COSIA Land EPA

2016 Mine Site Reclamation Research Report

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April 2017

Introduction

This report summarizes progress for projects related to mine site reclamation of the Canada's Oil Sands Innovation Alliance (COSIA) Land Environmental Priority Area (EPA).

Please contact the Industry Champion identified for each research project if any additional information is needed. COSIA Land EPA 2016 Mine Site Reclamation Research Report. Calgary, AB: Canadian Natural Resources Limited; Imperial; Shell Canada Energy; Suncor Energy Inc.; Syncrude Canada Ltd.; Teck Resources Limited.

Prepared For:

Canadian Natural Resources Limited

Imperial

Shell Canada Energy

Suncor Energy Inc.

Syncrude Canada Ltd.

Teck Resources Limited

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Aurora Soil Capping Study: Program Overview

COSIA Project Number: LJ0201

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

The Aurora Soil Capping Study (ASCS) is a study to address two 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 pre-development 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 is intended to provide guidance on the appropriate soil cover design and capping depth to mitigate any 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 community. 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.

The ASCS is located at Syncrude's Aurora North mine, and is situated on the Fort Hills overburden dump. The overburden of Fort Hills dump consists dominantly of lean oil sand (LOS) which contains petroleum hydrocarbons (PHCs) that generally range from <1% oil in soil (10,000 mg/kg soil) to approximately 7% oil in soil. 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 as large as a small vehicle. 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 that are replicated in triplicate in 1-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 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 and will continue until the conclusion of the research programs.

RESEARCH TEAM AND COLLABORATORS

The ASCS has involved a number of research disciplines for study within the project area. A list of these research projects, including the primary investigator and their classification within COSIA are provided in the table below. A more detailed description of the individual projects and their results to date can be found in their accompanying sections of this document. The project Water and Carbon Isotope Methods Development was competed in 2015.

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)

Aurora Soil Capping Study: Evaluation and Modelling of Soil Water Dynamics to Determine Land Capability of Coarse Textured, Hydrocarbon Affected, Reclamation Soils

COSIA Project Number: LJ0099

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd

Industry Collaborators: Suncor Energy Inc., Shell Canada Energy, Canadian Natural Resources Ltd., Imperial, Total E&P Canada Ltd.

Status: Year 5 of 6

PROJECT SUMMARY

As part of the Aurora Soil Capping Study (ASCS), this research program focuses on evaluating the soil water dynamics within the various cover designs at the research site with a specific focus on how the presence of hydrocarbons and soil material layering may affect soil water dynamics and nutrient transport. The research project has been divided into laboratory and field studies. The laboratory studies focus on material characterization that can be done relatively rapidly in a laboratory setting. The longer-term field research relies on the interpretation of site monitoring data which has been collected since 2012. The laboratory studies provide an initial assessment of the soil water dynamics within the different cover designs and help to further define the issues to be addressed in the long-term field studies. The field studies verify the hypotheses established in the laboratory studies and provide aggregated data for evaluating overarching questions regarding soil water dynamics, plant growth and nutrient transport. The methods of characterization (hydrophobicity and preferential flow), monitoring and modelling proposed in the project are unique and will provide valuable insight into the mechanisms controlling performance of these types of mine closure reclamation covers.

The objectives of the project are the following:

1) develop a better understanding of the physics associated with water and energy balance in reclamation cover prescriptions overlying lean oil sand overburden;
2) determine the optimal soil cover design options and placement thickness(es) of peat-mineral mix and upland surface soil which will result in reclamation soil cover designs with an equal capability to pre-disturbance conditions in terms of soil water in natural a/b ecosites of the region;
3) evaluate the possibility of separate placement of mineral soil layers (Bm, deeper subsoil lifts) for improving soil water retention and being worthy of consideration for salvaging separately; and
4) develop a water dynamic model for soil cover designs consisting of coarse textured, hydrocarbon-affected soils over lean oil sand overburden.

PROGRESS AND ACHIEVEMENTS

Effects of Petroleum Hydrocarbon Content (PHC) and Bulk Density on the Hydraulic Properties of Lean Oil Sand (LOS) Overburden

Trent Pernitsky (M.Sc.) conducted a study to determine the impact of bulk density and petroleum hydrocarbon (PHC) concentration on the hydraulic properties of lean oil sand (LOS). The study was a laboratory trial which used soil materials collected from the ASCS. Water retention, saturated hydraulic conductivity (Ks), pore size distribution and texture of the LOS materials were determined across a range of PHC concentrations at two packed bulk densities.

Mr. Pernitsky completed his M.Sc. in 2015 and in 2016 published results of his work in the Canadian Journal of Soil Science.

Observations of Soil Moisture Retention Associated with Hydrocarbon Affected Coarse Textured Soils

In 2016 Meghan Rosso completed her M.Sc. laboratory study using the range of subsoils present in the ASCS. Various treatments were created with these materials, amended with a range of proportions of naturally-occurring aggregated oil sand materials (AOSM) and different layering schemes. The study included material characterization through organic carbon and particle size analysis, hydrophobicity studies on the hydrocarbon affected material and reclamation soil material using contact angle analysis and the water droplet penetration time (WDPT) test. Water retention studies were also performed, along with larger scale column studies. Soil water content and hydraulic conductivity were measured and a chloride tracer study was performed to address hydrocarbon leaching concerns. The outflow solution was analyzed to determine the hydrocarbon type and concentration leached through the columns.

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

Eric Neil (M.Sc. candidate) is investigating the water repellency and hydraulic properties of AOSM at various stages of weathering. The study objectives are to: 1) investigate potential soil water repellency of AOSM and soil matrix materials; 2) characterize hydraulic properties, such as unsaturated and saturated hydraulic conductivity, of AOSM from various soil salvage depths and locations across portions of the AOSM (inner and outer); and 3) determine if texture, bulk density, and hydrocarbon content and type have a predictable effect on the repellency and hydraulic properties of AOSM and soil matrix. The degree and persistence of soil water repellency (SWR) of air-dry AOSM defines potential SWR of these materials, and the persistence of soil water repellency once water is introduced to its surface and the material continues to weather with time.

AOSM and soil matrix material was collected in 2013 and 2014 from different soil reclamation material types and salvage depths for the soils that comprise the different treatments of the ASCS. The degree (contact angle) and persistence (water drop penetration time) of SWR was determined for collected samples using a contact angle goniometer and auto-pipette. The study is focused on testing the repellency of inner and outer portions of AOSM to assess the relationship between SWR and depth within aggregates. Infiltration tests using a miniaturized infiltrometer have also been performed in order to characterize the hydraulic conductivity of these materials under various matric potentials.

Experiments have been completed and analysis is currently underway. The study will determine if there are relationships between SWR as well as hydraulic properties of AOSM and their salvage depth (and depth into AOSM). These tests will provide insight into the change in SWR and hydraulic properties of AOSM as they continue to weather after salvaging, stockpiling and later use in soil reclamation covers.

The Interactions of Jack Pine Trees and Soil-water at Depth in Natural Soils of the Region

Ivanna Lee Faucher (M.Sc. candidate) is working in natural "a1" ecosites to better understand how jack pine trees utilize soil water at depth. The first objective of the study is to determine if jack pine trees are contributing to changes in soil-water content at different depths through hydraulic redistribution (HR). HR is the process of roots passively redistributing soil water from areas of high soil-water potential to areas of low soil- water potential. The study is evaluating if HR by jack pine from deeper soil depths (>1 m) to near the surface (<1 m) occurs in water limited ecosites. The second objective is to study how jack pine trees utilize and store internal water within their elastic and inelastic tissues. Knowledge from this study may help in understanding how planted jack pine forests on reclamation sites with coarse textured soils utilize limited plant-available water.

Access for fieldwork in 2016 could not be conducted in the Athabasca oil sand region because of the wildfire. An alternative site for field data collection was selected at a comparable soil and vegetation community near Prince Albert, SK. The site is located in a 30-year old jack pine stand. A dual-isotope method was used to investigate if jack pine trees are contributing to changes in soil water content at different depths through HR. Soil water was labelled at different depths with known concentrations of ^{2}H or ^{18}O, and soil and tree samples were then collected and analyzed to determine the movement of soil water. To study how jack pine trees utilize and store internal water within their elastic and inelastic tissues, heat pulse probes were installed to measure the direction and rate of sap flow within jack pine trees. Dendrometers were installed to measure the diurnal fluctuations in tree circumference as well as tree growth. Data analysis from the 2016 field season is currently underway.

Utilizing the Cosmic-ray Soil Moisture Probe to Measure Soil Water Content and Snow Water Equivalent

Mark Sigouin (M.Sc.) tested the use of the Cosmic-ray Soil Moisture Probe (CRP) to measure soil water content (SWC) and snow water equivalent (SWE) in a reclamation landscape. The CRP is a relatively new, non-invasive and passive instrument that takes advantage of the relationship between the water content in soil and the resulting above-ground, low-energy neutron cloud. The measurement footprint of the CRP is a circular area with a radius of approximately 300 m. The main objectives were to: 1) to evaluate if CRP can be used to monitor SWE; and 2) to evaluate the SWC measurement efficacy of the CRP at a heterogeneous reclamation site like the ASCS.

CRP field data collection took place from 2013 to 2015 on an agricultural field in Saskatoon, SK during the winter of 2013/14 and 2014/15 and during the summers of 2014 and 2015 at the ASCS. In 2016 Mark complete his M.Sc. and published two papers from this study.

The Effects of Oil Sands Reclaimed Landscapes on Preferential Flow

Brianna Zoerb (B.Sc.) evaluated the prevalence and degree of preferential flow at the ASCS site. In August 2015, a large rainfall event was simulated at the ASCS, where water containing tracer dye was applied to two plots: an upland surface soil coversoil treatment and a peat coversoil treatment. Twenty-four hours after the first rainfall application, a second rainfall simulation was applied containing a different tracer in order to see the effect of varying antecedent water contents on the occurrence of preferential flow. Soil pits were excavated 24 hours after the second rainfall application and photos were taken of the soil profiles in order to analyze the wetting fronts. The same rainfall and dye applications were performed at a natural reference site for comparison purposes. Statistical analysis confirmed that the natural site had greater amount of preferential flow and deeper infiltration than the reclaimed sites.

In 2016 Brianna analyzed the data collected from the 2015 field program and completed her B.Sc. study report.

Thermal Properties of Peat-Mineral Mixtures Measured by the Dual-Probe Heat Pulse Method

Min Li's Ph.D. research sought to improve heat pulse probe methods by applying a dual-probe heat pulse (DPHP) to measure bulk density (ρb) of mature fine tailings (MFT), and develop a single-probe heat pulse (SPHP) for soil water content (θ) estimation. Three studies were conducted to:

1. evaluate the feasibility of determining soil solid percentage of MFT using the DPHP;
2. compare θ estimations from the relationships between θ and soil thermal conductivity (λ), normalized cumulative temperature increase (TNcum), and normalized maximum temperature increase (TNmax) using the SPHP; and
3. obtain the thermal contact conductivity (H) values experimentally and present the performance of θ estimation by the H(θ) relationships using the SPHP.

Min Li completed his Ph.D. program in 2016 and highlights of this research are in the Outcomes and Lessons Learned section.

Following Min Li's research, Ying Zhao (PDF) is measuring the thermal properties of peat and peat-mineral mix (PMM) coversoil reclamation materials at various ranges of temperature, bulk density, water content, and peat-mineral ratios in order to understand the change in thermal properties with varying mineral-organic matter proportions. To test various mineral-organic PMM ratios, a number of soil reclamation materials have been collected from the ASCS site and from a reclamation area approximately 10-years old near the ASCS that displays vibrant vegetation growth. Eight different peat-mineral ratios were created from the peat and mineral soils collected at the study, and their thermal properties are currently being measured in the laboratory using three-needled heat pulse probes. The results from this study will help inform on the change in soil thermal properties that occur with varying peat-mineral mix ratios and attempts to establish an appropriate peat-mineral range for PMM coversoil design. Laboratory studies are currently underway.

Effects of Oil Sands Reclamation Covers on Soil Water Storage and Soil Temperature

Wei Hu (Postdoctoral Fellow) evaluated the effects of oil sands reclamation covers on soil water storage (SWS) and soil temperature (ST) at the ASCS. Twelve treatments were constructed in the ASCS by using different combinations of reclamation materials from the 0 to 150 cm layer, overlying lean oil sand as overburden substrate. Daily SWS and mean ST of cover soil (0 to 30 cm) and subsoil (30 to 150 cm) collected from the field instruments were used to evaluate and compare the difference in SWS and ST of soil treatments with peat and upland surface soil material, as well different subsoil materials. The effect of variable placement depth of these materials was also investigated. A manuscript of the study results is currently underway.

Modelling the Effects of Tree Species Type, Soil Cover Design, Soil Bulk Density, and Petroleum Hydrocarbon Content of Lean Oil Sand Overburden on Soil-Water Recharge

Wei Hu and Eric Neil are developing a numerical model to simulate water dynamics in layered, coarse textured soils containing oil sand material that overlies lean oil sand substrate. The model will consider such variables as bulk density and tree species (different leaf area index ranges) along with regional climate data. Modelling is currently underway, and aims to improve our understanding of the role that soil physical characteristics (bulk density, presence of oil sand materials in soil reclamation materials, and presence of lean oil sand) and planting scheme (species and density) have on the soil water which is available for revegetation and potentially for the drainage of water (percolation) through the soil cover and into the underlying lean oil sand substrate.

OUTCOMES AND LESSONS LEARNED

Effects of Petroleum Hydrocarbon Content (PHC) and Bulk Density on the Hydraulic Properties of Lean Oil Sand (LOS) Overburden

Mr. Pernitsky completed his M.Sc. in 2015 and in 2016 published results of his work in the Canadian Journal of Soil Science. The main conclusions of his paper were that higher bulk density resulted in less macropores, while higher PHC contents led to less soil micropores, which also reduced connectivity of macropores. Therefore, higher bulk density and PHC led to lower Ks of the LOS, which has the potential for increased water and nutrient retention in the overlying soil profile.

Observations of Soil Moisture Retention Associated with Hydrocarbon Affected Coarse Textured Soils

Highlights from Meghan Rosso's M.Sc. study were that placement of aggregated oil sand material (AOSM) in the subsoil, at a range of concentrations and forms similar to what is found naturally and in a reclamation profile, did not result in a significantly different water retention curve and saturated hydraulic conductivity of the subsoil. This may be because the incorporation of a small amount of AOSM into subsoil did not substantially modify the subsoil water wettability, even though AOSM material is water repellent. For the same reason, under steady-state and transient flow conditions in large repacked columns, less than 5% AOSM material incorporated in subsoil reclamation material had no consistent effects on the water infiltration rate and nutrient retention. This implies inclusion of AOSM in the reclaimed subsoil horizon would not alter the capacity of subsoil to store and release water.

Utilizing the Cosmic-ray Soil Moisture Probe to Measure Soil Water Content and Snow Water Equivalent

Highlights from Mark Sigouin's M.Sc. study were that the CRP provided comparable large-scale measurements of stored water within the covers to that obtained by direct sampling and from soil moisture probes at a localized scale, despite the clear differences in soil organic matter contents at the Aurora Soil Capping Study site. The CRP also has a footprint of about 40 ha, which is well-suited for monitoring watershed scale soil water contents. Furthermore, it is possible to downscale, with modelling, the wide-area CRP measurement to individual peat mixes and mineral soil treatment plots, provided the variability between treatments is much larger than the variability within a treatment plot. The CRP also provides accurate real-time wide-area snow water equivalent (SWE) measurements over an area of approximately 40 ha.

Thermal Properties of Peat-Mineral Mixtures Measured by the Dual-Probe Heat Pulse Method

Highlights from Min Li's Ph.D. study are that the dual-probe heat pulse method can be used to accurately measure the solid percentage of mature fine tailings (MFT). The study concluded that potential opportunities exist with this method, but challenges remain to estimate θ from the λ(θ), TNcum(θ), TNmax(θ), and H(θ) relationships using the single-probe heat pulse (SPHP).

The Effects of Oil Sands Reclaimed Landscapes on Preferential Flow

The highlight from Brianna Zoerb's B.Sc. study was that the two reclaimed sites investigated had significantly less preferential flow and depth of dye penetration following the rainfall simulation ($p<0.05$) than the natural site used for comparison.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Rosso M. 2016. Observations of soil moisture dynamics associated with hydrocarbon affected and layered coarse textured soils. M.Sc. Thesis. University of Saskatchewan. Saskatoon, Saskatchewan. 136 pages.

Sigouin M.J.P. 2016. Monitoring soil water and snow water equivalent with the COSMIC-Ray soil moisture probe at heterogeneous sites. M.Sc. Thesis. University of Saskatchewan. Saskatoon, Saskatchewan. 113 pages.

Li M. 2016. Measuring thermal properties and water content of soil and oil sand mature fine tailing using the heat pulse probe method. Ph.D. Thesis. University of Saskatchewan. Saskatoon, Saskatchewan. 168 pages.

Zoerb B. 2016. Assessing preferential flow in natural and oil sand reclaimed soils using multiple-dye tracing methods, B.Sc. Thesis. Department of Soil Science, University of Saskatchewan. 32 pages.

Journal Publications

Sigouin M.J.P., B. C. Si. 2016. Calibration of a non-invasive cosmic-ray probe for wide area snow water equivalent measurement. The Cryosphere. 10:1181-1190.

Pernitsky T., W. Hu, B. C. Si, Lee Barbour. 2016. Effects of petroleum hydrocarbon concentration and bulk density on the hydraulic properties of lean oil sand overburden. Can. J. Soil Sci. 96: 435-446.

Sigouin M. J.P., M. Dyck, B. C. Si, Wei Hu. 2016. Monitoring soil water content at a heterogeneous oil sand reclamation site using a cosmic-ray soil moisture probe. Journal of Hydrology. 543: 510-522.

Li M., B. C. Si, W. Hu, M. Dyck. 2016. Single-Probe heat pulse method for soil water content determination: Comparison of methods. Vadose Zone J. 15. doi:10.2136/vzj2016.01.0004.

Li M., S.L. Barbour, B.C. Si. 2015. Measuring solid percentage of oil sands mature fine tailings using the dual probe heat pulse method. Journal of Environmental Quality. 44:293-298.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Bing Si; Co-investigator: Lee Barbour

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Trent Pernitsky	University of Saskatchewan	M.Sc.	2011	2015
Meghan Rosso	University of Saskatchewan	M.Sc.	2012	2016
Henry Chau	University of Saskatchewan	Ph.D.	2008	2014
Lindsay Tallon	University of Saskatchewan	Ph.D.	2010	2014
Min Li	University of Saskatchewan	Ph.D.	2011	2016
Eric Neil	University of Saskatchewan	M.Sc.	2013	Ongoing
Wei Hu	University of Saskatchewan	Post-Doctoral Fellow	2013	2015
Mark Sigouin	University of Saskatchewan	M.Sc.	2013	2016
Ivanna Faucher	University of Saskatchewan	M.Sc.	2014	Ongoing
Brianna Zoerb	University of Saskatchewan	B.Sc.	2012	2016
Ying Zhao	University of Saskatchewan	Visiting Professor	2016	Ongoing

Aurora Soil Capping Study: Hydrocarbon Degradation and Mobility

COSIA Project Number: LJ0219

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial, Shell Canada Energy, Suncor Energy Inc., Total E&P Canada Ltd.

Status: Year 7 of 7

PROJECT SUMMARY

This study focuses on two aspects of the Aurora Soil Capping Study (ASCS) related to hydrocarbon degradation and mobility:

1) Degradation rates of petroleum hydrocarbons (PHC) present in lean oil sand (LOS) overburden and near surface soil reclamation materials as a result of microbial activity and the effect of such processes on the reclamation performance at the ASCS; and
2) Rates of gas flux from the LOS to the surface through the reconstructed soil profile, as an indicator of, and factor potentially controlling subsurface microbial degradation of PHC and reclamation performance.

The project consists of laboratory-based studies, as well as field studies at the ASCS. Tomasz Korbas (M.Sc.) completed his study in 2013 and a Ph.D. study (Kyle Scale) is currently underway.

PROGRESS AND ACHIEVEMENTS

In 2011, Kyle Scale began a M.Sc. that has since been extended to a Ph.D. program. His study focuses on the temporal and spatial variability in gas flux and methane oxidation potential of reconstructed soils of the ASCS. The study is evaluating gas production and oxidation for a range of LOS PHC concentrations to evaluate the soil gas environment of a range of soil cover designs on LOS and its potential implications to plant growth. The interrelationships of soil properties (e.g., hydraulic conductivity, texture and bulk density), ambient conditions (e.g., temperature, water content) and LOS PHC concentration has on gas production, oxidation and advection/diffusion are being evaluated to develop a numerical predictive and explanatory model to estimate the risk of gas-related toxicity to plant growth in the closure reclamation landscape.

Field work which involved measuring gas concentrations in various cover soil treatments using flux chambers and soil vapour probes was completed in 2015. Results and interpretation of the data took place in 2016.

A laboratory study measuring methane oxidation rates in soil columns consisting of soil reclamation material from the ASCS was completed in 2016. The importance of reclamation material type (coversoil and subsoil), moisture content, temperature and bulk density soil gas flux rates were investigated. The results of the controlled, laboratory column study are being compared to the ASCS field results to better understand the conditions in a field setting.

OUTCOMES AND LESSONS LEARNED

The outcomes of the study from the published paper in 2016 were that LOS is predominantly composed of heavy-chain F3 and F4 PHC fractions and that temperature is the primary driver of carbon dioxide fluxes and PHC degradation. It was concluded, based on the environmental site conditions (e.g., soil temperature), that LOS present in the closure reclamation landscape will likely not release significant quantities of PHC into groundwater.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Korbas, T.S., Scale, Kyle O., Fleming, I.R. 2016. Degradation and mobility of petroleum hydrocarbons in oil sand waste. Environmental Geotechnics. Published online ahead of print. Published Online: February 02, 2016. DOI: http://dx.doi.org/10.1680/jenge.15.00035

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Ian Fleming

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Tomasz Korbas	University of Saskatchewan	M.Sc.	2010	2013
Kyle Scale	University of Saskatchewan	Ph.D.	2011	Ongoing

Aurora Soil Capping Study: The Roots of Succession: Relations Among Plants, Soils and Mycorrhizal Fungi in a Reclaimed Site

COSIA Project Number: LJ0100

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Shell Canada Energy Inc., Imperial, Total E&P Canada Ltd.

Status: Year 4 of 5

PROJECT SUMMARY

The link between vegetation and the soil environment is a major driver of community and ecosystem processes. Thus, forest restoration following landscape disturbances such as oil sands mining cannot be considered in isolation of soils and the biota contained within. A key revegetation objective for oil sands mine reclamation is to re-establish tree species native to the region. However, the appropriate species selection and planting density are dependent on the quality of the soil cover design and the underlying landform substrate. Conversely, the tree species selection, growth rates, and their planting densities can have an influence on the subsequent understory development, underlying soil development and cycling processes of the reclamation soil profile.

Through improved access to soil resources, tree species may depend on symbiotic microbes such as ectomycorrhizal (EM) fungi for establishment, increased growth or survival. EM fungi differ widely in their influence on tree hosts such that shifts in the composition of EM fungal communities may have important consequences for tree and stand productivity. The importance of EM fungi on above- and below-ground plant growth and the role that vegetation and soil play in EM fungi development is poorly understood.

At the Aurora Soil Capping Study a number of soil cover design treatments and planted tree species are available to evaluate the effect of soil and vegetation on EM fungi presence, and conversely, if they have an effect on vegetation growth. The objectives are to investigate the effects and potential of different soil cover and capping depth treatments on:

1) tree establishment and growth, including rooting behavior;
2) plant communities; and
3) the composition of ectomycorrhizal fungal communities and their role in vegetation growth.

As part of Objective 3, successional trajectories of ectomycorrhizal communities created through reclamation with those of selected ecological references are being compared. The research will inform the understanding of linkages among capping materials, tree establishment, and ectomycorrhizal community development for reclamation of upland boreal forests.

PROGRESS AND ACHIEVEMENTS

Objective 1: Effects of capping treatments on tree establishment and growth, including rooting behaviour

Jana Bockstette (M.Sc. candidate) has led growth measurements of all trees in the capping treatments between 2012 and 2014. Jana is currently writing her thesis.

In 2016 we collected the last set of tree growth data lead by Shauna Stack, (M.Sc.) who will be using the new data set in combination with the original data collected up to 2014 to provide a more complete picture of early tree establishment on different capping prescriptions. In addition to continuing the work examining the effects of different capping prescriptions on tree seedling performance, Shauna will also explore the impacts of tree composition and density on growth. The impact of fertilizer addition on growth will also be explored. Preliminary work (Jana Bockstette) has shown that tree seedlings could benefit from the specific additions of Phosphorous and Potassium. The timing of fertilizer additions could also be beneficial, as seedlings have developed larger root systems, likely improving the efficacy of a fertilizer treatment.

Rooting behavior as a function of capping material and the configuration of their placement, is being investigated by Simon Bockstette (PhD candidate). Simon is in the process of summarizing the data he collected from minirhizotron images and soil cores to build a more complete picture on how roots explore the different capping prescriptions and how they respond to inter and intro-specific belowground competition. Additional soil cores were taken in 2016 to determine rooting depth and distribution in response to capping material types and their arrangement. Analysis of these data is ongoing, but initial results show that total root biomass was strongly influenced by capping treatment for aspen and jack pine, while roots of white spruce were less responsive.

Objective 2: Effects of capping treatments on plant communities

As part of assessing the response of tree seedlings to capping treatments, we also expanded this objective to include vegetation surveys on the early development of colonizing plant communities on this site (under the IRC in Forest Land Reclamation [COSIA Project LE0012]). Caren Jones (M.Sc.) led this work and found significant differences in vegetation development in response to the coversoil materials. The planted tree species initially had no effect on the colonizing plant community; however planting density became more important after four growing seasons particularly in the forest floor material (FFM) treatments. Also included in Caren's research were field experiments testing whether areas covered with salvaged FFM can act as nucleation islands to promote the dispersal of understory species into the surrounding peat capped areas that had much lower cover and species richness. Her findings suggest that this applied nucleation technique does result in increased establishment of vegetation in the nearby peat material, although this egress appears to be mostly driven by vegetative regeneration rather than seeds and as a result is relatively slow.

Objective 3: Effects of capping treatments on the composition of ectomycorrhizal fungal communities

To determine how the assembly of fungal communities created through reclamation practices compare with that of selected benchmarks, we collected ectomycorrhizal root samples from seedlings planted in the three cover soils at Aurora (peat, FFM and subsoil) as well as references sites. Reference sites captured a gradient of aboveground disturbance over otherwise intact soils. Specifically, reference sites included an intact jack pine forest, a jack pine forest harvested approximately 10 years ago, and a similarly harvested site with the forest floor removed. We sampled ectomycorrhizal roots in 2013 (Stefan Hupperts, M.Sc.) and 2015 (Natalie Scott, M.Sc. candidate). Data from the 2013 and 2015 surveys are now being analyzed by Greg Pec (PDF) to provide a five year outlook on how succession of

ectomycorrhizal fungi occurs in reclaimed soils compared with that on sites varying in aboveground disturbance with intact soils. The expected completion of this final analysis is 2017. In addition to this research, Natalie Scott has also completed a study comparing the effects of single versus mixed tree species on the composition of ectomycorrhizal fungal communities occurring at Aurora. Results from this latter study are pending and expected for 2017.

OUTCOMES AND LESSONS LEARNED

Below are the key outcomes from the work that was completed in 2016.

- The main driver of early vegetation colonization is the propagule bank contained within the coversoil materials. Vegetation in areas where forest floor material (FFM) was used as the coversoil had much higher species richness, plant cover, and a community comprised of species found in upland forests than in treatments with peat and subsoils as surface material. During the initial years following reclamation, species and density of planted tree seedlings had little to no effect on vegetation development from the propagule bank.
- Nucleation strategies using areas with propagule rich coversoils in an overall landscape matrix with reduced propagule availability may be a viable revegetation technique to promote the dispersal of native forest species across reclamation landscapes. Using FFM as nucleation spots allowed for the spread of a diverse plant community; by the fourth growing season, species from the FFM comprised a greater proportion of the vegetation cover in the surrounding peat coversoil areas than species that were associated with the peat material.

PRESENTATIONS AND PUBLICATIONS

Published Theses:

Hupperts S. 2016. Ectomycorrhizal fungal community response to disturbance and host phenology. M.Sc. Thesis, 114 pages, University of Alberta

Jones C. 2016. Early vegetation community development and dispersal in upland boreal forest reclamation. M.Sc. Thesis, 130 pages, University of Alberta

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Simon Landhäusser and Justine Karst

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Simon Bockstette	University of Alberta	PhD	2011	ongoing
Jana Bockstette	University of Alberta	M.Sc.	2013	ongoing
Caren Jones	University of Alberta	M.Sc.	2013	2016
Stefan Hupperts	University of Alberta	M.Sc.	2014	2016
Natalie Scott	University of Alberta	M.Sc.	2015	ongoing
Shauna Stack	University of Alberta	M.Sc.	2016	ongoing
Greg Pec	University of Alberta	Postdoctoral fellow	2016	
Jake Gaster	University of Alberta	M.Sc.	2012	2015
Shanon Hankin	University of Alberta	M.Sc.	2012	2015
Ashley Hart	University of Alberta	Summer Assistant		
Trevor de Zeeuw	University of Alberta	Summer Assistant		
Robert Hetmanski	University of Alberta	Summer Assistant		
Fran Leishman	University of Alberta	Field Technician		
Pak Chow	University of Alberta	Lab Technician		

In collaboration with the Industrial Research Chair in Forest Land Reclamation, University of Alberta.

Aurora Soil Capping Study: Soil Carbon Dynamics and Nutrient Retention in Reconstructed Sandy Soils

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Collaborators: Alberta Innovates-Bio Solutions; Alberta Innovates-Energy and Environment Solutions

Status: Year 3 of 4

PROJECT SUMMARY

This project will help develop appropriate soil reclamation cover designs using coarse-textured (sandy loam to sand texture) reclamation materials. Re-establishment of forestland capability associated with water and nutrient limited coarse-textured reclamation soils, similar to ecosites present in the region, is a target for oil sands mine reclamation. Using the reconstructed soils at the Aurora Soil Capping Study, the project will also investigate if nutrient additions are required to re-establish nutrient limited soils similar to a natural a/b ecosite.

The following three objectives to be addressed in the overall project plan were defined:

1) To characterize the potential linkages between soil textural layering, soil nutrients, and site productivity in natural coarse-textured analogs;
2) To quantify the fate of water and nutrients (i.e., soil retention versus nutrient losses) following nutrient additions to soils; and
3) To investigate the interactions between water (and nutrient) redistribution within soil profiles, and plant root development.

PROGRESS AND ACHIEVEMENTS

Objective 1. Characterize the potential linkages between soil textural layering, soil nutrients, and site productivity in natural coarse-textured analogs

Brunisolic soils developed from coarse-textured parent material are the second most common upland soil type in the Athabasca oil sands region (AOSR). While these soils are typically moisture-limited, possess poor nutrient regimes and are generally associated with relatively low productivity jack pine-lichen communities, more productive aspen and white spruce communities with a more diverse array of understory species are also present. Even though the soils have a relatively similar soil texture profile ranging from sandy loam to sand (approximately >80% sand), it is hypothesized that slight decreases in sand proportion (and corresponding increases in silt and/or clay) and/or increased textural heterogeneity may significantly alter the soil-water storage and the resulting soil nutrient, site productivity and vegetation community development.

William Barnes (M.Sc.) selected seventeen undisturbed sites with predominantly sand to sandy loam parent material in an attempt to capture the natural range of variation in forest productivity found in the region. A suite of soil and vegetation measurements were collected at each site to determine if soil textural differences and discontinuities at the sites were influencing site productivity and canopy type through their alteration of water and nutrient fluxes.

Types of discontinuities found within the soil profiles included clay lenses, lenses of naturally occurring oil sands deposits and horizon texture differences related to parent material changes.

William successfully defended his M.Sc. thesis in June, 2016. Results of his study are provided in the Outcomes and Lessons Learned section below.

Objective 2. Quantify the fate of water and nutrients (i.e., soil retention versus nutrient losses) following nutrient additions to soils

While drainage can be very rapid in homogeneous coarse-textured soils, even small variations in texture may change the soil hydraulic properties, in particular at the interface of the two textural layers. Through this objective we are investigating the relationship between water redistribution and nutrient retention resulting from soil column textural discontinuities. To address this objective, fully instrumented laboratory soil columns (30 cm diameter by 60 cm height) are being used. Time-domain reflectometry (TDR) soil moisture measurements are collected at 1.5 cm intervals for water content profiling. In addition, the columns are equipped with four vacuum soil suction samplers for depth profiling of nutrients and five tensiometers to estimate soil matric potential through the soil column. Effluent will also be collected at the base of the soil column. In addition, PVC pipes of 10-cm internal diameter and 120 cm length (9.4 L volume) are used in a first series of column experiments where up to ten treatments can be examined simultaneously.

In preparation of the soil column work, potential nutrient release through mineralization was measured for the two coversoil types (forest floor material [FFM] and peat) which are used at the Aurora Soil Capping Study. Samples collected from the study site passed through a 4 mm sieve to achieve homogeneity and were kept at 4°C until the incubation started. Ten replicates of each material were incubated in the dark at room temperature (24–25°C) using microlysimeters. Potential mineralization rates (C, N, and P) of the materials were determined weekly by: 1) quantification of the CO_2 evolved through analysis of the headspace samples, and 2) simultaneous measurements of the nitrate, ammonium, and phosphate leached from the lysimeters. The incubation experiment took place in 2015/16 and was terminated after 325 days.

Objective 3. Investigate the interactions between water (and nutrient) redistribution within soil profiles, and plant root development.

This objective will provide a detailed understanding of rooting behavior and root distribution within different reclamation materials, in particular in relation to the textural discontinuities found within the soil columns. One important aspect of this work will attempt to maximize water uptake by plants as compared to deep drainage.

Five materials are being considered for the column work: Peat; FFM; Salvaged subsoil (SUB); Lean oil sands (LOS); and Tailing sands (TSS).

The soil cover design questions to be addressed are as follows:

- Nutrient application – How does the adsorption/retention of applied nutrients in FFM coversoil compare to Peat coversoil?
- Does soil cover design depth (i.e., thickness of the subsoil or depth to the lean oil sands [LOS]) affect the adsorption/retention of nutrients in the root zone?
- Retention of nutrients in soil reclamation cover material(s) – is nutrient retention in soil cover materials different when underlain by LOS as compared to tailing sands?
- Do the interfaces between coversoil, subsoil and the underlying LOS substrate create a capillary barrier that enhances root water and nutrient uptake?

OUTCOMES AND LESSONS LEARNED

Below are some key outcomes from the work conducted under Objective 1. Objectives 2 and 3 are ongoing and outcomes are not included in the current report.

Outcomes for Objective 1:

- Differences in forest floor total and available nutrients were found to largely be influenced by relatively small changes in the texture of the upper soil profile (94% sand in pine stands versus 88% sand in aspen stands), most likely through its influence on canopy type and vegetation productivity levels and therefore the quantity and quality of litter nutrient inputs to the forest floor. Because soil texture is a relatively permanent site property and has likely changed little in these sandy soils since they were deposited, it's believed that relatively small changes in soil profile texture (e.g., sandy loam versus loamy sand or loamy sand versus sand) and textural discontinuities in the subsoil has a significant influence on the development on the type of vegetation community. The small texture changes measured in the study resulted in a wide range of the vegetation community characteristics (pine dominated versus aspen dominated vegetation communities).
- Soil textural differences of 88% for aspen stands and 94% for pine stands in the topsoil and upper subsoil (above BC or C horizon) controls the nutrient status of the soil. In sand to sandy loam soils under jack pine, relatively small increases in silt and clay content (i.e., silt and clay content increasing by 8 % or less) were associated with a greater site index, greater total nutrient stocks in the forest floor, as well as a higher forest floor quality (lower C:N and C:Ca ratios), potentially linked to more optimal moisture conditions in finer textured jack pine stands. Interestingly, most Plant Root Simulator (PRS®) probes showed little nutrient relationship with soil texture under jack pine with soil texture under jack pine, while available NH_4, P and K actually increased with coarser textures.
- Forest floor (LFH) nutrient stocks under aspen related most strongly to B horizon texture, with finer B horizon texture (silt + clay) being associated with larger forest floor nutrient stocks (C, N, P, S, Ca, Mg, K). However, only soils with fine lower soil profile textures were associated with higher forest floor quality (lower C:N and C:Ca ratios). These results indicate that B horizon texture may control the quantity of forest floor nutrients while lower profile texture may control the quality of litter nutrient inputs under aspen. Therefore, while upper profile silt + clay may correlate best with differences in nutrient amounts and availability in sandy soils of the AOSR overall, and correlate strongly with soil nutrients under jack pine, more complex interactions between the relative textures of the B horizon and lower soil profile regulate soil nutrient stocks and forms under aspen.
- The range in jack pine productivity levels, and therefore forest floor nutrient quantities and quality, could be targeted with soils that vary little in their textures down to a depth of at least 2 m, as was the case for all but one jack pine site in this study, which were typically associated with textures that ranged from 94 to 99% sand in the upper and lower soil profile. The range in aspen productivity and its associated understory may be best targeted with sandy loam of finer soil profiles and/or textural discontinuities in the upper and lower soil profile textures.

PRESENTATIONS AND PUBLICATIONS

Published Theses

William Barnes. 2016. Nutrient distribution in sandy soils along a forest productivity gradient. M.Sc. Thesis. Department of Renewable Resources, University of Alberta. Edmonton, AB. 129 pages.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigators: Sylvie Quideau; co-principal investigators: Miles Dyck and Simon Landhäusser.

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
William Barnes	University of Alberta	M.Sc.	2013	2016
Najmeh Samadi	University of Alberta	PhD	2013	2015
Frédéric Rees	University of Alberta	PDF		
Pierre-Emmanuel Rogee	Université de Lorraine	B.Sc.	2016	2016
Sylyanne Foo	University of Alberta	B.Sc.	2016	Ongoing
Mathew Swallow	Mount Royal University	Assistant Professor		

Aurora Soil Capping Study: Re-Establishment of Forest Ecosystem Plants, Microbes, and Soil Processes in Coarse Textured Reclamation Soils

COSIA Project Number: LJ0201

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd

Status: Year 4 of 5

PROJECT SUMMARY

Vegetation and community development in reclaimed soils is dependent on nutrient pools, forms and their availability for uptake. In large part, this is related to soil profile characteristics and the soil microbial community. Re-establishment of key vegetation species and communities present in the pre-disturbance landscape will require soil cover designs with similar soil nutrient conditions as undisturbed soils of the area.

A range of soil cover designs, varying in material type and placement depth, at the Aurora Soil Capping Study are investigated to understand how the following soil nutrient priority areas are related to land reclamation of lean oil sand overburden using soil materials available in the mine leases of the area:

1) The ability to reclaim to some of the drier ecosites of the region including jack pine and aspen stands on coarse textured materials (a/b ecosites);
2) The effect of using salvaged soil material which contain naturally occurring oil sand materials on nutrient availability; and
3) The effect of different soil capping depths and soil cover types over lean oil sand overburden on plant growth and nutrient availability.

Based on these target areas, the following studies were developed:

Study 1 – Impact of different capping materials and canopy type on soil-plant relations

Research Question 1 – How does plant nutrient availability and uptake by tree species vary in the different soil cover types and depth treatments?

Research Question 2 – How does rhizosphere microbial ecology relate to nutrient availability and uptake by tree species in the different soil cover types and depth treatments?

Study 2 – Impact of different horizon sequences and canopy types on soil-plant relations

Research Question 1 – How does plant nutrient availability and uptake by tree species vary with horizon sequence?

Research Question 2 – How does rhizosphere microbial ecology relate to nutrient availability and uptake relate to horizon sequence?

Study 3 – Using spatial pattern analysis of soil-plant relations to determine the success of land reclamation

Research Question 1 – What are the spatial patterns associated with plant nutrient availability and uptake?

Research Question 2 – Are there ways to tie recognition of spatial patterns into tracking successional trajectories and therefore defining land reclamation success?

Study 4 – Effect of mixing peat and sub-soil on nutrient and microbial dynamics

Research Question 1 - Does mixing peat and subsoil affect soil biogeochemical performance?

Research Question 2 - Does mixing Peat and subsoil affect microbial structure and function?

In order to compare and test the reclamation treatments investigated in the study a range of benchmark conditions have been added to the studies. This includes boreal forest stands of different ages and community characteristics, as well as sites recovering from disturbances such as wildfire or human disturbance (e.g., harvesting). This study will understand and compare their site characteristics, potential to recover (for disturbed sites) and if they are appropriate analogues for comparison to specific oil sands reclamation situations (focusing on soil biogeochemical processes).

PROGRESS AND ACHIEVEMENTS

Study 1 was completed and reported in 2015. The following is the study progress in 2016.

Study 2 – Impact of different horizon sequences and canopy types on soil-plant relations

Jeff Hogberg (M.Sc. Candidate) completed processing and analysis of nutrient supply results in different nutrient pools from two different oil sands reclamation sites. He also created and tested two different multivariate analysis techniques to develop a similarity index for assessing reclaimed sites relative to other reclaimed sites and to natural reference sites. Mr. Hogberg is expecting to complete his M.Sc. and one manuscript in 2017.

Study 3 - Using spatial pattern analysis of soil-plant relations to determine the success of land reclamation

Sebastian Dietrich (PhD Candidate) completed the processing of his greenhouse samples and is in the process of writing up his data. He passed his candidacy exam in September 2016 and expecting to defend his dissertation in September 2017.

Study 4 – Effect of mixing peat and sub-soil on nutrient and microbial dynamics

Will Kirby (M.Sc. Candidate) is evaluating the effect of variable proportions of peat and mineral soil admixing, ranging from entirely peat to mineral subsoil to determine if similar function (soil respiration, biodiversity, carbon substrate use, carbon fixation) could be achieved compared to forest floor coversoil. Next generation sequencing was performed on bulk soil samples from replicated soil treatments to examine fungal and bacterial community structure and diversity. Mr. Kirby is expecting to complete his M.Sc. and one manuscript in 2017.

OUTCOMES AND LESSONS LEARNED

There were no outcomes or lessons learned in the 2016 reporting period.

PRESENTATIONS AND PUBLICATIONS

Conference presentations:

Dietrich, ST and MD MacKenzie. 2016. Admixing of Subsoil and Amendment of Peat Biochar Improves Productivity of Peat as a Substrate for Oil Sands Reclamation. Alberta Soil Science Workshop. Grande Prairie, Alberta, Canada. February 16-18, 2016.

Dietrich, ST and MD MacKenzie. 2016. Amendment of biochar improves growth of aspen on oil sands reclamation cover soils due to changes in nutrient availability and SOM stability. American Society of Agronomy (ASA), Crop Science Society of America (CSSA) and Soil Science Society of America (SSSA) Joint Annual Meeting. Phoenix, Arizona, USA. November 6-9, 2016.

Hogberg, J. I., MacKenzie, M. D., Pinno, B. D. 2016. Evaluating foliar nutrient concentrations as an indicator of belowground function in reclaimed soils of the Athabasca Oil Sands Region. Soil Science Society of America International Annual Meeting. Phoenix, Arizona, USA. November 7, 2016.

Hogberg, J. I., Pinno, B. D., MacKenzie, M. D. 2016. Evaluation of foliar nutrient concentrations as an indicator of ecosystem function. Alberta Soil Science Workshop. Grande Prairie, Alberta, Canada. February 16-18, 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: M Derek MacKenzie

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Sawyer Desaulniers	University of Alberta	Field Technician	2013	2013
Nicole Filipow	University of Alberta	Field Technician	2013	2013
Arezoo Amini	University of Alberta	Lab Technician	2013	2013
Maksat Igdyrov	University of Alberta	Field Technician	2014	2014
Mark Howell	University of Alberta	M.Sc.	2012	2015
Sebastian Dietrich	University of Alberta	PhD	2014	On-going
Nduka Ikpo	University of Alberta	Lab manager	2013	2015
Jeff Hogberg	University of Alberta	M.Sc.	2015	2017
William Kirby	University of Alberta	M.Sc.	2015	2017
Monica Shandal	University of Alberta	Lab Technician	2015	On-going
Sylyanne Foo	University of Alberta	Lab Technician	2015	On-going
Patrick Neuberger	University of Alberta	Lab Technician	2016	2016
Jhon Enterina	University of Alberta	Lab manager	2015	On-going
Jeff Battigelli	University of Alberta	Research Associate	2016	On-going
Shirin Zahraei	University of Alberta	Lab Manager	2016	On-going

Research Collaborators: Brad Pinno, Canadian Forest Service

Evaluating the Success of Fen Creation

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial, Shell Canada Energy

Status: Year 5 of 6

PROJECT SUMMARY

The primary research goal of the Evaluating Success of Fen Creation project has been to assess the success of a constructed fen design through a detailed examination of post-construction hydrological functioning, bio-geochemical interactions and ecological progression at the site. This has occurred in tandem with the characterization of a series of reference fen (RF) systems in the Fort McMurray area. This will provide a background understanding of the range and variability of ecohydrological characteristics of natural regional fens and assist in defining metrics of success.

Three linked projects have been established with the purpose of answering specific questions associated with the creation of a hydrologically functioning, ecologically successful, carbon sequestering fen wetland and the incorporation of processed tailings materials into the construction.

Broad-scale objectives of the research have been to:

1. Identify strengths and weaknesses in the conceptual fen design;
2. Test the methods of construction including materials, their placement and the sensitivity of design characteristics, through modelling of water and contaminant flows;
3. Develop thresholds and milestones for hydrological, water quality and carbon sequestration rates or thresholds as monitoring tools; and
4. Determine the most suitable vegetation communities and reintroduction methods for fen reconstruction.

Sub-scale objectives have been to:

1. Determine if upland areas facilitate sufficient recharge flow to the fen, and if sodium salts (Na) and naphthenic acids (NAs) leach from tailings and how quickly they flush from the upland tailings aquifer;
2. Determine if transport and attenuation processes in fen peat hold these contaminants below plant toxicity thresholds in the rooting zone;
3. Determine if the fen sequesters carbon (C), and if revegetation strategies for the fen affect C accumulation;
4. Determine if different functional relationships exist for vegetation communities at the upland and fen due to moisture or nutrient conditions;
5. Identify the most successful and appropriate revegetation methods for respective species and how varying hydro-geochemical gradients and propagule inputs affect vegetation survival, composition, photosynthesis and transpiration; and
6. Determine whether microbial communities at the constructed fen reflect those at the reference fen sites, and determine if these communities develop the ability to degrade NAs.

PROGRESS AND ACHIEVEMENTS

Definitions

The project's reference sites are referred to throughout this document and are comprised of a 'moderate-rich' fen, a 'poor' fen and a 'saline' fen wetland. Rich and poor denote the dominant vegetation assemblages. The constructed fen is hereby referred to on occasion as 'FEN' in the course of this document.

Reference fen hydrology

Quantification and standardised logging (water table, elevation, runoff, biometeorology) of reference fen hydrology is ongoing. The 2016 wildfire burned large portions of the moderate-rich fen (Poplar fen). As a result, some additional hydrological measurements were required to help understand the hydrological and meteorological conditions that led to the burning of the Poplar fen. The fire also necessitated the reliance on data previously collected in 2015 and early 2016.

The following activities were completed in 2016:

- Burnt wells and piezometers were repaired; pipes were cropped and fitted with PVC attachments.
- Weekly manual hydraulic head measurements were completed between June and August 2016.
- Pressure transducers were launched in wells/piezometers to continuously read hydraulic head.
- Burnt meteorological stations were replaced to allow for comparison of energy balance components and evapotranspiration between burned and unburned upland areas.
- Energy budget components including net radiation (Q*), ground heat flux (QG), sensible heat flux (QH), latent heat flux (QE), along with wind speed, relative humidity, temperature, and soil moisture were logged at halfhourly intervals.
- Half-hourly evapotranspiration (ET) was calculated using Penman-Monteith.
- Logging soil moisture profiles were replaced in the fen margin, and further profiles installed in burned and unburned uplands to quantify moisture changes and allow comparison of water holding capacities between the different land types.
- Accompanying leachate collectors were installed alongside moisture probe profiles and leachate sampled post-precipitation events.
- Additional water sampling was conducted, encompassing different landform types at Poplar fen. Samples have been submitted for major ions and isotope (^{18}O & ^{2}H) analysis.

Ecohydrological controls on evapotranspiration in reference fens

A modelling exercise examining seasonal ice retreat and ET fluxes within a densely treed and sparsely treed area of the reference poor fen is being conducted using the Cold Regions Hydrological Model (CRHM). Eddy covariance data has validated model results for evapotranspiration. The position of the seasonal ice was validated by logging ground temperature profiles.

Initial CRHM results indicate that its ability to model ET is promising. A scenario was run using meteorological data from the 2014 field season. The Root Mean Square Error (RMSE) was 0.05351 mm/30min, which indicates small differences between the modeled value and the observed value. Model bias (MB) was 0.924434, which indicates model over-prediction. The Pearson R was 0.80555 and there was an R^2 of 0.6489, so while the modeled values are well correlated with the observed values, it only can explain about 65% of ET variation.

The low R^2 value becomes apparent when reviewing the model output. Observed values show daily variations in ET fluxes, while the model tends to output a smooth curve that is within the range of the daily-observed values, but rarely reaches the maximum or minimum observed ET values. Reasons for this discrepancy may be because some of the radiation inputs had to be calculated assuming clear sky conditions and therefore, daily radiation variation is not parameterized for all time steps. Additionally, the current model treats the peatland as an isolated hydrological unit but it is known that ground water and surface water inputs are occurring from the surrounding hillslope. Future versions of the model will incorporate this factor.

Data is being prepared to run simulations using the Regional Atmospheric Forest Large Eddy Simulation (RAFLES). The data consists of meteorological and vegetation data that was either combined and corrected, or processed in the lab. It has been combined into workable files that RAFLES can process. RAFLES will be run using Ohio University's supercomputer.

The model examines the significance of peatland geometry and vegetation characteristics on turbulent structures within peatlands and assesses the impact that forest height and peatland vegetation characteristics have on turbulent structures within a peatland. Model results will be used to determine the significance of the reference fens' geometry on turbulent structures. This will allow us to determine the impact of varying internal boundary layers on turbulent structures and therefore the impact of turbulent sheltering on ET within peatlands.

Identification and comparison of methanogenic and methanotrophic microbes.

The effects of OSPW (Oil Sands Process Water) on aerobic and anaerobic carbon-cycling potential activity of microbial communities were tested in a laboratory setting using extracted peat. Samples were collected at the start, mid-season and end of the growing season from reference peatlands. This work was performed to determine contaminant potential on the activity of likely constructed fen microbe communities. Measurements of substrate-induced respiration (SIR) and methanogenic potential were taken allowing for a measure of the baseline aerobic and anaerobic carbon-cycling potential of the reference sites.

