciduous species, with enhanced litter fall characterizing the dominant early to mid-successional ground layer composition. Both peatland bog middle and margin vegetation communities were found to be dominated by feathermoss growth approximately 60 years following wildfire, which represents an accelerated trajectory from previous chrono-sequence analyses.

Q1.2b, Can mineral soil layers provide moisture conditions ideal for peatland vegetation recovery, and thus reduce the demand for peat in constructing wetlands?

Locations with high surface moisture content and low near soil surface tension exhibited substantial moss and other bryophyte recolonization, even where the peatland had been burned down to mineral soil (Lukenbach et al., 2015). The conditions that support rates of high post fire recovery are associated with the interaction of peat (or resultant mineral) hydrophysical properties and water table depth (Lukenbach et al., 2015); the latter dependent on the hydrophysical properties of the peat (associated ET) and the surficial geology and landscape position of the peatland (Lukenbach et al., 2016). Areas of low water table position and highly water repellent near-surface peat demonstrated low rates of moss recover (low productivity post disturbance), but supported high rates of water recharge (Bronson 2019).

Q1.2c, How does water loss via evapotranspiration vary through the range of wetland succession trajectories?

Peatlands are thermally diverse landscapes (Leonard et al., 2018). This thermal complexity significantly influences peatland scale ET (Leonard et., in prep b). This small scale complexity can induce substantial lags in the system response to disturbance (Leonard et al., 2017).

Objective 3: ***Modelling hydrological trajectories and peatland sustainability***

Q1.3a, What are the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession?

Low storage (whether composed of organics or mineral soil) increases the probability of moisture stress within moss species (Dixon et al., 2017).

Objective 4: ***Ephemeral draws***

Q1.4a, What is the water balance of an ephemeral draw and how does it change from early succession to mature?

Shallow soil swamps are able to generate water (precipitation greater than evapotranspiration) by on average ~70 mm per year (Hurley et al., in prep b). This generates ephemeral runoff to downstream systems (mean: 94 + / - 67 [sd]); two to three times per decade); Hurley et al., in prep a), in addition to supplying water to adjacent forestlands.

Q1.4b, What is the role of substrate layering and ice in generating lateral flow in ephemeral draws?

Low storage must be overcome (filled by rainfall or snow melt) to induce runoff from an ephemeral draw (Hurley et al., in prep a). Ice reduces the storage capacity of the ephemeral draw (Hurley et al., in prep a). Runoff from ephemeral draws is therefore most likely early within the growing season when snow melt and low storage (as a result of ice) combine. Zones of high storage along an ephemeral draw must be overcome both internally, and with runoff from further upstream within the draw, to induce runoff downstream.

Q1.4c, How does ephemeral draw (Shallow soil swamps) width and geometry control the proportion of flow to adjacent forestlands and downslope peatlands and wetlands?

Ephemeral draw width and geometry influence the frequency of runoff events and the magnitude of water loss to adjacent forest systems.

Implications: Ephemeral draw (shallow soil swamps) geometry can be designed to maximize the probability of downstream water generation. Designs with large upstream and narrow downstream widths will funnel water generated through large upstream areas of water generation (and minimal uptake/loss from adjacent forestlands) through zones of low downstream storage. Ephemeral draws can be used to increase landscape connectivity (between wetlands) within fine textured landscapes.

Objective 5: *Forestland hummocks and landscape water balance*

Q1.5a, How does hummock texture (HRA), configuration, height and size influence the proportion of vegetation water use versus recharge?

Rises in water table elevation occur with variable time-lags from wet periods, which are best defined as multi-year cumulative departures from the long-term mean precipitation. Initially analyses indicate that in coarse HRA, the time lag in groundwater recharge is directly related to the scale of groundwater flow, and in the hummocky moraine HRA it is related to the local storage properties of the hummock (Hokanson et al., 2019). Integrating numerical modeling with the field evidence found that hummock recharge was primarily dependent on the interaction between hummock texture, soil layering, water table depth, and vegetation characteristics (e.g., rooting depth and LFH thickness) (Lukenbach et al., 2019).

Q1.5b, How does the geometry and configuration of the hummock and forestland shelter, size and orientation of adjacent peatland influence evapotranspiration losses and peat thermal processes?

Wetlands with the same area and shape, but different orientation to the dominant wind direction experience significantly different ET loss and spatial patterns of ET. Reduced streamwise velocities and higher vapor concentrations and temperatures are observed in the sheltered region, following an interface between a rougher (i.e., forest) and smoother (i.e., peatland) surface, which produce an area of decreased ET. However, this is followed by a sharp transition to increased streamwise velocities and higher turbulence in the reattachment region, which will increase ET rates relative to the sheltered region (Green et al., Submitted-a). Moreover, increasing the surface roughness of the peatland results in greater overall evaporative demand from the surface, but decreases the spatial variability between the sheltered and the reattachment zones. Thus, the spatial configuration of areas of reduced and normal (or enhanced) ET in a sheltered peatland will be a function of the height of the forest and the roughness of the peatland itself.

Peatlands of different sizes (i.e., differing fetch lengths) exhibit similar surface resistance rates to ET across a range in fetch lengths, but differences in above canopy wind speeds and turbulence occurred when peatland geometry and geometry encouraged funneling of flow through the peatland, and above to the forest canopy (Green et al., Submitted-b). Such dynamics have the potential to influence the turbulent processes and evaporative stresses of downwind ecosystems.

Q1.5c How does the initial state and succession after fire influence the proportion of vegetation water use and recharge, and the sheltering role of the hummock on adjacent wetlands?

Recharge declines with succession and vegetation growth and is proportional to the leaf area index (LAI) of vegetation present (i.e., higher LAI results in lower recharge). Moreover, the development of an organic forest floor, even if only 0.10 m to 0.15 m thick, can substantially reduce recharge compared to the period just after fire when an organic forest floor has often been combusted.

Objective 6: *Wetland-forestland interface (WFI) and riparian areas*

Q1.6a, How does HRA and texture control the magnitude and direction of water across the WFI?

Within fine textured landscapes or within perched wetlands within coarse textured HRAs, lateral water flow between peatlands and forestlands is small in comparison vertical water fluxes (James 2017; Hokanson et al., 2019). During the dry and mesic periods observed during this study, the direction of flow has most often been from the wetlands to the forestlands. Within coarse texture landscapes, the scale and magnitude of water fluxes across the WFI increases and their direction is additionally controlled by water flows operating at the scale of the HRA. Deep combustion of peat within the forest-wetland interface modifies peatland atmospheric fluxes (Kettridge et al., 2017). While this removes dense low potassium (K) margin peat, it is only likely to substantially impact forest-peatland interactions if the hydraulic conductivity of the margin peat is substantially below that of the adjacent mineral soil.

Q1.6b, How does vegetation (succession, species, roots) modify the interaction?

Trees at the margin between wetlands and forestlands use available water in adjacent wetlands shortly after fire (Depante et al., 2019; Hurley et al., in prep b). However, early analysis suggests this water use is dependent on forest soil texture; trees within silt do not require the water resource from wetlands (as opposed to coarse texted hillslopes) and therefore do not utilize water from adjacent wetlands.

Q1.6c, What is the role of hydraulic redistribution into forest hummocks and resource exploitation from peatlands by roots on forestland and riparian productivity and how does this change with succession?

Initial analyses indicate differences between, and to some extent within, species in growth dynamics in response to hydroclimatic conditions (i.e., temperature, precipitation and moisture deficit) between locations. Fieldwork is complete and further analyses on delineating the impact of ephemeral draw water export are underway.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

Objective 7: *Influence of HU and HRA landscape distribution on runoff*

Q2.7, How does the proportion and connectivity of HRAs (coarse and fine) and HUs (wetland and forestland) modify coarse scale AET and storage type and influence overall catchment moisture state and long-term runoff response of BP catchments during different climate cycles?

In general runoff is low. Local processes do scale up, with higher runoff from coarse textured HRA's and enhanced flow from peatlands, and with reduced runoff from aspen ecosystems. Very low flow occurs from stagnation ice moraines (similar to overburden dumps) due to large surface depression and soil storage. There is a large variation in runoff with climate cycles; with base flow maintained only in coarse textured landscape or with large peatland areas (50% of catchment) (Devito et al., in prep).

Objective 8: *HRA connectivity and temporal and spatial background hydro-chemistry and forest biomass*

Q2.8a, How does surface and groundwater flow and hydro-chemistry vary across the landscape (HU interaction with HRA) in response to seasonal and climate forcing and succession (post-wildfire)?

Large ranges in nutrients and salinity naturally occurs among stream-pond, shallow and deep groundwater and peatlands (wetlands) influenced by catchment characteristics (peatland vs forestlands) and landform texture (surface vs subsurface flow) (Plach et al., 2014; Hokanson et al., 2019). Salinities can be high, with EC of greater than 2,000 uS common in shallow groundwater, and some surface streams. During wet cycles, shallow groundwater salinity and pond-wetland water may increase rather than decrease in fine textured HRA's, indicating cycling of salts rather than flushing and dilution. Differences in magnitude and timing (lags) in hydrologic response between coarse and fine textured HRA's was observed over long-term observation. Flow paths in coarse textured HRA's are dominated by groundwater flow with slower response to wetting and drying. Surface and shallow groundwater from peatlands dominate in fine textured HRA's, with rapid response to climate cycles (Olefeldt et al., 2013). Regional analyses revealed little difference between burned and unburned landscapes (ponds and peatlands) indicating limited connectivity between surface soils and regional water transport (Hokanson et al.,2019).

Q2.8b, How does forest biomass relate to the spatial weighting and configuration of wetland:forestland interfaces on different HRAs and during early succession (post-wildfire)?

The sub-humid climate and landscape topography-texture strongly limit the proportion of productive high water uptake (open water, deciduous forestlands) relative to lower productive water generation (peatlands-swamps, coarse textured forest) HUs that occur. In this region, there is a unique symbiotic relationship between wetlands and forestlands, heavily contrasting the dry climate of the ecozone. Examining typical landscape characteristics, the prevailing influences on wetland permanence was found to be hydrodynamics. In addition, prevailing characteristics do not seem to accurately correlate with the expected characteristics found in typical wetland environments, suggesting that perhaps the grid unit scale versus HRU is a critical element in accurate assessments. This work thus renews the call for identifying the proper delineation of wetlands in order to evaluate characteristics. In addition, hydrodynamics should be further studied for their large effects in predicting permanence. The typical ratio of wetland: forestland was also derived, and found to vary depending on the given landscape controls.

III. Scope 3: Integrated Modelling for Catchment Design and Application

Objective 9: ***Catchment design and application***

Q3.9a, Which initial configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems are more sustainable and resilient?

Different goals for mine closure design may be contradictory. Notably, frequent generation of water is not achievable from high productive forest landscapes. Therefore, while individual defined goals may be achieved, all goals are not, and the needs of the landscape must be prioritized. Further it was shown that assumptions that underpin traditional modelling approaches applied within mine closure planning may not be effective for the simulation of oil sand closure planning.

LESSONS LEARNED

I. Scope 1: Local Wetland and Forestland (HU) Function and Hydro-ecological Investigations of Disturbed Watersheds

Objective 1: ***Peatland substrate and ice layering***

Q1.1a, What is the role of wetland succession (vegetation, peat thickness) in peat and mineral soil layering, and subsequent promotion of frost formation in storage and conservation of moisture in peatlands and how does it vary across HRAs?

Creation of low storage areas (shallow cover material within fine grained landform, or shallow cover material above fine grained confining layer within coarse landform) will reduce system memory (James 2017). These areas within mine closure plans will; i) frequently dry and restrict ET; and ii) frequently wet and inducing low oxygen conditions that restrict vegetation growth and induces the potential for lateral water flow.

Q1.1b, Can layering soils in wetlands (including hydrophobicity and frost formation) be used to reduce ET to behave as an effective capping material and generate surplus fresh water and surface runoff in various AOS landscapes?

Hydrophobic peat may be used as a capping material to minimize evaporation from the soil surface which would produce regions in the mine closure landscape with low productivity but are water generating.

Objective 2: ***Peatland vegetation succession and moisture conservation***

Q1.2b, Can mineral soil layers provide moisture conditions ideal for peatland vegetation recovery, and thus reduce the demand for peat in constructing wetlands?

Rapid recovery of productive peatlands/wetlands takes place on either peat or mineral soils if the hydrological conditions (near water table depth/near surface tensions) are appropriate for species (re)establishment.

Q1.2c, How does water loss via evapotranspiration vary through the range of wetland succession trajectories?

System heterogeneity to support ecosystem recovery can be induced through a range of hydrological niches. Trees, shrubs and microtopographic variation each induce thermal heterogeneity, forming thermal niches in a reclaimed landscape.

Objective 3: *Modelling hydrological trajectories and peatland sustainability*

Q1.3a, What are the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession?

Low storage within mine closure designs will increase the severity of moss moisture stress, restricting vegetation productivity but concurrently reducing water loss.

Objective 4: *Ephemeral draws*

Q1.4a, What is the water balance of an ephemeral draw and how does it change from early succession to mature?

Ephemeral draws can be constructed (compacted soil regions) within mine closure designs to support water generation and to induce runoff at an intermediate frequency (runoff three to five years per decade).

Q1.4b, What is the role of substrate layering and ice in generating lateral flow in ephemeral draws?

Ephemeral draws within mine closure plans should minimize storage if runoff magnitude and frequency is to be maximized. Zones of high storage along a constructed draw, either designed or due to variability in construction, will inhibit runoff from the up-stream component of the draw.

Q1.4c, How does ephemeral draw (Shallow soil swamps) width and geometry control the proportion of flow to adjacent forestlands and downslope peatlands and wetlands?

Ephemeral draw (shallow soil swamps) geometry can be designed to maximize the probability of downstream water generation. Designs with large upstream and narrow downstream widths will funnel water generated through large upstream areas of water generation (and minimal uptake/loss from adjacent forestlands) through zones of low downstream storage. Ephemeral draws can be used to increase landscape connectivity (between wetlands) within fine textured landscapes.

Objective 5: *Forestland hummocks and landscape water balance*

Q1.5a, How does hummock texture (HRA), configuration, height and size influence the proportion of vegetation water use vs. recharge?

Consideration of texture (HRA) is mandatory in conceptualizing the hydrologic function of hummocks. Recharge and water generation is likely only from poor forest on coarse textured landforms, however the regional slope must be considered to predict direction of flow. Fine textured hummocks, or moderate depths of fines (30 cm) will not provide frequent surface or groundwater, and will be a negative influence on lease water balances.

Q1.5b, How does the geometry and configuration of the hummock and forestland shelter, size and orientation of adjacent peatland influence evapotranspiration losses and peat thermal processes?

Microclimates are produced leeward of the back facing side transitions, which result in spatially varying evaporative rates that could influence the success of newly reclaimed peatlands. However, study results show that by increasing the surface roughness leeward of the transition, the differences between these microclimatic zones can be lessened and thereby make the fluxes more predictable. Further, it may be advantageous to have a peatland with a fetch length shorter than that of the flow reattachment distance to increase the ratio of the peatland within the sheltered region. Such a configuration would have a higher surface resistance to moisture transfer, limiting potential water losses to an atmosphere with high evaporative demand. Furthermore, gap geometry and shape should be considered during peatland reclamation projects as they influence regional flow dynamics that can alter the evaporative dynamics of surrounding ecosystems.

Q1.5c How does the initial state and succession after fire influence the proportion of vegetation water use and recharge, and the sheltering role of the hummock on adjacent wetlands?

Water sources may be expected during and following initial construction, but hydrologic functions of hummocks (especially fine textured) are likely to reverse and act as water sinks at the lease scale.

Objective 6: *Wetland-forestland interface (WFI) and riparian areas*

Q1.6a, How does HRA and texture control the magnitude and direction of water across the WFI?

Landform texture informs the scale and controls on water flow across the WFI. For the vast majority of years within fine textured landforms, wetlands supply forests with water (forestlands do not supply wetlands). Within fine texture landforms, HU interactions are secondary to HRA scale water flows.

Q1.6b, How does vegetation (succession, species, roots) modify the interaction?

Water transport between wetlands and forestlands due to hydraulic redistribution at a landscape scale is considered small, which likely has a minimal impact on landscape water balances.

Q1.6c, What is the role of hydraulic redistribution into forest hummocks and resource exploitation from peatlands by roots on forestland and riparian productivity and how does this change with succession?

Interface zones between forestlands and wetlands can be used to support the development of productive forests and novel habitats within mine closure designs. However, the overall water transfer due to hydraulic redistribution at a landscape scale is considered small, with likely minimal impact on landscape water balances.

II. Scope 2: Large-Scale Interactions and Landscape Evolution

Objective 7: *Influence of HU and HRA landscape distribution on runoff*

Q2.7, How does the proportion and connectivity of HRAs (coarse and fine) and HUs (wetland and forestland) modify coarse scale AET and storage type and influence overall catchment moisture state and long-term runoff response of BP catchments during different climate cycles?

In general, runoff is low. This is an issue in designing landscapes since large coverage of both ecosystem or forest production and water production cannot occur simultaneously on an HRA. Closure design will need to consider the strong trade-off between water yield for downstream ecosystems and forest productivity. This highlights the relative importance of marginal forests (i.e., coarse textured Pine barrens) in closure design as important areas for generating consistent water for down slope ecosystems during drier climate cycles (i.e., End Pit Lakes).

Objective 8: ***HRA connectivity and temporal and spatial background hydro-chemistry and forest biomass***

Q2.8a, How does surface and groundwater flow and hydro-chemistry vary across the landscape (HU interaction with HRA) in response to seasonal and climate forcing and succession (post-wildfire)?

A design with specific proportion and configuration of HU and HRA is important in long term function (success versus failure) of the final closure landscape. This has implication for sources of water through climate cycles on constructed landscapes and expected rates of flushing of salts from surface waters.

Q 2.8b, How does forest biomass relate to the spatial weighting and configuration of wetland:forestland interfaces on different HRAs and during early succession (post-wildfire)?

Construction of closure landscapes should consider how current and future climate limits or constraints affect the amount of specific land cover types that may be maintained successfully. However, future work should incorporate additional variables in identifying significant influences. It should also revisit the effects of scale and the type of methodology used to derive ratios to compare the results from multiple linear regression analyses as well as proportions observed on varying grid unit sizes.

III. Scope 3: Integrated Modelling for Catchment Design and Application

Objective 9: ***Catchment design and application***

Q3.9a, Which initial configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems are more sustainable and resilient?

The hierarchical application of conceptual, empirical and process based modelling approaches can effectively support mine closure planning, enabling rapid and cost effective formulation of the optimum mine closure designs that may be verified through restrictive (due to expense and time periods) traditional modelling approaches. Caution should be given to these traditional modelling approaches due to the assumptions that underlie them.

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Principal Investigator: Kevin J. Devito

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WETLANDS

Peatland Reclamation Markers of Success

COSIA Project Number: LJ0273

Research Provider: Southern Illinois University

Industry Champion: Syncrude Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

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

The Sandhill Fen 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 Fen, 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 Fen 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

Monitoring of Key Ecological Attributes at Sandhill Fen

Water chemistry of the top 50 cm of the Sandhill Fen has changed dramatically over the seven years since Sandhill Watershed was commissioned. Both calcium and sodium concentrations have increased significantly, with sodium becoming the dominant ion in 2015. Current concentrations of sodium are just under 600 mg/L.

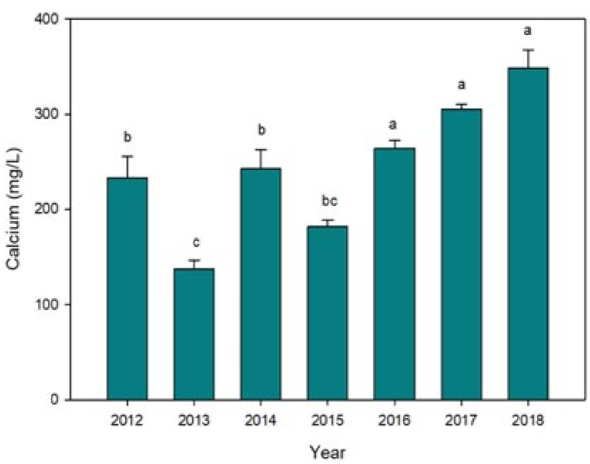

Figure 1: Mean (+ SEM) calcium from surface to 50 cm below water samples from wet up (August 2012) to 2018; different letters indicate significant differences (Tukey's $p < 0.05$).

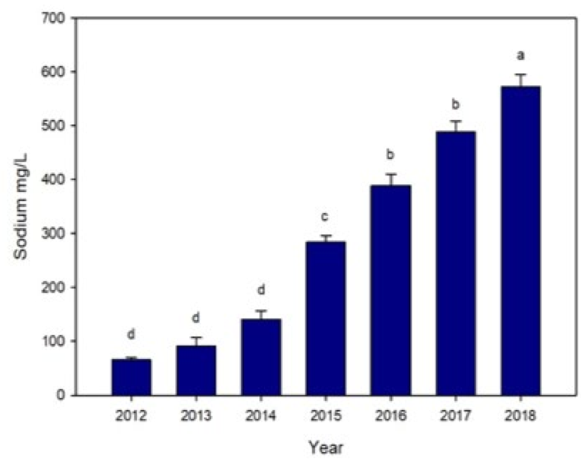

Figure 2: Mean (+ SEM) sodium from surface to 50 cm below water samples from wet up (August 2012) to 2018. Different letters indicate significant differences ($p < 0.05$).

Chemistry Patterns Across Sandhill Fen

Water chemistry and soil chemistry were both used to examine patterns of salinity and sodicity across the fen. Electrical conductance (µS/cm – as a measure of salinity from July 2019) varied from less than 1,000 µS to more than 5,000 µS, with most sites having values between 2,000 µS and 3,000 µS. In general, EC increases southward with highest values along the southern boundary of the fen (Figure 3). Soil sodium concentrations varied from less than 1 mg/g of soil to almost 6 mg/g, with most values less than 2.5 mg/g. Although more variable than EC, highest sodium (Na) concentrations were toward the eastern and southeastern portions of the fen (Figure 4).

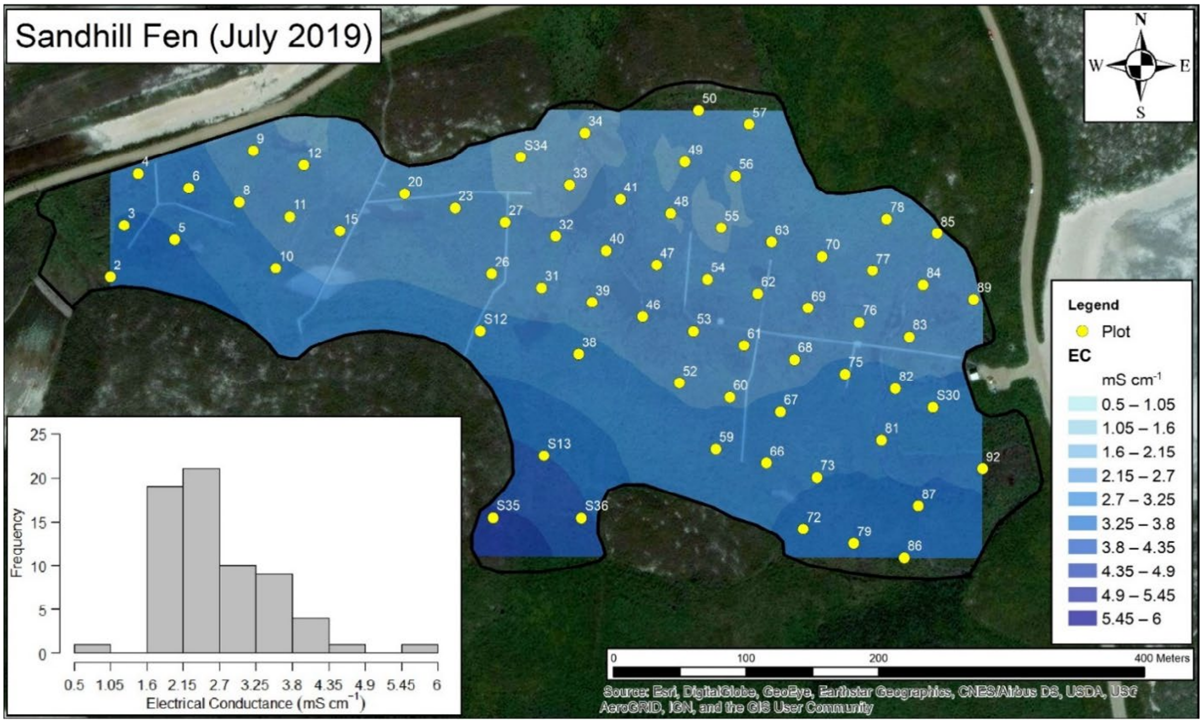

Figure 3: Electrical conductivity (mS cm^{-1}) across the fen; lighter colours indicate low EC and darker shades higher EC.

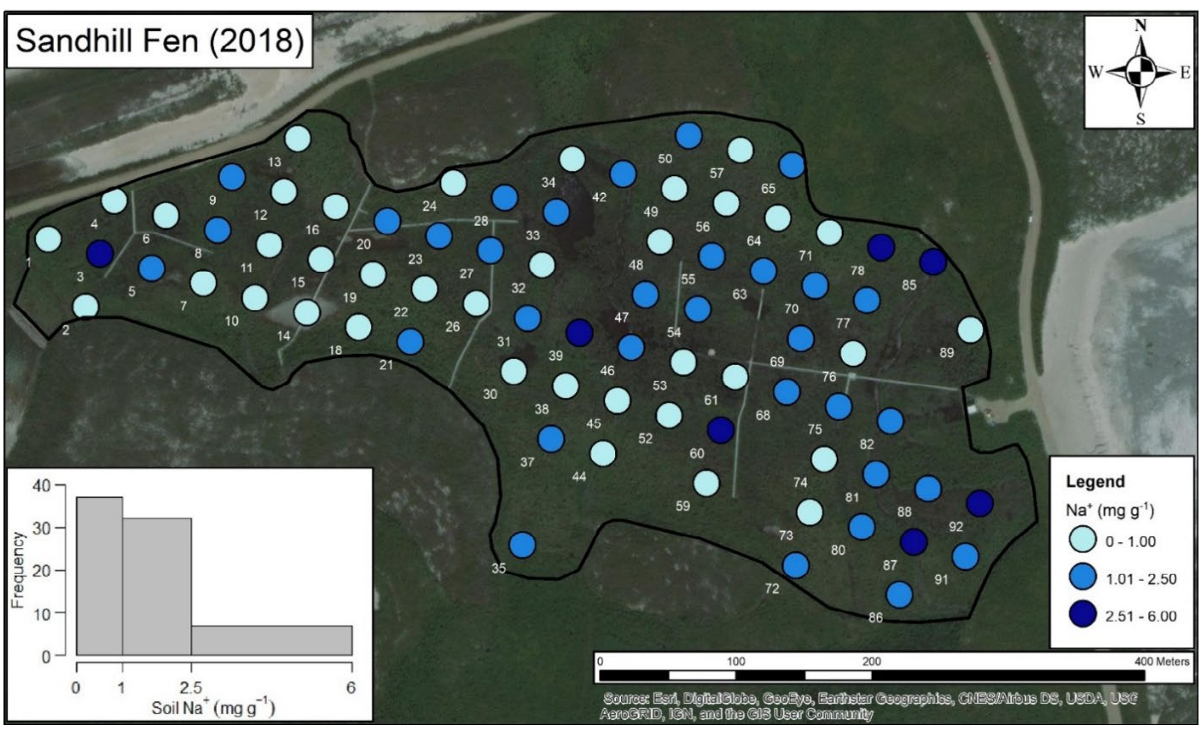

Figure 4: Soil sodium (mg g^{-1}) across the fen; lighter colours indicate lower sodium concentrations and darker shades higher sodium concentrations.

LESSONS LEARNED

Over the past four years, Sandhill Fen vegetation has changed markedly in association with changes in water levels and sodium chemistry. Significant trends that have been identified are: (a) *Carex aquatilis* remains dominant in areas with water table near surface; (b) *Typha latifolia* has remained dominant in the central portion of the fen, where the water table is above the ground surface; (c) both bryophyte and desirable species of vascular plants have decreased in numbers of species and occurrences; and (d) sodium concentrations have continued to increase. Decreases in species richness were especially noteworthy after the high-water anomaly in 2017, with no recovery evident. Sodium concentrations are variable over the fen, but have continually increased over the past four years, reaching concentrations in some areas that may impact vegetation performance.

Although Sandhill Fen exhibits similar chemistry to some natural wetlands, taken together, comparisons of vegetation, soil chemistry and water chemistry from Sandhill Fen with a number of natural wetland sites (12 sites) suggest that at the present time Sandhill Fen has little in common with any of the natural sites and can be considered a unique wetland site-type. Data from natural sites and Sandhill Fen are presently being collated for potential indicators of the progress of wetland reclamation and how reclaimed sites compare with natural wetlands (PhD – Jeremy Hartsock).

Sandhill Fen is currently at a critical point in its development due to the combination of increasing soil and water sodium concentrations along with variable water levels, and it is not clear how this unique site-type will change over the next few years. There are indications that if current trends continue, large portions of Sandhill Fen will develop as a brackish marsh. Although currently *C. aquatilis* continues to dominate and perform well, even in areas of high sodium, this project's photosynthesis studies suggest the beginnings of negative effects. Also, the lack of recovery of bryophytes and desirable vascular plants is a concern, with potentially suitable habitats either too sodium-rich or dominated by *C. aquatilis* and dense litter. Unfortunately, at this moment it cannot be predicted how Sandhill Fen vegetation will react to these changing conditions.

PRESENTATIONS AND PUBLICATIONS

Hartsock, Jeremy A., Bremer, Eric., and Vitt, Dale H. 2019. Nutrient supply patterns across the Sandhill Fen reclamation watershed and regional reference fens in Alberta, Canada: An ion exchange membrane study. Ecohydrology: DOI: 10.1002/eco.2188

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University Carbondale

Principal Investigator: Dr. Dale Vitt

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Jeremy Hartsock	Southern Illinois University	Researcher / PhD Student	2015	2019

cosia

Raised Bogs: Western and Traditional Knowledge Review

COSIA Project Number: LJ0323

Research Provider: Wood Canada Limited

Industry Champion: Suncor Energy Inc.

Status: Year 1 of 1

PROJECT SUMMARY

The main objective of this project, *Raised Bogs: Western and Traditional Knowledge Review*, was to combine western science and traditional knowledge to gain an understanding of what conditions are required to establish and maintain a localized permafrost bog in the oil sands area.

Information was collected through a literature review and consultation with Indigenous peoples. The literature and traditional knowledge reviews focused on the criteria needed to establish bog habitat on reclaimed landscapes and are considered the first step in determining the feasibility of constructing a bog over an ice lens.

Traditional ecological knowledge was gained through discussions with Indigenous participants during a site visit to the palsas (frost mounds) in Anzac, Alberta. As one of the primary users of permafrost, Indigenous peoples have valuable insights on frost mound development, persistence on the landscape, persistence during unseasonably warm periods and growth during cold periods.

The literature review summarized the key factors important in designing a constructed bog while also highlighting any knowledge gaps requiring further study or factors that need to be validated by field data.

PROGRESS AND ACHIEVEMENTS

- The literature review has been completed.
- First Nations participants attended a tour out to the Anzac frost mounds, participants shared their knowledge of permafrost, including traditional uses, persistence on the landscape and factors that affect its decline.
- A draft report has been completed and the final report is expected in the first quarter of 2020.

LESSONS LEARNED

The central purpose of oil sands reclamation is to return disturbed landscapes to sustainable ecosystems that existed prior to development. Bog type of wetlands occur in the natural landscape of the Athabasca Oil Sands Area. Traditional knowledge indicates that the establishment of bog wetlands will be an essential part of the wetland reclamation process. The scientific literature reviewed indicated that it may be possible to create a bog wetland in any position on a reclaimed oil sands landscape.

Literature Review

The scientific literature reviewed for this project indicate that the most common mechanism for the formation of permafrost bogs in the oils sands area starts with the development of local patches (several square metres) of dense tree growth on large bogs or as small island fens. The dense tree canopy reduces the insulating snow cover under the trees which causes frost to penetrate deeper. As the frost penetrates deeper into the soil it eventually stops thawing during the summer months and permafrost forms. These frost layers consolidate into larger ice lenses and grow in thickness as soil pore water is drawn in below (cryosuction) and freezes. Surficial peat is heaved above the water table by these thick lenses. The elevated peat becomes drier and provides more insulation against thawing during the summer months further enhancing ice lens and palsa growth.

Based on the literature, the specific conditions needed for ice lens development and maintenance are:

- A nearby water source;
- A raised dome shape that allows the peat moss on the hummock to dry in the summer (dry peat moss insulates and prevents or reduces ice lens melt in the summer);
- A dome high enough to isolate the water table, but low enough to keep the moss layer active (in winter the dome shape exposes the surface to wind, lessening snow depth and allowing the ice lens water that melted during the summer to re-freeze); and
- A significant cover of peat moss.

Bogs on mineral soil may require an underlying low hydraulic conductivity layer (clay or silty soil types). The low hydraulic conductivity soil layer prevents infiltration, keeping water within the frost zone. The ice lens slows decomposition allowing bog vegetation to perpetuate. The raised dome shape further ensures moisture is primarily ombrogenous (i.e., derived from precipitation low in nutrients) which promotes the growth of bog plant species.

The literature review indicated that a perched wetland is not reliant upon ground or surface water inputs, which suggests that similar wetlands could be constructed in any landscape position. The concept suggests that once the conditions for peat accumulation are in place, *Sphagnum* spp. will develop. The literature also suggests that incorporating a frozen ice lens into a depression and placing a raised peat dome above the surface may increase the likelihood of success in creating a bog. The ice lens would aid in keeping the peat moss temperature cool, slowing decomposition. The ice lens would not need to be persistent, but it would need to last long enough for the surface cover of peat moss/bog vegetation to develop.

In theory, a raised bog could be constructed by:

- Flooding and freezing water or cutting and placing frozen lake ice in a pit to a level above ground, stratified with silt/clay layers;
- Matching cryosuction hydrogeology;
- Covering the ice lens with blocks of bog peat and vegetation, excavated prior to mining and keeping the peat stratification intact; and
- Maintaining a low-domed core of silt or clay to ensure the area stays above the water table.

Ideally all peat moss should be salvaged from an area prior to disturbance along with its pore water (i.e., no muskeg drainage to take place prior to excavation). Where this is not feasible, drainage water should be collected. Water in existing bogs meets the criteria needed for sphagnum development, while water collected from rivers, marshes and other sources may be too alkaline.

Knowledge gaps identified in the literature include:

- Processes and properties not readily observed (e.g., ice lenses thickening, segregation and mineral particle size in each layer). Described characteristics should be validated at the local level;
- Equations for balancing water storage, water holding capacity and rates of evapotranspiration within the bog at the local level and by vegetation cover; and
- Applied processes, for example, how to provide mature tree shading to reduce evapotranspiration on the surface of a constructed bog, how to effectively cut and transport intact large blocks of peat and how to install monitoring instruments so that the installation does not inadvertently conduct heat downward along the cable or pipe and thaw the ice lens that are present.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Ashlee Mombourquette and Laura Robert, Bogs: Western and Traditional Knowledge Review, Suncor Lunch and Learn, 19-12-2018, 20 slides.