Hydrological links between UPLAND & FEN.

Evaluation of the recharge basins (2012-16) has found that recharge basins and raised landforms (meso-scale, 10-100 m long) are important for freshwater recharge to the underlying aquifer. Removal of upland forest soil (herein referred to as LFH) allows for overland flow detention and prolonged ponding results in substantial freshwater recharge. Contributions from the basins were calculated at 15% of lateral groundwater flow to the fen in 2014 (and again in 2016). Although the majority of recharge is from detaining and infiltrating overland flow. Recharge basins effectively promote subsurface storage and minimize runoff directly from UPLAND to FEN.

The east recharge basin was deemed to be the most successful of all four within the FEN. The success of the east recharge basin was attributed to a combination of positioning and geometry. It's positioned at the toe of the confluence between east and southeast hillslopes. These hillslopes generated considerable runoff during rainfall exceeding 10 mm/hr^{-1}. This allowed for frequent filling of the basin.

Basins had ponded water retained for 20-25% of the measured field season, taking around 7-10 days to infiltrate into the aquifer below. The East basin makes up >80% of total basin contribution from all basins. In 2014, the East basin alone contributed 45mm to the systems water balance when weighted to total fen area. In 2015 this contribution was 32mm and in 2016 – 35mm. This is equal to the minimum recharge contribution from of all other recharge basins.

It is speculated that enhanced recharge through recharge basins will lead to preferential flushing of Na^+ within the tailings sand. The large volumes of water ensured relatively low Na^+ concentrations within the groundwater.

Enhanced recharge likely mobilized more Na^+ from the tailings sand aquifer but the increased hydraulic gradients from increased recharge quickly flushed Na^+ down-gradient, creating localized areas of low Na^+ groundwater beneath the fen.

Distribution and movement of solutes in and between UPLAND & FEN

During periods of high freshwater recharge (2013 & 2014) the UPLAND was capable of supplying relatively low Na^+ water to the FEN. This resulted in a lower Na^+ load despite higher water fluxes. During drier conditions (2015) and with less freshwater recharge, UPLAND groundwater Na^+ concentrations increased, resulting in higher loads. The highly permeable coke underdrain leads to this counterintuitive Na^+ flux. In wet conditions, diluted groundwater is available for transport. However in drier conditions, it is predominantly Na^+ rich water supplied from the UPLAND satisfying the FEN water deficit. This results in substantial migration of Na^+ from the petroleum coke underdrain upwards into the peat deposit and introduces overall greater sodium concentrations.

High actual evapotranspiration (AET) demand within the FEN in 2015 resulted in evapoconcentration of Na^+ within the near surface peat. These results agree with the unsaturated transport column experiment previously conducted that assessed time scales for contaminant movement and accumulation in the topsoil.

Upland soil cover assessment

Quantification of the LFH development (upland soil capping) layer in the five years since placement is ongoing. This includes:

- Quantifying the spatial heterogeneity of the constructed upland LFH for hydrophysical parameters (infiltration rate, bulk density, organic matter content, porosity, moisture retention, and particle size distribution).
- Assessing the hydrologic functioning of the LFH layer within the UPLAND to calculate a water budget.
- Collecting data in 2016 including sampling at 60 randomly selected UPLAND locations. Two soil cores (5cm depth, 10cm I.D.) were extracted at each location for analysis.
- Performing infiltration tests – triplicates in each of the tilled and un-tilled areas.
- Collecting soil moisture survey data – collected twice in the 2016 season.
- Continuous logging of soil moisture data at four sites along a central North-South transect.

Observations for 2016:

- Assessment of the UPLAND between summer seasons (2015-2016), suggests significantly increased gross primary productivity (GPP) in the amount and size of vegetation. The difference in vegetation cover is particularly noticeable in the SE corner and crescent hummock recharge basins. In 2016, it is also evident that there is a significant difference in both the species composition and density of the furrowed areas compared to the untilled areas.
- Infiltration rates in the UPLAND LFH increased from 2015 to 2016. For example, in 2015 a centrally located, bare, untilled area had a recorded infiltration rate of .0010mm/s (86.4mm/day) while in 2016 the same location had a rate of 0.0018mm/s (155mm/day). This is likely due to successive freeze/thaw cycles and increasing plant growth.
- No topographic moisture or ion availability gradient was found within the UPLAND, related to placed cover soils lacking traditional stratigraphic structure. However, as organic matter accumulates, microorganisms should begin to develop ion mineral layers, leading to preferential flow paths and the potential for such gradients to develop.
- Major ions such as NO_3^-, NH_4^+ and soluble reactive phosphorus (SRP) did not periodically accumulate in the transition zone. Measured early and late-season ion availability (through use of PRS® probes) were fairly similar.

However differences were detected mid-season, likely due to the application of a Control Release Fertilizer (CRF). The CRF was applied mid-season, post-construction to aid sapling survival. Decreases in nitrogen concentrations over the growing season were observed in runoff samples and Plant Root Simulator (PRS®) probe data. No decrease in SRP was detected. This suggests available nitrogen is being immobilized by soil microbes and weedy vegetation.

- The N:P ratio steadily decreased throughout the growing season. This suggests nitrogen may be limiting and phosphorus potentially excessive.
- Groundwater chemistry sampling (NH_4, NO_3, SRP, K^+, SO_4^{2-}) was not found to correlate to surface ion availability, this may be due to the development of a capillary barrier at the textural interference between the LFH and the tailing sands aquifer.
- Dissolved Inorganic Nitrogen (DIN) (NH_4, NO_3) varied in relation to timing of sampling periods. NO_3 increased significantly within the recharge basins following sampling periods that preceded large precipitation events. While NO_3 is the dominant DIN form at soil surface, anoxic conditions in groundwater make NH_4 the dominant aqueous form. An increase of NO_3 within recharge basins and not the remainder of the upland's groundwater, signifies that NO_3 flushing occurs following recharge by precipitation.
- Forbs and grasses are dominating colonization of the upland canopy. They are colonizing areas elevated in SRP and TIN.
- Tree sapling survival is more successful on the slopes in PMM compared to LFH. This is most likely due to PMM's enhanced moisture retaining abilities, which appears limiting in the dry LFH.
- The East Slope has significantly different ion availability compared to South East and West slope. This may be due to time since reclamation (2007 vs. 2011) and differing origin donor site material used for the reclamation of the slopes despite the same prescription being used.

Modelling the transport and fate of Na and NA in the constructed system

The objectives of geochemical modelling are to:

1. Determine accumulation rates of Na^+ and NAs in the shallow subsurface
2. Determine whether the contaminants will exceed known toxicity thresholds of mosses and vascular plants in the future.
3. Evaluate the flow and transport of contaminants under stable climatic conditions, and under the four climate trajectory models developed by the Intergovernmental Panel on Climate Change (IPCC) (RCP2.6, RCP4.5, RCP6, and RCP8.5) to investigate how to optimally design a constructed fen to favourably control water and potential contaminant redistribution.
4. Assess the long-term viability of using self-sustaining, constructed fen wetlands as a technique to reclaim the post-oil sands landscape.
5. Suggest recommendations for improving the performance of these constructed wetlands.

In order to accomplish these objectives, a numerical hydro-geochemical model is being developed in HYDRUS 2D/3D. This includes the creation of the input data and files needed to build, run, and verify the geochemical model. These include synoptic groundwater elevations, precipitation, evapotranspiration, and material surface elevations.

Top-and-bottom elevations for each material have allowed for the construction of a 3-D stratigraphic model. This demonstrated that more petroleum coke was used in construction than originally thought. In some places the layer was 50% thicker than intended, however, this only represents an absolute increase of 25 cm.

A saturated groundwater flow model of the FEN has been created in USGS MODFLOW to verify measured hydraulic conductivities (K) of peat, petroleum coke, and tailings sand. The model aimed to address concerns raised about

field measured K within the coke and the implications that an anomalously low petroleum coke K could have on the fluxes of groundwater from the UPLAND aquifer and the overall water balance of the site. This model determined that the petroleum coke K is likely two orders of magnitude higher than what was measured in the field. Although the reasons for this are currently unknown, the most likely reason for this is bias introduced into the petroleum coke K because of the inability to measure quickly responding piezometers. Other possible explanations include piezometers not screened exclusively in the petroleum coke (therefore integrating the low K tailings sand or low K peat in the well response tests), or the clogging of screens with fine material. The modelling confirmed the hydraulic conductivities for the peat and tailings sand. However, the model did not incorporate variably saturated processes and the hydraulic properties of the LFH have not yet been verified.

Hydraulic lift and evapotranspirative demand in a constructed UPLAND.

Increases in AET (actual evapotranspiration) were attributed to UPLAND plant growth rates stabilising in 2015 and 2016 (for the period that the eddy covariance systems were operating post-wildfire) following initial growth in 2014.

Controls on carbon fluxes in the constructed FEN and UPLAND.

Several geochemistry and vegetation controls on CH_4 flux and pore water concentration were found across the constructed fen and reference sites. The supply rate of sulphur was the most dominant control on CH_4 flux and concentration, with high sulfur at the constructed fen inhibiting CH_4 production. Other significant controls included ammonium supply rate, pH, electrical conductivity, total belowground biomass, and total vegetation cover, along with shrub and gramminoid cover. These results suggest that a more thorough understanding of geochemistry and vegetation is necessary to understand CH_4 flux at reclaimed constructed fens.

CH_4 flux was higher at *J. balticus* plots compared to bare and moss plots. Pore-water CH_4 was lower at treatments that included vascular plants (*J. balticus*, *C.aquatilis*, mixed *J. balticus* + moss, and *C. aquatilis* + moss) compared to the bare and moss treatments. This suggests that vascular plants at the constructed fen are efficiently transporting CH_4 to the atmosphere. While no evidence of differences in CH_4 emissions between *C. aquatilis* and *J. balticus* were found in the present study, low flux values at the constructed fen made it challenging to parse out the vegetation influence on the flux. CH_4 flux was significantly higher across plots at the poor fen (Poplar) compared to both the saline fen and constructed fen, which had lower CH_4 fluxes compared to natural fens in Alberta in peer-reviewed literature. Pore-water CH_4 concentration at depth was higher at both the saline fen and poor fen compared to the constructed fen. These results suggest that constructed fens do not function similarly to natural reference fens in regards to methane production shortly after reclamation. Pore-water samples from 2013 and 2014 indicated significantly higher SO_4 concentrations with respect to surrounding reference peatlands near the region. Values for natural peatlands range ~4.5-50 mg/L. Pore-water samples from the constructed fen ranged from 417-947 mg/L, on a decreasing trend between 2013-2014 at 90 and 150cm.

Hydrologic carbon stock and export from the constructed FEN.

Previously unreported data analysis from May-August 2015 indicated that dissolved oxygen concentrations (DOC) in the FEN are increasing from previous years. The seasonal average increased from 30.0 to 39.9 mg/L, from 2013-2014. A further increase was seen in 2015 the average increasing to 41 mg/L in the FEN piezometer nests. Further study into the effect of depth on DOC concentrations indicates greater DOC concentrations in near-surface piezometer locations, the concentrations decreases through the peat profile. DOC concentrations in petroleum coke and tailings sand beneath the FEN were consistent throughout the growing season and did not differ significantly between the layers. Concentrations in June were consistent with depth, however significant increases were seen in July.

There was no significant increase in DOC concentrations in pore water samples between July and August, 2015. Soil temperatures increased between June and July, 2015 in high summer, decreasing in August. Outflow was dominated by two primary events: the spring freshet of melting snow and frozen moisture content which caused outflow to occur until mid-May, and a rise in the water table in response to a large storm event that occurred in late July. These events were responsible for all DOC outflow from the system, with 0.74 g/m^2 lost via outflow.

Hillslope samples were limited due to minimal precipitation events. Therefore, concentrations in runoff will be assessed using both 2016 and 2015 growing season values. Inputs from groundwater were minimal and insignificant relative to those from DOC production internally in the FEN. DOC production is therefore increasing within the FEN following construction completion, and greater concentrations near the surface may be due to a combination of greater inputs from vegetation and evapoconcentration. As the system is designed to have upward gradients, accumulation of DOC in the near-surface layers of peat will occur. This is likely compounded by the increase in soil temperature and decrease in the water table that promote DOC production from both degradation and consequent oxidation of existing peat, and root exudates as vegetation becomes more productive throughout the growing season. Low outflow volumes limit DOC losses hydrologically, but the FEN can release greater amounts of DOC during intense precipitation events, creating pulses of DOC into downstream ecosystems. Quality analysis of the DOC using spectrofluorescence has begun.

Evaluating carbon accumulation potential of constructed FEN.

Evaluation of carbon accumulation in the constructed fen can be conducted using a biogeochemical functional-based approach. This approach appears to be more appropriate than the traditional indicator species approach of reclamation evaluation. This broadly supports current thinking in restoration ecology that advocates moving away from the traditional view that restoration needs to reconstruct past systems, and that novel and hybrid systems – which may not be structurally equivalent to natural analogues, but support similar functions – should be accepted as possible, and desirable outcomes. If the current functional characteristics of the FEN persist in the longer term, then the FEN may remain a net sink of nutrients and greenhouse gases due to the regulation of water chemistry by vegetation and microbial competition for nutrients. Revegetation of the constructed FEN reduced N_2O production potential due to the high N demand of establishing vascular plants, which also increases CO_2 uptake.

Constructed fen was a C source in 2013 as vegetation was establishing after planting. It remained a small C sink in 2014 and 2015, at rates characteristic of other natural fens in the Western Boreal Plain (WBP). The constructed upland remains a source of C as woody debris biomass within the LFH promotes fungal decay related emissions and the dense soil likely stresses plant productivity. However, gross ecosystem productivity (GEP) and net ecosystem exchange (NEE) values indicate a trend of slowly increasing productivity with C sink “windows” in both the early and late growing seasons.

Antecedent moisture and nutrient status controls on C sequestration along a reclamation trajectory.

Microbially-mediated nutrient transformation processes such as mineralization, present a potential functional indicator of a constructed fen’s functioning. The recovery of below-ground FEN nutrient transformation processes are constrained by poor peat quality, characterised by high bulk density, low organic matter and low nutrient (N and P) concentrations. However, above-ground C cycling is facilitated by vegetation development on the FEN, with the combination of vascular plant seedlings and moss species transferred from the donor salvage site.

Substrate quality and water chemistry at the FEN appears to override the ability of vascular plants to stimulate CH_4 production, making the FEN, a net sink of CH_4. Further research is ongoing to try to determine the dominant control on the low CH_4 dynamics apparent at the constructed fen.

Surface and atmospheric controls on water use efficiency

In 2016 the Fort McMurray wildfires resulted in the loss of the initial measurement period. In 2016 for the day of year (DOY) period 179-232, precipitation (P) was recorded at 120mm, AET was 188mm, total net ecosystem productivity (NEP) was -164g C/m^2, total GEP was -539 g C/m^2. Average water use efficiency (WUE = GEP/AET) was 3.06 g C/kg H_2O. For the same DOY period in 2015, P was 80mm, AET 226mm, NEP -71 g C m^2, GEP was -420 g C m^2. WUE was 1.97 g C/kg H_2O. The larger WUE value in 2016 as compared to 2015 is indicative of fen vegetation sequestering greater amounts of C per unit volume of H_2O lost from the watershed. Although these values appear to be moving the watershed overall to a more efficient system, in terms of sequestering more carbon, this can be largely attributed to extensive growth of *Typha* vegetation. Precipitation input is another important factor since it was 50% greater in 2016 than 2015 for the same measurement period. This limited the number of sunny days for high ET. This partly explains the lower AET in 2016. The lower ET also inflates the WUE value. WUE has essentially doubled between 2015 and 2016. While desirable to find an annual increase in WUE, the attributable causes – extensive invasive vegetation growth (increasing GEP numerator of WUE); and high P inputs limiting sunlight and AET (decreasing the denominator of WUE), are undesirable.

Bryophyte establishment method assessment, controls on bryophyte growth and production by species, in-situ photosynthesis and transpiration on a plant level, and long-term survival by species

In July and August 2016, vegetation and abiotic data (water table, bulk electrical conductivity [EC]) were collected on all treatment plots, including a comprehensive survey of vascular and non-vascular plant species and moss biomass in all treatments plots. The collected data allow for evaluation of vegetation establishment methods on the FEN, moss community establishment and biomass accumulation in response to cover treatments and abiotic gradients, and vegetation composition compared to the harvested donor site, the unharvested donor site and saline fen.

Spreading moss material from the donor site introduces a variety of moss and vascular plants species. In the first year post-construction (2014), there was minimal moss growth without mulch or seedling cover. In the second year (2015), moss cover did not differ between mulched and un-mulched plots, likely due to the increase in vascular plant cover providing a suitable microhabitat for moss establishment. In the third year (2016), moss cover was significantly reduced in plots where *Carex* species had flourished to the point of creating a thick litter layer that impeded light to the moss layer. Moss establishment was greatest in drier plots that do not undergo flooding events, and when planted beneath *Juncus* seedlings canopy. Seeding plots have the greatest establishment of *T. maritima*, *C. aquatilis* and *J. balticus*. Seedling plots have greatest cover of litter and soil carbon input. Seedlings reduced non-peatland (weedy) species cover. This also contributed to the FEN seed bank – producing flowering stocks and seeds in the second year. Bare-peat (unplanted) control plots have largest relative cover of weedy species.

Cover and biomass analysis for 2014-2016, shows moss height averaged 3 cm and biomass averaged 430 g/m^{-2} yr^{-1}. This is greater than literature averages from non-constructed fens (116 g/m^{-2} yr^{-1} [SD = 66]) suggesting maintenance of ideal water levels may support continuous moss growth throughout the season. It should be noted that our production value does not consider the decomposition that occurs in natural systems, which may be accounted for in the reference value. Additional analysis is ongoing to support these trends.

Weeding treatment conducted from 2013-2015 reduced non-peatland (weedy) species to an average cover of 4%, a value comparable to weedy species cover in the seedling plots. The seedling planting treatment provides comparable results in limiting weedy species without the need for a manual annual weeding treatment.

Vascular plant establishment, controls on above and below ground growth and production, photosynthesis and plant level transpiration, clone formation, and long-term survival

Analysis of total above-ground biomass collected in 2015 indicate 'moss + seedling' plots had the greatest quantity of total above-ground production. 2016 biomass analysis is underway. Seedling, seed, control, and moss planting methods appear to generate ultimately similar above-ground biomass production totals. For vascular species, *C. aquatilis* appears to be the dominant producer of above-ground biomass in 'seedling' and 'moss + seedling' plots compared to *J. balticus*. Above-ground biomass in seedling plots are closest in comparison between those two species than any other planting method. *C. aquatilis* appears to produce greater amounts of above-ground biomass in unplanted plots (control and moss transfer method), and planted plots (seed, seedling, and moss transfer method + seedling) than *J. balticus*.

Analysis of below-ground biomass collected from the site in 2015 found *C. aquatilis* producing more below-ground biomass than *J. balticus* in treatment plots where seedlings were not planted. Below-ground production by *J. balticus* was near equal to or greater than *C. aquatilis* in the moss transfer method + seedling and seedling plots. *J. balticus* was present where seedlings were not planted (control, seed, and moss transfer methods), however, volunteer (self-seeded) *J. balticus* recruitment (juvenile organisms survive to be added to a population) tends to be significantly lower than treatment plots.

OUTCOMES AND LESSONS LEARNED

- Low CH_4 flux from the constructed fen is likely beneficial in future fen creation projects by reducing GHG emissions. However, the low flux also indicates differences in functionality between a recently constructed fen and mature reference fens. Since CH_4 production and flux is indicative of highly reduced conditions that would otherwise inhibit organic matter decomposition, resulting in its peat accumulation, the lack of these conditions at the constructed fen may have undesired impacts for long-term peat accumulation. Long-term monitoring will determine how CH_4 flux and its controls relate to the success of constructed fen projects, particularly over the long-term. Future constructed fen projects need to develop clear reclamation goal(s) that consider functional outcomes (e.g., greenhouse gas sink vs. similar biogeochemical function as natural fens on the post-mined landscape).
- To support hydrologically-sustainable fen watersheds, recharge basins should be strategically placed at slope toes or in areas of high anticipated water flow. Existing recharge basins at the FEN could be enlarged if water availability becomes an issue in the future since the east recharge basin frequently fills to capacity and overflows.
- Heavy metals analysis from the construction material digestions, leaching batch experiment and field sampling indicates that although petroleum coke contains high concentrations of heavy metals, such as V and Ni, leaching is being limited under the aqueous alkaline, anaerobic conditions.
- 2.5 years post-construction measurements indicate all examined heavy metals (except Mn) were below maximum environmental fresh water guidelines, indicating that incorporation of petroleum coke into reclamation design projects or storage under specific geochemical conditions presents relatively low risk of leaching with respect to the examined heavy metals.
- Aerobic carbon-cycling potential does not differ between the saline rich fen peat and the poor fen peat. Both sites showed significantly greater aerobic carbon-cycling potential than the treed rich fen peat at the start of the growing season. Peat sampled mid-season showed aerobic carbon-cycling potential did not significantly differ between the peat types. The low potential of the treed rich fen peat was attributed to phosphorus limitation indicated by a substrate preference for low molecular-weight organic acids. No reference site peat displayed significant change in overall SIR on exposure to OSPW, however the saline peat did show an SIR preference for saccharide compounds when under contamination. This is attributed to a salt stress response from the high levels of Na^+ present in OSPW. Overall, the lack of significant microbial response to OSPW contamination was

either due to the immobilization of OSPW contaminants through physical and chemical interactions with the peat substrate, or from short incubation times of the laboratory experiments.

- Field methanogenic potential is highest at the treed rich fen, significantly lower at the poor fen, and lowest at the saline fen. The low methanogenic potential of the saline rich fen site is likely due the sulfate rich pore water (and thus inhibition of methanogenesis via the presence of a more thermodynamically favourable terminal electron acceptor). In the laboratory incubation, OSPW exposure significantly decreased methanogenic potential in both the treed rich fen peat and the saline fen peat, but had no significant impact on methanogenic potential in the poor fen peat. As amendment with OSPW containing twice its usual concentration of Na^+ did not significantly further decrease methanogenic potential, it is unlikely that high sodium concentrations are responsible for the inhibitory effect. The mechanism of resistance to OSPW inhibition in the poor fen peat is unclear, but may be the consequence of a more-resilient microbial community or immobilization of the inhibitory agent by some physical or chemical quality of the peat substrate (e.g., isolation via dead-end pores or via sorption to peat particles, humic or fulvic acids, etc.).

PRESENTATIONS AND PUBLICATIONS

Published Theses

Date, V. 2016. Response of peatland microbial community function to contamination by naphthenic acids and sodium in the Athabasca Oil Sands Region, Alberta, Canada. M.Sc. thesis. University of Waterloo, ON.

Gabrielli, E. 2016. Partitioning evapotranspiration in forested peatlands within the Western Boreal Plain, Fort McMurray, Alberta, Canada. M.Sc. thesis. Wilfrid Laurier University, ON.

Kessel, E. 2016. The hydrogeochemistry of a constructed fen peatland in a post-mined landscape in the Athabasca Oil Sands Region, Alberta, Canada. M.Sc. thesis. University of Waterloo, ON.

Ketcheson, S.J. 2016. Hydrology of a constructed fen watershed in a post-mined landscape in the Athabasca Oil Sands Region, Alberta, Canada. Ph.D. thesis. University of Waterloo, ON.

Murray, K. 2016. Methane dynamics of a constructed fen in the Athabasca Oil Sands Region, Alberta. M.Sc. thesis. University of Waterloo, ON.

Nwaishi, F. 2016. Evaluating the biogeochemical functioning of a constructed fen on the post-mining landscape of Athabasca oil sands region, Fort McMurray, Alberta, Canada. Ph.D. thesis. Wilfrid Laurier University, ON.

Journal Publications

Khadka, B., Munir, T. M., & Strack, M. 2016. Dissolved organic carbon in a constructed and natural fens in the Athabasca oil sands region, Alberta, Canada. Science of the Total Environment, 557: 579-589. DOI:10.1016/j.scitotenv.2016.03.0810048-9697

Ketcheson, S.J., Price, J.S. 2016. Hydrophysical properties of mine reclamation materials (LFH, tailings sand, petroleum coke and organic peat soils) in a constructed watershed. International Journal of Mining, Reclamation and Environment. MS# NSME-2016-0189. Accepted.

Ketcheson, S.J., Price, J.S., Carey, S.K., Petrone, R.M., Mendoza, C.A. and Devito, K.J. 2016. Constructing fen peatlands in post-mining oil sands landscapes: challenges and opportunities from a hydrological perspective. Earth-Science Reviews 161: 130-139. DOI: 10.1016/j.earscirev.2016.08.007

Ketcheson, S.J., Price, J.S. 2016. A comparison of the hydrological role of two reclaimed slopes of different age in the Athabasca Oil Sands Region, Alberta, Canada. Canadian Geotechnical Journal. DOI: 10.1139/cgj-2015-0391

Ketcheson, S.J., Price, J.S. 2016. Snow hydrology of a constructed watershed in the Athabasca Oil Sands Region, Alberta, Canada. Hydrological Processes 30: 2546-2561. DOI: 10.1002/hyp.10813

Murray, K.R., Barlow, N., Strack, M. 2016. Methane emission dynamics from a constructed fen and reference sites in the Athabasca Oil Sands, Alberta. Science of the Total Environment. Accepted.

Nwaishi, F.C., Petrone, R. M., Macrae, M.L, Price, J. S., Strack, M., Andersen, R. 2016. Preliminary assessment of greenhouse gas emissions from a constructed fen on post-mining landscape in the Athabasca Oil Sands Region, Alberta Canada. Ecological Engineering, 95: 119-128

Nwaishi, F.C., Petrone, R. M., Macrae, M.L, Price, J. S., Strack, M., Slawson, R., Andersen, R. 2016. Above and below-ground nutrient cycling: criteria for assessing the biogeochemical functioning of a constructed fen. Applied Soil Ecology, 98: 177–194

Conference Presentations/Posters

Brummell, M.E., Lazcano, C., Strack, M. 2016. The role of vascular plants in N_2O emissions from restored peatlands. Canadian Association of Geographers of Ontario Conference (CAGONT). Oct. 28-29. Waterloo, ON. [Presentation]

Irvine, S., Price, J. and Strack, M. 2016. Vegetation controls on DOC concentration on a constructed fen in the Athabasca Oil Sands Region, Alberta. Annual Eastern Student Meeting of the Canadian Geophysical Union (CGU). Feb. 6, 2016. Waterloo, ON. [Poster]

Irvine, S., Price, J., Strack, M. 2016. Dissolved organic carbon dynamics in a constructed fen following oil sands extraction. Mer Bleue Peatland Science Workshop. Feb. 29, McGill University, Montreal, QC. [Poster]

Irvine, S., Price, J., Strack, M. 2016. Doc dynamics in a constructed fen in the Athabasca Oil Sands Region, Alberta. Joint Canadian Geophysical Union (CGU) annual meeting with the Canadian Meteorological and Oceanographic Society (CMOS). May 29-Jun. 2. Fredericton, NB. [Poster]

Irvine, S.E., Strack, M., Price, J.S. 2016. Dissolved organic carbon dynamics in a constructed fen in the Athabasca Oil Sands Region, Alberta. Canadian Association of Geographers of Ontario Conference (CAGONT). Oct. 28-29. Waterloo, ON. [Presentation]

Messner, L. 2016. Competition between *Carex aquatilis* and *Juncus balticus* along a salinity gradient in reclaimed systems. Front Range Student Ecological Symposium; Feb. 22-24. Colorado State University, Fort Collins, CO. [Poster]

Murray, K., and Strack, M. 2016. Controls on methane flux from a constructed fen in the Athabasca Oil Sands Region, Alberta. Joint Canadian Geophysical Union (CGU) annual meeting with the Canadian Meteorological and Oceanographic Society (CMOS). May 29-Jun. 2. Fredericton, NB. [Presentation]

Murray, K., Strack, M. 2016. Controls on methane flux from a constructed fen in the Athabasca Oil Sands Region, Alberta. Water Institute Symposium. Apr. 28. Waterloo, ON. [Poster]

Murray, K., Strack, M. 2016. Controls on methane flux from a constructed fen in the Athabasca Oil sands region, Alberta. 22nd Symposium of the Peatland Ecology Research Group. Feb. 29-Mar. 2. Montreal, QC. [Presentation]

Murray, K., Strack, M. 2016. Methane emission dynamics with an emphasis on vegetation effects from a constructed fen including comparison to reference sites in the Athabasca Oil Sands, Alberta. Annual Eastern Student Meeting of the Canadian Geophysical Union (CGU). Feb. 6. Waterloo, ON. [Presentation]

Sutton, O., Price, J. 2016. Numerical groundwater flow modelling at a constructed fen, Alberta. Canadian Geophysical Union & Canadian Meteorological and Oceanographic Society conference, May 29 – Jun 2, Fredericton, NB. [Poster]

Sutton, O., Price, J. 2016. Numerical modelling of sodium transport at a constructed fen, Alberta. Canadian Geophysical Union Hydrology Section (CGU-HS) conference, Feb. 6, 2016, Waterloo, ON. [Poster]

Van Huizen, B., Petrone, R.M. 2016. Assessing the spatial and temporal trends of seasonal ice in a peatland in the Western Boreal Plains; methods and preliminary results. Canadian Association of Geographers of Ontario Conference (CAGONT). Oct. 28-29. Waterloo, ON. [Poster]

Volik, O., Petrone, R.M., Wells, C.M., Hall, R.I., Price, J.S. 2015. Evolution of a saline wetland in western boreal Canada: a study based on diatoms, pollen and non-pollen palynomorphs. AGU Fall Meeting, San Francisco, USA [Poster]

Volik, O., Petrone, R.M., Wells, C.M., Hall, R.I., Price, J.S. 2016. Long-term precipitation-driven salinity change in a saline peat forming wetland in the Athabasca oil sands region, Canada. Joint CMOS-CGU Meeting, Fredericton, NB [Presentation]

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Sandhill Fen: Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multiple researchers and institutions

Industry Champion: Syncrude Canada Ltd

Status: Multi-year project

PROJECT SUMMARY

The Sandhill Fen Research Watershed (SFRW) is a large scale pilot fen wetland research program designed to address two challenges in oil sands reclamation and closure: 1) the ability to re-establish fen wetlands and 2) technology and practices for reclamation of 'soft tailings'. Syncrude Canada Ltd (SCL) has undertaken over 30 years of research and monitoring efforts on understanding and developing best practices for out of pit landforms and structures (i.e., upland landscapes conducive to the development predominantly of upland forests) such as overburden disposal areas and dyke beaches and slopes of tailings storage areas. In pit hydraulic placement of sand and composite tailings (CT) presents both a new challenge and a new opportunity for oil sands mine reclamation and closure. The challenge is developing technologies suitable for this landform strategy; the opportunity is to advance wetland reclamation because these facilities are more conducive to supporting the development of persistent wetland complexes. Initial studies conducted at the U-shaped cell study site in 2008 were a precursor to this work. That work used wetland reclamation test cells to address the same challenge and opportunity on which SFRW has continued and expanded.

The Sandhill Fen Research Watershed is located in the North West corner of Syncrude's East in Pit (EIP). EIP is the former east mine, which was actively mined between 1978 and 2000. After completion of mining, EIP has been back filled hydraulically with composite tailings. The SFRW area is 57 hectares. It contains 7 upland hummocks ranging in height, shape and orientation. These hummocks were constructed from tailings sand and mechanically placed in 2010. Various soil prescriptions have been applied to the hummocks utilizing coarse sand, surface soil salvaged from either an a/b or d ecosite and standard peat-mineral mix. Coarse woody debris has been applied to all the hummocks. All hummocks were planted with a conventional mix and density of trees (2,000 stems per hectare: aspen, white spruce and jack pine) as well as some shrub species. In experimental plots on each hummock, densities were adjusted. These plots were planted with 0, 5,000, and 10,000 stems per hectare. Simon Landhäusser's group from the University of Alberta leads the revegetation research program on the upland hummocks. They are working collaboratively with Carl Mendoza and Kevin Devito's (University of Alberta) program looking at hummock hydrology and the movement, availability, and interaction of water between the hummocks and the wetland.

The SFRW also contains a 17 hectare wetland. The wetland is surrounded by the upland hummocks. The soil prescription for the wetland is 50 cm of clay till, overlaid with 50 cm of peat-mineral mix. The peat material was salvaged on the Syncrude oil sands lease and stockpiled for less than 1 year before being placed in 2011. The wetland area was seeded in the winter of 2011 with a wetland seed mix collected from reference wetlands in the region. Planting of several native boreal wetland species took place in the summer of 2012. Dale Vitt (Southern Illinois University) is the lead for the wetland revegetation program, looking at suitable native boreal wetland plants and their ability to survive and reproduce across a range of expected conditions. Lee Foote from the University of Alberta is also working in the wetland portion of the study, assessing optimum peat depths and the use of rhizomes for revegetation. Jan Ciborowski from the University of Windsor is executing an invertebrate monitoring research program in the wetland as well. There are two eddy covariance monitoring stations located on the SFRW. One is in the centre of the wetland and the other is in the southern portion of the uplands. These stations, combined with

meteorological data being collected across the site, inform Sean Carey's (McMaster University) program looking at the water, salt and carbon balances.

An online metadata and mapping tool system, developed by the University of Windsor, has been piloted as part of the SFRW as a tool for supporting multidisciplinary research. The tool allows researchers access to information about the type and location (metadata) of data being collected by others who are part of the overall research program. This tool is assisting in collaboration and aids in the ability to cohesively interpret data within the context of the entire project and not just each program component. The specific objectives of the SFRW research program are to gain knowledge and provide guidance for future oil sands lease development and reclamation. Three key study areas are:

- Understanding the nutrient, carbon and water balances;
- Landform design guidance, especially hummock landform technology; and
- Wetland reclamation guidance.

PROGRESS AND ACHIEVEMENTS

The SFRW has recognized a number of research disciplines for research study. The research programs are discrete Projects, integrated under the larger SFRW. A list of these research projects, including the primary investigator and their classification within COSIA are provided in the table below. A more detailed description of the individual projects and their results to date can be found in the accompanying project updates in this document.

Project Type	COSIA Project Number	Project Title	Principal Investigator(s)
Single Industry	LJ 0204	Water and Carbon Balance in the Constructed Fen	McMaster University and Carleton University Dr. Sean Carey Dr. Elyn Humphreys
Single Industry	LJ 0204	Forest reconstruction on upland sites in the Sandhill Fen Watershed	University of Alberta Dr. Simon Landhäusser Dr. Brad Pinno
Single Industry	LJ 0204	The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development	Southern Illinois University and Villanova University Dr. Dale Vitt Dr. Stephen Ebbs Dr. Kelman Wieder
Single Industry	LJ 0204	Hydrogeologic Investigation of Sandhill Fen and Perched Analogues	University of Alberta Dr. Carl Mendoza Dr. Kevin Devito
Single Industry	LJ 0204	Influence Of Peat Depth, Hydrology and Planting Material on Reclamation Success Within a Created Fen-Like Setting	University of Alberta Dr. Lee Foote
Single Industry	LJ 0204	Early Community Development of Invertebrates in Sandhill and Reference Fens – Local Effects of Vegetation, Substrate, and Water Quality	University of Windsor Dr.Jan Ciborowski
Single Industry	LJ 0204	Sandhill Fen Geospatial Metadata System	University of Windsor Alice Grgicak
Single Industry	LJ 0204	Assessing the Sodium Buffering Capacity of Reclamation Materials in Sandhill Fen	University of Saskatchewan Dr. Matthew Lindsay

OUTCOMES AND LESSONS LEARNED

See individual SFRW COSIA project updates for more details.

PRESENTATIONS AND PUBLICATIONS

See individual SFRW COSIA project updates for more details.

RESEARCH TEAM AND COLLABORATORS

See table above and individual SFRW COSIA project updates for more details.

Industry Lead: Carla Wytrykush and Jessica Piercey; Syncrude Canada Ltd

Sandhill Fen: Water and Carbon Balance of the Constructed Fen

COSIA Project Number: LJ0204

Research Provider: McMaster University and Carleton University

Industry Champion: Syncrude Canada Ltd

Status: Year 5 of 6 (one year extension)

PROJECT SUMMARY

The objectives of this research program are to:

1) Measure the ecosystem-scale annual water/energy and carbon (C) balance for the reclaimed fen over a 5 year period (2012–2016) based on complete year measurements of all the major inputs and outputs to the system;
2) Establish the intra-fen variability in net ecosystem production (NEP) and methane flux FCH_4 to establish which areas of the fen are more productive (successful) than others and link this to the ecosystem-scale flux (2012–2016);
3) Characterize the quantity and quality of dissolved organic carbon (DOC) and particulate organic carbon (POC) released from the Sandhill Fen through surface and subsurface hydrological pathways (2012–2016);
4) Monitor changes in DOC and POC quantity and quality across a range of hydrological conditions (2012–2016); and
5) Establish whether the concentrations, fluxes, and quality of DOC and POC are similar to reference wetlands in the local area and other reclaimed fens.

PROGRESS AND ACHIEVEMENTS

Excellent progress continues to be made on water and carbon balances of the Sandhill Fen Research Watershed with continuous year-over-year measurement since 2013. There have been considerable changes in all aspects of the water and carbon cycle, reflecting the evolution of the watershed in terms of vegetation and its integration with the surrounding landscape. A distributed water balance is being completed for each year, utilizing the three meteorological stations, three eddy covariance systems, approximately 25 near-surface wells and annual snow surveys.

Water balances are continuous from January 2013 and are ongoing. Fluxes of water are largely vertical, with evapotranspiration being the major loss of water from the system offset by snow and rain inputs. The general precipitation regime has been slightly drier than normal since commissioning and the bulk of the inputs are from rain, often during intense summer storms. As the surface weir is largely shut off, there is some subsurface loss of water to the down-gradient Kingfisher watershed and groundwater moves in from East-in pit. The magnitude of these fluxes are presently unknown but are being determined by Dr. Carl Mendoza's team at the University of Alberta with program entitled "Hydrogeologic Investigation of Sandhill Fen and Perched Analogues". Evapotranspiration (ET) has been relatively conservative through the years, with some increase in the uplands as vegetation develops. Since commissioning, the vegetation has not been observed to become stressed and limit water uptake, as ET has largely been driven by climate conditions. One of the most notable changes that is occurring in the watershed is ongoing salinization in certain lowland and transition/margin areas, presumably where tailings water is reporting to the surface. Carbon balances indicate that the watershed is moving towards a net carbon sink status, although at this point it is likely carbon neutral. Methane fluxes remain very low.

OUTCOMES AND LESSONS LEARNED

Six graduate students and one post-doctoral fellow have completed their work at Sandhill, and two students continue to do work there. In addition, there are several undergraduates who have completed theses at the site.

Some additional activities in this program include the following:

1. Mercury (Hg) assessment has been completed. As led by Dr. Claire Oswald, a pilot study of Hg output from the fen has been completed and compared to reference fens in the area. A paper has been published in Environmental Pollution.
2. Soil nutrient assessment. Ms. Chelsea Thorne's thesis is using Plant Root Simulator (PRS®) probes and soil chemical analysis to understand the availability and limitations of nutrients for plant growth and assess intra-fen variability in soil quality status.
3 Ms. Kelly Biagi is using stable isotopes and hydrochemistry to better understand the linkage between runoff flow pathways and sources of water.

Objective 1) Balances

Water Balance

Snow water equivalent is measured continuously at three sites on the constructed fen and is supplemented by snow surveys each spring. There was considerable variability in snow depth in 2013, although for the past three years, snow has been less variable and far below the long-term Ft McMurray average of approximately 100 mm. It is generally observed that the research watershed is not a sink for snow compared to other sites at Mildred Lake. A possible strategy for increased percolation could be to design the landscape to create lee (sheltered) slope positions where snow accumulates and flushing is enhanced.

Rainfall is measured at a number of sites on and adjacent to Sandhill Watershed. Rainfall is not highly variable across the watershed. 2013 and 2016 were relatively wet, although 2016 was not wet during the growing season and received considerable late-season precipitation. 2014 and 2015 were comparatively dry compared with the Fort McMurray climate normal. Much of the precipitation is delivered in large convective events of short duration that can occur at any time throughout the year.

Evapotranspiration was measured using the eddy covariance technique at three sites: a tower located in the centre of the wetland area (2013-2016), one to the south of the fen representing the terrestrial surface (2012-2016) and one at the perched fens (2014-2015). Evapotranspiration among the four comparable study years was relatively conservative at the fen, and differences among years may in part be due to missing data. The rate of evaporation during the growing season has not changed considerably, although at upland sites it appears that with time evaporation is increasing (which is expected) as vegetation develops. At this point, there is not much difference between evaporation across the landscape types in a given year. Inter-annual differences are largely due to differences in weather that are driving evaporative demand.

Shallow water tables were measured at a large number of sites throughout the fen (reduced in 2016 due to wildfire). There is considerable intra-fen variability in water table dynamics, which appear to influence geochemistry as areas of the watershed become connected and disconnected from each other. Over the four years, at the centre of the fen portion of the watershed, the water table is virtually always above the surface, and in early years water management had a strong influence on the system.

As observed last year, the upper fen is disconnected in terms of water table from the lower fen. Water drains from west to east when the system is wet, but as it dries, the upper portions of the wetland disconnect and water flows

from the centre of the wetland towards the outlet and also back towards the inlet pond. This suggests that there are areas of hydrological isolation in the upper fen that will be more susceptible to drying and water level decline. In addition, in 2015 the upper fen did not respond to the pumping test, again suggesting its isolation.

While not definitive, there is some preliminary evidence that at the margins of hummocks on the north side of the watershed some recharge from upland to lowland positions is occurring. Further collaboration with the University of Alberta is needed to confirm the extent of this water table mounding and the magnitude of recharge.

Carbon Balance

Vertical CO_2 balances for the fen are calculated at several instrumented towers. Sites are accumulating carbon during the growing season, and at the tower in the centre of the fen, it appears that the site is now a weak carbon sink on an annual basis. At the fen tower, ecosystem productivity dramatically increased in 2015 and was similar in 2016.

Salinity and Water Chemistry

The fen appears to be increasing in salinity year-over-year, through 2016. This is particularly evident along the margins of the wetlands and uplands. A general trend of increasing salinity is evident, particularly among the margins where values are in excess of 4000 µS/cm in 2016. Water in the central part of the fen typically remains below 2000 µS/cm. In addition, the chemical composition of the water has changed from predominantly Ca-SO_4 to NaCl along the margins. Finally, stable isotopes indicate that oil sands process water (OSPW) is reporting along the margins of the uplands and lowlands, particularly along the south side of the fen where water emerges along the toes of the hummocks. The OSPW is tightly associated with sites that have sharp increases in Na concentration.

Objective 2) Methane Flux

Methane flux is very low measured at the fen tower for all years and is low compared with natural reference fens. The working hypothesis is that high sulphate levels suppress CH_4 due to redox conditions.

Objective 3, 4 and 5) DOC and POC

The quantity and quality of dissolved organic carbon (DOC) has been assessed at the fen since 2013 using a variety of techniques and compared with reference fens operated by the University of Waterloo. Results indicate that DOC concentrations are greater in the fen than in reference systems (although not greatly) and more importantly that the quality of the DOC as determined via optical absorption (specific u-v absorption) indicates that the quality of DOC is more degraded than reference systems which is not unexpected considering the peat was oxidized prior to fen establishment.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Nicholls EM, Carey SK, Humphreys ER, Clark MG, Drewitt GB. 2016. Multi-year water balance assessment of a newly constructed wetland, Fort McMurray, Alberta. Hydrological Processes. Hydrological Processes, 30: 2739-2753. doi: 10.1002/hyp.10881.

Oswald CJ, Carey SK. 2016. Total and methyl mercury concentrations in sediment and water of a constructed wetland in the Athabasca Oil Sands Region. Environmental Pollution, 213, 629-637. http://dx.doi.org/10.1016/j.envpol.2016.03.002

Ketcheson SJ, Price JS, Carey SK, Petrone RM, Mendoza CA, Devito KJ. 2016. Constructing fen peatlands in post-mining oil sands landscapes: Challenges and opportunities from a hydrological perspective. Earth-Science Reviews, 161: 103-139. http://dx.doi.org/10.1016/j.earscirev.2016.08.007

Theses

(2015 theses not included in the 2015 Annual Report have been included here).

Kelly Biagi. M.Sc. Thesis. 2015. Understanding flow pathways, major chemical transformations and water sources using hydrochemical data in a constructed fen, Alberta, Canada. 96 pp. McMaster University.

Erin Nicholls. M.Sc. Thesis. 2015. Multi-year water balance dynamics of a newly constructed wetland, Fort McMurray, Alberta. 114 pp. McMaster University.

Chelsea Thorne. M.Sc. Thesis. 2015. A comparison of soil nitrogen availability for a previously mined reclaimed wetland and two natural wetlands in Fort McMurray, Alberta. 105 pp. McMaster University.

Jessica Rastelli. M.Sc. Thesis. 2016. Dissolved organic carbon concentrations, patterns and quality at a reclaimed and two natural wetlands, Fort McMurray, Alberta. 127 pp. McMaster University.

Haley Spennato. M.Sc. Thesis. 2016. An Assessment of the Water Table Dynamics in a Constructed Wetland, Fort McMurray, Alberta. 65 pp. McMaster University.

Conference Presentations

Clark MG, Humphreys, ER, Carey SK. Low methane fluxes from a constructed boreal wetland. Presented at American Geophysical Union Annual Fall Meeting, December 2016.

Biagi K, Oswald, C, Carey SK, Nicholls EM. Understanding the hydrochemical evolution and patterns of a constructed wetland in the Athabasca oil sands region, Canada. Presented at CGU Annual General Meeting, May 2016.

Spennato H, Carey SK. An assessment of water table dynamics within a constructed reclaimed fen, Fort McMurray, Alberta. Presented at CGU Annual General Meeting, May 2016.

Rastelli J, Carey SK, Oswald C. Evaluating the composition of dissolved organic carbon (DOC) with the use of fluorescence indices between a reclaimed and two natural wetlands, Fort McMurray, Alberta. Presented at CGU Annual General Meeting, May 2016.

Clark MG, Humphreys ER, Carey SK. Evolution of function in a constructed wetland over the first two years. Presented at CGU Annual General Meeting, May 2015.

RESEARCH TEAM AND COLLABORATORS

Institution: McMaster University

Principal Investigator: Sean Carey

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Sean Carey	McMaster University	Professor		
Elyn Humphreys	Carleton University	Associate Professor		
Michael Treberg	McMaster University	Research Technician		
Gordon Drewitt	McMaster University	Research Technician		
Graham Clark	Carleton University	PhD	2014	2018
Chelsea Thorne	McMaster University	M.Sc.	2013	2015
Erin Nicholls	McMaster University	M.Sc.	2013	2015
Kelly Biagi	McMaster University	M.Sc.	2013	2015
Jessica Rastelli	McMaster University	M.Sc.	2014	2016
Haley Spennato	McMaster University	M.Sc.	2014	2016
Arthur Szybalski	McMaster University	B.Sc.	2014	2015

Research Collaborators: Carl Mendoza, University of Alberta; Kevin Devito, University of Alberta

Sandhill Fen: Forest Reconstruction on Upland Sites in the Sandhill Fen Watershed

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd

Status: Year 5 of 7 (2 year extension)

PROJECT SUMMARY

The overall goal of this research project is to examine the inter-relationships among tree species, density, understory development and potential water use on upland coarse-textured (a/b ecosite) and fine-textured (d-ecosite) capping materials in a reclamation area. This work will be completed and presented in the context of water availability for adjacent wetlands.

PROGRESS AND ACHIEVEMENTS

- Soil water matric potential in addition to soil temperature were recorded using Decagon MPS-2 sensors installed in 2012 at 10cm and 20cm depths in each of the revegetation plots. These data have been collected throughout the project beginning in May 2013.
- Stand level leaf area was measured using an LAI-2200 (LI-COR Inc., Lincoln, Nebraska, USA) on July 12, 14 and August 26, 2016.
- An inventory of all tree seedlings found in the 78 revegetation plots was performed August 2016 as a follow-up to initial seedling mensuration performed during the 2012, 2013 and 2014 field seasons. Root collar diameter, height and crown diameter were recorded on up to ten target trees for each species in each plot. Survival and natural regeneration ingress was also determined.
- Leaf tissues were collected August 2016 from a subset of planted aspen and pine trees in each plot to determine foliar nutrition. We are still processing nutrient samples.
- Four pairs of Plant Root Simulator (PRS®) probes (Western Ag Innovations, Saskatoon, Canada) were installed in each revegetation plot July 13th to August 23rd, 2016, and pooled for one analysis per plot. PRS®-probes will help determine nutrients available to plants.
- Linear models were performed to determine the effect of aspect, coarse woody debris, and planting density on plant vegetation community development on the two capping materials present on the upland areas of the watershed. Elizabeth Hoffman, analyzed these data as the first part of her Master's project. She used data collected in the 78 revegetation subplots established in 2012.
- Data collected from plant community association plots established in 2014 on both mesic and xeric capping materials were analyzed by Elizabeth Hoffman as the second part of her Master's project with the aim to determine spatial relationships among young plant communities and the possible biotic and abiotic factors that drive those communities.
- Analysis of aspen and pine seedling performance from 30 slope and aspect plots (measured in 2014 and 2015) is underway. This analysis is a follow-up to initial seedling outplanting performance observed in August 2012 by Shaun Kulbaba and Alex Goeppel as part of their Master's projects. Root collar diameter and height were

recorded on aspen and pine stocktypes planted on south and north facing slopes and in hydrogel amended plots in all three years of measurement.

- Using various abiotic and biotic variables collected since 2012, multivariate analyses are being conducted in order to better understand and try to explain tree seedling success in the upland areas of the watershed. Structural equation modelling will be the main tool used to perform these analyses.
- Leaf area index (LAI) measurements could not be performed in May or June of 2016, due to the Fort McMurray wildfire event. Stomatal conductance measurements were also not performed on planted pine or aspen seedlings in order to accommodate other field measurements that were not achieved earlier in the growing season.

OUTCOMES AND LESSONS LEARNED

Results over the first five growing season indicate that surface soil conditions drive tree seedling performance on these sites with the mesic sites producing better growth performance than the xeric sites. Vegetation colonization is driven by the legacy seedbank contained in the respective coversoil material with much greater cover thicknesses on the mesic sites as compared to the xeric sites. Results suggest further that seedling planting density and topographical aspect primarily influenced vegetation diversity, while coarse woody debris abundance primarily influenced vegetation cover. Diversity was higher on cooler aspects and in areas with higher seedling planting density. Cover was negatively associated with coarse woody debris abundance.