Ashlee Mombourquette, 2018, Climate Influence on Bog Evolution in the Oil Sands Region, Alberta. Independent study report in fulfilment of co-op student requirements, Submitted to: Dr. Laura Chasmer, Department of Environmental Science, University of Lethbridge, December 14, 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: Wood Canada limited

Principal Investigator: Laura C. Robert

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ashlee Mombourquett	Suncor/ University of Lethbridge	Environmental Science Co-op student	2016	2020

COMPENSATION LAKES AND AQUATICS

Horizon Lake Monitoring Program

COSIA Project Number: LJ0011

Research Provider: Canadian Natural, Hatfield Consultants

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 2018 monitoring program became available in 2019 after the publication of the 2018 COSIA Land EPA Mine Site Reclamation Research Report, and are therefore presented in this report.

In 2018, the Horizon Lake Monitoring Program completed the tenth year of monitoring. Results have demonstrated that Horizon Lake provides a variety of functional habitats and food sources that are suitable to support resident fish populations, and that the physical and chemical environment is well suited to the establishment and proliferation of aquatic life.

Fish Populations

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

The sampling program in 2018 processed 2,691 fish, of which seven individuals were recaptures. The recaptures were initially tagged between October 2011 and June 2017. Sampling techniques included fyke netting, minnow trapping, electrofishing, eDNA collection (COSIA Project LJ0327: Environmental DNA for Canadian Toad, Burbot and Arctic grayling), snorkel surveys and gill netting. The spring catch consisted of eight species, mostly of forage fish consisting primarily of fathead minnow, and large bodied captures consisted of an almost equal amount of longnose and white suckers (46 and 47 respectively), and five Arctic grayling. The fall capture consisted of 85% forage species, 11% sucker species and 4% sportfish, with seven 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 river. In 2018, PIT tags were implanted in 151 large bodied fish throughout the year, with 23 Arctic grayling, 59 longnose sucker and 69 white sucker tagged. PIT tag detections over the PIT antennae have totalled 1,274 of the 4,136 tagged individuals since the installation of the first array in 2013, demonstrating fish from the lake are using the upper Tar River and providing clear evidence of population connectivity and recruitment.

Water samples were collected from Horizon Lake and the Tar River to use in the development of a regionally specific assay for the detection of Arctic grayling through eDNA. Further details on this work can be found in the project summary page for (COSIA Project LJ0327: Environmental DNA for Canadian Toad, Burbot and Arctic grayling).

Fish tissue sampling for total metals and organic compounds in Horizon Lake, and background reference samples from the Calumet watershed, were taken. Concentrations continue to be below human health consumption guidelines, with the exception of arsenic, chromium and mercury. These three were at concentrations that exceeded the consumption guidelines in both the Horizon Lake and the Calumet watershed. Horizon Lake total and methyl mercury in juvenile white sucker were at the lowest concentrations observed since monitoring began in 2011, and were lower than the Calumet watershed samples. Adult white sucker tissue plugs taken for total and methyl mercury concentrations in 2018 were lower than in all previous years, and 2018 was the first year total mercury was below Health Canada guidelines for subsistence fisheries. As was initially predicted, mercury apparently 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 sixth year of annual hydroacoustic surveys was completed in 2018. The surveys estimate productivity and abundance of fish in the lake. The resultant production estimates were near or above the total production requirement of 2,543 kg/year that is stipulated in the DFO (Fisheries and Oceans Canada) Authorization in three of the survey years (2013, 2014 and 2016), and below this target in the other three survey years (2015, 2017 and 2018). Only five 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 sampling in 2018 followed historical trends, with an abundant and diverse community present in Horizon Lake. Diptera (true flies, midges and mosquitoes) were the most dominant taxon, followed by Oligochaetes (worms). Density and pooled species richness were highest near the shore, followed by littoral and mid-lake areas. Diversity measurements followed the same trend, being greatest near the shore with the average Simpson's diversity at 0.27, and lowest at the littoral area with 0.18. Sensitive ETO (Ephemeroptera, Trichoptera and Ordonata) species were present at five of nine 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. 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.

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, other than total mercury in February 2019 at 6.4 ng/L. Ranging higher than concentrations from 2015 to 2018, the concentration remained within the 95th percentile of historical observations. The majority of the analytes sampled in the bi-annual sampling remained within the range of water quality guidelines for protection of aquatic life, with the exception of total phenols, total iron (fall), and total mercury (winter), but remained within historically observed ranges. This low variability is similar to conditions documented in the Tar River by RAMP/JOSM (Regional Aquatics Monitoring Program/Joint Oil Sands Monitoring Plan), including the exceedance observations prior to the construction of Horizon Lake.

Continuous data from the thermistor string in Horizon Lake shows spring turnover in mid-May, with an establishment of a thermocline until mid-September. Seasonal surface temperatures in 2018 were near or below historical observations, reaching a peak at the one metre depth of 22.8°C on June 24. 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 2.2 mg/L at 5 m in mid-August, and 0.6 mg/L at 10 m in late 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 ranged from 6.78 to 8.48 in 2018/2019, remaining within the water quality guidelines for protection of aquatic life. Generally, pH profiles remained within the historical range in the spring and fall, and above historical levels at all depths in the summer and winter. 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) in the bottom 4 m to 6 m in the pelagic zone in all months except October. DO in profundal areas declined between July and September, with near bottom concentrations decreasing to below 1 mg/L at depths greater than 14 m. 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 61 in the fall (2018) and 42 in the winter (2019), suggesting a eutrophic system in the fall and mesotrophic system in the winter. 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.

Plankton

In 2018, average phytoplankton density and biomass were lowest in the spring and highest in the fall. This was only the second time since monitoring began when density was highest in the fall. Generally, density and biomass has been highest during the summer. Biomass and density were within historical ranges for spring and fall, but below the historical minimum in the summer. The majority of the biomass was comprised of cyanobacteria and dinoflagellates in 2018 (44% and 43% respectively). Mean species richness ranged from 12 species in spring to 37 species in summer, the highest species richness observed in a season since monitoring began. Mean Simpson's diversity was lowest in the spring (0.58) and highest in the summer (0.74). Community composition was dominated by cryptophytes, followed by diatoms and cyanobacteria. Generally, Horizon Lake has supported a moderately to highly diverse (≥ 0.5) phytoplankton community since monitoring began.

Zooplankton density and biomass in 2018 were found to be lowest in the spring, highest in the summer, and within historical ranges. The zooplankton community's highest contributors to density and biomass in all seasons during 2018 were rotifers and ciliates. Mean species richness was highest in the fall (15) and lowest in the spring (8), lower than the historical spring minimum. Historically, higher variability has been observed in the spring and summer, while the fall has been relatively stable. Diversity was lowest in the summer and highest in the fall. This was the fourth consecutive year of highest diversity in the fall. Mean evenness was lowest in summer and highest in spring. The Horizon Lake's zooplankton community is dominated by few taxa which has produced low evenness scores since monitoring began (0.06 to 0.24).

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).

Habitat

Horizon Lake has a successful range of fish habitat that provides foraging and cover for a variety of small and large bodied fish. Constructed habitat types include gradual and steep sloping littoral areas, varied substrates including soft bottomed areas with extensive macrophytes production, gravel beds with various sized gravel, angular cobble/ boulder gardens, rocky reef features, a well-developed and diverse macrophytes community, and a large profundal zone that provides habitat for plankton and the fish species that forage on these organisms.

LESSONS LEARNED

The monitoring strategy for Horizon Lake was to evaluate the establishment of various ecological attributes for five years following construction, and then to transition to a focus on the development of fish production in subsequent monitoring years. Through ten years of monitoring, it is clear that Horizon Lake provides suitable habitat for all resident fish species.

Hydroacoustic surveys have indicated overall abundance and distribution of fish sizes have remained consistent for the last four years. 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.

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. 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 & Other Publications

Hatfield Consultants. 2019. Horizon Lake Monitoring Program – 2018 Technical Report. Prepared for Canadian Natural. North Vancouver, British Columbia. p. 531.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Daniel Moats

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Cory Bettles	Hatfield Consultants	Fisheries and Aquatics Manager		
Meghan Isaacs	Hatfield Consultants	Environmental Specialist		
Tim Poulton	Hatfield Consultants	Senior Environmental Specialist and Manager		
Ben Beall	Hatfield Consultants	Senior Environmental Specialist and Manager		
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Corey Lavin	Hatfield Consultants	Environmental Specialist		
Seumas McGrath	Hatfield Consultants	Environmental Specialist		
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Joanne Hogg	Canadian Natural	Lead, Research		
Devon Versnick-Brown	Canadian Natural	Coordinator, Environment		

Compensation Lake Studies

COSIA Project Number: LJ0260

Research Provider: Golder Associates

Industry Champion: Imperial

Status: Ongoing (started in 2013)

PROJECT SUMMARY

Construction of the Kearl Oil Sands (KOS) Phase I Compensation Lake (Muskeg Lake) was completed in 2010. Monitoring to evaluate the biological development of the lake commenced when the basin was filled in 2013. Muskeg Lake is connected to Kearl Lake via a connector channel. The purpose of Muskeg Lake is to provide permanent compensation for fish habitat impacted by the KOS project, and the overarching objective of the study is to evaluate the effectiveness of the constructed lake in supporting self-sustaining fish populations.

To understand this early biological development of Muskeg Lake, the following parameters are monitored and evaluated:

- Water and sediment quality
- Fish habitat and population
- Benthic invertebrates in littoral and pelagic habitats
- Aquatic vegetation establishment
- Phytoplankton and zooplankton

PROGRESS AND ACHIEVEMENTS

Ongoing Muskeg Lake field observations, as well as data collection and analysis, occurred in 2019.

Water and Sediment Quality

- The water and sediment quality in Muskeg Lake now meet the stated objective in that they are suitable for aquatic biota, are typical of a natural regional lake, and are similar to conditions in Kearl Lake (the source water for Muskeg Lake).
- The water quality in Muskeg Lake was characterized as slightly alkaline and well-oxygenated.
- Concentrations for almost all water quality parameters were below the relevant Water Quality Guidelines for the protection of aquatic life established by the Government of Alberta and for drinking water established by Health Canada, including conventional parameters, major ions, nutrients and metals. Polycyclic Aromatic Hydrocarbons (PAHs) and Polycyclic Aromatic Nitrogen Heterocycles (PANHs) were either non-detectable or below the guidelines. Total phenolics were sometimes above the chronic guideline. Mercury data showed that

methyl mercury was non-detectable in Muskeg Lake and total mercury levels were lower than in Kearl Lake. Based on nutrient levels, Muskeg Lake has achieved a trophic status (mesotrophic) similar to Kearl Lake.

- Concentrations of most sediment-quality parameters were below the interim sediment quality guidelines established by the Canadian Council of the Ministers of the Environment. Concentrations of aluminum, calcium, iron and magnesium were high but were similar to the natural levels in Kearl Lake. Total mercury was non-detectable in Muskeg Lake sediment.

Fish Habitat and Population

- Most fish habitat characteristics in Muskeg Lake now meet the objective of providing year-round habitats for all life stages of the target fish species and meet the values predicted by the fish habitat suitability index (HSI) models used in the design of Muskeg Lake. An exception to the previous point is the average density of aquatic vegetation in the littoral zone, which has not yet reached the final expected value for the northern pike HSI (i.e., is currently < 57% average littoral cover).
- Fish species diversity in Muskeg Lake has reached the highest level possible via natural colonization. All nine species that are known to occur in the Kearl Lake watershed are present.
- Fish abundance data, as calculated by catch-per-unit-effort, show that Muskeg Lake has achieved abundances of forage fish and large-bodied species that exceed those of Kearl Lake. Fish populations for the target species in Muskeg Lake have also achieved abundances similar to natural regional waterbodies, including those with deep-water pelagic habitats.

Benthic Invertebrates in Littoral and Pelagic Habitats

- Benthic invertebrate communities in Muskeg Lake are now at levels of abundance (organisms/m^2) and taxonomic richness similar to those found in a natural regional lake and have higher levels of diversity than waterbodies that lack deep-water pelagic habitats.
- In comparison to Kearl Lake (the source of water and biological colonization), parameters for the benthic invertebrate community in Muskeg Lake are similar to, or higher than, average taxonomic richness (> 32 taxa) and higher for maximum density (> 10,500 organisms/m^2).

Aquatic Vegetation Establishment

- Mapping of aquatic vegetation in the littoral zone of Muskeg Lake showed that the number and density of vegetation stands has been increasing steadily since a portion of the littoral zone was planted in 2013.
- Vegetation is now present throughout the entire littoral zone but the expected final average vegetation coverage density of 57% has not yet been achieved.

Phytoplankton and Zooplankton

- Planktonic communities in Muskeg Lake are now at levels of biomass (µg/m^3) and taxonomic richness similar to a natural regional lake (objective met).
- In comparison to Kearl Lake (the source of water and biological colonization), parameters for the Muskeg Lake zooplankton and phytoplankton communities are similar to, or higher than, average levels for taxonomic richness (> 17 taxa zooplankton and > 53 taxa phytoplankton) and biomass (100,000 µg/m^3 zooplankton to 230,000 µg/m^3 zooplankton and 3 million µg/m^3 phytoplankton to 8.6 million µg/m^3 phytoplankton).

LESSONS LEARNED

A summary of the current level of development and trends for the biological components of the Muskeg Lake, based on the monitoring data for the period 2013 to 2019, is highlighted below. Overall, the monitoring results to date demonstrate that the direct connection of the constructed habitats in Muskeg Lake to natural habitats (i.e., Kearl Lake) has allowed for rapid biological development in the constructed lake. In addition, providing offsetting habitats that address a key habitat limitation, in this case the lack of deep-water areas with secure overwintering habitats, provided a high probability of success.

Water and Sediment Quality

- The excavation of the Muskeg Lake basin, with all organic material/soils removed prior to flooding, allowed water quality to develop so as to be very similar to the natural source and did not result in mercury methylation or increases in mercury concentrations in the water or sediment.

Aquatic Macrophytes

- Success of planted pondweed stands was low to moderate for shallow plantings and nil for deep plantings, indicating shallow planting techniques are more likely to be successful.
- Bulrush plantings along the lake margin were completely successful (high survival and moderate to high vigour with evidence of spreading) indicating a high probability of success for planting emergent vegetation.
- Natural colonization of other aquatic vegetation has been observed in the littoral zone and vegetation mapping indicates continuing year-to-year expansion of aquatic macrophytes in the lake.
- Most physical fish habitat features constructed or intended for Muskeg Lake developed rapidly following flooding, but growth and expansion of aquatic vegetation to the desired littoral density will require more than the six years of development to date. Additional vegetation planting at the time of lake flooding would be needed if more rapid vegetation establishment is required.

Plankton (indicator of lake productivity)

- Zooplankton biomass in Muskeg Lake increased annually following lake filling and has been within or above the range of biomass observed in Kearl Lake since 2016. Zooplankton taxonomic richness in Muskeg Lake increased rapidly after lake filling and has been within the range recorded in Kearl Lake since 2014.

- Phytoplankton biomass and taxonomic richness developed more rapidly than zooplankton, followed by variable levels from year to year. By completion of the filling of Muskeg Lake in 2013, phytoplankton biomass and richness had already achieved levels similar to the lower ranges of Kearl Lake.

Benthic Invertebrate Communities (indicator of lake productivity and development of the food base for fish)

- Muskeg Lake is providing a strong food base for fish – colonization and development of the benthic invertebrate community in the littoral zone of Muskeg Lake has been rapid, reaching density and richness levels typical of Kearl Lake in less than two years after filling.
- The heterogeneous habitat in Muskeg Lake is likely contributing to observable high density and richness, with greater habitat diversity than Kearl Lake.

Fish Populations

- The number of fish species captured in Muskeg Lake steadily increased over the monitoring years and all fish species present in Kearl Lake colonized Muskeg Lake by 2017.
- Muskeg Lake is providing secure overwintering habitat for both Muskeg and Kearl Lake fish populations as well as year-round habitat for forage fish, suckers and sport fish.
- Muskeg Lake is providing suitable habitat for large-bodied fish.
- Colonization for the target fish species and population development to levels of abundance (i.e., catch-per-unit-effort) similar to natural regional lakes required two years post-filling for forage fish populations and four years for northern pike and white suckers.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates

Principal Investigator: Golder Associates

Assessing the Role of Habitat in Determining Age and Growth Relationships of Fish

COSIA Project Number: LJ0170

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 5 of 5

PROJECT SUMMARY

Canadian Natural is in the process of developing a compensation lake (Horizon Lake/Wāpan Sākahikan), which is designed to permanently compensate for fish habitat loss resulting from the development of the Horizon Oil sands. To assess the role of habitat in determining age and growth relationships in fish populations in compensation lakes such as Horizon Lake, several different approaches have been undertaken including:

- Food Web analysis (age structures, blood, liver and muscle tissues; 2016 to present)
- Hydroacoustic monitoring (biomass, vegetation, substrate; 2013 to present)
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality; 2008 to present)

Implementation of this data collection will provide further insight into the role of habitat in determining age and growth relationships in fish populations within the Lower Athabasca region. Information and knowledge gained from this project will support future compensation lake developments and the subsequent management of ongoing projects such as the Horizon Lake.

This project is a collaboration with COSIA Project LJ0171, Assessing the Productive Capacity of Compensation Lakes. The specific objective of this project is to relate habitat to growth relationships of fish.

PROGRESS AND ACHIEVEMENTS

Sampling

- Eight lakes have been sampled from 2016 to 2019. Waupau, Kirby, Steepbank, Goodwin, Unnamed Lake 1 (near Conklin), Unnamed Lake 2 (near Conklin), Unnamed Lake 5 (near Conklin) and Horizon Lake (Canadian Natural Horizon Oil Sands) were sampled for fish, invertebrates, and basal resources in winter 2018.

Laboratory Analysis

- Otiliths (all species) and cleithra (northern pike) were extracted and analyzed from four species: northern pike, white sucker, lake whitefish and yellow perch from six lakes in the Lower Athabasca region.

Table 1: Sample sizes of age structures extracted from four species of fish from lakes in the Lower Athabasca region.

Lake	Northern Pike	White Sucker	Lake Whitefish	Yellow Perch
Steepbank	30	17	NA	NA
Unnamed 1	30	13	NA	NA
Unnamed 2	24	17	NA	NA
Goodwin	30	11	30	30
Kirby	30	8	16	30
Wappau	30	17	NA	28
Total	**174**	**83**	**46**	**88**

LESSONS LEARNED

Growth rates varied considerably for the fish species sampled in lakes in the Lower Athabasca region. For example, the size of northern pike at age six, varied from approximately 450 mm at Unnnamed Lake 1, to 750 mm in Kirby Lake. At Wappu Lake, the maximum age of northern pike was 11. Future analysis will determine if habitat and/or other factors (e.g., pH, conductivity, primary productivity) are important predictors of fish growth.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Theis, S., Ruppert, J. W. R., Roberts, K. and M. S. Poesch. (2020) Compliance with and ecosystem function of biodiversity offsets in North American and European freshwaters. Conservation Biology 34 (1): 41-53.

Conference Presentations/Posters

Roberts, K. and M. S. Poesch (2019) Exploring Fish Species Richness and Co-existence in Natural and Constructed Boreal Lakes with Isotopic Niches. 2019 Joint Conference of the Alberta Chapter and the Canadian Section of the Wildlife Society, Banff, AB, March 2019. (Poster)

Terry, M. and M. S. Poesch (2019) Acoustic based estimates of fisheries productivity in northern boreal lakes: Implications for offsetting. 2019 Joint Conference of the Alberta Chapter and the Canadian Section of the Wildlife Society, Banff, AB, March 2019. (Oral)

Roberts, K. and M. S. Poesch (2019) Exploring Fish Species Richness and Co-existence in Natural and Constructed Boreal Lakes with Isotopic Niches. Graduate Research Symposium, University of Alberta, Edmonton, AB, March 2019. (Oral)

Roberts, K. and M. S. Poesch (2019) Exploring Fish Species Richness and Co-existence in Boreal Lakes with Isotopic Niches. Northern Research Day, University of Alberta, Edmonton, AB, March 2019. (Poster)

- Awarded Best Poster.

Theis, S. and M. S. Poesch (2019) Assessing habitat enhancements to improve the restoration and development of northern boreal lakes. Northern Research Day, University of Alberta, Edmonton, AB, March 2019. (Poster)

- Awarded Runner-Up Best Poster.

Theis, S. and M. S. Poesch (2019) Using hydroacoustics to quantify fisheries productivity in northern boreal lakes. Bentley Lecture Research Symposium, University of Alberta, Edmonton, AB, March 2019. (Poster)

- Awarded Best Poster.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark S. Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	MSc	2016	2020
Karling Roberts	University of Alberta	PhD	2016	2020
Sebastian Theis	University of Alberta	PhD	2017	2022

Research Collaborators: Dr. Jonathan Ruppert, Research Scientist, Toronto Region Conservation Authority; Dr. Ken Minns, University of Toronto (formerly Fisheries and Oceans Canada); Dr. Eva Enders, Fisheries and Oceans Canada

Assessing the Productive Capacity of Compensation Lakes

COSIA Project Number: LJ0171

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 5 of 5

PROJECT SUMMARY

Canadian Natural is in the process of the development of a compensation lake (Horizon Lake/Wāpan Sākahikan), which is designed to permanently compensate for fish habitat loss resulting from the development of the Horizon Oil Sands. To assess the productive capacity of fish populations in compensation lakes, such as Horizon Lake, several different approaches have been undertaken including:

- Food Web analysis (age structures, blood, liver and muscle tissues; 2016 to present).
- Hydroacoustic monitoring (biomass, vegetation, substrate; 2013 to present).
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality; 2008 to present).
- Historical data analysis (local, regional and global).

Implementation of this data collection will provide further insight into productive capacity of fish populations in compensation lakes within the lower Athabasca region, which includes the Oil Sands area. This could have an impact on future compensation lake developments and subsequent management of ongoing projects such as Horizon Lake.

The key objectives of the project are:

1. Assess methods for measuring fisheries productivity across compensation lakes and natural systems.
2. Assess how habitat influences fisheries productivity.
3. Compare food-web structure (e.g., stable isotopes, fatty acids) of compensation lakes as compared to pristine, minimally impacted, and highly disturbed lakes and rivers.

PROGRESS AND ACHIEVEMENTS

Sampling

- Four lakes, Steepbank, Goodwin, Unnamed Lake (near Conklin) and Horizon Lake (Canadian Natural), were sampled for fish, invertebrates, and basal resources across seasons in 2018 and 2019.
- Invertebrates and basal resources were sampled in three lakes (Steepbank, Goodwin, and Unnamed Lake [Conklin]) in summer 2019.

Stable Isotope Analysis

- 1,500 samples from fish, invertebrates, and basal resources from nine lakes and three sampling seasons were prepared and sent for stable isotope analysis.

Hydroacoustics Surveys

- 14 Hydro acoustic surveys completed – day and night.
- Sampled fish species (N = 244) included; pike, white sucker, perch, lake whitefish, spottail shiner, ninespine and stickleback.
    - Otoliths, length, weight, sex, stomach, gonads, liver, tissue, scales, fin clip.

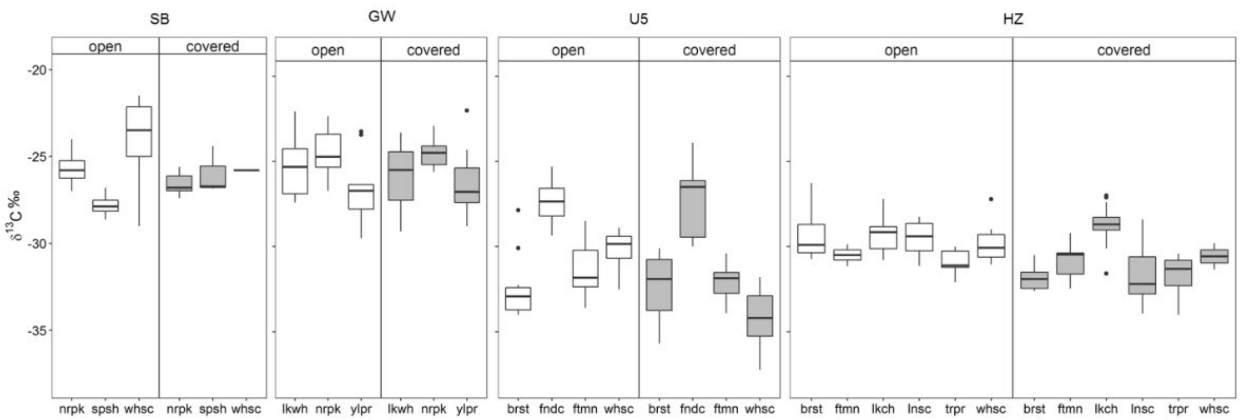
LESSONS LEARNED

Stable Isotope Analysis.

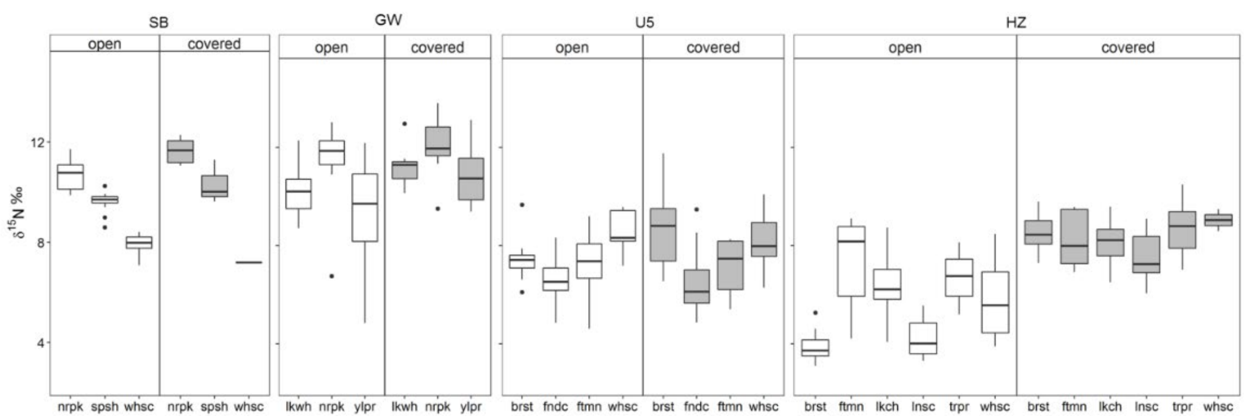
General Linear Mixed Models (GLMM) were run separately for each lake with season as a fixed factor and fish species as a random factor. The models suggest that season does not affect $\delta^{13}C$ (stable isotope of carbon) in Steepbank Lake ($p = 0.33$) or Goodwin Lake ($p = 0.96$). However, season does effect $\delta^{13}C$ in Unnamed Lake 5 ($p = 0.017$) and Horizon Lake ($p = 0.0071$). In general, $\delta^{13}C$ is more depleted in the ice covered season than in the open water season in these two lakes (Graph 1). The exception to this is lakechub in Horizon Lake, which have enriched $\delta^{13}C$ in the ice covered season compared to the open water season. The stable isotope of nitrogen ($\delta^{15}N$) increases in the ice covered season compared to the open water season in Steepbank Lake ($P = 4.98e-06$), Goodwin Lake ($p = 0.00073$), and Horizon Lake ($p < 2.2e-16$). However, there is no change in $\delta^{15}N$ between seasons in Unnamed Lake 5 ($p = 0.38$) (Graph 2).

Standard ellipse areas (SEA) of population isotopic niches changed between open water and ice covered seasons and varied between species and lakes (Graph 3). Many populations showed no or very little change in SEA between seasons, while in other populations SEA was smaller in the ice covered season compared to the open water seasons. In general, species found within the same lake show similar directions of change in SEA between open water and ice covered seasons. For example, in Unnamed Lake 5, three quarters of the species show an increase in SEA in the ice covered season compared to open water season, while in Goodwin two-thirds of species show a decreasing trend, and in Horizon Lake all five populations have relatively stable SEAs between seasons. To test whether season has a significant effect on fish population SEA, a GLMM was run on SEA results for each population with season as a fixed factor and lake and species as random factors. Results from the GLMM suggest that season does not have a significant effect on SEAc ($Pr = 0.90$)

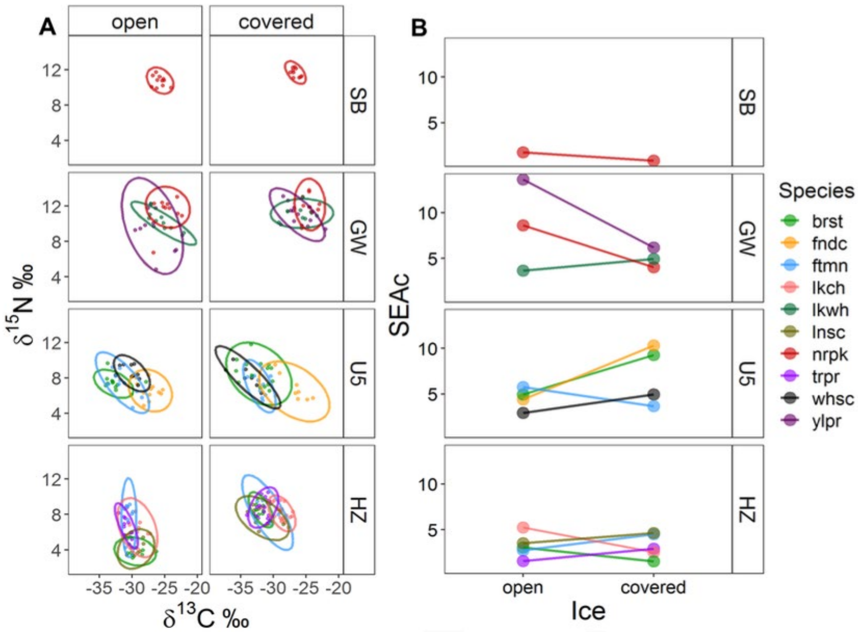
Analysis of hydroacoustic data showed a broad range in biomass and productive capacity/fisheries productivity within the Lower Athabasca region. For example, analysis of hydroacoustic data collected in fall 2018 across five lakes, revealed a mean fish density of between 0.04 fish/m^3 to 1.50 fish/m^3, with an average lake density of 0.55 fish/m^3. Preliminary analysis clearly illustrates fish density was variable across each lake and the observed distribution patterns are consistent with what would be expected given the life history characteristics of the species present. For example, lakes containing lake whitefish and yellow perch exhibited significantly higher fish densities at lower depths compared to lakes where the only sport fish was northern pike. These species regularly inhabit deeper regions of the lake typically not visited by northern pike, which are generally observed at depths less than five metres.



Graph 1: $\delta^{13}C$ values for all species sampled in both seasons in the four lakes.



Graph 2: $\delta^{15}N$ values for all species sampled in both seasons in the four lakes.



Graph 3: (A) Isotope biplots with 95% standard ellipses for fish species from the four lakes that were sampled in both seasons. (B) Direction of change in standard ellipse area between the open water and ice covered seasons.

General Lessons Learned

Ruppert et al. (2018) showed there are large variations in fish and invertebrate community biomass in Horizon Lake through time. In particular, fish community composition is drastically different in Horizon Lake than in natural lakes in the region, providing management challenges.

In the global synthesis provided by Theis et al. (2020), they show that in general, offsetting in aquatic systems has high compliance, but compliance does not necessarily mean increased ecosystem function.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Theis, S., Ruppert, J. W. R, Roberts, K. and M. S. Poesch. (2020) Compliance with and ecosystem function of biodiversity offsets in North American and European freshwaters. Conservation Biology 34 (1): 41-53.

Ruppert, J. L. W., Hogg, J., and M. S. Poesch. (2018) Community assembly and the sustainability of habitat offsetting targets in the first compensation lake in the oil sands region in Alberta, Canada. Biological Conservation 219: 138-146.

Conference Presentations/Posters

Roberts, K. and M. S. Poesch (2019) Exploring Fish Species Richness and Co-existence in Natural and Constructed Boreal Lakes with Isotopic Niches. 2019 Joint Conference of the Alberta Chapter and the Canadian Section of the Wildlife Society, Banff, AB, March 2019. (Poster)

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- Awarded Best Poster.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	MSc	2016	2020
Karling Roberts	University of Alberta	PhD	2016	2020
Sebastian Theis	University of Alberta	PhD	2017	2022

Research Collaborators: Dr. Jonathan Ruppert, Research Scientist, Toronto Region Conservation Authority; Dr. Ken Minns, University of Toronto (formerly Fisheries and Oceans Canada); Dr. Eva Enders, Fisheries and Oceans Canada

SOILS AND RECLAMATION MATERIALS

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 4 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 & 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 Protocol

Soil monitoring for Year 3 (2019) was conducted in late October to early November for the six stockpiles. A summary of the sampling protocol is provided below.

Sampling Protocol Requirements	2018 Annual Monitoring
Sampling period	October to November, 2019
Number of sample sites per stockpile	Nine
Depths sampled at each site	Surface = 0.5 m, Mid = 2.0 m, Deep = 4.0 m
Number of composite samples per depth, per stockpile (e.g., replicates)	Three
Total number of composite samples	54 samples, plus 18 pairs of bulk density samples
Soil parameters	pH Salinity Sodicity Cations and anions Available NPKS TOC (Total Organic Carbon) Texture Bulk density
Vegetation parameters	Abundance Species richness Community evenness Community diversity

Soil Parameters

In 2019, soil parameters were assessed at the 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 – TOC, Total Kjeldahl Nitrogen (TKN) and available nitrogen (N), phosphorus (P), potassium (K), sulphur (S).

Soil physical parameters were generally not influenced by soil type, with the exception of percent sand and percent clay. Percent sand was significantly higher in ABSS than in MIXED or OSS. Percent clay was significantly higher in MIXED stockpiles compared to OSS or ABSS, although the increase of 3% may not be physically or statistically meaningful. Percent sand decreased with sampling depth and percent clay increased with sampling depth. Percent silt also changed over time, but there was no consistent increase or decrease. Physical parameters have remained relatively constant over time, but in 2019 bulk density was significantly lower than in other assessment years. While this decrease was statistically significant, it may not be practically important; average bulk density in 2019 was 1.2 g/cm^3, compared to 1.4 g/cm^3 for previous assessment years.

Salinity parameters were dependent on soil type; pH and SAR were both significantly higher in OSS stockpiles compared to MIXED or ABSS stockpiles, and EC was significantly higher in MIXED stockpiles compared to ABSS or OSS stockpiles. Both EC and SAR were lower in 2016 than in other assessment years; however, pH was not dependent on the assessment year. Salinity parameters were dependent on sampling depth; EC and SAR both increased significantly with sampling depth, while pH decreased. Despite some treatment effects and changes over time, SAR values are not considered to be at levels that would affect soil quality or vegetation growth (SAR < 4). EC levels at mid (ABSS and MIXED) and deep (ABSS, MIXED and OSS) sampling depths are high enough that they could affect soil quality and vegetation growth (EC > 2 dS/m).

Soluble ions were generally dependent on soil type, assessment year and sampling depth, but the trends were not consistent for all parameters. Soluble Ca and Mg were significantly higher in MIXED stockpiles compared to ABSS and OSS stockpiles, and soluble K was significantly higher in ABSS stockpiles. Soluble Na was not affected by soil type. All soluble ions were dependent on assessment year, but only soluble Na had an observable pattern, with significantly higher values recorded in 2018 and 2019 compared to 2017 and 2016. Soluble Ca, Mg and Na also increased significantly with sampling depth, while soluble K decreased significantly with sampling depth.

TKN and available P, K and S nutrients were dependent on soil type. TKN was significantly higher in MIXED stockpiles than in ABSS and OSS stockpiles, while available P, K and S were highest in ABSS stockpiles. All nutrient parameters were dependent on assessment year. TOC values were significantly lower in 2017 than in other assessment years, while TKN was significantly lower in 2018 than in other assessment years. Available P decreased from year to year, while available S increased. No observable trend in available K over time was noted. Finally, available P, K and S were also dependent on sampling depth. Available P decreased significantly with sampling depth while available K and S increased. Statistical analyses were not performed on available N because measured concentrations were typically below detection limits.