Other significant learnings from this program include:

- Vegetation community development and spatial complexity of plant communities develop at different time scales.
- Spatial complexity is driven by micro-topographical variation and variation in tree species cover.
- Introduced/non-forest associated species have been found to be proportionally more prevalent in areas capped with rich-mesic coversoil, however, these species become less important to driving community on older mesic sites.
- Construction of topography at large and small scales can increase landscape heterogeneity. At the Sandhill watershed, variations in large-scale topography (i.e., aspect), was found to influence vegetation diversity, with more diversity on north-facing slopes.
- Dense planting of tree seedlings can be used to attain higher diversity of native species and coarse woody debris placement can be used to attain higher diversity by moderating harsh environmental conditions.
- Survival of planted tree seedlings overall was very high across the upland areas of the watershed (85%), with 95.5% of pine surviving on xeric sites and 64.8% of aspen surviving on mesic sites. At present, the salvaged capping materials do not appear to limit survival. That being said, tree growth on xeric materials does appear to be limited when comparing tree growth to similar sites of the same age.
- In 2015 and 2016 vegetation communities and tree performance continued to be very different on the xeric and mesic capping materials.
- Planted pine growth is becoming significantly higher on north facing slopes, again indicating a more favourable environment for growth as seen with the understory vegetation.
- On the xeric sites, higher understory diversity was associated with north facing slopes and higher planting densities, indicating that these site characteristics are more favourable environments for emergence and growth of native, forest adapted species, resulting in a more diverse community.
- Generally speaking, increasing coarse woody debris (CWD) will result in decreases in understory vegetation cover (there appears to be a threshold). On xeric south-facing slopes, however, understory plant diversity was positively affected by higher CWD, indicating CWD has the potential to help moderate (shelter) harsh environmental conditions. This is supported by other studies in our research group.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Hoffman, E. 2016.Influence of environmental and site factors and biotic interactions on vegetation development following surface mine reclamation using coversoil salvaged from forest sites. M.Sc. Thesis, Department of Renewable Resources, University of Alberta, Edmonton, AB.

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)
Ruth Errington	Canadian Forest Service	Peatland Technician		
Alex Goeppel	University of Alberta	M.Sc.	2012	2014
Elizabeth Hoffman	University of Alberta	M.Sc.	2013	2016
Shaun Kulbaba	University of Alberta	M.Sc.	2011	2014
Simon Landhäusser	University of Alberta	Professor		
Frances Leishman	University of Alberta	Research Technician		
Ellen Macdonald	University of Alberta	Professor		
Katherine Melnik	University of Alberta	M.Sc.	2008 (B.Sc.) 2013 (M.Sc.)	2013 (B.Sc.) 2017 (M.Sc.)
Morgane Merlin	University of Alberta	PhD	2014	2020
Brad Pinno	Canadian Forest Service	Research Scientist		

Sandhill Fen: The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development

COSIA Project Number: LJ0204

Research Provider: Southern Illinois University

Industry Champion: Syncrude Canada Ltd

Status: Year 5 of 5

PROJECT SUMMARY

This project addresses questions centered on plant establishment and development of critical ecosystem functions on a soft tailings deposit that has been reclaimed to a 57-hectare wetland complex at Syncrude East in Pit (EIP). This research is a field scale follow-up to the research performed at Syncrude's U-shaped cell study site. From that research it was learned which species might be selected for wetland and specifically fen species establishment on tailings substrates. In addition, it was learned that invasive species may be a real concern and that several invasive species tolerate the saline conditions predicted for tailings closure features. Despite these advances in our knowledge, we still know little about how plants will respond to reclamation conditions. It is also important to understand how critical ecosystem functions will return on the reclaimed landscape. The specific research being addressed in this program will be:

1. Chemical gradients within Sandhill Fen:
    - Vertical and horizontal gradients in base cations, pH, and alkalinity
    - Wetness

2. Species establishment responses:
    - Vascular plant establishment and growth
    - Moss establishment and growth
    - Invasive species
    - Changes in resource allocation (light, nutrients)

3. Community development:
    - Development of community complexity and species richness
    - Effects of density and competition

4. Nitrogen mineralization, nitrification, and utilization:
    - Atmospheric inputs
    - Dissolved inorganic nitrogen (DIN)/ dissolved organic nitrogen (DON) pools
    - Development of microbial communities

5. Reference sites:
    - Naturally occurring young fens (5-10 years old) as benchmarks
    - Old fens

PROGRESS AND ACHIEVEMENTS

During the 2016 field season at the Sandhill Fen Watershed, researchers continued to:

1) sample water to a depth of 50 cm using sipper wells;
2) collect *Carex aquatilis* tissue from sipper sites;
3) sample soil from the research plots;
4) re-install atmospheric deposition collectors for sulphur and nitrogen compounds; and
5) initiated a more in-depth decomposition study.

In addition to the Sandhill Fen Watershed study area, 10 benchmark peatlands were sampled. From these sites, surface water and volumetric soil cores were collected from the surface to a depth of 10 cm. At the end of the field season, analyses began in the laboratory. A vegetation survey was carried out in August 2016, and plants growing in the fen were identified. Key findings are summarized below

Soil bulk density and water samples were collected in July and September. In July, *Carex aquatilis* leaf tissue for sodium extraction was collected from plants close to the sipper locations. Winter 2016 resin tubes were removed and summer resin tubes were installed and later removed. Winter resin tubes were re-installed and will be removed in May 2017. The resin tubes are currently being extracted for nitrogen and sulphur deposition. A vegetation survey was carried out to determine the species living in Sandhill Fen; community analysis and undesirable plant cover have been completed. Benchmark sites used as natural reference points for Sandhill Fen were sampled again this year. To date the analysis of the surface water samples collected for electrical conductivity (EC), pH, ammonium, nitrate, and soluble reactive phosphorus have been completed. We have analyzed soil samples for bulk density and carbon and nitrogen content.

Renee Hazen concluded her study to determine what wetland species are best for adding organic matter to the peat column. Renee successfully completed her M.Sc. Thesis in December 2016.

OUTCOMES AND LESSONS LEARNED

Water Chemistry: Surface water was collected from plots across the Sandhill Fen (SHF) and from 10 benchmark natural fen sites in the region. The 10 peatland benchmarks (discussed throughout this report) are comprised of 3 poor fens, 3 moderate rich fens, 3 rich fens, and 1 saline fen. Sandhill Fen water samples fell within the range of benchmark values for pH, ammonium, nitrate, and soluble reactive phosphorus. Electrical conductivity at SHF was 2 - 40 times higher than at benchmarks, excluding the saline fen.

Soil Properties: Volumetric samples were collected from the surface to a depth of 10 cm at SHF plots and at 10 benchmark sites. Soil samples were analyzed for bulk density and carbon and nitrogen content. Nitrogen content at SHF fell within the range of the benchmark sites. Bulk density at SHF was higher, and soil carbon content was lower at SHF than at benchmark sites.

Vegetation: A vegetation survey of 85 plots uniformly spaced across SHF revealed 3 species groups that were spatially mapped. Group 1 is dominated by *Typha latifolia* and occurred in areas with deep, standing water. Group 2 is dominated by *Carex aquatilis*, and plots in this group hosted the highest cover of desirable fen species. Group 3 is dominated by *Calamagrostis canadensis*, and occurred in areas of the fen that were relatively dry compared to plots with Group 2 vegetation. Group 3 also had an abundance of seedlings of *Populus balsamifera*. It is concluded that there are both abundant and diverse vascular plants and bryophytes on Sandhill Fen, and that these species are clearly distributed into species groups. Peat-forming species characteristic of natural fen habitats in the region form only a portion of the diversity and abundance on the fen and occupy about 48% of the fen – suggesting that this area has similarities to natural fens of the region. Species groups dominated by upland and undesirable species occupy

38% of the fen, while the species group of marsh plants occupies 9% of the fen - suggesting that these areas may not be on a trajectory to peat-forming fens, but represent early stages of either marsh or riparian plant communities. An additional 2% of the plots were outliers not belonging in any of the first 3 groups, another 2% of the plots lack peat and were too dry to be considered wetland plots. Bryophytes, as major peat-forming species, occur most frequently in only two of the four groups, and never in the group dominated by marsh species. The occurrence of a diverse set of peat-forming bryophytes that occur not only with peat-forming vascular plants, but also in some plots dominated by upland species, suggests that it is too early to determine the fate of these areas. The dominating occurrence of *Calamagrostis canadensis* in these areas may strongly influence their fate.

After analyzing the relationships between sedge species' traits and environmental conditions at the SHF site (Hazen, 2016), it still appears three sedges are highly recommended for returning function to disturbed sites, like Sandhill Fen. *Carex aquatilis*, *C. hystericina*, and *S. microcarpus* were similar in terms of total net primary productivity (NPP), gross photosynthesis, and net ecosystem exchange. Variations were not great between the carbon and nitrogen content of the sedge tissues and the environmental influences on carbon and nitrogen content of these species were minimal. Additionally, the cumulative monthly carbon exchange for the three species during both of the growing season months were positive, while *C. canescens* remained an overall carbon source throughout both years. Based on results from previous chapters and correlations between plant traits and environmental conditions, the species from most robust to least robust in terms of the potential for adding organic matter to the peat column are as follows: *Carex hystericina* > *Carex aquatilis* > *Scirpus microcarpus* > *Carex canescens*.

Three distinct plant communities were found in Sandhill Fen, and when spatially mapped 3 vegetation zones were found within the fen. Zone 1 is characterized by standing water and *Typha latifolia* dominance. *Carex aquatilis* dominates Zone 2, which hosts the largest abundance of desirable fen species. Zone 3 is dominated by *Calamagrostis canadensis* and is drier than peatlands of the region. 48% of the fen is characterized by peat forming species, 34% is dominated by upland and undesirable species, and 9% is dominated by marsh plants.

The area with the highest abundance and diversity of peatland species increased by 8% from 2015 to 2016, and occupies slightly less than 50% of the fen area.

After one year of sampling benchmarks, Sandhill Fen compares well with the 10 sites, except for surface water EC, soil carbon content, and bulk density.

R. Hazen's M.Sc. thesis suggested that there are several species that can add organic matter to the peat column, and that these have the potential to move colonized areas to a carbon sink in the near future.

LITERATURE CITED

Hazen, R. (2016) Fen reclamation in the Alberta oil sands: organic layer development and CO_2 flux of four sedges. M.Sc. thesis, Southern Illinois University, 135 pp.

PRESENTATIONS AND PUBLICATIONS

Hartsock, J., House, M., and Vitt, D.H. (2016) Net nitrogen mineralization in boreal fens: A potential performance indicator for peatland reclamation. Botany. 94: 1015-1025.

Hazen, R. (2016) Fen reclamation in the Alberta oil sands: organic layer development and CO_2 flux of four sedges. M.Sc. thesis, Southern Illinois University, 135 pp.

Vitt, D. H., House, M., and Hartsock, J. (2016) Sandhill Fen, an initial trial for wetland species assembly on in-pit substrates: lessons after three years. Botany. 94: 1027-1040.

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University

Principal Investigator: Dale Vitt

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Melissa House	Southern Illinois University	Research Scientist		
Jeremy Hartsock	Southern Illinois University	Ph.D.	2015	ongoing

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 5 of 8 (3 year extension)

PROJECT SUMMARY

This program looks at integrated hydrologic studies to quantify and generalize landscape and transition zone hydrologic interactions within the Sandhill Fen Watershed 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 reconstruction. This work is tightly integrated with several 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. It also links with Lee Barbour's Industrial Chair for defining landscape hydrology through isotope sampling. 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.

PROGRESS AND ACHIEVEMENTS

This season largely involved the collection of enough field data to document the evolution of hydrogeological conditions for the third year of the now unmanaged system. Over 175 piezometers or wells have been installed at over 70 sites throughout the watershed. About 45 of these installations are continuously monitored (i.e., every hour) and all installations were manually measured weekly to bi-weekly from July to September 2016. Over 120 shallow access tubes have been installed for manually measuring soil-moisture content profiles. Detailed soil pits have been established at 8 hillslope-wetland interface locations to continuously monitor soil-moisture content and tension. Saturation mapping of open water and saturated areas was conducted approximately every two weeks from July to September using the global positioning system (GPS) and an ArcMap enabled iPad.

Most activities in the reporting period involved ongoing collection of data, interpretation of past data, new laboratory measurements and integration of field results conceptual models. Analysis of field data is ongoing. Saturation mapping was further refined this year and has been highly successful.

Field activities:

- Piezometers and wells are nested (70 sites total) and oriented along rough transects (designed for manual and data-logger transducer measurements).
- Measured water levels, temperature and electrical conductivity (EC) manually at weekly to bi-weekly intervals in piezometers, wells and associated surface water.

- Mapped qualitative soil saturation, water depth and EC within the fen watershed (locations, qualitative degree of saturation or depth of water, electrical conductivity and photos) on a bi-weekly basis over the field season. Improved procedure even more with ArcMap enabled iPad.
- Obtained water chemistry samples from all wells and piezometers (early August).
- Maintained and downloaded 45 Solinst data-logging pressure transducers (recording at 1 hour intervals).
- Manual measurements of 126 soil-moisture content access tubes. Collaborative with Simon Landhäusser for all tree plots.
- Downloaded data from 8 soil-moisture content and tension soil-pit stations (hourly data-logger recording at 4 depths each). Focussed on hillslope-toe/wetland-edge interfaces.
- Monitored evaporation pan in the primary fen (seasonal).
- Monitored manual rain gauges at soil-moisture pits and evaporation pan (seasonal).

Data processing (ongoing):

- Hydraulic head and gradient calculations
- EC distributions
- Saturation mapping
- Detailed analysis of soil moisture access tube and soil pit data
- Quality assurance/Quality control (QA/QC) of Sandhill Fen Watershed water chemistry samples

Modelling:

- Ongoing simulation of local hummocks and wetland-hummock interfaces at Sandhill Fen Watershed with respect to URSA sites

OUTCOMES AND LESSONS LEARNED

Similar to last year, preliminary results show that groundwater flow is largely downward beneath the hummocks and the isolated (“perched”) fens, but resulting in negligible groundwater mounding. Mounding beneath the hummocks was less than one metre at the end of the season. Lateral flow gradients are present. Electrical conductivity values increase slightly along the flow path and with depth. The saturation mapping shows a dynamic system that gradually dried out over much of the summer, and rapidly saturated following large precipitation events in the fall.

The following general comments can be made about groundwater flow:

- Some flow reversals appear to occur at the toes of hillslopes;
- Water flows can be influenced by water management or construction activities in adjacent areas;
- Very little, if any, snowmelt reaches water tables below hummocks; and
- Ponded water accumulates at the base of ephemeral draws, coinciding with (a) different reclamation treatments, (b) changes in slope and/or (c) edges of drains.

It is too early to tell which directions water will eventually flow (e.g., forest to wetland vs. wetland to forest, or frequent water reversals).

The electrical conductivity at depth (within 10 m of the ground surface) is 2000 to 3000+ µS/cm, but is lower and highly variable in shallow piezometers and wells.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications for public release in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Carl Mendoza, Kevin Devito

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	M.Sc.	2016	2018
Lindsay James	University of Alberta	M.Sc.	2014	2017
Nicole Brazzoni	University of Alberta	Research Assistant		
David Storm	University of Alberta	Research Assistant		
Chris Spencer	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

NSERC -Syncrude Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms
Collaborator: Lee Barbour, University of Saskatchewan

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

Sandhill Fen: Influence of Peat Depth, Hydrology and Planting Material on Reclamation Success within a Created Fen-Like Setting

COSIA Project Number: LJ0204

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd

Status: Complete and awaiting final report/thesis

PROJECT SUMMARY

Wetlands are largely defined by three criteria: wetland-adapted plants, wetland-specific soils and hydrologic conditions. All three criteria will be tested as measured, controlled factors in this growth trial. Viable rhizomes and seeds of *Carex aquatilis* will be placed in replicated beds of peat installed at 4 distinct depths across a continuum of water depths along a shoreline moisture gradient. The objective is to test peat minimum requirements, operationally feasible rootstock placement, and hydrologic optima at the Sandhill Fen.

PROGRESS AND ACHIEVEMENTS

All field work for this program is complete and the Primary Investigator for this program is on sabbatical. Thesis writing is in progress and defence expected in 2017.

OUTCOMES AND LESSONS LEARNED

This project has no outcomes or lessons that are ready for release to the public. Information sharing is expected once final reports and thesis are available.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications for public release in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Lee Foote

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Mallory Hazell	University of Alberta	M.Sc.	2013	~2017

Research Collaborators: Jan Ciborowski, University of Windsor

Sandhill Fen: Early Community Development of Invertebrates in Sandhill and Reference Fens – Local Effects of Vegetation, Substrate, and Water Quality

COSIA Project Number: LJ0204

Research Provider: University of Windsor

Industry Champion: Syncrude Canada Ltd

Status: Year 3 of 3

PROJECT SUMMARY

Invertebrate community composition and production are affected by many factors. Constraints on the aquatic invertebrate community characteristic of marshes are becoming relatively well understood. However, factors that affect the development and ultimate success of the invertebrates associated with wet meadow, fen and semiterrestrial habitats of peatlands are more poorly understood. Invertebrates are an essential feature of the food web, converting plant material and detritus (peat) into biomass that sustains higher trophic levels (amphibians, birds, mammals).

Sandhill Fen has been the focus of intensive research to document the early community development of the key components of the food web. This project is assessing the zoobenthic community of submerged habitats of Sandhill Fen. We are also collaborating with other Fen researchers who are assessing the effectiveness of soil prescriptions (peat thickness), hydrological regimes (water depth) and plant community characteristics (species and density). The objective of this project is to assess the early community development of the semi-aquatic and upland invertebrates of Sandhill Fen, and its relationship to the plants, water and soil characteristics on which the invertebrates depend for habitat and food.

This study will document the development of a fundamental component of the wetland food web as Sandhill Fen ages.

PROGRESS AND ACHIEVEMENTS

Processing the identification and enumeration of zoobenthic samples collected over the 3 years of the study was completed in December 2016. A final report for this program is expected in 2017. All submerged areas of the fen that were sampled supported a diverse insect fauna, typical of local marsh habitats. In particular sprawling dragonflies (Libellulidae), damselflies (Coenagrionidae, Lestidae), diving and water scavenger beetles (Dytiscidae and Hydrophilidae), and minnow mayflies (Baetidae) were common, all occurring in at least 25% of all benthic samples. Midges (Chironomidae) and worms (Oligochaeta) were found in almost all samples. In contrast, other non-insect invertebrates typical of marsh habitats were absent (snails, leeches, amphipods) in 2013. Snails became increasingly frequent in 2014 and 2015, but few amphipods and no leeches were collected. Measurements of water depth, dissolved oxygen concentration, electrical conductivity, and aquatic plant cover were longitudinally consistent and changed minimally over the course of each field season. But mean electrical conductivity increased each year of the study.

To further assess zoobenthic, and flying insect community composition in Sandhill Fen and adjacent wetlands, the pilot design developed in 2013 to provide baseline information on zoobenthic community composition and distribution in aquatic and semiaquatic habitats of Sandhill Fen was continued in 2014 and 2015 to assess saturated

areas near the boardwalks (20 sites sampled on 3 dates) and drier areas on selected hummocks and near the perched fens (20 sites allocated in groups of 5 among 4 hummock locations). A variety of sampling methods were used, and are described below.

Semi-aquatic and dry areas were sampled at a number of locations; sticky trap samples were deployed at each location identified for submerged sampling (above) as well as in hummock areas. In addition, multiple-trap sampling (sticky traps, vacuum sampling, sweep net sampling pit trapping) was used at a series of damp and dry locations on hummocks and adjacent to the perched wetlands. Sticky traps (8.5 x 11 cm acetate sheets coated with Tanglefoot adhesive) were set in place for three consecutive 24-h periods, and stored frozen for transport to the lab. There, insects were removed from the traps using BirdX solvent, preserved in 70% ethanol and ultimately identified to family level and enumerated.

For comparative purposes, three other sampling methods were employed at the 20 hummock locations – aerial sweeping, vacuum sampling with a modified gasoline-powered leaf blower and pitfall trapping. For Sweep net sampling, triplicate 30-s travelling sweeps were used to collect invertebrates flying among or perched on vegetation. Vacuum samples were also collected at each location. A 0.129 m^2 area of vegetation and substrate was delineated within a plastic box from which the bottom had been removed. Sampling proceeded in 3 stages to collect invertebrates from vegetation proper, from the surface litter, and from the soil, respectively. Pitfall traps were used to collect soil-dwelling invertebrates. Each trap was a 100-mL glass jar filled with a mixture of 95% ethanol and water and buried in the ground so that the rim of the jar was level with the soil. This allowed for mobile soil invertebrates to fall into the trap. A total of 11 pitfall traps were placed randomly in the fen in order to test the suitability of using this collection method. Traps were left out for 24 hours and collected. They were then stored and brought back to the university.

Invertebrates from all types of samples were tabulated and identified to the family or genus level. Debris was dried and weighed to provide an estimate of detrital biomass. Invertebrate biomass was determined by measuring the length of each individual and applying published family-specific length-biomass regression equations.

Multivariate analyses (nonmetric multidimensional scaling and cluster analyses) were used to document similarities and dissimilarities among groups of sites based on plant community composition and subsequently on invertebrate composition. Three distinct groups of sampling sites could be identified based on the dominant vegetation present. *Carex, Typha, Scirpus*-dominated sites occurred in the wettest areas of the fen (which tended to have peat substrate). Drier sites characteristic of the uplands were dominated either by a *Fragaria-Rubus* association or by a *Medicago, Sonchus, Hordeum* association. Each vegetation type tended to support distinctive assemblages of invertebrates. The saturated sites were dominated by planthoppers, thrips, and ladybird beetles. *Medicago, Sonchus, Hordeum*-dominated sites had fauna consisting of thrips, spiders, ants and wasps. In contrast, the *Fragaria-Rubus* dominated sites were distinguished primarily by reduced relative abundances of thrips.

The species richness of plants was determined at sites sampled in 2014 and 2015. Invertebrate taxa richness was assessed relative to plant species richness to determine whether sites with higher plant diversity supported greater invertebrate diversity. There was no correlation between the diversity of the two groups.

Reference lists and representative specimens have been recorded and curated by Kellie Menard as part of her M.Sc. thesis expected in 2017. The catalogue will be included as an appendix of her thesis. The reference collection will reside at the University of Windsor.

Multivariate analysis of the plant and semi-terrestrial invertebrate communities of reference fens revealed marked differences in composition, reflecting differences in the dominant vegetation of particular fen types. The biota of Sandhill Fen was more diverse than that of any of the reference fens, and included elements of fens of quite different type. This reflects the habitat heterogeneity of Sandhill Fen relative to natural fens in the region.

OUTCOMES AND LESSONS LEARNED

The rapid colonization and apparent success of all biota – plants, invertebrates, birds, etc. has been sustained despite evidence of increasing salinity in the ground and surface waters of the constructed fen. This may reflect the ionic composition of the water (enriched in calcium leached from the placed peat and clays); alternatively, local zoobenthos may be more tolerant of elevated electrical conductivity than is commonly thought. It will be especially important to continue tracking water quality, especially the relative concentrations of calcium and sodium, and carbon balance as well as productivity as the fen develops.

Both composition of aquatic invertebrate assemblages and of semi-terrestrial communities are influenced by soil prescription, either directly (peat vs. sand vs. clay vs. LFH) or indirectly through the composition of the plant community that establishes on the different soil types.

Detailed analysis of zoobenthic community composition and abundance relative to local environmental variables (water depth, associated vegetation, electrical conductivity, dissolved oxygen) will help determine the limits of tolerance and will validate provisional reclamation guidance.

Revised estimates of zoobenthic tolerance of saline sodic conditions may be possible (provisionally 3,000 µS/cm vs. former operational definition of 1,500 µS/cm).

PRESENTATIONS AND PUBLICATIONS

This project has no publications or presentations released in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Windsor

Principal Investigator: Jan Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jan Ciborowski	University of Windsor	Professor, Principal Investigator		
Kellie Menard	University of Windsor	M.Sc.	2014	2017
Chantal Dings-Avery	University of Windsor	M.Sc.	2014	2017
Rachel Boutette	University of Windsor	B.Sc.	2013	2017
Hearthy Mayordo	Keyano College	Undergrad	2013	2017

Sandhill Fen: Geospatial Metadata System

COSIA Project Number: LJ0204

Research Provider: University of Windsor

Industry Champion: Syncrude Canada Ltd

Status: Year 5 of 5

PROJECT SUMMARY

To develop a Geospatial Metadata and Mapping system with the objectives of:

1) Improving communication among peers and across disciplines, between researchers and their students, and between researchers and Syncrude.
2) Surmount communication problems that occur as a result of the collection of large datasets in the Sandhill Fen project for a variety of purposes by diverse methodologies and by different researchers.

The overall purpose of the Sandhill Fen Mapping and Metadata System (SFMMS) is to:

a) improve access to and integrated use of spatial data and metadata information amongst researchers and Syncrude Canada Ltd;
b) support decision making and adaptive management for the Sandhill Fen (long-term and short-term);
c) promote multidisciplinary approaches to addressing research questions; and
d) enhance understanding of the benefits of structured archived metadata systems.

PROGRESS AND ACHIEVEMENTS

This program is complete. The tool has been developed and deployed.

The project is currently in an evaluation phase, during which all active research on the Sandhill fen watershed is mandated to use the tool. The system is being evaluated against the objectives described above.

OUTCOMES AND LESSONS LEARNED

To date, the SFMMS worked very well technically. Access and availability to various data sets are very well designed and function well in their web based form.

The University of Windsor's geographic information system (GIS) team successfully created the online metadata cataloguing and mapping system. This includes developing a process for uploading metadata and measurement data related to research assets found on the Sandhill Fen project. In addition to the online tools, the University of Windsor also delivered:

- An editable document (PDF form) was developed using the International Organization for Standardization ISO metadata template with a focus on asset based information;
- A file transfer protocol (FTP) site was set up for data transfer;
- A metadata and data submission schedule;
- Assessed, edited, converted and uploaded information into the SFMMS; and

- Tools that include an expandable map, a database view, drawing tools, print and export map functionality, and aerial history of the site

In terms of the system meeting its objectives, to date a significant improvement in communication among the research team or collaboration through the site has not been observed. However, this impediment could be due to timing. The research watershed is only now finishing its first research phase and approaching a time when collaboration and synthesis activities are beginning. In 2017, the SFMMS will be evaluated to assess if it is capable to surmount communication problems and enable advanced collaboration and synthesis.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Windsor

Principal Investigator: Alice Grgicak-Mannion

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Alice Grgicak-Mannion	University of Windsor	Geospatial Learning Specialist/GLIER Researcher		
Courtney Spencer	University of Windsor	Mapping and Metadata Technician		
Richard Zeng	University of Windsor	Geospatial Applications Programmer		

Sandhill Fen: Assessing the Sodium Buffering Capacity of Reclamation Materials in Sandhill Fen

COSIA Project Number: LJ0204

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd

Status: Year 2 of 2

PROJECT SUMMARY

This project is focused on ion exchange reactions in reclamation materials used in Sandhill Fen. Although the clay reclamation layer in the fen was not designed to provide sodium buffering of oil sands process affected water (OSPW) influx, there was evidence from other research and monitoring that this might be occurring. This research program was undertaken to validate the potential of the clay reclamation material performing a sodium buffering function for the wetland.

The specific objectives of this project are to: (1) assess the distribution of dissolved ions in pore waters of the reclamation cover; (2) determine cation exchange capacity (CEC) of the reclamation materials; and (3) evaluate the sodium buffering capacity of these materials under dynamic flow conditions. This project integrates field and laboratory research activities aimed at meeting these objectives.

The material reclamation material being assessed in this program and associated placement depths from within the watershed are as follows:

- Pleistocene fluvial (Pf) sand – ~10 cm on a/b upland sites
- Pleistocene (Pl) Clay Till – ~50 cm placed in all expected wetland areas
- Peat mineral mix – ~ 100 cm placed in all wetland areas

PROGRESS AND ACHIEVEMENTS

The research activities carried out during the reporting period include: (1) analysis of pore-water and solid-phase data from the field-sampling program; (2) sampling and analysis of effluent water from laboratory column experiments; (3) interpretation of geochemical results from both field and laboratory studies.

OUTCOMES AND LESSONS LEARNED

Initial findings from the field component of this study indicate that elevated calcium concentrations in surface waters are potentially associated with initial clay till pore waters rather than ion exchange with sodium during migration of OSPW through the upper subsoil and peat-mineral mix. Nevertheless, elevated sodium and chloride concentrations at some locations indicated that OSPW has migrated through the reclamation cover. Data from other research groups has shown that electrical conductivity (EC) values have increased in these areas with time. These results generally agree with the laboratory column experiments, which revealed that both Pl clay and peat offer limited sodium attenuation.

Results of this research project indicate that sodium-rich OSPW has migrated through the reclamation cover at some of the sampling locations. Reclamation cover soil pore water from locations immediately south of the primary

fen exhibited sodium and chloride concentrations, and isotopic signatures, consistent with OSPW. This result is consistent with groundwater discharge areas identified in the hydrogeological model (U of A, BGC Engineering) and increasing electrical conductivities identified in surface and groundwater sampling programs (McMaster, SIU, Windsor). Overall, these studies indicate that salt concentrations are increasing due to OSPW migration and discharge, and that the reclamation soil cover will provide limited capacity for sodium buffering moving forward.

The most important lesson learned from this research project is that reclamation cover materials used in Sandhill Fen do not provide substantial sodium buffering capacity. The laboratory experiments revealed that Pl clay and peat possess similar sodium for calcium ion exchange capacities. Additionally, ion exchange reduced sodium concentrations (input versus effluent) by a maximum of 50%, meaning that high sodium concentrations would likely persist despite these reactions. Overall, these results suggest that the Pl clay layer will provide short-lived sodium buffering within the Sandhill Fen Watershed.

PRESENTATIONS AND PUBLICATIONS

Poster Presentations: (Presenting Author)

Vessey, C.J. and Lindsay, M.B.J., (2016). Ion exchange reactions in a constructed watershed for oil sands mine closure. Saskatchewan Geological Open House, November 28 – 30, Saskatoon, Canada.

Vessey, C.J. and Lindsay, M.B.J., (2016). Ion exchange reactions in reclamation cover materials for oil sands mine closure. 2016 Joint Annual Meeting of the Geological Association of Canada and the Mineralogical Association of Canada, June 1–3, Whitehorse, Canada.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Matt Lindsay

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Colton Vessey	University of Saskatchewan	B.Sc. (Geology)	2013	2017
Lee Barbour	University of Saskatchewan	Professor		

NSERC – Syncrude Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms

COSIA Project Number: LJ0210

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 5 of 6 (1 year extension)

PROJECT SUMMARY

The overarching goal of this research is to develop methods of characterizing, monitoring, and simulating water movement through reconstructed oil sands mine closure landscapes. The development of investigative and interpretative tools is focused on the evolving hydrogeology of two of the largest mine closure landscapes: overburden shale and tailings sands. Two relatively large (100–1,000 ha) closure landscapes – South West 30 Dump (SWD, overburden shale) and South West Sand Storage (SWSS, tailings sand) – are the primary study sites supplemented by two smaller landforms comprised of the same materials but with less complexity (W2, a shale overburden dump, and Sandhill Fen Tailings Sand Hummocks, TSH).

The overall objectives are as follows:

1) Develop conceptual and numerical models of reconstructed oil sands mine closure landforms (shale overburden and sand tailings) as Hydrologic Landscape Units (HLUs).
2) Define the magnitude and spatial variability of current rates of recharge into shale overburden and tailings sand landforms.
3) Develop a set of new monitoring tools to track the hydrological evolution of oil sands mine closure landforms over the next 100 years.
4) Develop a model of the transient hydrogeology of large-scale shale overburden and tailings sand landforms.

PROGRESS AND ACHIEVEMENTS

The major activities over the past year are summarized by individual research projects, generally linked to a particular graduate student or research staff member.

Fatemeh Madaeni (PhD – discontinued)

Integrated Modelling of Surface Water and Groundwater Flow and Contaminant Transport within the Southwest Sand Storage Facility

A numerical model of Syncrude's Southwest Sand Storage (SWSS) was developed. The purpose of the numerical modelling was to evaluate the importance of incorporating landform construction chronology and annual variations in net percolation (NP) on the long-term (operating life through 100 y post-closure) performance of a mine closure landform. The modelling approach was to calibrate a one-dimensional (1D) Soil-Vegetation-Atmosphere-Transfer (SVAT) model using long-term site monitoring data (e.g., climate and soil profile monitoring). This calibrated model was then used to simulate annual average net percolation for the operational and long-term, post-closure time frame. A two dimensional (2D) model was then developed to simulate water flow and the flushing of process water from the landform over both operational and post-closure time frames. Four different scenarios are being run which include: a) the use of a single final dump geometry or incorporation of the dump and reclamation cover history into

the model; b) using one annual average value of NP or incorporating changes in average annual NP. Although the PhD has been discontinued, the modelling project is being advanced with paper preparation underway (Madaeni et al. 2017). The expected date of paper submission is April 2017.

James Tipman (M.Sc.)

Calibration and Use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms

This study evaluated if new or existing (i.e., existing geotechnical monitoring) high sensitivity, vibrating wire piezometers placed in foundational aquitards or confined aquifers below mine waste, can be calibrated to detect soil moisture loading such as rainfall or evapotranspiration. This application is referred to in the literature as a Geologic Weighing Lysimeter (GWL). Seven purpose installed piezometers, and four existing geotechnical piezometers, along with three barometric pressure transducers have been monitored at high frequency (15-30 minutes). Various calibrations methods from the literature are compared and contrasted for use in the calibration of GWLs. Barometric response functions (BRFs) have been established for each GWL using observed barometric pressure. Methods for filtering the collected pressure data for instrumentation noise and interference from other loading such as earth tides have been developed. The soil moisture loading observed by the GWLs at the SWSS dyke is being evaluated by comparing the observed soil moisture loading to conventional soil and climate monitoring (O'Kane soil cover monitoring and rain gauges), as well as a specially installed Eddy Co-variance system. Thesis writing is ongoing with completion date tentatively scheduled for April 2017.

Charles Dourado (M.Sc.)

Characterization of Aquitard Geomechanical Properties using Pore-pressure Responses to Surface Barometric and Point Loading

This project is a more fundamental, geotechnical evaluation of the coupled geomechanical and hydraulic responses of a GWL to surface loading. The research is exploring whether the GWL responses to either soil moisture loading or barometric loading can be interpreted more rigorously using geomechanical models to provide better definition of in situ grout and aquitard material properties. The study combines numerical modelling and field testing using localized surface loading adjacent to a set of GWLs to further explore the time dependent pore-pressure response of a GWL to surface loading.

Saidur Chowdhury and Willemijn Appels (PDF)

Salt Generation in Reclaimed Shale Overburden

The rate of salt flushing from saline-sodic overburden dumps must be characterized in order to evaluate the potential impact on surface and groundwater quality post-closure. In this project, field observations from previous M.Sc. studies (e.g., Wall 2005; Joel Hilderman 2011) were synthesized and re-interpreted to characterize the distribution of salts within saline-sodic overburden and to develop estimates of the long-term generation of salt associated with ongoing oxidation. A model analysis of oxygen diffusion into the overburden suggests the hydrology of the soil reclamation covers plays a role in the depths and rates of oxidation of the saline-sodic overburden. The paper (Appels et al. 2017) is complete and under review by the journal Mine Water and the Environment.

Matthew Buchynski (M.Sc.)

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils

This project involved a column test in which isotopically enriched water is infiltrated into a column of unsaturated sand. The isotopes were then allowed to redistribute as a result of diffusion through both the liquid and vapour phases present in the column. Repeated sampling of the profile following infiltration is used to measure the movement of the isotopes over time. A numerical model of water migration and isotope redistribution has been developed and is being used to interpret the data. A newly derived dual-phase (liquid, vapour) diffusion model, along with literature based relationships for dispersion, were incorporated into the transport model. This transport model was then used to interpret the column data. The dual-phase diffusion model appeared to provide a good prediction of the

ongoing stable isotope diffusion. All testing and data analyses are complete with final thesis completion expected by February 2017.

Shahabul Alam (PhD)

Spatial and Temporal Variability in Net Percolation into Reclaimed Oil Sands Mine Waste

Three various study components were advanced over the past year: i) the impact of climate change and variability on long-term reclamation cover performance; ii) field mapping of the spatial variations in the distribution of the stable isotopes of water within oil sands sand tailings; and iii) evaluation of spatial and temporal variability associated with inverse modelling (i.e., calibration) of SVAT models using water balance modelling data.

The first study area led to the development of a journal publication which evaluates the impact of climate change on the water balance for reclamation covers placed over oil sands mine waste (i.e., for saline-sodic overburden and for sand tailings) in comparison to three natural sites (Alam et al. 2017a). Local climate change data was developed (i.e., by downscaling) based on the two different global climate change models (General Circulation Models, GCMs) combined with three associated representative concentration pathways (RCPs). Calibrated SVAT models for the sites were then used to compare changes in water balance for the five soil profiles over four time periods: a 30- year historical (i.e., 1961-1990) climate, and three future (i.e., 2016-2040, 2041-2070 & 2071-2100) time periods. The paper has been finalized and is scheduled for submission sometime in January 2017 (Alam et al. 2017a). An abstract has also been recently submitted for the GeoOttawa 2017 conference (Alam et al. 2017b).

The second study involved a field program in which boreholes and gas monitoring ports were installed along a single transect across a series of slopes and benches in Cell 32 of the SWSS sand tailings dyke. The stable isotope of water composition profile at each borehole location was determined in the laboratory using cores taken during drilling and is being compared to direct field measurements made on soil vapour pumped from each of the gas ports. Combined with detailed mapping of soil water storage at each of the sites (see Spencer Chuhaniuk M.Sc.), it is expected that mapping of the spatial distribution of net percolation can be developed. This research activity is ongoing.

The third study utilizes the data being collected from the Aurora Soil Capping Study (ASCS) on a lean oil sands (LOS) dump at Syncrude's Aurora Mine site. The site contains a range of alternate cover treatments monitored in triplicate, many containing the same types of cover soils and underlying LOS. Inverse modelling using an SVAT model was used to obtain calibrated material parameters from the same monitoring location for multiple years of data (temporal variability), as well as from multiple sites with the same soils (spatial variability). A calibrated model that incorporates these sources of uncertainty is then used to evaluate the impact of the various cover designs on the long-term water balance. The study is ongoing; however, development of a conference paper (Alam et al. 2017c), and then later a journal paper on the study is underway.

Spencer Chuhaniuk (M.Sc.)

A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste

Preliminary testing of the prototype design for the CPT/TDR instrument completed in 2015 highlighted the need to improve the robustness of the design to handle the loading required for full depth (e.g., 20 m) penetration. A final design for the probe was completed and tested under field conditions during the late summer of 2016. More controlled laboratory scale testing is currently underway to further define the operational limits for the instrument (e.g., pore-fluid salinity) and to test the probe on other materials such as Fluid Fine Tailings (FFT). Thesis writing is underway and completion of the M.Sc. is scheduled for May 2017. An abstract has been submitted for the GeoOttawa 2017 conference (Chuhaniuk and Barbour 2017).

Spencer Chad (M.Sc.)

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit

Sampling of site wide waters for the stable isotopes of water at both the Mildred Lake and Aurora mine sites has been ongoing for the past 4-5 years. The data associated with the tailings ponds have shown there is seasonality in the stable isotope of water composition which is associated with seasonal cycles in evaporation rates. This pattern has been observed previously for natural lakes and ponds by researchers such as Dr. John Gibson (UVic). Spencer will utilize these field observations along with site operational data (e.g., recycle water operations and pumping volumes) to evaluate if the seasonal cycles in the stable isotopes of water can provide insight into the water balance for the recycle water circuit (RCW).

Matthew Armoh (M.Sc.)

An Assessment of the Water Balance for Reclamation Soil Covers Placed over Unsaturated Coke and Fluid Fine Tailings

Two prototype reclamation covers were built on hydraulically placed coke that had been placed over fluid fine tailings at the Mildred Lake Settling Basin in 2005. Although these covers were similar in thickness and texture to those used successfully to reclaim overburden elsewhere, early monitoring data at this site highlighted low levels of water storage that may have contributed to challenges with tree growth. This study will undertake a re-evaluation of the water balance for these reclamation covers over the past decade of monitoring with a particular focus on identifying the mechanisms that led to low volumes of stored water within the cover. Matthew has only recently started his M.Sc. and is currently working towards completing course requirements.

OUTCOMES AND LESSONS LEARNED

Integrated Modelling of Surface Water and Groundwater Flow and Contaminant Transport within the Southwest Sand Storage facility

Incorporating material placement chronology has little effect on the location of the water table and the rates of water flow through the sand tailings dyke since the transients associated with changes in the model geometry and net percolation are relatively small (i.e., < 1 year). However, the degree of flushing of process affected water is strongly related to the evolution of the landform over time, as models which incorporate material placement chronology demonstrate more advanced flushing of the landform prior to the end of operating conditions.

Calibration and Use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms

The interpretation of GWLs require that careful processing of the data be undertaken to minimize ‘noise’ which interferes with the soil moisture loading signal. However, once the GWL data is cleaned, it appears that soil moisture loading in the order of 5 mm is well defined by the monitoring data. Improved design and operation of GWLs should enable this threshold to be lowered even further.

Characterization of Aquitard Geomechanical Properties using Pore-pressure Responses to Surface Barometric and Point Loading

Interpretation of the rate of rise and magnitude of the pore-pressure response within the barometric response function (BRF) is interpretable relative to both the compressibility and the hydraulic conductivity of the formation.

Salt Generation in Reclaimed Shale Overburden

Sulphate production rates (e.g., pyrite weathering) and depths estimated from solids chemistry and oxygen diffusion profiles were similar. These rates of sulphate production can be used to constrain salt production rates from overburden dumps.

A model analysis of oxygen diffusion into the overburden suggests the hydrology of the soil reclamation covers plays a role in the depths and rates of oxidation of the saline-sodic overburden.

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils
Numerical modelling of coupled water flow, and vapour and aqueous transport of the stable isotopes of water was able to capture the observed rates of transport measured in large scale column tests.

Spatial and Temporal Variability in Net Percolation into Reclaimed Oil Sands Mine Waste
Fine-textured overburden (D3) had the highest actual evapotranspiration (AET) and the lowest net percolation (NP) during the baseline as well as during future periods, while the reclaimed coarser textured SWSS had a higher AET and lower NP than the coarse-textured natural sites. The two 'a1' natural ecosites (SV10 and SV27) had similar AET and NP rates, while the third more productive 'd2' natural ecosite (SV60) had AET and NP values more similar to the SWSS site. Overall, the use of future climate projections resulted in increased precipitation, potential evapotranspiration (PET), AET, and NP in the reclamation covers and natural sites throughout the 21st century, regardless of which representative concentration pathway (RCP) or time period was used.

Inverse modelling of 4 cover treatments over lean oil sand overburden showed that spatial uncertainty in model parameters was greater than temporal uncertainty; however, spatial variability as measured by direct testing (Guelph and Air-K testing) was similar to that obtained through inverse modelling.

A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste
A robust probe can be built to obtain measurements of stored water volume within deep (> 10m) profiles of sand tailings.

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit
Seasonal cycles in the stable isotopes of water in tailings ponds are similar in pattern as those associated with natural freshwater ponds in the region.

LITERATURE CITED

Alam, M. S., Barbour, S.L., Elshorbagy, A., Huang, M. (2017a). "Evaluating the impact of climate change on the water balance of oil sands reclamation covers", In preparation for submission to: Journal TBD.

Alam, M. S., Barbour, S.L., Elshorbagy, A., Huang, M. (2017b). "The Impact of Climate Change on the Performance of Oil Sands Reclamation Covers: A Comparison of Multiple General Circulation Models and Representative Concentration Pathways". Abstract submitted to: GeoOttawa 2017 (Cdn Geot. Conf).

Alam, M. S., Huang, M., Barbour, S.L. (2017c). "Calibration of HYDRUS-1D for the reclamation cover on Lean Oil Sands (LOS) overburden in Northern Alberta, Canada: Uncertainty in the model parameterization". Abstract submitted to: GeoOttawa 2017 (Cdn Geot. Conf).

Appels, W.M., Wall, S.N., Barbour, S.L., Hendry, M.J., Nichol, C.F., Chowdhury, S.R., (2017). "Pyrite weathering in reclaimed shale overburden at an oil sands mine near Fort McMurray, Canada", Mine Water and the Environment (In revision).

Chuhaniuk, S., Barbour, S.L. (2017). "Real Time Monitoring of Volumetric Water Content in Reclaimed Mine Waste Using Cone Penetration – Time Domain Reflectometry", Abstract in preparation for submission to: GeoOttawa 2017 (Cdn Geot. Conf).

Hilderman, Joel (2011). "Net percolation as a function of topographic variation in a reclamation cover over a saline-sodic overburden dump", M.Sc. Thesis, Dept. of Civil and Geological Engineering, University of Saskatchewan, May.

Madaeni, F., Barbour, S.L., Mendoza, C. (2017). “The Impact of Spatial and Temporal Evolution of Landform Evolution on Salt Release from an Oil Sands Tailings Dyke”, In preparation for submission to: Mine Water and the Environment.

Wall, Susan (2005). “Characterizing the Geochemical Reactions in an Overburden Waste Pile: Syncrude Mine Site, Fort McMurray, Alberta, Canada”, M.Sc. Thesis, Dept. of Geological Sciences, University of Saskatchewan, January.

PRESENTATIONS AND PUBLICATIONS

Published Theses

None in 2016

Journal Publications Related to the IRC

Cook, S., Timms, W.A., Kelly, B.F., Barbour, S.L. (2016). “Improved barometric and loading efficiency estimates using packers in monitoring wells”, Hydrogeology J., Dec.9, (Accepted).

Dompierre, K., Barbour, S.L. (2016). “Thermal properties of oil sands fluid fine tailings: Laboratory and in-situ testing methods”, Cdn Geot. J., doi: 10.1139/cgj-2016-0235, Oct.

Baer, T., Barbour, S.L., Gibson, J.J., Villeneuve, S. (2016). “The stable isotopes of site wide waters at an oil sands mine in northern Alberta, Canada”, J. Hydrol., http://dx.doi.org/10.1016/j.jhydrol.2016.08.017, (in press, available online), August 16.

Nichol, C.F., Froese, K., Sharma, J., Barbour, S.L. (2016). “Effects of oxidation on residual shear strength of shales within the Lea Park Formation”, Cdn. Geotech. J., 10.1139/cgj-2015-0398, published on the web August 1, pp.1-13.

Smith, L.A., Barbour, S.L., Hendry, J., Novakowski, K., van der Kamp, G. (2016). “A multiscale approach to determine hydraulic conductivity in thick claystone aquitards using field, laboratory and numerical modeling methods”, Water Resources Res., doi:10.1002/2015WR018448, 52, July 10.

Pernitsky, T., Hu, W., Barbour, S.L., Si, B.C. (2016). “Effects of Petroleum Hydrocarbon Concentration and Bulk Density on the Hydraulic Properties of Lean Oil Sand Overburden”, doi: 10.1139/CJSS-2015-0126 Cdn. J. Soil Sci., published on the web: June 29.

Dompierre, K., Barbour, S.L. (2016). “Characterization of physical mass transport through oil sands fluid fine tailings in an end pit lake: a multi-tracer study”, J. Contam. Hydrol., June, 189:12-26.

Barbour, S.L., Hendry, M.J., Carey, S.K. (2016). “High-Resolution Profiling of the Stable Isotopes of Water in Unsaturated Coal Waste Rock”, J. Hydrol., March, 534: 616-629.

Pratt, D.L., Lu, M., Barbour, S.L., Hendry, M.J. (2016). “An evaluation of materials and methods for vapour measurement of the isotopic composition of pore water in deep, unsaturated zones”, Isotopes in Enviro. Health & Studies, doi: 10.1080/10256016.2016.1151423, March, 22:1-15.

Huang, M., Zettl, J., Barbour, S.L., Pratt, D. (2016). “Characterizing the spatial variability of the hydraulic conductivity of reclamation soils using air permeability”, Geoderma, doi: 10.1016/j.geoderma.2015.08.014, January 15, 262: 285-293.

Conference Presentations/Posters Related to the IRC

Dompierre, K, Barbour, S.L. (2016). 'Evaluating water and chemical release from oil sands fluid fine tailings using multiple tracers", CYGEGC 2016, Whistler, BC, Sep.29-Oct.1, Dompierre presenting.

North, R.L., Barbour, S.L., Carey, S., Lindsay, M., Dompierre, K. (2016). "Lakes from Waste: Are freshwater-capped tailings ponds sources or sinks for Major Ions?", ASLO 2016 Summer Mtg, Santa Fe, New Mexico, Poster Presentation (Abstract published), Session #: CS10 Aquatic Sciences in the Anthropocene, June 7.

Appels WM, Ireson, AMI, Barbour SL. (2016). "Impact of textural and structural heterogeneity on unsaturated flow and transport through mine waste rock", EGU General Assembly 2016, Vienna, Austria, Ap.18, Poster in: Transfer processes in soil-plant-atmosphere systems.

Reports & Other Publications Related to the IRC

Lindsay, M., Barbour, S.L., Bews, B.E. (2016). "Brief Scientific Update Report Y1: Examining Controls on Mass Loading to an Oil Sands End Pit Lake", NSERC CRDPJ 476388-14, Prepared for Christina Wood (NSERC) for period covering June1 2015 to May 31 2016, May 2, 6pp.

Barbour, S.L., Yarmuch M. (2016). "Water and Carbon Isotope Methods Development", Annual Report for COSIA (Canada's Oil Sands Innovation Alliance) entitled: COSIA Land EPA 2015 Mine Site Reclamation Research Report (April/16), COSIA Proj.No. LJ 0201, Prepared for Angela Hartley: Project Lead, Gather Communications, Jan.18, 3pp.

Barbour, S.L., Heisler, D., Bews, B.E. (2016). "NSERC/Syncrude Canada Ltd. Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms, University of Saskatchewan", Annual Report for COSIA (Canada's Oil Sands Innovation Alliance) entitled: COSIA Land EPA 2015 Mine Site Reclamation Research Report (April/16), Prepared for Angela Hartley: Project Lead, Gather Communications, Jan. 16, 6pp.

Si, Bing, Barbour, S.L., Yarmuch M. (2016). "Evaluation and Modeling of Soil Water Dynamics to Determine Land Capability of Coarse Textured Hydrocarbon Affected Reclamation Soils", Annual Report for COSIA (Canada's Oil Sands Innovation Alliance) entitled: COSIA Land EPA 2015 Mine Site Reclamation Research Report (April/16), COSIA Proj.No. LJ 0099, Prepared for Angela Hartley: Project Lead, Gather Communications, February.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Lee Barbour

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dyan Pratt	University of Saskatchewan	Res. Engineer	-	-
Brenda Bews	University of Saskatchewan	Res. Engineer	-	-
Mingbin Huang	University of Saskatchewan	Res. Scientist	-	-
Stephanie Villeneuve	University of Saskatchewan	Res. Scientist	-	-
Thomas Baer	University of Saskatchewan	M.Sc.	2012	2014
Mengna Lu	University of Saskatchewan	M.Eng.	2014	2014
Mike Amos	University of Saskatchewan	M.Sc.	2012	2015
James Tipman	University of Saskatchewan	M.Sc.	2013	In Progress

Matthew Buchynski	University of Saskatchewan	M.Sc.	2013	In Progress
Charles Dourado	University of Saskatchewan	M.Sc.	2015	In Progress
Spencer Chuhaniuk	University of Saskatchewan	M.Sc.	2016	In Progress
Spencer Chad	University of Saskatchewan	M.Sc.	2016	In Progress
Matt Armoh	University of Saskatchewan	M.Sc.	2016	In Progress
Arash Janfada	University of Saskatchewan	Ph.D.	2012	Withdrew Aug 2014
Fatemeh Madaeni	University of Saskatchewan	Ph.D.	2013	Withdrew Dec 2015
Shahabul Alam	University of Saskatchewan	Ph.D.	2015	In Progress
Willemijn Appels	University of Saskatchewan	PDF	2015	2015
Saidur Chowdhury	University of Saskatchewan	PDF	2015	2015

Research Collaborators:

Integrated Modelling of Surface Water and Groundwater Flow and Contaminant Transport within the Southwest Sand Storage facility (Fatemeh Madaeni)
Collaborator: Dr. Carl Mendoza, University of Alberta

Calibration and Use of Geolysimeters for the Measurement of Hydrologic Fluxes in Mine Closure Landforms (James Tipman)
Collaborators: Dr. Garth van der Kamp, University of Saskatchewan and Dr. Sean Carey, McMaster University

Characterization of Aquitard Geomechanical Properties using Pore-pressure Responses to Surface Barometric and Point Loading (Charles Dourado)
Collaborator: Dr. Jim Hendry, University of Saskatchewan

Salt Generation in Reclaimed Shale Overburden (Willemijn Appels)
Collaborator: Dr. Jim Hendry, University of Saskatchewan

Characterizing the Transport of Stable Isotopes of Water in Unsaturated Soils (Matthew Buchynski)
Collaborators: Dr. Amin Elshorbagy, University of Saskatchewan and Dr. Bing Si, University of Saskatchewan

A Time Domain Reflectometry (TDR)/Cone Penetration Testing (CPT) Probe for Profiling the Stored Volume of Water in Reclaimed Mine Waste (Spencer Chuhaniuk)
Collaborator: Dr. Dave Elwood, University of Saskatchewan

Application of Stable Isotopes of Water to Characterize the Water Balance for Tailings Ponds and the Recycle Water Circuit (Spencer Chad)
Collaborators: Dr. Jeffrey McDonnell, University of Saskatchewan and Dr. John Gibson, University of Victoria

NSERC-Syncrude Industrial Research Chair in Mine Closure Geochemistry

COSIA Project Number: LJ0292

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 3 of 5

PROJECT SUMMARY

Dr. Lindsay's Associate NSERC/Syncrude Industrial Research Chair (IRC) in Mine Closure Geochemistry was established on April 1, 2014 with support from NSERC (Natural Sciences and Engineering Research Council), Syncrude Canada Limited (Syncrude), and the University of Saskatchewan (U of S). The overall goal of this IRC program is to develop geochemical and conceptual models to inform oil sands mine closure planning. Achieving this goal requires that a comprehensive understanding be developed of the geochemical characteristics and evolution of oil sands processing facility wastes within mine 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 are being conducted to elucidate controls on the release, transport, and attenuation of contaminants in oil sands mine closure landscapes. This research examines relationships between geochemical and hydrogeological processes, and assesses the influence of geochemical variability on contaminant mobility across a range of measurement scales. Emphasis is being placed on processes occurring at environmental interfaces, including grain margins and material boundaries. This research addresses four principal objectives:

Objective 1: Define the geochemical characteristics of existing oil sands processing 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 were initially focused on centrifuged fine tailings (CFT, referred to as cake in the IRC proposal) and fluid petroleum coke. Selection of these oil sands processing wastes as principal research foci was based upon three considerations: (i) information on their geochemical characteristics and evolution are limited; (ii) large volumes of these materials will be stored in the closure landscape; and (iii) geochemical research can be immediately applied to ongoing closure planning.

PROGRESS AND ACHIEVEMENTS

The original start date proposed for this IRC program was September 2013; the actual start date was offset by seven months to April 1, 2014. Consequently, some milestones described in the Activity Schedule of the original IRC proposal have become misaligned with actual timing of individual research activities. Nevertheless, progress toward meeting the research objectives has been very strong with excellent progress being made on several objectives during 2016. Details of progress related to the research objectives are described below, in relation to specific research activities outlined in the original IRC proposal.

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

This research objective was focused on CFT and coke deposits and has involved several field-sampling campaigns. Detailed analysis of these samples has been performed to constrain their geochemical, mineralogical, microbiological, and physical characteristics. This research objective was accomplished during 2016; however, preparation of associated publications will continue in 2017.

Activity 1.1 – Characterization of existing centrifuge cake deposits

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 M.Sc. in Geological Sciences on this topic between September 2013 and December 2015. Mattea Cowell subsequently conducted a related B.Sc. honours research project between January and April 2016. This research activity was completed in April 2016 and preparation of two manuscripts for publication in peer-reviewed journals is ongoing.

Activity 1.2 – Characterization of existing petroleum 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 M.Sc. thesis, which he successfully defended in May 2016. This research activity was completed in May 2016 and one journal article was accepted for publication in December 2016 (Nesbitt et al., 2017). One additional manuscript is currently under revision and another one is in preparation.

Objective 2: Identify processes and conditions controlling water quality

This objective includes two principal activities, which aim to improve understanding of relationships between biogeochemical and physical processes influencing water quality in CFT and coke deposits. This objective is dependent upon findings of initial field studies (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 examines interactions among the chemical, biological, and physical processes that influence the geochemical evolution of CFT. Field studies by Heaton (M.Sc.; Activity 1.1) demonstrated that evaporation and freeze-thaw cycling are important controls on pore-water chemistry in CFT deposits. This activity was initially planned to start in 2015; however, in retrospect it made more sense to initiate this research once results from Activity 1.1 were available.

Overall, this research focuses on ion exchange dynamics and biogeochemical sulfur and carbon cycling within CFT deposits. Laboratory experiments were initiated by Mattea Cowell (M.Sc. Student) in December 2016 to examine the influence of gypsum addition rates on hydrogen sulfide and methane production. Additional column experiments to be initiated in 2017 will examine the influence of successive freeze-thaw and evaporation cycles on salt migration and ion exchange reactions. These experiments will utilize CFT produced using different chemical amendment rates (i.e., gypsum, polyacrylamide amendment rates) and will provide additional information on the influence of these chemical treatments on water chemistry. It is anticipated that this research activity will be completed in August 2018.

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

The objective of this activity is to further constrain controls on pore-water chemistry – specifically metal release and attenuation – within coke deposits. Nesbitt's M.Sc. thesis research (Activity 1.2) demonstrated that vanadium, nickel, and molybdenum are leached during infiltration of meteoric water through the vadose zone of coke deposits. The subsequent mobility of these potentially hazardous elements is strongly controlled by pH and reduction-oxidation (redox) conditions.

This research activity was initiated in September 2016 by Mojtaba Abdolahnezhad (M.Sc. Student). He is examining element leaching (i.e., vanadium, nickel, molybdenum, etc.), under varied geochemical conditions. Input solutions representing various site waters are being passed through columns filled with fresh fluid petroleum coke. The geochemical characteristics of effluent from these columns, is being monitored over time to assess element leaching rates and mechanisms under controlled conditions. The start of this research activity was delayed until September 2016 due to challenges recruiting a suitable M.Sc. student. However, this delay has proved beneficial as the experimental design was fine-tuned to reflect field observations (i.e., Activity 1.2).

Objective 3: Constrain geochemical implications of potential closure scenarios

Research focused on this objective was initiated in October 2015 and will continue through 2018. This objective involves 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 examines chemical, biological, and physical processes controlling the evolution of water chemistry under relevant closure scenarios. Research included in this objective is principally focused on layered coke and CFT deposits with and without reclamation soil covers. Results of these experiments will also support development of geochemical and conceptual models of contaminant transport within these closure landscapes.

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

Lysimeter experiments were constructed and instrumented in October 2015 using oil sands processing wastes and reclamation cover materials to emulate three potential closure scenarios: (A) reclamation cover (0.5 m) overlying coke (1.0 m) overlying CFT (1.5 m); (B) coke (1.0 m) overlying CFT (2.0 m); and (C) CFT (2.0 m) overlying tailings sand (1.0 m). These three scenarios have been replicated under water saturated and unsaturated conditions to mimic in-pit and out-of-pit closure landscapes. The scenarios have been modified somewhat from the original IRC proposal to reflect continuing development of mine closure plans.

Specific progress during 2016 included: (1) ongoing field measurements using data logger systems (i.e., water content, matric potential, electrical conductivity, temperature); and (2) water and solid-phase sampling to constrain initial biogeochemical conditions. A suitable PhD student was not identified to initiate this research on the original schedule. Therefore, this research is being conducted by Carlo Cilia (M.Sc. student) and Lawrence Swerhone (M.Sc. student), who will benefit from involvement of a Postdoctoral Fellow (PDF) who has been recruited and will start in May 2017.

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

This objective is 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, therefore, 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 1–3 will support this final activity. This study will integrate the field measurements, laboratory observations, and modelling by PhD, M.Sc., and B.Sc. students into a guidance document that will support ongoing mine closure planning. Lindsay (NSERC IRC) will lead this research activity from 2016 through 2018.

OUTCOMES AND LESSONS LEARNED

Research conducted over the past year has provided valuable insight into the biogeochemical characteristics of CFT and coke deposits. Specifically, this research has shed some light on the biogeochemical processes controlling water chemistry within these deposits.

CFT: Results of this research suggest that gypsum amendment rates vary, often substantially, from the target rate of 1.5 kg t^{-1} dry fluid fine tailings (FFT). The gypsum amendment rate has important implications for cake pore-water chemistry and for biogeochemical processes that influence pore-water chemistry. Specific implications include: (1) higher electrical conductivity (EC) values; (2) higher sodium concentrations; (3) increased potential for sulfate reduction and hydrogen sulfide production; and (4) suppression of methanogenesis and associated hydrocarbon degradation. Research conducted during 2016 observed a systematic increase in dissolved hydrogen sulfide concentrations with increasing gypsum – and therefore sulfate – addition. Linkages between sulfate reduction and methanogenesis are being examined during 2017 (Activity 2.1).

Petroleum Coke: Research conducted in 2016 has further constrained the forms of vanadium and nickel present in fluid petroleum coke. Although vanadium(IV) porphyrins generally account for more than 90% of total vanadium within coke, the remainder was attributed vanadium(III) in octahedral coordination. Similarly, nickel(II) porphyrins generally account for more than 90% of total nickel, while the remainder was attributed to nickel(II) oxides or similar compounds. Research suggests that these non-porphyrin components, which may form during thermal degradation of porphyrin molecules, are a potential source of vanadium and nickel in coke leachates. Moreover, this research indicated that vanadium mobility is enhanced under oxic conditions at pH above 7, whereas nickel mobility is enhanced at pH below 7.

Potential Closure Scenarios (Lysimeters): Initial results have demonstrated substantial differences in salt and trace element mobility, which are attributed to differences in water movement (i.e., saturated vs. unsaturated) and geochemical conditions (e.g., pH, redox potential). Elevated sodium and chloride concentrations were observed in adjacent coke and sand layers. Dissolved hydrogen sulfide concentrations were very high in CFT pore water, and trace elements (e.g., arsenic, selenium) were detected at concentrations generally consistent with those observed in CFT deposits (Activity 1.1). Elevated vanadium and molybdenum concentrations were observed in pore waters obtained from saturated coke layers; however, nickel concentrations were consistently low. Mechanisms of salt and trace element release and migration within these lysimeters are being investigated.

PRESENTATIONS AND PUBLICATIONS

Journal Articles

Nesbitt, J.A., Lindsay, M.B.J., Chen, N., 2017. Geochemical characteristics of oil sands fluid petroleum coke. Applied Geochemistry 76: 148-158.

Theses

Nesbitt, J.A., 2016. Geochemical investigation of fluid petroleum coke deposits at an oil sands mine in northern Alberta, Canada. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Canada, 120 pp.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Saskatchewan

Principal Investigator: Dr. Matthew Lindsay

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Kaitlyn (Scott) Heaton	University of Saskatchewan	M.Sc.	2013	2015
Jake Nesbitt	University of Saskatchewan	M.Sc.	2014	2016
Carlo Cilia	University of Saskatchewan	M.Sc.	2015	In progress
Mattea Cowell	University of Saskatchewan	B.Sc.	2015	2016
Lawrence Swerhone	University of Saskatchewan	M.Sc.	2016	In progress
Mattea Cowell	University of Saskatchewan	M.Sc.	2016	In progress
Mojtaba Abdolahnezhad	University of Saskatchewan	M.Sc.	2016	In Progress
Dr. Lee Barbour	University of Saskatchewan	Professor and NSERC IRC		
Dr. Joyce McBeth	University of Saskatchewan	Assistant Professor		
Dr. Ning Chen	Canadian Light Source	Staff Scientist		

Coal Watershed Research and Development Program

COSIA Project Number: LJ0160

Research Provider: University of Saskatchewan, Montana State University, McMaster University, SRK Consulting, Integral Ecology, O'Kane Consultants Inc.

Industry Champion: Teck Resources Limited

Status: Year 5 of 7

PROJECT SUMMARY

In 2011 Teck Resources Limited (Teck) embarked upon an applied research and development (R&D) program focused on managing constituents of interest (CIs) in mining-affected watersheds. The overall objectives of the program are to:

1. Develop new technologies and techniques and/or enhance existing technologies to manage water quality; and
2. Communicate the results of this program through Teck's internal technology transfer process.

The applied R&D program is focused on research and development projects to investigate contaminant sources and advance source control methods, specifically related to mine design and water management strategies to manage CIs. The program is directed towards developing the scientific and engineering information required to inform geochemical, hydrological (including hydrogeological) and biological conceptual and numerical models that underpin mining activities, to evaluate their impacts, and to identify feasible methods to limit the production and release of CIs from mine wastes. A separate, but integrated, effort is the active water treatment technology program which is focused on the investigation of active water treatment technologies to remove and reduce CIs present in mine-affected water. The active water treatment research is focused on identification of improvements for active water treatment technologies.

As highlighted above, rapid technology transfer is one of the two overall objectives of the applied R&D program. This focus is represented in the overall approach to research and development wherein there is:

- pro-active identification of opportunities to demonstrate and test promising practical strategies or technologies at a field scale (development) to rapidly work through and document the critical engineering design and construction questions and solutions (often the predominant issues) in a practices manual; and
- support of pilot-scale and full-scale applications with research projects, which address specific questions arising from the planning and implementation of the field tests, thereby focusing the research projects to clearly and directly support implementation of the specific practical strategies or technologies and to inform risk/benefit analyses.

PROGRESS AND ACHIEVEMENTS

The original five focal research areas identified in the watershed R&D program include:

- ex-pit waste rock dump design and management;
- water balances to aid water management decisions;
- rock drain design and operation;
- saturated zone design and operation; and
- reclamation and selenium (Se) management.

Substantial time and resources have been invested in sampling and instrumenting research areas to commence data collection in support of these research areas. This program continues to answer research questions and many of the original projects continued through 2016. Additional focal areas were added in subsequent years, including research into nitrate management, and an increased focus on evaluating practical strategies for mine design. In 2016, the focus of the program was on a field scale trial of one of the more promising alternatives to active water treatment for the mitigation of selenium and nitrate – saturated rock fills.

Saturated rock fills – field scale trial

The results from the laboratory studies conducted in 2015 indicated that an appropriate microbial community, capable of reducing selenium and nitrate, existed in the waste rock obtained from the test site. Those results, coupled with characterization studies for the same site, were positive indications that saturated rock fills should be a viable technology for mitigation of CIs. However, the potential for unintended consequences and the existence of unknown variables from the differences in scale between the laboratory and the field required a field-scale trial.

Prior to conducting a field-scale trial, a site selection process was conducted. The selection process considered a number of variables related to the experiment (thickness of saturated zone, geochemistry of source water, etc.), as well as practical concerns (potential impacts to the site from mining operations, discharge possibilities, etc.). The same site where the characterization was conducted in 2015 was selected for the field trial and the well and piping infrastructure was slightly modified to conduct the field-scale trials.

The infrastructure for the trials consisted of a fairly simple configuration of injection, extraction, and monitoring wells. The field-scale trials consisted of a number of phases – the first ones were necessary to establish some fundamental understanding of the hydrologic characteristics of the saturated rock fill. Subsequent phases were necessary to establish that reduction reactions were occurring and to estimate an approximate rate at which both selenium and nitrate were being removed from the mine affected water by these reactions. The results of the field-scale trials indicated that an appreciable percentage of the selenium and nitrate in the water injected to the saturated fill was being removed from the water.

Saturated rock fills – function at laboratory and field scale

The proposed use of saturated rock fills as a treatment for mine affected water is predicated, in part, on the assumption that an indigenous community of microorganisms in the waste rock is capable of reducing and removing selenium and nitrate from the aqueous phase. Column studies conducted in 2014 and 2015 indicated that selenium and nitrate reduction by the microbial communities in the waste rock does occur and can result, under laboratory conditions, in appreciable removal of these CIs from mine affected water.

In 2016, laboratory column studies continued and focused on addressing several of the risks identified in the 2015 workshop on risk assessment. Principal questions related to the ability and capacity of the microbial community to continue removing selenium and nitrate when stressed by changes in the influent water chemistry. Results of the studies indicated that continued reduction did occur.

Saturated rock fills – risk assessment

The use of saturated rock fills as a treatment for mine affected water is not without some level of risk. To evaluate the level of risk, two workshops were conducted in 2016 to identify and quantify risks associated with this technology. The first was an update of the workshop conducted in 2015. In this workshop, the potential failure scenarios developed in 2015 were reviewed and updated with results of the experiments and assessments that had

been developed and conducted based on the 2015 workshop outcomes. The second workshop focused on risks associated with effluent. In each workshop, a risk scenario was identified (or reviewed), and the likelihood of that scenario occurring, as well as the severity of consequences resulting from that scenario were estimated in order to establish a level and range of potential risks.

Risks were generally focused on biogeochemical issues that affected either water quality, or the release of gases that would affect human health and safety. Geotechnical risks associated with the stability of the saturated fills, as well as risks around stewardship and cost were also identified. The conclusion from both of the 2016 workshops is that there are risks associated with this technology, but all appear to be manageable with appropriate controls.

OUTCOMES AND LESSONS LEARNED

As noted in the project descriptions above, many of the projects are in mid-stages with data synthesis underway. Outcomes and lessons learned are not ready for release to the public. Interim draft results are summarized in the *Research and Technology Development Progress Report*, which will be available to COSIA April 1, 2017.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Kirk, L., et al., 2016, Selenium Biomineralization Applied to Mine Facility Design. Abstract and Presentation submitted to the Goldschmidt Conference, Yokohama, Japan, June 25-July 1, 2016.

Koepnick, H. et al., 2016, Selenium Bioreduction in Mine Waste Rock at Cold Temperatures. Poster submitted to the Montana Biofilm Meeting, Bozeman, United States, July 15, 2016.

Mahmood, N., Hendry, J. Barbour, S. L., Klein, R., Kennedy, C., 2016, Origin and Fate of Nitrate in Coal Waste-Rock Dump in the Elk Valley, British Columbia, Canada. Abstract and Presentation submitted to the University of Saskatchewan, Graduate Student Conference, Saskatoon, Canada, March 4-6, 2016.

Villeneuve, S. A., Barbour, S. L., Hendry, M. J., 2016, An Evaluation of Net Percolation Through a Waste Rock Dump in the Elk Valley, British Columbia, Canada. Abstract submitted to the GeoVancouver Conference, Vancouver, Canada, October 2-5, 2016.

Published Theses

Mahmood, N., 2016, Nitrate in Coal Waste Rock Dumps, Elk Valley, British Columbia, Canada. Thesis submitted to the College of Graduate Studies and Research, University of Saskatchewan, Saskatoon. August 2016.

Schabert, M., 2016, The Application of Push-Pull Testing to Define Biogeochemical Controls on Selenium and Nitrate Attenuation in Saturated Coal Waste Rock. Thesis submitted to the College of Graduate Studies and Research, University of Saskatchewan, Saskatoon, October 2016.

RESEARCH TEAM AND COLLABORATORS

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jim Hendry	University of Saskatchewan	Principal Investigator		
Lee Barbour	University of Saskatchewan	Principal Investigator		
Brent Peyton	Montana State University	Principal Investigator		
Lisa Kirk	Montana State University, Enviromin	Principal Investigator		
Sean Carey	McMaster University	Principal Investigator		
Chris Kennedy	SRK Consulting	Principal Investigator		
Stephen Day	SRK Consulting	Principal Investigator		
Daryl Hockley	SRK Consulting	Principal Investigator		
Dan Mackie	SRK Consulting	Principal Investigator		
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Justin Straker	Integral Ecology	Principal Investigator		
Tyler Birkham	O'Kane Consultants, Inc.	Principal Investigator		

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 Resources Limited

Status: Year 2 of 4

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 16 years. This work is focused on informing the Oil Sands industry about the natural functioning of aquatic, peatland and forestland systems with heterogeneity in vegetation and geology representative of the Ft. McMurray region. The recently burned Utikuma region encompasses 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 risk of landscape failure is most significant. Knowledge gained from this research will support future management and catchment area 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, and 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 ecosystem 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 – 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 vs. productivity varies in succession (or development) of wetland vs. forestland ecosystems, and
- the role of organic (peat) depth vs. local (soils) and regional (HRA-connectivity) geology on the successional trajectory of natural and constructed wetlands and forestlands. By testing this on natural ecosystems in succession following watershed burning we can provide an understanding of the controls on the maintenance of ecosystem function.

These findings can be used directly in developing landscape design criteria at both the local and oil sands 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 flux and storage of water within natural analogue landscapes. The research is examining 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). The resulting information will be used to determine how the interactions affect the trade-offs between catchment runoff and ecosystem productivity.

Specific objectives to address the hypotheses and questions are addressed in 3 Scopes of research and 9 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 evapotranspiration (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 provide inputs for modelling and assessment of peatland sustainability.

Objective 4: ***Ephemeral draws.*** Determine the controls on ephemeral draw wetland formation and the role of ephemeral draws 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 system.

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) and HU (wetland and forestland) proportion and connectivity on coarse scale AET, water 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: Integrate the research questions and results from the larger catchment runoff responses and process field studies to parameterize "fuzzy box models" for different landform and landscape configurations which will aid in determining the initial configurations of constructed catchment hummocks, forestland, riparian and wetland/ peatland ecosystems that are more sustainable and resilient.

PROGRESS AND ACHIEVEMENTS

2016 represented the second year of a four-year COSIA project. All projects listed as objectives or deliverables have been initiated and results are presented in the outcomes section and scientific publications listed below for the 2016 year.

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

At the end of the field season all sites had been selected and detailed hydro-meteorological, eco-hydrological and hydrogeological instrumentation was installed, and investigations were initiated along forestland-riparian-wetland transects to answer questions associated with objectives 1, 2, 4, 5 and 6.

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

The work to address both research questions (Q1.1 and Q1.2) associated with this objective has been initiated.

Q1.1, Can layering soils in peatlands (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 Alberta Oil Sands (AOS) landscapes?

- Continuing from earlier studies on Q1.1 (Lukenbach et al. submitted), L. James (M.Sc.) completed water balance studies of an isolated peatland, and results indicate that high storage (low density) surface or acrotelm peat conserves water for the peatland. S. Probert (M.Sc.) has explored the effect of leaf litter layers on evaporation rates within peatland and swamp margin interfaces.
- Ecosystem scale flux measurements and transects of vegetation structure and composition, ice layer dynamics and soil moisture in an isolated peatland, lead by Sutherland, Kessel and Chasmer (Tech), will be used to relate internal controls of above and below ground layering on ET and water use efficiency (WUE); data has been collected, analysis is in progress with publications pending (De Haan [UGRAD]).
- Dixon (PDF) has completed simulations exploring the control of soil layering on storage and conservation of moisture in peatlands. Thompson (PhD) has completed the conceptual and numerical modelling to examine the influence of peat and mineral soil layers on peatland and forestland moisture conservation and water movement at the catchment scale and is completing and documenting simulations on the influence of ice.

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

- S. Dixon (PDF) has conducted modelling work, Hurley (PhD) has initiated experimental and field based work, and L. James (M.Sc.) completed hydrologic response studies on clay rich soils in ephemeral draws and peat margin swamps. These studies indicate that mineral soils with low water storage properties and rapid water table responses to precipitation events through the year maintain soil saturation and anoxia that support wetland (swamp) conditions.

- Deep peat burning during wildfire was observed to expose fine-textured mineral substrates at the surface near peat margins. Following wildfire, this results in frequent soil saturation and flooding (Lukenbach et al., submitted). While these wet conditions can foster the establishment of wetland species, if flooding is too deep or prolonged, it is likely not conducive to peat-forming vegetation (Lukenbach et al., submitted).

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

Work to address research questions (Q2.1 and Q2.2) associated with this objective has been initiated by R. Leonard (PhD) and S. Wilkinson (PhD).

Q2.1, What are the expected recovery rates and succession of wetlands (peatlands) with large-scale wildfire disturbance?

- B. MacKinnon (M.Sc.) has demonstrated that hydrophobicity exerts a large control on vegetation (moss) with regions with no peat cover having higher moss cover post-disturbance.
- Field work examining surface and above-ground vegetation recovery/trajectory (K. Housman, M.Sc.) and peat accumulation (R. Ingram, M.Sc.) was completed this year in peatlands across HRAs at sites ranging from 5 to 100+ years post-fire.
- Sutherland and Kessel (Tech) are leading the comparison of surface energy balance, evapotranspiration (ET) and CO_2 among burned and unburned peatlands.

Q2.2, How does water loss via evapotranspiration vary through the range of wetland succession trajectories and changes in peat and mineral soil layer, frost formation, and storage?

- Ecosystem scale flux measurements and transects of a space for time chronosequence of vegetation structure and composition, ice layer dynamics and soil moisture in an isolated peatland, led by Sutherland, Kessel and Chasmer (Tech), will be used to relate internal controls of above and below ground layering on ET and water use efficiency (WUE). Data has been collected and analysis is in progress with publications pending (De Haan (UGRAD)).
- Samples spanning HRAs and time-since-fire have been collected. Lab analysis of unsaturated hydraulic conductivity of peat from the vadose zone is ongoing (S. Wilkinson, PhD; C. McCann , Tech.).
  - Results from lab analysis will be used to parametrize the Peatland Hydrologic Impact (PHI) model to understand how peat properties limit evaporation and change with wetland succession (P. Moore, PDF; S. Wilkinson, PhD)
  - Results from samples along the forest-wetland interface also have important implications for Objective 6, wetland-forestland interfaces.

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.

It will be a focus of our research over the next two years and we expect it will be completed by the end of year 4.

- Addressing this objective relies largely on further progress in the earlier work by N. Kettridge, R. Leonard (PhD) and M. Lukenbach (PhD).This work has been continued by S.Dixon (PDF) and P. Moore (PDF).
- Sophie Wilkinson (PhD) has been recruited to continue the modelling. Samples to parameterize model simulation were collected during 2016 field season.

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

One more year of fieldwork is expected and data analyses and write up has begun. Final completion of the three questions below is expected by year 4.

- The instrumentation and detailed hydro-meteorological and eco-hydrological studies of an ephemeral draw and adjacent forestlands, was completed by A. Hurley (PhD).
- G. Sutherland (Tech), L. James (M.Sc.) and undergraduate students (Hrach and De Haan) conducted the second year of hydro-chemical measurements and detailed hydro-meteorological and eco-hydrological studies of a perched peatland and riparian swamp to address the three questions below.

  Q4.1, What is the water balance of an ephemeral draw and how does it change from early succession to mature?

  - Hokanson (Tech) and Hurley (PhD) continued analyses on the water balance for the ephemeral draw.
  - L. James (M.Sc.) completed the water balance of an isolated peatland and riparian swamp. Results indicate that net precipitation is greater than actual evapotranspiration and the site is a net source of water to the adjacent forests. Similar soil storage-precipitation relationships exist between the isolate peat-swamp system and the nearby study ephemeral draw.
  - Site selection (C. Alison, TECH) and measurements (K. Housman, M.Sc.; R. Ingram, M.Sc.; S. Wilkinson, PhD; C. McCann, Tech.) of chronosequence to assess how the water balance of riparian area or ephemeral draws may change with succession have been conducted.

  Q4.2, What is the role of substrate layering and ice in generating lateral flow in ephemeral draws?

  - Studies on a perched peatland margin swamp (L. James, M.Sc.) combined with earlier studies on the ephemeral draw indicate that a shallow depth to clay confining layer and ice play a large role in maintaining wet soil conditions and generating lateral flow to adjacent forestlands from both peatlands and margin swamps.

  Q4.3, How does ephemeral draw width and geometry control the proportion of flow to adjacent forestlands and downslope peatlands and wetlands?

  - A. Hurley (PhD) completed instrumentation of the ephemeral draw study site and examined the role of ephemeral draw width and geometry on lateral flow and adjacent forestland water use. Data analyses were initiated and one more year of data collection is anticipated.

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.

The instrumentation and detailed hydro-meteorological and eco-hydrological studies of the forestland hummock to address the three research questions has been completed. Data analyses continue, numerical model simulations have been initiated, and final completions of the questions are expected by year 4.

Q5.1, How do hummock texture, configuration, height and size influence the proportion of vegetation water use vs. recharge?

- Hokanson (Tech) completed well and soil pit instrumentation on a burned forest hummock. Lukenbach (PDF) is completing analyses and comparison with reclaimed oil sands forested hummocks.

- Lukenbach (PDF) and Dixon (PDF) have initiated modelling scenarios of different sizes and textures of forestland hummocks adjacent to peatlands to infer ranges in recharge, water use and surface-groundwater interactions expected in closure lease designs.

Q5.2, 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?

- Boundary-layer dynamics and forest sheltering of peatlands has been conducted by A. Green (M.Sc.); Validation data and canopy/vegetation structures have been acquired
- The model RAFLES is being setup to simulate how upland forest structure influences turbulence in adjacent peatlands and their energy and mass fluxes.

Q5.3 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?

- Results from forestland hummocks (Objective 4) and WFI (Objective 6) on both fine textured and coarse textured locations are being used to parameterize models to simulate influence of texture and vegetation state (Thompson et al. 2016).
  - The studies of forested and regenerating aspen forest show that in general runoff and recharge is low, but does vary greatly with substrate texture (HRA), layering (coarse over fine) and height of hummock.

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 system.

Q6.1a, How does HRA and texture control the magnitude and direction of water across the WFI?

- Hokanson (Tech), Lukenbach (PDF), and Dixon (PDF) have started to collate information and begin the synthesis of information from Objectives 5 and 6 (Depante, James).
- Hokanson (Tech) has completed analyses of several transects across URSA (see also Hokanson et al. 2016)
- Surface topography, mineral soil, and peat properties have been measured along the WFI and across HRAs (R. Ingram, M.Sc.; C. McCann, Tech.). A chronosequence approach was used to determine whether there are systematic differences in peat properties at the WFI with time since fire. Analysis of field samples (C. McCann, Tech.) and data is ongoing.

- Analyses of field data were completed at three burned (early succession) WFIs, each in different HRAs (Lukenbach et al., submitted).
  - The magnitude and direction of water fluxes across burned WFIs is largely influenced by HRA.
  - In coarse-textured HRAs, water level fluctuations are limited at WFIs when they are well connected to large-scale groundwater flow and water movement across WFIs is influenced by larger-scale groundwater flow direction.
  - Fine-textured soils underlying WFIs, which can be present in coarse-textured HRAs as well, result in highly variable water table configurations that occasionally (during wet periods) result in water movement from the WFI to adjacent wetlands and forestlands. These fine-textured soils also limit water losses from peatlands and WFIs.
  - Lukenbach (PDF) has initiated modelling scenarios to further address this question.

- S. Dixon (PDF) is currently developing conceptual models that characterize the influence of landscape position and layering on hydrologic function of WFI. 2-D numerical simulations have been initiated to test these models.

Q6.2, How does vegetation (succession, species, roots) modify the interaction?

- Variation in vegetation community (K. Housman, M.Sc.) and tree stand characteristics (S. Wilkinson, PhD) along the WFI have been measured across HRAs using a chronosequence approach to infer succession patterns post-fire. Analysis of field samples (C. McCann, Tech) and data is ongoing.

Q6.3, 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?

- Detailed hydro-meteorological and eco-hydrologic studies of a burned peatland-riparian and upland forest hummock have been completed (Depante, M.Sc.; Hokanson,Tech; Hrach; De Haan (UGRAD); Sutherland; and Wells, Tech) and journal articles prepared.
- Preliminary studies of water use and flow of mature and regenerating aspen on hummock tops and mid-position and the adjacent peatland (Depante, M.Sc.; Carron and Pow, UGRAD), indicate large water demand and use in mid-hillslope position and peatland areas by riparian aspen. This indicates that water and nutrients do move from peatlands into riparian areas and up into forestlands.

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

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

- K. Hokanson (Tech), P. Moore (PDF) and Devito have completed the regional runoff estimates from natural HRAs and HUs of the central mixed wood boreal forest.
- The first manuscript on long-term runoff has been submitted to a scientific journal (see Devito et al. 2016b), and the manuscript examining threshold responses will be submitted in early April.

Q7.1, How does the proportion and connectivity of HRA (coarse and fine) and HU (wetland and forestland) affect coarse scale AET, storage type and long-term runoff response of BP catchments during different climate cycles?

- The regional analyses indicate that local processes (Scope 1) appear to scale up to larger catchments similar in size to Oil Sands leases. The lowest ET and highest runoff (i.e. source of water) is associated with terrestrial wetlands (peatlands and swamps), and runoff appears to be further enhanced in course textured HRA's. Long-term runoff is reduced in catchments with aquatic wetlands (lakes and marshes). Low long-term runoff is associated with aspen ecosystems, and further reduced with the presence of hummocky moraine HRA's in the catchment.
- Ratios of about 2:1 of aspen forest and open water wetlands to peatland and swamp ecosystems represent the minimum percent cover of peatlands (i.e., 30% peatland) needed to sustain reasonable long-term runoff from natural landscapes.
- There is a large variation in runoff with climate cycles, and large spatial variations in threshold responses during wet cycles that depends on the proportion of HRA and HU. However, in general runoff is low which is an issue in designing landscapes (Devito et al. in review).

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

Q8.1, 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)?

- K. Hokanson (Tech) and E. Pugh (PhD) continued hydro-chemical sampling across the URSA sites, completing a 17-year data set from 1999-2016 that now includes samples through a dry, mesic and wet climate cycle, and pre and post fire.

- K. Hokanson has completed regional analyses and revealed large differences in recharge-discharge functions of lakes and wetlands across different HRAs and landscape positions. However, lake and wetland chemistry and isotopic characteristics indicate limited interaction between surface waters and deeper groundwater (Hokanson et al. 2016).
- In aspen dominated moraine HRAs, similar to overburden storage on the Oil Sands, modelling studies indicate that there is large difference in hydrologic response of peatlands relative to pond and aspen hillslopes over the different climate cycles, and that ponds and aspen forest may be much more susceptible to long-term climate warming (Schneider et al. 2016; Thompson et al., 2015, 2016).
- The hydrological and geochemical responses of peatlands to and its evolution following soil and vegetation disturbance by fire is complex;
  - Early field work and recent analyses (E. Pugh) indicates little net increase in surface peat nutrients or mobility of carbon following fire.
- Modelling studies also indicate that the timing of the disturbance, relative to long-term climate cycles and the antecedent moisture of the ecosystems, influences the hydrologic connectivity and the magnitude of the hydro-chemical response to disturbance. In most years, which are either periods of dry or mesic (near average rainfall) climate, limited response to harvest disturbance occurs as source areas are poorly connected hydrologically to receiving waters (Thompson et al. 2016).

Q 8.2, How does forest biomass relate to the spatial weighting and configuration of wetland-forestland interfaces on different HRAs and during early succession (post-wildfire)?

- Work is still ongoing to parameterize Lambert's allometric equations and apply LiDAR data to quantify biomass to the hydrologic units to determine the critical threshold in relative sizes controlled by surficial geology (Chasmer; collaborator; Marczak and Sutherland, Tech).
- Preliminary analyses indicate that stand and HRA water balance will be influenced by the configuration of HUs and wetland-forestland interfaces.

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

Objective 9: ***Catchment design and application.*** Parameterization of "fuzzy box models" to use in the design and construction of catchment areas to maximize water use for sustainable and resilient catchments.

- Initial refinement of existing and developing alternative conceptual models for numerical model development based on findings from Scope 1 and Scope 2 are ongoing.
- Initial parameterization of "fuzzy box models" has been conducted to determine the influence of the configurations of constructed catchment hummocks, forestland, riparian and wetland/peatland ecosystems on water use and movement.
- Lukenbach (PDF) is comparing existing constructed landscapes on the Syncrude sites with current forest hummock-riparian-peatland studies.
  - Lukenbach (PDF) has analyzed field data from natural and reconstructed sites. Results indicate that in early successional stages reconstructed hummocks in coarse-textured HRAs function similarly to those in natural systems, where larger groundwater flow direction exerts a strong influence on water movement and connectivity with adjacent wetland ecosystems.
  - Flow reversals between WFIs and wetlands occur at both natural and reconstructed sites.
  - Lukenbach (PDF) has initiated modelling to understand changes during succession, potential time lags occurring in reconstructed landscapes, and the range of variability occurring during climate cycles.

OUTCOMES AND LESSONS LEARNED

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

- Our independent field and numerical modelling studies indicate that soil layering, both in wetlands (including hydrophobicity and frost formation) and ephemeral draws, of shallow soils with high storage (low density) on top of soils with low storage (high density) in wetlands, either mineral or organic, can keep the water level below the surface - greatly reducing evaporation and creating accessible water.
  - This layering can be used to reduce ET and promises to behave as an effective capping material and generate surplus fresh water and surface runoff in various Oil Sands landscapes.
- Exposed or shallow depth to fine-textured mineral substrates results in frequent soil saturation and flooding (Lukenbach et al., submitted; Dixon, PDF; James, M.Sc.) and these wet conditions can foster the establishment of wetland species. However, if flooding is too deep or prolonged it is likely not conducive to peat-forming vegetation (Lukenbach et al., submitted).
  - This has implications for designing wetlands that require less peat on reconstructed landscapes and can be optimized to support wetland vegetation.
  - This has implications for designing localized perched systems on constructed landscapes to potentially generate water with moderate salinity.
- Our field studies and numerical modelling show that HRA and material soil texture controls the magnitude and direction of water across the wetland- forestland interfaces (WFI) and influence water use and movement in catchments. In coarse-textured HRAs, water level fluctuations and water movement across WFIs is influenced by larger-scale groundwater flow direction.
  - This has implications for understanding and predicting the hydrological function and connectivity between hummocks and wetlands in reconstructed coarse-textured landscapes.

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

- The regional analyses show that in large catchments peatland wetlands act as the primary source areas for generating runoff, while aspen dominated fine-textured moraines are largely water sinks reducing catchment runoff even during wet periods.
  - Aspen dominated hummock moraines resemble overburden storage systems, and this has implications in estimating runoff from Oil Sands landscapes (Devito et al. 2016b).
  - The large difference in hydrologic function between aspen forestland dominated versus peatland dominated landforms has large implications for the design of constructed landscapes and adequate water inputs to downstream ecosystems (Devito et al. in review).

LITERATURE CITED

Thompson, C., C.A. Mendoza, K.J. Devito and R.M. Petrone, 2015. Climatic controls on groundwater–surface water interactions within the Boreal Plains of Alberta: Field observations and numerical simulations. Journal of Hydrology, 527, pp. 734–746. doi: 10.1016/j.jhydrol.2015.05.027

PRESENTATIONS AND PUBLICATIONS

Published Theses

Depante, M., 2016. Nutrient and Hydrologic Conditions Post-Fire: Influences on Western Boreal Plain Aspen (Populus tremuloides Michx.) Re-establishment and Succession. M.Sc., University of Waterloo (Department Geography). 86p.

MacKinnon, B., 2016. Interacting effects of post-wildfire hydrophobicity and vegetation recovery in a poor fen peatland. M.Sc., McMaster University (School of Geography and Earth Sciences). 125p.

McCann, C., 2016. Utilizing low-level remote sensing to monitor peatland disturbance. M.Sc., McMaster University (School of Geography and Earth Sciences). 84p.

Probert, S., 2016. The ecohydrology of the wetland-forestland interface: water repellency in leaf litter affects surface evaporation. M.Sc. Thesis, School of Geography, Earth and Environmental Science, University of Birmingham. 41p.

Journal Publications

Bold for contribution from Highly Qualified Personnel

Devito K., C. Mendoza, R.M. Petrone, N. Kettridge, M. Waddington. 2016a. Utikuma Region Study Area (URSA) – Part 1: Hydrogeological and ecohydrological studies. The Forestry Chronicle, 92: 57-61

Granath G., P.A. Moore, M.C. Lukenbach, J.M. Waddington. 2016. Mitigating wildfire carbon loss in managed northern peatlands through restoration. Nature Scientific Reports 6: 28498, doi:10.1038/srep28498.

Hokanson K.J., M.C. Lukenbach, K.J. Devito, N. Kettridge, R.M. Petrone , J.M. Waddington. 2016. Groundwater connectivity controls peat burn severity in the Boreal Plains. Ecohydrology 9: 574-584, doi: 10.1002/eco.1657

Ketcheson S.J., J.S. Price, S.K. Carey, R.M. Petrone, C.A. Mendoza, K.J. Devito. 2016. Constructing fen peatlands in post-mining oil sands landscapes: challenges and opportunities from a hydrological perspective,. In Press, Earth-Science Reviews, 161:130-139

Kettridge N., **A.S. Tilak**, K.J. Devito, R.M. Petrone, C. Mendoza, J.M. Waddington. 2016a. Moss and peat hydraulic properties are optimized to maximise peatland water use efficiency. Ecohydrology, 9(6):1039-1051 doi: 10.1002/eco.1708.

Leonard Rh., N. Kettridge, S. Krause, K.J. Devito, G. Granath, R. Petrone, C. Mendoza, J.M. Waddington. 2016a. Lack of Peatland Bryophyte Responses to Canopy Disturbance. Accepted 30 Oct 2016, ECO-16-0146.R1, Ecohydrology Letters

Petrone R., K. Devito, C. Mendoza. 2016a. URSA – Part 2: Aspen Harvest and Recovery Study. The Forestry Chronicle, 92 (1) : 62-65, 10.5558/tfc2016-018

Plach J.M., J.-M. Ferone, Z. Gibbons, B. Smerdon, A. Mertens, C. Mendoza, R. Petrone; K.J. Devito. 2016a. Influence of glacial landform hydrology on phosphorus budgets of shallow lakes on the Boreal Plains. Journal of Hydrology, 535:191-203.

Plach J., R. Petrone, J. Waddington, N. Kettridge, K.J. Devito. 2016b. Hydroclimatic Influences on Peatland CO2 Exchange Following Upland Forest Harvesting on the Boreal Plains. Ecohydrology, 9: 1590-1603. DOI: 10.1002/eco.1750

Schneider R., K.J. Devito, N. Kettridge, E. Bayne. 2016. Moving beyond bioclimatic envelope models: integrating upland forest and peatland processes to predict ecosystem transitions under climate change in the western Canadian boreal plain. Ecohydrology, 9(6):899-908. DOI: 10.1002/eco.1707

Sutherland, G., L. Chasmer, N. Kljun, K.J. Devito, R.M. Petrone. 2016, Using high resolution LiDAR data and a flux footprint parameterization to scale evapotranspiration estimates to lower pixel resolutions. Accepted Dec 2016, Canadian Journal of Remote Sensing.

Thompson C., C.A. Mendoza, K.J. Devito. 2016a, Potential Influence of Climate Change on Ecosystems within the Boreal Plains of Alberta. Accepted with Revisions, 21 Nov 2016, Hydro Process. HYP-16-0499.

Conference Presentations/Posters

Depante, M., K.J. Devito, N. Kettridge, J.M. Waddington, R. Petrone. Hydrologic Controls on Trembling Aspen (Populus tremuloides) Regeneration and Succession Post-Fire. CGU-CMOS joint annual meeting, May 29-June 2, 2016, Frederickton.

Hokanson, K.J., K.J. Devito, C. Thompson, and C Mendoza. The interaction of climate and glacial landforms on subsurface and surface hydrology and chemistry across a heterogeneous boreal plain landscape. , European Geosciences Union General Assembly, Vienna, 17th-22nd April (poster), 2016.

James, L., K.J. Devito, D. Alessi, C.A. Mendoza, **Rh. Leonard**, N. Kettridge. Perched Peatland Formation and Maintenance on the Boreal Plains of Canada. CGU-CMOS joint annual meeting, May 29-June 2, 2016, Frederickton.

Kettridge, N., **M. Lukenbach, K. Hokanson**, K. Devito, C. Hopkinson, R. Petrone, C. Mendoza and JM. Waddington Water repellency diminishes peatland evaporation after wildfire, European Geosciences Union General Assembly, Vienna, 17th-22nd April. 2016

Kettridge, N., **A. Tilak**, K. Devito, R. Petrone., C. Mendoza and JM. Waddington. Moss and peat hydraulic properties are optimized to maximise peat water use efficiency, European Geosciences Union General Assembly, Vienna, 17th-22nd April (oral), 2016.

Kettridge, N., **M. Lukenbach, K. Hokanson**, K. Devito, C. Hopkinson, R. Petrone, C. Mendoza and JM. Waddington. Water repellency diminishes peatland evaporation after wildfire, European Geosciences Union General Assembly, Vienna, 17th-22nd April (poster), 2016.

Leonard, R., N. Kettridge, S. Krause, J.M. Waddinton, K. Devito, R. Petrone, Carl Mendoza. New insights from high spatio-temporal measurements at the pedosphere-atmosphere interface, European Geosciences Union General Assembly, Vienna, 17th-22nd April (oral), 2016

Leonard, R., N. Kettridge, S. Krause, K. Devito, G. Granath, R. Petrone, C. Mendoza, J.M. Waddington (2016) Medium term ecohydrological response of peatland bryophytes to canopy disturbance, European Geosciences Union General Assembly, Vienna, 17th-22nd April (poster), 2016.

Moore, P.A., M.C. Lukenbach, J.M. Waddington. Post-fire moss recovery in northern peatlands: Separating the effects of species and water content on moss water repellency, European Geosciences Union General Assembly, Vienna, 17th-22nd April, 2016

Waddington J.M, **P.A. Moore**. Ecohydrology by thinking outside the bog: Shifting paradigms in an era of shifting peatland ecosystems, European Geosciences Union General Assembly, Vienna, 17th-22nd April, 2016

Reports & Other Publications

Devito, K.J., N. Kettridge, C. Mendoza, R.M. Petrone, J.M. Waddington. 2016c. Applying natural analogues to constructing and assessing long-term hydrologic response of Oil Sands reclaimed landscapes. Collaborative Research and Development (CRD) Grants Progress Report - CRDPJ 477235 – 14, 23pp

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Kevin Devito

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Kevin Devito	University of Alberta	Professor		
Nick Kettridge	University of Birmingham	Associate Professor		
Carl Mendoza	University of Alberta	Professor		
Rich Petrone	University of Waterloo	Professor		
Mike Waddington	McMaster University	Professor		
Laura Chasmer	University of Lethbridge	Assistant Professor		
Kelly Hokanson	University of Alberta	Research Hydrologist	2014	In Progress
Madison Chamzuk	University of Alberta	Data Technician	2015	2016
Emily Jones	University of Alberta	Technician	2016	2016
Kele Little-Devito	University of Alberta	Data Technician	2014	2016
George Sutherland	University of Waterloo	Technician	2014	In Progress
Corey Wells	University of Waterloo	Technician	2014	2016
Eric Kessel	University of Waterloo	Technician	2016	In Progress
Cameron McCann	McMaster University	Ecohydrology Technician	2016	In Progress
Craig Alison	McMaster University	GIS Technician	2016	2016
Max Lukenbach	University of Alberta	PDF	2015	In Progress
Paul Moore	McMaster University	PDF	2014	In Progress
Janina Plach	University of Waterloo	PDF	2013	2015
Simon Dixon	University of Birmingham	PDF	2015	In Progress
Craig Thompson	University of Alberta	PhD	2010	2017
Emily Pugh	University of Alberta	PhD	2016	In Progress
Max Lukenbach	McMaster University	PhD	2011	2015
Sophie Wilkinson	McMaster University	PhD	2016	In Progress
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Emily Jones	University of Alberta	Undergraduate	2015	2015
Joseph Hopkins	University of Alberta	Undergraduate	2015	2015
Lucas Poitras	University of Alberta	Undergraduate	2015	2015
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Rachel Ellis	University of Birmingham	Undergraduate	2015	In Progress
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FORWARD III: Modelling to Contribute to Cumulative Effects Management in the Canadian Boreal Forest

COSIA Project Number: LJ0009

Research Provider: Lakehead University

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Syncrude Canada Ltd., Total E&P Canada Ltd., Alberta-Pacific Forest Industries, Alberta Newsprint Company, Hinton Pulp, Millar Western Forest Products Ltd., Slave Lake Pulp

Status: Year 5 of 5

PROJECT SUMMARY

The Forest Watershed and Riparian Disturbance Project (FORWARD) is a consortium of university, government, and industry partners with the overarching goal of better understanding how natural and anthropogenic disturbances influence the dynamics of forest watersheds, and in particular those that redound to aquatic impacts. Its primary focus is the development of soil and watershed assessment tools and appropriate bio-indicators to support reclamation efforts within forestry, energy and mining sectors. It provides information critical in shaping evolving regulatory approaches to reclamation and water management and support components of progressive reclamation.

The objectives of FORWARD III are organized in a framework consisting of four components:

Component 1. Watershed load and contaminant fate modelling that integrates the current knowledge base of process-specific studies into a watershed modelling framework. The models developed in this component are intended to support industry and regulators as they manipulate the landscape and design reclamation strategies – for example those found in Detailed Forest Management Plans (DFMPs) and mine closure plans. The models are intended to ensure the desired hydrologic and biogeochemical outcomes so that successful reclamation of watersheds occurs. FORWARD II (2006 – 2011) contributed substantively to these outcomes at the small watershed scale for forestry and FORWARD III expanded this to oil sands sites. FORWARD III further developed modelling of transport and fate in the Athabasca River so that cumulative effects management could be predictive in nature as both industries manage a shared boreal forest resource base.

Component 2. Benchmarks for reclaimed and engineered soils that characterize physical, biogeochemical and microbial features of oil sands sites and their changes through time and compare these states and changes to those in reference, burned and forest/reforested soils. Improvements in these aspects derived from the oil sands sites were also applied to the knowledge already generated for forestry-impacted sites that were the basis of FORWARD II research.