Values for key parameters in 2019 are presented in Figure 1. Changes in key parameters over time for surface, mid and deep sampling depths are presented in Figures 2 to 4.

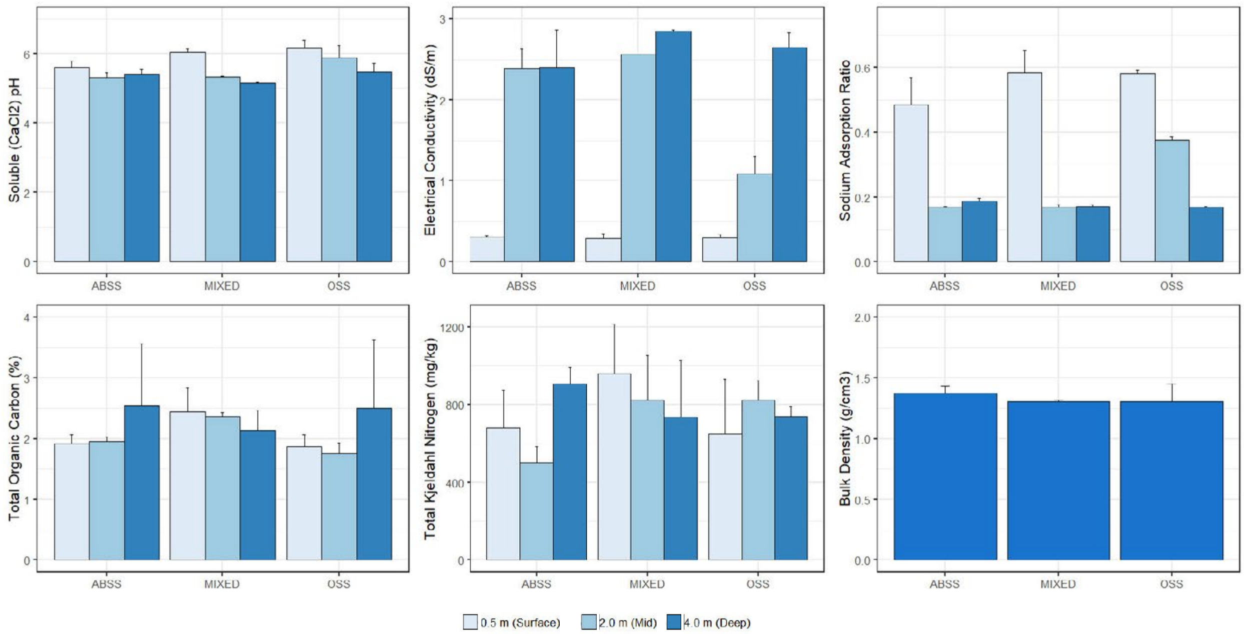

Figure 1: Salinity, nutrients and bulk density for surface soil types in 2019.

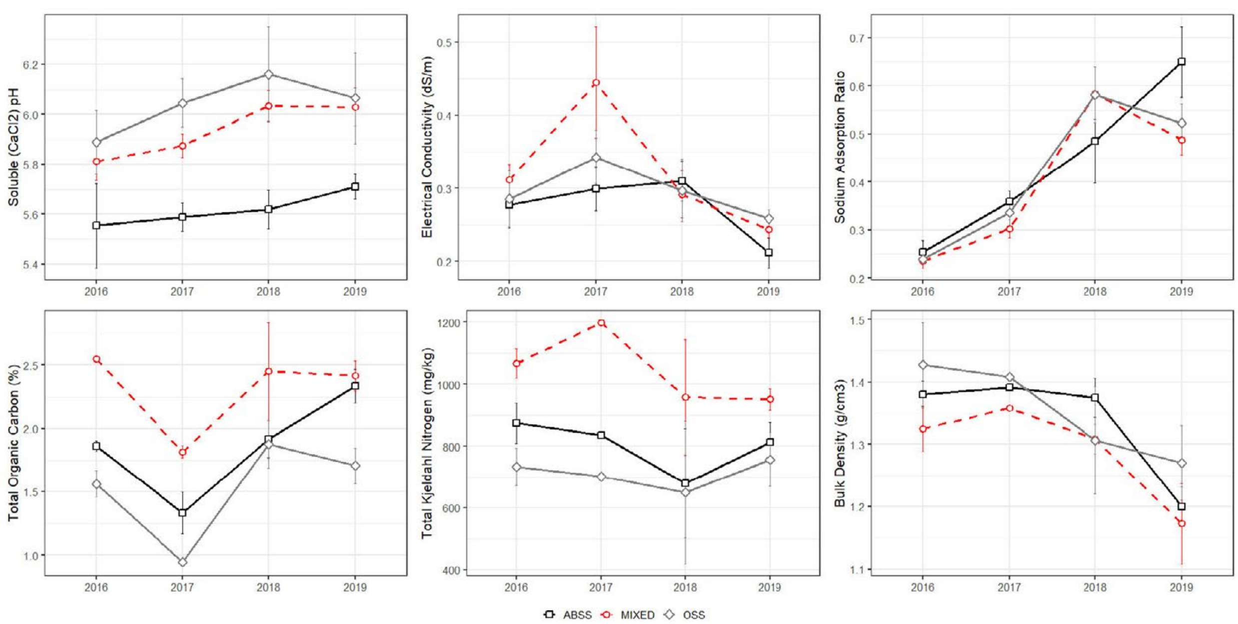

Figure 2: Surface (0.5 m) measurements for salinity, nutrients and bulk density for surface soil types (2016 to 2019).

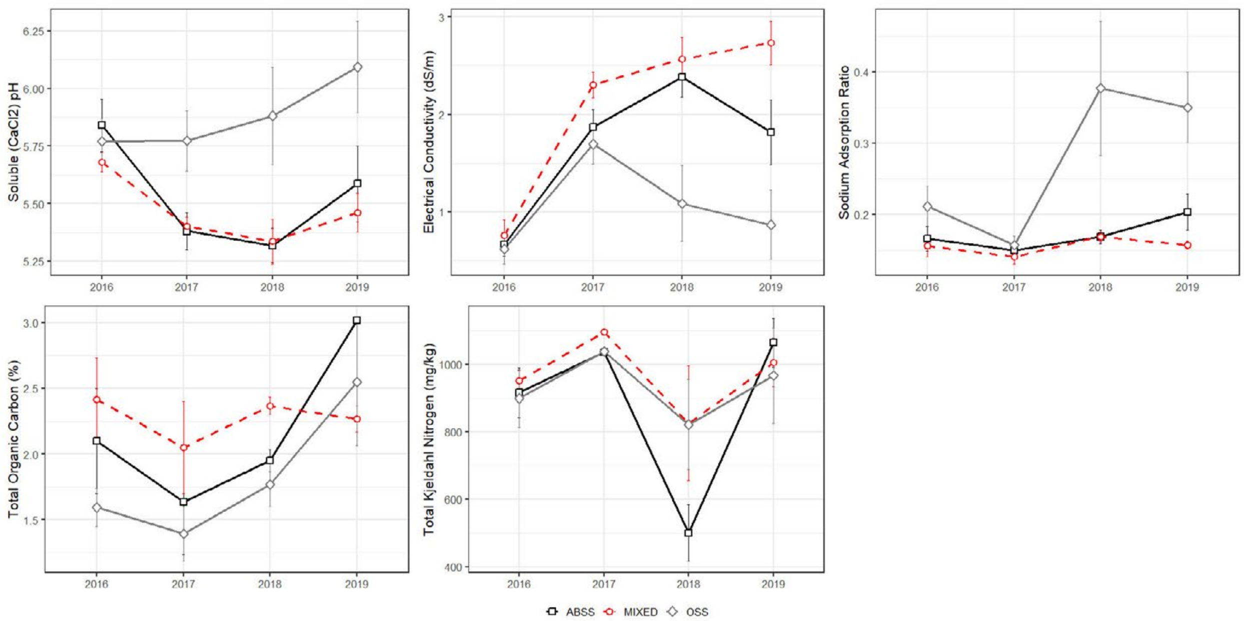

Figure 3: Mid-depth (2.0 m) measurements for salinity and nutrients for surface soil types (2016 to 2019).

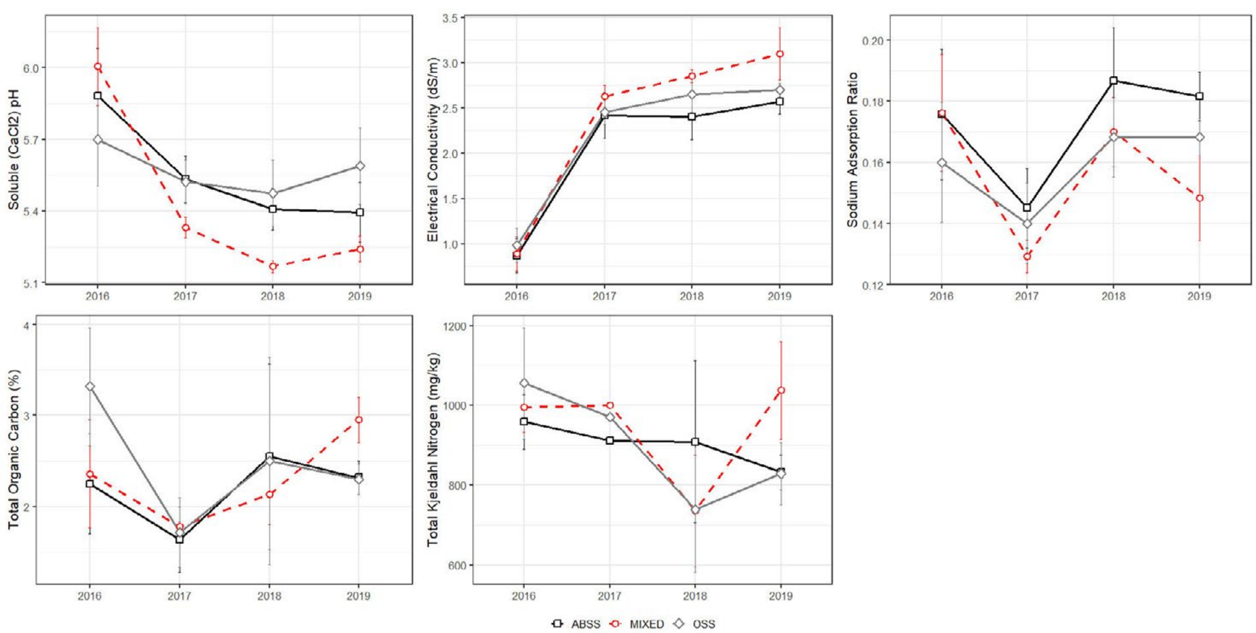

Figure 4: Deep-depth (4.0 m) measurements for salinity and nutrients for surface soil types (2016 to 2019).

Vegetation Parameters

Vegetation performance parameters were calculated for the stockpiles in 2019. These included total vegetative cover, species richness per plot, species richness per stockpile, evenness and diversity (Shannon Diversity Index). Diversity and species richness per plot were dependent on soil type, with ABSS stockpiles supporting lower diversity and richness per plot and OSS stockpiles supporting higher diversity and richness per plot. Total cover, richness per plot and total species richness were dependent on assessment year. Total cover increased between 2018 and 2019, while richness measures decreased. Evenness values were dependent on aspect, with higher values calculated for southern slopes (0.709 ± 0.02) compared to northern slopes (0.674 ± 0.02).

Vegetation performance parameters for 2018 and 2019 are presented in Figure 5. Data from 2017 were excluded due to a protocol change following the first year of assessments. Vegetation data were not collected the year the stockpiles were constructed (2016).

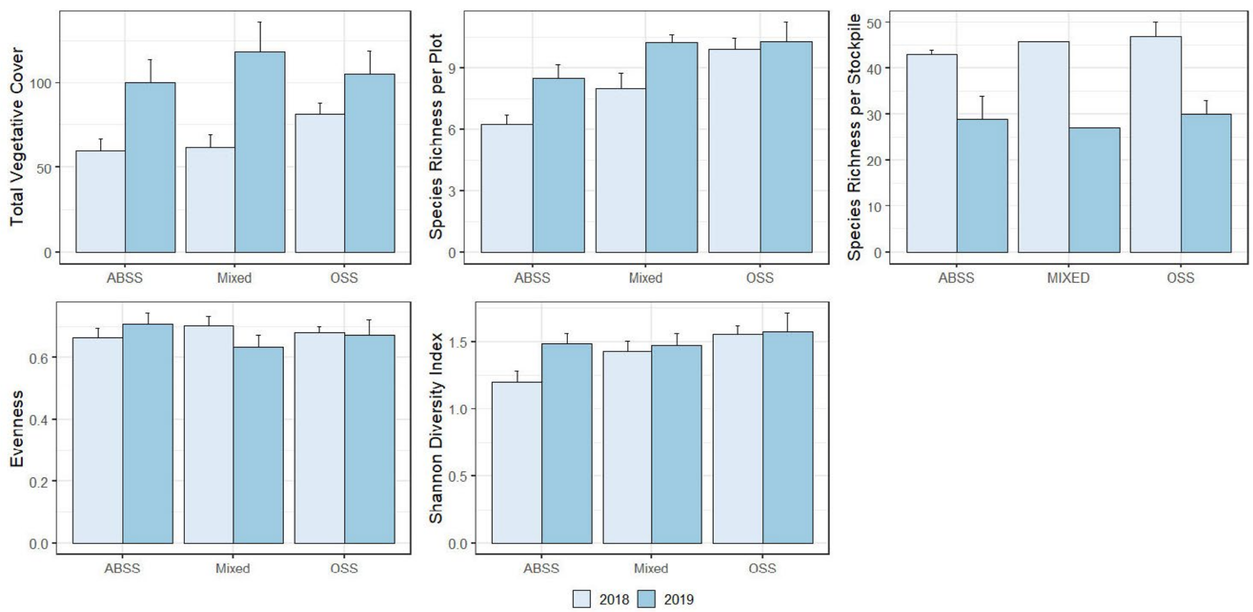

Figure 5: Vegetation performance parameters for surface soil types in 2018 and 2019.

LESSONS LEARNED

Lessons learned will be summarized after the final year of the program (2020).

LITERATURE CITED

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

Beckingham, J. D., Archibald, J. H. 1996. *Field guide to ecosites of Northern Alberta.* Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Special Report 5.

MacKenzie, D. 2013. *Oil Sands Mine Reclamation using Boreal Forest Surface Soil (LFH) in Northern Alberta*. PhD. Thesis. University of Alberta pp.120-140.

PRESENTATIONS AND PUBLICATIONS

No public presentations were released in 2019.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil & Environmental Consulting Inc.

Principal Investigator: Brittany Flemming, PhD

Potential Limitations of Stockpiled Soil

COSIA Project Number: LJ0300

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 2 of 2

PROJECT SUMMARY

Coversoil stockpiles will be used in the future to reclaim a large portion of land disturbed by oil sands mining and in-situ projects. There are potentially deleterious impacts on physical, biological and chemical properties of these coversoils when they are stored long term. This study will seek to understand the differences between using stockpiled versus directly placed coversoils in new reclamation areas, along with the potential mitigation activities on areas reclaimed using stockpiled soil, specifically tilling the soil.

Some of the specific questions to be answered include:

1. How are potential plant communities of stockpiled and directly placed coversoils different?
2. Does initial soil compaction during soil placement limit plant community establishment, and are de-compaction treatments successful in mitigating these effects?
3. Is soil from within the stockpile (i.e., greater than 10 cm or 30 cm from the outer surface of the stockpile) viable for plant regeneration, both as a propagule source and as a plant growth medium?

The outcomes from this study are expected to lead to a better understanding of the impacts of using stockpiled soils for reclamation, and aid in the development of operational reclamation practices that can be implemented to reduce these potential impacts.

The overall goal of this project is to identify limitations to plant community development and tree growth on different reclamation soil types. This project involves a number of sub-projects:

1. Ecosystem development on sites constructed with stockpiled versus direct placed material;
2. Plant community development on the Islands reclamation area (upland forest floor soil from d-ecosites surrounded by peat mineral mix material on Dyke 10 at Canadian Natural Resource Limited's Horizon site); and
3. Examining the role of coarse woody material and buried wood in reclamation soils.

All work is based on previously reclaimed sites and therefore offers real-world examples of ecosystem responses to different reclamation techniques.

PROGRESS AND ACHIEVEMENTS

The following progress was made toward each sub-project in 2019:

1. Ecosystem development on sites constructed with stockpiled versus direct placed material

a. No work was completed on this project in 2019.

2. Plant community development on the Islands reclamation area

a. The initial plant communities were very different between the peat-mineral mix (PMM) and forest floor mineral mix (FFMM) soil types. This is likely due in part to the seed bank differences among soil with FFMM having approximately five times more seeds in the seed bank. However, by Year 4 (2019) of seed development within the stockpile, plant communities were quite similar with both soil types averaging approximately 40% in total vegetation cover.

b. There is evidence that seed rain originating from off-site, along with vegetative expansion and competition, are responsible for changes in the plant community over time.

c. Other results indicate that the cover of non-native weedy species is not related to the cover of native species. However, cover of grasses (predominantly *Calamagrostis Canadensis*) was negatively related to native forb cover.

3. Examining the role of coarse woody materials and buried wood in reclamation soils

a. For coarse woody materials composed of large aspen logs, spaced approximately 5 m apart placed on the surface of reclamation soils, there is an increase in total plant cover immediately adjacent to the placed logs relative to areas in between logs on both PMM and FFMM soil types. However, the dominant control on both soil properties and plant community was reclamation soil type and not coarse woody materials.

b. No work occurred related to buried wood in reclamation soils, due to the focus on CWM in the form of logs.

LESSONS LEARNED

Lessons learned to date include:

- Initial differences in plant community between soil types are largely gone by Year 4 (2019).
- The presence of non-native weedy species does not appear to be negatively impacting the development of native species.
- The placement of coarse woody materials logs on reclamation soils appears to have some positive benefits on the plant community but these effects are minor relative to the effect of reclamation soil type properties and plant community.

PRESENTATIONS AND PUBLICATIONS

2019 Journal Publications

Das Gupta, S., Kirby, W. and Pinno, B.D. 2019. Stockpiling and organic matter addition changes nutrient bioavailability in reclamation soils by modifying microbial functions. Soil Science Society of America Journal. In press. doi:10.2136/sssaj2018.07.0273.

deBortoli, L.A, Pinno, B.D., MacKenzie, M.D., and Li, E.H.Y. 2019. Plant community composition and trembling aspen establishment in response to seeding and weeding treatments on different reclamation cover soils. Canadian Journal of Forest Research. In Press. DOI:10.1139/cjfr-2018-0363.

Jean, S.A., Pinno, B.D. and Neilsen, S.E. 2019. Trembling aspen root suckering and stump sprouting response to above ground disturbance on a reclaimed boreal oil sands site in Alberta, Canada. New Forests. In Press. DOI: 10.1007/s11056-018-09698-2.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Brad Pinno

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The GERI (Genomics Enhanced Reclamation Index) Stockpile Project: Creating Ecologically Viable Soil Stockpiles for Future Reclamation

COSIA Project Number: LJ0299

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 3 of 3

PROJECT SUMMARY

Although direct placement of salvaged soil on a reclamation site is the preferred mechanism for land reclamation, in some cases this approach is not possible (Alberta Environment and Water, 2011). On these occasions, soil must be stockpiled, in some cases for years or even decades prior to placement for reclamation. It is unclear what impact soil stockpiling has on soil health and the stability and function of ecosystems developing on these reclamation substrates, although anecdotal evidence and the literature indicates that the health of stockpiled soil declines over time, including impacts on physical, chemical, and biological parameters (Abdul-Kareem, et al., 1984).

This project seeks to answer two main research questions:

1. Does stockpiled topsoil contribute to healthy, functioning ecosystems over time? Will these stored soils require enhancement prior to placement for reclamation? If so, what enhancements will be required?
2. In reclaimed ecosystems, can below ground ecosystem parameters be linked to above-ground ecosystem parameters for a more complete indication of ecosystem health? Importantly, will it be possible to develop this information into a more rapid assessment of ecosystem health (and reclamation trajectory) than is currently used?

To address these questions, this project is assessing soil physical, chemical, and biological parameters as well as above ground plant parameters, in operational stockpiles. Cutting edge genomic tools are linking above ground and below-ground parameters to obtain a better assessment of soil health.

This project represents the first phase of a larger study investigating soil stockpile health. This phase seeks to understand the ecosystem dynamics present within and between stockpiles. A second, future phase of the project would investigate approaches to maximize soil stockpile viability for reclamation, based on findings in this first phase.

In at least some cases, using stockpiled soils has led to increased soil compaction, decreased nutrient availability, and increased weediness relative to directly placed soils when used for reclamation (I. Sherr, pers. comm.). These and other impacts have been observed with stockpiled soils at other sites around the world (Abdul-Kareem and McRae, 1984) The primary value of this work is the confidence that it could give operators in understanding how to approach their long-term stockpiled assets in the future to maximize their quality as a reclamation substrate, and the development of tools for assessing soil health that are more directly relevant to reclamation practices than current methods.

Four topsoil stockpiles and two mature reference sites were sampled from the Horizon mine (Fort McMurray site), and four topsoil stockpiles and four mature reference sites from Primrose/Wolf Lake in situ operations (Cold Lake site). Stockpiles ranged in age from six months to older than 28 years. The stockpiles at the Fort McMurray site were of various heights (from 3 m to 10 m) and were built over multiple years via different mechanisms (dozing into place and truck dumping). The stockpiles at Wolf Lake were all approximately 10 m tall and were dozed into place. Samples to assess seed bank, soil chemical and physical parameters, and microbiology were taken from stockpiles from depths of 0 cm to 5 cm, 5 cm to 10 cm, 10 cm to 20 cm, 20 cm to 30 cm, and 80 cm to 90 cm. A deeper sample was also taken from depths greater than 1 m for six of the stockpiles. Plant Root Simulator probes (PRS®; Western Ag Innovations, Saskatoon, SK, Canada) were used to measure bioavailability of soil nutrients; nitrate (NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), dihydrogen phosphate ($H_2PO_4^-$), hydrogen phosphate (HPO_4^{2-}) and sulfate (SO_4^{2-}). Aboveground vegetation cover was also estimated at these locations. The seed bank composition was determined in a greenhouse using the seedling emergence method. Changes in soil physical quality were assessed based on; basic properties (clay content, bulk density, and total soil carbon); capacity-based measurements (field capacity, plant available water content, air capacity, macroporosity, and Sv-index value); and energy parameters (air and water retention energies).

PROGRESS AND ACHIEVEMENTS

Stockpiles had higher seedling abundance (Figure 1) and species richness than nearby forested sites but were dominated by grasses and non-native forbs. Most seeds germinated from the surface layer, with 92% of seeds germinating from the litter layer in the forested sites, and 68% from the 0 cm to 5 cm layer in the stockpiles (Figure 2). The aboveground vegetation cover and seed-bank communities in the mature forest sites were similar to one another. However, this was not the case for stockpiled soils – aboveground communities and seed banks were much more dissimilar between stockpiles than for the mature reference sites (Figure 3).

Stockpiles have higher species diversity when compared to mature forest sites (Figures 1 and 3). However, many of the species, such as grasses and non-native forbs present on the stockpiles, may not be desirable for reclamation sites. Non-native species are also found within the stockpiles at depths below 5 cm.

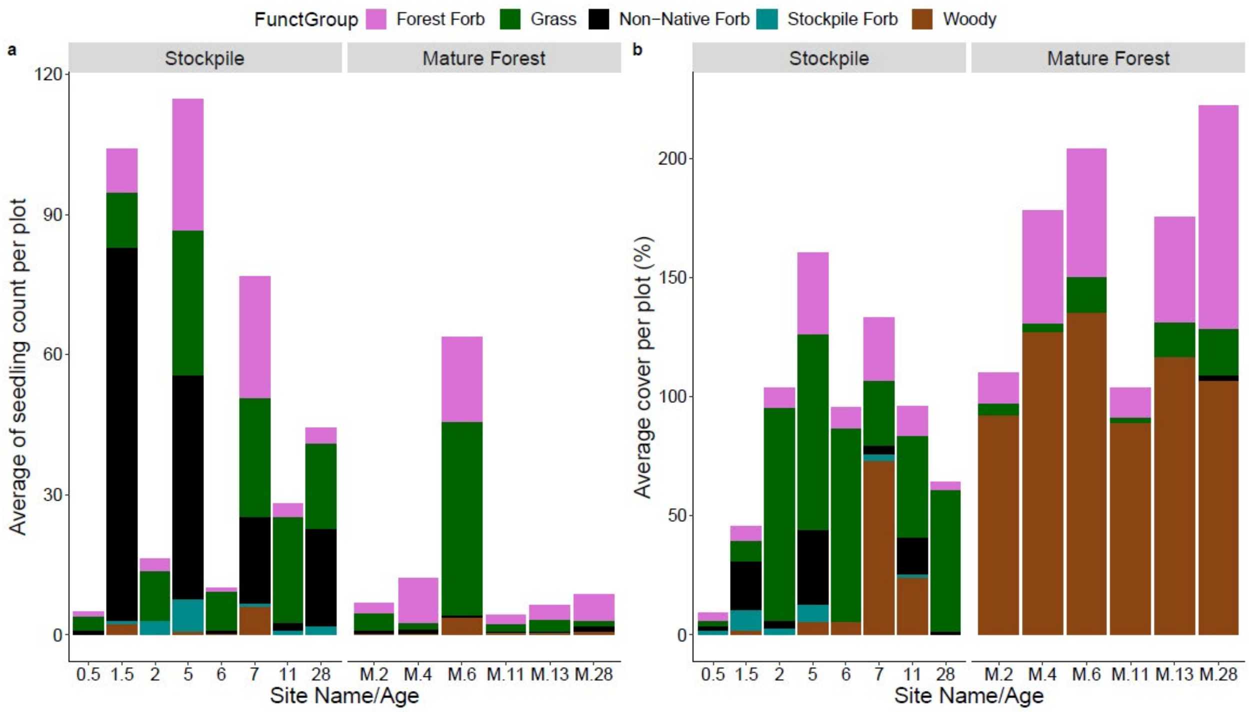

Figure 1: Species abundances for aboveground (a) and seed bank (b) communities divided into functional groups (n = 3). Site names are included on the x-axis, with all mature forest sites starting with M.

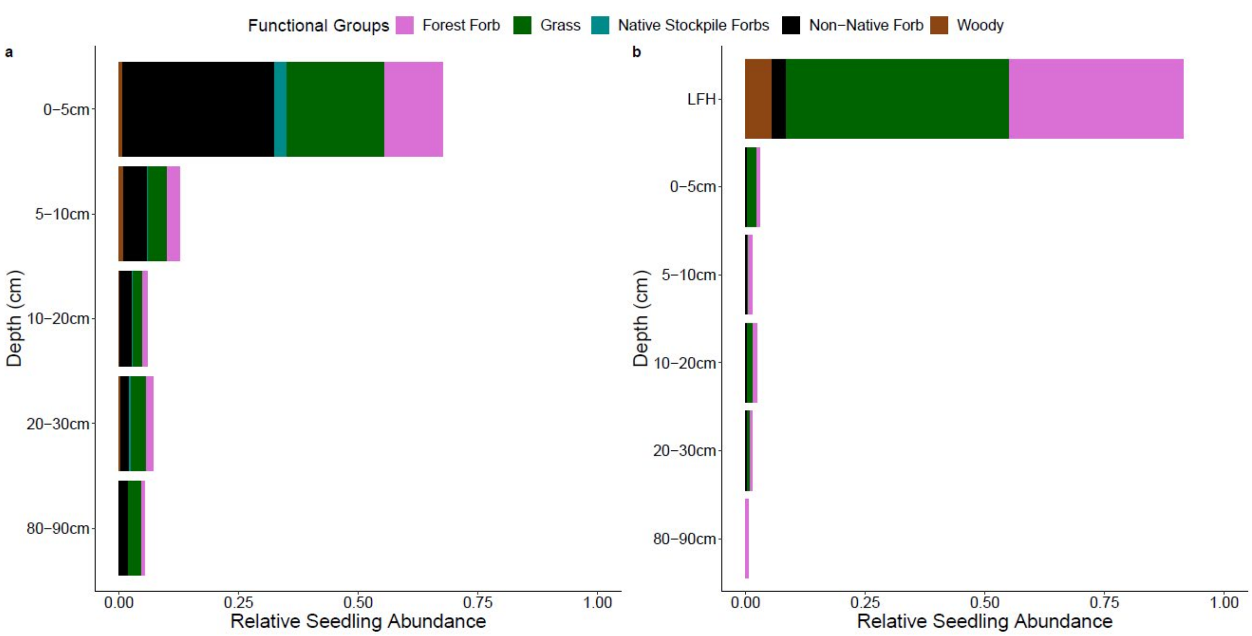

Figure 2: Proportion of relative seedling abundance for stockpile (a) and mature forest sites (b) as a function of soil depth. Relative abundance was calculated by dividing seedling abundance for each functional group at a given depth by the total seedling abundance for that depth.

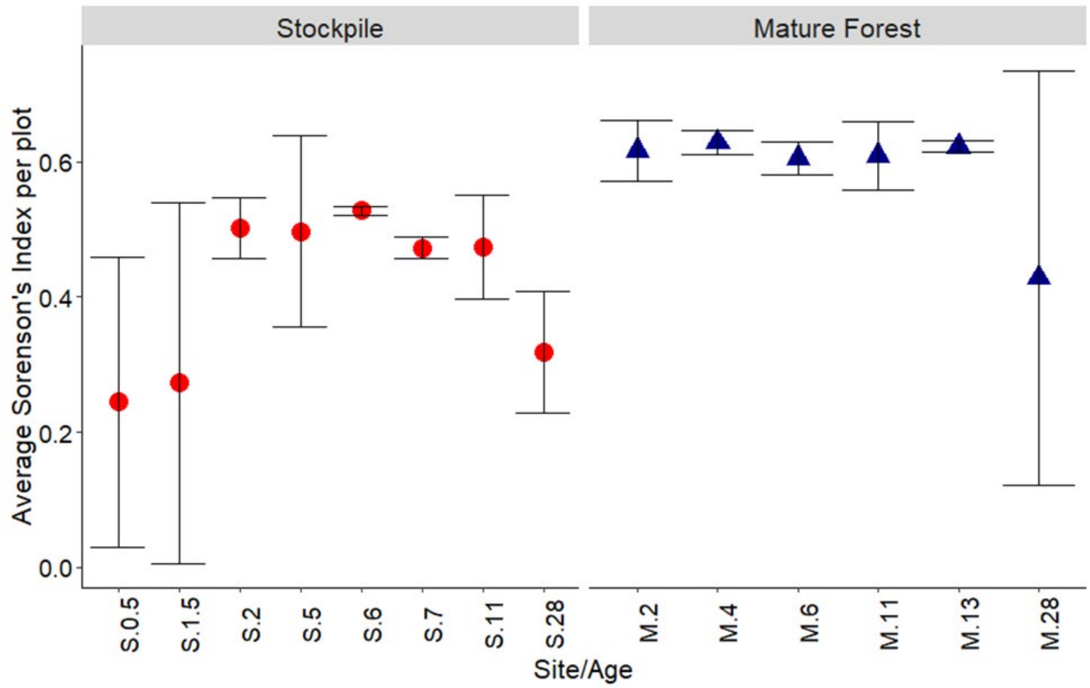

Figure 3: Average Sorensen's index per plot. Species with low abundances were excluded. Error bars represent one standard deviation around mean values (n = 3).

The stockpile sites had higher supply rates of Ca^{2+}, Mg^{2+}, and NO_3^-, pH and clay content at 0 cm to 10 cm, but similar rates for K^+, $H_2PO_4^-/HPO_4^{2-}$, or SO_4^{2-} compared to the mature forest sites (Table 1). The bioavailability of SO_4^{2-} was higher on stockpiles at the Fort McMurray site than the Cold Lake site (Figure 4). The bioavailability of Ca^{2+}, Mg^{2+}, NO_3^-, K^+, and SO_4^{2-} varied widely across stockpile and mature forest sites, with no clear trends with stockpile age (Figure 4). However, phosphate bioavailability was highest in the youngest stockpile. Also, the high NO_3^- bioavailability below 20 cm could be evidence that this zone of the stockpiles are not becoming anaerobic over time.

Table 1: Average probe supply rate (µg/10 cm²/7 days) of nutrients, pH and clay content (%) for stockpile and mature forest sites at 0 cm to 10 cm and 20 cm to 90 cm. Results of hierarchical GLMM models using gamma or normal distributions. Random effects included sampling region, stockpile or mature site and plot.

0 cm to 10 cm			
	Stockpile avg. supply rate	**Reference avg. supply rate**	**p-value**
NO3-N	15.3	2.6	< 0.001
Ca	575.9	231	< 0.001
Mg	109.7	53.8	< 0.001
S	25.1	7.8	0.561
P	5.5	2.4	0.970
K	49.6	37.1	0.096
pH	6.4	5.7	0.001
Clay	19.4	17.5	0.016
20 cm to 90 cm			
	Stockpile avg. supply rate	**Reference avg. supply rate**	**p-value**
NO3-N	41.5	2.8	0.039
Ca	678.5	417.2	0.105
Mg	164.3	116.0	0.259
S	7.4	38.3	0.121
P	2.3	1.3	0.331
K	63.8	26.3	0.121
pH	6.3	6.8	0.556
Clay	19.4	31.2	0.001

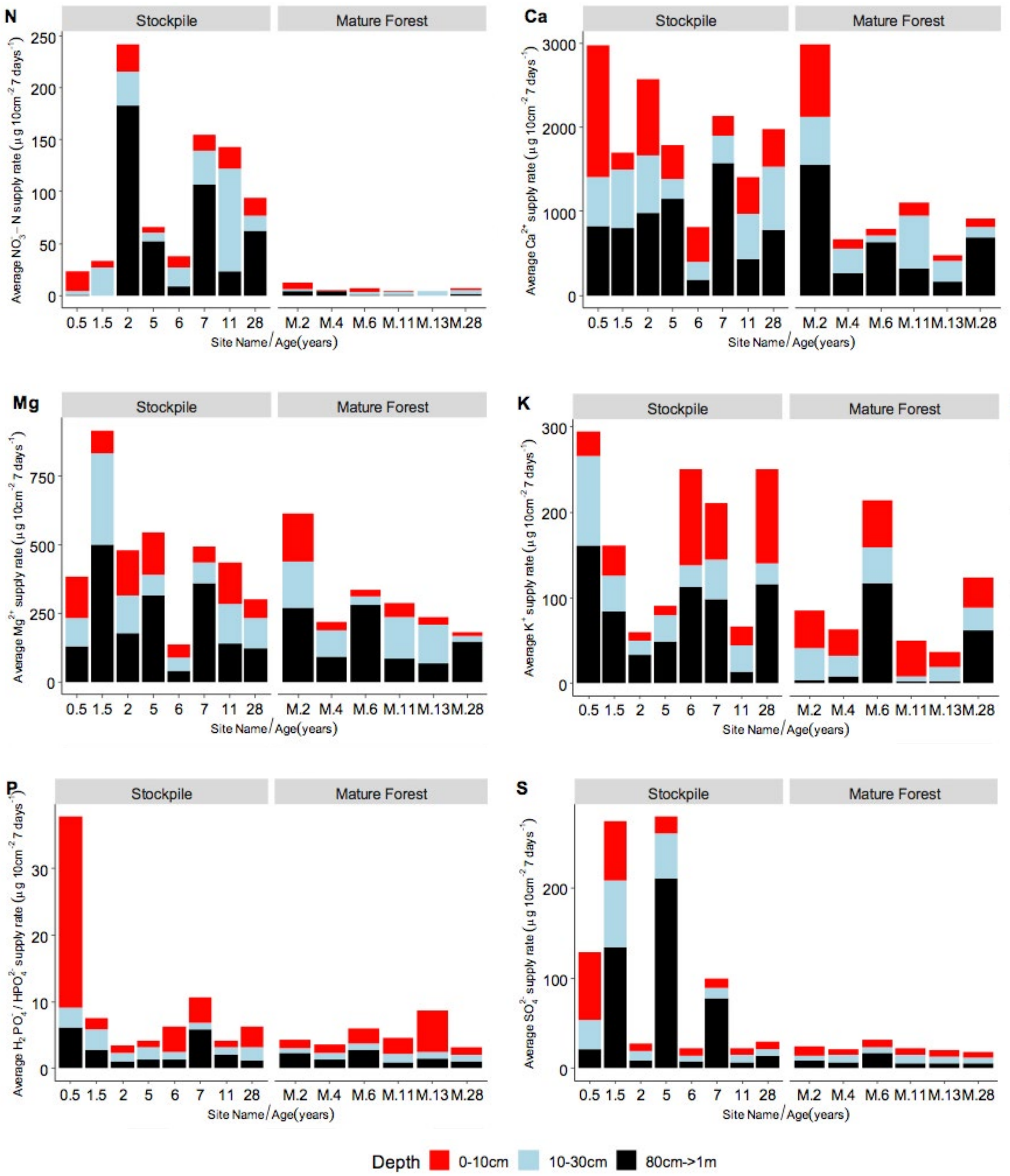

Figure 4: Average supply rates of NO_3^-, Ca^{2+}, Mg^{2+}, K^+, $H_2PO_4^-/HPO_4^{2-}$, and SO_4^{2-} across stockpile and mature forest sites. Rates were averaged for three depths; 10 cm to 20 cm; 20cm to 30 cm; and for 80 cm to > 1 m samples.

Clay content and bulk density were higher in natural soils. Whereas, total soil carbon, S-index value, field capacity, plant available water content, air capacity, macroporosity, and air and water retention energies, were higher in stockpiled soils (Tables 2 and 3). Significant differences between natural and stockpiled soils were present only in the subsurface depths. Differences also existed within natural soil profiles between the surface and subsurface depths. In contrast, soil chemical and physical parameters remained uniform across all sampling depths in the stockpiles.

Natural soils were found to have lower values of capacity-based and Sv soil physical quality indices than in stockpiles, but higher energy-based soil physical quality indices (air and water retention energies), creating contradicting results.

Changes in the distribution of the 4 mm and 250 µm aggregate size classes, carbon distribution (total carbon and light fraction carbon), carbon dynamics (basal respiration rates), and soil organic matter quality criteria (C to N ratios and $\delta^{13}C$ values) were assessed at both the whole soil and individual aggregate scale (Table 4). No significant differences in aggregate size proportions were found between natural and stockpiled soils for any of the sampling depths, although higher proportions of 4 mm and 250 µm aggregates were present in natural soils. Higher basal respiration rates and $\delta^{13}C$ values were also found in natural soils, whereas stockpiled soils had higher amounts of both total and light fraction carbon, along with elevated C to N ratios (Table 5). Significant differences between natural and stockpiled soils were largely confined to the two subsurface sampling depths. Differences within natural soils were between surface and subsurface depths, whereas stockpiles remained uniform across all sampling depths. Basal respiration rates were found to negatively correlate with total carbon, light fraction carbon proportions, and whole soil C to N ratios, and positively correlate with whole soil light fraction C to N ratios and $\delta^{13}C$ values. Similar trends were observed at the individual aggregate size scale.

Table 2: Estimated marginal means and standard errors for soil clay content, bulk density, total soil carbon, and the S index. For each property, uppercase letters denote significant differences between natural and stockpiled soils at a particular depth. Lower case letters represent significant differences within natural or stockpiled site types between difference depths. Significant differences were declared when $p < 0.05$.

	Clay Content (%)	Bulk Density (g cm^{-3})	Total Soil Carbon (%)	S^v (cm^3 cm^{-3} cm^{-1})
Depth = 0cm to 10 cm				
Natural	20.7 ± 9.6 Aa	1.14 ± 0.10 Aa	0.96 ± 2.09 Aa	0.022 ± 0.006 Aa
Stockpiled	19.4 ± 9.5 Aa	0.96 ± 0.09 Aa	1.49 ± 1.78 Ba	0.034 ± 0.005 Aa
Depth = 20 cm to 30 cm				
Natural	35.4 ± 9.6 Ab	1.43 ± 0.10 Ab	0.84 ± 2.06 Aa	0.020 ± 0.006 Aa
Stockpiled	18.4 ± 9.5 Ba	0.96 ± 0.09 Ba	1.50 ± 1.78 Ba	0.035 ± 0.005 Ba
Depth = 80 cm to 90 cm				
Natural	39.1 ±9.6 Ab	1.33 ± 0.10 Ab	0.85 ± 2.06 Aa	0.016 ± 0.006 Aa
Stockpiled	21.5 ± 9.6 Ba	0.91 ± 0.09 Ba	1.30 ± 1.83 Bb	0.037 ± 0.006 Ba

Table 3: Estimated marginal means and standard errors for field capacity (FC), plant available water content (PAWC), air capacity (AC), and macropores. For each property, uppercase letters denote significant differences between natural and stockpiled soils at a particular depth. Lower case letters represent significant differences within natural or stockpiled site types between difference depths. Significant differences were declared when p < 0.05.

	FC ($cm^3\ cm^{-3}$)	PAWC ($cm^3\ cm^{-3}$)	AC ($cm^3\ cm^{-3}$)	Macropores ($cm^3\ cm^{-3}$)
Depth = 0 cm to 10 cm				
Natural	0.24 ± 0.06 Aa	0.14 ± 0.02 Aa	0.11 ± 0.02 Aa	0.06 ± 0.01 Aa
Stockpiled	0.35 ± 0.05 Ba	0.18 ± 0.01 Aa	0.16 ± 0.02 Aa	0.08 ± 0.01 Aa
Depth = 20 cm to 30 cm				
Natural	0.27 ± 0.06 Aa	0.08 ± 0.02 Ab	0.05 ± 0.02 Ab	0.03 ± 0.01 Ab
Stockpiled	0.35 ± 0.05 Aa	0.17 ± 0.01 Ba	0.16 ± 0.02 Ba	0.07 ± 0.01 Ba
Depth = 80 cm to 90 cm				
Natural	0.27 ± 0.06 Aa	0.09 ± 0.02 Ab	0.09 ± 0.02 Aab	0.05 ± 0.01 Aa
Stockpiled	0.34 ± 0.05 Aa	0.18 ± 0.02 Ba	0.15 ± 0.02 Ba	0.06 ± 0.01 Aa

Table 4: Estimated marginal means and standard errors for 4 mm and 250 µm water stable aggregate proportions, total carbon associated with each aggregate size fraction, and whole soil light fraction carbon (LFC) proportions. For each property, uppercase letters denote significant differences between natural and stockpiled soils at a particular depth. Lower case letters represent significant differences within natural or stockpiled site types between difference depths. Significant differences were declared for p < 0.05.

	4 mm Aggregate Proportion	250 mm Aggregate Proportion	4 mm Aggregate Carbon (%)	250 mm Aggregate Carbon (%)	LFC Proportions
Depth = 0 cm to 10 cm					
Site = Natural	0.24 ± 0.07 Aa	0.16 ± 0.01 Aa	1.55 ± 1.59 Aa	3.87 ± 2.31 Aa	0.20 ± 0.06 Aa
Site = Stockpiled	0.20 ± 0.06 Aa	0.04 ± 0.01 Aa	5.78 ± 1.37 Ba	9.04 ± 1.96 Aa	0.39 ± 0.05 Ba
Depth = 20 cm to 30 cm					
Site = Natural	0.38 ± 0.07 Ab	0.26 ± 0.01 Aa	0.70 ± 1.56 Ab	1.25 ± 2.26 Ab	0.08 ± 0.05 Ab
Site = Stockpiled	0.20 ± 0.06 Aa	0.03 ± 0.01 Aa	5.22 ± 1.37 Ba	9.82 ± 1.96 Ba	0.41 ± 0.05 Ba
Depth = 80 cm to 90 cm					
Site = Natural	0.26 ± 0.07 Aa	0.03 ± 0.01 Ab	0.76 ± 1.56 Ab	0.97 ± 2.26 Ab	0.06 ± 0.05 Ab
Site = Stockpiled	0.29 ± 0.06 Aa	0.06 ± 0.01 Aa	4.44 ± 1.42 Ba	8.09 ± 2.03 Ba	0.34 ± 0.05 Ba

Table 5: Estimated marginal means and standard errors for basal respiration rates as well as whole soil C to N and $\delta^{13}C$ concentrations. For each property, uppercase letters denote significant differences between natural and stockpiled soils at a particular depth, while lower case letters represent significant differences within natural or stockpiled site types between difference depths. Significant differences were declared for $p < 0.05$.

	Basal Respiration (µgC/gC/h)	Whole Soil C:N	Whole Soil ^{13}C
Depth = 0 cm to 10 cm			
Site = Natural	210 ± 45 Aa	17.0 ± 2.1 Aa	-26.4 ± 0.4 Aa
Site = Stockpiled	84 ± 38 Ba	19.3 ± 1.9 Aa	-26.6 ± 0.4 Aa
Depth = 20 cm to 30 cm			
Site = Natural	212 ± 43 Aa	13.0 ± 2.1 Ab	-25.6 ± 0.4 Aa
Site = Stockpiled	89 ± 38 Ba	20.1 ± 1.9 Ba	-27.0 ± 0.4 Ba
Depth = 80 cm to 90 cm			
Site = Natural	245 ± 43 Aa	14.2 ± 2.1 Ab	-24.0 ± 0.4 Ab
Site = Stockpiled	166 ± 40 Ba	18.8 ± 2.0 Ba	-27.0 ± 0.4 Ba

Microbial community analysis is still underway. Preliminary findings are that stockpiled soils may have significantly higher microbial diversity overall (Shannon and Inverse Simpson's Indexes) than undisturbed native soils (Figure 5). Variability in diversity appears to be higher in stockpiled soils than in undisturbed soils. There do not appear to be significant differences in overall diversity between the Horizon mine and the Wolf Lake in situ sites. Furthermore, while the majority of stockpile soil microbial communities do not fall into the range of variability of undisturbed soil microbial community composition, some do fall into that range (Figure 6). Variability in composition of stockpiled soil microbial communities also appears to be higher than for undisturbed sites. Please note that these findings are preliminary and subject to change on further analysis.

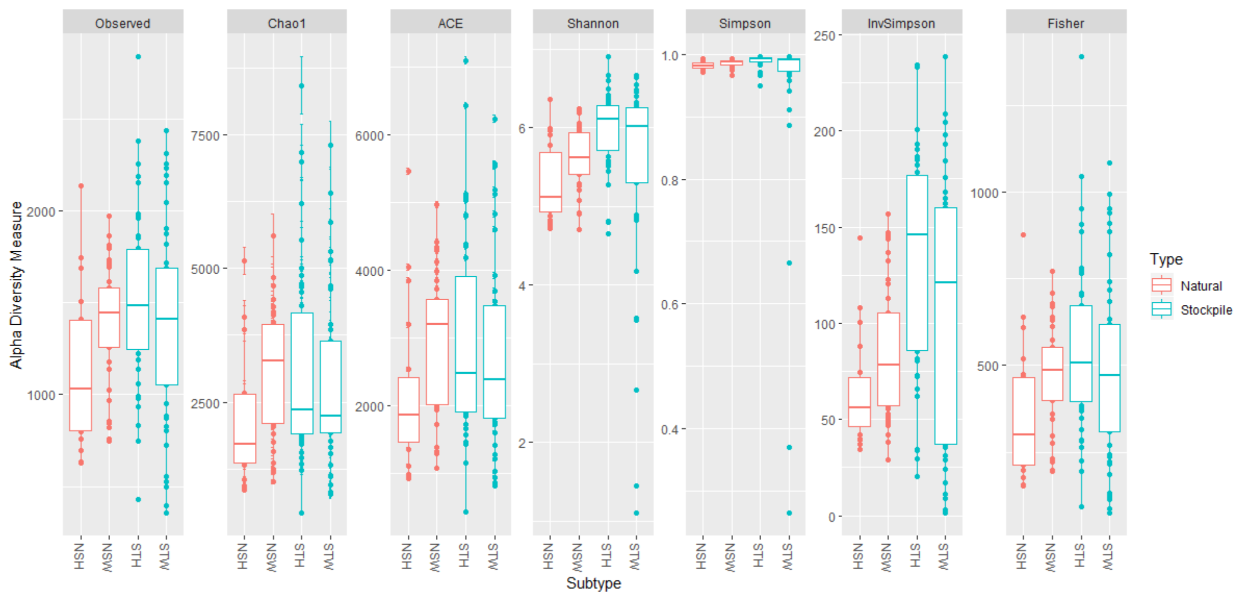

Figure 5: Alpha diversity metrics for stockpiled (STH and STW) and undisturbed (NSH and NSW) soils. H soils (STH and NSH) are from the Canadian Natural Horizon mine site; W sites (STW and NSW) are from the Wolf Lake in situ sites.

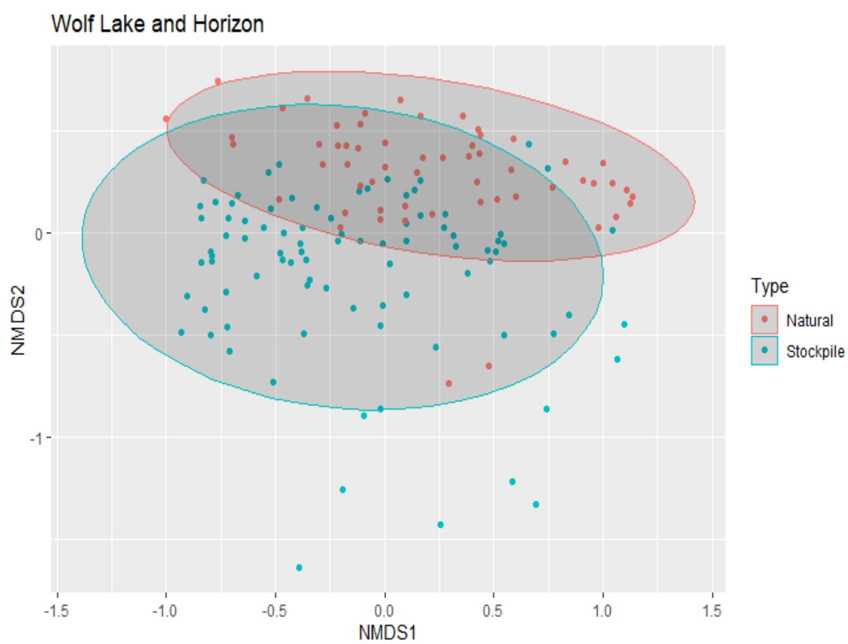

Figure 6: Non-metric multidimensional scaling ordination of undisturbed (red) and stockpiled (blue) soil community composition. Stress is 0.148.

LESSONS LEARNED

Based on study findings to date:

Composition of plant communities on stockpiles and the viability of seedbank stocks with depth: If many non-native species are present in the stockpile, soil could be stripped from deeper depths when salvaging stockpiles for future reclamation sites in order to dilute the non-native seed bank and give native species the biggest chance to establish. Overall, there could be a disconnect between the species seen aboveground and in the seed bank; therefore, sampling of the seed bank before planting or seeding is recommended.

Nutrient availability: Overall, stockpiles seem better off in terms of bioavailability of Ca^{2+}, Mg^{2+}, and NO_3^-, and pH levels compared to the mature forest sites; this could be beneficial for plant growth. However, the higher NO_3^- concentrations could also lead to leaching, or to an increase in unwanted weedy species. The variability in the bioavailability of nutrients among stockpiles could mean that future management of stockpiles and reclamation sites should be done on a smaller scale (i.e., match the stockpile to the reclamation site), and should focus on differences across stockpiles. There is unlikely to be a one-size-fits-all approach to dealing with stockpiled soils.

Soil chemical and physical parameters: The consistent differences between natural and stockpiled soils in subsurface depths and a lack of differences at the soil surface, suggests that there may be a recovery trend for the measured variables at the stockpile surface towards more natural conditions, while the subsoil depths in stockpiles continue to represent more novel soil conditions. As such, utilizing soils from stockpile surfaces may increase the likelihood of successful reclamation, due to the existence of more natural soil physical properties, carbon attributes, and microbial activity.

Microbial communities: The increased variability in composition and diversity in the stockpiled soils may be beneficial to subsequent reclamation. However, the differences in the composition of most stockpiled microbial communities and undisturbed sites suggests that the soils may not carry out equivalent functions to undisturbed native sites when soils have been stockpiled.

These findings are preliminary and are subject to change once the microbiology analyses are complete and the data are better integrated and modelled. We expect to make more definitive findings in our final report next year.

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Alberta Environment and Water. 2011. Best Management Practices for Conservation of Reclamation Materials in the Mineable Oil Sands Region of Alberta. Prepared by MacKenzie, D. for the Terrestrial Subgroup, Best Management Practices Task Group of the Reclamation.

Abdul-Kareem, A. W., & McRae, S. G. (1984). The effects on topsoil of long-term storage in stockpiles. Plant and Soil, 76(1-3), 357-363.

Buss, J. and B. Pinno. (2019) Soil stockpile seed viability declines with depth and is impacted by surface vegetation. J. Amer. Soc. Mining Reclam. **8**:23-44.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Jennifer Buss. MSc A comparison between reclamation stockpile and boreal forest seed banks and plant communities. (In press; thesis defended).

Kyle Stratechuk. MSc Effects of Stockpiling on Soil Physical Properties and Soil Carbon. (In preparation; to be defended in approximately March, 2020).

Julian Ariel Cabrera Hernandez. MSc Soil stockpiling impacts on microbial communities. (In preparation; to be defended in approximately January, 2021).

Journal Publications

Buss, J. and B. Pinno. 2019. Soil stockpile viability declines with depth and is impacted by surface vegetation. J. Am. Soc. Mining Reclam. 8. 23-44.

Conference Presentations/Posters

Lanoil, B. 2019. Reclamation genomics. Alberta Soil Network. Oral presentation. 1 hour.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Brian Lanoil

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Brad Pinno	University of Alberta	Assistant Professor		
Jennifer Buss	University of Alberta	MSc	2018	2020
Kyle Stratechuk	University of Alberta	MSc	2018	2020
Julian Hernandez	University of Alberta	MSc	2019	2021

Reclamation Soils Index of Biological Integrity (IBI)

COSIA Project Number: LJ0296

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Status: Year 2 of 2

PROJECT SUMMARY

Microorganisms and soil arthropod communities play important roles in soil nutrient and carbon cycling, and underlie most soil biogeochemical and soil health processes. They are also highly responsive to changes in the soil environment, adjusting types and levels of activity as well as community composition/biodiversity. As such, they may be optimal markers for soil function in disturbed ecosystems, such as those found in oil sands mines. The research question for this project is: Can soil arthropod and microbial biodiversity be used to assess soil function in reclamation areas?

The objective of this study is:

1. Examine the biological implications of soil chemistry in an upland subsoil-surface soil column across a range of sites (both disturbed and undisturbed) on the Horizon lease, where soils have not yet been salvaged and on reclamation areas. This objective will be achieved by:

- Testing upland subsoil for chemical suitability parameters including pH, sodium adsorption ratio (SAR) and electrical conductivity (EC), while simultaneously examining soil nutrients from the upland surface soil in the soil column.
- Examining the community structure of soil microorganisms and arthropods in the upland surface soil of the soil column.
- Determining if biological communities in upland surface soils (arthropods or microorganisms) segregate along a stress gradient, based on the chemistry of the subsoil immediately below. This stress gradient could be a result of sodicity, or perhaps other chemical parameters.
- Using these data to develop a Soils Index of Biological Integrity (if possible) that may be used to further understand how soil health can be measured and understood in the context of reclamation. The Soils IBI will be further refined and tested with data as new reclamation comes online, and will be used as a tool to monitor reclamation progress and success.

Canadian Natural's Horizon mine operating approval stipulates that a minimum average depth of one metre of subsoil or suitable overburden shall be used to cap Clearwater overburden (KC) material prior to the placement of a 0.20 m layer of coversoil. The one metre of subsoil is intended to provide a beneficial growth medium and to act as a buffer against plumes of salinity that may originate from highly sodic KC parent material. During salvage and prior to placement, overburden (subsoil) materials are tested to determine if they meet suitability criteria, based on several chemical parameters including pH, SAR and EC.

As of August 2015, a new approval requirement required that all upland surface soils and subsoils must be salvaged and used in reclamation. Specific suitability criteria were established for identifying suitable overburden material, but no suitability criteria were established for upland subsoils. This creates a conflict between the risk management employed for the placement of upland subsoil versus suitable overburden. This would place upland subsoil in close proximity (usually within 50 cm) of upland surface soil (and therefore the rooting zones of reclamation vegetation), and yet there are no requirements for subsoil to meet the chemical parameters required for suitable overburden. From a regulatory perspective, soil that once supported a productive forest should be able to do so again when salvaged and placed as reclamation material. However, if upland subsoil does not meet approval criteria for suitable overburden, exceeding criteria may not preclude suitable overburden from developing a productive upland forest ecosystem.

This field study investigated the potential of soil biota as an indicator of a reclamation soil's ecosystem function. Samples of coversoil and subsoil were taken from reclaimed, cleared and natural sites on Canadian Natural's Horizon oil sands mine site. Coversoil samples were collected to a consistent depth of 15 cm from locations that were identified as or targeted to become d-ecosites (Beckingham and Archibald 1996). From the coversoil samples collected, mesofauna were extracted and identified and microbial communities were identified at the University of Alberta. ALS labs in Edmonton analyzed coversoil samples and subsoil samples for texture, pH, SAR and EC.

PROGRESS AND ACHIEVEMENTS

Mesofauna and microbial samples were collected over three summers (2016, 2017, 2018). Mesofauna have been identified, counted and categorized into relative abundances and densities in both coarse and fine textured soils (Figure 1). Statistical analyses were used to determine if any relationships exist between the natural, cleared, and reclaimed treatment sites. There are some distinct relationships that have emerged between the treatment types and the arthropod communities. For example, arthropod densities were often significantly lower in the reclaimed sites, compared to natural or cleared sites. In terms of the abundance of arthropods, there is not as dramatic a difference between different treatment sites this is especially true in coarse textured soil.

Microbial samples have undergone DNA analysis and this data is being compiled and then incorporated into the development of the IBI.

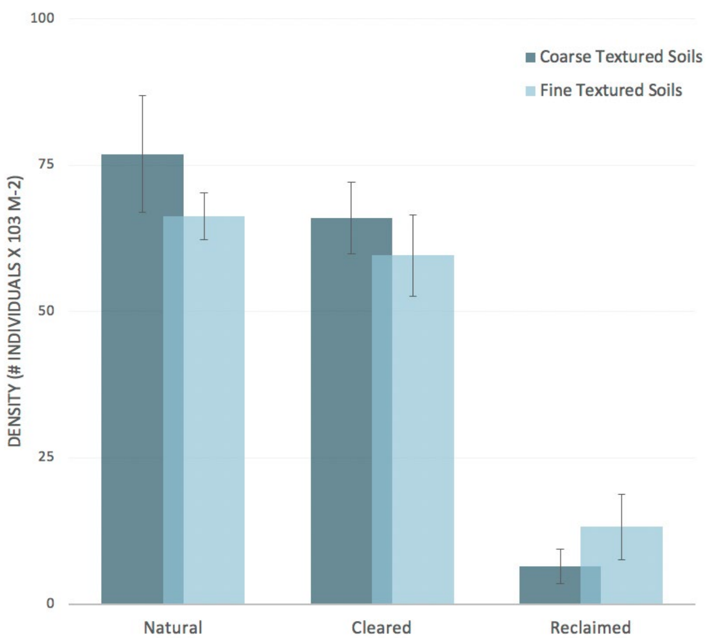

Figure 1: Total mean densities of mesofauna among treatment types grouped by Coarse Textured Soils (CTS) and Fine Textured Soils (FTS).

LESSONS LEARNED

Study results to date indicate that disturbance to soils during the process of reclamation is reducing the quantity of arthropods within the soil, rather than altering the community structure.

While densities of both Acari and Collembola were significantly lower in soils on reclaimed sites compared to natural and cleared sites, relative abundances of many of the groups investigated did not differ significantly among soils in the natural, cleared and reclaimed sites.

Further analysis of these data, and integration of microbial communities data as well as soil chemical and physical properties information, will be used to generate a potential model to define recovery trajectories of soil biota in soils on reclaimed sites as a first attempt to assess reclamation success and soil recovery.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

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RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Derek Mackenzie

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Brian Lanoil	University of Alberta	Assistant Professor		
Jeff Batigelli	University of Alberta	Research Associate		
Gregory Hook	Canadian Natural/ Royal Roads University	Reclamation Specialist/ MSc	2017	2019
Juan Marinez	University of Alberta	MSc	2018	2020

Lean Oil Sand Soil Capping Synthesis and Risk Assessment

COSIA Project Number: LJ0305

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural, Imperial, Suncor Energy Inc.

Status: Year 2 of 2

PROJECT SUMMARY

Some geologic formations in the oil sands mine region contain an appreciable amount of naturally-occurring petroleum hydrocarbons (NPHCs). Mine overburden material containing these petroleum hydrocarbons is sometimes referred to as lean oil sands (LOS).

Although the petroleum hydrocarbons in LOS are naturally occurring, uncertainty exists regarding their risk to the environment when they are disturbed and relocated to new positions in closure landscapes. Prior to mining, geologic formations containing NPHCs are in a relatively stable state in the environment and in most cases several meters below the soil solum or rooting zone. However, during mining activities, the formation is removed and transported to another location on the mine site where an overburden landform is constructed and reclaimed. This can result in NHPCs occurring directly below the soil reclamation profile with the potential to come in contact with receptors such as vegetation roots, groundwater and surface water.

A soil reclamation or overburden cap with an acceptable concentration of NPHCs which buries LOS and provides a buffer from potential receptors (e.g., plant roots, wildlife, surface water) is a mitigation measure that is employed by oil sands mine operators to alleviate the environmental risk(s) of the closure landscape. To a lesser degree the reclamation material type and configuration may also be employed as a mitigation measure.

There is a large body of oil sands mining reclamation research related to characterization and assessment of overburden landforms/substrates containing NPHCs that has been conducted (e.g., Aurora Soil Capping Study [LJ0201], Cumulative Environmental Management Association [CEMA] and industry reclamation monitoring programs). The objectives of this project were to compile these findings and reclamation practice recommendations, and conduct a risk assessment on NPHCs to inform future reclamation activities. This also included a field study of LOS overburden reclamation with mature forest stands to assess the impact LOS have on tree growth. Most of the LOS reclamation is still in the early years post-reclamation, and thus, most of the research and monitoring has only been able to evaluate early reclamation response. However, an opportunity was identified to assess tree growth response in mature forest stands on early reclamation at Suncor's Base Mine lease, which is overburden material that is similar to what is now classified as LOS overburden (similar PHC concentration and physical characteristics such as soil texture, bulk density and consistence).

PROGRESS AND ACHIEVEMENTS

Tree Growth on Reclaimed Overburden Sites Containing Petroleum Hydrocarbons at the Suncor Base Mine

The final report of a field study conducted in 2017, that assessed the growth performance of mature forest stands (approximately 20 to 40 years of age) growing on reclaimed lands constructed on overburden materials containing NPHCs, was completed in 2018. Soil information and samples were collected at 20 sites consisting of peat-mineral mix (PMM) over LOS overburden. Mean PMM capping depth thickness was 24 cm and a range of 8 cm to 56 cm. Upper subsoil depths (defined as the depth of overburden with evidence of weathering) averaged 27 cm with a range of 13 cm to 49 cm.

PHC concentrations of the upper and lower subsoil did not exceed Alberta Tier 1 Guidelines (AEP, 2016; Natural Area Land Use – coarse-grained soil), with respect to Fraction (F)1, benzene, toluene, ethyl benzene and total xylenes (BTEX). However, the average and maximum F2 concentrations exceeded Alberta Tier 1 Guidelines and all F3 concentrations exceeded Alberta Tier 1 Guidelines. A combination of F4 and F4G also exceeded Alberta Tier 1 Guidelines. The percentage of NPHCs above C50 ranged from 13 to approximately 40%, with an average of 26% and 24% for the upper and lower subsoil, respectively. The PHC composition and concentration at the sites was considered to be generally consistent with other current mine operations conducting LOS overburden reclamation.

Tree site indices for all species present at each plot were measured at each site (white spruce and trembling aspen were the primary species present). The mean site index for trembling aspen was 18.6 (standard deviation = 3.10) and 19.5 for white spruce (standard deviation = 2.31). These site indices were found to be in the range of tree growth for other substrates (e.g., tailings sand and non-LOS overburden) that have been collected from long-term vegetation monitoring programs at Suncor Energy Inc. and Syncrude Canada Ltd. These site index values are also within the range of site indices of the dominant natural upland forests in the region (i.e., b and d ecosites). Although the data set of the study is small, the results do not indicate a negative impact on tree growth (as measured by site index) from the presence of NPHCs in LOS, even at the highest concentrations and with soil reclamation capping depths ranging from 8 cm to 56 cm.

Literature Review of Naturally-Occurring Petroleum Hydrocarbons in Oil Sands Mining Reclamation Practice

A literature review of NPHCs in oil sands mining reclamation practice was completed to collate existing information related to characteristics, environmental risk and reclamation performance of soil materials, interburden and overburden containing NPHCs. The literature review was used to support the supplemental step of a risk identification and assessment process of NPHCs in oil sands mine reclamation. The literature review consisted of a bibliographic summary of peer-reviewed sources, stakeholder advisory groups (e.g., Cumulative Environmental Management Association [CEMA]), internally-developed studies from Joint Industry partners (JIP) and other gray literature sources.

Risk Assessment Matrix for the Placement of Naturally-Occurring Petroleum Hydrocarbons in Oil Sands Mining Reclamation Practice

A Risk Assessment Matrix (RAM) was completed as part of the development of a Conceptual Site Framework (CSF) for NPHCs in oil sands mining reclamation. Two workshops were conducted as part of the RAM and CSF, consisting of industry members, representatives from the Alberta Energy Regulator and third-party experts. The RAM was created to consider the severity of potential impacts on receptors assuming a scenario that the landform is reclaimed, ready for certification, and receptors would be free to access, or be in contact with, constituents of concern (CoCs) as part of full integrated closure landscape. This RAM is intended to guide immediate decisions about capping depth design and research/monitoring data collection, but is not a complete or binding assessment of risks associated with NPHCs in oil sands mining reclamation.

A risk evaluation scale was agreed upon by the workshop participants, consisting of a scale of probability and severity classes. A risk matrix was established for the probability and severity classes, establishing a risk ranking for each potential event that was identified by the workshop participants. A summary of risk level rankings was completed to identify which events have the highest to lowest concern or risk to achieving land closure (certification).

Conceptual Site Framework for the Assessment of Risk Related to the Placement of Naturally-Occurring Petroleum Hydrocarbons in Oil Sands Mining Reclamation Practice

A CSF was developed to support a risk assessment to evaluate capping thickness and cover design guidance for overburden landforms containing NPHCs. The CSF was a compilation of identified risk elements from the literature review and a workshop consisting of industry members, representatives from the Alberta Energy Regulator and third-party experts. The CSF considered all significant CoCs in overburden landforms containing NPHCs, major exposure routes or pathways by which CoCs can reach the receiving environment and receptors, receptors that can be adversely affected by released CoCs and data collection requirements to validate and refine the CSF and 'complete' pathways from sources to receptors. The goal of the CSF was to provide a toolkit for the oil sands industry to assess and implement capping depth decisions for reclamation of overburden landforms containing NPHCs.

LESSONS LEARNED

A summary of the key outcomes from this program are the following:

- A literature review of the current state of knowledge of characteristics, environmental risk and reclamation performance related to NPHCs in oil sands mining reclamation. This document compiled information from peer-reviewed sources, stakeholder advisory groups, internal industry activities and other gray literature sources.
- An individual field study of mature tree growth on reclaimed overburden containing petroleum hydrocarbons found that growth rates (site indices) of trees were not correlated with petroleum hydrocarbon concentrations in the overburden. The study also found the measured site index values were in the range of growth of other oil sands reclamation substrates such as tailings sand and non-LOS overburden, as well as natural upland forest communities in the region.

- A risk assessment was completed which identified potential risk events of reclaimed overburden landforms containing NPHCs and ranked the probability and severity of those events. This included identifying receptors and potential pathways of contact, as well as quantification of the magnitude and probability of occurrence. This assessment could be used as an immediate guide to selecting an appropriate soil cover design and identifies areas for future research and monitoring.
- A CSF was developed for overburden landform reclamation containing NPHCs which identifies applicable pathways and receptors in the closure landscape. The CSF is a guidance tool that can be used to assess and implement capping depth decisions for reclamation of NPHC-containing overburden landforms, as well as identifying gaps for future research and monitoring.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

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Paragon. 2018. Tree Growth on Reclaimed Overburden Sites Containing Petroleum Hydrocarbons at the Suncor Base Mine. Prepared for the COSIA Joint Industry Project Partners. August 31, 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil & Environmental Consulting Inc.

Principal Investigator: Vivienne Wilson

Reclamation Material Stockpiling Opportunity and Gap Assessment

COSIA Project Number: LE0043

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Suncor Energy Inc., Teck Resources Limited

Status: Year 1 of 1

PROJECT SUMMARY

Storing soil reclamation materials in stockpiles is a common practice for in situ and mining oil sands operations. Effects of stockpiling can be immediate or long-term, depending on a number of factors, and may affect an operator's ability to achieve required reclamation outcomes. While a large body of research exists regarding the implications, limitations, and benefits of stockpiling reclamation material, technology transfer from these studies is not easily accessible to operators, and it is unclear how they can be applied to the current and planned operator assets for in situ and mining operations in the Athabasca oil sands region.

Canada's Oil Sands Innovation Alliance (COSIA) Land Environment Priority Area (EPA) commissioned Paragon Soil and Environmental Consulting Inc. (Paragon) to undertake a reclamation material stockpile gap assessment and inventory of existing in situ and mining stockpiles in the Athabasca oil sands region. Specifically, the project consisted of the following:

1. A literature review and summary report of knowledge related to reclamation soil stockpiling, within and outside the oil sand region. This review focused on the key priority areas of stockpile soil quality and impact on reclamation performance (soil preservation), management of stockpile conditions while in storage and footprint design and construction.
2. The creation of an inventory (database) of current stockpiles using available COSIA member data.

No field activities were undertaken for the project. A summary report which accompanies the database, describes the methods used to develop the database and its structure.

PROGRESS AND ACHIEVEMENTS

Literature Review Summary

The literature review was organized into three key priority areas: (1) Soil Preservation for Reclamation, (2) Stockpile Management, and (3) Stockpile Footprint. Each priority area was further organized into focus areas:

1. **Soil Preservation for Reclamation**: Organized into focus areas of Long-term Soil Storage and Post-placement Management Options
2. **Stockpile Management**: Organized into focus areas of Volume Loss, Weed Management and Maintaining Stockpile Integrity and Quality
3. **Stockpile Footprint:** Organized into focus areas of Mixing/Segregation Topsoils and Mixing/Segregating Subsoils

The literature reviewed was identified using scientific indexing services, and the search criteria used are documented in the summary report. In total, 116 papers were reviewed and summarized in fact sheets which include background information, gaps, risks and opportunities.

The literature review found limited to no information in the areas of, volume loss/change while in storage, stockpile design optimization, and mixing/segregation of subsoil.