Component 3. Acceptable vegetation complexes: impacts and recovery after disturbance will compare vegetation recovery trajectories after oil sands activity to trajectories after reforestation treatments for wildfire and harvest activities, as a means to predict mid- to late-stage vegetation recovery trajectories for oil sands sites.

Component 4. Risk of toxicity to bio-indicators from natural and anthropogenic load and impacts of organic and inorganic contaminants associated with oil sands extraction and forestry related activities including pulp mill effluents that characterize acute and chronic toxicity to amphibians, macroinvertebrates and fish.

PROGRESS AND ACHIEVEMENTS

The FORWARD III research program is grounded in hydrologic monitoring and model development with focused studies in microbiology and physical characteristics of soils, vegetation diversity, and toxicological effects of oil sands contaminants to invertebrates, fish and amphibians. 2016 saw the completion of three graduate student studies (PhD Klemish, MSc Blain, MSc Chow) and progress toward completion of ongoing studies by six graduate students (PhD Bendzsak, PhD Lari, PhD Mitter, PhD Parratt, MSc Novak, MES Templeton).

Hydrological monitoring provides essential field data for the calibration and verification in model development and allows comparison of measured data to model output. This year 282 samples were collected (240 water, 42 snow) from sampling locations on two oil sands sites (Canadian Natural Reclamation Area 1, Suncor Wapisiw Lookout) in the Fort McMurray area and reference sites in the Virginia Hills near Whitecourt, AB. In addition to the collection of both static grab and flow-activated water samples, core monitoring includes the continuous recording of stream water level, flow rate, temperature and corresponding climatic measurements.

Stream hydrological monitoring commenced in mid-April with a weekly sampling schedule at the Whitecourt reference sites. Fort McMurray sites were visited and instrumented with water level and temperature loggers but monitoring of the sites was postponed until mid-June due to forest fires in the area. Following reopening of Fort McMurray sites, sampling at both oils sands and reference sites resumed on a bi-weekly schedule. This year, a temporary flow-concentrating weir was installed at a Suncor Wapisiw Lookout site to improve flow rate measurements. Conductivity, pH, turbidity, TDS, water temperature, and dissolved oxygen (DO) were measured on site. At Canadian Natural RA1, piezometers were monitored for groundwater activity, and soil moisture probes for water content, bulk salinity and temperature to allow for the assessment of water quality and quantity within the coversoil and subsoil layers.

Snow surveys took place in late February/early March 2016 at oil sands and reference sites. Bulk measurements were taken for determination of snow pack thickness and snow melt characteristics and samples collected from 11 Canadian Natural RA1, 20 Suncor Wapisiw Lookout and 11 Virginia Hills sites.

All water and snow samples were analyzed at the Lakehead University Nutrient Ecology laboratory for phosphorus, colour, alkalinity, conductivity, total nitrogen, nitrate & nitrite, ammonia, silicate, dissolved organic carbon (DOC), cations, chloride/sulfate, suspended solids, and trace metals.

Weather data were collected from three automated meteorological stations: one located at Suncor Wapisiw Lookout and two at reference sites in the Virginia Hills, and precipitation readings were recorded bi-weekly from manual rain gauges situated at two locations on Canadian Natural RA1, three locations on Suncor Wapisiw Lookout and four locations in the Virginia Hills.

Component 1: Development of watershed load and contaminant fate models

- **Model development of Environmental Fluid Dynamic Code for the lower Athabasca River (EFDC-LAR).** Sediment transport calibration and validation was conducted and work is underway on the contaminant transport within the EFDC-LAR model. Expected completion of model updates is Spring 2017.
- **Model development for Soil and Water Assessment Tool for the Boreal Forest ($SWAT_{BF}$).** Progress has been made in the integration of the forest tree growth model 3-PG with $SWAT_{BF}$. This began by: updating $SWAT_{BF}$ 2005 model code to the latest version of SWAT, which was released in May 2015 (SWAT2012 rev.637); modifying the upland and lowland wetland modules of $SWAT_{BF}$; and adding parameters to the solar radiation, litter layer, soil water, wetlands and HRU connectivity and temperature-related processes. The development of an auto calibration

procedure for the updated $SWAT_{BF}$ 2012 and coding of the lasted version of 3-PG into FORTRAN was necessary before the models could be integrated. Expected completion of model updates is expected by Fall 2017.

- **Investigating the influence of black spruce trees upon canopy snowmelt, ground temperature, winter infiltration, and snowpack recharge.** Two peatland sites were instrumented with automated soil moisture/temperature probes in the Virginia Hills study area and data were collected throughout the winter 2014/15 and 2015/16. Data collected and visual observations will be used to determine if black spruce trees in peat bogs are biologically active during the winter and affecting ground temperature and snowmelt. The objective of this study is to formulate a snowmelt energy balance equation suitable for the Boreal Plain peatlands, which incorporates the effect of black spruce trees, and to develop a numerical model for treed wetland snowmelt infiltration that can be incorporated into existing hydrological models such as $SWAT_{BF}$ or other hydrological models to strengthen their subsurface and winter hydrological component.

Component 2: Benchmarks for reclaimed and engineered soils

Kris Novak (MSc Student) completed all field and laboratory aspects of his research on the physical and chemical properties of soils in 2015. He has since completed writing his thesis while leading the hydrological monitoring program. He is expected to defend his thesis in Spring 2017.

Michael Bendzsak (PhD Student) focused on two research questions in 2016: 1) do tree leaf decomposition patterns follow similar functional pathways on reclaimed tailing sands as natural sites; and 2) despite low bioavailable soil phosphorus (P) on reclaimed sites, how do P profiles within the trees themselves compare to natural conditions? For the first question, samples of jack pine, white spruce and trembling aspen leaves were collected from Suncor Wapisiw Lookout in 2016. Leaf samples were analyzed for total decomposition and nutrient concentration. Soil samples were also taken from these sites and analyzed for carbon and nutrient concentrations.

The second part of this study required the collection of cores from mature trees growing adjacent to select CEMA plots. However, the trees at Wapisiw Lookout were too small to core so whole trees were harvested. Whole trees of similar age to those harvested at Wapisiw Lookout were also harvested off-site and mature trees growing off-site were cored. Cores from mature trees adjacent to CEMA plots were collected in 2015 and all others were collected in 2016. Wood samples will be analyzed for variation in total P concentrations and compared. Samples collected from Wapisiw Lookout will be further analyzed by Nuclear Magnetic Resonance to investigate what forms of P are present.

Laboratory work was completed in December 2016 and data are currently being assembled/analyzed. Research results will be ready for distribution in 2017.

Eduardo Mitter (PhD Candidate) concluded his laboratory work on the diversity of bacterial endophytes associated with plants growing on reclaimed landscapes and is writing up his results. He has one manuscript submitted for publication in the journal FEMS Microbiology Ecology and is on track to complete his program by Summer 2017.

Natalie Blain (MSc Graduate) began her program in 2013, conducted vegetation surveys of Bitumount Provincial Historic Site in 2014, conducted laboratory analyses in 2015/16 and defended her thesis in September 2016. Her work showed that the natural revegetation of the hydrocarbon contaminated soils at Bitumount supported diverse root endophytic communities. The identification of the healthy plant species growing at this site will assist future reclamation efforts.

Bethany Templeton (MES Student) conducted a laboratory-based study to assess the tolerance of some of the plant species that are approved for soil reclamation and remediation to various metals and salts. Seeds were placed on spiked semi-solid water agar and left to grow for seven days. The agar was spiked using cadmium, copper, chromium or

nickel in the form of nitrates, or with chlorine or sulfate salts associated with potassium and sodium. After seven days, germination was determined and root and shoot lengths of the seedlings was measured using WinRHIZO software.

Seeds were also assessed in artificially contaminated soil whereby the soil was spiked with one of the aforementioned elements and subsequently planted with one of the five test species. Work is underway to measure the plants' metal and salt uptake to determine if these are effective plants when it comes to phytoremediation. Bethany is scheduled to complete her program in Spring 2017 at which time full results of this study will be available.

Component 3: Determination of vegetation complexes

In 2016, this component focused on dissemination of data collected by Timothy Sobey (MSc Graduate) and work initiated by Dr. Rebecca MacDonald (Postdoctoral Fellow). Two manuscripts were finalized this reporting period by Shekhar Biswas (Postdoctoral Fellow). The first is based on MSc graduate Sobey's work and highlights the effects of different reclamation treatments on species composition and diversity of understory plant communities – it was submitted to the Journal of Applied Ecology. The second, accepted for publication in Landscape Ecology, is based on work by Dr. MacDonald.

Component 4: Characterization of toxicity to macroinvertebrates, fish and amphibians.

Sylvia Chow (MSc Graduate) concluded her program in December 2016. Her work focused on whether or not local populations of fish were naturally adapted to the conditions associated with natural bitumen relative to populations from pristine environments. Field experiments included a 28 day fathead minnow (*Pimephales promelas*) reciprocal cross-transplant study between sites containing natural bitumen and downstream of industry. Pre- and post-exposure neurophysiological, metabolic, and contaminant exposure endpoints were measured to better understand if local adaptation to natural and anthropogenic sources of bitumen exists in fish populations and how local fish populations may respond to oil sands mining and development. Understanding this sensitivity of fathead minnows may be translated to other cyprinids and further optimize reclamation and remediation efforts to protect fish populations.

Ebrahim Lari (PhD Candidate) has worked to investigate the effects of oil sands process-affected water (OSPW) on the macroinvertebrate *Daphnia magna*. In 2016 he concluded his *Daphnia* work with an examination of role of sediment in OSPW and then turned his focus to the interaction of OSPW with the olfactory system and olfactory-mediated behaviour of fish.

Embrahim Lari is expected to complete his program in Summer 2017.

Jaimie Klemish (PhD Graduate) completed her program with FORWARD III in May 2016. Her field-based study conducted at oil sands sites and using wood frog (*Lithobates sylvaticus*) and boreal chorus frog (*Pseudacris maculata*) tadpoles ran from 2013-2014. These in-situ experiments were followed by laboratory work in 2015 that examined the effects of sediment in water (collected from the same reference and oil sands wetlands) on the health and behaviour of the wood frog tadpoles. The study was designed to examine toxicity associated with water-only, sediment-only, or a combination of water and sediment. Results from this study demonstrated that waterborne contaminants contributed little to toxicity. Instead, toxicity was almost entirely attributed to contaminants associated with sediments.

OUTCOMES AND LESSONS LEARNED

Component 1:

Early analysis of the data collected by PhD Parratt demonstrates that black spruce tree's root mass begins to warm during the middle of winter and thaws prior to the melting of the snowpack. Monitoring of the groundwater table within the peatlands showed infiltration occurring during the winter due to canopy snowmelt from black spruce trees. Wintertime infiltration is an important hydrological process that accounts for a significant portion of recharge to the Boreal Plains wetlands and has yet to be incorporated within any hydrological models.

Component 2:

PhD Bendzsak and MES Templeton are completing analyses of their field and laboratory studies, respectively, and will fully report their findings in 2017.

MSc Blain's study showed that the diverse plant species naturally recolonizing Bitumount Provincial Historic site, have the root-associated bacteria (endophytes) necessary to overcome hydrocarbon toxicity. Culture dependent techniques demonstrated that some of these bacteria are culturable in the laboratory and that their abundance differed between plant species and sampling locations. The increased colonization of hydrocarbon degrading bacteria within grass species emphasizes their ability to be used for reclamation efforts. Since the natural vegetation at Bitumount also contained distinct microbial communities, further research is warranted to understand if these distinct communities are aiding in plant establishment and growth in hydrocarbon contaminated soils.

Component 3:

In examination of the data collected by MSc Sobey, Postdoctoral Fellow Biswas found tailings sand to be a less suitable substrate from the perspective of promoting understorey plant species diversity and composition, and postulated that it would be better utilized for lower layers and topped with overburden/secondary overburden material, where possible. This work affirmed that revegetation prescriptions should target broadleaf and mixed-wood stands in addition to conifer stands. Biotic influences, particularly stand age and stand composition, are among the main drivers of aboveground biomass within reclaimed ecosystems after oil sands mining.

Component 4:

PhD Lari's work on the effects of OSPW to *Daphnia magna* has demonstrated that full-strength oil sand process-affected water (OSPW) is not lethal to *D. magna*. However, OSPW diluted to 1% or 10% can induce sublethal effects causing impaired growth and reproduction. Impaired food intake is mainly attributable to the presence of clay in the OSPW. When clay is ingested, it reduces both feeding rate and digestion efficiency. In addition, impaired food intake is partly due to the presence of chemical toxicants, such as hydrocarbons and metals. One potential mitigation measure for remediating OSPW prior to release to the environment is to reduce the particulate fraction, which will minimize its potential toxicity to primary consumers inhabiting the receiving environment. Ebrahim is also working with rainbow trout; however, at the time of this writing his experiments are ongoing.

MSc Chow's reciprocal cross transplant and 28-day exposure studies provided no evidence to support local adaptation in fish populations. Populations that are unaffected by industrial operations but inhabit environments naturally contaminated by bitumen show equivalent stress to those populations living downstream of industrial operations. Pristine animals that are caged at either naturally contaminated sites or sites downstream of industrial

operations show elevated stress and signs of sublethal toxicity. Despite the fact that study populations were separated by hundreds of kilometres, the lack of reproductive barriers ensures continuous gene flow all along the Athabasca River and its tributaries, which prevents local adaptation from occurring. Although it has been suggested that lab-stock animals used in toxicity evaluations may overestimate toxicity owing to adaptation in indigenous populations, our data suggest otherwise.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Blain, N.P., 2016. A survey of the bacterial root endophytes associated with the natural vegetation at the Bitumount Provincial Historic Site, Alberta, Canada. A thesis submitted to the College of Graduate Studies and Research in partial fulfillment of the requirements for the Degree of Master of Science, Department of Soil Science, University of Saskatchewan.

Chow, S.S., 2016. Local adaptation of fathead minnows (*Pimephales promelas*) found in the Lower Athabasca River basin. A thesis submitted to the School of Graduate Studies in partial fulfilment of the requirements for the degree Master of Science, Department of Biological Sciences, University of Lethbridge.

Klemish, J.L., 2016. Response of native amphibians to wetlands in the Athabasca oil sands region. A dissertation proposal presented to the College of Graduate and Professional Studies in partial fulfillment of the requirements for the degree Doctor of Philosophy, Department of Biology, Indiana State University.

Journal Publications

Beery, S.R., P.T. Gauthier, and G.G. Pyle. (in press). Testing local adaptation in five populations of *Hyalella azteca* in northern Alberta's oil sands region. Archives of Environmental Contamination and Toxicology.

Biswas, S.R., R.L. MacDonald and H.Y.H. Chen. (accepted) Disturbance increases negative spatial autocorrelation in species diversity. Landscape Ecology.

Klemish, J.L., S.R. Beery, S.S. Chow, M.J. Lannoo, and G.G. Pyle. (provisionally accepted). Aquatic ecotoxicological effects of the northern Alberta oil sands operations: A review. FACETS.

Lari, E., Steineky, D., and Pyle, G.G. 2017. A novel apparatus for evaluating contaminant effects on feeding activity and heart rate in *Daphnia* spp. Ecotoxicology and Environmental Safety 135: 381-386.

Gauthier, P.T., W.P. Norwood, E.E. Prepas and G.G. Pyle. 2016. Behavioural alterations from exposure to Cu, phenanthrene, and Cu-phenanthren mixtures: linking behavior to acute toxic mechanisms in the aquatic amphipod, *Hyalella azteca*. Aquatic Toxicology (Special edition on behavioural aquatic toxicology) 170: 377-383.

Lari, E., S. Wiseman, E. Mohaddes, G. Morandi, H. Alharbi and G. Pyle. 2016. Determining the effect of oil sands process-affected water on grazing behavior of *Daphnia magna*, long-term consequences, and mechanism. Chemosphere 146: 362-370.

McEachern, P., 2016. Forest Watershed and Riparian disturbance Project (FORWARD). The Forestry Chronicle 92:29-31.

Conference Presentations/Posters

Lari, E., Steinkey, D., Mohaddes, Pyle, G.G., 2016. The effects of oil sands process-affected water on *Daphnia magna*. 2016 Oil Sands Science Symposium, November 22-23, Calgary, AB, Canada. [Poster]

Chow, S.S., Pyle, G.G., 2016. Impairment or local adaptation: Physiological scope of fathead minnows (*Pimephales promelas*) affected by natural and anthropogenic bitumen in Alberta oil sands region. SETAC North America 37th Annual Meeting, November 6-10, Orlando, FL, USA. [Poster]

Lari, E., Steinkey, D., Mohaddes, E., Pyle G., 2016. Long-term effects of oil sands process-affected water (OSPW) on growth, reproduction, and energy reserves of *Daphnia magna*. SETAC North America 37th Annual Meeting, November 6-10, Orlando, FL, USA. [Oral]

Chow, S.S., Pyle, G.G., 2016. Natural selection and aquatic ecotoxicology in the oil sands: fathead minnows (*Pimephales promelas*) affected by natural and anthropogenic bituminous toxicants. 43rd Canadian Ecotoxicity Workshop, September 25-28, Edmonton, AB, Canada. [Oral]

Lari, E., Pyle, G.G., 2016. First encounter with oil sand process-affected water: detection and effects in rainbow trout (*Oncorhynchus mykiss*). 43rd Canadian Ecotoxicity Workshop, September 25-28, Edmonton, AB, Canada. [Oral]

Steinkey, D., Lari, E., Pyle G.G., 2016. The effects of oil sands processed water on *Daphnia magna*. 43rd Canadian Ecotoxicity Workshop, September 25-28, Edmonton, AB, Canada. [Oral]

Chu, Y., Watson, B., Putz, G., Parratt, T., 2016. Further development of SWATBF to simulate streamflow from forested watersheds in the central mixed-wood natural subregion of Alberta, Canada. 2016 International SWAT Conference, July 27-29, Beijing, China. [Oral]

Mitter, E., de Freitas, R., Germida, J.J., 2016. Structure of root associated bacterial communities in oil sands reclamation covers. 16th International Symposium on Microbial Ecology (ISME16), August 21-26, Montreal, QC, Canada. [Poster]

Chow, S.S., Pyle, G.G., 2016. Adaptation in the oil sands? Physiological changes in fathead minnows (*Pimephales promelas*) affected by natural and anthropogenic sources of bituminous toxicants. SETAC PNC, June 16-17, Winnipeg, MB, Canada. [Oral]

Steinkey, D., Lari, E., Mohaddes, E., Pyle, G., 2016. The effects of oil sands processed water on *Daphnia magna*. SETAC PNC, June 16-17, Winnipeg, MB, Canada. [Poster]

Lari, E., Steinkey, D., Mohaddes, E., Pyle, G.G., 2016. The mechanism of oil sands process-affected water on feeding-behaviour impairment in *Daphnia magna*. SETAC Europe, May 22-26, Nantes, France. [Oral]

Templeton, B., Germida, J.J., 2016. Assessment of native plant species for tolerance to metals and salts. Canadian Society of Soil Science Annual Conference, May 14-19, Kelowna, BC, Canada. [Poster]

RESEARCH TEAM AND COLLABORATORS

Institution: Lakehead University

Principal Investigator: Dr. Ellie Prepas

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Dr. Greg Pyle	University of Lethbridge	Professor and CAIP Chair		
Dr. Daniel W. Smith	University of Alberta	Professor Emeritus		
Dr. Ken Van Rees	University of Saskatchewan	Professor and Agro-Food Innovation Chair		
Samuel Bartels	Lakehead University	Postdoctoral Fellow	2015	2015
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Sagar Chhabra	University of Saskatchewan	Postdoctoral Fellow	2013	2015
Rebecca MacDonald	Lakehead University	Postdoctoral Fellow	2013	2013
Michael Bendzsak	University of Saskatchewan	Ph.D.	2014	2017
Patrick Gauthier	Lakehead University	Ph.D.	2012	2015
Jaimie Klemish	Indiana State University	Ph.D.	2012	2016
Nancy Martin	University of Alberta	Ph.D.	2012	2013
Eduardo Mitter	University of Saskatchewan	Ph.D.	2012	2017
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Research Collaborators: Dr. Renato deFreitas, University of Saskatchewan; Dr. John Headley, Environment Canada; Dr. Bobbi Helgason, University of Saskatchewan; Dr. Michael Lannoo, Indiana University School of Medicine; Jonathan Russell, R.P.F.; Dr. Brett Watson, Saskatchewan Polytechnic/University of Saskatchewan

Wetlands

Wapisiw Wetland Early Ecological Succession Monitoring

COSIA Project Number: LJ0112

Research Provider: University of Windsor, University of Alberta and Keyano College

Industry Champion: Suncor Energy Inc.

Status: Year 6 of 6

PROJECT SUMMARY

Suncor Energy Inc. (Suncor) is the first oil sands company to have transformed an oil sands tailings pond (Pond 1) into a surface solid enough to be actively reclaimed and revegetated. The 220-hectare watershed is now composed of a growing mixedwood forest, stream channels and a wetland (Wapisiw Marsh), which supports a variety of native plants and wildlife. It was anticipated that novel initiatives to provide habitat structural complexity (small islands, hibernacula, snag trees, rock piles), carbon (LFH and peat-mineral reclamation soils) and propagules (seedlings and vegetated plugs selected according to the Riparian Classification and Monitoring Guidelines), will have facilitated developmental processes.

The objective of the program is to provide baseline information on the initial successional processes that can be used to track the development of plant, amphibian, and avian communities toward an integrated, self-sustaining ecosystem that is functionally equivalent to a natural marsh.

Each year between 2010 (the year of construction) and 2015 the study tracked species richness, community composition, and abundance of selected taxa (amphibian, avian, and riparian vegetation) in Wapisiw Marsh and up to 8 reference wetlands of various ages and construction characteristics, in order to assess age-specific effects and inter-annual variation. Amphibian species composition and abundance were assessed annually in spring 2011, 2013, 2014 and 2015 using calls, netting, and visual records at each study wetland. Nest boxes around the study wetlands were assessed by frequency of use, fecundity, and fledgling success annually between 2011 and 2015. The presence of avian species around the wetland watershed was tracked by 10-minute point counts each spring from 2011 to 2015. Aquatic invertebrates were sampled from Wapisiw Marsh itself in 2010, 2014 and 2015.

A within-wetland focus of this study contrasted the effects of reclamation soil type (peat-mineral vs. LFH) and revegetation strategy (seedling/vegetated plug vs. natural colonization) on riparian vegetation establishment in 12 plots (9 x 30 x 12 m) along the shoreline of Wapisiw Marsh. Permanent transects were designed within each plot. Point and quadrat assessment of plant composition and vegetation cover was annually assessed from 2010 to 2015. For more details on the experimental design see Daly (2010).

PROGRESS AND ACHIEVEMENTS

All fieldwork on this project was completed in 2015. Work in 2016 entailed processing and identification of aquatic invertebrates collections and detailed analyses of the time trends observed in the Wapisiw study area relative to the suite of reference wetlands, and an assessment of the effectiveness of prescription soil and propagule placements within the Wapisiw riparian zone.

Over the course of the project, the avian component of the study surveyed a total of 31 natural and reclaimed wetlands. A total of 117 species was observed. The mean number of avian species detected per wetland in any single year (with standard deviation) was 13.8±5.1 in natural wetlands and 14.3±5.1 in constructed wetlands. Ten

species were observed in Wapisiw Marsh in 2011 (a year in which counts were uncharacteristically low everywhere), but richness in all subsequent years ranged from 15-21. Wapisiw Marsh typically supported the greatest number of species observed at any constructed wetland monitored, and richness was significantly greater than the overall mean for all wetlands ($p<0.001$). An analysis of wetland features with which species richness was associated among wetlands (Nakhaie 2013) revealed that species richness was positively correlated with the gross area (i.e., hectares) of natural wetlands but not of constructed wetlands. In contrast, habitat heterogeneity was a significant correlate of species richness in constructed but not natural wetlands.

The same bird species were most commonly encountered each year of the study: White-throated sparrow (*Zonotrichia albicollis*), red-winged blackbird (*Agelaius phoeniceus*) , tree swallow (*Tachycineta bicolor*), American robin (*Turdus migratorius*), chipping sparrow (*Spizella passerine*), sora (*Porzana Carolina*) and song sparrow (*Melospiza melodia*), were the most widespread taxa. This list includes primarily song birds with the exception of the sora which is a rail species. Overall, aquatic bird species tended to be more common in natural wetlands than in constructed wetlands, reflecting the larger size and greater extent of open water habitat in study wetlands compared to constructed wetlands. By the same token woodland species tended to be more predominant in constructed wetlands, which were relatively small and had limited amounts of open water

Overall, Wapisiw Wetland supported among the greatest number of bird species and attracted as many or more tree swallows as other, older constructed wetlands. Overall occupancy of nest boxes was 75%, with 5-6 eggs per clutch being produced. Fledging success was between 50 and 100% annually. Occupancy was comparable to or exceeded that of two other constructed wetlands at which nest boxes were present. However, boxes at those wetlands were subject to bear predation and had much lower fledging success overall. Wapisiw Wetland appears to provide adequate habitat to support the richness of bird species and fledging success expected in a natural wetland of equivalent size in the study region even though it is younger and its structure (i.e., vegetation) and habitat (i.e., food sources) are still under development within the wetland.

Three amphibian species were observed to develop in Wapisiw Marsh over the course of the study as evidenced by the presence of tadpoles and/or recent metamorphs. Adult boreal chorus frogs (*Pseudacris maculate*) were present each year of the study. Tadpoles were observed in 2013 and 2015. Adult Canadian toads (*Bufo hemiophrys*) were detected at Wapisiw Wetland each year except 2014, indicating that it is sufficiently connected to other amphibian habitat that male amphibians have found it. Adults, tadpoles and recent metamorphs of wood frogs (*Rana sylvatica*) were observed in 2014.

Plant species richness and extent of ground cover of the Wapisiw Marsh riparian increased substantially over the course of the study. Mean±SE species richness per 1 m^2 quadrat increased from 6±0.5 in 2011, to 8 ±0.7 in 2012 and 2013, and 16 ±1 in 2014 and 2015. Ground cover ranged from 35±5 percent in 2011 to approximately 70 percent in 2012 and subsequent years when averaged over all vegetation zones (submergent, emergent, wet meadow, upland). Complete plant cover was observed in most quadrats of the wet meadow and upland zones by 2015. Submergent aquatic vegetation covered between 10±8 and approximately 40±20 percent of quadrats in the submergent zone of the wetland. Transects that had been planted with propagules exhibited significantly more ground cover during the first few years of the study. After 5 years, submergent cover in planted transects was 2-3 times more extensive than in unplanted transects. However, differences in ground cover in the other zones were no longer evident.

Aquatic invertebrate taxa richness and composition changed markedly over the course of the study. In the year of construction, samples were dominated by midge larvae, water boatmen and beetles (typical early colonists of a newly formed wetland). Thirty taxa were found, with a mean±SD of 4.6 ±2.2 taxa per sample. By 2015, the community had changed substantially. The same taxa dominated, but over 50 taxa were present, averaging 14.0 ±4.2 taxa per sample. Larvae of damselflies, dragonflies, mayflies, dragonflies and caddisflies, which are representative of reference wetlands were common in samples. Overall, Wapisiw Marsh exhibited a diverse aquatic invertebrate

fauna dominated by aquatic insects. Only limited natural colonization by non-insect invertebrate fauna (snails, leeches, crustaceans) has been observed, likely due to its relative remoteness from other wetland systems.

Project start date: 2011. Project end date: 2016.

OUTCOMES AND LESSONS LEARNED

Detailed outcomes and lessons learned will be provided in a final report that is scheduled for completion in March 2017.

LITERATURE CITED

Daly, C.A. 2010. Riparian Study at Wapisiw Wetland. Technical Report Prepared for Suncor Energy Inc., Calgary, AB. 8 p + appendices

Nakhaie, S.J. 2013. Avian species-area relationships and environmental covariates in natural and constructed wetlands of northeastern Alberta. M.Sc. Thesis, University of Windsor. Windsor, Ontario, Canada. 127 p.

PRESENTATIONS AND PUBLICATIONS

None in 2016

RESEARCH TEAM AND COLLABORATORS

Senior Principal Investigator: Dr. Jan Ciborowski, University of Windsor

Co-Principal Investigator: Dr. Lee Foote, University of Alberta

Co-Principal Investigator: Dr. Danna Schock, Keyano College

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Kellie Menard	University of Windsor	M.Sc.	2014	2017
Chantal Dings-Avery	University of Windsor	M.Sc.	2014	2017
Katherine Williams	University of Windsor	M.Sc.	2011	2014
Marie-Claude Roy	University of Alberta	PhD	2008	2014
Sheeva Nakhaie	University of Windsor	M.Sc.	2010	2013
Andrea Borkenhagen	Colorado State University	Research Assistant		

Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel

COSIA Project Number: LJ0227

Research Provider: Suncor Energy Inc., Hatfield Consultants, Millennium EMS Solutions Ltd. (MEMS)

Industry Champion: Suncor Energy Inc.

Status: Year 2 of Ongoing

PROJECT SUMMARY

In March 2005, Suncor Energy Inc. received approval to construct a tailings storage facility for the Millennium Mine project in the upper portion of the McLean Creek watershed. The construction of the tailings pond required the alteration of 3,870 m^2 of fish habitat in upper McLean Creek and approximately 53,000 m^2 of the McLean Creek wetlands system. As part of the project development, a compensation plan was prepared by Suncor, which included a new diversion channel to maintain flow to lower McLean Creek, and a dispersed-flow wetlands system. The South Tailings Pond (STP) Wetlands Complex was constructed between 2004 and 2006; the development included approximately 66 hectares of semi-permanent wetlands and an additional 82 hectare inundation zone consisting of a series of four cross-dykes, with re-vegetation encouraged through natural colonization. Fisheries and Oceans Canada (DFO) specified that monitoring in the area must take place to compare the development of the constructed wetlands condition/function to natural wetlands over time, to ensure the constructed wetlands conform to regional norms and meet DFO expectations.

A long-term wetland monitoring program for McLean Creek and the STP Wetlands Complex has been implemented since 2006 to track hydrologic conditions, water and sediment quality, and benthic invertebrate and vegetation communities through the ecological progression of the constructed wetlands. The monitoring program was designed to compare any changes in wetland condition/function over time to the natural wetlands in the upper portion of the McLean Creek watershed.

Many wetland monitoring programs in Alberta are effects-based as stipulated in project environmental approval conditions. Effects-based monitoring programs have a primary goal of measuring and quantifying potential (predicted) environmental or biological changes resulting from ongoing projects; however, little guidance exists for monitoring of created wetlands to address or minimize the effects of development. Specifically, no guidelines existed for setting performance standards and success criteria for the STP Wetlands Complex.

The objectives of this study are to:

- Establish performance indicators (i.e., measurable ecological indicators for each monitoring component) and success criteria (e.g., range of conditions from natural wetland systems); and
- Determine the variability in performance indicators over time and how they compare to the criteria in order to judge whether success has been achieved across all conditions (i.e., annual and seasonal variability). The performance indicators and success criteria were developed to evaluate whether the ecological function of the created STP Wetlands Complex is sustainable and consistent with the natural wetland systems in the watershed.

The "Criteria to Assess the Ecological Function of the STP Wetlands Complex and Diversion Channel" provides an outline of the performance indicators and success criteria to determine when the ecological function of the STP Wetlands Complex conforms to regional norms. The data gathered will help determine the success of these constructed wetlands.

PROGRESS AND ACHIEVEMENTS

Monitoring continued in 2016, the data review and analysis will be included in the 2016 McLean Creek / STP Wetlands Complex Annual Report (to be completed April 30th, 2017). A summary of the 2015 assessment (Hatfield and MEMS, 2016) is provided below:

Comparisons of performance indicators of each monitoring component to the reference range of variability (i.e., success criteria) indicated that there are some performance indicators that have not achieved the success criteria, particularly related to water and sediment quality at all constructed wetlands, and benthic invertebrate communities at station STP-2 (Table A7.9). The results of the vegetation community assessment indicated that some performance indicators at stations STP-1, STP-2, STP-3, and STP-4 were outside of the reference range of variability, primarily due to lower plant species diversity. It also identified a lower percentage of obligate species in the submergent zones of station STP- 1, a lower percentage of hydrophytic species in the emergent zone of stations STP-1 and STP-2, and lower FQAI values for stations STP-3 and STP-4. However, it was apparent from the data collected over time that there continues to be a progression towards reference conditions as the constructed wetlands continue to mature. With the exception of station STP-1, vegetation communities at all stations achieved a 'pass' rating in 2015.

OUTCOMES AND LESSONS LEARNED

Results of the 2015 monitoring program indicated that since their construction, there have been positive progressions in the development of benthic, vegetation, and plankton communities in the compensation habitat of the STP Wetlands Complex. Despite a few isolated differences, indices of the biological communities were relatively consistent between reference and test stations of the McLean Creek watershed. Fluctuations in hydrological and water quality conditions were observed across the open water season, primarily related to rainfall events in July and September, and seasonal variability. Overall, the results indicate that hydrologic, chemical, and biological conditions of McLean Creek and the STP Wetlands Complex were representative of a functioning and healthy ecosystem. However, they did not meet all success criteria in 2015 indicating that more time is needed for the constructed wetlands to show similar function to mature-wetland systems (reference wetlands). The performance indicators developed in 2013 have now been applied to 2013, 2014, and 2015 monitoring data, and will continue to be evaluated in future monitoring years.

PRESENTATIONS AND PUBLICATIONS

Hatfield Consultants and Millennium EMS Solutions Ltd. 2016. Suncor Millennium project 35(2): 2015 monitoring program for the McLean Creek watershed. Prepared on behalf of Suncor Energy Inc. April 2016. North Vancouver, BC.

RESEARCH TEAM AND COLLABORATORS

Institution: Suncor Energy Inc.

Principal Investigator: Sarah Aho, Sr. Hydrologist

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Peatland Restoration within the Suncor Millennium Mine (Phase One): Southeast Dump Wetland Hydrologic and Vegetation Monitoring Program

COSIA Project Number: LJ0221

Research Provider: Hatfield Consultants

Industry Champion: Suncor Energy Inc.

Status: Year 3 of 3

PROJECT SUMMARY

In April 2011, a group of international wetland experts were invited to participate in a Total E&P Canada (TEPCA)-organized workshop on boreal wetland reclamation. One of the key learnings from that workshop was that stakeholders want to see conservation of the natural landscape and, when conservation is not possible, restoration of disturbed wetlands, instead of the complete removal and reconstruction of reclaimed wetlands as a result of open-pit oil sands mining. This ideal wetland management philosophy has also been adopted into the revised Alberta Wetland Policy (AEP, 2013). While conservation and restoration opportunities in open-pit mining are limited, some opportunities do exist, such as near the boundaries of mine leases or areas overlying lean oil sands deposits within the mine that are not economical to mine.

One opportunity to investigate an area for peatland restoration at Suncor was at a 20 ha disturbed fen wetland. The wetland is located south of a reclaimed overburden dump called the Southeast Dump and south-east of Tailings Pond 7. The trees were harvested and the peat drained in this wetland as part of the development of the Steepbank Mine. The peat is currently saturated enough to sustain understory vegetation (i.e., shrubs, grasses, sedges, mosses, lilies, cranberries), and trees are regenerating. However, the understory vegetation remains visibly stressed because of the lowered water table.

PROGRESS AND ACHIEVEMENTS

To assess the viability of the Southeast Dump Wetland, various monitoring activities took place from spring to early fall (2014-2016). Monitoring included assessment of land cover using historic air photos, climate at nearby stations, vegetation type (to determine the extent and health of hydrophytic vegetation), soil type and quality, mapping and delineation of the wetland, water level in eight shallow wells, and water quality.

OUTCOMES AND LESSONS LEARNED

Key findings from the monitoring activities at the Southeast Dump Wetland include:

- Historically, the Project Area was likely a treed fen;
- Overall, the monitoring period took place in drier and warmer than normal conditions (relative to Fort McMurray climate normals), potentially leading to drier than expected soil moisture and a deeper than normal water table;
- About half of the Project Area is currently covered by wetland species or water. The remainder is vegetated by upland species;

- During field work in 2014 and 2016, soil moisture in the Project Area was qualitatively drier than expected given the vegetation type;
- The Project Area is dominated by organic Hartley series soils, which are characteristic of poorly drained wetland regions;
- The water table was rarely sufficiently high enough during the monitoring period to saturate the critical upper 30-60 cm of the soil where rooting occurs. Water levels were highest following snowmelt and large precipitation events;

The presence of hydrophytic vegetation and wetland soils suggest that the area historically functioned as a wetland. However, restoration efforts are likely needed to increase water levels to ensure the wetlands in the area are healthy and viable. In particular, the water table could be raised and soil wetness could be increased by increasing water inputs, increasing infiltration, and/or decreasing outflow.

LITERATURE CITED

Alberta Environment and Parks, 2013. Alberta Wetland Policy. Available at: http://aep.alberta.ca/water/programs-and-services/wetlands/documents/AlbertaWetlandPolicy-Sep2013.pdf.

PRESENTATIONS AND PUBLICATIONS

Hatfield Consultants. 2017. Southeast Dump Hydrologic and Vegetation Monitoring Program (2014-2016). Prepared on behalf of Suncor Energy Inc. January 2017. North Vancouver, BC.

RESEARCH TEAM AND COLLABORATORS

Institution: Suncor Energy Inc.

Principal Investigator: Sarah Aho and Josh Martin, Suncor

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Ecohydrogeologic Investigation of Opportunistic and Constructed Wetlands on Syncrude's Mildred Lake Lease

COSIA Project Number: LJ0275

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

Status: Year 1 of 2

PROJECT SUMMARY

This project is assessing small-scale opportunistic wetlands on reclaimed sites. Opportunistic wetlands are the cumulative result of geology/material type, surface and/or groundwater flows, as well as physical features of the landform. These wetlands can occur at a range of scales and may or may not be spatially explicit.

This research considers small-scale opportunistic wetlands that develop on the closure landscape as a result of reclamation activities that are not spatially explicit. Because these wetlands are not spatially explicit, they are difficult to predict or account during the closure planning process. Wetlands, including these small-scale wetlands play an important role in landscape function (Devito et. al, 2012) and will be critical landscape components for closure success. This work will attempt to understand the conditions under which these small-scale opportunistic wetlands develop and their predictability and performance throughout climate cycles. The results from this research will allow improved prediction of the occurrence and performance of these wetlands, and ultimately provide guidance for enhancing opportunities for the wetlands to develop. This work will also be crucial in more accurately accounting for all wetlands that we expect on the closure landscape.

PROGRESS AND ACHIEVEMENTS

During the 2016 field season, transect surveys on the abundance, extent, and location of opportunistic wetlands on reclaimed areas on the Syncrude Mildred Lake lease (South Bison Hills [SBH], Southwest Sands Storage [SWSS], and W1 Dump) were conducted. Wetlands located along transects were categorized using soil, vegetation, and hydrologic parameters. Similar transects were conducted in natural sites at the Utikuma Region Study Area (URSA) near Utikuma Lake, Alberta to record wetland parameters in natural systems. One opportunistic wetland on each landform (SBH, SWSS, and W1) was chosen for detailed study. Detailed sites were instrumented with shallow wells and measured every two weeks from mid-August to mid-September. Pressure transducers were installed in select wells to measure changes in water levels or depth of water, and are continuously monitored (i.e., every hour).

OUTCOMES AND LESSONS LEARNED

Preliminary results suggest opportunistic wetlands are common on all reclaimed landforms, are characterized by a near-surface confining layer, and are located on flat to low gradient areas.

LITERATURE CITED

Devito, K., Mendoza, C., and Qualizza, C. (2012). Conceptualizing water movement in the Boreal Plains. Implications for watershed reconstruction. Synthesis report prepared for the Canadian Oil Sands Network for Research and Development, Environmental and Reclamation Research Group. 164p.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Drs. Kevin Devito and Carl Mendoza

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Coke Wetland Research

COSIA Project Number: LJ0212

Research Provider: University of Windsor

Industry Champion: Syncrude Canada Ltd.

Status: Final Year of Multi-Year Project

PROJECT SUMMARY

The placement of petroleum coke in constructed aquatic systems in the post-mining landscape has been proposed as an effective storage option, and potentially as a means of both improving habitat quality and speeding the early biological development of the wetland ecosystem. Concerns associated with such a strategy include whether fine fluid tailings are strong enough to support a cap of inorganic and/or organic materials long enough that the cap will develop a viable and productive biological community; whether these capping amendments can truly speed the colonization of invertebrates and aquatic plants; and whether the physical or residual chemical characteristics of coke are suitable for zoobenthic colonization and community development.

This study was undertaken to complete sample processing, data analysis, and interpretation of field work that started in 2002 to determine the effects of coke capping on biological communities. Multiple small patches of petroleum coke, sand or native substrate were placed *in situ* in 3 constructed wetlands beginning in 2002. Additional patches were placed in each wetland at 3 to 6-month intervals over 2 years. All patches were sampled semi-annually. Zoobenthic samples collected up to the end of 2003 (documenting effect of coke in patches of ages up to 1 year) were processed and analyzed by Baker (2007). The remaining samples, providing information over a 2-year aging period were archived. In 2013, supplementary funding was provided by Syncrude Canada Ltd. to process, enumerate and statistically analyze the archived samples.

PROGRESS AND ACHIEVEMENTS

The project final report is currently undergoing review and is expected to be finalized in 2017.

OUTCOMES AND LESSONS LEARNED

Patterns of zoobenthic abundance, taxa richness and variation in community composition among wetlands and experimental treatments observed in this extended study are consistent with the preliminary findings of Baker (2007) and laboratory assessments of the effects of petroleum coke on chironomid growth in laboratory bioassays (Squires 2005). Differences in zoobenthic colonization among sediment types were detectable in Shallow Wetland South Ditch, the reference wetland that supported greater density, diversity and variety of zoobenthos. Greatest abundance and diversity were found on the native silt/clay sediment of the wetland. Reduced numbers and richness were collected on the 3 introduced materials – washed tailings sand and two varieties of petroleum coke. The degree of reduction appeared to be a reflection of the coarseness of the introduced materials, a finding consistent with Squires (2005) interpretation of the causes of reduced chironomid growth in bioassays conducted with Suncor and Syncrude coke.

LITERATURE CITED

Baker, L.F. 2007. Effects of petroleum coke amendments on macrophytes and aquatic invertebrates in northern Alberta, Canada constructed wetlands. M.Sc. Thesis, University of Windsor, Windsor, ON. 289 p.

Squires A.J. 2005. Ecotoxicological assessment of using coke in aquatic reclamation strategies at the Alberta Oil Sands. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Windsor

Principal Investigator: Jan Ciborowski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Jan Ciborowski	University of Windsor	Principal investigator		

Peatland Reclamation Markers of Success

COSIA Project Number: LJ0273

Research Provider: Southern Illinois University

Industry Champion: Syncrude Canada Ltd.

Status: 5 year program (work will be initiated in 2017)

PROJECT SUMMARY

The Sandhill Fen wetland vegetation community has changed considerably in its early development: from having an open unvegetated surface to one richly covered with a variety of plant species. We have gained much experience in understanding how early development proceeds in Sandhill Fen and how we might use benchmark sites to provide a framework for evaluating the progress and success of the reclamation effort. This program is a set of projects building on our 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. After three years of data collection at Sandhill Fen, we have identified four important variables 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 fen outside of our plots. Each of these variables plays a key role in the success of the fen, and continued monitoring of these factors will supply valuable information for understanding wetland performance and function.

PROJECT 2. Areas of increased salinity 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 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. Fundamental to understand 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

Contract signed December 2016.

OUTCOMES AND LESSONS LEARNED

This project has no outcomes or lessons learned since the program will commence in 2017.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University

Principal Investigator: Dr. Dale Vitt

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Dale Vitt	Southern Illinois University	Principal Investigator		
Dr. Stephen Ebbs	Southern Illinois University	Research Associate		
Melissa House	Southern Illinois University	Research Associate		
Jeremy Hartsock	Southern Illinois University	Research Associate		

Reclamation Wetlands Index of Biotic Integrity (IBI)

COSIA Project Number: LJ0297

Research Provider: Canadian Natural Resources Limited

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 4

PROJECT SUMMARY

Although large-scale engineered fens have been constructed and are currently monitored in the industry, these projects represent only one of many potential wetland types or developmental trajectories that reclamation wetlands may exhibit. Currently, the most common wetland types on reclamation areas are shallow open water wetlands and marshes. However, knowledge gaps exist concerning how these wetlands develop over time.

From 2007-2011, Dr. Suzanne Bayley worked to develop and test an approach to evaluate ecological integrity across a range of constructed disturbed and natural shallow open water marshes in the Athabasca Oil Sands Region. Dr. Bayley's work was funded by CEMA (contract 2007-2015). Ecological integrity is analogous to measuring homeostasis as an indicator of health (Costanza et al., 1992) – it focuses on a balance of ecosystem components, and is a particularly useful perspective in understanding how systems return to equilibrium or maintain natural ecological structure in the face of disturbance. Therefore, evaluating the ecological integrity of a system is an important step to determine if it is self-sustaining, and exhibits the regulatory requirement of equivalent land capability.

The objectives for this project were: 1) Characterize an environmental stress gradient for shallow open water wetlands and marshes; 2) Select suitable biological metrics; 3) Develop an IBI (Index of Biological Integrity); and 4) Test the IBI on an independent set of wetlands. An IBI is a multi-metric approach that characterizes the range of natural variability of systems and the degraded condition that they exhibit. It then uses a suite of metrics to situate sites of interest along that gradient.

Sixty-three wetlands were tested in total (38 "reference", 12 "oil sands reference" [undisturbed, reference wetlands on oil sands leases], and 13 "oil sands process affected" [wetlands receiving process-affected water]). All wetlands exhibited similar ranges in salinity, surface area, depth, and turbidity. To characterize the stress gradient, fifty-two environmental variables were tested at each wetland site, and through Principle Components Analysis it was found that eight variables were the most influential to wetland stress: water cation concentration; total Nitrogen in water; percent water in sediment; max depth of wetland; Secchi disc depth; amplitude; % oil in sediment, and chlorine (Cl^-) concentration in water (Rooney & Bayley, 2010).

To evaluate the biotic integrity of reclaimed wetlands, a vegetation-based IBI was developed. Vegetation was selected over other biotic elements (i.e., invertebrates, algae, etc.) because it is relatively easy to sample, integrative of temporal and environmental trends, indicative of ecosystem functions, biologically important, and can provide diagnostics based on species (i.e., halophytes, low light tolerators, etc.). From this data, a Submerged Aquatic Vegetation metric and a Wet Meadow Vegetation metric were developed and tested. The Wetlands IBI consists of a combination of the Stress Gradient metrics (above), the SAV-IBI and the WM-IBI to calculate an overall performance indicator score – the Marsh Condition Index (MCI).

Despite the considerable effort and resources put into the technology transfer of this project, it has not yet been adopted for operational practice on oil sands leases. The objective of this Joint Industry Project (JIP) is to implement

these procedures on five voluntary shallow open water wetlands on the Horizon lease, located within reclamation areas. Wetlands will be assessed annually in order to understand how they are developing in early seral stages. This study is significant as it will provide a means to understand the developmental trajectory of shallow open water wetlands on reclamation areas.

PROGRESS AND ACHIEVEMENTS

Five wetlands were measured for all metrics (submerged aquatic vegetation, abiotic stress, and wet meadow composition) in the summer 2016. Data is still being analyzed. The 2017 season will repeat these measurements, and implement small operational improvements to the sampling program to increase efficiencies.

OUTCOMES AND LESSONS LEARNED

The data analysis is not complete, and so there are no conclusions to report.

LITERATURE CITED

Costanza, R., Norton, B., Haskell, B. (1992). Ecosystem health: New goals for environmental management. Washington, D.C. Island press.

Rooney, R.C. and Bayley, S.E. (2010). Quantifying a stress gradient: An objective approach to variable selection, standardization and weighting in ecosystem assessment. Ecological Indicators 10(6): 1174-1183.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

All research provided by Canadian Natural Resources Limited, Horizon.

Compensation Lakes and Aquatics

Horizon Lake Fisheries Monitoring

COSIA Project Number: LJ0011

Research Provider: Canadian Natural Resources Limited, Hatfield Consultants

Industry Champion: Canadian Natural Resources Limited

Status: Year 9 - Ongoing

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of developing the Horizon Oil Sands (Horizon), which includes the development of a compensation lake (Wāpan Sākahikan) to permanently offset areas of fish habitat that will be affected by Horizon developments. The primary purpose of the compensation lake development, hereafter referred to as Horizon Lake, is the establishment of habitat that will support self-sustaining resident fish populations. Horizon Lake is located approximately 60 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 the compensation lake will be based on satisfying conditions identified in Canadian Natural's Fisheries Act Authorization, which 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 2015 monitoring program became available in 2016 after the publication of the COSIA Land EPA Mine Site Reclamation Research Report and are therefore presented in this report.

Fish Populations

A total of 10 species of fish have been documented in Horizon Lake since monitoring was initiated in 2008, consisting of Arctic grayling, brook stickleback, burbot, finescale dace, fathead minnow, lake chub, longnose sucker, slimy sculpin, trout-perch, and white sucker.

1,783 fish were caught from the lake in 2015, including 25 recaptures of fish tagged between 2010 and 2015. An additional 567 PIT tags were also deployed during the 2015 sampling period. The assemblages of fish species caught by the different fishing methods have been relatively consistent from 2012 to 2015, though the relative proportions of each species have varied over time. Fathead minnow and white sucker were the dominant forage fish and large-bodied fish species in 2015, respectively. The relative abundance of fathead minnows appears to be increasing over time, possibly coinciding with a decrease in lake chub abundance. Slimy sculpin and Arctic grayling captures continue to be low, and no finescale dace or burbot were captured in 2015.

Fish Abundance And Production Estimate

A hydroacoustic survey was conducted in 2015 to measure abundance and production of the four most common species in Horizon Lake (fathead minnow, lake chub, longnose sucker and white sucker). Total production for these four species was 3,560 kg in 2015, with the two sucker species comprising 98% of the total production biomass.

Abundance in 2015 was within the range of estimates from the 2013 and 2014 hydroacoustic surveys, while biomass and production estimates were higher than previous years; however, the overall P:B ratio was lower in 2015 indicating that production was driven by faster growing small-bodied fish in 2013 and 2014.

Abundance estimates could not be calculated for the 2015 mark-recapture survey due to low tag returns (only four of the 759 tagged fish were recaptured).

Water Quality

Seasonal in situ profile data from Horizon Lake reflected the effects of regionally warm temperatures and low precipitation during the spring of 2015.

Continuous water temperature data from the thermistor strings showed a strong thermocline had already developed when logging was initiated at the start of July, and that the stratification persisted until late-September. Average surface water temperature from July to August was 19°C, which decreased to 13°C in September. Daily average temperatures in the deepest portions of the lake were coldest during July and warmest at the end of September, following lake turnover.