Stockpile Database Summary

An Excel file and accompanying spatial database were created from the stockpile information provided as of June 15, 2018 from the oil sand operations of Canadian Natural, Cenovus Energy Inc., Imperial, Suncor Energy Inc. and Syncrude Canada Ltd. Upon submission, the data was reviewed for quality, completeness, and consistency. Fifty-nine distinct fields were created for the database and these were populated where possible for all stockpiles based on the information provided by the operators. Key fields in the database include such things as; stockpile name assigned by operator, operator owner, location coordinates, year established, footprint area and volume, soil material type, soil texture, management activities and general soil characteristics. The database has been designed to allow for future updates as more information becomes available for both existing stockpiles and newly constructed stockpiles.

LESSONS LEARNED

A summary of the key outcomes from this program are the following:

1. The summary report of the literature review provides a collation of existing research findings and knowledge related to reclamation soil stockpiles. It can be used as a resource tool to help identify gaps and opportunities for future stockpile research programs in the oil sands.
2. A database of existing stockpiles of oil sands operations has been created, which contains characteristics such as soil material type, construction details and general soil quality. The database can be used as a resource to identify available stockpiles to develop research/monitoring activities.
3. While the literature review found a relatively large body of reclamation stockpile research that has been conducted outside of the Athabasca oil sands region, it is a challenge to apply those findings to the identified priority areas of concern when one or more of the following differences exist:
   - **Scale of operations**: Stockpile sizes in oil sand operations are often larger than those of other operations worldwide.
   - **Duration of activities**: Oil sand operations may have a longer timeline than most other operations, requiring longer soil storage in stockpiles.

- **Soil material type**: Soils differ across geographic regions, making it a challenge when applying those findings to soils present of the Athabasca oil sands region.
- **Climate**: Climate conditions (e.g., temperature and precipitation) vary across regions which can affect the soil environment and conditions while in storage.
- **Land use targets and reclamation objectives:** Regulatory, stakeholder and certification requirements differ across jurisdictions; therefore, the definition of 'success' or 'acceptable conditions' of research findings/ conclusions may differ from the targets and objectives for oil sands operations.

4. Stockpile research has been conducted in the oil sands, with most of the work focused on identifying changes in soil conditions (e.g., soil chemical and physical changes while in storage). However, most research has not investigated if those soil changes have an impact on performance when they are used in reclamation and if these changes will ultimately restrict the ability of operators to achieve land certification. Future stockpile studies should be designed to be able to assess whether changes that occur in stockpile have an impact on reclamation performance and land closure outcomes.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Paragon Soil and Environmental Consulting Inc. (Paragon). 2018. Reclamation Material Stockpiling Opportunity and Gap Assessment for Oil Sands In Situ and Mining Operations: Literature Review Summary. Prepared for Canada's Oil Sands Innovation Alliance (COSIA). 184 pp.

Paragon. 2018. Reclamation Material Stockpiling Opportunity and Gap Assessment for Oil Sands In Situ and Mining Operations: Database Development Summary. Prepared for COSIA. 7 pp.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil & Environmental Consulting Inc.

Principal Investigator: Brittany Cranston

REVEGETATION

NSERC – Industrial Research Chair in Forest Land Reclamation

COSIA Project Number: LE0012

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: TransAlta Corporation, Canadian Natural, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Suncor Energy Inc., Teck Resources Limited

Status: Year 6 of 6

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. Great progress has been made in developing better aspen planting stock and increasing the establishment success of aspen on stressed sites, which that hastened the development of a closed tree canopy. Building on this, the renewed IRC program is examining critical issues related to growth constraints, such as competition and limited soil nutrients, during stand initiation and development. In addition, it is exploring the use of different topographical features to promote more spatially diverse site conditions resulting in more diverse plant communities.

The Industrial Research Chair is addressing three general topic areas and associated 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?
- Can a fast-growing herbaceous cover crop be used as a deep soil amendment to improve growing conditions on nutrient-poor sites?
- What is the impact of specific fertilization prescriptions on newly planted trees across different capping materials and what is their effect on understory vegetation and competition?
- What is the impact of increased land surface roughness on environmental gradients and microsite variability? 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-shoot ratios be developed? How feasible is it to use tall aspen seedling stock on high competition sites?
- 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 oilsands sites?
- What role do aspen roots play in soil water redistribution along drought gradients?
- How do confining soil layers (chemical or physical) affect root growth behaviour and rooting space?
- How does the relationship between leaf area/LAI and water use/availability vary on reclaimed sites as a result of stand composition, canopy development and age, and what is the impact on productivity?

To provide Canadian resource industries with a clear path to reconstruct boreal forests, deliverables from the project include:

- Further development of new techniques to manage the establishment and growth of trees on reclamation sites;
- Development of indicators for site conditions suitable for the natural establishment of understory species;
- Assessment of risks associated with forest development, in particular ones related to water use and availability in reclaimed forest landscapes; and
- The development and testing of planning tools.

PROGRESS AND ACHIEVEMENTS

This program is drawing to a close, with a complete synthesis of learnings due in the second quarter of 2020. Activities completed in 2019 along with key outcomes are listed below by topic area.

Accelerating Forest Establishment

To answer 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 measured on an operational scale study site on the Canadian Natural Albian Sands lease. Sophie Aasberg (MSc candidate) continued work on vegetation establishment started earlier by Kate Melnik (MSc 2017), and Trevor de Zeeuw (MSc 2019) studied early tree establishment. Field measurements for the vegetation work were completed in 2019 and will be analyzed in 2020.

Key observations from the tree establishment work as published in 2019 include:

- Significant increases in the growth of planted trees were observed based on some but not all combinations of microtopographic expression (graded smooth versus ridges [40 cm x 150 cm furrows] versus small hills [1.5 m high x 3.5 m wide]), species and aspect. Growth increases were more commonly associated with the greatest increases in microtopographic expression, with this effect more notable on a south aspect as compared to an east aspect: Aspen growth was influenced on both aspects but pine and spruce only on the south aspect.
- Natural establishment rates for trees (primarily aspen) were positively correlated to increases in microtopographic expression (levelled < ridged < hilled), while natural regeneration of shrubs (primarily willows) was not. Natural regeneration of both shrubs and trees was greater on east-facing compared to south-facing slope aspects. Additionally, seedling regeneration of both trees and shrubs in the hilled treatment was favoured in mid- and toe-slope microtopographic positions as opposed to crests.

Influencing Forest Stand Trajectories

Following initial stand establishment, many reclamation sites take more than 10 to 15 years to reach canopy closure. In this time, understories are developing that can be dominated by undesirable species, with potentially detrimental effects on stand development. The IRC program is exploring stand management strategies (e.g., intervention practices) that could facilitate and improve forest canopy and understory development on older reclamation sites with sparse canopies.

In a controlled study, we explored the feasibility of cutting juvenile (eight to 12 years) aspen trees of seedling origin to increase stem density through root suckering. 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 regions in 2017, which were subsequently disturbed (manually felled) to promote suckering in 2018, and measured in the late summer of 2018. In 2019 we collected additional site (soil) information from the SAGD site and analyzed the complete results of the experiment.

Key observations from this work include:

- Cutting alone provided sucker densities ranging from 6,700 stems to 24,900 stems per ha (five to eight times higher than pre-treatment). Sucker heights averaged almost 1 m.
- Attempts to control low vegetation that would compete with suckers, using glyphosate herbicide, resulted in reduced suckering and growth, possibly due to an adverse effect of the herbicide on the aspen despite attempts to isolate the herbicide from the trees.
- In the absence of herbicide treatment, suckering did not appear to be impacted by understory species composition or cover. However, the cover levels may not have been high enough to have the adverse impacts noted in studies from the forest industry.
- The number of suckers was positively correlated to the pre-treatment stand density and basal area.
- Depending on location, the number and vigour of suckers was adversely impacted by browsing by deer.

Assessing Trajectories of Forest Reclamation

There have been over 30 years of forest land reclamation in the 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 are being explored as the main drivers of forest stand performance on reclamation sites are being explored.

Morgane Merlin (PhD candidate) has successfully analyzed a very complex dataset that explores how leaf area, rooting depth, and climatic and edaphic variables can be linked to water use as measured by sap flow, and how those linkages change with different tree species. Key outcomes include:

- Sap flux variations matched theorized relative water use based on correlations to tree sapwood area, leaf area and tree size.
- Capping depth (35 cm versus 100 cm) impacted water use, presumably as a result of reduced volumetric supply in the thinner cover. Aspen trees were impacted more than spruce. These observations match cumulative tree growth trends.
- Water use, as indicated by sap flux, declined throughout the growing season with declining soil water availability. Spruce trees were more able than aspen to take advantage of late season re-wetting of the soil after a prolonged dry period. This potentially suggests spruce were better adapted to the variable seasonality of precipitation.

To explore in more depth the accuracy of sap flow measurements to estimate tree water use, an additional study was executed to validate the Heat Ratio Method for Sap Flow estimation using the cut tree method (whole tree lysimeter). For that study, the stem of a mature aspen (21 m tall) was cut under water and maintained in an upright position using a support tower. Actual water uptake was measured using weighed differences in the basal reservoir, and compared with sap flow measurements taken at various locations along the stem. Merlin has taken the lead in these studies and will be defending her thesis in early 2020.

Merlin and Ashley Hart (MSc candidate) executed a controlled greenhouse study that explored the lateral movement of water (hydraulic redistribution) in soils through aspen root systems. Measurements on the trial have been completed and final analysis and report preparation are currently underway.

LESSONS LEARNED

Key learnings from projects under this IRC that will have positive impacts on oil sands reclamation include:

1. The diversity of desirable boreal forest species can be enhanced through appropriate soil placement practices:
   - Localized variations in (i) soil roughness and (ii) soil moisture and temperature regimes provide a wide range of niches for seed lodgment, seed germination, and budding from rhizomes, roots and stem fragments in reclamation soils.
   - Soil placement methods noted to have positive effects on desired vegetation diversity included:
     - Increased local microtopography (scale differences of 0 m to 3 m horizontally and 0 m to 1.5 m vertically); and
     - Variations in organic and mineral surface exposure.

2. Planted trees exhibited similar variability in growth as did the expression of plant species diversity with increases in microtopographic expression. Consistent with silvicultural literature from the forest industry, tree growth can be improved where treatments to increase microtopographic expression are appropriately applied to alleviate growth-limiting factors such as cold spring soil temperatures and seasonal water availability.
3. Placing salvaged forest floor material in patches on a reclamation landscape can improve the spread of native boreal forest species. However, it appears that this spread might be relatively slow, as the early colonization of these species into new areas is dominantly through vegetative means such as belowground rhizomes.
4. Cutting of juvenile seedling-origin aspen stands (10 to 20 years) can be used to promote suckering and can lead to improved aspen stocking; however, responses are closely related to aspen performance and site conditions of the original stand.
5. High root to shoot ratios for aspen seedlings are more important than seedling size to promote above- and below-ground competitiveness with existing vegetation on out-planting sites.
6. Organic amendments, such as municipal compost, are suitable materials to increase the organic component in reclamation surface soils lacking organic matter. However, caution needs to be taken as these amendments (depending on the source materials) can also produce negative effects such as increased competition and higher salinity in the reclamation surface soils.
7. Sap flux sensors are a useful method of monitoring relative water use and seasonal variation for trees established on reclaimed sites.

A complete synthesis of findings from this Industrial Research Chair is being compiled in Q1-Q2 2020.

PRESENTATIONS AND PUBLICATIONS

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Pec, G. J.; Scott, N. M.; Hupperts, S. F.; Hankin, S. L.; Landhäusser, S. M.; Karst, J. 2019. Restoration of belowground fungal communities in reclaimed landscapes of the Canadian boreal forest. Restoration Ecology, 27: 1369-1380, doi: 10.1111/rec.12990.

Scott, N., Pec, G. J., Karst, J., Landhäusser, S. M. 2019. Additive or synergistic? Early ectomycorrhizal fungal community response to mixed tree plantings in boreal forest reclamation. Oecologia, 189: 9-19, doi:10.1007/s00442-018-4241-0.

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Landhäusser, S. M., Pinno, B. D., Mock, K. E. 2019. Tamm Review: Seedling-based ecology, management, and restoration in aspen (*Populus tremuloides*). Forest Ecology and Management, 432: 231-245, doi:10.1016/j.foreco.2018.09.024.

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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
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	2020
Sophie Aasberg	University of Alberta	MSc	2018	2020
Coral Fermaniuk	University of Alberta	MSc	2018	2020
Rachel Hillabrandt	University of Alberta	Post-Doctoral Fellow	2019	
Alana Beniot	University of Alberta	Research Assistant		
Brittany Hynes	University of Alberta	Research Assistant		
Johannes Mueller	Visiting student Germany	Research Assistant		
Caren Jones	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

Research Collaborators: Kevin Devito, University of Alberta; Brad Pinno, University of Alberta; Miles Dyck, University of Alberta

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NSERC – Industrial Research Chair in Terrestrial Restoration Ecology – Revised June 2020

COSIA Project Number: LE0034

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Suncor Energy Inc., Teck Resources Limited

Status: Year 4 of 6

Publisher Correction: An earlier version of this Annual Report (APRIL 2020) contained an incorrect version of this report. COSIA regrets the error. The correct version is below. Dated: June 11, 2020.

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

Objective 1: What are natural dimensions and mechanisms underlying rooting zones of boreal plants?

As the bulk of the research under the Industrial Research Chair (IRC) requires identification of roots, our first task was to refine and develop existing molecular tools designed for this purpose. We have created a reference data base of DNA markers for approximately 200 plant species occurring in the region. This database is used to identify roots to species, and is now published (Metzler et al, 2019).

Understanding the ecological factors influencing root distribution of target plant species desired in revegetation of reclaimed sites is an important step in designing cover soils. Together, two MSc students investigated how abiotic and biotic factors influence root distributions of boreal forest communities. Specifically, one project focused on characterizing root distributions in soils that differ in texture (Ariel Brown, MSc student), and a second project focused on how root profiles change with stand age (Josh Wasyliw, MSc student). The former project was carried out in aspen stands located near Edmonton. This study showed that for contrasts of medium and coarse-textured soils, roots decrease in abundance with depth up to 40 cm but this pattern is not strongly influenced by texture. For the latter project, Wasyliw sampled roots occurring up to 90 cm below the soil surface of jack pine stands varying in age. He found that after approximately 15 years, pine roots were reaching similar depths as to those in mature stands (> 65 years old).

Objective 2: What are the effects of oil sand on root structure and function?

Shallow (< 50 cm) oil sand deposits occur naturally in this region and forests have been growing on these deposits since the last ice age. Understanding how tree roots respond to natural bituminous deposits may help predict root behaviour, and ultimately forest establishment, on LOS. However, locating roots of individual trees is an arduous, time-consuming and destructive activity. Dendrochemistry is a growing branch of science that has historically been used largely to study environmental contamination from nearby industrial practices. MSc student La Flèche used techniques from this field to evaluate tree rings for signs of tree interactions with bitumen in soils. Specifically, he determined the potential of trace metals vanadium (V), molybdenum (Mo), nickel (Ni) and rhenium (Re) to act as indicators of root contact with hydrocarbons.

On five natural sites having shallow natural bituminous deposits and two sites free of bitumen (all confirmed with tests of soil hydrocarbons) he sampled for trace metals in boles of jack pine trees and soils. He found that concentrations of Ni in trees growing on shallow bitumen deposits were significantly higher than those growing in bitumen-free soils. Vanadium also showed some promise as an indicator, but detected differences from the current study were not sufficiently discriminatory. Molybdenum was lower in trees growing on bituminous sites.

On Canadian Natural's Jack Pine Mine site, La Flèche characterized root growth and the presence of trace metals in tree seedlings and pore water on a recently reclaimed LOS landform. The goal here was to examine whether the trace metals (V, Mo, Ni and Re) could be used to infer when roots interacted with LOS as the planted trees matured. These initial measurements will be used as a reference for comparison to future measurements. La Flèche found that roots rarely penetrated the LOS overburden (50 cm from surface), although the mechanism of limitation was not investigated. Elevated concentrations of hydrocarbons throughout the peat mineral mix (possibly biogenic in origin) may complicate the use of these metals in determining when roots begin interacting with the LOS. Three of the target metals (V, Mo, and Re) were enriched in both the peat mineral mix and LOS, but only Vanadium was significantly more enriched in the LOS than the peat mineral mix. However, Vanadium displayed poorer relative availability in soil pore water due to its lower solubility. These initial results can be used to establish reference values against which future studies can compare, but because we did not find a distinct trace metal signature in LOS, caution will be needed when interpreting future results.

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 is building his research around this particular focus. To date, he has conducted a broad survey of natural bituminous sites, and sampled fungi from these sites in addition to soils from several bitumen-free forest sites. Using next generation sequencing, he will characterize arbuscular and ectomycorrhizal fungi occurring in the samples. Franklin will develop this project over the next year to include experiments that test for the importance of these symbionts in mediating tree survival in oil sands reclamation.

In a parallel study, recently recruited MSc student Nicholas Brown is investigating whether we can adopt current tree species used in revegetation to degrade hydrocarbons present in LOS. Specifically, his research will assess the capacity of roots of aspen and jack pine to degrade hydrocarbons through their exudates. This research is in the design phase.

LESSONS LEARNED

- DNA markers are available to identify roots to species for common boreal plants. This tool could be used to identify plant species from soils where reliable morphological traits are not available.
- With strong analytical methods and good reference conditions, dendrochemistry may be a feasible methodology for monitoring root growth in bituminous soils with V and Ni acting as potential signal elements. This presents reclamation practitioners and researchers with a useful tool to monitor plant growth across both constructed landforms and natural landscapes along with data against which to compare future values.

PRESENTATIONS AND PUBLICATIONS

Published Theses

La Flèche M. 2019. Tree cores for root bores: Exploring tree rooting behaviour in bituminous soils. MSc, University of Alberta, Department of Renewable Resources

Wasyliw J. 2019. Ectomycorrhizal functional diversity parallels fine root and leaf abundance with forest stand age. MSc, University of Alberta, Department of Renewable Resources

Brown A. 2019. Cutin and suberin in mixed-wood boreal forest plants and their use as markers for origin of soil organic matter. MSc, University of Alberta, Department of Renewable Resources

Journal Publications

Metzler P., La Flèche M., Karst J. 2019. Expanding and testing fluorescent amplified fragment length polymorphisms for identifying roots of boreal forest plant species. *Applications in Plant Sciences* 7(4): online. doi: 10.1002/aps3.1236

La Flèche M., Cuss C.W., Noernberg T., Shotyk W., Karst J. Trace metals as indicators of tree rooting behaviour in natural bituminous soils. Submitted to *Ecological Indicators*

Wasyliw J., Karst J. Shifts in ectomycorrhizal exploration types do not offset fine root abundance in mature pine stands. Submitted to *Journal of Ecology*

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: 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; Willima 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 Canada Ltd.

Status: Year 6 of 7

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.

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 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 (Treatment 3) were included as a second control to compare the Al-Pac CPP clones to a local unscreened 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 in the southeast corner of Sandhill Watershed and trial three was established on Sand Islands "A" and "B" within the Sandhill 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).

PROGRESS AND ACHIEVEMENTS

Measurements from a final growing season were collected in 2019. High tree mortality associated with flooding after a severe rain event in August 2018 has negatively impacted both sites in the Sandhill Watershed, and it has been confirmed that these sites will be abandoned. Final reporting is underway.

LESSONS LEARNED

Lessons learned will be reported after delivery of the final project report in 2020.

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta-Pacific Forest Industries Inc. and University of Alberta[1]

Principal Investigator: [1]Dr. Barb Thomas

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
David Kamelchuk	Alberta Pacific Forest Industries	Management Forester		

Oil Sands Vegetation Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting, Inc.

Industry Champion: Canadian Natural

Industry Collaborators: Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Suncor Energy Inc., Syncrude Canada Ltd., Teck Resources Limited

Status: Ongoing

PROJECT SUMMARY

The Oil Sands Vegetation Cooperative (OSVC) was established in 2009 to enable collaborative harvesting and banking of native boreal forest seed for use in revegetation and research. In 2014, the OSVC became a project under Canada's Oil Sands Innovation Alliance (COSIA) Land group. The OSVC is providing support for seed collection initiatives in the Northern Athabasca Oil Sands (NAOS), Southern Athabasca Oil Sands (SAOS) and Cold Lake (COLK) regions, and the identification and development of research projects relevant to revegetation of reclaimed oil sands lands.

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

PROGRESS AND ACHIEVEMENTS

In 2019, activities supporting the OSVC initiatives included:

1. Reached annual seed harvest goals
2. Advanced and directed research related to:
   - Vegetative propagation of beaked hazelnut (*Corylus cornuta*) and lowbush cranberry (*Viburnum edule*)
   - Outplanting success of shrubs on reclaimed sites
   - Logistical concerns surrounding the establishment of stooling beds and/or seed orchards
3. Initiated a trial to test the feasibility of rooting cuttings of beaked hazelnut and lowbush cranberry as a precursor to developing stooling beds for these species
4. Completed annual reporting and administration of the OSVC seed collection and banking activities
5. OSVC members met monthly to discuss knowledge gaps and research required to address these gaps
6. Published the twice-yearly newsletter

In addition, in honour of the 10th seed harvest, an outreach project which included a video was undertaken. The video can be viewed at https://vimeo.com/371007306.

The OSVC continued to evaluate and improve methods for the harvest of aspen seeds. Due to environmental constraints, aspen (*Populus tremuloides*), a keystone species widely deployed for reclamation, continued to prove difficult to harvest in ample quantities. There has been an increased emphasis on communications among harvesters, administrators and industry operators, with the goal of improving response to identified environmental factors.

In 2019, the OSVC harvested 451 litres (L) of seed from two seed zones in northeastern Alberta for the NAOS division. The following were extracted and registered:

Table 1: Species harvested

NAOS	
Alnus viridis (green alder)	*Ribes glandulosum* (skunk currant)
Amelanchier alnifolia (Saskatoon)	*Ribes hudsonianum* (northern black currant)
Betula neoalaskana (Alaska birch)	*Ribes lacustre* (black gooseberry)
Betula papyrifera (paper birch)	*Ribes triste* (wild red currant)
Cornus sericea (red-osier dogwood)	*Rhododendron groenlandicum* (Labrador tea)
Linnaea borealis (twinflower)	*Salix bebbiana* (beaked willow)
Populus tremuloides (trembling aspen)	*Shepherdia canadensis* (buffaloberry)
Prunus pensylvanica (pin cherry)	*Vaccinium myrtilloides* (blueberry)
Prunus virginiana (chokecherry)	*Vaccinium vitis-idaea* (lingonberry)
Ribes americanum (wild black currant)	*Viburnum edule* (lowbush cranberry)

LESSONS LEARNED

The OSVC continues to explore research opportunities that were identified in earlier knowledge gap analysis, with a particular focus in the areas of seed handling practices, shrub mortality, vegetative propagation of shrubs and the subsequent establishment of seed orchards and stooling beds for specific species, and the role of natural dispersal and colonization in reclamation success.

Seed requirements for reclamation are such that harvesting on an as-needed basis is not feasible. Ongoing seed banking is necessary and is a key component of oil sands reclamation planning as is research into the most efficient use of seed harvested. In 2019, handling of harvested seed was examined and best management practices were updated to improve banked seed quality and longevity.

Lowbush cranberry and hazelnut, two species that have proved difficult to harvest and/or grow, were evaluated for vegetative production. Softwood cuttings that were harvested in late June 2019, rooted when they were treated with rooting hormone and maintained under mist. This outcome not only provides an alternative method for growing seedlings for operation purposes but will be the starting point for establishing stooling production units.

LITERATURE CITED

Oil Sands Vegetation Cooperative (2019), Vimeo video, Available online at: https://vimeo.com/371007306, Canada's Oil Sands Innovation Alliance (COSIA) (2019).

PRESENTATIONS AND PUBLICATIONS

Newsletters

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

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

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu

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

Research Collaborators: Dr. Jean-Marie Sobze, NAIT Centre for Boreal Research

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Jack Pine Establishment

COSIA Project Number: LJ0263

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 4 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. 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°C to 10°C relative to ambient air temperature. The temperature under the tarps might have reached 33°C to 38°C as the air temperature was 28°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 4 (2019) of vegetation monitoring for the Trial took place in mid-July 2019 at the Bouchier site. The plots at the Willbros site were not assessed as part of the Year 4 (2019) monitoring because of dense graminoid cover and the absence of jack pine seedlings at the site. Year 4 monitoring at the Bouchier site captures the fourth growing season for the treatment plots, and Year 8 post-fire for the natural burned area. Year 8 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. These vegetation metrics from the three years were compared using analysis of variance. The number of established seedlings in each height class (<5 cm, 6 cm to 15 cm, and >100 cm) was too low to perform statistical analysis.

Jack pine seedlings in plots established at the natural burned site (N1 and N2) in 2016 (Year 5) were present in higher abundances than in the treatment plots in 2019 (Year 4; Figure 1). While statistical analyses were not possible, the number of emerged seedlings in the broadcast seeding treatment at the Bouchier laydown is closest to the number of seedlings in the natural burned sites. Several seedlings from the heat-treated cones treatment also emerged at the Bouchier laydown. Very few seedlings emerged from the untreated cones treatment.

Seedling emergence and growth in the treatment plots has been slower than in the natural burn area. By Year 5 (2016) in the natural burn area, most seedlings were taller than 1.0 m. By Year 4 (2019) in the treatment plots, most seedlings were still shorter than 30 cm. None of the community metrics calculated were dependent on seeding treatment in 2019. Values for diversity, species richness and evenness in subplots were comparable between treatment and natural burned plots in all assessment years (2016 to 2019), with the exception of subplot species richness, which was greater in the natural burn area than in treatment plots in 2016. Total species richness was greater in the broadcast seeding and untreated cones plots than in the natural burn plots in 2017. Percent vegetative cover was generally greater in treatment plots than in the natural burn area, suggesting that shade from jack pine seedlings in the natural burn area has precluded the persistence of early-successional forb and graminoid species in the natural burn area. These early successional species still dominate the treatment plots, particularly graminoid species. As in previous years, the number of characteristic species was higher in the natural burn area (three to four species) than the treatment plots (one species) in 2019. The threshold as presented in the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (AENV 2010) for the Dry site type (*a*1 ecosite phase, pure jack pine dominated) is two species.

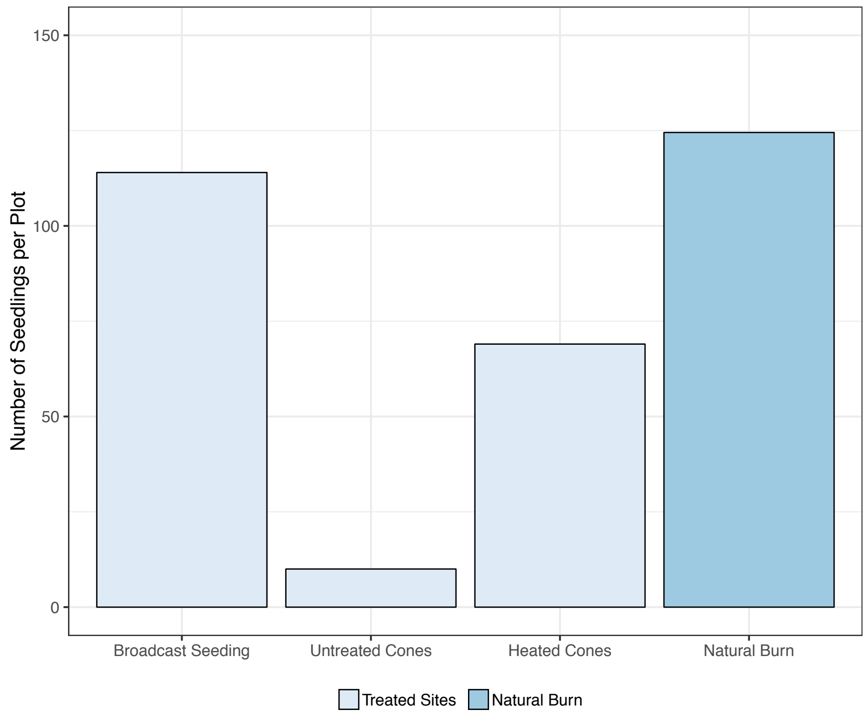

Figure 1: Average number of jack pine seedlings in Year 4 Treatment plots (2019) compared to Year 5 (2016) Natural Burn plots.

LESSONS LEARNED

At this stage in the Trial, broadcast seeding appears to be the most effective treatment for establishing jack pine from seed; however, as evidenced by the lack of germination, establishment and survival at the Willbros laydown, the treatment is ineffective if there is a high abundance of graminoids present (i.e., if the site has been heavily seeded to grass). Soil limitations (i.e., compaction) at the Willbros laydown were not observed in 2016 (Paragon 2016). Some performance metrics were similar to, or approaching, those in the natural burn area, but a continuing shift away from early successional species was observed for the natural burn area in Year 8 (2019). The treatment plots are still dominated by early successional graminoids and forbs by Year 4 (2019).

LITERATURE CITED

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

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 Soil and & Environmental Consulting Inc.

Principal Investigator: Paragon Soil and & Environmental Consulting Inc.

Establishment of Ericoid Mycorrhizal Associated Shrub Species (Blueberry, Labrador Tea and Lingonberry) in Oil Sands Reclamation Soils

COSIA Project Number: LJ0128

Research Provider: University of Alberta

Industry Champion: Canadian Natural

Industry Collaborators: Imperial

Status: Year 4 of 4

PROJECT SUMMARY

The reestablishment of blueberry (*Vaccinium myrtlloides*) and other plant species from the Ericaceae family on reclaimed land is of considerable interest to the oil sands industry. This is due to the ecological importance of Ericaceae plants in the boreal forest, and their status as cultural keystone species for First Nation communities (Garibaldi and Straker, 2009). The growth of these species in reclamation sites is severely impacted by a number of environmental stresses, including high soil pH and salinity. Ericaceous plants are known to form symbiotic associations with ericoid mycorrhizal (ERM) fungi (Sharples et al., 2000; Mitchell and Gibson, 2006). However, the importance of ERM associations for the survival and sustained growth of ericaceous plants under different environmental conditions that are present in oil sands reclamation sites is not known. In the present project, we examine the diversity of ERM in the roots of several Ericaceous species growing in natural forest sites and reclamation soils, as well as their role in conferring tolerance to high pH, salinity and drought. The results of the study are intended to guide the improvement of revegetation plans of oil sands reclaimed areas by gaining a better understanding of how Ericaceous plants will perform.

Specific objectives are to:

1. Identify the ericoid mycorrhizas in the roots of upland- and lowland-harvested blueberry (*Vaccinium myrtlloides* Michx.), Labrador tea (*Rhododendron groenladicum* [Oeder] Kron & Judd) and lingonberry (*Vaccinium vitsidaea* var. minus Lodd) plants in natural forest sites, oil sands reclamation soils and nurseries;
2. Examine whether ERM associations enhance high pH, drought and salinity tolerance in these plant species;
3. Determine the effects of ERM associations and pH on water relations of upland and lowland blueberries, and the role of plant and fungal aquaporins in these responses; and
4. Examine the growth responses of ERM colonized plants following planting in oil sands reclamation areas.

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

Study 1. Effects of ERM on drought resistance and water transport properties of lowland and upland blueberry (*Vaccinium myrtilloides* Michx.)

Study 2. Effects of soil type (fresh versus stockpiled) and salinity on mycorrhizal and non-mycorrhizal ericaceous plants

2.1 Identification of ERM fungi species in plant roots grown in fresh and stockpile soil types

2.2 Effect of ericoid mycorrhizal fungi on ericaceous plants under salt stress

Study 3. Effects of ERM fungi association on field growth of blueberry plants in oil sands reclamation sites

PROGRESS AND ACHIEVEMENTS

Studies 1 and 2 were completed in 2018. A summary of the findings of these studies is included in the lessons learned below.

Study 3. Effects of ERM associations on field growth of blueberry plants in oil sands reclamation sites

In 2018, blueberry seedlings were inoculated with *Pezizella ericae* (isolate #38) and *Oidiodendron maius* (isolate #96) ERM fungi. The seedlings were planted in two blocks at the reclamation site on the Horizon mine, and one block at the reclamation site on the Albian mine. In the summer of 2019, researchers had planned to measure the growth and physiological parameters, and colonization rate of the plants to examine the effects of ERM associations. However, in early 2019, due to geotechnical stability considerations, the dyke at Horizon mine was reconstructed and the field study site was completely buried. Therefore, this study had to be terminated and will be repeated in the future.

LESSONS LEARNED

Study 1. Effects of ERM on drought resistance and water transport properties of lowland and upland blueberry (*Vaccinium myrtilloides* Michx.)

Both the upland and lowland blueberry inoculated with four ERM fungi (#96: *Oidiodendron maius*, #38: *Pezicula ericae*, #50: *Pezoloma ericae*, #81: *Meliniomyces variabilis*) had a greater growth rate (higher biomass) than the uninoculated control seedlings in drought and non-drought treatments. Under drought stress, the ERM-inoculated seedlings had a higher survival rate than the uninoculated control seedlings. ERM fungi helped the blueberry seedlings maintain higher water potential, net photosynthesis and transpiration rates under drought stress.

Among the four ERM fungi, *Pezicula ericae* (#38) was most effective in enhancing growth in both lowland and upland blueberry. The results obtained from this study demonstrated that all of the selected ERM fungi could potentially be used in the reclamation sites for better revegetation of blueberry plants. Additionally, the selected four ERM fungi improved drought resistance and reduced mortality of both lowland and highland blueberry populations. We recommend confirming the benefits of *Pezicula ericae* (#38) for blueberry and other ericaceous plants through more field studies to be carried out in the oil sands reclamation area.

Study 2. Effects of soil type (fresh versus stockpiled) and salinity on mycorrhizal and non-mycorrhizal ericaceous plants

The results of the study demonstrated that one-year stockpiled soil had lower mycorrhizal abundance and diversity compared with fresh topsoil. Therefore, the use of fresh topsoil is highly recommended for revegetation of ericaceous plants in reclamation areas. We have found that inoculation of Labrador tea, cranberry and blueberry seedlings with both ERM isolates #38 and #96 had significant beneficial effects for all measured growth and physiological parameters. Therefore, inoculating ericaceous plants with these fungi at the nursery stage could be highly effective in improving survival rate and growth of plants in oil sands reclamation areas.

Study 3. Effects of ERM associations on field growth of blueberry plants in oil sands reclamation sites

In early 2019, due to geotechnical stability considerations, the dyke at the Horizon mine was reconstructed and the field study site was completely buried, resulting in the termination of Study 3.

LITERATURE CITED

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PRESENTATIONS AND PUBLICATIONS

Published Theses

Fadaei S. 2019. Effects of Ericoid Mycorrhizal Fungi on Growth and Salt Tolerance of Blueberry (*Vaccinium myrtilloides*), Lingonberry (*Vaccinium vitis-idaea*), and Labrador tea (*Rhododendron groenlandicum*): Implications for Oil Sands Reclamation. M.Sc. Thesis, University of Alberta, Edmonton, Canada, 105 pp.

Journal Publications

Fadaei S., Vaziriyeganeh M., Young M., Sherr I., Zwiazek J. J. 2019. Ericoid mycorrhizal fungi enhance salt tolerance in ericaceous plants. Mycorrhiza (accepted subject to revisions).

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)
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Deyu Mu	University of Alberta	PhD	2016	2020
Sepideh Fadaei	University of Alberta	MSc	2016	2019

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 4 of 5

PROJECT SUMMARY

Non-Segregating Tailings (NST) are a waste product of oil sands bitumen processing in northeastern Alberta. In the near future, 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 limited nutrient supply, high pH, elevated salt concentrations, or the presence of phytotoxic substances such as fluoride and naphthenic acids present in the NST substrate. 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 species that are used in reclamation revegetation, and are representative of the locally common Boreal forest, will respond in the reclamation of NST deposits.

Several plant species used in reclamation are of special significance to Aboriginal communities living in the area. Therefore, an important part of the investigation of NST reclamation will be to understand if potential contaminants derived from the NST beneath the reconstructed soil profiles could greatly reduce establishment or growth and yield, as well as the quality of these plants, especially for medicinal uses. Mycorrhizal associations have been identified on 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 send deep roots beyond the reconstructed soil profile and into NST. These associations are essential to provide plants with sufficient nitrogen and phosphorus nutrition, as well as protection from abiotic stressors. 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 and 7 have been completed. Studies 3 and 4 will be conducted in 2020.

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

The study was conducted with one-year-old seedlings of aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), tamarack (*Larix larcinia*), jack pine (*Pinus banksiana*), lodgepole pine (*Pinus contorta*) and black spruce (*Picea mariana*). Non-segregated tailings water (NSTW) was obtained from Canadian Natural's oil sands mining areas near Fort McMurray. The study was conducted in a controlled-environment growth room. Four treatments were applied to the seedlings for two months: (1) Oxygenated control (50% Hoagland's solution, 7-8 mg O_2 L^{-1}); (2) Hypoxic control (50% Hoagland's solution, 2-3 mg O_2 L^{-1}); (3) Oxygenated NSTW (50% NST release water in 50% Hoagland's solution at 7-8 mg O_2 L^{-1}); and (4) Hypoxic NSTW (50% NST release water in 50% Hoagland's solution at 2-3 mg O_2 L^{-1}). At the end of treatments, mortality rate, root collar diameter growth, height growth, total plant fresh and dry weights, relative electrolyte leakage rate, net photosynthesis and transpiration rates, and leaf elemental concentrations were measured.

It was found that pure NST water had a pH of 9 and an electrical conductivity (EC) of 5.5. When mixed with an equal amount of 50% modified Hoagland's solution, the pH of fresh solutions was 7.95 ± 0.28 and reached an average of 8.73 ± 0.17 after the experiment ended. In contrast, hydroponic solutions of only 50% Hoagland's solution had a pH of 6 and were kept above 5.5 by periodically adding potassium hydroxide. The EC of 50% Hoagland's solution and 50% NST water solutions was 4.09 ± 0.11 mS cm^{-1}.

Lodgepole pine was the only species that showed mortality in all treatments, including the oxygenated control treatment with Hoagland's solution. Aspen, balsam poplar, black spruce and tamarack died only in the treatment containing NST water. With all species grouped, mortality was two-fold higher in the hypoxic NST water treatment than any other treatment.

The relative root collar diameter growth (RRCDG) and relative shoot height growth (RSHG) were significantly higher for aspen and balsam poplar growing in the NSTW-free treatments. Based on statistical analysis, the amount of root collar growth was significantly different between the first month and second month for balsam poplar and jack pine.

By the end of the experiment, dry weights were significantly lower in aspen and balsam poplar seedlings grown in both 50% Hoagland's solutions with NST water, compared with those grown in 50% aerated Hoagland's solution. For jack pine seedlings, total plant weights were significantly lower in hypoxic treatments than in oxygenated treatments. Black spruce, lodgepole pine and tamarack showed no differences across all treatments. In aspen and balsam poplar, root to shoot ratios were significantly higher in treatments with NSTW. Water contents of aspen, balsam poplar and jack pine seedlings were significantly lower in all treatments. Aspen and jack pine also showed significantly lower water contents in hypoxic versus oxygenated treatments.

Both the type of hydroponic medium and the degree of aeration significantly affected the EC leakage rate (an indicator of plant injury) of aspen seedlings; it was higher in tailings water and oxygenated treatments. The rate of leakage was highest in the oxygenated NST water treatment and lowest in the hypoxic control treatment. Balsam poplar EC leakage was higher in treatments with NST water but did not show a significant overall effect of aeration.

Net photosynthesis was significantly lower for all species (aspen, balsam poplar, black spruce, jack pine, lodgepole pine and tamarack) when seedlings were grown with added NST water. Treatments with lower amounts of aeration also showed significantly lower amounts of net photosynthesis in aspen, balsam poplar, jack pine and tamarack seedlings.

Hydroponic media with NST water significantly reduced transpiration rates in seedlings of all species (aspen, balsam poplar, black spruce, jack pine, lodgepole pine and tamarack). The transpiration rates were significantly lower in aspen, balsam poplar, jack pine, lodgepole pine and tamarack seedlings in hypoxic treatments.

The leaf elemental concentrations are presently being analyzed.

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

The study was carried out with one-year-old greenhouse-grown trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) seedings. The seedlings had been stored for two weeks at 4°C in cold storage prior to the experiments. Five growth media were used in this study including: topsoil (TS); peat-mineral mix (PMM); non-segregating tailings (NST); mixture of NST and TS (1:1, v/v); and mixture of NST and PMM (1:1, v/v). Topsoil from the upper 30 cm of soil surface was collected from the boreal forest near the Canadian Natural Horizon mine, north of Fort McMurray. PMM and NST were collected from the Canadian Natural Horizon mine. The clods, stones, grass and tree branches in these media were removed and the media was air-dried for three to four days before mixing. Two nitrogen (N) and phosphorus (P) concentrations were in the nutrient solutions: (1) 10% N and P solution representing the concentrations present in 10% Hoagland's solution (0.6 ml/L KNO_3 and 0.2 ml/L $NH_4H_2PO_4$); and (2) 100% N and P solution which was created by increasing the concentration of KNO_3 and $NH_4H_2PO_4$ to 6 ml/L and 2 ml/L.

The experiment was a 5 x 2 complete randomized factorial design, with five types of growth media mentioned above, and with two N and P nutrient solutions (10% and 100%) applied. All plants were watered every second day and nutrient solutions were applied weekly. These seedlings were grown in a controlled-environment growth room for two months before harvesting. At the end of the experiment, shoot lengths, stem diameters, shoot and root dry weights, leaf chlorophyll concentrations, net photosynthesis and transpiration rates, and leaf elemental concentrations were measured.

It was found that aspen plants growing with the 100% N and P solution had significantly increased shoot lengths when compared to those growing with the 10% N and P solution. For the 10% N and P nutrient solution, plants grown in topsoil showed the largest stem diameter growth, while plants grown in NST had the smallest stem diameter growth. There was no significant difference in stem diameter growth between treatments in white spruce. In aspen, N and P nutrient concentrations did not significantly affect shoot and root total dry weights, while plants growing in topsoil had significantly higher total dry weights compared with plants growing in the other media. In white spruce, there was no significant difference in dry weights across all treatments.

In aspen and white spruce, both the type of the growth media and the concentration of N and P in the applied solution had significant effects on total chlorophyll concentration. In aspen, the highest total chlorophyll concentration was measured in plants growing in topsoil and the lowest was measured in NST for both 10% and 100% N and P solutions. The total chlorophyll concentrations measured in plants growing with 100% N and P solution were significantly higher compared to the plants with 10% N and P solution. White spruce growing in topsoil had the highest total chlorophyll concentration compared with the other growth media. Different N and P levels did not have a significant effect on total chlorophyll concentration in white spruce.

In aspen, both the type of the growth media and nutrient concentrations had significant effects on net photosynthesis rate. For the growth media treated with the 10% N and P solution, plants growing in topsoil showed the highest net photosynthesis rate, while plants growing in NST had the lowest net photosynthesis values and the difference was significant. The net photosynthesis rate of plants grown in a mixture of NST and topsoil was also significantly higher than that in NST. The net photosynthesis rate measured in plants growing in growth media treated with the 100% N and P solution was significantly higher compared with the 10% N and P solution. In white spruce, for both 10% and 100% N and P solutions, plants growing in NST had lower net photosynthesis rate compared with the other growth media.

Aspen seedlings growing with 100% N and P solution had higher transpiration rates when compared to the plants grown with the 10% N and P solution. Seedlings growing in NST had lower transpiration rates compared with the other growth media. In white spruce, for both 10% and 100% N and P solutions, plants showed significantly higher transpiration rates in topsoil, and the mixture of NST and topsoil.

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

One-year-old blueberry (*Vaccinium myrtilloides*), lingonberry *(Vaccinium vitis-idaea*) and raspberry (*Rubus idaeus*) seedlings were grown for a period of 10 weeks in four growth media: topsoil; peat mineral mix (PMM); mixture of non-segregating tailings (NST) and topsoil (1:1, v/v); and mixture of NST and PMM (1:1, v/v). The plants were watered every second day and fertilized weekly with 25% Hoagland's solution. At the end of the treatment period, the plants were harvested and measured for the leaf, stem and root dry weights; net photosynthesis and transpiration rates; leaf chlorophyll concentration; and leaf element concentration including the trace elements of mercury (Hg), lead (Pb), manganese (Mn), cadmium (Cd), strontium (Sr), copper (Cu), zinc (Zn), boron (B) and fluorine (F).

At the end of the experiment, lingonberry and blueberry plants had significantly higher total dry weights when grown in topsoil and PMM compared with those grown in either of the NST mixtures. However, for raspberry plants, there was no significant difference in dry weights between the treatments. For blueberry plants, there were significantly higher shoot to root dry weight ratios in plants grown in topsoil and PMM when compared with the other growth media.

Raspberry plants grown in topsoil and PMM had significantly higher net photosynthesis rates compared with the media containing NST. For lingonberry and blueberry plants, there was no significant difference in the net photosynthesis rate for plants grown in the different media.

Raspberry plants grown in PMM had the highest transpiration rates and the plants grown in NST mixtures showed the lowest transpiration rates. The raspberry plants grown in topsoil had intermediate transpiration rates. For lingonberry and blueberry plants, there was no significant difference in transpiration rates between plants grown in the different media.

For raspberry, lingonberry and blueberry plants, there were no significant differences in total chlorophyll concentration between the plants grown in the different media.

The leaf elemental concentrations are presently being analyzed.

LESSONS LEARNED

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

The high pH and salinity of NST water severely impaired plant growth, caused mortality, reduced net photosynthesis rates and water uptake and increased electrolyte leakage of studied plants. Hypoxic conditions aggravated the stress that NST tailings water imposed on plants. Among the studied species, lodgepole pine was most sensitive to NST tailings water and it showed mortality across all treatments. Black spruce and tamarack were more tolerant to NST tailings water and hypoxia compared with the other examined species.

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

For study 5, the original treatment plan of three N and P nutrient concentrations (10%, 25, and 100% of Hoagland's solution) was revised to two N and P concentrations (10% and 100%), as a previous study showed that the effects of 10% and 25% nutrient solution on plant growth were similar.

For both aspen and white spruce, seedlings grown in topsoil showed better growth and physiological performance compared with the other media. The increased availability of N and P had larger beneficial effects in aspen and resulted in increased net photosynthesis, transpiration rates and leaf chlorophyll concentrations.

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

Our results from a previous study (Study 1) demonstrated that adding 25% NST to topsoil, or peat mineral mix, had only minor effects on plant growth. Therefore, this study design increased the ratio to 50% NST mixed with topsoil and peat mineral mix.

Raspberry plants showed the highest net photosynthesis and transpiration rates when grown in PMM. In NST and topsoil, or PMM mixtures, the growth of lingonberry and blueberry plants was inhibited compared with the seedlings grown in topsoil or PMM. However, the leaf chlorophyll concentrations in seedlings of the three species grown in NST mixtures were the same as the seedlings grown in pure topsoil or PMM.

LITERATURE CITED

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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

Journal Publications

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

Conference Presentations/Posters

Zhang W. Revegetation in Canada's oil sands land reclamation. Presented at: Sun Yat-sen University Forum for Young Scholars, April 28, 2019, Vancouver, Canada

Sun X. Effects of elemental sulphur on growth of plants. Poster presentation at: Forest Industry Lecture Series, March 07, 2019, University of Alberta, Edmonton, Canada

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta, Department of Renewable Resources

Principal Investigator: Janusz Zwiazek

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Wenqing Zhang	University of Alberta	Post-Doctoral Fellow		
Killian Fleurial	University of Alberta	PhD	2017	2021
Xuehui (Chris) Sun	University of Alberta	MSc	2018	2020

The Long-Term Plot Network

COSIA Project Number: LJ0295

Research Provider: Forcorp Solutions Inc., Paragon Soil and Environmental Consulting Inc.

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial, Syncrude Canada Ltd.

Status: Ongoing

PROJECT SUMMARY

The Long-Term Plot Network (LTPN) is a large-scale vegetation monitoring program for reclaimed mine sites in the Athabasca oil sands region. The LTPN collects data on a wide variety of indicators, including vegetation dynamics, soil dynamics, and the growth rates of commercial timber species on reclaimed sites. The long-term collection of this type of information not only supports achieving regulatory requirements for monitoring, but also the development of generalized trends and hypotheses relating to the effectiveness of reclamation practices.

The goals of the LTPN are to:

1. Develop and maintain a continuous, robust, long-term sampling program over a wide range of reclamation prescriptions across the oil sands mineable region, which supports inductive trend analysis of reclamation treatments and the response of soil and vegetation dynamics over time.
2. Develop and implement a field sampling program to measure and capture soil, vegetation and tree dynamics over time.
3. Develop and maintain a structured and comprehensive dataset of sampling measurements over time that are held to rigorous data quality control and quality assurance standards.
4. Develop an understanding and facilitate trend analyses of soil development, plant community composition, and timber yields over the short term (5 to 30 years) and long term (30 to 100 years) to guide reclamation planning, the evolution of best management practices, and support future research.
5. Develop an understanding of how the conditions on reclaimed sites compare to natural conditions within the Alberta oil sands region.
6. Develop analysis methods and reports that can be used to effectively communicate insights from the program to reclamation practitioners, regulatory bodies, researchers and concerned stakeholders.

The LTPN provides a strong foundation for tracking the progress of reclaimed sites over the long term, evaluating equivalent land capability, and for supporting a range of applied research. The collaborative nature of the program also provides a range of benefits to industry; including cost-sharing for monitoring programs, supporting the achievement of regulatory reporting requirements for monitoring of reclaimed sites, achieving a greater understanding of reclamation trends over a wide range of mine site conditions, and the opportunity for effective knowledge exchange between companies.

PROGRESS AND ACHIEVEMENTS

Program Development

In 2019, work continued on the development of a rationale document to develop and refine the LTPN's goals and objectives. The document is approaching the final draft stage and is expected to be completed in early 2020. A major focus of work for the rationale document was the development and finalization of a sampling matrix based on reclamation material prescriptions. This sampling matrix will be used to guide the establishment of new plots in 2020 and subsequent program years.

In addition, a standard reporting template summarizing trends from data collected on an annual basis was developed in 2019. The template includes a number of metrics for vegetation, tree and soil data.

Field Sampling

No new plots were established in 2019, as the sampling matrix to guide the selection of new plots was developed throughout the year. Sixteen existing plots were sampled for soils measurement, vegetation measurement, tree mensuration, and foliar analysis sampling. Based on the lessons learned in 2018, the first field visit included a plot maintenance inspection. During the second field visit, wooden centre posts were replaced with PVC pipes.

LESSONS LEARNED

The 2019 field sampling program highlighted a number of ambiguous, inconsistent or outdated protocols; and some issues with data collection. Some of the minor issues were corrected immediately following the field season, such as adjustments to drop-down menus in the data collection tablets (to reduce the amount of time spent on data entry in the field) and an analysis of previous tree stem maps and databases (to correct some inconsistencies in tree numbering and tagging). Additional issues, such as outdated methods for assessing tree site index, ambiguities in collecting broadleaf material for foliar analysis, and clarification on methods for photo documentation will be addressed during the update of the data collection protocol document, in 2020.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2019.

RESEARCH TEAM AND COLLABORATORS

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Becky Doherty	Forcorp Solutions Inc.	Resource Analyst		
Ted Gooding	Forcorp Solutions Inc.	Senior Partner		
Kerry Nice	Forcorp Solutions Inc.	Partner & Application Development Manager		
Bob Christian	Forcorp Solutions Inc.	Partner & Senior Analyst	2017	2021
Vincent Futoransky	Paragon Soil and Environmental Consulting	Senior Ecologist	2018	2020

Hitchhiker Field Trial at Kearl Operations

COSIA Project Number: LJ0324

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 2 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 established in July 2018 were monitored at the end of the 2019 growing season (mid-September). This monitoring included shrub performance metrics including height and health.

Vegetation Performance

Survivorship of shrubs over the first growing season was generally high. Green alder had 79% survival in hitchhiker planting treatment plots and 90% survival in companion planting treatment plots. Willow had 94% survival in hitchhiker planting treatment plots and 92% survival in companion planting treatment plots. Overall, survivorship of planted shrubs was 86% in the hitchhiker planting treatment plots, and 91% in companion planting treatment plots. Survivorship of forb partner species was low in the hitchhiker planting treatment. In the hitchhiker planting treatment, average survival of common fireweed was 50.4% and survival of bunchberry was 22.7%. Partner forb survival in the companion planted treatment was higher, averaging 78.6% for common fireweed and 82.4% for bunchberry.

Results of the Year 2 analyses suggest that the planting method did not have a significant effect on the height of green alder seedlings ($P = 0.480$), but did have a significant effect on the height of willow seedlings ($P < 0.001$). After the second growing season, willow shrubs were taller in the hitchhiker planting treatment than in the companion planting treatment. Willow shrub height also increased significantly between 2018 and 2019 ($P < 0.001$), while the average height of green alder shrubs decreased significantly ($P = 0.002$). The loss of height in green alder shrubs over time is attributed to the mortality of taller individuals, and the death of leader branches.

The forb partner species had a significant effect on shrub seedling height for both green alder and willow. Regardless of planting method, green alder seedlings were significantly taller when planted with a forb partner than when planted alone ($P = 0.013$). Conversely, willow seedlings were significantly taller when planted with a common fireweed partner than when planted alone ($P < 0.001$). Willow seedlings planted with bunchberry partners were also taller than when planted alone, but this effect was only significant when the hitchhiker planting method was used ($P < 0.001$).

Average health scores for planted shrubs were generally high and varied between Good and Excellent. As with shrub height, willow seedling health was dependent on the method of planting ($P < 0.001$), but the health of green alder seedlings was not ($P = 0.123$). Willow seedlings were significantly healthier when planted using the hitchhiker planting method than when using the companion planting method ($P < 0.001$).

The health score of green alder seedlings planted with a common fireweed partner was significantly lower than the health score of those planted with a bunchberry partner or when planted alone ($P = 0.003$). Conversely, the health score for willow seedlings planted with a common fireweed partner was significantly higher than those planted with a bunchberry partner or when planted alone ($P < 0.001$).

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 Soil and & Environmental Consulting Inc.

Principal Investigator: Paragon Soil and & Environmental Consulting Inc.

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 14 – 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. 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 2019.

PROGRESS AND ACHIEVEMENTS

Between 2006 and 2019 a total of 27 cameras were deployed in the three habitat types (Athabasca Corridor, n = 10 cameras; Horizon Lake, n = 11 cameras; Reclamation Area 1, n = 6 cameras). A total of 57,647 camera-triggering events were recorded, with 3,997 events being false triggers (i.e., non-wildlife). Of the remaining 53,650 wildlife events, 47,293 were duplicate photos of the same event. Of the 9,912 unique wildlife sighting events, 9,834 could be identified to the species level. A total of 71 species of wildlife were recorded on cameras with detections of nine species dominating the sample: white-tailed deer (Odocoileus virginianus, n = 4,149 detections), red fox (Vulpes vulpes, n = 1,116 detections), American black bear (Ursus americanus, n = 1,071 detections), American moose (Alces americanus, n = 648 detections), coyote (Canis latrans, n = 412 detections), snowshoe hare (Lepus americanus, n = 342 detections), grey wolf (Canis lupus, n = 220 detections), American red squirrel (Tamiasciurus hudsonicus, n = 187 detections) and Canada lynx (Lynx canadensis, n = 165 detections). The seasonal (monthly) and annual detections (2006 to 2019) for the six most frequently photographed species are shown in Figure 1 which provides an indication of the annual and seasonal variation in sighting events in each habitat.

Most species were detected in all three habitats with one exception: American moose was 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 there were still 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). The number of wildlife sighting events 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).

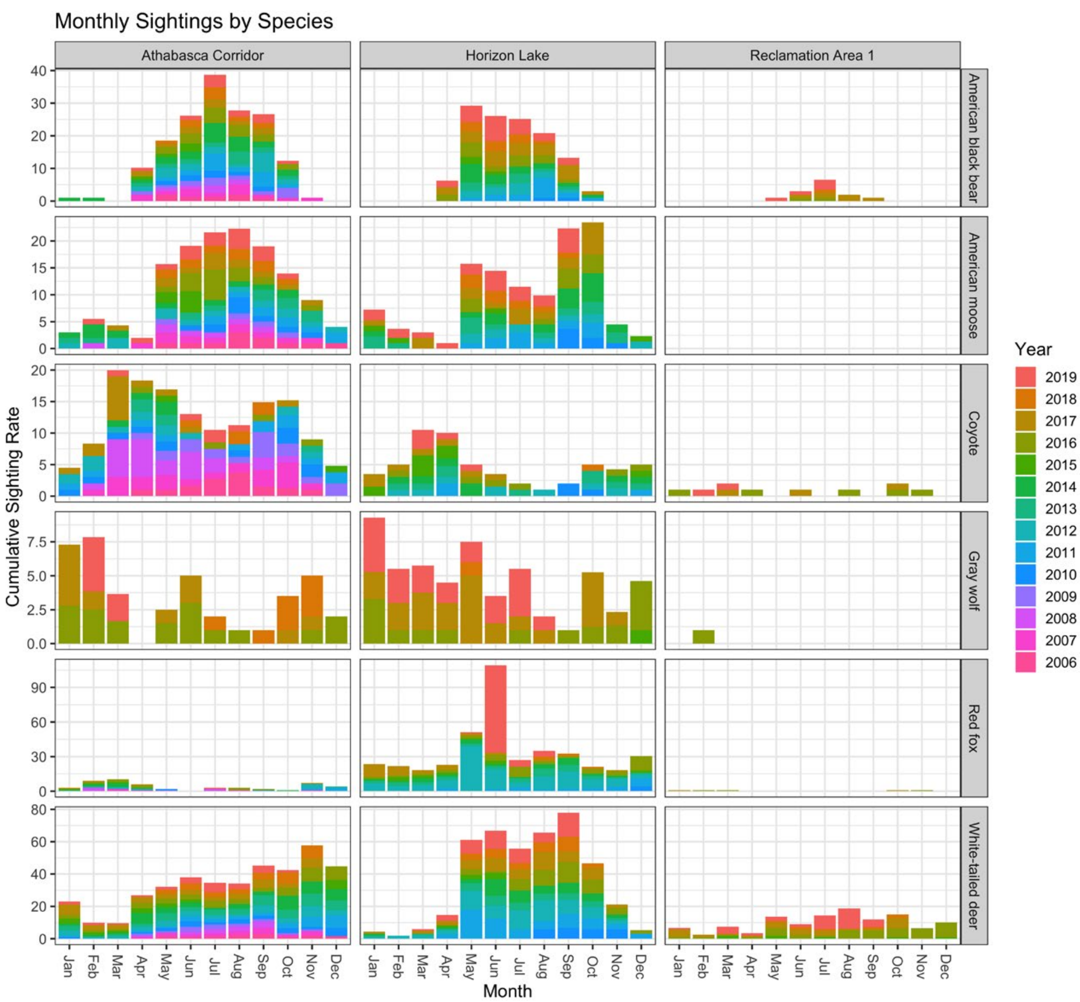

Figure 1: Seasonal (monthly) and annual (2006 to 2019) sightings of the six most frequently photographed species of wildlife in each camera array on and adjacent to Canadian Natural's Horizon Oil Sands. Sighting counts adjusted for number of available cameras per array.

Dynamic occupancy models (MacKenzie et al., 2003; MacKenzie et al., 2006) were fitted 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 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 was 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 t, 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 complement 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 2019. 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.

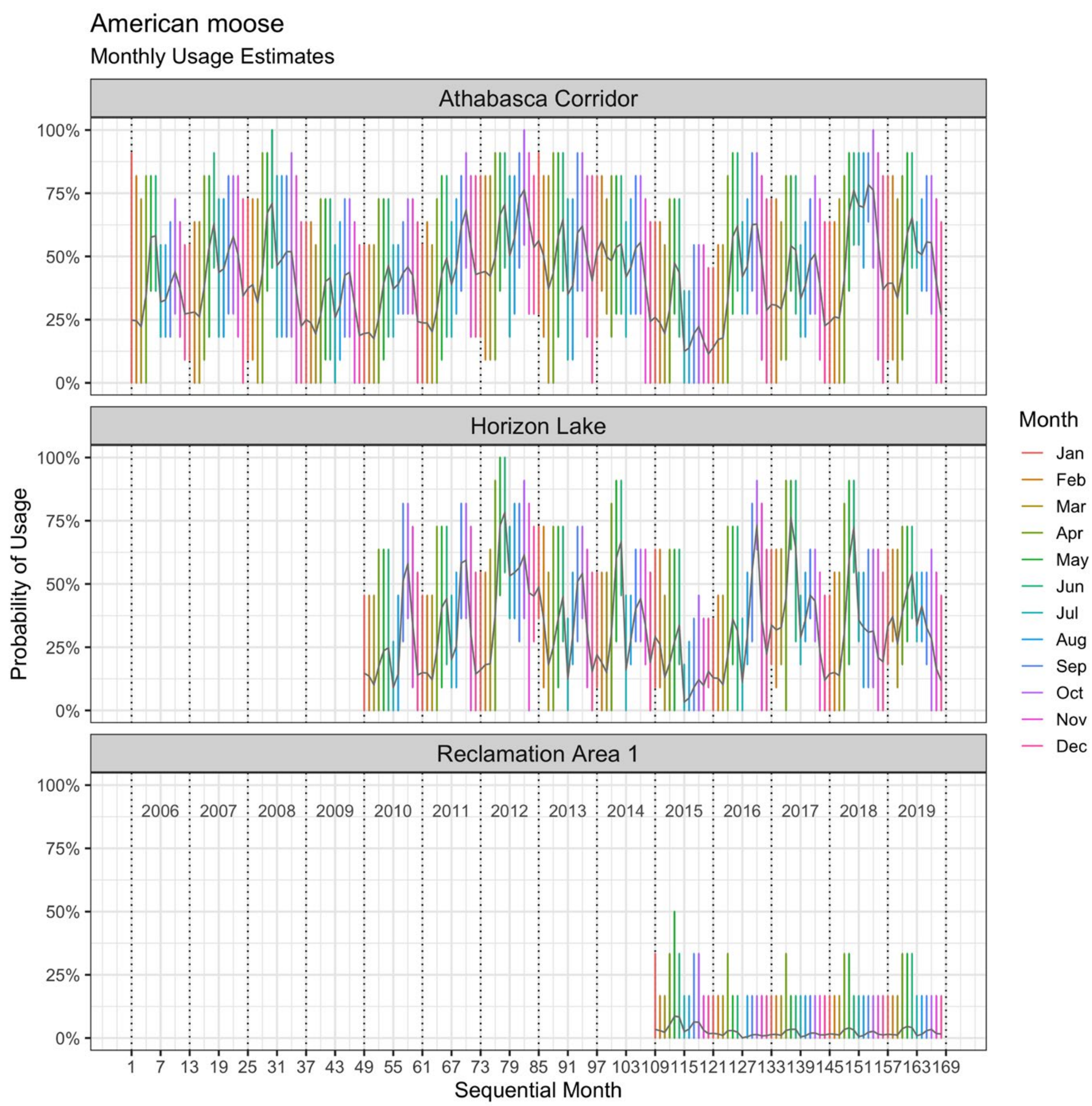

Figure 2: Monthly usage estimates generated from the monthly time-step occupancy model for American moose (*Alces americanus*). Error bars indicate 95% credible intervals, with colour indicating month. Vertical dotted lines indicate assessment year. The time series associated with each camera array is Athabasca Corridor: 2006-2019, Horizon Lake: 2010-2019; Reclamation Area 1: 2015-2019.

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 six analyzed species showed stable long-term trends in site usage, with an example for white-tailed deer provided in Figure 3. In this example, there is evidence of a relatively stable and cyclical pattern 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).

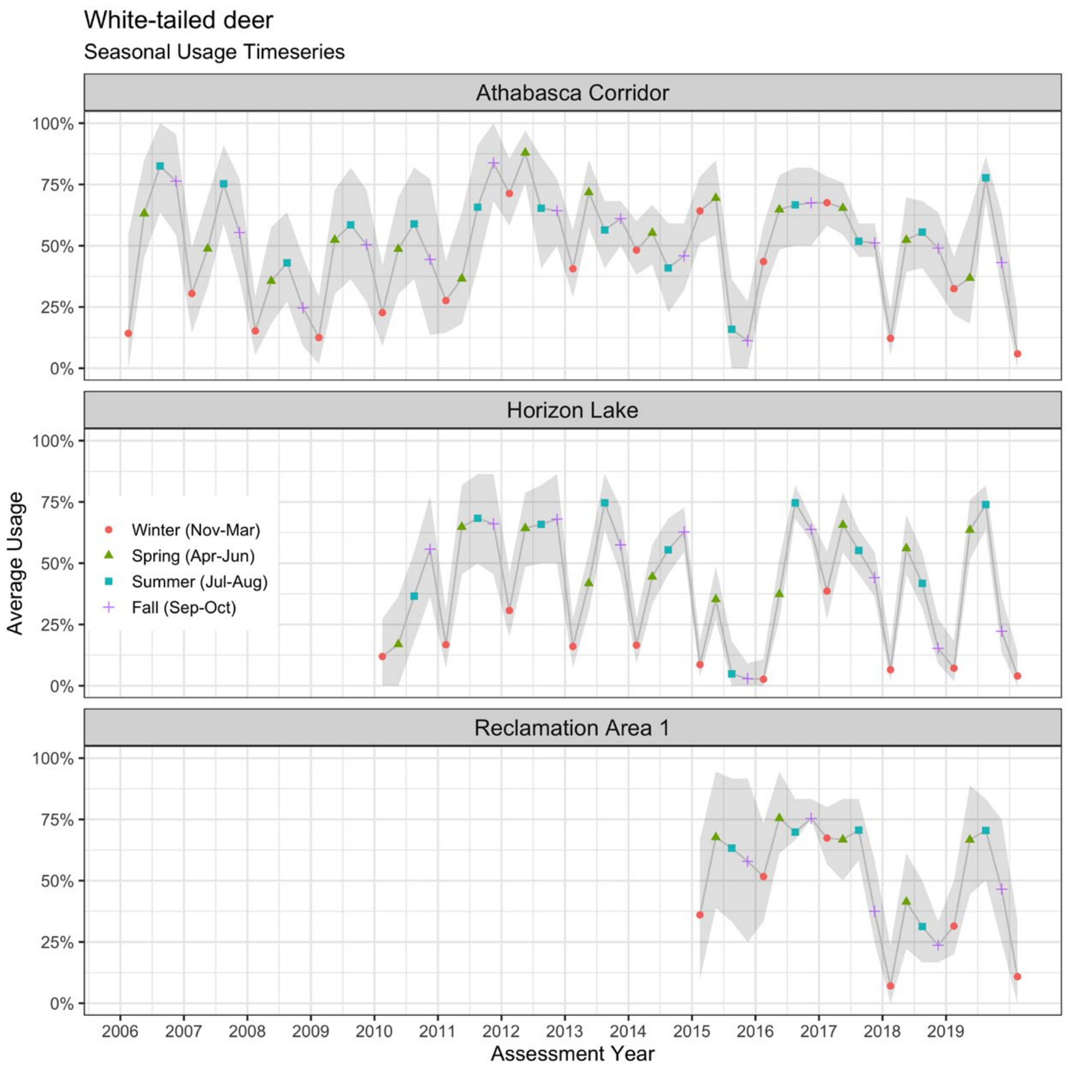

Figure 3: Longer-term seasonal usage estimates derived for white-tailed deer (*Odocoileus virginianus*) by averaging the appropriate monthly estimates. Shading indicates the 95% credible intervals for a given season. Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct).

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. Only red fox showed a systematic seasonal difference in usage with less use in Reclamation Area 1 compared to all other areas. Red fox also exhibited the most stable seasonal usage patterns relative to habitat type compared to species such as white-tailed deer and American moose (Figure 4).

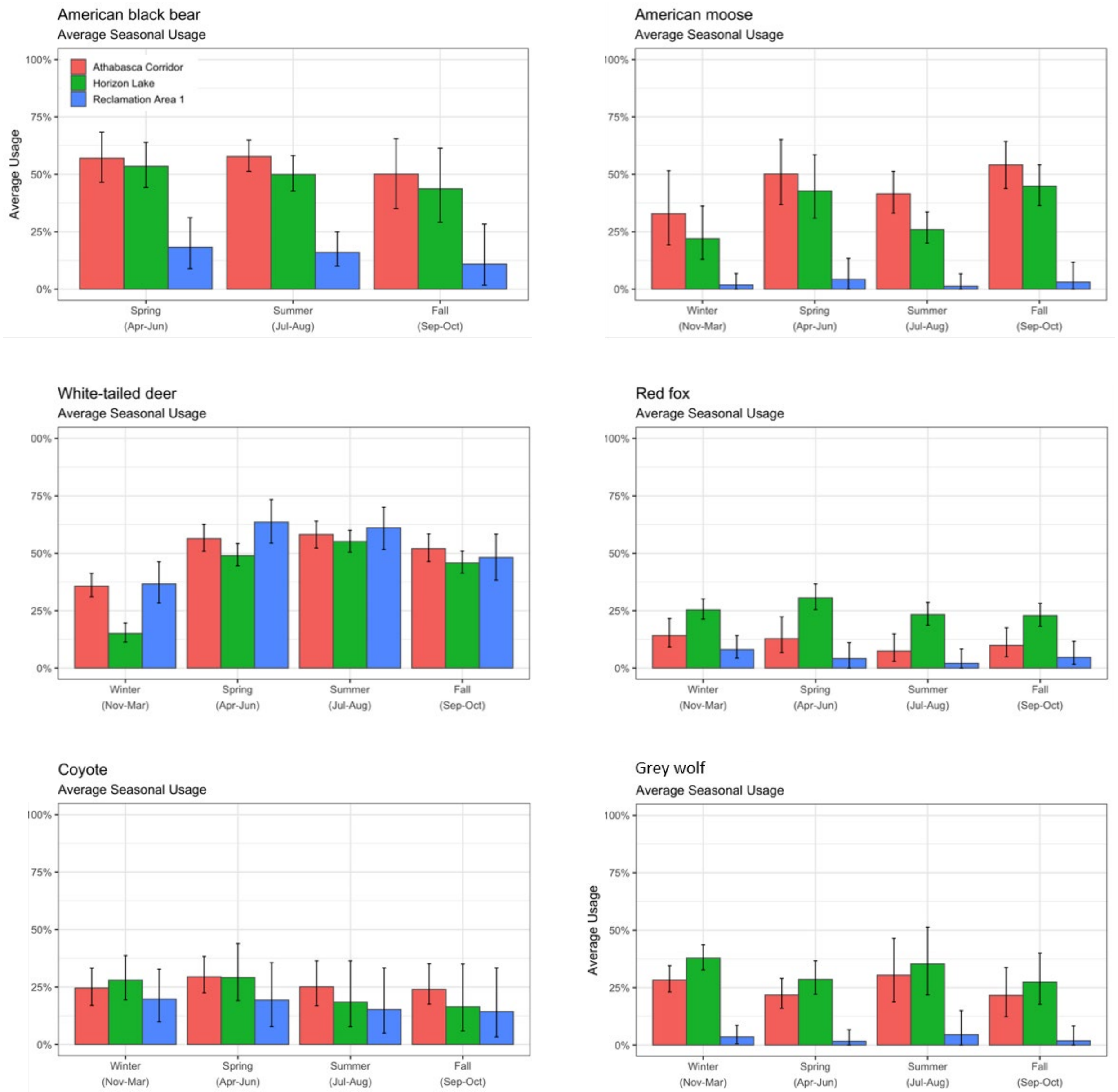

Figure 4: Average estimated seasonal usage for six species captured on wildlife cameras over the assessment period by area. Error bars indicate the 95% credible intervals for a given seasonal estimate. Winter (Nov-Mar); Spring (Apr-Jun); Summer (Jul-Aug); and Fall (Sep-Oct). See Figure 3 for definition 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 2019, 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. 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 in 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.
4. Remotely triggered wildlife cameras provide a cost-effective way of collecting data on wildlife occurrence and distribution.
5. Wildlife 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.