Vertical profiles of pH showed moderate variability through the water column, with values ranging from 6.8 and 9.0; all pH measurements were within the tolerance ranges of the lake's fish community.

Dissolved oxygen (DO) profiles identified a decline in profundal DO between late-May and mid-July, with near-bottom DO concentrations decreasing to below 2 mg/L at depths greater than 7 m; however, there was abundant access to well-oxygenated water in the lake at this time, and fish would be expected to simply avoid the low oxygen areas of the lake until fall turnover.

Seasonal and inter-annual variability in select water quality analytes has been relatively low since monitoring began in 2008. The majority of the variability observed is attributable to regular seasonal events like freshet and lake turnover, although inter-annual variability has also been observed in response to specific climactic events, such as the flood conditions during the spring of 2013 and the very dry period that occurred during the spring of 2015. Compared to previous years, there were no substantial increases in metal concentrations observed in the spring (i.e., mercury and aluminum); most analytes were within historical ranges in 2015, and within relevant water quality guidelines for the protection of aquatic life.

Historically, the lake has generally been a eutrophic system. In 2015, the lake was mesotrophic, and, as of winter 2016, dropped to oligotrophic. This is the first time the Trophic State Index (TSI) values have indicated an oligotrophic state since monitoring began in 2008.

Aquatic Macrophytes

Macrophytes were predominately comprised of submergent species in 2015, which was similar to observations made during previous surveys of the lake. A review of macrophyte distribution in 2013 (i.e., the last time macrophytes were surveyed) found that cover in the littoral zone has not changed substantially over the last two years. Overall,

macrophytes appear to be well established in the littoral zone, with the 38% total cover observed in 2015 exceeding the 33% predicted in the No Net Loss Plan (NNLP), (Golder 2004).

Plankton

Phytoplankton abundance in 2015 was similar to previous years, although total biomass was lower. Simpson's diversity has been relatively consistent since monitoring commenced in 2008, and suggests a moderately diverse community. After a four-year increasing trend, mean annual phytoplankton richness showed a one-year decrease in 2013 before increasing again in 2014 and 2015.

Cyanobacteria, chrysophytes, and diatoms have consistently been the most abundant taxonomic groups in Horizon Lake since monitoring began in 2008, with cyanobacteria comprising the majority of plankton biomass in the lake. Differences in abundance and biomass dominance are the result of differences in cell sizes (i.e., larger taxa which were present in small numbers did not dominate based on abundance, but dominated based on biomass because of their size). In 2015, seasonal peaks in phytoplankton abundance and biomass occurred in July. The dominant phytoplankton group, by abundance and biomass, varied depending on the sampling event.

Zooplankton total abundance was generally higher in 2015 than previous monitoring years, which was due, in part, to the large number of small-bodied rotifers captured. In 2015, zooplankton biomass was higher in July than May or September, while total abundance was high in both May and July. The dominant zooplankton group by abundance was Rotifera and by biomass was Rotifera and Cyclopoida.

Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both seasonally and temporally (Findlay and Kling 2001 and 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, they can further influence phytoplankton biomass, abundance, and community composition through top-down control (Carpenter and Kitchell 1984).

Benthic Invertebrates

Similar to previous years, total species abundance and richness were much lower in mid-lake and littoral sites than in near-shore sites in 2015, which was expected given shallower lake regions generally have greater amounts of oxygen, higher habitat heterogeneity, and greater food resources available. Total abundance at all three near-shore sites was substantially higher in 2015, relative to previous years. Diversity and evenness at the three near-shore sites generally fell within the variability observed in previous years. All metrics at the littoral and mid-lake sites were generally within the range of previous years.

In 2015, Diptera (true flies, midges, and mosquitoes) were the most abundant taxa by density at all stations. Other abundant taxa included copepods (small aquatic crustaceans), oligochaetes (worms), and cladocerans (water fleas), which were amongst the most abundant at two of the littoral sites. Diptera and Oligochaeta have been the most abundant taxa in the pelagic and littoral sites since 2008; Oligochaeta and Diptera were also abundant in 2015, although there was also a high abundance of Cladocera and Ephemeroptera that was not seen in previous years. The presence and abundance of these benthic invertebrate species was not unexpected, as they are commonly found in shallow lakes.

OUTCOMES AND LESSONS LEARNED

The monitoring strategy for the compensation lake has been to evaluate the establishment of the various ecological attributes of the lake for five years following construction, then transition to a focus on the development of fish production in subsequent monitoring years.

The monitoring program has been conducted since the summer of 2008, and the data collected have determined that the lake provides suitable habitat for all life stages of two sucker and six forage fish species. Arctic grayling, a provincially sensitive species, has been documented using the lake for overwintering.

LITERATURE CITED

Carpenter, S.R., Kitchell, J.F. 1984. Plankton community structure and limnetic primary production. Amer Nat 124:159-172.

Findlay, D. L. and H. J. Kling. 1976. A species list and pictorial reference to the phytoplankton of central and northern Canada. Fisheries and Environment Canada, Fisheries and Marine Service, Manuscript Report No. 1503. 619 pp.

Golder 2004. Canadian Natural resources Limited Horizon Project – No net loss habitat compensation and monitoring plan. Prepared for Fisheries and Oceans Canada. Calgary, AB.

Paterson M. 2002. Ecological Monitoring and Assessment Network (EMAN) Protocols for Measuring Biodiversity: Zooplankton in Fresh Waters. Available at: http://www.ec.gc.ca/Publications/7A547B5A-FBD2-42BC-8C6E-98E826F4C9EE%5C FreshwaterMonitoringProtocolZooplanktonFreshwater.pdf. Accessed: March 2015.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants

Principal Investigator: Dan Moats

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dan Moats	Hatfield Consultants	Senior Partner		
Cory Bettles	Hatfield Consultants	Fisheries & Aquatics Manager		
Meghan Isaacs	Hatfield Consultants	Environmental Specialist		
Colin Schwindt	Hatfield Consultants	Environmental Specialist		
Derek Donald	Hatfield Consultants	Environmental Specialist		
James Morgan	Hatfield Consultants	Environmental Specialist		
Jennifer Carter	Hatfield Consultants	Environmental Specialist		
Jocelyn Beniuk	Hatfield Consultants	Environmental Specialist		
Mike Rutter	Hatfield Consultants	Environmental Technician		
Brian Moore	BioSonics, Inc.	Senior Hydroacoustic Scientist		

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 to support 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 invertebrate in littoral and pelagic habitats
- Aquatic vegetation establishment
- Phytoplankton and zooplankton

PROGRESS AND ACHIEVEMENTS

Water quality

Results show that Muskeg Lake was well-oxygenated, slightly alkaline, with low concentrations of TSS in 2016. Concentrations of total and dissolved metals, as well as nutrients, were generally within the range of concentrations documented in previous years. Naphthenic acids, total recoverable hydrocarbons, and PAHs were below the detection limits (DLs) with the exception of naphthalene and some substituted naphthalenes.

Sediment quality

Total organic carbon (TOC) was low and sand was the dominant fraction of inorganic bottom sediments. Concentrations of metals were generally low and similar to those observed in previous years, however, concentrations of boron, sodium and uranium were higher than those observed previously. Concentrations of hydrocarbons (HCs) and polycyclic aromatic hydrocarbons (PAHs) were generally higher than those observed in previous years which may reflect the influence of the 2016 wildfire.

Fish and Fish Habitat:

Fish sampling, via gill-netting, electrofishing and trapping, was conducted in June and September in 2016.

A total of eight fish species were captured in 2016. The total number captured (in spring and summer) and the average weight in grams (g) of the captured species is summarized below:

- Brook stickleback (*Culaea inconstans*): 9776 (average weight 2.4 g)
- Northern redbelly Dace (*Chrosomus eos*): 4 (average weight 1.2 g)
- Fathead minnow (*Pimephales promelas*): 1731 (average weight 2.4 g)
- Finescale dace (*Phoxinus neogaeus*): 4479 (average weight 1.6 g)
- Lake chub (*Couesius plumbeus*): 315 (average weight 2.1 g)
- Pearl dace (*Margariscus margarita*): 408 (average weight 5.2 g)
- Northern pike (*Esox lucius*): 7 (average weight 2120 g)
- White sucker (*Catostomus commersonii*): 11 (average weight 673 g)

Littoral and pelagic zone habitat data recorded in 2016 included: continuous water temperature, dissolved oxygen, pH and specific conductivity.

Aquatic vegetation

In 2016 the distribution of the aquatic macrophytes in the near shore portion of the littoral zone were mapped. 39 areas of aquatic macrophytes were identified along the shoreline. The vegetation identified included sedges (*Cyperaceae*), sago pondweed (*Potamogeton pectinatus*), cattails (*Typha*), coon tail (*Ceratophyllum demersum*), northern water milfoil (*Myriophyllum exalbescens*) and floating leaf pondweed (*Pontamogeton natans*).

Benthic invertebrate

Data were collected in fall 2015 but sample analysis was not completed at the time of the COSIA Land EPA 2015 Mine Site Reclamation Research Report, so this summarizes the results of the 2015 sampling. Samples were collected from both deep and shallow (littoral) sampling locations. Both mean total density and taxonomic richness of the benthic invertebrates were moderate at the littoral sampling location and low at the deep sampling location. Diversity indices were high at both locations however evenness was low indicating that although the communities were diverse the distribution of organisms was uneven among the taxa.

The benthic invertebrate community at the deep water location was dominated by non-biting midges (*Chironomus* sp.), seed shrimp (*Ostrada*) and glassworm midges (*Chaoborus* sp.) which comprised 55%, 15% and 10% of the community respectively.

Plankton

Similarly, this data were collected in fall 2015 but sample analysis was not completed at the time of the COSIA Land EPA 2015 Mine Site Reclamation Research Report, so this summarizes the results of the 2015 sampling. Mean taxonomic richness of zooplankton was found to be 14.0 +-0.6; while that for phytoplankton was found to be 36.3 +-2.0. Total and percent abundance and biomass as well as dominant taxa by biomass were also determined for both phyto and zooplankton.

Comparison of results to date have shown that richness has increased for both phytoplankton and zooplankton; while mean abundance and biomass haves been variable for both.

OUTCOMES AND LESSONS LEARNED

This study is in its early stages so there are no emerging outcomes or lessons learned.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates

Principal Investigator: Golder Associates

Fisheries Sustainable Habitat Committee: Refinement of Fish Habitat Pre-Disturbance Models

COSIA Project Number: LJ0225

Research Provider: Hatfield Consultants, Ecofish Research

Industry Champion: Shell Canada Energy

Industry Collaborators: Suncor Energy Ltd., Canadian Natural Resources Limited, Imperial, Total E&P Canada Ltd., Teck Resources Limited.

Status: Year 4 of 4 (one year extension)

PROJECT SUMMARY

Developing the oil sands resource in northeast Alberta often results in both temporary and permanent losses of fish and fish habitat. To properly offset those impacts as required by Fisheries Act Authorizations, it is necessary to understand and quantify the level of disturbance using a scientifically defensible and repeatable measurement of habitat. This same approach can then be used to ensure a commensurate offset. The regional habitat suitability index (HSI) models currently in use for this purpose were developed using a combination of scientific literature and expert judgment and have not been regionally validated.

The primary goal of the Fisheries Sustainable Habitat (FiSH) Committee's Refinement of Fish Habitat Pre-Disturbance Models Program (the Program) is to develop a dataset that will allow scientists to refine the existing HSI models to quantify fish habitat in the Athabasca oil sands region in a reliable and scientifically credible manner. The Program has been implemented in two phases. Phase 1 consisted of creating a database of existing fish and fish habitat data collected in support of individual operator programs. Phase 1 provided a synopsis of the information collected to date, which allowed data gaps to be assessed and also identified compatible data that could be used as direct inputs to the process of refining and validating the HSI models. Phase 1 was completed in 2013, and found that individual operators had obtained substantial data for several fish species, but that the information was not sufficient for a number of key fish species, especially commercial, recreational and Aboriginal fishery species. Historically, the various site-specific studies collected data on a limited set of species because the majority of the study areas were located in the upper portion of tributary watersheds, which predominantly consist of small streams and wetland areas.

Phase 2 of the Program involved the design and implementation of a three-year study focused on collecting data for key riverine species. These species had not been captured in sufficient quantities in past years, to facilitate model validation and refinement. Phase 2 aims to meet the following key objectives:

- Collect fish habitat use observations to address the data gaps identified in Phase 1.
- Develop a methodology to integrate data from previous studies into the Phase 2 analysis.
- Assess sample size requirements for model validation.
- Explore relationships in the data that may lead to new suitability indices.
- Develop regionally specific HSI models that are validated with empirical data.
- Satisfy HSI model validation conditions in a number of operator Fisheries Act Authorizations.

PROGRESS AND ACHIEVEMENTS

2015 represented the third and final year of Phase 2 data collections, dedicated to analysis, modelling and report writing. 192 mesohabitat units were sampled over the course of the study, and 180 fish and fish habitat records were collected for the five priority fish species (Arctic grayling, burbot, northern pike, walleye, and longnose dace). In 2015 alone, 2,884 fish were caught from 68 mesohabitat units located within 14 different streams. Over 30 habitat variables were measured at each mesohabitat unit, encompassing aspects of channel structure (stream size, water depth, and substrate composition), habitat complexity (types of cover), water velocity, and water quality (temperature, pH, and dissolved oxygen).

Fish habitat modelling was completed in the spring of 2016 with a detailed review ongoing. The final product will provide the necessary evidence to refine the HSI models for 14 fish species from the Athabasca oil sands region. The fish species include the priority fish species noted above, two sucker species (longnose sucker and white sucker) and some small-bodied fish species (brook stickleback, finescale dace, fathead minnow, lake chub, pearl dace, slimy sculpin, and troutperch). The analysis uses a model selection and weight-of-evidence approach to identify habitat variables that limit fish abundance. These variables will then be incorporated into a revised HSI model for each species.

OUTCOMES AND LESSONS LEARNED

Using the methods employed, HSI validation on a watershed scale may be possible but not on a regional scale. Work to confirm this emerging outcome will be the focus of the committee's work in 2017.

LITERATURE CITED

Hatfield and Ecofish, 2016. Refinement of Fish Habitat Pre-Disturbance Models: Draft Technical Report – Phase 2. Prepared for: CANADA'S OIL SANDS INNOVATION ALLIANCE (COSIA), FISHERIES SUSTAINABLE HABITAT (FiSH) COMMITTEE. In review.

PRESENTATIONS AND PUBLICATIONS

The draft final report for this study is complete and has been reviewed. However, further analysis is warranted and will be required before the final report is produced. The new HSIs and supporting analysis may be submitted to a peer-reviewed scientific journal for wider public availability. A Field Sampling Protocols Manual was also developed during the first year of Phase 2.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants[1], Ecofish Research[2]

Principal Investigators: Daniel Moats[1], Dr. Todd Hatfield[2], Dr. Morgan Hocking[2], Steve Tang[1]

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Daniel Moats	Hatfield Consultants	Project Director		
Dr. Todd Hatfield	Ecofish Research	Scientific Advisor		
Dr. Morgan Hocking	Ecofish Research	Modelling Specialist		
Steve Tang	Hatfield Consultants	Project Manager		

Government Collaborators: Fisheries and Oceans Canada, Alberta Environment and Parks

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 Resources Limited

Status: Year 2 of 5

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of the development of a compensation lake (Wāpan Sākahikan/Horizon Lake), 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-present)
- Hydroacoustic monitoring (2013-present)
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality; 2008-present)

Implementation of these approaches will provide further insight into the role of habitat in determining age and growth relationships in fish populations. This could have an impact on future compensation lake developments and subsequent management.

PROGRESS AND ACHIEVEMENTS

In May 2016 the project welcomed two graduate students (see below). With the new students, the project expanded to include sampling on 8 natural lakes within the lower Athabasca region (Goodwin Lake, Steepbank Lake, Wappau Lake, Kirby Lake, Hay Lake, Unnamed Lake 1, Unnamed Lake 2, Unnamed Lake 3), with the objective of assessing the relationship between habitat and age-growth relationships in natural and compensation lakes. This will allow the determination of the natural limit of age and growth in relation to habitat, while relating these findings to the design and management of compensation lakes. All of the work completed in 2016 was field based. To summarize, the following progress and achievements were made during 2016:

- Hydroacoustic, age and tissue collection, and data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected in 8 lakes in the lower Athabasca during 3 seasons (spring, summer/fall, and winter; ongoing)
- Hydroacoustic, age and tissue collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected on Horizon Lake (ongoing).

Stable isotope analysis: Age-structured food web analysis

Estimates of fisheries productivity are associated with high levels of uncertainty (Minns, 2015) and provide little information about the structure and functioning of the ecosystem. Food web structure is considered to be an important factor regulating the sustainable functioning and dynamics of ecosystems, including primary production,

nutrient cycling, and biomass accumulation (Carpenter et al., 2001). Food webs, which are supported by available habitat, can be modeled accurately using stable isotope analysis (SIA) (Parnell et al., 2010). This project will use SIA to model food webs and investigate how food web structure can influence fisheries productivity and ecosystem function in both compensation and natural lakes in the oil sands region of Alberta. Specifically, this includes: 1) modelling food webs in natural and compensation lakes in order to characterize their food web structure; 2) investigating the differences and similarities between the food webs of compensation lakes and natural lakes; and 3) identifying whether food web structure confers different fisheries productivities between lakes, where habitat amount and configuration differs, in the northern Boreal region of Alberta. All of this will be completed in an age-structured manner, whereby fish populations will be portioned not only by species, but age (juvenile or adult).

SIA uses ratios of carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) isotopes to deduce the composition of an organism's diet (Fry, 2006). In 2016, we collected tissue or whole organism samples from primary producers (including attached algae and phytoplankton), invertebrates (including zooplankton, benthic, and terrestrial invertebrates), lower tropic level fish, and piscivorous fishes present in each of the 8 natural lakes and Horizon Lake. Tissue samples are now in the process of being prepared and stable isotope ratios will be measured using a continuous flow mass-spectrometry system (Fry, 2006). Subsequent analysis will be conducted using a Bayesian stable isotope mixing model to construct age-structured food webs for each lake. The results will be used to characterize food web interactions within each lake. This will allow us to determine where resources are being acquired for species and whether it differs within species defined age classes. Post hoc analyses will be used to compare food web interactions, organisms' trophic levels, and trophic niche ellipses among lakes and to investigate relationships between fisheries productivity estimates, lake trophic structure and habitat differences. This portion of the project is currently ongoing, with collection of data throughout 2017.

Stable isotope analysis: Energetic bottlenecks

Food webs can be modelled accurately using stable isotope analysis (SIA), which is based on a defined trophic level for each species and age class. While traditionally muscle tissue is used to determine trophic level as it can provide a long-term diet signal, other tissues, such as liver and blood, can provide insight into short-term diets (Matich et al., 2015). As winter is often thought to be a difficult season for fish populations to acquire the resources they need to persist and grow (Shuter et al., 2012), we investigate the age-growth relationship of species and link this with seasonal trophic signatures using age structures alongside liver and blood tissues to construct ratios of carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) isotopes to deduce the composition of an organism's diet (Fry, 2006). Our objective is to determine to what degree seasonal variation in resources limits growth in relation to the age of individuals within a population.

In 2016, we collected samples and whole organisms from 8 natural lakes and Horizon Lake. We plan to sample 3 of those natural lakes and Horizon Lake in March 2017 and continue collection of data throughout the spring and summer of 2017. This project will also use SIA to model variability in resources for fish populations and investigate how this variability influences fisheries productivity and ecosystem function in both compensation and natural lakes in the oil sands region of Alberta. This portion of the project is currently ongoing, with collection of data throughout 2017.

Hydroacoustic Monitoring

Hydroacoustic units use a series of acoustic pulses to monitor both the biological and physical characteristics of a waterbody to provide an accurate, low-impact alternative for estimating fish abundance (Simmonds & MacLennan, 2005). Furthermore, hydroacoustic data can help to better define habitat-productivity relationships, a current knowledge gap, by providing valuable information on spatial and temporal distributions of fish within a system

(Minns et al., 2011). This project will use a combination of hydroacoustics and traditional sampling methods to better define habitat-productivity relationships and determine how lake characteristics may influence age-structured fisheries productivity in natural and compensation lakes.

In 2016 acoustic data was collected on 5 natural lakes and Horizon Lake using a Biosonics DTX unit equipped with a 200 kHz split-beam transducer mounted to a survey vessel during a spring (May/June) and summer/fall (August/September/October). All surveys followed recommended guidelines outlined in the standard operating procedures for fisheries acoustic surveys in the Great Lakes (Parker-Stetter et al., 2009). Hydroacoustic data will be analyzed to determine biomass and abundance of fish species in each lake. These results will be compared to direct sampling (i.e., gill netting) to establish species presence and age-growth relationships for the species in each lake. Finally, productivity will be approximated for each lake using an average production to biomass ratio. This portion of the project is currently ongoing, with collection of data throughout 2017.

OUTCOMES AND LESSONS LEARNED

This project is in early stages so there are no emerging outcomes or lessons learned to report for 2016.

LITERATURE CITED

Carpenter SR, Cole JJ, Hodgson JR, Kitchell JF, Pace ML, Bade D, Cottingham KL, Essington TE, Houser JN, and Schindler DE (2001) Trophic cascades, nutrients, and lake productivity: whole-lake experiments. Ecological Monographs 71:163-186

Fry B. (2006) Stable isotope ecology. Springer: New York.

Matich P, Kiszka JJ, Heithaus MR, Mourier J, and Planes S (2015) Short-term shifts of stable isotope (delta C-13, delta N-15) values in juvenile sharks within nursery areas suggest rapid shifts in energy pathways. Journal of Experimental Marine Biology and Ecology 465:83-91

Minns CK (2015) Canadian Fish Habitat Management: Symptoms and Remedies. Pages 213-248 In: Fisher N, Leblanc P, Rose CA and Sadler B, (eds) Managing the Impacts of Human Activities on Fish Habitat: The Governance, Practices and Science. Amer Fisheries Soc, 5410 Grosvenor Lane, Ste 110, Bethesda, Md 20814-2199 USA

Minns CK, Randall RG, Smokorowski KE, Clarke KD, Velez-Espino A, Gregory RS, Courtenay S, and Leblanc P (2011) Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going? Canadian Journal of Fisheries and Aquatic Sciences 68:2204-2227

Parker-Stetter SL, Rudstam LG, Sullivan PJ, and Warner DM. (2009) Standard operating procedures for fisheries acoustic surveys in the great lakes. Great Lakes Fish. Comm. Spec. Pub. 09-01.

Parnell AC, Inger R, Bearhop S, and Jackson AL (2010) Source Partitioning Using Stable Isotopes: Coping with Too Much Variation. Plos One 5:5

Shuter BJ, Finstad AG, Helland IP, Zweimuller I, and Holker F (2012) The role of winter phenology in shaping the ecology of freshwater fish and their sensitivities to climate change. Aquatic Sciences 74:637-657

Simmonds EJ, and Maclennan DN. (2005) Fisheries acoustics. 2nd ed. Oxford: Blackwell Science.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2016.

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)
Karling Roberts	University of Alberta	M.Sc.	2016	2018
Michal Terry	University of Alberta	M.Sc.	2016	2018
Jonathan Ruppert	University of Alberta	Post-Doctoral Researcher		

Research Collaborators: Department of Fisheries and Oceans

Assessing the Productive Capacity of Compensation Lakes

COSIA Project Number: LJ0171

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 5

PROJECT SUMMARY

Canadian Natural Resources Limited (Canadian Natural) is in the process of the development of a compensation lake (Wāpan Sākahikan / Horizon Lake), 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:

- Hydroacoustic monitoring (2013-present)
- Analysis of blood metabolites in fish populations to determine energetic bottlenecks (2016-present)
- Long-term monitoring (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) and analysis (2008-present)

Implementation of these approaches will provide further insight into the sustained productive capacity of compensation lakes. This could have an impact on future compensation lake developments and its subsequent management.

PROGRESS AND ACHIEVEMENTS

In May 2016 the project welcomed two graduate students (see below). With the new students, the project expanded to include sampling on 8 natural lakes within the lower Athabasca region (Goodwin Lake, Steepbank Lake, Wappau Lake, Kirby Lake, Hay Lake, Unnamed Lake 1, Unnamed Lake 2, Unnamed Lake 3), with the objective of assessing the relationship between habitat and age-growth relationships in natural and compensation lakes. This allows us to determine the natural limit of productive capacity in lakes for the region, while relating these findings to the design and management of compensation lakes. A majority of the work completed in 2016 was field based. However, historical data available from Horizon Lake (2008–2015) provided an opportunity to understand what processes contribute to fish population productivity during its initial establishment, which in turn can provide insight into the sustained productive capacity of fisheries in the lake. To summarize, the following progress and achievements were made during 2016:

- Hydroacoustic, blood collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected on 8 lakes in the lower Athabasca during 3 seasons (spring, summer/fall, and winter; ongoing)
- Hydroacoustic, blood collection, and long-term data (fish, invertebrates, zooplankton, phytoplankton, water and sediment quality) collected on Horizon Lake (ongoing)
- Analysis of historical fish population and invertebrate data from Horizon Lake (completed)

Hydroacoustic Monitoring

Metrics of fisheries productivity currently rely on extensive fish sampling, however, new advancements in hydroacoustic technology can reduce the amount of effort required to sample fish communities (Simmonds & MacLennan, 2005). Hydroacoustic units use a series of acoustic pulses to monitor both the biological and physical characteristics of a waterbody to provide an accurate, low-impact alternative for estimating fish abundance. Furthermore, hydroacoustic data can help to better define habitat-productivity relationships, a current knowledge gap, by providing valuable information on spatial and temporal distributions of fish within a system (Minns et al., 2011).

This project will use a combination of hydroacoustics and traditional sampling methods to: 1) establish natural ranges of productivity throughout lakes in the oil sands region and 2) determine how lake characteristics may influence fisheries productivity in natural and compensation lakes. In 2016 acoustic data was collected on 5 natural lakes and Horizon Lake using a Biosonics DTX unit equipped with a 200 kHz split-beam transducer mounted to a survey vessel during spring (May/June) and summer/fall (August/September/October). All surveys followed recommended guidelines outlined in the standard operating procedures for fisheries acoustic surveys in the Great Lakes (Parker-Stetter et al., 2009). Hydroacoustic data will be analyzed to determine biomass and abundance of fish species in each lake. This portion of the project is currently ongoing, with collection of data throughout 2017.

Energetic Bottlenecks

Winter kill is a common phenomenon in Alberta lakes and is a good example (at the extreme end) of how productivity can be limited through what is often thought to be a difficult season for fish populations to acquire the resources they need to persist and grow (Shuter et al., 2012). To understand how seasonal variation in resources and environmental conditions available to fish populations may impact the productive capacity of compensation and natural lakes within the boreal region of Alberta, in 2016 we collected and analyzed blood samples from fish populations in Horizon Lake and 5 natural lakes in the lower Athabasca. We plan to sample 3 of those natural lakes and Horizon Lake in March 2017 and throughout the spring and summer. Doing so can provide levels of metabolites and glucose that are a cue for the amount of stress experienced by fish populations (which can come about when competition is high and resources are scarce)(Cooke et al., 2008).

To do so, we used an iSTAT handheld and an over-the-counter glucose meter to measure the amount of glucose, lactate and partial pressures of oxygen and carbon dioxide within the blood sample. This data will help to address: (1) if seasonal stress, such as limited resources in winter, may influence the productive capacity of northern boreal lakes and compensation lakes and (2) if specific habitat features (e.g., depth) may impact the degree of stress experienced by fish populations. Understanding the key factors that contribute to limiting the productive capacities of lakes within the boreal region will help to develop better compensation lake designs and ultimately confer higher levels of productivity in habitat offsets. This portion of the project is currently ongoing, with collection of data occurring throughout 2017.

OUTCOMES AND LESSONS LEARNED

Historical Analysis

Compensation lakes are a relatively new concept and there are many uncertainties regarding their design and management (Minns, 2015). In 2016 we used long-term (2008-2015) data set of fish populations and benthic invertebrates from Canada's first compensation lake in the oil sands region of Northern Alberta, Horizon Lake, to address: (1) how fish community structure changes through time, (2) whether there is a similar evolution between

fish and invertebrate communities, and (3) we compare the fish assemblage in Horizon Lake to those found in natural lakes within the lower Athabasca region. These findings were summarized in a manuscript that has been submitted to a peer-reviewed journal (see below).

In 2016 we completed analysis and wrote up a manuscript detailing how the fish community is significantly changing through time. This manuscript has been submitted for review and if approved will be available in 2017. We find that there is no significant concordance between fish and benthic invertebrate communities (i.e., they are not changing in the same manner). Additionally, the assemblage and composition of fish species in the compensation lake is unique compared to other surveyed lakes within the lower Athabasca region. Although new lakes are expected to be different from natural lakes, these results suggest that to increase overall productive capacity, introducing large-bodied predators into the lake would help to ensure sustainable productive capacity of commercial, recreational and Aboriginal fisheries. We also highlight the need for better regional data to assess fisheries productive capacities of boreal lakes and the need to establish the role of habitat in determining age-growth relationships to insure long-term sustained no net loss in fisheries productivity.

LITERATURE CITED

Cooke SJ, Suski CD, Danylchuk SE, Danylchuk AJ, Donaldson MR, Pullen C, Bulté G, O'toole A, Murchie KJ, Koppelman JB, Shultz AD, Brooks E, and Goldberg TL (2008) Effects of different capture techniques on the physiological condition of bonefish *Albula vulpes* evaluated using field diagnostic tools. Journal of Fish Biology 73:1351-1375

Minns CK (2015) Canadian Fish Habitat Management: Symptoms and Remedies. Pages 213-248 In: Fisher N, Leblanc P, Rose CA and Sadler B, (eds) Managing the Impacts of Human Activities on Fish Habitat: The Governance, Practices and Science. Amer Fisheries Soc, 5410 Grosvenor Lane, Ste 110, Bethesda, Md 20814-2199 USA

Minns CK, Randall RG, Smokorowski KE, Clarke KD, Velez-Espino A, Gregory RS, Courtenay S, and Leblanc P (2011) Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going? Canadian Journal of Fisheries and Aquatic Sciences 68:2204-2227

Parker-Stetter SL, Rudstam LG, Sullivan PJ, and Warner DM. (2009) Standard operating procedures for fisheries acoustic surveys in the great lakes. Great Lakes Fish. Comm. Spec. Pub. 09-01.

Shuter BJ, Finstad AG, Helland IP, Zweimuller I, and Holker F (2012) The role of winter phenology in shaping the ecology of freshwater fish and their sensitivities to climate change. Aquatic Sciences 74:637-657

Simmonds EJ, and Maclennan DN. (2005) Fisheries acoustics. 2nd ed. Oxford: Blackwell Science.,

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2016.

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)
Karling Roberts	University of Alberta	M.Sc.	2016	2018
Michal Terry	University of Alberta	M.Sc.	2016	2018
Jonathan Ruppert	University of Alberta	Post-Doctoral Researcher		

Research Collaborators: Department of Fisheries and Oceans

Soils and Reclamation Materials

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 1 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 and 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.

Current regulations stipulate that a/b surface soil (ABSS) and d/other surface soil (OSS) must be stockpiled separately to preserve soil texture and other soil qualities and to maintain separate and distinct seed banks. Recent research, however, suggests that plant propagules do not retain their viability in stockpiles. Storing ABSS and OSS separately is also very costly and requires more space than if combined in one stockpile.

The purpose of this research project is to determine whether ABSS and OSS can be co-mixed in the same pile without negatively affecting soil chemical and physical properties, or potential vegetation community establishment. Soil quality parameters as well as vegetation will be monitored for at least 6 years in duplicate mixed and unmixed stockpiles (Stockpile ABSS; Stockpile OSS; Stockpile ABSS + OSS).

PROGRESS AND ACHIEVEMENTS

Due to the Fort McMurray fire in May 2016 and the migratory bird nesting window, soil salvage and stockpile construction originally scheduled for May 2016 was delayed until September 2016. A total of six research stockpiles were constructed at Kearl Operations, in the East Reclamation Material Stockpile area – two ABSS stockpiles; two OSS stockpiles and two mixed stockpiles (ABSS + OSS). Each pile is approximately 3,000 m^3 in volume and 5 m high. The ABSS and OSS piles were constructed purely of ABSS and OSS respectively (inclusive of their respective leaf litter components), while the ABSS + OSS pile is constructed by co-mixing the two surface soils. To mimic operational procedures as closely as possible, mixing in the ABSS + OSS pile was not perfectly homogenous, rather alternate loads of ABSS and OSS were placed in the stockpile. Each stockpile is surrounded by a 5 m buffer zone.

A monthly and annual soil monitoring protocol was developed and is shown below in Table 1.

Table 1. Sampling Protocol for Monthly and Annual Soil Monitoring

	Monthly Monitoring	Annual Monitoring
Sampling periods	2016: Oct 2017: May, June, July, Aug, Oct	September 2016-2021
Number of random sample locations per stockpile	3	9
Sampling depths	0.5 m, 2.0 m, 4.0 m	0.5 m, 2.0 m, 4.0 m
Number of composite samples per stockpile	Three (one per sampling depth)	Nine (three per sampling depth)
Total number of composite samples (six stockpiles)	18	54
Soil parameters	pH Salinity Sodicity Cations and anions Available NPKS Total Organic Carbon (TOC)	pH Salinity Sodicity Cations and anions Available NPKS Total Organic Carbon (TOC) Texture Bulk Density
Vegetation parameters	NA	Abundance Species richness Community evenness Community diversity

Year 0 (2016) and Year 1 (2017) monthly soil sampling will be used to track chemical changes over time in the stockpiled soil during the critical first year of storage. Annual sampling will be used to identify and quantify differences in measured soil parameters among the three soil types (ABSS, OSS, ABSS + OSS).

Due to construction delays, only one monthly sampling event was undertaken in Year 0 (October 2016) and the first annual sampling event was undertaken in September 2016. Soil will be monitored until 2021.

Results of the first sampling event show soil quality in stockpiles is not affected by soil type during the first few months following construction. There was no significant effect of surface soil type on any of the parameters measured, with the exception of the soil type × sampling depth interaction for TOC, which was higher at the lowest sampling depth (4.0 m) than the shallower sampling depths in OSS stockpiles only. Location within the stockpile (i.e., sampling depth) was a significant determinant of levels of some soil parameters (e.g., EC, SAR, soluble Ca, soluble Mg, soluble Na, available K, and available SO_4- S), where samples near the surface differed from deeper samples near the base.

Salinity measured by electric conductivity (EC) and sodicity reflected by the sodium adsorption ratio (SAR) varied with sampling depth for all surface soil types. Values were lowest near the surface for EC, but highest near the surface for SAR. Significant variation with sampling depth was also observed for soluble Ca, soluble Mg, soluble Na, available K, and available SO_4- S.

As this is the first year of the annual monitoring program, subsequent assessments will provide important insight into whether these trends are important, or if they simply reflect variation in the data.

OUTCOMES AND LESSONS LEARNED

This project is in early stages so there are no emerging outcomes or lessons learned for 2016.

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.

Nutrient Biogeochemistry 2: Tracking Nutrient Fluxes Through Reconstructed Soils

COSIA Project Number: LJ0120

Research Provider: University of Alberta, University of British Columbia

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Canadian Natural Resources Limited, Imperial, Shell Canada Energy, Suncor Energy Inc., Total E&P Canada Ltd.

Status: Year 6 of 6

PROJECT SUMMARY

Following surface mining, reclamation of landforms necessitates the reconstruction of soil profiles using salvaged surface mineral materials and organic soils (peat or peat-mineral mix) as the coversoil (topsoil) layer and mineral parent materials as subsoil. Establishment of biogeochemical cycling between these reconstructed soils and plants is required to ensure long-term sustainability in reclaimed landscapes. While vegetation growing on recently reconstructed soils relies primarily on the coversoil for its nutrient needs, over time in situ litterfall and the build- up of a forest floor layer, like undisturbed upland soils in the region, should play a prominent role. This project, which represents a collaborative effort between several oil sands operators and the University of Alberta and the University of British Columbia, directly contributes to ongoing research efforts in land reclamation by characterizing forest floor development and associated biogeochemical processes in chronosequences of reclaimed ecosystems. These characteristics are being compared to the forest floor characteristics developing in recently burned ecosystems, another disturbance that is common in northern Alberta.

The following specific objectives were developed to provide discrete thesis topics for individual graduate students while being sufficiently complementary to allow integration into one comprehensive study:

- **Objective 1.** How does the addition of fresh litter and forest floor materials interact with the peat amendment, and does this result in a cumulative or a synergistic effect?
- **Objective 2.** How does forest floor development in reclaimed soils compare to naturally disturbed (fire) soils, and how does this influence nutrient availability?
- **Objective 3.** Does litter decompose via the same pathways in reconstructed soils as it does in natural soils, and are the carbon (C) and nitrogen (N) fluxes from the litter to the soil organic pools comparable?
- **Objective 4.** Does forest floor development and soil organic matter accumulation at the reclaimed sites occur faster under planted aspen than under spruce, and is it related to populations and activities of soil fauna?
- **Objective 5.** How does the spatial variability in aboveground vegetation and forest floor, as well as belowground nutrient availability, microbial ecology and enzyme activities, within reclaimed soils compare to fire-disturbed soils?
- **Objective 6.** Are the nitrifying communities in reclaimed soils similar to those in soils recovering from fire, and how does this influence nitrification rates?
- **Objective 7.** For this last objective, results from the studies of the first six objectives are combined and further analyzed so that a mechanistic model of C and N fluxes in reclaimed soils can be developed.

PROGRESS AND ACHIEVEMENTS

All or a portion of the outcomes for Objectives 1 to 5 were described in the 2014 and 2015 COSIA Land EPA Mine Site Reclamation Research Reports. Below is a summary of the progress and achievements from the work conducted under Objectives 3, 4, 6 and 7.

Objective 3. Organic carbon and nitrogen cycling in boreal forest soils

Charlotte Norris (PhD) utilized stable isotopes (^{13}C and ^{15}N) to trace C and N fluxes from new litter to various soil organic matter pools. She generated double labelled (^{13}C and ^{15}N) aspen litter and applied the labelled leaves as an amendment to the forest floor of aspen and spruce stands in a 16 month field experiment. Some of these results were published in 2016 in Soil Biology and Biochemistry.

Characterizing substrate utilization pathways of microbial communities at a range of natural aspen and spruce sites and a chronosequence of reclaimed sites (8–31 years) is ongoing. All field and laboratory work was completed by a M.Sc. student (Cassandra McKenzie). Cassandra is currently writing up a manuscript to be submitted for publication in 2017.

Objective 4. Effects of faunal communities on forest floor and soil organic matter accumulation

Part of this research was completed by Jeff Anderson (M.Sc.), who assessed soil bioturbation activity, and by Meghan Laidlaw (M.Sc.), who focused on soil structure development and its relationship to soil carbon accumulation. Their work was conducted in both reclaimed and naturally-disturbed (fire) sites, which ranged in age between 20 and 35 years post disturbance.

A last part of Objective 4 is to assess mesofaunal diversity at a chronosequence of 20 reclaimed and natural sites. Oribatid mites may prove useful in monitoring the development of soil ecological functions due to their high abundance in the humus layer and their key role in nutrient cycling processes. Brittany McAdams (M.Sc. student) is conducting this part of the research. All field and laboratory work was completed. Brittany is currently writing up a manuscript to be submitted for publication in 2017.

Objective 6. Microbial communities in reconstructed soils

Jacynthe Masse (PhD) measured the gross rates of nitrogen transformations under different vegetation treatments in both reclaimed and naturally disturbed (fire) sites using ^{15}N pool-dilution. The ^{15}N tracing approach allowed her to separate the contribution of the labile and the recalcitrant organic nitrogen pool, which highlighted key distinctions in nitrogen cycling processes between natural soils that have undergone wildfire disturbance versus reconstructed soils. In addition, microbial communities participating in the N-cycle were characterized using functional genes amplification and next-generation sequencing techniques. Prokaryotic α- and β- diversity was assessed using massively parallel sequencing of 16S rRNA genes. Jacynthe defended her PhD thesis in June 2016 and the key findings are provided in the Outcomes and Lessons Learned section below.

Objective 7. Development of a mechanistic model for C and N fluxes within reclaimed sites

The main objectives of Nilusha Welegedara's research (PhD) are to understand and model the carbon, water, and nutrient cycling, salt redistribution, and productivity in reclaimed landscapes. She is using the ecosys model to analyze the structure, processes and functional connections of cycling at the South Bison Hill experimental site reclaimed in the late 1990s to better understand regeneration of ecosystem productivity in reclamation landscapes

with different cover thicknesses. This understanding is being tested with detailed site measurements of soil water content, soil salinity, soil and plant nutrient status and plant biomass accumulation recorded in this reclaimed landscape over the past decade. Nilusha is also comparing results for ecosystem productivity modelled for these landscapes to that of a natural site to establish the extent to which productivity is being re-established through the different reclamation covers.

The hypotheses on which this research is based are the processes by which shallower vs. deeper reclamation covers impose greater vs. smaller limitations to ecosystem productivity through effects on salinity, and on water and nutrient uptake. In addition, topography influences the cycling of water and nutrients, and salt redistribution by increasing moisture content and ecosystem productivity from high to low slope positions.

Modelling and interpretation of results continued in 2016.

OUTCOMES AND LESSONS LEARNED

Below are some key outcomes derived from the work conducted under Objective 6. Please note that some or all of the outcomes for Objectives 1-5 were described in the 2014 and 2015 COSIA Land EPA Mine Site Reclamation Research Reports. Work continues for Objectives 3, 4 and 7, hence outcomes for these objectives are not included in the current report.

Objective 3:

Organic matter composition and microbial community structure differ between aspen and spruce humified forest floors (H soil layer). The study showed nitrogen mineralization from the isotope labelled litter added to the surface occurred on both the aspen and spruce sites, as evidenced by the higher stable isotope N concentration in roots and live aboveground vegetation. Stable isotope C analysis found slight enrichment of the forest floor microbial PLFAs at the aspen and spruce sites, likely due to leaching of enriched C from the labelled aspen litter. In the aspen stand, continued enrichment of most of the PLFAs was maintained through both growing seasons investigated.

Objective 6:

Reclaimed sites nitrified and produced more NO_3^- than they immobilized, which likely accounts for the significantly higher NO_3^- concentrations noted in reclaimed soils. Vegetation type did not appear to influence nitrogen transformation rates in reconstructed soils, indicating that the characteristics of the soil material used during soil reconstruction still dominates nitrogen dynamics.

β-diversity, but not α-diversity, differed between reconstructed and natural forest soils. Bacteria associated with a copiotrophic lifestyle (i.e., adapted to a nutrient-rich environment) were more abundant in reconstructed soils, whereas bacteria associated with an oligotrophic lifestyle (i.e., adapted to a nutrient-poor environment) were more abundant in natural forest soils. In terms of fungal diversity, α-diversity was higher in reconstructed soils planted with trees than in reconstructed soils planted with grasses and in natural forest soils. In addition, fungal β-diversity differed between reconstructed soils and natural forest soils, and differences were mostly driven by soil characteristics, in particular nitrate content and cation exchange capacity. On the other hand, vegetation was the main factor explaining α-diversity, emphasizing the importance of above- and below-ground interactions in these reclaimed and natural ecosystems.

PRESENTATIONS AND PUBLICATIONS

Publications:

Norris, C.E., S.A. Quideau, and S.W. Oh. 2016. Microbial utilization of double-labeled aspen litter in boreal aspen and spruce soils. Soil Biology and Biochemistry 100: 9-20.

Das Gupta S, and M.D. MacKenzie. 2016. Spatial Patterns of Soil Respiration Links Above and belowground processes along a boreal aspen fire chronosequence. PLOS ONE 11(11): e0165602.

Masse, J., C.E. Prescott, C. Müller, and S.J. Grayston. 2016. Gross nitrogen transformation rates differ in reconstructed oil-sands soils from naturally disturbed boreal forest soils as revealed using a ^{15}N tracing method. Geoderma 282: 37-48.

Published Theses:

Masse, J. 2016. Nitrogen cycling processes and microbial communities in reconstructed oil-sands soils. Ph.D. Thesis. University of British Columbia, Forest Sciences, 229 pages.

RESEARCH TEAM AND COLLABORATORS

Institutions: University of Alberta and University of British Columbia

Principal Investigators: S.A. Quideau, M.D. MacKenzie, S.M. Landhäusser, C. Prescott, S. Grayston, R.F. Grant, R.E. Wasylishen.

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Preston Sorenson	University of Alberta	M.Sc.	2008	2011
Tyrel Hemsley	University of Alberta	M.Sc.	2009	2012
Aria Hahn	University of Alberta	M.Sc.	2009	2012
Mark Beasse	University of Alberta	M.Sc.	2009	2012
Charlotte Norris	University of Alberta	PhD	2009	2013
Jill Martin	University of Alberta	M.Sc.	2010	2015
Emily Lloret	University of Alberta	PDF	2011	2013
Sanatan Das Gupta	University of Alberta	PhD	2011	2015
Jeff Anderson	University of British Columbia	M.Sc.	2011	2014
Meghan Laidlaw	University of British Columbia	M.Sc.	2012	2015
Mathew Swallow	University of Alberta	PDF	2012	2014
Jacynthe Masse	University of British Columbia	PhD	2011	2016
Nilusha Welegedara	University of Alberta	PhD	2013	Ongoing
Brittany McAdams	University of Alberta	M.Sc.	2015	Ongoing
Cassandra McKenzie	University of Alberta	M.Sc.	2015	Ongoing

Potential Limitations of Stockpiled Soils – A Case Study

COSIA Project Number: LJ0300

Research Provider: Canadian Forestry Services

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 6

PROJECT SUMMARY

It is a widely-held belief within the Oil Sands Industry, that Upland Surface Soil (i.e., topsoil) is the preferential coversoil to be salvaged and used in reclamation activities. However, most of the data that supports this assumption is derived from directly placed topsoil material. The effect that stockpiling has on the quality of topsoil has not been extensively researched and is not well understood. The limited research that has been conducted indicates that soil quality in the stockpile degrades over time.

The goal of this study is to gather data from a reclaimed area that has been reconstructed using stockpiled upland surface soil and peat. The data will be gathered over the first few years of development. Field studies will be used to determine the operational potential of stockpiled coversoils in comparison to direct placed soils on the plant community. In addition, a greenhouse level study will be used to compare the potential of stockpiled versus direct placed soil to regenerate the seed/propagule bank.

The Project will attempt to answer the following questions:

1. What is the reclamation plant community potential of stockpiled coversoils in comparison to direct placed soils?
2. Does initial soil compaction limit plant community establishment and are the de-compaction treatments successful?
3. Is soil from within the stockpile (i.e., greater than 30cm from the outer surface of the stockpile) viable for plant regeneration both as a propagule source and as a plant growth medium.

PROGRESS AND ACHIEVEMENTS

In 2016 the following progress has been made:

1. Study location has been established.
2. Stockpiled soils were placed in the reclamation area (uplands surface soil and peat-mineral mixture that has been stockpiled for 4 years).
3. Tree planting was conducted in the summer of 2016.

Compaction of the stockpiled topsoil was observed following its placement. As part of this study, a portion of the area was tilled using a disk plow to help break up the soil for tree planting operations.

LITERATURE CITED

Mackenzie, D. (2013). Oil Sands mine reclamation using boreal forest surface soil (LFH) in Northern Alberta (Doctoral dissertation, University of Alberta). Retrieved from https://era.library.ualberta.ca/files/m613mx79d/

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

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 Environment Management Association, Fort McMurray, AB. March 9, 2011.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Brad Pinno	Canadian Forest Service	Research Scientist		

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, Canadian Forest Service

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 3

PROJECT SUMMARY

Soil that is salvaged for use in oil sands reclamation may be either directly placed on a new reclamation area, or stockpiled for later use if timing or resource constraints do not allow for its immediate placement. Although stockpiled soil will ultimately be used in reclamation, some soils may remain in stockpiles for years or even decades before it is removed for placement. Evidence suggests that the passage of time imparts significant ecological repercussions to stockpiled soils, including severely limiting propagule viability (Rivera et al., 2012; MacKenzie, 2013). Additionally, as vast quantities of soil are stockpiled in the most spatially-efficient means possible, this creates conditions in which large portions of the soil experience long-term anaerobic or anoxic conditions, as well as altered temperature profiles with depth.

All stockpiled soils will ultimately be used in reclamation in order to create self-sufficient closure ecosystems that are aligned with the surrounding landscape. Oilsands reclamation may alternate between the use of directly-placed reclamation soils and stockpiled soils, however *in situ* reclamation does not have this opportunity; operational footprints must be reclaimed all at once (i.e., Direct placement is not possible). Therefore it is important to characterize the risks associated with the aging process of stockpiled soils, in order to determine how to manage these resources to ensure successful reclamation in the medium- to long-term.

The objectives of this study are to:

1) Investigate the aging processes and characterize the risks of stockpiled soils, to determine if stockpiled soils may contribute to healthy, functioning ecosystems over time. This investigation will also inform the potential use of stockpiled soil enhancements prior to reclamation placement. Stockpiles will be studied in four contexts: plant community structure, soil biogeochemistry, soil physics, and soil microbiology and genomics.
2) Investigate the possibility of linking below-ground and above-ground ecosystem parameters for a more complete indication of ecosystem health. If possible, this will result in the creation of the GERI (Genomics-Enhanced Reclamation Index) that will serve as a means to understand and communicate the ecological health of a stockpile.

PROGRESS AND ACHIEVEMENTS

The research team developed the project scope and budget in 2016. Additional funding was sought in 2016. The project agreements are being created for an anticipated start in the 2017 field season.

OUTCOMES AND LESSONS LEARNED

This project is in early stages and there are no outcomes or lessons learned to report at this time.

LITERATURE CITED

Rivera, D., Jáuregui, B. M., and Begona Peco. 2012. The fate of herbaceous seeds during topsoil stockpiling: Restoration potential of seed banks. Ecological Engineering 44: 94-101.

Mackenzie, D. 2013. Oil sands mine reclamation using Boreal forest surface soil (LFH) in Norther Alberta (Doctoral dissertation). Retrieved from the University of Alberta Education and Research Archive. (doi:10.7939/R3V36X).

PRESENTATIONS AND PUBLICATIONS

There have been no publications or presentations in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Brian Lanoil

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Brian Lanoil	University of Alberta	Researcher		
Dr. Sylvie Quideau	University of Alberta	Researcher		
Dr. Brad Pinno	Canadian Forest Service	Researcher		
Dr. Myles Dyck	University of Alberta	Researcher		

Reclamation Soils Index of Biological Integrity (IBI)

COSIA Project Number: LJ0296

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 3

PROJECT SUMMARY

Horizon's operating approval stipulates that a minimum average depth of 1 m of suitable overburden shall be used to cap Clearwater Formation (Kc) overburden prior to the placement of 0.20 m of coversoil. The 1 m of subsoil is intended to act as a buffer against plumes of salinity that may originate from highly saline and/or sodic Kc parent material. At all stages of salvage and placement, overburden is tested to determine if it meets suitability criteria that are based on the chemical parameters of pH, sodium adsorption ratio (SAR), and electrical conductivity (EC).