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Monitoring Avian Productivity and Survivorship in the Oil Sands Region (Boreal MAPS)

COSIA Project Number: LJ0214

Research Provider: Owl Moon Environmental Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: ConocoPhillips Canada Ltd., Devon Canada Corporation, Hammerstone Infrastructure Materials, Husky Oil Operations Ltd., Suncor Energy Inc., CNOOC Petroleum North America ULC, Canadian Natural

Government Collaboration: Oil Sands Monitoring Program (Alberta Environment and Parks; Environment and Climate Change Canada)

Status: 2011 – Present (annual participation)

PROJECT SUMMARY

Monitoring Avian Productivity and Survivorship (MAPS) is a continent-wide mark-recapture (bird-banding) program dedicated to understanding population demographics and vital rates of landbirds (passerines and woodpeckers), most of which are Neotropical migrant species. Indices of avian vital rates provide a strong indication of habitat quality and structural complexity in consideration of the various life history requirements of each species. Data collected using captured and banded birds are useful in evaluating many aspects of landbird dynamics, including effects from industrial activities. In northeastern Alberta, there is significant interest in boreal forest ecology in response to industrial operations, habitat disturbances, and habitat reclamation and restoration efforts. The overall value from this program is the understanding of what is driving changes in avian population dynamics and diversity for bird species nesting in the boreal forest in the oil sands region.

Vital-rate data are lacking for landbird species that rely on the boreal forest (Thompson 2006; Wells 2011), limiting our ability to address underlying causes of population changes for those species that are experiencing population declines (Rosenberg et al., 2016). Measurement of vital rates within disturbed and natural habitats over time provides an assessment of local scale effects, including habitat performance, and identifies regional effects resulting from pressures or stress experienced during migration or on the wintering grounds (Newton 2004; Albert et al., 2016). Low or declining productivity would indicate that effects are occurring on the breeding grounds, while low or declining adult and/or juvenile survivorship would suggest that the effects are caused on the wintering grounds or during migration (Newton 2004; Wilson et al., 2018). Understanding factors within the annual cycle leading to population declines is critical to the effective management and recovery of bird populations, including decisions on whether to devote resources to management on breeding or wintering grounds.

The Monitoring Avian Productivity and Survivorship in the Oil Sands Region Program (Boreal MAPS Program) has been established to acquire data for use in estimating population vital rates for bird species nesting in the boreal forest. The industry-specific value from this program is twofold:

1. It advances the understanding of local and regional effects on landbird populations, relative to those encountered during migration or on the wintering grounds; and
2. It provides the opportunity for industry to potentially optimize reclamation, mitigation and habitat restoration best practices considering the habitat requirements of select species that are experiencing population declines as a result of low productivity on the breeding grounds.

A third goal, although not a formal program objective, is to provide a field platform for use by other researchers undertaking complementary programs. This results in opportunities for the leveraging of data and research collaboration.

In 2011, six MAPS stations were established in the oil sands region and the program has since expanded to include 38 (from Conklin area to north of Fort McKay), although not all stations have been operated in each year. In 2019, the Oil Sands Monitoring (OSM) Program joined as a sponsor, committing funding to support the operation of the regional, predominantly natural, component of the MAPS program. In 2019, 28 stations were collaboratively operated with OSM and industry funding support. Five additional sites were operated independently and intended to address industry-specific questions. Five sites remained suspended pending funding support.

The dataset discussed in this report represents the 33 stations collaboratively operated in three or more years since 2011. These are divided among 16 natural or reference (> 90% of habitat unaffected by disturbance), 16 disturbance-affected (< 90% natural, < 55% reclaimed) and one reclaimed (≥ 55% reclaimed habitat) stations. Five natural stations have been affected by non-human disturbance: one station was flooded in 2013, and this station and four others burned in the 2016 regional wildfire. Operations at 30 stations have yielded sufficient data to be included in demographic analyses.

Each MAPS station consists of eight to fourteen, 12-m mist nets operated for six hours per day on six days between June 10 and August 8 each year, in accordance with the standardized protocol developed by The Institute for Bird Populations (DeSante et al., 2018).

For captures of unbanded birds, a uniquely numbered, aluminum leg band issued by the Canadian Wildlife Service was applied to the leg. Data on species, age, sex, breeding characteristics, moult status and other physical characteristics were recorded, along with biometrics such as wing length and weight. Age classes were assigned as HY (hatched during the monitoring year) or AHY (hatched before the monitoring year) and most AHY birds were separated into SY (hatched in the previous year) or ASY (hatched before the previous year) (Pyle, 1997). Where birds are difficult to age, photographs are taken for later evaluation and confirmation of bird age.

Computer entry, data proofing, and verification of banding, mist-net effort and breeding status data are conducted using specially designed entry, verification and editing programs. For analyses, the number of adult birds captured per 600 net-hours was used as an index of adult population size, and post-fledging productivity was estimated by the ratio of individual young (HY) to adult (AHY) birds captured. A minimum of 2.5 adult captures per 600 net-hours is required to derive adult population size and productivity index estimates. Survival estimates require an average adult capture rate of ≥ 2.5 adults per year and at least two between-year recaptures over a minimum of four consecutive years of station operation. More years of data improves the precision of the survival estimate, and up to 10 years may be required to collect sufficient data for some species. For species with sufficient capture and recapture data, survivorship was estimated using Modified Cormack-Jolly-Seber capture-mark-recapture models (Pollock et al., 1990; Lebreton et al., 1992). Recruitment and adult age class structure (SY:ASY) are being evaluated as additional demographic indices.

PROGRESS AND ACHIEVEMENTS

Quality assurance review and analyses of the 2019 data are ongoing, and the numbers presented here are preliminary and may change as the data are validated. In 2019, fieldwork comprised 10,074 net-hours of operation, resulting in 3,047 birds newly banded, 29 released unbanded and 1,205 recaptures of previously banded birds, for a total of 4,281 captures (255 total captures per 600 net-hours). This capture rate is consistent with those from 2018 (255 per 600 net-hours), 2017 (230 per 600 net-hours), 2016 (255 per 600 net-hours), but lower than those in the 2011 to 2015 period (328 to 500 per 600 net-hours). From 2011 to 2019, 88 species have been captured during MAPS operations.

With the data collected within the MAPS program, possible explanations for population trends on a per species basis, including the effects occurring on the breeding grounds in the region relative to the effects of stresses on populations occurring outside the region, can be examined. The population trends observed are consistent with continental findings of a general decline in bird populations.

Objective 1: To advance the understanding of avian population dynamics and diversity in habitats subject to disturbances associated with industrial and human activities, as compared to natural, unaffected areas

Across the 33 stations and over all nine years, 39,105 bird captures of 88 species have been recorded, of which 29,103 were newly banded, 566 were released unbanded, and 9,436 were recaptures of birds banded earlier in the same season or in previous seasons.

Monitoring at the five stations at which the habitat burned in the 2016 Horse River wildfire provides an opportunity to track avian community recovery in a natural disturbance area and in future compare it to that observed in habitats recovering from anthropogenic disturbances. In the three years post-fire, early colonizing sparrow species continued to predominate in the recovering burn habitats. A few warbler species present before the fire have been recaptured. It is expected that as the burned habitats grow and mature, a broader range of species will occur, although the timing and rates of colonization are not known.

Using the habitat structure data collected in 2012/2013 and 2018, it will be possible to statistically model vital rate and species composition responses to habitat changes among undisturbed natural habitats, natural habitats recovering from the 2016 wildfire, and disturbed (anthropogenic) habitats.

With each yearly increment of data to the database, the demographic analyses become more robust (greater statistical precision for more species), allowing us to differentiate long-term, naturally cyclic population patterns from changes due to anthropogenic habitat disturbance. MAPS data are also used to determine which species are experiencing declines as a result of breeding grounds stresses (productivity; which may be mitigatable in the oil sands region), or by stresses in migratory and/or winter habitats (survivorship) for which fewer options for mitigation by the oil sands industry may be available.

Objective 2: To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest

Data from 2019 are currently being integrated into the trend analyses and updating of population size, productivity and survivorship estimates. These analyses will provide insight into the contribution of regional stresses on the population trends for these species, and identify the species that may benefit from regional efforts (e.g., productivity effects indicate breeding ground stresses) and those that would not (e.g., survivorship effects indicate stresses outside the breeding grounds). This analysis is core to the question of whether or not changes in bird populations in the region reflect local stresses or are an expression of changes in these populations at a continental level.

A preliminary evaluation of proximal cause of population change for 20 species based on vital rates analyses is presented in Table 1 (data from 2011 to 2018). For each of the species showing significant (at $p < 0.05$ or $p < 0.10$) or consistent ($r > 0.400$) change in adult population sizes and/or productivity, stresses are indicated on the breeding and/or wintering grounds. Regional productivity for a species is considered to be low if the mean index over the period of monitoring (2011 to 2018) is < 0.50, moderate if between 0.50 and 0.95, and high if ≥ 0.95 (regardless of whether or not a trend was observed). Survivorship values for these species, derived from Boreal MAPS Program data to the mean survivorship values for these same species derived from the 1992 to 2006 MAPS continental database (DeSante et al., 2015), were compared as the basis for a preliminary assessment of adult survivorship. Boreal MAPS survivorship was characterized as being low (lower than 25% of the 1992 to 2006 mean survivorship), medium (plus or minus 25% of the mean survivorship) or high (higher than 25% of the mean survivorship).

Declining or low productivity was interpreted as being indicative of possible breeding ground stresses, and low adult survivorship was interpreted as being indicative of possible wintering ground stresses. It is important to recognize that this evaluation is preliminary, and not the product of detailed analyses. Annual variability in vital rate data, not yet taken fully into account, may result from short-term weather events (Rockwell et al., 2017) coupled with longer-term climate changes and cycles (Mazerolle et al., 2005), or the cyclic nature of some populations associated with food supply, resulting in shifts from increasing to decreasing vital rate trends when examining data over short periods. A full analysis and interpretation of proximal causes requires the application of appropriate statistical models as was done for the Canada warbler (Wilson et al., 2018), and completion of similar robust analyses for the additional species for which sufficient data are now available is anticipated.

Table 1: Interpreted (Preliminary) Proximal Causes of Population Change in 20 Species in the Boreal MAPS Program

Species[1]	Adult Population Size Trend	Productivity		Adult Survivorship Rating[2]	Interpreted (preliminary) Proximal Cause	
		Trend	Rating		*Breeding*	*Wintering*
Yellow-bellied Sapsucker	Decline ($p < 0.10$)	Decline ($p < 0.10$)	-	-	Unclear	
Least Flycatcher	Decline ($p < 0.05$)	Increase ($p < 0.05$)	Low	Low		X
Red-eyed Vireo	Decline ($p < 0.05$)	No trend	Low	Medium	X	
Black-capped Chickadee	Decline ($p < 0.05$)	Consistent decline ($r > 0.400$)	High	High	X	
Ovenbird	Decline ($p < 0.05$)	Decline ($p < 0.05$)	Medium	Low	X	X
Northern Waterthrush	Consistent decline ($r > 0.400$)	Consistent increase ($r > 0.400$)	Medium	Medium	Unclear	
Black-and-white Warbler	Decline ($p < 0.05$)	No trend	Medium	Medium	Unclear	
Tennessee Warbler	Decline ($p < 0.05$)	Decline ($p < 0.05$)	High	Low	Irruptive, cannot interpret	
Mourning Warbler	Consistent decline ($r > 0.400$)	No trend	Low	High	X	
Common Yellowthroat	Consistent decline ($r > 0.400$)	Consistent decline ($r > 0.400$)	Low	Low	X	X
American Redstart	Decline ($p < 0.05$)	No trend	High	Medium	Unclear	
Yellow Warbler	Decline ($p < 0.05$)	No trend	Medium	Medium	Unclear	
Myrtle Warbler	No trend	Decline ($r > 0.400$)	Medium	Low	Unclear	
Canada Warbler	Decline ($p < 0.05$)	No trend	Medium	High		X[3]
Wilson's Warbler	Decline ($p < 0.05$)	Consistent increase ($r > 0.400$)	High	Medium	Unclear	
Chipping Sparrow	Decline ($p < 0.05$)	No trend	Low	Medium	X	
Swamp Sparrow	Decline ($r > 0.400$)	No trend	High	Low		X
White-throated Sparrow	Decline ($p < 0.10$)	Decline ($p < 0.10$)	Medium	Medium	X	
Rose-breasted Grosbeak	No trend	Consistent decline ($r > 0.400$)	Low	Medium	X	
Purple Finch	Decline ($p < 0.05$)	No trend	High	Low		X

Notes:
[1] Yellow shading indicates species listed as Sensitive (Alberta); rose shading indicates species listed as Threatened (SARA)
[2] Categorized as Low, Medium or High based on comparison against survivorship derived from the continental database (DeSante et al., 2015)
[2] Declining Canada warbler population is due to low juvenile survival, attributed to stresses occurring on the wintering grounds (Wilson et al., 2018)

These analyses, on a species-by-species basis, are supportive of conservation action planning, as species experiencing breeding ground stresses are those that would benefit from habitat improvements. For those species where the primary driver of declining populations appears to be occurring outside of the breeding grounds (low survivorship, high productivity), specific reclamation or disturbance restoration practices focused on these species are unlikely to have measurable population-level effects.

With our partner, The Institute for Bird Populations (IBP), a manuscript was prepared and submitted for publication in 2019 that described yearling proportion as it correlated with habitat structure in the boreal forest landbird community. Yearling proportion, represented by the probability that a breeding bird is one year of age (expressed as the SY:ASY ratio), has been studied only minimally in a few landbird species. We related yearling proportion to habitat-structure covariates for 29 landbird species. This is also the first publication to examine the accuracy of age determination (yearling or older) based on recapture data and error rates, which were estimated at a mean of 8.1% (range 0.0% to 19.4%) among the 29 species, with 20 species showing age-error rates < 10%. Our results suggest that yearling birds are being excluded from preferred breeding habitats by older birds through despotism and/or that yearlings are selecting poorer habitat due to lack of breeding experience or other factors. This dynamic appears to be operating in multiple species within this forest landbird community. Our results suggest that stations with high yearling proportions could be located within sink, as opposed to source, habitats. Overall, yearling proportion may become an important vital-rate measure of habitat quality and reclamation efforts, when combined with indices of population size, productivity, reproductive condition and survivorship.

Although not an objective of this program, collaboration with other researchers is sought. While no field-level collaborations took place in 2019, discussions within the OSM process have identified numerous opportunities for integration of Boreal MAPS program activities into a broader biodiversity monitoring framework.

Objective 3: To understand the effectiveness of reclaimed lands to support avian populations, and the performance of reclaimed habitats as compared to natural habitats

Data were collected at five stations on reclaimed lands in support of industry-specific questions regarding the effectiveness of reclaimed habitat to support avian populations. These data provide valuable vital rate information, particularly for early colonizing species such as some sparrows and will address industry-specific questions. Data collection is complete but analysis is not yet available.

LESSONS LEARNED

Understanding regional landbird population trends and their underlying vital rates provides a necessary context for the interpretation of population trends of species in disturbed (anthropogenic and natural) and undisturbed natural habitats in the oil sands region. The MAPS protocol is a robust protocol that can be applied across a large range of species and habitats, and is capable of providing evidence of avian habitat use and the proximal causes of population change for individual species. Data collected using other methods such as bird point counts and automated recording units can be put into context by comparison against MAPS vital rate data. Data from point counts and automated recording units can identify increasing or decreasing population trends, while data from MAPS can provide insights as to why these populations are changing. A statistical analysis is underway to determine which of the species showing a consistent, regional population decline are driven by low productivity on the breeding grounds, and which species appear to be driven by low adult survivorship during migration or on the winter grounds. Preliminary analyses show:

- Low or declining productivity would indicate that effects are occurring on the breeding grounds, as potentially demonstrated (2011 to 2018 data) for red-eyed vireo, black-capped chickadee, mourning warbler, chipping sparrow, white-throated sparrow and rose-breasted grosbeak.
- Low or declining adult and/or juvenile survivorship would indicate that the effects are occurring on the wintering grounds or during migration, as demonstrated for Canada warbler (Wilson et al., 2018), and potentially for least flycatcher, swamp sparrow and purple finch.

- Ovenbird and common yellowthroat are potentially experiencing both breeding ground and winter ground effects.

The proximal causes of trends in adult population size remain unclear for a number of other species.

Species-by-species demographic analyses, correlated with habitat structure data, can directly inform habitat reclamation and restoration planning by targeting species experiencing stresses on the breeding grounds. With the addition of the 2019 data, this analysis can be completed for those species for which sufficient data are now available (in progress). The analysis to address industry specific question of how reclaimed lands support avian populations is not yet available.

This program is measuring substantial short-term (annual) variability, superimposed on population cycles that operate on long-term (i.e., decadal) time scales. Long-term monitoring is important in understanding the contribution of resource development and human activity in the region to avian population changes, in the context of natural variability and population cycles.

- Understanding vital rates for species of conservation concern (e.g., Canada warbler, least flycatcher, common yellowthroat) is a critical requirement in being able to prepare and implement effective recovery strategies and will help to focus efforts on reducing the more substantial stresses in the life cycle for these species.
- The Boreal MAPS Program is the first to assess the accuracy of age determination, showing a program-wide error rate of < 10%. The SY:ASY (age class ratio) is being utilized to demonstrate that yearling birds are being excluded from preferred breeding habitats by older birds (manuscript submitted for publication). The SY:ASY appears to be an indicator of habitat quality, and may be used to determine the presence of source or sink habitats.

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RESEARCH TEAM AND COLLABORATORS

Institution: Owl Moon Environmental Inc.

Principal Investigator: Kenneth R. Foster

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James Saracco	The Institute for Bird Populations	Research Ecologist		
Chris Ray	The Institute for Bird Populations	Research, Biostatistics		
Lauren Helton	The Institute for Bird Populations	Staff Biologist		
Steve Albert	The Institute for Bird Populations	Assistant Director for MAPS and MoSI		

Bison Research, Mitigation and Monitoring Program

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck Resources Limited

Industry Collaborators: Canadian Natural

Status: Year 4 of 4

PROJECT SUMMARY

The goal of the Bison Research, Mitigation and Monitoring project is to fill knowledge gaps, which have been identified by the Ronald Lake Bison Herd Technical Team[1], related to the habitat and population ecology of the Ronald Lake wood bison herd in northeast Alberta[2]. Ultimately, this project will inform herd management planning by the Ronald Lake Bison Herd Cooperative Management Board, as well as strategies to mitigate the potential effects of industrial activities (operational as well as reclamation) on the Ronald Lake herd. Specifically, the Bison Research, Mitigation and Monitoring project will address the following four key questions:

1. What is the spatial distribution of male and female bison in relation to season, habitat type, and natural and anthropogenic disturbances?
   a. What is the spatial distribution of male and female bison on an annual and seasonal basis?
   b. What are the patterns of habitat selection?
   c. What is the influence of natural and anthropogenic disturbances on habitat selection?
2. What bottom-up (forage & habitat supply) or top-down (predation) factors limit the Ronald Lake wood bison herd?
   a. What are the projected changes in forage supply for wood bison with resource developments?
   b. Does insect harassment and ground firmness affect summer forage availability?
   c. How do winter conditions and wolf predation risk influence winter habitat use and survival?
   d. What mechanisms promote selection for dry marsh meadow habitat in summer and what influence does this have on recruitment and calf survival?

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 wood bison herd also is culturally significant for local aboriginal communities (Candler et al., 2015). The proposed Frontier Oil Sands Mine Project intersects a portion of the home range of the Ronald Lake wood bison 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. The work is technically directed by the Ronald Lake Bison Herd Technical Team, as the work is of keen interest to multiple parties.

PROGRESS AND ACHIEVEMENTS

Knowledge gaps, as defined by the Ronald Lake Bison Herd Technical Team's Work and Action Plan, that were prioritized for study in 2019 included:

- What limits the northward movement of Ronald Lake bison into Wood Buffalo National Park (WBNP)?
- How does spring green-up influence the Ronald Lake wood bison herd's annual migration?
- How are different habitats used by large mammals in the Ronald Lake wood bison herd range?
- What comprises the Ronald Lake wood bison herd's diet; how does the quality and quantity of available forage change seasonally; and do these changes influence the herd's diet?
- How do anthropogenic and natural disturbances affect the mechanisms driving habitat selection?
- How do snow dynamics influence movement and habitat selection by the Ronald Lake wood bison herd?

Preliminary results of these studies are in the Lessons Learned section.

An additional area or study looked at how potential wolf predation influences the Ronald Lake wood bison herd. In 2019 three wolves, from two packs, were fitted with radio collars and data analysis is planned for 2020.

LESSONS LEARNED

- Ronald Lake bison herd habitat preferences were mapped with a focus on their northern range in four seasons, and compared differences between sexes. Preferred bison habitats become less common at the northern limit of the herd's range.
- A preliminary analysis indicates that there are two preferred spring migration corridors for the Ronald Lake bison herd and there is a positive correlation between bison locations and higher quality forage.
- Long-term wildlife monitoring plots showed differential habitat selection by bison in winter and summer, particularly for marshes.
- A literature review of American bison diets revealed selection for more browse items with greater amounts of lipids and protein at higher latitudes. The results of the review were used to predict the composition of the Ronald Lake bison herd's diet, which is currently being analyzed.
- An initial analysis of bottom-up effects on habitat selection did not show selection for greater biomass, rather it indicated selection for more open habitats.
- Snow monitoring stations disclosed greater snow depth in upland deciduous habitats and maximum snowpack in January and February of 2019.

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Journal Publications

DeMars, C.A., Nielsen, S. E. & Edwards M. A. 2020. Effects of linear features on resource selection and movement rates of wood bison (*Bison bison athabascae*). Canadian Journal of Zoology 98: 21-31.

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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RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott Nielsen

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Research Collaborators: Alberta Environment and Parks, Environment 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 Energy Oil Sands Limited Partnership (Suncor Energy and Fort Hill Operations), Imperial

Status: Year 5 of 5

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 understudied.

To address this deficiency, a five-year program is underway 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 from reclaimed habitats, mature forest and cleared, burned and logged juvenile stands on leases operated by Canadian Natural (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 is underway 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 will be compared to mature forests, which represent the desired endpoint of upland reclamation in the Athabasca Oil Sands Region, as well as to 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 are in compliance with 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 a compensation lake (COMP); (3) mature forest (MF); (4) cleared habitats (CLR); (5) logged (LOG); and (6) burned (BRN). A standardized sample unit is used that includes a small mammal live-trapping grid, songbird point count stations, autonomous recording units 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, 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 plots types.

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, with the next comprehensive report scheduled for 2020.

PROGRESS AND ACHIEVEMENTS

This project started in 2015, with a projected completion of Phase 1 in 2020 (a five-year program). Sampling in 2019 occurred from 37 sites on: Canadian Natural's Horizon Oil Sands (n = 12 sites); Suncor Energy's Base Lease (n = 11 sites), Fort Hills (n = 3 sites); Canadian Natural's Albian Sands Muskeg River and Jackpine Mines (n = 7 sites); and Imperial's Kearl Oil Sands (n = 4 sites).

The 37 sites were distributed among six main habitat types:

1. Reclaimed sites are those reclaimed to upland habitats (with the year of reclamation ranging from 1984 to 2015);
2. Comp Lake sites are reclaimed terrestrial habitats adjacent to compensation lakes;
3. Cleared areas were cleared (all vegetation removed) and left to regenerate on their own;
4. Logged sites were planted with tree species following clear-cut logging;
5. Burned sites are sites that were burned to mineral soil in 2011 (part of the Richardson fire); and
6. Mature Forest sites are mixedwood forests at least 60 years of age (usually 80 to 120 years) that represent the desired end point of upland reclamation in the Athabasca Oil Sands Region.

Site Type	Canadian Natural Horizon	Suncor Base	Canadian Natural Albian Sands	Fort Hills	Imperial Kearl Oil Sands	Total
Reclaimed	5	7	1	--	1	14
Comp Lake	3	--	1	1	1	6
Cleared	--	2	--	1	--	3
Logged	--	--	3	--	--	3
Burned	2	--	--	1	1	4
Mature Forest	2	2	2	--	1	7
Total	12	11	7	3	4	37

The following data were collected from each site in 2019:

- Small mammal live-trapping: spring and fall sampling;
- Songbird point counts: all leases;
- Deployment of autonomous recording units (ARUs): all leases;
- Wildlife camera data collection: all leases;
- Incidental wildlife observations (animals not targeted during systematic surveys): all leases;
- Vegetation sampling: all leases;
- Amphibian surveys: all leases (some via incidental observations);
- Insect sampling (pilot): Canadian Natural's Horizon Oil Sands, Canadian Natural Upgrading Albian Sands, Suncor Base Lease and Fort Hills; and

Remotely triggered cameras were deployed in late 2017 to target winter-active animals. This method replaced snow-tracking. Cameras were deployed on all leases in 2017 except for Suncor's Base Lease, which were deployed in early 2018.

Data collection occurred in all months of the year, with most occurring during the snow-free period (May to October). Data collected in 2019 contributed to the development of a dataset that will be used to assess the developmental trajectories of reclaimed habitats relative to natural analogs (i.e., the burned, logged and cleared sites) and to the desired endpoint of reclamation (i.e., the mature forest sites). Because compensation lakes are being built to offset habitat loss on most leases, it is also desirable to understand how wildlife are using habitats adjacent to those features. To ensure that the variability associated with animal populations is considered in the development of the trajectories associated with each type of site, a multi-year dataset is required. The 2019 data constitute year four of the five-year Phase 1 dataset.

All data collected in 2019 are undergoing quality assurance and quality control analysis and integration with previous data (into a relational and fully documented SQL database). It will be analyzed (along with all other data) in 2020 (following data collection for all taxa) and a five-year summary report will be generated.

Data collected for this project between 2015 and 2018 were integrated with similar data collected between 2010 and 2013 to generate a regional dataset of wildlife use of reclaimed habitats in the Athabasca Oil Sands Region. These data were analyzed to assess wildlife usage patterns of habitats reclaimed to upland forest types and published in 2019 (Hawkes and Gerwing 2019). Hawkes and Gerwing (2019) reported that data collected via systematic wildlife surveys (e.g., small mammal live-trapping, songbird point count surveys) are augmented by data collected incidentally (i.e., non-systematic, observer-based data collection). A total of 182 species of wildlife from three taxonomic groups were documented from all sampled oil sands leases. Overall, more species were detected on reclaimed habitats (n = 133) and those habitats were also associated with the largest number of unique species (n = 25). Terrestrial habitats adjacent to compensation lake habitats were associated with 127 species, of which 20 were unique. On burned sites, 72 species were observed and only 2 were unique. Logged and cleared habitats were the least with 54 and 55 species, respectively, and neither treatment was associated with any unique species of wildlife (Hawkes and Gerwing 2019). Finally, 95 species of wildlife were observed in mature forest reference sites, 15 of which were unique. Each of the species associated with a given treatment was expected based on known patterns of wildlife habitat use, occurrence and distribution. This includes those species unique to a given habitat type.

The results of a similarity percentages analysis suggest that wildlife communities increase in similarity between sites reclaimed to an upland forest type and mature forests as a function of time (i.e., years post-reclamation). Hawkes and Gerwing found that sites reclaimed 33 years ago supported wildlife communities that were between 31% and 62% similar to mature forests (avg. = 52%). These results indicate there is a progression towards wildlife communality similarity between reclaimed habitats and mature forests in the mineable portion of the Athabasca Oil Sands Region. This result is consistent with Wilson and Bayne (2019). While there is no certainty that reclaimed upland habitats will resemble or function identically to naturally occurring boreal forest, the degree of similarity observed further suggests that similar functionality is possible, increasing the probability that oil sands operators will be able to fulfill their regulatory requirements and duty to reclaim regarding wildlife and wildlife habitat (Hawkes and Gerwing 2019).

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 researchers' 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) and the 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 trends 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 may 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. Relative to the previous point, we currently record all species of wildlife targeted by standardized surveys. Preliminary analyses suggest that an indicator species approach could be used to focus surveys to 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. Current research 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 fulsome assessment and understanding of reclamation efficacy and success.
7. Similarity indices are commonly used to compare species assemblages between treatments types (e.g., reclaimed versus mature forest). While informative, the degree of similarity might provide misleading data. For example, the percent similarity between two habitat types might overlap, but following the previous point, the productivity and function of the two habitat types may differ substantially with one habitat providing sub-par habitat relative to the other. The use of an index of similarity also poses the risk of setting a threshold against which to proclaim reclamation success. Wildlife communities are non-uniformly distributed across the landscape and can exhibit a high degree of natural variation. The similarity index may be confounded by this natural variation. Using a value of similarity to assess reclamation success only partially supports the requirement to reclaim habitats to a similar (but not identical) pre-disturbance land capability.
8. 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, V. C. and T. G. Gerwing. 2019. Wildlife usage indicates increased similarity between reclaimed upland habitat and mature boreal forest in the Athabasca Oil Sands Region of Alberta, Canada. PLoS ONE 14(6): e0217556. https://doi.org.10.371/journal.pone.0217556

Conference Presentations/Posters

Presentation: Canadian Land Reclamation Association – AGM 2019. Red Deer, Alberta, February 2019. Wildlife Usage Indicates Increased Similarity between Reclaimed Upland Habitat and Mature Boreal Forest in the Athabasca Oil Sands Region of Alberta, Canada.

Presentation: 2019 Oil Sands Innovation Summit, June 2019. Calgary Alberta. Red Deer, Alberta, February 2019. Wildlife Usage Indicates Increased Similarity between Reclaimed Upland Habitat and Mature Boreal Forest in the Athabasca Oil Sands Region of Alberta, Canada.

Video

See also https://vimeo.com/354291366 for an online video describing the Early Successional Wildlife Dynamics Program.

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Environmental DNA (eDNA) for Canadian Toad, Burbot and Arctic Grayling

COSIA Project Number: LJ0327

Research Provider: Stantec and Precision Biomonitoring Inc. (PBI)

Industry Champion: Canadian Natural

Status: Year 2 of 3

PROJECT SUMMARY

Horizon Lake is a compensation lake designed and built by Canadian Natural to permanently offset areas of fish habitat affected by developments associated with the Horizon Oil Sands Mine (Horizon). Horizon Lake contains spawning, rearing and overwintering habitat for several fish species found within the Athabasca River watershed. Canadian Natural monitors fish populations in Horizon Lake to demonstrate the effectiveness of Horizon Lake as an offsetting (i.e., compensation) measure.

Environmental DNA (eDNA) sampling at Horizon Lake and the Tar River was conducted concurrently with the ongoing fish population study in order to test the potential for eDNA sampling to be used as part of ongoing biomonitoring programs at Horizon. eDNA methods provide an advantage over conventional capture methods by sampling the environment for DNA that is shed by organisms where they live, without having to capture, sample or even observe them in the environment. For protected species, eDNA avoids harm to individuals and their habitat, and is very sensitive and can detect very low levels of eDNA in the environment.

eDNA tools were developed for use by Canadian Natural at Horizon to detect the presence of target fish for ongoing monitoring in Horizon Lake. Species-specific eDNA assays were developed for Arctic grayling (*Thymallus arcticus*) and burbot (*Lota lota*) by the University of Guelph in a research and development partnership with Stantec.

Samples collected from Horizon Lake and the Tar River were re-examined in 2019 using eDNA extracts of samples collected in the 2018 study, and this time used the metabarcoding approach to examine the broader fish community represented in the samples. The use of metabarcoding may support much broader detection of the biological community beyond the target fish community to better document the success of Horizon Lake as a compensation lake.

Through an additional Stantec partnership, Precision Biomonitoring Inc. (PBI) began development of a Canadian toad eDNA assay in May 2018 using tissue samples (i.e., buccal swabs) provided by Canadian Natural as part of Canadian Natural's ongoing Canadian toad (*Anaxyrus hemiophrys*) monitoring and relocation program on Horizon Oil Sands. This Canadian toad research is closely tied to other research programs which have summaries included in this report (COSIA Project #LJ0325: Canadian Toad [*Anaxyrus hemiophyrus*] Monitoring on Canadian Natural's Horizon Oil Sands and COSIA Project #LJ0326: Canadian Toad Habitat Suitability Model Update).

The goal of using eDNA techniques as part of the toad relocation program is to broaden the survey window for detection and protection of Canadian toads (CATO) beyond a few weeks when adults can be visually confirmed, to several more weeks and months to detect egg and larval stages. The advantage of eDNA is better detection of CATO presence, which supports conservation efforts.

PROGRESS AND ACHIEVEMENTS

This summary covers progress and achievements for both 2018 and 2019 since a summary was not included in last year's (2018) report.

Fall 2018 eDNA Sampling Program

Quality control: All three positive controls for Arctic grayling (sample IDs ConAG-1a, ConAG-1b and ConAG-2) had 100% positive detection of Arctic grayling eDNA (Table 1). The negative control had 0% detection of either Arctic grayling or burbot (Table 1). This provided confidence in testing of unknown samples from Horizon Lake and Tar River for presence of eDNA for Arctic grayling.

EDNA-3, located in Horizon Lake near the inlet of the Tar River, was the only site that had a positive detection of Arctic grayling eDNA (Table 1). Arctic grayling was captured at EDNA-3 and EDNA-5 during the conventional sampling program the previous day. However, detection of Arctic grayling eDNA at EDNA-5 was negative (Table 1).

None of the sites had positive detection of burbot eDNA (Table 1) and burbot were not captured during the conventional sampling program prior to eDNA sampling.

Table 1: October 2018 Environmental DNA Results

Site ID[1]	Waterbody	Arctic Grayling eDNA Detection	Burbot eDNA Detection
Tar-1	Tar River	-	-
Tar-2	Tar River	-	-
HZL1	Horizon Lake	-	-
EDNA-1	Horizon Lake	-	-
EDNA-2	Horizon Lake	-	-
EDNA-3	Horizon Lake	Positive	-
EDNA-4	Horizon Lake	-	-
EDNA-5	Horizon Lake	-	-
ConAG-1a	Positive control for Arctic grayling[1]	Positive	-
ConAG-1b	Duplicate positive control for Arctic grayling[1]	Positive	-
ConAG-2	Positive control for Arctic grayling[1]	Positive	-
ConN-1	Negative control (deionized water)	-	-

NOTES:
- Species-specific eDNA not detected
[1] See Stantec (2019) for site locations
[2] Arctic grayling positive controls consisted of sampling water used for holding Arctic grayling captured in Horizon Lake

Metabarcoding

Metabarcoding results for analysis of samples from Horizon Lake and Tar River showed the presence of eDNA from seven fish taxa that are expected to be in Tar River or Horizon Lake:

- longnose sucker (*Catostomus catostomus*)
- white sucker (*Catostomus commersonii*)
- lake chub (*Couesius plumbeus*)
- fathead minnow (*Pimephales promelas*)
- brook stickleback (*Culaea inconstans*)
- trout-perch (*Percopsis omiscomaycus*)
- Arctic grayling (*Thymallus arcticus*)

Burbot was not detected using metabarcoding or using the previous targeted species assay (Stantec 2019); this is consistent with no captures in 2018 using conventional sampling. Low concentration of DNA in five of the samples and no fish detections in two of these samples reflects low density of DNA in the environment at these sites.

Additional wildlife: American beaver (*Castor canadensis*) was detected in one of the lake samples (EDNA-5).

Canadian Toad Assay Development

Development of a Canadian toad eDNA assay moved forward in May 2018 using tissue samples provided by Canadian Natural. Progress was made by PBI in development of the *Anaxyrus* spp. assay which amplifies both Western toad (*Anaxyrus boreas*) and Canadian toad. PBI encountered technical challenges identifying a specific sequence to differentiate the Canadian toad from other *Anaxyrus* species. In order to progress toward a Canadian toad specific assay, PBI obtained additional Canadian toad swabs from Canadian Natural in the form of buccal swabs and used these samples to obtain additional DNA barcodes to obtain a species-specific sequence for primer development.

Using the additional swabs, PBI validated and optimized the Canadian toad assay in the lab, applied the assay to Canadian toad samples obtained from Canadian Natural, and DNA amplification was confirmed. PBI determined that the original Canadian toad DNA sequence used to develop the assay is extremely similar to those belonging to some non-Canadian toads (e.g., *Bufo americanus, B. woodhousii* and *B. houstonensis*). However, it is possible that other sequences are non-overlapping and that there is a suitable sequence to use as a basis for an assay if the noted *Bufo* species are not cohabiting in the same area. Additional steps were identified to develop the assay for field deployment to confirm the presence of Canadian toads of any life stage (e.g., adult, egg, larvae) in ponds and discriminate this from sympatric species within the same genus (i.e., western toad). This assay would enhance the ability to detect presence of any life stage of Canadian toad in ponds in development areas to enhance management plans to protect this species.

LESSONS LEARNED

Using a species-specific eDNA assay for Arctic grayling, positive detections of Arctic grayling eDNA in the Tar River and Horizon Lake samples were consistent with the conventional fish sampling program conducted concurrently. Quality assurance and quality control protocols demonstrated that the eDNA sampling method is effective at collecting eDNA from a site where the target species is known to be present, that decontamination procedures were effective, and that the species-specific Arctic grayling assay is working effectively. This study provides evidence that eDNA sampling is an effective method for detecting fish presence. Information from the eDNA pilot study in 2018/2019 provides valuable baseline information to inform the design of future sampling programs to optimize the probability of detection of eDNA of target species.

Metabarcoding results showed the presence of eDNA from seven fish taxa that are expected to be in Tar River or Horizon Lake. A low density of eDNA retrieved in five of the eight samples could be attributed to several factors including lower rates for eDNA production from fish to water (Klymus et al., 2015; Cutting et al., 2016) or limited diffusion of eDNA through the water column (Takahara et al., 2012). A more intensive sampling program over space and time may be warranted in the future to increase the probability of detection of eDNA from fish species present in Tar River and Horizon Lake. The results of this study demonstrate the benefits of using metabarcoding to detect fish species in the community for comparison with conventional capture-based sampling. Although metabarcoding focused on fish species, this method can also be used to assess broader biodiversity by analyzing the sequence data obtained in this study for additional aquatic species and terrestrial wildlife with aquatic connections; e.g., by the detection of American beaver.

The main challenge in developing the Canadian toad assay was the sparsity of suitable DNA sequences in the data base available for assay designs. This means that independent DNA sequences must be obtained by barcoding new samples from specimens. The more barcodes, the higher the chance of identifying useful sequences. In order to progress toward a Canadian toad specific assay, additional Canadian toad buccal swabs were critical to obtain additional DNA barcodes and obtain a species-specific sequence for primer development. Obtaining tissue samples from rare species can be difficult and requires early planning to include collection (e.g., swabbing animals, tissues or wastes, or by filtering water) on research licences, coordination with field programs for conducting surveys within a target species' habitat, and sampling positively identified individuals using trained staff.

To confirm that an assay is highly specific, it is beneficial to obtain tissue samples from sympatric amphibian species whose ranges overlap with the target species. One area of concern remaining for the Canadian toad assay is to develop an assay for a closely related and sympatric species, the western toad. It will be important to develop an assay to detect the western toad in addition to the Canadian toad to distinguish between them where they co-occur in northern Alberta.

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PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

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Reports & Other Publications

Stantec Consulting Ltd. 2019. Horizon Oil Sands Mine Project Environmental DNA Sampling Program for Arctic Grayling and Burbot. Prepared for Canadian Natural. Calgary, Alberta.

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

COSIA Project Number: LJ0326

Research Provider: LGL Limited Environmental Research Associates

Industry Champion: Canadian Natural

Industry Collaborators: Canadian Natural Upgrading Limited

Status: Year 1 of 1

PROJECT SUMMARY

An update to the Canadian toad (*Anaxyrus hemiophrys*) habitat suitability index (HSI) model was undertaken to address regulatory requirements associated with Canadian Natural's *Environmental Protection and Enhancement Act* (EPEA) approvals (Horizon Lease: 149968-01-00; Albian Sands Lease: 20809-02-00 [Muskeg River Mine] and 00153125-01-00 [Jackpine Mine]) and to inform recent initiatives regarding Canadian toad relocations on Canadian Natural's Horizon Oil Sands.

The updated HSI model considered habitat attributes used in previous models (i.e., 1999, 2005 and 2007) but placed increased weight on overwintering habitat, while reducing the relative importance of the presence of breeding habitat. The updated model emphasizes the relationship between what is considered suitable wintering habitat (friable soils up to 1.25 m in depth in the a and b ecosites), suitable breeding habitat (certain shallow water ponds and wetland habitats), and the distance between those two important and limiting habitat features. Both wintering and breeding habitat must occur in certain combinations (distances) to provide suitable habitat for Canadian toads.

A base layer comprised of the derived ecosite phase (DEP) dataset, which is based on Alberta Vegetation Inventory (AVI) and LiDAR-derived datasets, was used to display the results of the model. The DEP was preferred over the individual soil and ecosite layers available for the Horizon Oil Sands lease because the soil layers are predicated on parent materials and are therefore of little utility when considering how those materials related to the provision of suitable wintering habitat for Canadian toads. The DEP is also more analogous to the map base used in Canadian Natural's application for mine project approval, providing the ability to make valid visual comparisons of the distribution of suitable toad habitat considered in that application relative to this update.

A field validation of soils data was undertaken to validate the use of the DEP in the updated habitat suitability mapping. This included visual assessments of surficial soil characteristics and the digging of soil pits to determine the depth of suitable soils on the Horizon and Albian Leases. The field data were used to refine the habitat suitability scores for overwintering habitat on each lease.

Updated habitat suitability mapping was produced for the non-disturbed portion of each lease (i.e., Horizon Oil Sands and Albian Sands) and compared to previous outputs. A comparison between the habitat suitability map produced for the mine expansion environmental impact assessments (EIAs) from 1999, 2005 and 2007 suggests that the current distribution of highly and moderately suitable habitat on Canadian Natural's Albian Sands lease is less

than previously thought. The updated suitability maps are based on more recent information regarding Canadian toad ecology and are a better representation of the occurrence and distribution of Canadian toad habitat on each lease. The updated suitability maps also align with recent observations of Canadian toads on the Horizon and Albian leases.

The outputs of HSI models can be thought of as hypotheses of species habitat relationships that aim to be biologically valid and operationally robust; however, they are derived from expert opinion and literature review. As such, the model outputs presented here should be considered relative to the somewhat limited knowledge available regarding Canadian toad overwintering habitat in the Athabasca Oil Sands Region. Based on the available literature it is reasonable to assume that loose or very friable (e.g., sandy) soils of 1 m to 1.2 m in depth will provide highly suitable overwintering habitat for Canadian toads. However, it is unknown if other potential wintering habitats such as old squirrel middens, small mammal burrows, or even American beaver (*Castor canadensis*) lodges could provide suitable overwintering habitat. Furthermore, the suitability of various wetland types has not been adequately assessed and the current model is based on toad ecology in general and on the characterization of known breeding habitat on Horizon Oil Sands. As with all habitat suitability index models, further validation may be required as more information regarding Canadian toad ecology becomes available.

PROGRESS AND ACHIEVEMENTS

The habitat maps for Canadian Natural's Horizon Oil Sands lease and Albian Sands lease were updated in 2019. The updated maps were based on an algorithm that considered the importance and interaction of suitable overwintering habitat with suitable breeding habitat. For each lease the mapping was produced for the non-disturbed portion of the lease.

The model used to rate each polygon associated with the DEP dataset considered the three suitability indices (SI):

1. SI1: Overwintering habitat
2. SI2: Breeding habitat
3. SI3: Distance between overwintering and breeding habitat.

Foraging and/or summer habitats were not considered in the development of this model. It is assumed that if suitable overwintering habitat and breeding habitat occur together, then there must also be suitable foraging and/or summer habitat in the area between those two important habitat attributes. This assumption is based on observations made by Hawkes and Papini (2018) who observed toads, fitted with very high frequency radio transmitters, foraging in habitats adjacent to known or suspected breeding habitats and on the observation of Canadian toads in upland habitats near known breeding habitats.

Values for each suitability index were determined as follows:

SI1 Overwintering Habitat

The ratings for overwintering are High, Moderate and Nil. These correspond to Suitability Index values of 1.0, 0.75 and 0, respectively (Figure 1). Most ecosites were assigned an overwintering suitability rating of Nil which is a reflection of the presence of soils lacking the required consistency for digging by toads. Only ecosite a1 was rated High, while aa1, aa2, b1, b2, b3, b4, b6 and b7 were rated as having Moderate suitability. Table 1 includes the soil type and ecosite label from the DEP dataset.

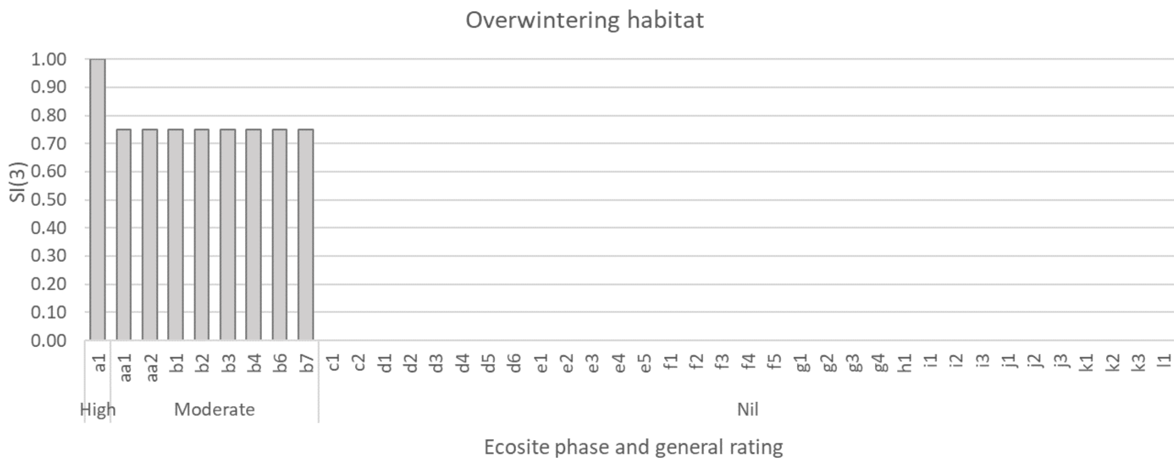

Figure 1: Suitability Index (SI) relationships regarding ecosite and overwinter habitat potential on Canadian Natural's Horizon Oil Sands Lease. Ecosite phase was extracted from the DEP and used as a proxy for soil type and ecosite name. An SI value of 1 is assigned to the a1 ecosite phase, which is characterized by very dry/sandy soils on a lichen-Pj (jack pine) dominated habitat.

Table 1: Soil type associations for each ecosite phase. Ecosite names follow Beckingham and Archibald (1996) and Moisey et al. (2012).

Landform	Soil Type	Ecosite Phase	Ecosite Name	Overwintering Rating
Hydrography (open water)	NA	NA	NA	NA
Riparian	Moist/Fine Loamy-Clayey	e1	dogwood – Pb-Aw	0.00
Riparian	Moist/Fine Loamy-Clayey	e2	dogwood – Pb-Sw	0.00
Riparian	Moist/Fine Loamy-Clayey	e4	dogwood – shrubland	0.00
Riparian	Moist/Fine Loamy-Clayey	e3	dogwood – Sw	0.00
Riparian	Moist/Fine Loamy-Clayey	f1	horsetail – Pb-Aw (Bw)	0.00
Riparian	Moist/Fine Loamy-Clayey	f2	horsetail – Pb-Sw	0.00
Riparian	Moist/Fine Loamy-Clayey	f4	horsetail – shrubland	0.00
Riparian	Moist/Fine Loamy-Clayey	f3	horsetail – Sw	0.00
Riparian	Moist/Fine Loamy-Clayey	g1	Labrador tea-subhygric – Sb-Pj	0.00
Riparian	Wet/Peaty	h1	Labrador tea/horsetail – Sw-Sb	0.00
Uplands	Dry/Sandy	aa1	grassland	0.75
Uplands	Moist/Fine Loamy-Clayey	c1	Labrador tea-mesic – Pj-Sb	0.00
Uplands	Moist/Fine Loamy-Clayey	d1	low-bush cranberry – Aw	0.00
Uplands	Moist/Fine Loamy-Clayey	d2	low-bush cranberry – Aw-Sw	0.00
Uplands	Moist/Fine Loamy-Clayey	d4	low-bush cranberry – shrubland	0.00
Uplands	Moist/Fine Loamy-Clayey	d3	low-bush cranberry – Sw	0.00
Uplands	Moist/Fine Loamy-Clayey	d5	low-bush cranberry – tame	0.00
Uplands	Very Dry/Sandy	b2	blueberry – Aw (Bw)	0.75

Landform	Soil Type	Ecosite Phase	Ecosite Name	Overwintering Rating
Uplands	Very Dry/Sandy	b3	blueberry – Aw-Sw	0.75
Uplands	Very Dry/Sandy	b4	blueberry – Sw-Pj	0.75
Uplands	Very Dry/Sandy	a1	lichen – Pj	1.00
Uplands	Very Dry/Sandy	aa1	grass/shrubland (xeric/poor)	1.00
Uplands	Very Dry/Sandy	aa2	grass/shrubland (xeric/poor)	1.00
Wetlands	Organic	i3	bog – graminoid	0.00
Wetlands	Organic	i2	bog – shrubby	0.00
Wetlands	Organic	i1	bog – treed	0.00
Wetlands	Organic	j2	poor fen – shrubby	0.00
Wetlands	Organic	j1	poor fen – treed	0.00
Wetlands	Organic	k1	rich fen – treed	0.00
Wetlands	Wet/Mineral	l1	marsh	0.00

SI2: Breeding Habitat

With the exception of rivers and streams, all wetland and pond types that occur on the Horizon Oil Sands were assigned a breeding suitability rating between 0.50 and 1.0 (Figure 2). This approach was used to account for the relative uncertainty with respect to Canadian toad distribution on the lease, as well as the limited information available regarding the extent to which Canadian toads will breed in each of the wetland types. Wetland codes are expanded in Table 2.

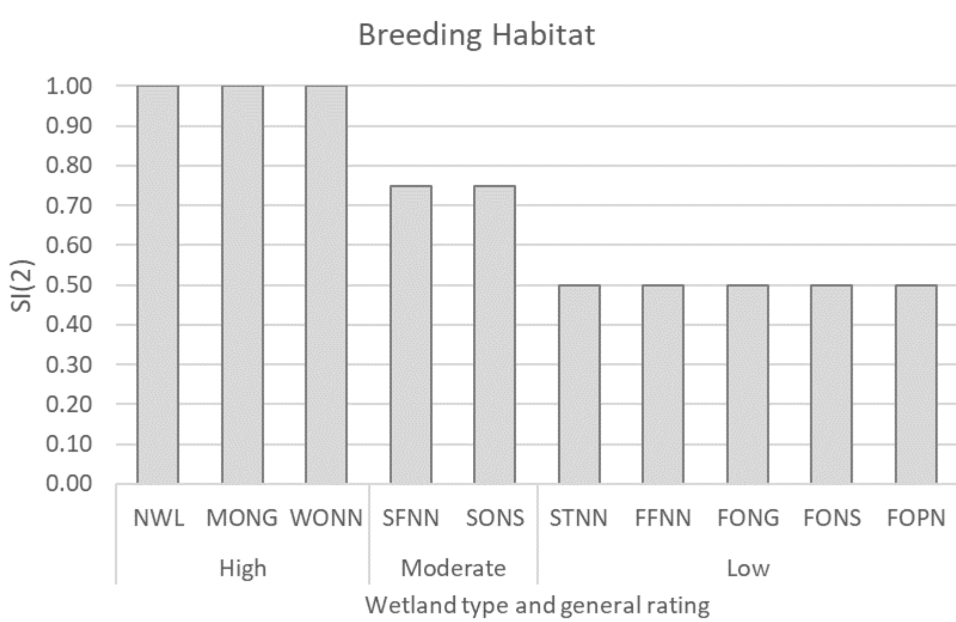

Figure 2: Suitability Index (SI) relationships regarding wetland types and breeding habitat potential on Canadian Natural's Horizon Oil Sands lease.

SI3: Distance Between Winter and Breeding Habitat

Suitable Canadian toad habitat must include a habitat matrix of suitable wintering habitat and breeding habitat. As the distance between these two habitats increases, suitability decreases.

SI3 values were assigned as follows:

<= 1,000 m: 1.0; between 1,000 m and 1,500 m: 0.75; between 1,501 m and 2,000 m: 0.25; >= 2,001 m: 0 (Figure 3).

Table 2: Expansion of wetland codes used in Figure 2 and associated SI score and ratings.

Type	Code	Rating	SI
Deep Water Lakes, Ponds	NWL	High	1.00
Graminoid Marsh	MONG	High	1.00
Shallow Open Water	WONN	High	1.00
Forested Swamps	SFNN	Moderate	0.75
Shrubby Swamps	SONS	Moderate	0.75
Wood Swamps	STNN	Moderate	0.50
Forested Fen	FFNN	Moderate	0.50
Graminoid Fen	FONG	Moderate	0.50
Shrubby Fen	FONS	Moderate	0.50
Patterned Open Fen	FOPN	Moderate	0.50

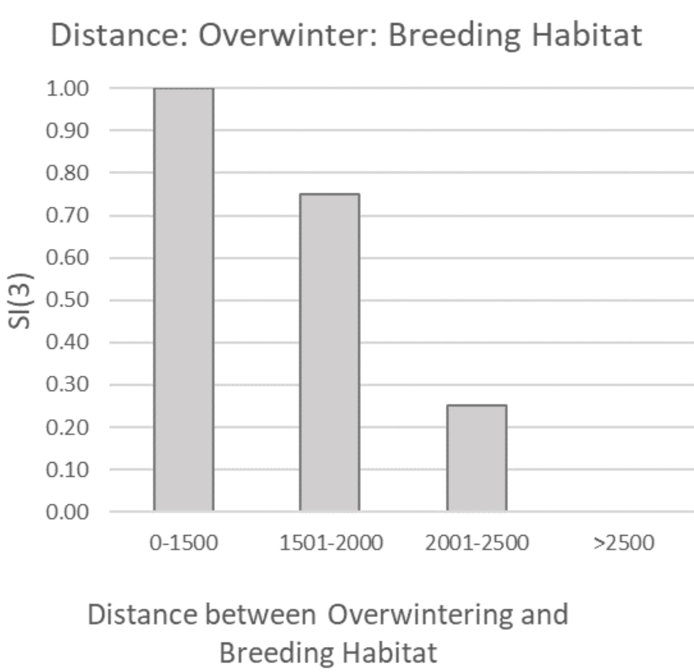

Figure 3: Suitability Index (SI) relationships regarding distance (m) between overwintering and breeding habitat on Canadian Natural's Horizon Oil Sands lease.

The HSI Overall Formula is:

$$HSI = \left\{ \frac{(SI1 \times SI2)}{2} \right\} \times SI3$$

This results in the addition of the HSI value for SI1 (overwintering) to SI2 (breeding habitat), divides the result by the number of parameters (n = 2) to ensure a positive value that is ≤ 1 and multiplies that value by the HSI value assigned for SI3 (distance between potential breeding and overwintering habitat). The rationale for the use of this model is that Canadian toad habitat is a function of both winter and breeding habitat – they both need to be present to support populations of Canadian toads, but the value of one affects the other. Adding the HSI values for overwintering and breeding together followed by dividing by number of parameters returns an average value that represents both winter and breeding habitat. This value is then modified by the distance between winter and breeding habitat, which incorporates information reported in the literature as well of the suspected energy costs associated with long-distance movements by toads. The final HSI value is a product of the average habitat condition as determined by the value of overwinter and breeding habitat modified by the distance between those two important habitats. To display the resultant HSI scores as a habitat map, we used the following thresholds for each suitability category: Nil: 0; Low: > 0 to 0.25; Moderate: > 0.25 to < 0.5; High: > 0.5.

The results of the updated mapping are provided in Table 3.

Table 3: Comparison between the EIA outputs and the HSI model update (2019) in terms of total hectares rated as High, Moderate, Low and Nil suitability for the Canadian toad on Canadian Natural's Horizon Oil Sands lease (A) and Albian Sands lease (B). Note that the EIA for Horizon Oil Sands lease assessed the pre-disturbance condition; the 2019 update considered the undisturbed portion of the mineral surface lease as of 2018, so a direct comparison between the two datasets should not be made.

A. Horizon Oil Sands			**HSI Update 2019**					
	EIA (1999)		**Lease**		**500-m Buffer**		**Total (Lease + Buffer)**	
Rating	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**Area (ha)**
High	15,923	57.3	403	2.10	126	3.77	529	2.35
Moderate	1,683	6.1	2,443	12.74	435	13.01	2,877	12.78
Low	7,917	28.5	4,564	23.81	360	10.77	4,923	21.87
Nil	2,263	8.1	11,760	61.35	2,421	72.45	14,181	63.00
Total (ha)	27,786		19,169		3,341		22,510	

B. Albian Sands			**HSI Update 2019**					
	EIA (2005/2007)		**Lease**		**500-m Buffer**		**Total (Lease + Buffer)**	
Rating	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**Area (ha)**
High	2,474	28.61	213	2.47	126	3.77	339	2.84
Moderate	3,497	40.42	884	10.27	435	13.01	1,319	11.04
Low	2,046	23.66	2,987	34.70	360	10.77	3,347	28.01
Nil	632	7.31	4,524	52.56	2,421	72.45	6,945	58.12
Total (ha)	8,650		8,608		3,341		1,949	
Total Suitable	8,018	92.69	4,084	47.44	921	27.55	5,005	41.88

The revised suitability mapping differs markedly from that produced for the environmental impact assessments. In both cases (Horizon and Albian), a much smaller proportion of the area mapped was rated as highly suitable for Canadian toads. This difference is attributable to the emphasis placed on the importance of overwintering habitat in proximity to suitable breeding habitat in the model update. The distribution of Canadian toad habitat depicted in the updated suitability maps is supported by Canadian toad observations on each lease and data reported in Hawkes and Papini (2018). Moreover, as Constible et al. (2010) point out, Canadian toads occupy a wide geographic range in North America, but most study of this species has occurred in the prairies where the species is closely associated with aquatic habitats. This association could have influenced earlier models used to depict the distribution of suitable Canadian toad habitat on the Horizon Oil Sands and Albian Sands leases. Canadian toads are associated with aquatic habitats in the boreal forest, but this appears to be linked to a reliance on upland habitats for overwintering.

The model used to reassess Canadian toad habitat suitability on the Horizon and Albian leases took into account both wintering and breeding habitat and the distance between them to derive maps that were representative of what can be considered the two most limiting habitat types. Canadian toads are suspected of burrowing up to 1.25 m below ground during winter (Garcia et al., 2004; Constible et al., 2010). Like other toads, Canadian toads are also known to breed in a variety of water bodies provided they are shallow, slow moving and relatively devoid of wood debris and dense vegetation. Without suitable wintering or breeding habitat, it is assumed that Canadian toads are unlikely to occur. The updated maps are therefore a reflection of these assumptions and of the data collected on the Horizon Oil Sands lease. The distribution of suitable Canadian toad habitat is also a reflection of the suspected low density of Canadian toads in parts of the boreal forest, which may be related to limited availability of overwintering sites (Constible et al., 2010). As Constible et al., (2010) suggest, further work is needed to determine the locations and characteristics of hibernation sites for these toads.

The updated habitat suitability map does not account for the presence of non-permanent suitable habitat within highly disturbed areas that are prone to re-disturbance. Canadian toads have been documented using large sandy roadcuts (i.e., artificial hillsides) for overwintering (Timoney 1996). Sand piles or berms, common throughout active mine areas, could similarly function as accidental overwintering habitat. Likewise, Canadian toads have been documented calling from several disturbed sites in varying states of naturalization on the Horizon lease. These water bodies were diverse, but all featured the main requirements listed previously.

LESSONS LEARNED

Findings related to the update of the Canadian toad habitat suitability maps for the Horizon Oil Sands and Albian Sands leases are:

1. Recent data should be used to update the habitat suitability maps used in the EIA to either (a) validate the models, or (b) update the mapping to better match the ecological requirements of the species being assessed.
2. HSI models used during the EIA process were based on the data available at the time. However, more recent data describing habitat associations or species occurrences should be used to update HSI models. This will result in a more accurate depiction of the distribution of suitable habitat for each lease. Doing so will provide information relevant to closure and reclamation planning.
3. Updates to HSI models address regulatory requirements in EPEA approvals. In this case, the Derived Ecosite Phase dataset is available for much of the Athabasca Oil Sands Region and provides a suitable dataset upon which to generate updated suitability maps for the Canadian toad.

4. Certain data are required to address the assumptions of the updated HSI model. Specifically, data on overwintering habitat in the Athabasca Oil Sands Region is required to validate the model.
5. More rigorous field sampling is required to ensure adequate validation of the habitat suitability model relative base upon which the model results are expressed (i.e., the Derived Ecosite Phase dataset).

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PRESENTATIONS AND PUBLICATIONS

No presentations of publications in 2019.

RESEARCH TEAM AND COLLABORATORS

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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 2 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 (COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling);
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 (COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling).

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. This Canadian toad research is closely tied to other research programs which have summaries included in this report (COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling and COSIA Project #LJ0326: Canadian Toad Habitat Suitability Model Update).

PROGRESS AND ACHIEVEMENTS

This is the first year this summary has been included in this report and therefore the progress from 2018 and 2019 is included.

In 2018, mitigation translocations were used to remove Canadian toads from habitats that would be modified through mine expansion activities:

- A total of 235 Canadian toad individuals were encountered, and 211 of these were caught and relocated from three sites (Sandpit North, South and East) to habitats adjacent to Horizon Lake (Oxbow and Bean, Figure 1).
- Adult individuals were captured from Sandpit North and Sandpit South, fitted with small waterproof Very High Frequency (VHF) radio transmitters (Model BD-2, Holohil Systems Ltd., Carp, Ontario), and tracked temporarily until the testing for a fungal pathogen *Batrachochytrium dendrobatidis* (Bd) was completed.
- Dermal swabs were collected to evaluate the presence of Bd within the Tar River watershed.
- Following testing for Bd, as many toads (of varying age classes) as possible were captured and moved to the Horizon Lake area between June and August 2018. Individuals were released at two ponds (Bean and Oxbow) as those locations were within the Tar River watershed and both sites provided what appeared to be suitable summer habitat for a fungal pathogen Canadian toads.
- Any sufficiently large adults were fitted with transmitters (if not already fitted) and tracked for as long as possible.

Short-term post-translocation movements pointed to an outward dispersal in all directions away from the release point. Few toads retained their transmitters into early September and those that did either shed them or they were deliberately removed by the research team. In all cases, none of the final locations of the released toads were consistent with what is assumed to be suitable wintering habitat (i.e., deep, friable or sandy soils). As such, the researchers were unable to characterize wintering habitat following the first year of study.

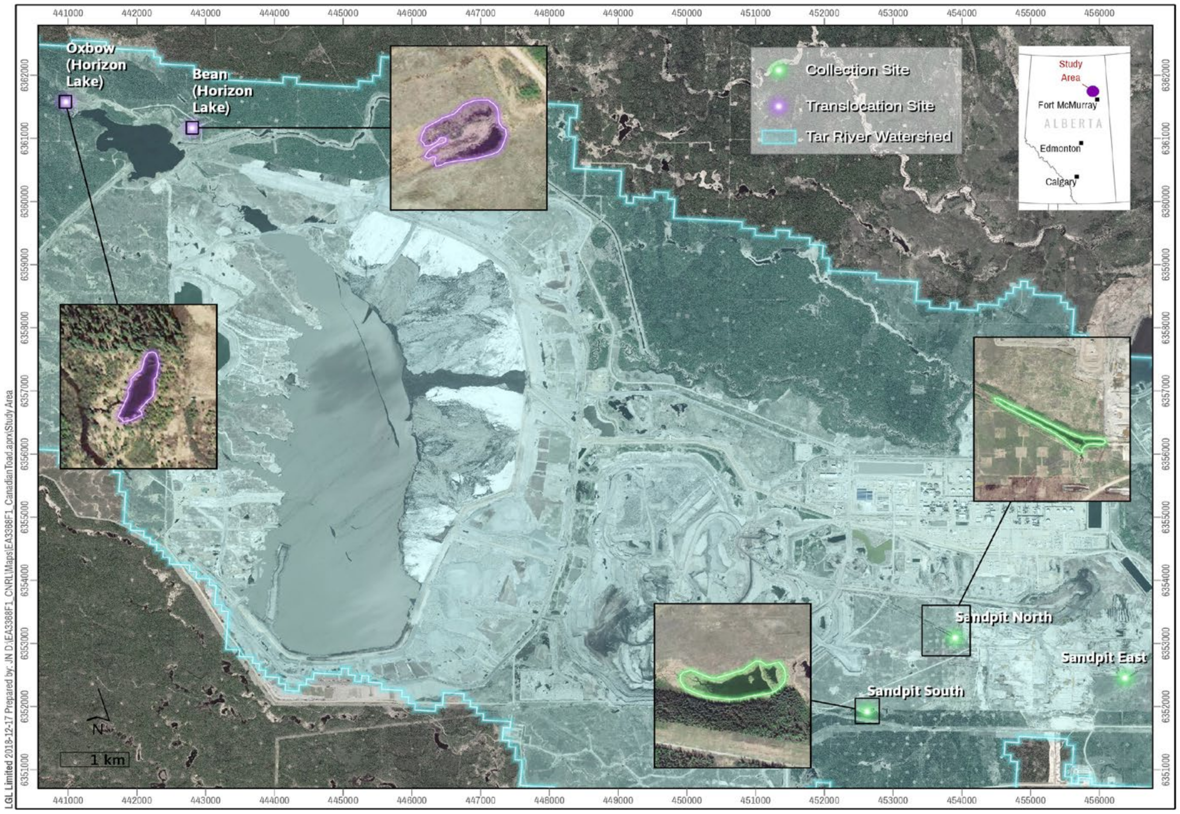

Figure 1: Distribution of ponds and wetlands targeted for Canadian toad (*Anaxyrus hemiophrys*) collection (green ponds/dots) and translocation (purple ponds) within the Tar River watershed (light-blue polygon) on Canadian Natural's Horizon Oil Sands.

The efficacy of the mitigation translocation attempted in 2018 was assessed in 2019.

- Between May 18 and July 29, teams consisting of two to eight people searched for toads in the Horizon Lake area for approximately 191 hours.
- Autonomous Recording Units (Acoustic SM4, Wildlife Acoustics Inc.) were deployed at eight possible breeding locations around Horizon Lake. They were programmed to record for 10-minute intervals, every hour, for 24 hours (total hours ~1,786 between April 21, 2019 and June 22, 2019).
- Recordings were reviewed regularly for Canadian toad calls using human listening and Song Scope Analysis Software (Wildlife Acoustics Inc.). The Canadian toad recognizer was used to process the ARU data. The recognizer was developed by researchers and made available by the Bioacoustic Unit (http://bioacoustic.abmi.ca/), a group within the Alberta Biodiversity Monitoring Institute (http://www.abmi.ca).

In total, two Canadian toads were encountered in the Horizon Lake area: one adult male and one adult female. Neither individual belonged to the cohort of toads translocated in 2018 (as determined through a review of a searchable photo database created in 2018 which was based on a standardized photo of the unique dorsal spot pattern of each toad), and they were encountered within two weeks of each other, along Diversion Ditch 4 (located to the east of Bean [Horizon Lake] in Figure 1).

In 2019, 16 unique DNA samples were collected by swabbing the buccal cavities of 14 adult and two sub-adult Canadian toads. These samples were provided to the University of Guelph to further the development of the Canadian toad eDNA primer (COSIA Project #LJ0327: eDNA for Canadian Toad, Burbot and Arctic Grayling).

Results of the 2018 work suggest that short-term (within-year) relocations of Canadian toads is associated with a high degree of survivorship. However, because toads were either not relocated or dropped their transmitters prior to winter, we were unable to determine if toads accessed suitable wintering habitat near the relocation sites. Furthermore, we did not document any of the toads moved in 2018 during visual and auditory surveys in 2019. The lack of detection in 2019 is likely related to multiple factors including: the cryptic nature of toads; the probable low density of Canadian toads in the region, which can make them difficult to locate; the potential that they moved out of the relocation area following relocation; or they occupied habitats outside of the search area. However, it was evident that the wetlands in the relocation sites were not occupied by Canadian toads in 2019, as evidenced by a lack of calling male activity.

Researchers were able to complete the majority of tasks towards achieving the primary project objective. However, more work remains. The usefulness of translocations as a viable mitigation strategy for habitat loss on active oil sands mines remains in question.

LESSONS LEARNED

Several lessons related to Canadian toad monitoring and relocation on the Horizon Oil Sands can be shared at this point:

1. The current outcomes of this project may have been affected by a limited understanding of what constitutes suitable Canadian toad wintering habitat in the boreal forest, and what habitat attributes are likely to be most limiting for Canadian toads. The proximity of suitable wintering habitat to suitable breeding habitat may have also affected the project's effectiveness. When relocations were undertaken in 2018 the receiving sites were selected based on their overall similarity to the collection sites, which were effectively spring and summer habitats, and the proximity to suitable wintering habitat was not initially considered.
2. Canadian toads should be relocated to the most suitable habitats, which have recently been defined as friable soils up to 1.25 m deep that are within 1,000 m to 2,500 m of suitable breeding habitat. Updated habitat suitability maps (Hawkes et al., 2019a,b) can be used to identify candidate relocation sites (COSIA Project #LJ0326: Canadian Toad Habitat Suitability Model Update).
3. Relocation sites should be selected based on the criteria listed above, but also based on the expected persistence of those habitats on the landscape – to avoid having to undertake multiple movements of toads.
4. Researchers only considered relocation sites within the same watershed. However, there may be highly suitable habitats in adjacent watersheds that could be considered as suitable receiving sites. Restricting relocations to within a given watershed may limit the number of suitable relocation sites.
5. Wintering habitat for Canadian toads in the boreal has not been characterized, at least not for the mineable portion of the Athabasca Oil Sands. Characterizing winter habitat for Canadian toads is needed to refine the habitat suitability models, which are used to map the distribution of Canadian toad habitat. The models can then be used to guide the selection of possible relocation sites.

6. Radio telemetry of Canadian toads should be used with caution. Only the largest males or females should be fitted with a transmitter to ensure that the mass of the transmitter does not exceed ~5% of the mass of the toad as this can affect overall health of the individual.

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