As of August 2016, a new approval condition requires that all upland surface soil and subsoils must be salvaged and used in reclamation. However, there are no requirements to test upland subsoil for the same criteria as suitable overburden. A contradiction therefore exists between the risk management employed for placement of upland subsoil and suitable overburden: upland subsoil will be in closest proximity (usually within 50 cm) of upland surface soil (and therefore the rooting zones of reclamation vegetation), and yet there is no requirement to test subsoil for salinity parameters. From the regulatory perspective, the logic in this gap is that the soil once supported a productive forest, so it should be able to do so once salvaged and placed as reclamation. However, this raises the question: If upland subsoil criteria does not meet approval criteria for suitable overburden, are the criteria for suitable overburden valid? This study aims to understand potential biological impacts of salinity in the closer upland subsoil layer, so that suitability criteria for overburden may be reassessed using new evidence.

The objective of this study is to examine the biological implications of soil chemistry in the 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. This objective will be achieved by:

- Testing upland subsoil for chemical suitability parameters (pH, EC, SAR), 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 gradient could be caused by salinity, or perhaps other chemical parameters.
- If possible, using these data to develop a Soils Index of Biological Integrity (IBI), 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 areas of the mine are reclaimed, and will be used as a tool to monitor reclamation progress and success.

PROGRESS AND ACHIEVEMENTS

Forty-seven sites were sampled across the Horizon lease in the late summer of 2016. These sites were selected in order to include a range of post-disturbance (i.e., tree clearing) ages, soil types, and disturbance types. This data will serve as a preliminary data set to inform data collection in the 2017 field season. Upland subsoil was collected for salinity analyses, and surface soils and organic layers were collected for nutrient analyses, microbial community analyses, and arthropod analyses. Soil chemical analyses have been completed. Arthropod analyses are underway, and microbial analyses will occur in 2017.

Soil chemistry in upland subsoil and surface soil has been analyzed, and biological community analyses within the surface soil have begun.

The study was started in 2016. The first phase will run until the end of 2018.

OUTCOMES AND LESSONS LEARNED

The project is in its early stages and data is still being collected and analyzed.

PRESENTATIONS AND PUBLICATIONS

No publications or presentations in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Jeff Battigelli

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Jeff Battigelli	University of Alberta	Researcher		
Dr. Brian Lanoil	University of Alberta	Researcher		
Ashley Gilliland	University of Alberta	B.Sc.	2015	2019

Revegetation

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 Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Nexen, Shell Canada Energy, Statoil Canada Ltd., Suncor Energy Inc., Teck Resources Limited

Status: Year 3 of 5

PROJECT SUMMARY

Oil sands extraction is a major component of the Albertan and Canadian economy but the associated surface mining completely disrupts forest ecosystems. A pressing objective of land reclamation in the boreal forest region is to return disturbed sites to fully functioning and self-sustaining ecosystems. Early in the recovery of forests, the main challenge is rapid re-development 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 that hastened the development of a closed tree canopy. Building on this, the renewal of the IRC program is examining critical issues related to growth constraints, such as limited soil nutrients and high competition, 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 Chair is addressing three general topic areas and associated research questions:

Accelerating Forest Establishment

- How does the application of organic amendments 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 its effect on understory vegetation and competition?
- What is the impact of loose dumping 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 does soil water redistribution play in aspen roots along drought gradients?
- How do confining soil layers (chemical or physical) affect root growth behavior 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 its 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

Accelerating forest establishment:

To expedite initial forest establishment (stand initiation and early growth), the IRC program is investigating the use of various soil amendments and techniques to ameliorate limiting site conditions, enhance meso- and micro-topography, and explore the use of less dominant tree species for reclamation purposes.

To explore the use of tall aspen stock types for planting on competitive grassy sites Kyle Le (M.Sc. candidate) re-measured the performance of aspen stock on sites that had been established in 2014. The experimental portion of the project was completed in mid-2016. Overall seedling performance had been poor due to very dry conditions in 2015; however, some trees showed recovery and effects of stock type differences were confirmed. Since then Kyle has been working on his thesis and is currently writing his last chapter.

An operational scale field study at Highvale (TransAlta) was set up in the fall/spring of 2015/16 to test the arrangement and usage of different soil amendments for successful tree establishment on nutrient limited sites. Seedlings were planted in the spring of 2016 and monitoring will continue through at least 2017. Erika Valek (M.Sc. candidate) is leading this experiment.

Another study was set up at Shell's oil sands mine in 2014 to test questions related to the feasibility of using enhanced meso-topography to promote natural establishment of vegetation and trees. Kate Melnik (M.Sc. candidate) has taken a lead in evaluating non-tree vegetation establishment. In 2016 she collected some additional data on soils in the study area and started with writing her thesis. She has completed one research chapter of her thesis and is currently working on a second chapter. Trevor de Zeeuw (M.Sc.) was recruited in 2016 to evaluate tree seedlings planted on the same site in 2016 and 2017. This study is just starting and initial results can be expected in 2017.

Shauna Stack (M.Sc.) is exploring whether nutrient limitations (in particular phosphorous and potassium) may exist and be affecting seedlings at a field site. We monitored foliar nutrients in 2016 and evaluated the feasibility of a fertilization subproject that will be executed in summer of 2017.

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 undesirable 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 2015 we explored the feasibility of cutting juvenile (8-12 years) aspen of seedling origin to increase stem density through root suckering and in 2016 we cut a whole stand of 12-year-old planted seedling-origin aspen and examined the sucker regeneration. Carolyn King (M.Sc. candidate) took the lead in this study and is currently working on the second research chapter of her thesis. Carolyn is expected to have her thesis finished in the spring of 2017. Under the same topic, Caren Jones (M.Sc.) explored the influence of planted tree selection on understory plant community development. This study was closely linked to the Aurora soil capping study (see separate report "Roots of Succession"). Caren successfully defended her thesis in 2016 and has submitted a manuscript to Forest Ecology and Management, which presents her results on the impact of long distance seed dispersal on understory vegetation dynamics on reclamation sites.

Assessing trajectories of forest reclamation:

There has 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 primary influences of forest stand performance on reclamation sites.

A study was established in the summer of 2014 on Syncrude's South Bison Hills. Dr. Jeff Kelly (PDF) initially led this study where we investigated the relationships between climate driven water use (sapflow) of aspen and spruce canopy trees and how it is influenced by capping material thickness and rooting depth. These measurements were repeated in 2015 in order to get a more complete data set. Morgane Merlin (Ph.D. candidate) took over this project in 2016 and started the data analysis. In addition to the sapflow measurements, a number of soil cores were collected in 2016 to explore rooting depth and root mass distribution on this site. No firm results are yet available but correlations of sapflow data with other climatic and edaphic data collected by other projects on the same site is expected in 2017.

OUTCOMES AND LESSONS LEARNED

This project is not yet at the stage to report on outcomes and lessons learned.

PRESENTATIONS AND PUBLICATIONS

No publications have yet been produced under the current chair. The list below list includes work completed under the initial IRC program and, since the grant supports the chair as a position, other publicly available papers produced in the reporting period that were supported by the presence of the chair.

Refereed publications resulting from the initial chair

Schott KM, Snively AEK, Landhäusser SM & Pinno BD. 2016. Nutrient loaded seedlings reduce the need for field fertilization and vegetation management on boreal forest reclamation sites. New Forests 47: 393-410.

Completed theses resulting from the initial chair

Jones CE. 2016. Early Vegetation Community Development and Dispersal in Upland Boreal Forest Reclamation. M.Sc. thesis, University of Alberta. 118 pages.

Refereed publications supported by the chair position, with research funding from other sources

Schoonmaker AS, Lieffers VJ & Landhäusser SM. 2016. Viewing forests from below: fine root mass declines relative to leaf area in aging lodgepole pine stands. Oecologia 181: 733-747.

Wiley E, Rogers BJ, Hodgkinson R & Landhäusser SM. 2016. Nonstructural carbohydrate dynamics of lodgepole pine dying from mountain pine beetle attack. New Phytologist 209: 550-562.

Karst J, Gaster J, Wiley E & Landhäusser SM. Stress differentially causes roots of tree seedlings to exude carbon. Tree Physiology (available online)

Hupperts SF, Karst J, Pritsch K &·Landhäusser SM. Host phenology and potential saprotrophism of ectomycorrhizal fungi in the boreal forest. Functional Ecology (available online)

O'Brien M, Engelbrecht B, Joswig J, Pereyra G, Schuldt B, Jansen S, Kattge J, Landhäusser SM, Levick S, Preisler Y, Väänänen P & Macinnis-Ng C. A synthesis of tree functional traits related to drought-induced mortality in forests across climatic zones. Journal of Applied Ecology (available online)

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

Hupperts SF. 2016. Ectomycorrhizal fungal community response to disturbance and host phenology. M.Sc. thesis, University of Alberta. 114 pages.

Wilson AMJ. 2016. Effects of Biochar, Fertilizer and Shelter Treatments on the Vegetation Development following Coal Mine Reclamation. M.Sc. thesis, University of Alberta. 104 pages.

Hoffman E. 2016. Influence of Environmental and Site Factors and Biotic Interactions on Vegetation Development Following Surface Mine Reclamation Using Coversoil Salvaged From Forest Sites. M.Sc. thesis, University of Alberta. 118 pages.

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	M.Sc.	2013	2017
Caren Jones	University of Alberta	M.Sc.	2013	2016
Kyle Le	University of Alberta	M.Sc.	2014	2017
Katherine Melnik	University of Alberta	M.Sc.	2014	2017
Simon Bockstette	University of Alberta	PhD	2011	2017
Morgane Merlin	University of Alberta	PhD	2015	2019
Carolyn King	University of Alberta	M.Sc.	2015	2017
Erika Valek	University of Alberta	M.Sc.	2015	2018
Shauna Stack	University of Alberta	Research Assistant		
Trevor de Zeeuw	University of Alberta	Research Assistant		
Ashley Hart	University of Alberta	Research Assistant		
Fran Leishman	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

Developing a Functional Approach to Assessment of Equivalent Capability: Utilizing Ecosystem Water, Carbon and Nutrient Fluxes as Integrated Measures of Reclamation Performance

COSIA Project Number: LJ0127

Research Provider: McMaster University, University of Waterloo and Integral Ecology Group

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: Suncor Energy Inc.

Status: Year 4 of 5

PROJECT SUMMARY

This project seeks to develop an alternate approach to the assessment of equivalent capability and reclamation performance directly based on, and linked to, ecosystem function, by leveraging long-term eco-hydrological research that measures growing-season water and carbon balances across a range of reclamation and recovering boreal forest ecosystems. This alternative function-based approach is based on the following premises:

- that long-term and intensive research on water, carbon and nutrient fluxes on a small number of instrumented reclamation sites can provide in-depth mechanistic understanding of ecosystem function and trajectories on these sites; and provide detailed records of performance over time;
- that identified relationships between flux measurements and a select number of more easily assessed biometrics (e.g., vegetation characteristics) will permit this mechanistic understanding to be extended to non-instrumented sites, thereby allowing a spatially extensive, low-intensity application of findings across reclaimed landscapes, for inferring ecosystem productivity components of equivalent capability and reclamation performance; and
- that conducting similar research in juvenile ecosystems on non-mine sites disturbed through fire or forest harvest can provide ranges of natural variation for key parameters, and thus the performance “envelopes” for definition and evaluation of equivalent capability.

Through this approach, alternate metrics for reclamation assessment that are directly linked to the fundamental processes of ecosystem function may be discovered. This will allow more relevant and realistic evaluations of equivalent capability as well as defining time frames for this evaluation.

This project is divided into three work packages: WP1, WP2 and WP3. WP1 is being undertaken by McMaster and Waterloo universities, WP2 is being completed by Integral Ecology Group, while WP3 is a cooperative effort among all three entities.

PROGRESS AND ACHIEVEMENTS

WP1: Monitoring continued in 2016 to characterize the linkages between hydroclimatic (water table, soil moisture and tension distributions, evapotranspiration [ET]) properties, soil physical properties and nutrient (nitrogen N, phosphorous P, potassium K) availability and pathways and carbon exchange (net ecosystem exchange, NEE) at the ecosystem scale for existing installations over a range in canopy conditions and successional stage. This activity has been underway since 2013 and will continue through the 2017 field season with a number of students/post-doctoral

fellows engaged in this project. Bio-meteorological stations are running on each of the identified sites along with concurrent canopy measurements (i.e., leaf area index [LAI]) to continue long-term data collection.

One manuscript is in final preparation for submission to the journal, Hydrological Processes, that addresses whether reclaimed forest systems (e.g., Syncrude's South Bison Hills) demonstrate irregular water use patterns over the successional path from grassland to forest, and when do reclaimed "novel" boreal forest ecosystems reach a steady state in terms of their water use efficiency. Manuscripts are being prepared that synthesize the relationships of water use efficiency among natural sites spanning a range in age and disturbance, and reclaimed sites. Such relationships will then be assessed using biometric-derived measurements to develop a preliminary conceptual model which will be used to assess upland/forest ecosystems using a simple biometric approach. Building on these papers, we have initiated a study that will use SPOT & LANDSAT data and statistical approaches to present proof of concept approaches to doing such assessments at the landscape scale using remote sensing.

WP2: The purpose of this work has been to characterize vegetation and soil conditions and trends over time on the instrumented research sites in order to link eco-hydrologic measures with vegetation-based measures of reclamation development and success. Field work in 2016 focused on characterizing upland sites co-located with active eddy-covariance-towers (five reclamation, two reference). Measurements in 2016 were conducted in 82 permanent sample plots (59 reclamation, 23 reference). At each site, data was collected on forest-stand characteristics (tree densities, heights, diameters, and ages); foliar nutrition (chemistry) of dominant tree species; and vegetation-community characteristics (prominent species presence and cover, LAI). The 2016 dataset is in the process of being compiled before synthesis with the WP1 data from co-located flux towers as part of the WP3 package. At this time, we have installed 194 permanent sampling plots on 17 sites over four field seasons. 2016 was scheduled to be the fourth and final year of the WP2 field program, but logistical issues related to the 2016 wildfires prevented the establishment of 2 new ecohydrology sites and several other planned WP2 field activities. Options are being discussed with industry collaborators for compensatory field work in 2017.

WP3: This work package consists of synthetic interpretations of data collected in WP1 and WP2, and previous related work. It is scheduled to be completed in Q1-2 2018, which made 2016 the 3rd year of a 4-year program, with the majority of effort still to come in data processing, interpretations and reporting in 2017. Our work thus far examining relationships of biometric parameters with measured fluxes has continued to demonstrate robust relationships, such as that between LAI, site age and ET, which will continue to be explored during the WP3 synthesis phase of the project. Research meetings were held with industry representatives in March 2016, and research team participants in November 2016. At this time collaborative discussions are ongoing between research groups, and 2016 data processing from the WP1 and WP2 packages is underway. A timeline for future research meetings and knowledge synthesis activities has been established with a spring 2017 meeting forthcoming between research partners and industry representatives.

OUTCOMES AND LESSONS LEARNED

Outcomes and lessons learned through 2016 consist of incremental understanding from an additional year of monitoring the study sites and exploring relationships between ecosystem fluxes and patterns of vegetation development. The primary trends, as reported for 2016, relate to evapotranspiration (ET), carbon fluxes (as expressed in gross ecosystem photosynthesis), water use efficiency (WUE) and empirical measures of vegetation development. The majority of synthesis on this information is being initiated in 2017.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

R.M. Petrone, S.K. Carey, J. Straker. 2016. Water, Energy & Carbon Balance Research: Recovery Trajectories for Oil Sands Reclamation and Disturbed Watersheds in the Western Boreal Forest. Annual Meeting of Agronomy Society of America, Crop Science Society of America, and Soil Science Society of America, November 6 - 9, 2016, Phoenix, Arizona. [Poster]

Strilesky, S.L., E. R. Humphreys and S. K. Carey. 2016. Water Use Development of an Oil Sands Boreal Forest Reclamation Site during the First 12 Years Following Inception. 32nd Conference on Agricultural and Forest Meteorology / 3rd Conf. on Atmospheric Biogeosciences, June 20 - 24, 2016, Salt Lake City, USA. [Poster; Student Poster Award]

Gingras-Hill, T., R.M. Petrone, F. Nwaishi, M.M. Macrae. 2016. Assessing initial biogeochemical characteristics of a 3-yr old forested upland following reclamation procedures in a constructed watershed, Fort McMurray, Alberta. Canadian Geophysical Union – Canadian Meteorological and Oceanographic Society Joint Congress, May 29 – June2, 2016, Fredericton, New Brunswick. [Abstract]

RESEARCH TEAM AND COLLABORATORS

Institutions: McMaster University/ University of Waterloo/ Integral Ecology Group

Principal Investigators: Sean Carey / Richard Petrone / Justin Straker

Name	Institution	Degree	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Stacey Strilesky	McMaster / Carleton	PhD	2014	2018
Gordon Drewitt	McMaster University	Research Associate	2015	2017
Erin Nicholls	McMaster University	MSc	2013	2015
Chelsea Thorne	McMaster University	MSc	2013	2015
Felix Nwaishi	University of Waterloo	Partial Post-Doctoral Fellow	2015	2018
George Sutherland	University of Waterloo	Research Associate	2015	2018
Elise Gabrielli	University of Waterloo	MSc	2013	2016
Tristan Gingras-Hill	University of Waterloo	MSc	2014	2016
Midori Depante	University of Waterloo	MSc	2013	2016
Laura Chasmer	University of Waterloo	Research Associate	2016	2018
Jeff Anderson	Integral Ecology	Consultant		
Trevor Baker	Integral Ecology	Consultant		
Meghan Laidlaw	Integral Ecology	Consultant		

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 3 of 6 (contract was amended)

PROJECT SUMMARY

The main objective of this research is to identify and select balsam poplar clones from the Alberta-Pacific (Al-Pac) Controlled Parentage Program Plan (PB1 – CPP) for balsam poplar (*Populus balsamifera*) (2011) (CPP) 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 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 PB1 – CPP 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 in fall 2014: trial one was established on the south shore of Base Mine Lake, trial two was established in the southeast corner of Sandhill Fen and trial three was established on Sand Islands "A" and "B" within the Sandhill Fen. 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).

On the sand islands, there was 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

At the end of July 2016, the trial sites were visited to collect leaf samples for tissue analysis. Leaves were collected from the Sandhill Fen and Base Mine Lake trial sites, but not the Sand Island A site. No work was done on Sand Island B in 2016, as the site was flooded in 2015 causing heavy mortality. All tissue samples were analyzed at a commercial laboratory for boron, calcium, copper, iron, magnesium, manganese, molybdenum, phosphorous, potassium, sodium, sulfur, zinc and nitrogen. Tissue samples for the Syncrude Stream 1 trees were also analyzed for an additional 33 heavy metals. Statistical analysis is in progress.

Tree heights and diameters were measured at the end of the 2016 growing season, once the trees had set bud. Basal diameter rather than diameter at breast height was measured for trees in the Sandhill Fen and Sand Island A sites where breast height (1.3 m) has not been reached. Maintenance was undertaken to address missing flags, pins and tags.

The trials were installed in October of 2014 and the project is expected to be completed in the fall of 2019.

OUTCOMES AND LESSONS LEARNED

Very large growth differences have been noticed between the trial sites (mean increments of 111 cm at Base Mine Lake, 11 cm on Sand Island A and 3 cm on Sandhill Fen), indicating dramatic differences in potential productivity. Such differences were one of the reasons for multiple trial sites.

No clonal differences have yet been detected. Once clonal trends can be established then conclusions will be made with respect to achieving the goal of identifying salt tolerant clones. Until then, determination of outcomes cannot be completed.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta-Pacific Forest Industries Inc.

Principal Investigator: Dr. Barb Thomas

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
David Kamelchuk	Little Creek Agroforestry Inc.	Consultant		
Davis Weber	Alberta-Pacific Forest Industries Inc.	Field Assistant		

Selected Willow Clones for Use in Reclaimed Ecosystems Impacted by Elevated Salt Levels

COSIA Project Number: LJ0203

Research Provider: Natural Resources Canada, Canadian Forest Service

Industry Champion: Syncrude Canada Ltd.

Status: Year 3 of 4

PROJECT SUMMARY

In Alberta oil sands reclamation, oil sands process-affected water (OSPW) is expected at varying concentrations in the closure landscape. OSPW contains various constituents including naphthenic acids and elevated concentrations of salts. If concentrations of these compounds reach levels that are theorized to be detrimental, plant growth may be adversely affected. Potentially impacted ecosystems include water bodies and their shorelines, peatlands, lowland forests and seepage discharge sites.

Many species of willow commonly occur in the environments most at risk from exposure to OSPW, and are frequently a major structural component of lowland and riparian ecosystems. Willows are often deployed early in reclamation of these areas based on their value for slope and shoreline stabilization. As such, they often play an important role in oil sands mine reclamation efforts.

A greenhouse study conducted by Natural Resources Canada (NRCan) has identified several clones of various native willow species that appear to have particularly high tolerance to OSPW. The current study is a field deployment of 15 native willow clones previously identified as having the highest tolerance levels.

The objectives of the study are to:

1. Determine if willow clones, previously identified in greenhouse studies as tolerant to OSPW, are also tolerant to in-situ conditions when planted along the shoreline of an end-pit lake containing OSPW. This will be done by monitoring:
    a. survival
    b. growth rate
    c. foliar chemistry
2. Monitor the soil moisture and soil chemistry in the rooting zone of the willows.

The experimental design is a completely randomized arrangement of 15 species-genotype combinations planted at 30, 60, 120 and 240 centimeter distances from the nominal lake shore, with either three or four replicates of each combination. Seedling assessments include survival, stem length, stem diameter, root development and foliar chemistry. Associated environmental measurements include soil pore water chemistry, soil texture, bulk density, soil water content, photosynthetically active radiation and temperature. Establishment of the trial was completed in spring of 2014.

A minor modification to the original plan is the harvesting and weighing of all biomass on the trial early in 2017 as an alternate measure of clonal growth variability.

PROGRESS AND ACHIEVEMENTS

Planned vegetation assessments completed in 2016 include seedling survival in the spring and 3rd-year height and diameter growth in the fall.

There were few soil pore water samples collected in 2016, as many of the installed lysimeters did not produce water, possibly due to the lower lake level in 2016 as compared to previous years. Soil samples (0-15, 15-30cm) were collected in the same planting row as the soil lysimeters and were analysed for soil water content. Soil water content is being continuously monitored 15 cm below the soil surface at two locations at the shoreline and 60, 120 and 240 cm planting positions along the slope.

Based on very high levels of foliar sodium observed in a limited sample in 2015, additional foliage samples were collected to evaluate sodium uptake and storage in the fall of 2016 from at least two replications of each of the 15 willow clones planted at the site. Soil samples were collected at 4 random locations from the 0-30cm soil depth at the same three slope positions. Samples were processed and sent for chemical analysis in the winter of 2016.

We initiated a collaborative research project with Dr. Doug Muench at the University of Calgary to determine the effects of inorganic and organic salts on willow growth. This genetic analysis will identify marker genes that can be used to select willow genotypes that show tolerance and/or high remediation efficiency of OSPW. A component of this research is the analysis of the gene expression profile of willow roots from different willow genotypes. The gene expression profiling involves next generation DNA sequencing that is being performed at McGill University at the Genome Quebec sequencing facility. We collected and processed root samples from 2 genotypes of four willow species at the shoreline and 240 cm slope position. The Data analysis is ongoing. This work received additional funding from the Natural Resources Canada, Canadian Wood Fibre Centre Opportunity Funds program and is a part of a larger project.

We have completed the three planned field seasons for this project, with only the additional 2017 biomass collection yet to come. Data analysis and final reporting is underway.

OUTCOMES AND LESSONS LEARNED

No additional mortality was observed in the spring of 2016. Based on the survival results to date, OSPW in the rooting zone as represented by slope position in this trial did not impact seedling survival.

All of the outplanted willow clones were selected from a greenhouse screening trial using an aeroponics system where they exhibited some degree of tolerance to OSPW. To date, the combined greenhouse and field planting results show that native willows tolerant to OSPW (salt impacted water/soils) are present in the wild and can be identified through greenhouse screening processes.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Johnston, S. 2016. Growing like a weed. Synergy. Syncrude Canada Ltd. Newsletter. pp24-25

Krygier, R. 2016 Salt tolerant willows help oil sands reclamation. Radio Interview on CKUA's Innovation Anthology program. 07 July 2016. http://innovationanthology.com/programs.php?id=829&mode=full.

RESEARCH TEAM AND COLLABORATORS

Institution: Natural Resources Canada, Canadian Forest Service, Edmonton

Principal Investigator: Richard Krygier

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Martin Blank	Natural Resources Canada-Canadian Forest Service	Land Reclamation Technician		

Research Collaborators: Dr. Doug Muench, University of Calgary

A Forest Fertilization Trial in a Mildred Lake Jack Pine Stand

COSIA Project Number: LJ0209

Research Provider: University of British Columbia

Industry Champion: Syncrude Canada Ltd.

Status: Year 6 of 6

PROJECT SUMMARY

This study includes application of fertilization in a controlled experiment in a reclaimed 19-year old (at start of study) jack pine stand. The soil cover design is a single strip salvage of peat and underlying fine textured mineral material and a single strip of placement at a target depth of 50 cm directly over tailings sand. The hypothesis is that fertilizer blends identified during an initial screening trial would result in increases in tree growth. The initial screening trial employed 16 exploratory fertilizer treatments applied to 80 two-tree plots (five replicates per treatment). Vector analysis of changes in needle mass and foliar nutrient content after the first growing season was used to recommend fertilizer rates and composition for the main study. Final treatments included nitrogen (N), phosphorus (P), sulfur (S), potassium (K), and the micronutrients copper (Cu) and magnesium (Mg) formulated as NPS and NPKS + Cu and Mg. An original option to also thin the stand as part of the suite of treatments is not being pursued.

The trial is set up as a randomized block design, with blocking by initial mean tree height. Twenty plots were established with four replicates of (originally) five treatments: control, NPS fertilizer, NPKS + micronutrient fertilizer, thin, and thin + NPS fertilizer. Given that the thinning will not be undertaken, the control and NPS treatments have effectively been duplicated with eight replicates each.

Each fertilizer plot is 35 m square, including a 5 m treated buffer. The measurement area of each plot is divided into three sections, with half the plot in each case being evaluated for tree growth. One quarter of each plot is available for evaluations of understory vegetation response, and one quarter for the addition of supplementary studies. As of autumn 2015, the plots had been measured five times (with the first occurring prior to treatment).

An additional post-hoc study, initiated following early observations in the stand, has been completed. The objective of this study was to identify correlations between observed variations in tree growth and measurable soil parameters. A journal article highlighting correlations between organic matter and closely associated soil properties with tree growth (Farnden et al. 2013) has been produced.

PROGRESS AND ACHIEVEMENTS

In the current reporting period, data from repeated measurements on the trial have been analyzed and a draft final report is in preparation.

OUTCOMES AND LESSONS LEARNED

The screening trial indicated a likely growth response to a combination of N, P and S based on first year foliar mass increases. Following four-years of monitoring on a longer-term experiment, significant growth increases as a result of fertilizer treatments have not been observed. This experiment has failed to provide evidence that fertilizer treatments on this site or similar reclamation sites will provide any benefits to tree growth or overall ecosystem performance. Jackpine stands typically respond well to fertilizer applications on many natural sites (Newton and

Amponsah 2006). This suggests that growth of this reclaimed stand is limited by nutrition to a lesser degree than for many jack pine stands on natural landscapes.

LITERATURE CITED

Farnden, C., R.J. Vassov, M. Yarmuch and B.C. Larson. 2013. Soil reclamation amendments affect long term growth of jack pine following oil sands mining. New Forests 33:799-810.

Newton PF, Amponsah IG (2006) Systematic review of short-term growth responses of semi-mature black spruce and jack pine stands to nitrogen-based fertilization treatments. For Ecol Manag 237:1–14. doi: 10.1016/j.foreco.2006.10.009

PRESENTATIONS AND PUBLICATIONS

There were no publications or presentations in 2016

RESEARCH TEAM AND COLLABORATORS

Institution: University of British Columbia

Principal Investigator: Dr. Bruce Larson

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Adam Polinko	University of British Columbia	Ph.D.	2014	2018

Nutrient Loading of Seedlings to Improve Growth and Land Reclamation Success

COSIA Project Number: LJ0141

Research Provider: The University of Alberta

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Shell Canada Energy, Imperial, Total E&P Canada Ltd.

Status: Year 4 of 4

PROJECT SUMMARY

Oil sands reclamation in northern Alberta is affected by several factors, one of which is the low nutrient supply from some of reclamation materials used. The growth and survival of planted seedlings are often limited by low soil nitrogen availability and high understory vegetation competition. Field fertilization has been commonly used as one of the potential approaches to increase soil nitrogen (N) availability and growth of planted seedlings. However, field fertilization does not only increase available N in the soil and to seedlings but also provides nutrients to competing understory vegetation that could limit the growth of planted seedlings. In this context, management practices such as nursery loading of nutrients into seedlings and weed control would help improve the growth of planted seedlings in the early years of outplanting that could eventually enhance revegetation and reclamation of oil sands disturbed landscapes.

The main objective of the project was to examine the potential application of the nutrient loading technique (nursery fertilization) to enhance revegetation success in oil sands reclaimed soils. In the first phase of the project, a greenhouse experiment was conducted to optimize nutrient loading of seedlings of trembling aspen (*Populus tremuloides*), jack pine (*Pinus banksiana*) and white spruce (*Picea glauca*) in the nursery and in the second phase, growth performance of the nutrient-loaded seedlings was tested in the field in combination with weed control (using a gas powered weed cutter and pulling the residual weeds by hand). We hypothesized that, i) nursery nutrient loading can build up nutrient reserves in these seedlings that would improve seedlings early growth after outplanting by increasing nutrient retranslocation within the seedlings, and ii) weed control can improve seedlings growth by increasing nutrient availability in the soil in highly competitive reclaimed sites. We studied the growth and biomass allocation, N retranslocation within seedling components and N uptake from the soil in nutrient-loaded (by exponential fertilization) seedlings planted on reclaimed oil sands sites in field experiments for two years. Nitrogen retranslocation and N uptake from the soil were traced using ^{15}N labeling and soil N availability was determined using foliar $\delta^{13}C$.

If nursery nutrient loading of seedlings and weed control were found to be effective to improve growth of the planted seedlings, these management practices could be recommended to enhance revegetation and reclamation of disturbed oil sands sites. By improving revegetation, the reclamation process in the oil sands region can be accelerated.

PROGRESS AND ACHIEVEMENTS

Seedlings of trembling aspen (*Populus tremuloides*), jack pine (*Pinus banksiana*) and white spruce (*Picea glauca*) were produced in nursery with exponential and conventional fertilization regimes and planted on weed competitive reclaimed sites amended with peat mineral soil mix (PMM) and upland forest or LFH mineral soil mix (LFH). The field

experiments were established on an overburden dump at the Suncor Energy Inc. mine, approximately 25 km north of Fort McMurray. Three separate field experiments were established with one each for aspen, jack pine and white spruce. Field studies were conducted from June 2014 to October 2015 to assess the survival rate of seedlings, nitrogen retranslocation and uptake from the soil and growth of these planted seedlings. To assess the growth of the seedlings, height, root collar diameter, seedling component biomass, foliar and root size were measured for two years in field experiments. Nutrient status of the seedlings was evaluated based on N concentration and total N content in seedling components. Nitrogen retranslocation and N uptake from the soil were determined using ^{15}N isotope labeling in the seedlings during nursery production. Those measurements were conducted to evaluate the treatment (nutrient loading in nursery seedling production and weed control in field planting) effects on the planted seedlings.

All data for the survival and growth of these planted seedlings were collected and analyzed. The data were presented in various national and international conferences including the Alberta Soil Science Workshop, the Canadian Society of Soil Science Annual Meeting and the Soil Science Society of America Annual Meeting. A manuscript for the growth and nitrogen retranslocation in trembling aspen has been published in a peer-reviewed journal. Two other manuscripts (for jack pine and white spruce) have been submitted to peer-reviewed journals and are under review.

OUTCOMES AND LESSONS LEARNED

Outcomes

Experiment 1

At the end of nursery production, exponentially fertilized seedlings had greater nutrient reserves than that of conventionally fertilized ones but they had similar size and biomass. In the field experiment, exponential fertilization and weed removal significantly increased seedling size on both PMM and LFH sites. The effect of nursery fertilization on seedling height and root collar diameter (RCD) growth was similar on PMM and LFH sites but the effect of weed removal was more pronounced on the LFH than on the PMM site due to the greater abundance of weeds on the LFH site. In terms of biomass growth, the effect of exponential fertilization was consistent in the first and second growing seasons but the effect of weed removal was greater in the second than in the first growing season. Percent root biomass allocation was not affected by nursery fertilization or weed competition while new stem biomass allocation was significantly increased by both exponential fertilization and weed removal on the PMM site and by weed removal on the LFH site. The N concentration was not significantly affected by both treatments at the end of the first growing season in the field experiment; however there was a greater reduction of N concentration in field growth as compared with the nursery stage in exponentially than in conventionally fertilized seedlings. Exponential fertilization increased N content in the seedlings on both the PMM and LFH sites while weed competition reduced N content only on the LFH site.

The N retranslocation from old to new tissue was much greater than N uptake from the soil in both treatments on both soils. On average, 80% of the total N demand of new tissue growth was met by N retranslocation on the PMM site and 73% on the LFH site during the first year growth of seedlings after outplanting. There was no significant difference in percent N retranslocation among the treatments but the total N derived from plant (NDFP) was significantly increased by exponential fertilization and weed control on PMM as well as on LFH site. The N derived from soil (NDFS) was increased by the weed removal treatment on the LFH site while the effect of exponential fertilization was not significant on both PMM and LFH sites.

Experiment 2

Exponential fertilization increased N concentration and total N in seedling components but did not affect the biomass of seedlings during nursery production. Height and RCD of exponentially and conventionally fertilized seedlings

were also not significantly different. Vector analysis of biomass, N concentration and N content in the seedlings showed that the exponentially fertilized seedlings had luxury consumption of N during nursery production that increased nutrient reserves in these seedlings. In the field experiment, seedling size and biomass were significantly increased by the exponential fertilization but not by the weed removal treatment. Exponentially fertilized seedlings had greater N concentration in old tissues at the end of the first growing season but the N concentration in new tissues were not affected by exponential fertilization. Weed removal did not change the N concentration of new or old tissues. Exponential fertilization increased N content of new and old tissues but weed removal was ineffective to change N content of the seedlings. In terms of biomass allocation, a greater percent of biomass was allocated to new tissues in exponentially fertilized seedlings. But the percent root biomass allocation was greater in conventionally than in exponentially fertilized seedlings. Exponential fertilization also increased needle length and decreased root weight ratio and specific root length of the seedlings. Exponential fertilization increased but weed removal decreased N retranslocation. The N uptake from the soil was increased by both exponential fertilization and weed removal treatments. In the first year growth, N retranslocation was more important than N uptake from the soil as N retranslocation contributed about 82% in exponentially fertilized and 70% in conventionally fertilized seedlings to meet the total N demand of new tissues.

Experiment 3

Exponential fertilization in white spruce seedlings increased root:shoot biomass but not nutrient content in the seedlings compared to conventional fertilization during nursery production. Biomass production was affected by both nursery fertilization and field weed control in the second but not in the first growing season. Exponential fertilization increased percent height growth and weed control increased percent RCD growth in seedlings in the second growing season. Foliar N concentration of the seedlings was decreased in field growth regardless of the treatments compared to the seedlings during nursery production. Within the weed control treatment, foliar N concentration and the total N content were significantly increased by weed removal. Seedlings on weed-removed plots had lower foliar $\delta^{13}C$ than on weed-intact plots indicating that weed removal increased soil available N to the planted seedlings. In the second growing season, foliar $\delta^{13}C$ was positively correlated with seedling biomass, RCD and foliar N concentration, suggesting that the growth of planted white spruce seedlings was limited by N availability in the soil. Exponential fertilization didn't affect N retranslocation within the seedling but increased N uptake from the soil. Weed removal increased both N retranslocation and N uptake from the soil. Increase in N uptake by weed removal can be attributed to the increase in soil N availability.

LESSONS LEARNED

These studies demonstrated the potential benefit of applying the nutrient loading technique through exponential fertilization in nursery seedling production to enhance vegetation re-establishment on reclaimed soils by improving growth and nutrient status of planted seedlings of aspen and jack pine. In white spruce, further study is needed to optimize the exponential fertilization regime during nursery production. Vegetation management by weed control could be used to help seedling growth for aspen on LFH sites and white spruce on PMM sites. However, the study examined the field growth performance of exponentially fertilized seedlings of aspen and white spruce for two growing seasons and jack pine for one growing season; the utility of the nutrient loading technique needs to be operationally tested for the longer term and applied in future land reclamation practices in the oil sands region.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Pokharel, P., Chang, S. X., 2016. Exponential fertilization promotes seedling growth by increasing nitrogen retranslocation in trembling aspen planted for oil sands reclamation. Forest Ecology and Management, 372: 35-43.

Conference Presentations/Posters

Pokharel, P., Kwak, J.H, Chang, S. X., 2016. Nursery nutrient loading increased growth and nitrogen retranslocation in jack pine (*Pinus banksiana* L.) seedlings planted on an oil sands reclaimed soil. American Society of Agronomy (ASA), Crop Science Society of America (CSSA) and Soil Science Society of America (SSSA) Joint International Annual Meeting. Phoenix, AZ, USA. November 6-9, 2016 [poster].

Pokharel, P., Chang, S. X., 2016. Growth, nitrogen uptake and retranslocation in exponentially fertilized trembling aspen seedlings planted for oil sands reclamation. American Society of Agronomy (ASA), Crop Science Society of America (CSSA) and Soil Science Society of America (SSSA) Joint International Annual Meeting. Phoenix, AZ, USA. November 6-9, 2016 [oral].

Pokharel, P., Chang, S. X., 2016. Effects of exponential fertilization and understory vegetation competition on growth of white spruce seedlings planted on reclaimed soil of oil sands. Canadian Soil Science Society (CSSS) - Pacific Regional Society of Soil Science (PRSS) Joint Conference. Kamloops, British Columbia, Canada. May 14-19, 2016 [oral].

Pokharel, P., Chang, S. X., 2016. Exponential fertilization promotes the growth of trembling aspen seedlings by increasing N retranslocation in reclaimed soils. Alberta Soil Science Workshop. Grande Prairie, Alberta, Canada. February 16 - 18, 2016 [oral].

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott X. Chang

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Prem Pokharel	University of Alberta	M.Sc.	2014	2017 (thesis defense on January 11)
Jin-hyeob Kwak	University of Alberta	Research Assistant		
Kangyi Lou	University of Alberta	Research Assistant		
Stephanie Ibsen	University of Alberta	Research Assistant		

Research Collaborators: Technical support and guidance from Suncor Energy Inc., Total E & P Canada Ltd., Shell Canada Energy and Imperial

Plant Community Succession of Oil Sands Reclamation

COSIA Project Number: LJ0129

Research Provider: University of Alberta

Industry Champion: Shell Canada Energy

Industry Collaborators: Suncor Energy Inc., Canadian Natural Resources Limited, Syncrude Canada Ltd.

Status: Year 1 of 2

PROJECT SUMMARY

An understanding of the effects of reclamation treatments on plant community assembly and succession would assist in developing realistic indicators and targets for the reclamation of upland oilsands sites to forest ecosystems. This should include a better understanding of the effects of topography, subsoil and substrate, cover/donor soil, soil moisture regime, coarse woody material, surface characteristics, fertilization, agronomic cover crops, planting and seeding of native species, weeds, and other factors on plant community development.

Over the 2-year duration of this project we will assemble information and data to better inform reclamation of upland oilsands sites to sustainable forest communities through a literature review, workshops, analysis of data from the Cumulative Environment Management Association long-term plot network (CEMA LTPN), and supplemental field data collection.

Deliverables will include:

1) a report describing how successional processes and ideas relating to plant community assembly can be effectively used in oilsands reclamation, including a literature review, analysis of existing monitoring data and collection of personal observations from individual experts and practitioners;
2) a strategy and framework to guide future plant establishment, research and monitoring projects, towards a better understanding of vegetation prescriptions;
3) a peer-reviewed paper submitted for publication in an appropriate peer reviewed journal; and,
4) two workshops for exchange of information relating to plant community succession on reclaimed upland oilsands sites.

PROGRESS AND ACHIEVEMENTS

Amalesh Dhar was hired as a research associate and began work coordinating this project in May 2016. In addition, a research team lead by Dr. Phil Comeau from the University of Alberta and a technical steering committee led by Rob Vassov from Shell Canada Energy, were formed to guide the development and completion of this project in June 2016.

A literature review relating to plant community assembly and succession on upland oil sands reclamation sites has been prepared and is now in internal review. This report provides a synthesis of information relating to the current understanding of successional processes and plant community assembly and identifies knowledge gaps. In addition, analysis of data from the CEMA LTPN (long-term plot network) data on the impact of stockpiling on plant community assembly and succession in oil sand reclamation sites has been completed and a manuscript based on this analysis is in preparation. A questionnaire is being prepared for circulation to specialists to provide professional input regarding effects of reclamation practices on vegetation development. A one-day workshop is planned for

March 2017 to: review and discuss ideas relating to application of plant community assembly theory and succession in oilsands reclamation; identify key questions and knowledge gaps facing reclamation practitioners in relation to applying ideas about succession and assembly theory; and, to discuss approaches for filling data gaps.

This project began on May 01, 2016 and expected date of completion is April 30, 2018.

OUTCOMES AND LESSONS LEARNED

None to report at this time

LITERATURE CITED

No literature cited

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Dhar, A., Comeau, P. 2016. How can assembly theory and a knowledge of succession assist in oil-sands reclamation? Presentation at 1st project technical steering committee, June 16, 2016, Edmonton, Alberta

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Phil Comeau

Research Team:

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Justine Karst	University of Alberta	PhD, Assistant Professor		
Scott Chang	University of Alberta	PhD, Professor		
M. Anne Naeth	University of Alberta	PhD, Professor		
Rob Vassov	Shell Canada Energy	Reclamation and Research Coordinator		
Amalesh Dhar	University of Alberta	PhD, Research Associate		

Research Collaborators: Alberta Environment and Parks, Canada Forest Service

Trembling Aspen Seedling Establishment, Survival and Growth Related to Soil Properties on Reclaimed Sites

COSIA Project Number: LJ0007

Research Provider: Canadian Forest Service

Industry Champion: Canadian Natural Resources Limited

Status: Year 4 of 4

PROJECT SUMMARY

The purpose of this project is to investigate the effects of soil types and soil compaction typically found in oil sands reclamation surface soils, on aspen regeneration from seed. The reclamation soils tested were peat-mineral mix and forest floor-mineral mix with and without early fertilization. The field study was based at an operational overburden dump capped with suitable overburden and then 50 cm of the reclamation soils. These reclamation soils are known to have differences in terms of water holding capacity, nutrient supply rates, and vegetative competition levels which could significantly impact natural tree seedling establishment and productivity. The focal species for this study was trembling aspen which has a very small seed that is widely distributed and in this study the nearest aspen seed source was a mature forest less than 500 m away from the reclamation site.

Both greenhouse and field studies were conducted with the ultimate goal of making recommendations to improve reclamation practices to optimize natural aspen seedling establishment potential. The greenhouse studies were used to test the impacts of specific soil and site properties on aspen seedling establishment and were reported on previously. The field studies built upon the greenhouse findings and answer questions related to soil and topographic impacts on natural trembling aspen, and to a lesser extent balsam poplar, seedling establishment (i.e., not planted) and longer-term questions related to aspen survival and growth rates.

PROGRESS AND ACHIEVEMENTS

Field sampling related to this project was completed in summer 2016. Field data collected included trembling aspen and white spruce density and height after the 6th growing season on different reclamation soils at Reclamation Area 1 (RA1) and in the Richardson Burn benchmark sites. The summary analysis of this data is presented here. Environmental data, such as soil nutrients, water, and vegetative competition, were also collected and will be used to determine the ecological drivers of tree productivity on these reclaimed sites. This part of the analysis is ongoing.

OUTCOMES AND LESSONS LEARNED

Seedling establishment

Reclamation soil type had the largest impact on the natural seedling regeneration of trembling aspen. Peat-mineral mix soils have higher aspen densities than forest floor-mineral mix soils. Past research at our sites indicates that these differences are due to the higher water holding capacity and increased surface roughness of the peat-mineral mix soil. Fertilization in years 1 and 2 resulted in decreased aspen density, likely due to an increase in vegetative competition. Overall, the highest aspen regeneration was in the peat-mineral mix soil with no fertilization (average of 15,500 stems per ha). The lowest aspen regeneration was in the forest floor-mineral mix soil with fertilization

(average of 2,300 stems per ha). For comparison, the Richardson Burn benchmark stands had an aspen sucker density of approximately 30,000 stems per ha. The difference in aspen stem density between the reclaimed and natural stands is decreasing over time, likely due to self-thinning in natural stands and continued recruitment in the reclaimed stands, particularly on the peat-mineral mix soils.

Tree productivity: After six growing seasons, the average height of the planted white spruce crop trees (tallest 2,000 stems per ha) was greater on forest floor-mineral mix (average height 63 cm) than on peat-mineral mix (average 53 cm). In contrast, the average crop tree height of the seedling origin trembling aspen was greater on peat-mineral mix (average 126 cm) than on forest floor-mineral mix (85 cm). Fertilization in year 1 and 2 resulted in decreased growth of both white spruce and trembling aspen, likely due to increased vegetative competition. For comparison, the average height of aspen in the sucker origin benchmark stands was 245 cm. The relative difference in height between reclaimed and natural stands is decreasing over time, particularly on the peat-mineral mix soils.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Howell, D.M., Das Gupta, S., Pinno, B.D. and MacKenzie, M.D. 2017. Reclaimed soils, fertilizer, and bioavailable nutrients: Determining similarity with natural benchmarks over time. Canadian Journal of Soil Science. In press.

Conference Presentations/Posters

Pinno, B., Howell, M., Das Gupta, S. and Mackenzie, D. Similarity in nutrient profiles of reclaimed and natural benchmark soils in the Alberta oil sands. Soil Science Society of America Conference. Oral presentation. November 2016. Phoenix, AZ.

Hogberg, J., Pinno, B., and Mackenzie, D. 2016. Evaluating foliar nutrient concentrations as an indicator of belowground function in reclaimed soils of the Athabasca oil sands region. Soil Science Society of America Conference. Oral presentation. November 2016. Phoenix, AZ.

Stefani, F., Séguin, A., Isabel, N. and Pinno, B. 2016. How does contrasting cover soil used in oil sands reclamation affect the genetic diversity of trembling aspen and its associated soil microbiome? Presentation at ISME 2016. Montreal. August 2016.

Das Gupta, S., Pinno, B., Thiffault, E. and Thompson, D. 2016. Reclamation success in the mineable oil sands: Identifying potential criteria and indicators. Oral presentation at the Society for Ecological Restoration – Northwest conference on Monitoring Ecological Restoration. Portland, OR. April 2016.

Hogberg, J., MacKenzie, M.D. and Pinno, B. 2016. Evaluating foliar nutrients as an indicator of ecosystem function in natural and reclaimed soils in the Alberta oil sands region. Poster presentation submitted to the Alberta Soil Science Workshop. Grande Prairie, AB. February 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ruth Errington	Canadian Forest Service	Researcher		
Edith Li	Canadian Forest Service	Research technician		
Jim Weber	Canadian Forest Service	Research technician		
Armand Séguin	Canadian Forest Service	Researcher		
Stephanie Jean	Canadian Forest Service	Research technician		
Kyle Stratechuk	Canadian Forest Service/ University of Alberta	Student intern		
Jenn Buss	Canadian Forest Service/ University of Alberta	Student intern		
Shelby Feniak	Canadian Forest Service	Summer student		
Pierre-Yves Tremblay	Université Laval	M.Sc.	2015	2017
Jeff Hogberg	University of Alberta	M.Sc.	2014	2017
Evelyne Thifault	Université Laval	Professor		
Derek MacKenzie	University of Alberta	Professor		

Understory Plant Community Development on Reclaimed and Natural Sites

COSIA Project Number: LJ0005

Research Provider: Canadian Forest Service

Industry Champion: Canadian Natural Resources Limited

Status: Year 3 of 3

PROJECT SUMMARY

Establishing functioning upland plant communities on land reclaimed after oil sands mining is an important goal for reclamation practitioners. These plant communities, which include trees, shrubs and understory vegetation, are important for their role in establishing nutrient cycling, providing biodiversity and wildlife habitat, contributing to primary productivity and many other ecological functions. In general, the goal for reclaimed plant communities is that their species composition is similar to that of native stands in the area and that the successional trends are similar between reclaimed and natural sites.

On reclaimed sites, peat-mineral mix (PMM) and upland forest floor-mineral mix ([FFMM], consisting of LFH and A horizon materials) are currently being used as surface soils to provide the initial growing medium for plants. However, these organic–mineral soil mixes differ greatly in their resource availability with peat-mineral mix having greater nitrogen availability but lower phosphorus availability than the forest floor-mineral mix which could have an impact on vegetation development. Initial results from Canadian Natural Horizon Reclamation Area 1 (RA1) and other studies also indicate that forest floor treatments have higher initial species richness than the peat–mineral mix treatments, likely due to the greater propagule bank stored in the forest floor, but the longer term successional trends are not known.

The overall goal of this study is to determine the impacts of these different reclamation options, i.e., soil type, fertilization, coarse woody debris and weed management on vegetation development and then compare vegetation development on the reclaimed sites to nearby natural stands. The results of this study will be used to make recommendations to improve reclamation practices that optimize long-term vegetation development.

PROGRESS AND ACHIEVEMENTS

Field sampling related to this project was completed in summer 2016. Field data collected included plant community composition at Waste Area 2 (WA2) and RA1. A greenhouse experiment was also conducted to study the growth of understory invasive plants (*Galium boreale* [northern bedstraw], *Vicia americana* [American vetch], and *Matricaria perforate* [scentless chamomile]) in different reclamation soils with and without fertilization.

OUTCOMES AND LESSONS LEARNED

Field data: Based on the results of the plant community assessment at WA2 after the third growing season, species richness is greater on forest floor-mineral mix soil and transitional soil (average 29 species per 5 m x 5 m plot) compared to peat-mineral mix soil (average 12 species). Overall plant cover followed the same pattern, being greatest in forest floor-mineral mix (average 34%) and lowest in peat-mineral mix (10%). Weeding of non-native plants also changed the relative proportions of different species groups but these impacts are still being analyzed.

Greenhouse data: Across soil types, *Galium boreale* had lower aboveground biomass than both *Vicia americana* and *Matricaria perforata*. *Vicia* biomass did not vary among the soil types or fertilizer treatments likely due to the nitrogen fixing ability of *Vicia*. In contrast, biomass of both *Galium* and *Matricaria* was lowest in peat-mineral mix and highest in forest floor-mineral mix, representing an increase in growth with nitrogen availability. When grown together, the relative proportion of *Vicia* and *Matricaria* varied with nitrogen availability, with *Vicia* dominating in low nitrogen soils and *Matricaria* dominating in high nitrogen soils. The greatest growth response to fertilization was in the non-native *Matricaria* indicating that fertilization may not be beneficial for native plants.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Pinno, B.D., Sherr, I., Errington, R.C., and Shea, K. 2016. Islands – soil patches and plant community dynamics on a new oil sands reclamation design. Journal of the American Society of Mining and Reclamation. 5:28-44.

Errington, R.C. and Pinno, B.D. 2016. Early successional plant community dynamics on a reclaimed oil sands mine in comparison with natural boreal forest communities. Ecoscience.22:133-144.

Conference Presentations/Posters

Pinno, B.D., Sherr, I., Errington, R.C., and Shea, K. 2016. Islands – plant community dynamics on a new reclamation design. American Society of Mining and Reclamation 2016 Conference. Oral presentation. June 2016. Spokane, Washington.

deBortoli, L., MacKenzie, D., Pinno, B., Li, E. and Errington, R. 2016. Initial plant community development and tree establishment on different reclamation soil types. Poster presentation submitted to the Alberta Soil Science Workshop. Grande Prairie, AB. February 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ruth Errington	Canadian Forest Service	Researcher		
Jim Weber	Canadian Forest Service	Research technician		
Stephanie Jean	Canadian Forest Service	Research technician		
Kyle Stratechuk	Canadian Forest Service/ University of Alberta	Student intern		
Jenn Buss	Canadian Forest Service/ University of Alberta	Student intern		
Leah deBortoli	University of Alberta	M.Sc.	2016	2017
Derek MacKenzie	University of Alberta	Professor		

Oil Sands Vegetative Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting Inc.

Industry Champion: Shell Canada Energy

Industry Collaborators: Canadian Natural Resources Limited, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Imperial, Nexen, Statoil Canada Ltd., 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 COSIA Land EPA Led project that provided support for seed collection initiatives that were applied in the Northern Athabasca Oil Sands (NAOS), Southern Athabasca Oil Sands (SAOS) and Cold Lake (COLK) regions.

In 2016, an emphasis was placed on completing collections for the individual divisions. Increased activities were conducted in the NAOS in the aftermath of the Horse River wildfire with the introduction of a new harvest contractor. A bi-annual newsletter was published, and ongoing maintenance of a cross-company record keeping system and administration of the cooperative seed bank were undertaken.

PROGRESS AND ACHIEVEMENTS

Progress in 2016 was hindered and delayed by the Horse River wildfire in Fort McMurray and the surrounding area. There was a focus of activity (pre-harvest planning, field assistance, and seed lot auditing) on the NAOS following the fire with a new collection contractor and a shortened collection season. Ongoing maintenance of a cross-company record keeping system and administration of the cooperative bank continued. A twice-yearly newsletter was developed and published.

In 2016, the OSVC harvested 657.25 litres (L) of seed from 4 seed zones in northeastern Alberta. The following were extracted and registered:
COLK – 79.25 L of seed from 5 seed lots representing 4 species from seed zone CM 3.1.
SAOS – 201.5 L of seed from 9 seed lots representing 6 species from seed zone LBH 1.5.
NAOS – 376.5 L of seed from 34 seed lots representing 18 species from seed zones CM2.1 and CM 2.2.

Table 1. Species harvested

COLK
Pinus banksiana (jackpine)
Populus tremuloides (aspen)
Rosa acicularis (prickly rose)
Shepherdia canadensis (buffaloberry)

SAOS
Alnus viridis (green alder)
Betula papyrifera (paper birch)
Betula pumila (bog birch)
Rhododendron groenlandicum (Labrador tea)
Vaccinium myrtilloides (blueberry)
Vaccinium vitis-idaea (bog cranberry)

NAOS
Alnus incana (river alder)
Alnus viridis (green alder)
Amelanchier alnifolia (Saskatoon)
Arctostaphylos uva-ursi (bearberry)
Betula papyrifera (paper birch)
Cornus sericea (redosier dogwood)
Corylus cornuta (beaked hazelnut)
Dasiphora fruticosa (shrubby cinquefoil)
Prunus virginiana (chokecherry)
Ribes americanum (wild black currant)
Ribes hudsonianum (northern black currant)
Ribes triste (wild red currant)
Rosa acicularis (prickly rose)
Shepherdia canadensis (buffaloberry)
Vaccinium myrtilloides (blueberry)
Vaccinium vitis-idaea (bog cranberry)
Viburnum edule (lowbush cranberry)

OUTCOMES AND LESSONS LEARNED

Seed requirements for reclamation are such that we cannot possibly harvest on an as-needed basis. Ongoing seed banking is required and should be a key component of oil sands reclamation planning. The 2016 Horse River wildfire drew attention to this critical need for reliable sources of native shrub seed for the oil sands industry. Aspen is a keystone species and widely deployed for reclamation and needs to be targeted in the 2017 harvest season.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

There were no public presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu, M.Sc.

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		
Lori Neufeld	Imperial	Senior Environmental Advisor, Land Use and Biodiversity		
Robert Vassov	Shell Canada Energy	Reclamation and Research Coordinator		

Research Collaborators: Alberta Tree Improvement and Seed Centre (Government of Alberta)

NSERC Terrestrial Restoration Ecology Industrial Research Chair

COSIA Project Number: LE0034

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 1 of 5

PROJECT SUMMARY

After mining, some landforms are reconstructed with oil sands that do not meet the criteria for bitumen processing yet contain some petroleum hydrocarbons. As a result, this lean oil sand (LOS) forms all or considerable portions of some reconstructed landform substrates. As such, LOS can be in close proximity to or even forming part of the rooting zone of reclaimed sites.

Oil sands in the rooting zone are not unique to reclaimed sites. In this region of boreal forest, oil sand outcrops occur naturally, and some of the local forests have developed on these deposits over thousands of years. However, 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 a risk to 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 reclaimed with this material. Currently there is a lack of science-based evidence guiding reclamation practice and the associated regulatory framework for LOS landforms.

This research program is building on knowledge from other programs related to LOS in reclaimed ecosystems such as the Aurora Capping Study. It will develop further knowledge on belowground features that support self-sustaining forests in both reclaimed and natural systems. The overarching research focus is characterizing rooting behaviour in regional soils (both natural and reclaimed), with a particular focus on the influence of hydrocarbons within or in close proximity to the rooting zone. As such, it will investigate whether LOS acts as a barrier to or a medium for root growth of plants (herbaceous, shrubs and trees) comprising typical boreal forest. Several lines of inquiry will be followed through the research to answer the overarching questions:

1) What are natural dimensions of and mechanisms influencing 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

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

To identify natural dimensions and mechanisms underlying rooting zones, we are a) refining existing molecular tools to identify roots to species, b) testing how root profiles differ with soil texture and c) testing how root profiles differ with stand age. Towards addressing these objectives, an MSc student, Paul Metzler, has been recruited to refine existing molecular tools. His project involves surveying ~ 200 plant species in the oil sands region to build a database

of DNA markers to be used as reference material for identifying roots. The library of molecular markers will be useful for all future rooting studies in the Region. Currently, he is analysing DNA and we expect the database to be complete by May 2018. Two other MSc students have been recruited to address objectives b) and c); their projects will begin in 2017.

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

To identify the effects of oil sand on root structure and function, we will a) compare tree growth and rooting in natural oil sands outcrops with that in reclaimed LOS, and b) test whether LOS is a barrier to root growth in a reclaimed area, and determine its impact on water uptake by trees. Students will be recruited in 2017 to address these objectives.

3. Do root microbial symbionts mediate tree survival on oil sand?

To test the role microbes forming mycorrhizas with tree roots play in mediating tree survival on oil sands deposits, we will a) survey species of ectomycorrhizal and arbuscular fungi across soils that differ in oil sand concentration and extent of weathering to screen for fungi specialized to occur in oil sand, and b) inoculate tree seedlings with fungi from different origins to test for seedling growth differences when grown in soils containing bitumen. A PhD student has been recruited, to start in 2017, to lead this project. Pedro Antunes (Algoma University) has agreed to collaborate to supervise this student and provide technical skills in working with arbuscular mycorrhizal fungi.

OUTCOMES AND LESSONS LEARNED

This project is not yet at the stage to report on outcomes and lessons learned. Preliminary analyses are being conducted to establish database of DNA markers to identify root species of boreal plants.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

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	M.Sc. candidate	2016	2018
Pak Chow	University of Alberta	Laboratory technician		
Alison Wilson	University of Alberta	Field technician		

Jack Pine Establishment

COSIA Project Number: LJ0263

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial

Status: Year 1 of 5

PROJECT SUMMARY

Following surface mining, oil sands operators are required to reclaim the land such that reclaimed soil and landforms are capable of supporting a self-sustaining, locally common boreal forest regardless of the end land use, and ensuring that land is integrated with the surrounding areas. Establishment of jack pine (*Pinus banksiana* Lamb.) stands on sandy materials (a1 ecosites) 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 (JPRT) was initiated as a "proof-of-concept" trial to mimic the effect of fire and revegetate two former laydowns (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 three treatments are: 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, applying a heat treatment on site using black polyethylene covering for 24 hours.

Specific objectives of the trial include: evaluating jack pine revegetation success (via seeding) based on establishment of desired plant communities and trajectory towards target a1 ecosite phase; comparison of results of the three treatments to jack pine establishment and height in natural burned areas at "Year 5 post-treatment" (2021) 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 indication(s) that alternative revegetation strategies (e.g., other than via seedling planting) are possible.

PROGRESS AND ACHIEVEMENTS

Seed extraction pre-trial; plot establishment; soil sampling; vegetation monitoring; and data analyses were undertaken in 2016. Prior to applying the field treatments, two pre-trials were conducted to determine the most effective combination of temperature and exposure time to open serotinous jack pine cones.

Three plots were established on each of the reclaimed Bouchier and Willbros laydowns located adjacent to the north side of the RWI access road in June 2016. Two monitoring plots were established on the previously burned RWI pipeline RoW in September 2016, conveniently located near the established Bouchier former laydown plots.

An attempt was made to locate the plots within each laydown such that surficial variation across each plot was minimized. In order to control the number of seeds and cones applied to each plot, an effort was made to collect the jack pine cones already present within the plots due to coarse woody debris placement. Seed was applied at approximately 14.5 kilograms (kg) of cones, or the amount of seed released from 14.5 kg of cones, on each of the 100 m^2 Bouchier and Willbros laydown treatment plots. No seed or cones were applied to the natural (burned) comparison plots.

To maintain consistency with the 100 m^2 standard assessment plot recommended in the Guideline for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (AENV 2010) for determining the threshold and mean characteristic species values, and with the current Reclamation Monitoring Protocol, "proof-of-concept" and natural burned area monitoring plots were set at 10 m × 10 m. The four corners of each plot were marked with white polyvinyl chloride (PVC) pipe for future identification; plot locations were recorded using a hand-held Global Positioning System (GPS) receiver. At each corner of the 100 m^2 monitoring plot, nested subplots were established and temporarily marked using metal "pigtails" and coloured flagging.

Soil sampling to determine pH, salinity and nutrient status of the upper 30 cm (surface soil) was undertaken at all plots at the time of plot establishment.

Year 1 jack pine revegetation monitoring took place mid-September 2016, the year of plot establishment. Year 1 monitoring coincides with the first year of growth for the three treatment plots, and Year 5 post fire within the natural burned area.

Indicators of revegetation success and progress towards target ecosite include measures of plant community composition, namely, species richness, species diversity, evenness and abundance. Each subplot was assessed for percent cover of trees, shrubs, forbs, graminoids, bryophytes and lichens, leaf litter and bare ground. Information collected from the vegetation quadrats was used to calculate species abundance, species richness, evenness, and diversity, using Shannon Diversity Index.

Results of the pre-trial indicated that as the temperature and time in the soil oven increased from 50 °C to 200 °C and 30 to 300 seconds, the total seed yield (number of seeds/g of cone) released from the jack pine cones increased. The polyethylene seed extraction trials demonstrated that cones opened under the polyethylene cover treatment.

None of the soil parameters measured were dependent on treatment in 2016, although some significant differences were identified between the two laydown areas (sites). Jack pine seedlings have emerged in all treatment plots by the end of the Year 1 growing season (2016), although at low rates. In addition to seedling emergence, community performance parameters were also assessed in the event that trends observed in seedling establishment were not explained by soil data or seeding treatment. None of the community parameters calculated were dependent on seeding treatment in 2016. Total vegetative cover was significantly greater in plots at the Willbros site than at the Bouchier site; no other parameter was dependent on site.

LITERATURE CITED

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

OUTCOMES AND LESSONS LEARNED

This project is not yet at the stage to report on outcomes and lessons learned.

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 Resources Limited

Industry Collaborators: Imperial, Shell Canada Energy

Status: Year 1 of 4

PROJECT SUMMARY

The reestablishment of blueberry (*Vaccinium myrtilloides*) and other plant species from the Ericaceae family in oil sands reclamation areas is of considerable interest due to their ecological importance in the boreal forest and 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 different environmental stresses, including high soil pH and salinity. Ericaceous plants are known to form symbiotic associations with ericoid mycorrhizal fungi (ERM) (Sharples et al., 2000; Mitchell and Gibson, 2006). However, the importance of ERM associations in the survival and sustained growth of ericaceous plants under different environmental conditions 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 resistance to high pH, salinity, and drought. The results of the study will be used to improve revegetation of oil sands areas with Ericaceous plants.

Specific objectives are to i) identify the ericoid mycorrhizas in the roots of upland and lowland blueberry (*Vaccinium myrtilloides* Michx.), Labrador tea (*Rhododendron groenladicum* (Oeder) Kron & Judd) and lingonberry (*Vaccinium vitis-idaea* var. *minus* Lodd) plants in natural forest sites, oil sands reclamation soils and nurseries, ii) examine whether ERM associations enhance high pH, drought and salinity tolerance in these plant species, iii) 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 iv) examine the growth responses of ERM colonized plants following planting in oil sands reclamation areas. The project consists of four studies that include both field and environmentally-controlled experimental conditions.

PROGRESS AND ACHIEVEMENTS

During this first year we have mostly focused on the completion of Study 1, which addressed the first objective of the project. A total of 130 plants, 10 per species and collection site, were excavated from natural forest sites around the oil sands reclamation areas: 4 sites for blueberry (3 upland and 1 lowland), 6 sites for Labrador tea (3 upland and 3 lowland) and 3 sites for lingonberry (upland). The original study planned to collect roots from 3 upland and 3 lowland populations of blueberry, but it was difficult to find enough plants in lowland locations with fruits to obtain seeds needed for the subsequent studies (Studies 2 and 3). Soil samples were also collected from each population source and analyzed for pH, electrical conductivity and nutrient content.

After each root system was thoroughly washed, the fine roots were excised and divided into 3 groups: i) group 1, surface-sterilized and cultivated in agar plates for endophyte isolation and identification, ii) group 2, stored at -80°C for assessment of ERM through DNA analysis, and iii) group 3, stored in fixative (FAA, 95% ethanol: glacial acetic acid: formalin: distilled water 10:1:2:7, by volume) for subsequent microscopy analysis.

1: Isolation of fungi from roots:

Six plates per root system were prepared, three with potato-dextrose-agar (PDA) medium and three with Merlin Norkrans (MMN) medium (total of 780 plates). Plates were incubated in darkness and observed periodically for fungal growth. All the different colonies that appeared in the plates, based on morphological characteristics such as colour, texture and growth pattern, were isolated and re-cultured in new plates in order to get pure cultures. In many cases several different morphotypes were observed in a single root segment. Three plates were cultured for each morphotype isolated from the original plate, resulting in about 2,000 plates until pure cultures were obtained. Over 50 different morphotypes were identified across the entire collection. A database was built with the description of each morphotype and in which species and collection site it was found.

Isolates were later re-cultured on PDA medium covered with cellophane membrane in order to harvest the hyphae for DNA extraction and molecular identification of the species. In the case of morphotypes that appeared to be the same in more than one site and species, one specimen of each source was taken for DNA identification (total of approximately 150 plates). We have completed the analysis of 114 samples (76% from the entire collection). From them, 98 samples have been identified at the Species or Genus level, while the rest have been identified at the Family level. The remaining samples are currently under analysis. Some plates had to be re-cultured onto cellophane membranes in order to get more material due to different problems during the process (poor DNA extraction, non-specific PCR amplification, low concentration of the final purified PCR product to be sent for sequencing, etc.).

From the samples analyzed so far we have identified 5 ERM species and a dark-septate root endophyte that commonly associates with ericaceous plants: *Rhizoscyphus ericae* (Labrador tea, upland population, site 2), *Pezicula ericae* (blueberry, upland population, site 2), *Oidiodendron maius* (Labrador tea, lowland population, site 3), *Geomyces* sp. (Labrador tea, lowland population, site 3), *Meliniomyces variabilis* (Labrador tea, upland population, site 2; Labrador tea, lowland population sites 1-3), and *Phialocephala fortinii* (blueberry, upland population, site 2, lingonberry, site 1; Labrador tea, upland population, site 2; Labrador tea, lowland population, site 1). In addition to ERM species, we found a considerable number of other fungal species that are considered pathogenic (e.g., several *Fusarium* species) or saprophytic (*Rhizoctonia*, *Umbelopsis*, *Gymnopus subnudus*). The entire collection is currently being maintained by periodic subculture in fresh PDA medium.

2: Identification of ericoid mycorrhizal (ERM) fungi in roots by DNA analysis

Root samples stored at -80°C were originally processed in a similar manner to the fungal isolates from subsample 1. However, preliminary results showed the need to modify both the DNA extraction as well as the PCR protocols. Therefore, we have changed both the kit used for genomic DNA extraction as well as the primers for PCR amplification and we have currently successfully finished 40% of the root samples. We have confirmed several of the ERM species that have been isolated in subsample 1 and are now part of our collection (e.g., *Rhizoscyphus ericae*, *Meliniomyces variabilis* and *Phialocephala fortinii*). Furthermore, several different fungal species have been identified from a single root sample, confirming the high fungal diversity found during the culture of root segments.

3: Microscopic analysis

Microscopic assessment of ERM colonization in roots, i.e., presence of coils in epidermal and cortex cells, is currently under way.

4: Survey of ERM in plants from nurseries:

In May of 2016, nursery plants of the three species were purchased and processed in a similar way to those collected from the forest sites. Identification of ERM by DNA analysis of roots is currently under way.

5: Survey of ERM in reclamation soils (LFH and peat-mineral soil):

The ERM inoculum potential of LFH topsoil was tested in a greenhouse experiment conducted during May-November of 2016. Approximately 100 L of upland surface soil was collected from a natural forest site around the oil sands mining areas and transported to the University of Alberta. The soil was manually homogenized and sieved to remove small branches and other big debris. Half of the soil was autoclaved to use as a control of potential contamination in the greenhouse. Three 24-cell (700 mL each) styrofoam blocks were filled with either autoclaved or non-autoclaved soil, and seedlings of the three species collected during the survey of plants in the field were transplanted into the blocks (8 per each species per block). Due to the low germination rate and slow growth of the three plants species, which was determined in previous essays, surface-sterilized seeds were sown and maintained in agar plates with MS medium two months before being planted. Plants were watered every 3 days and fertilized with N-P-K (20-20-20) fertilizer every other week for six months. Fine roots were subdivided into two samples; one was stored at -80°C for assessment of ERM colonization by DNA analysis while the other one was stored in FAA for microscopy analysis. Root samples are currently being processed for DNA analysis. The ERM inoculum potential of peat mineral soil will be evaluated in a similar manner during 2017.

Due to its time-consuming nature, all members of the group were involved in the execution of Study 1. In addition to the work associated with Study 1, protocols needed to successfully grow the three plant species from the seeds collected in the field were also developed. Germination tests were conducted on all 13 seed sources. Due to the very slow growth rate of all these species, a protocol involving in-vitro culture of sterilized seeds was developed in order to increase germination rates and seedling development before they are used for experiments.

From the ERM that have been successfully isolated in Study 1, two to three species will be used for the experiments proposed for Study 2 (“Effects of ERM on drought resistance and water transport properties in lowland and upland populations”) and Study 3 (“Effect of ERM on high pH and salinity tolerance of ericaceous plants”).

OUTCOMES AND LESSONS LEARNED

The results obtained so far from Study 1 revealed a diversity of fungal root endophytes much higher than originally expected. Once we have completed the analysis of all the samples we will be able to fully analyze how ERM associations vary among different ericaceous species growing in different habitats.

LITERATURE CITED

Garibaldi A, Straker J. 2009. Cultural keystone species in oil sands mine reclamation, Fort McKay, Alberta, Canada. In British Columbia Mine Reclamation Symposium. Available from http://hdl. handle. net/2429/24607.

Mitchell DT, Gibson BR. 2006. Ericoid mycorrhizal association: ability to adapt to a broad range of habitats. Mycologist 20:2-9.

Sharples JM, Chambers SM, Meharg AA, Cairney JW. 2000. Genetic diversity of root-associated fungal endophytes from *Calluna vulgaris* at contrasting field sites. New Phytologist 148:153-62.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Janusz Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Beatriz Sánchez-Romera	University of Alberta	Postdoctoral Fellow		
Deyu Mu	University of Alberta	PhD Student	2016	in progress
Sepideh Fadaei	University of Alberta	Master Student	2016	in progress
Alejandra Equiza	University of Alberta	Research Assistant		

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 Resources Limited

Status: Year 1 of 5

PROJECT SUMMARY

Non-Segregating Tailings (NST) are a waste product of oil sands processing in northeastern Alberta. In the near future, NST deposits at the Horizon lease must be reclaimed: capped with suitable overburden, upland subsoils, upland cover soils, and revegetated. However, there are significant knowledge gaps 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. 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 revegatation activities and 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 from within the NST in reconstructed soils could greatly reduce establishment, growth and yield, as well as the quality of these plants, especially for medicinal uses. Additionally, successful growth of many plants in oil sands reclamation areas is dependent on the successful establishment of mycorrhizal associations, but to that effect there is little understanding of the impacts of NST on the inoculation potential of mycorrhizal fungi on reclamation plants. These associations are essential to provide plants with sufficient nitrogen and phosphorus nutrition, as well as protection from abiotic stressors.

The objectives of the project are:

1) To examine growth and physiological parameters in 20 native boreal forest plant species growing in 6 types of growth media containing a combination of NST, reclamation cover soils, or coke.
2) To examine effects of NST on uptake and tissue distribution of trace elements in three selected species of plants of special significance to Aboriginal communities.
3) To examine effects of NST on the inoculation potential and diversity of ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM) fungi in reconstructed soils and roots of reclamation plants.
4) To examine effects of different nitrogen and phosphorus supplies on plants growing in NST-amended soil.

PROGRESS AND ACHIEVEMENTS

Towards the achievement of objective 1, we conducted two successive experiments in 2016:

Experiment 1:

From March to June of 2016, one-year-old nursery-grown seedlings of jack pine (*Pinus banksiana*), balsam poplar (*Populus balsamifera*), tamarack (*Larix laricina*), and Canadian buffalo berry (*Shepherdia canadensis*) were planted in specially-designed pots made of PVC pipes that were 50-cm in length and 10-cm in diameter. The PVC pipes were filled with the following six types of growth media: 40-cm upland forest floor soil; 40-cm peat-mineral mix (PMM); 40-cm NST; 30-cm NST capped with 10-cm forest floor soil; 30-cm NST capped with 10-cm PMM; 30-cm NST capped with 10-cm coke and 10-cm topsoil. The seedlings were placed in a controlled-environment growth room and grown for three months. They were watered every two days and fertilized weekly with 50% modified Hoagland's solution. Seedling shoot heights were measured before and after the three-month growth period. At the end of the experiment, leaf gas exchange parameters (net photosynthesis, transpiration, stomatal conductance) were measured with the LICOR-6400 infrared gas analyzer and leaves were sampled for chlorophyll and elemental analysis. Seedlings were harvested and shoots and roots separated and oven-dried for dry biomass determination.

Experiment 2:

From July to September of 2016, one-year-old nursery-grown seedlings of white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and green alder (*Alnus viridis*) were planted in 1000 ml pots filled with five types of media: upland forest floor soil; PMM; NST; NST mixed with forest floor soil (2/1, v/v); NST mixed with PMM (2/1, v/v). The plants were watered and fertilized as in Experiment 1, and the same growth and physiological measurements were conducted. In addition, at the end of the experiment, root hydraulic conductivity was measured in paper birch and white spruce with a high-pressure flowmeter (HPFM).

The results of the two experiments are presently being analyzed.

OUTCOMES AND LESSONS LEARNED

Samples and data are still under analysis. No outcomes and lessons are available at this time.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Janusz Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Wenqing Zhang	University of Alberta	Postdoctoral Fellow	2016	

Long-Term Plot Network – 2016 Sampling

COSIA Project Number: LJ0295

Research Provider: Paragon Soil and Environmental Consulting Inc., FORCORP

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Imperial, Shell Canada Energy, Suncor Energy Inc., Syncrude Canada Ltd.

Status: Year 1 of 1

PROJECT SUMMARY

This project has been initiated to preserve CEMA's Long-Term Plot Network (LTPN) reclaimed plot re-measurement schedule for the 2016 field season. In 2016, CEMA's ability to sponsor projects was significantly reduced, leaving a number of projects that were once housed and administered by CEMA with an uncertain future. In order to prevent gaps in data collection within the larger monitoring timeline, a number of COSIA members worked together to create the 2016 Sampling JIP (Joint Industry Project) to organize the scope and hire contractors to collect re-measurement data on reclaimed plots.

In addition to re-measurement sampling of certain reclamation plots, the 2016 Sampling project also included scope to update, consolidate, and perform quality assurance/quality control (QA/QC) on the Long-Term Plot Network database. FORCORP (formerly The Forestry Corp.) was engaged to provide data management functions for the Long-Term Plot Network database, which included database updates, data entry, and QA/QC of the 2016 field data.

The key objectives of this project were:

1) Re-measure and sample vegetation and soils on reclamation plots located within Suncor and Syncrude's leases as per the re-measurement schedule's recommendations for the 2016 field season
2) Update the LTPN database: consolidate 2015 and 2016 data, and perform QA/QC on the LTPN database
3) Summarize the 2016 season's field work, challenges, and solutions for both field sampling and database contexts, at a year-end wrap-up meeting

PROGRESS AND ACHIEVEMENTS

Thirteen of the planned 22 reclamation plots were re-measured on the Syncrude and Suncor leases. Re-measurements were planned for plots on Canadian Natural and Shell leases, but the tremendous impact of the 2016 Fort McMurray wildfire made this sampling impossible within the project schedule. In addition to re-measurements, a number of technical problems involving reclamation plots were identified and remediated in the field using established protocols. No reference plots were re-measured in 2016, nor were any new reference or reclamation plots established. The 2016 Fort McMurray forest fire provided some obstruction to the project scheduling, site access, measurement opportunities, and data accuracy.

OUTCOMES AND LESSONS LEARNED

No major outcomes or lessons arose from this season, as the project's goal was to ensure continuity of the long-term data collection.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and Environmental Consulting, Inc.

Principal Investigator: Vincent Futoranski

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Vincent Futoranski	Paragon	Senior Ecologist		
Kerry Nice	FORCORP	Application Development Manager		

Wildlife Research and Monitoring

Wildlife Monitoring – Horizon Oil Sands

COSIA Project Number: LJ0186

Research Provider: Canadian Natural Resources Limited, LGL Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Status: Year 11 - 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 (Hawkes, et al. 2016). 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 deployed on the Horizon Oil Sands consistently since 2006. Cameras are currently deployed in a number of areas for regulatory requirements and in areas to assess key habitat types including riparian, reclamation and compensation lake habitat types. Remote camera use contributes important data on the occurrence and distribution of wildlife, and the time of day and year that certain species occupy and utilize various habitats. For species with enough data, we evaluated the efficacy of species-specific occupancy models based on their variances under different sparseness and detection criteria (Hawkes et al. 2016).

Wildlife camera data can be used to test assumptions of potential use of reclaimed habitats relative to area and proximity to intact habitats. However, species-specific detection rates will also vary relative to multiple factors, which may be related to the population abundance of a given species, but also to camera location, movement patterns, and inter-specific interactions (Burton et al. 2015), and of relevance to Canadian Natural Resources Limited (Canadian Natural), to mitigation strategies implemented to deter wildlife from using certain portions of the Horizon Oil Sands Lease (Hawkes et al. 2016). These variations are being considered when assessing wildlife use based on camera trap data.

PROGRESS AND ACHIEVEMENTS

Wildlife camera data were used to assess spatial and temporal patterns of wildlife occurrence and use (occupancy) in select areas of Canadian Natural's Horizon Oil Sands. A total of 59 species were documented over time, with the number of wildlife species documented varying relative to year and camera location. Occupancy, which in this case is a proxy for use, changed little over time for all clusters of cameras (Hawkes et al. 2016).

The number of photographs of some species contributed to the development of a fairly robust data set that was less sensitive to changes in sparseness and detection criteria (e.g., white-tailed deer and coyote) while smaller data sets required the use of smaller values for both sparseness and detection (e.g., Snowshoe Hare and Canadian lynx). Because species-specific detection rates will vary relative to multiple factors including population abundance of a given species, camera location, movement patterns, and inter-specific interactions (Burton et al. 2015), consideration of how these factors influence species detectability is required when assessing wildlife occupancy. For this exercise we did not consider how these factors might be influencing occupancy (Hawkes et al. 2016). However, we acknowledge that the number of photographs is not a representation of population abundance nor do they

provide absolute assessments of wildlife use on a seasonal or annual basis. The data provide evidence of occupancy (use) that can be modelled over time to determine whether any trends in occupancy are apparent.

Overall, wildlife use of the riparian and compensation lake areas is higher than the reclamation area, which is likely related to seral stage, proximity to intact boreal forest, the generally higher use of riparian areas by wildlife, and the reclamation areas assessed, which is bordered by roads to the north and south, which may reduce wildlife use of the area. Data collected from remote cameras revealed interesting patterns of habitat use over time for a variety of wildlife and for select species, finer-scale temporal trends (daily and seasonal) are also indicated, but in general, there does not appear to a decline in occupancy (or use) by wildlife relative to the camera trap locations sampled in both areas (Hawkes et al. 2016).

Data from all riparian, Horizon Lake, and reclamation cameras were pooled to generate three data sets – one for each cluster of cameras. Pooling data increases sample size and generates data sets that are less sensitive to changes in sparseness and detection criteria; however, wildlife activity around certain cameras may be higher than at others – a possibility that is not taken into consideration when pooling data. A cursory assessment of the number of wildlife species documented per camera and year, particularly mammals, suggests that the number of mammal species photographed each year was relatively stable (Hawkes et al. 2016). However, to better assess the potential effects of changes to the landscape or implementation of mitigation strategies, it may be necessary to model occupancy for a subset of cameras within each cluster to assess those effects.

The use of camera traps has increased in recent years with numerous projects implemented to better understand the distribution, abundance and behaviour of wildlife. Despite the apparent widespread adoption of this method, there are certain limitations of the data that need to be recognized (Burton et al. 2015). For example, generating density estimates of unmarked animals and using occupancy models to estimate use continue to be controversial and debateable, although possible (Rowcliffe et al. 2008). However, defining key attributes and methodological aspects of camera trap studies can mitigate for some of these limitations. Understanding the assumptions (e.g., unequal detectability) associated with the statistical tests being applied to the data (e.g., occupancy models) will lead to improved interpretation and inference of the data collected. Limiting the inference of camera trap data to only similar site types (in this case active oil sands leases) will also ensure the data are used appropriately (Hawkes et al. 2016).

OUTCOMES AND LESSONS LEARNED

- Data collected from remote cameras revealed interesting patterns of habitat use over time for a variety of wildlife and for select species, finer-scale temporal trends (daily and seasonal) are also indicated, but in general, there does not appear to be a decline in occupancy (or use) by wildlife relative to the camera trap locations sampled.
- Pooling data increases sample size and generates data sets that are less sensitive to changes in sparseness and detection criteria; however, wildlife activity around certain cameras may be higher than at others – a possibility that is not taken into consideration when pooling data.
- To better assess the potential effects of changes to the landscape or implementation of mitigation strategies, it may be necessary to model occupancy for a subset of cameras within each cluster to assess those effects.

LITERATURE CITED

Burton, A.C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J.T., Bayne, E., and S. Boutin. 2015. REVIEW: Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. J Appl Ecol 52(3): 675–685. doi: 10.1111/1365-2664.12432.

Hawkes, V.C., C.M Wood, N. Hentze, B. McKinnon, J. Sharkey, J. Gatten, W. Challenger, N.N. Johnston, and M. Miller. 2016. Early successional wildlife monitoring program Canadian Natural Resources Limited Horizon Oil Sands. Year 4 2015–2016 annual report. LGL Report EA3368C. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for Canadian Natural Resources Limited, Fort McMurray, AB. 104 pp + Appendices.

Rowcliffe, J.M., J. Field, S.T. Turvey and C. Carbone. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology 45: 1228–1236.

PRESENTATIONS AND PUBLICATIONS

There were no publicly available presentations and publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Environmental Research Associates

Principal Investigator: Virgil C. Hawkes

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Virgil Hawkes	LGL Limited	MSc., Senior Wildlife Biologist, Vice-President		
Steven Roias	LGL Limited	BSc., Wildlife Biologist		
Wendell Challenger	LGL Limited	Ph.D. Senior Biologist/ Analyst		
Bryce McKinnon	LGL Limited	BSc., Wildlife Biologist		
Janean Sharkey	LGL Limited	BSc., Wildlife Biologist		
Krysia Tuttle	LGL Limited	M.Sc., Wildlife Biologist		
Joanne Hogg	Canadian Natural	BSc., Lead, Research		
Jordan Smith	Canadian Natural	BSc., Environmental Coordinator		
Shawn Filteau	Canadian Natural	BSc., Environmental Specialist		
Christine Dennis	Canadian Natural	BSc., Environmental Coordinator		

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

Industry Collaborators: ConocoPhillips, Hammerstone, Husky Energy, Suncor Energy Inc., Imperial, Canadian Natural Resources Limited, Devon, Nexen

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 complexity in consideration of the varying life history requirements of each species. Data collected using captured and banded birds is 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 reclamation efforts.

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). The underlying causes of population changes are poorly understood, and vital rate data may provide insight into the underlying causes of these population trends. Measurement of vital rates within reclaimed, fragmented or otherwise disturbed and natural habitats over time, provides an assessment of local scale effects including habitat performance and regional effects resulting from pressures or stress experienced during migration or on the wintering grounds. Low or declining productivity would indicate that effects are occurring on the breeding grounds, while low or declining survivorship would suggest that the effects are caused on the wintering grounds or during migration (Newton 2004). 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 Oil Sands Region Program* (Boreal MAPS Program) has been established to address three objectives:

1) To advance the understanding of avian population dynamics and diversity in reclaimed habitats and in habitats subject to disturbances associated with industrial and human activities, as compared to natural, unaffected areas;
2) To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest; and
3) To provide a platform for other researchers undertaking complementary projects.

In 2011, six MAPS stations were established in the oil sands region and the program was expanded to 24 stations in 2012, to 35 stations in 2013, and to 38 stations by 2015. In 2016, 33 of the 38 MAPS stations were operated; operations at four stations were either truncated or suspended in 2016 due to safety and access constraints imposed

by the Horse River wildfire, commonly referred to as the Fort McMurray wildfire, and one was not operated due to funding constraints.

Stations have been established in an approximate ratio of 1:1 natural (unaffected) stations vs. those in reclaimed or disturbed habitats. Each MAPS station consisted of 8 to 14, 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. 2015). For captures of unbanded birds, a Canadian Wildlife Service-issued, uniquely numbered, aluminium leg band was applied to the leg and data on species, age, sex, breeding characteristics, moult status, and other physical characteristics were recorded, along with biometrics such as wing length and bird 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). Computer entry, data proofing, and verification of banding, mist-net effort, and breeding status data were completed using specially designed data 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 to adult birds captured. 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).

PROGRESS AND ACHIEVEMENTS

In 2016, effort comprised 10,966.33 net-hours of operation, resulting in 3,783 birds being newly banded, 67 being released unbanded, and 1,237 recaptures of previously banded birds, for a total of 5,087 captures. These values are much lower than those recorded in 2015 (with generally comparable effort), when 8,315 captures were recorded. Both adult population size (142.5 adults captured per 600 net-hours) and productivity (0.58 young to adult birds) were lower than these values recorded after the 2015 season, by 17.1% and 31.7%, respectively, and the 2016 values were also much lower than 5-year (2011-2015) mean values, when 171.1 adults were captured per 600 net-hours and productivity was 0.84 young per adult.

Reduced adult population sizes and productivity in 2016 relative to earlier years may reflect the effects of the 2016 Horse River wildfire. It is worth noting that avian vital rates were relatively high in 2011, the year during which the Richardson wildfire affected a large area, but which was north of the majority of our MAPS stations.

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

Across all stations and over all six years, 32,718 bird captures of 90 species have been recorded, of which 24,749 were newly banded, 562 were released unbanded, and 7,407 were recaptures of birds banded earlier in the same season or in previous seasons. Averaged over the first five years of the program (2016 data analyses ongoing), adult population size (all species pooled) at stations with reclaimed and/or disturbed habitats fell within the range of natural variability, as characterized by stations at which more than 70% of the habitat was undisturbed (Figure 1). Productivity (all species pooled) over the same 2011 to 2015 period is shown in Figure 2. As for adult population size, productivity at the majority of stations fell within the range of natural variability as represented by productivity at stations having 70% or more natural habitat.

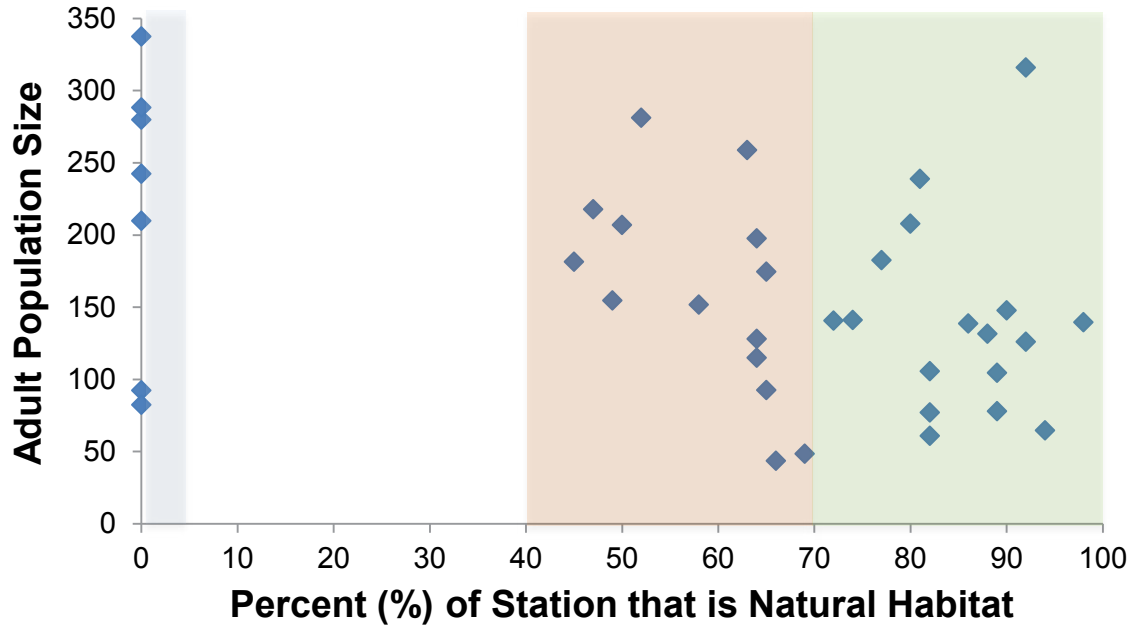

Figure 1: *Index of landbird adult population size (all species pooled) in fully reclaimed (grey), and along a gradient of percent reclaimed, disturbed or fragmented (peach), and relatively undisturbed or natural habitats (>70% of station habitat undisturbed; green).*

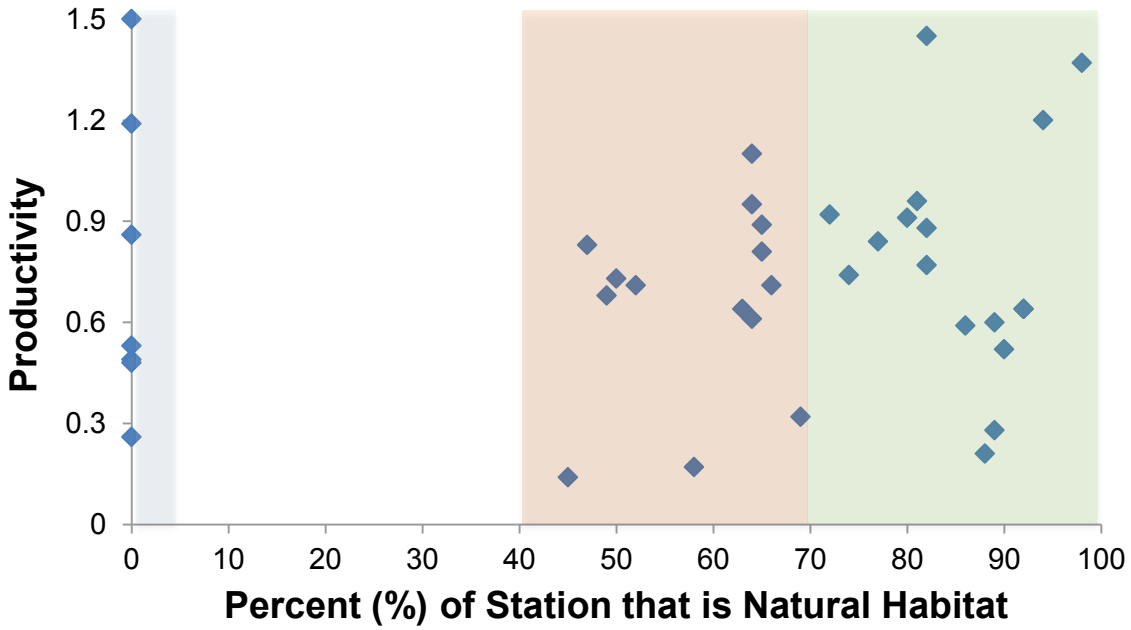

Figure 2: *Index of landbird productivity (all species pooled) in fully reclaimed (grey), and along a gradient of percent reclaimed, disturbed or fragmented (peach), and relatively undisturbed or natural habitats (>70% of station habitat undisturbed; green).*

Habitat assessment data obtained in 2012-2013 were used in the analysis of landbird abundance and productivity indices (obtained over the same period) in habitats affected by reclamation, surface disturbances, and in natural habitats. Principal component analysis explained 83.2% of the variation in 21 habitat-structure variables and we found 39 significant relationships between habitat covariates and both adult population size and productivity among 12 landbird species (Foster et al. 2016). We also found responses to years since reclamation that were as expected, given habitat preferences of our target species.

The number of species (species richness) characterized as breeding in stations encompassing a gradient of habitat disturbances is shown in Figure 3. Stations with a substantial proportion of disturbed habitat are within the range of natural variability as are stations in older reclaimed habitats, while very early reclaimed habitats have yet to reach the lower range of natural variability.

In conclusion, species richness, and adult population sizes and productivity (all species pooled) at stations with up to 70% of 10-year-old or older reclaimed and/or disturbed habitats fall within the range of natural variability (represented by these metrics measured at stations with >70% natural habitat).

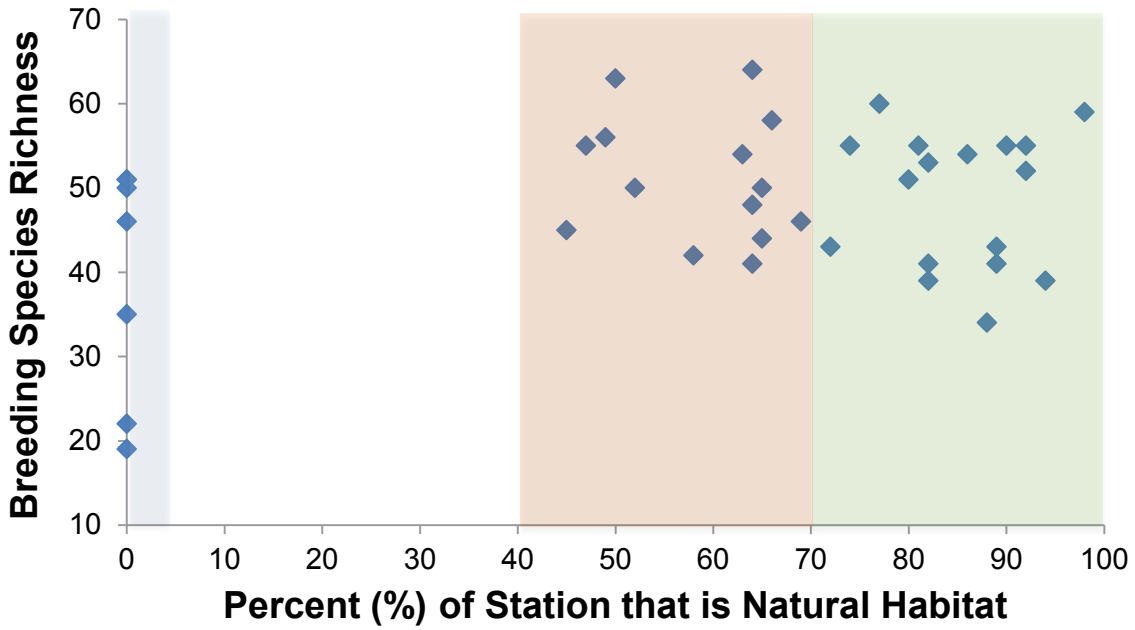

Figure 3: *The species richness (cumulative number of species 2011-2015) of all birds confirmed breeding in fully reclaimed (grey), and along a gradient of percent reclaimed, disturbed or fragmented (peach), and relatively undisturbed or natural habitats (green).*

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

Six-year (2011-2016) trends in population size and productivity were estimated using constant-effort comparisons for 32 species, including 29 species for which enough data are now available to calculate survivorship estimates. For all species pooled, adult population size declined consistently (defined as absolute $r > 0.4$) but non-significantly ($P = 0.143$), by 2.5% per year during 2011 to 2016, and productivity declined consistently and highly significantly ($P < 0.001$), by 12.9% per year during 2011 to 2016. Among the 32 species, adult population size showed consistent declines for 10 species, which were marginally significant ($0.10 < P < 0.05$) for five species, and consistent increases for seven species, which were significant ($P < 0.05$) for two species. Productivity showed consistent declines for 14

species (significant for six species and marginally significant for one species) but consistent increases for only six species (significant for two species). Reasonable values for both productivity and survivorship were obtained for most species, and the precision of the survivorship values were greatly improved with the addition of a sixth year of data in 2016 (coefficient of variance for the estimate decreased from 31.1 to 23.7). Productivity across all species appears to have consistently declined during the period of 2011 to 2016, potentially indicating a region-wide stress on avian populations.

Among the 10 species showing consistent population declines in the region, five appear to have been driven by low adult survivorship during migration or on the winter grounds, whereas four appear to be driven by low productivity on the breeding grounds. One species appeared to have high productivity, while survivorship was also high. In such cases, other factors such as low juvenile survival, emigration, or low recruitment on the breeding grounds may be driving population declines. Among the seven species showing consistent population increases in the Boreal MAPS region, two species appear to be driven by both high productivity and survivorship, two species appear to be driven by high survivorship, and those of two other species appear to be driven by high productivity. The causes for one species are not yet discernable with our data.

Of special interest are results on Canada warbler (Threatened in Canada). Canada warbler adults showed significant correlations with habitat-specific covariates responding to mature forested habitats (Foster et al. 2016). We compared vital rates for Canada warbler derived from data acquired from the Boreal MAPS Program against those derived from broader regional datasets (e.g., Bird Conservation Region 6, MAPS Alaska [AK] and Boreal & Arctic Canada [B&AC] regions) and to those derived from the continental database (DeSante et al. 2016) to provide context for our data and to determine why populations are changing, and whether these changes are being driven by stresses on or beyond the breeding grounds, or both. Our data suggest that Canada warbler populations in the region may be healthy due to high productivity on the breeding grounds, while survival on and away from the breeding grounds may be moderately good.

As of the end of 2016, the Boreal MAPS project included up to six years of data from 38 stations including at least four consecutive years of data from 31 stations, providing a substantial increase in the data acquired in this expansive and important biome. We can now begin to analyze causes for increasing and decreasing population trends for the species in which we were able to estimate productivity, survivorship, and/or productivity trends, by comparing values calculated from the Boreal MAPS Program from 2011 to 2016 with those from the combined MAPS Alaska/B&AC Regions from 1992 to 2016. Overall, the 32,718 captures of 90 species recorded from 2011 to 2016 in the Boreal MAPS Program, represents almost three times the 11,379 captures (of 75 species) recorded over 28 years (1989-2016) from the entire MAPS Region 8 (Boreal and Arctic Canada; B&AC). The oil sands region is also contained within the continentally defined Bird Conservation Region 6, the Boreal Taiga Plains Region, a geographic unit defined by the North American Bird Conservation Initiative (2012) consisting of Canadian Boreal Forests from Yukon and British Columbia to Manitoba. At intervals, MAPS data (including those from the Boreal MAPS Program) are integrated into the BCR6 database. The Boreal MAPS Program data represent a significant contribution to this broader initiative, contributing over 80% of the capture data collected from this region.

3. To provide a platform for other researchers undertaking complementary projects:

Collaborations with other researchers in 2016 focused on preparation of manuscripts for publication describing the analyses of feather samples collected in 2013 and 2014 (Nordell et al. 2016), the data collected by the geolocators attached to the ovenbirds at BCDS and VWET in 2013 that were recovered in 2014 (Haché et al. submitted), and an analysis of wing chord lengths across populations of three species captured at stations in the Boreal MAPS Program and at the Lesser Slave Lake Bird Observatory (French et al. 2016).

OUTCOMES AND LESSONS LEARNED

- Habitat structure is an important driver of avian breeding habitat use, as reflected in species richness and total species (pooled) and species-specific vital rates (adult population size, productivity) (Foster et al. 2016).
- We have found significant relationships between habitat-structure variables and adult population size and productivity for landbird species. We have also found responses to years since reclamation that were as expected given habitat preferences of our target species (Foster et al. 2016).
- Low or declining productivity for some species indicate that effects are occurring on the breeding grounds, while low or declining survivorship for other species suggest that the effects are caused on the wintering grounds or during migration as demonstrated from MAPS data analyses (Albert et al. 2016).
- Among the 10 species showing consistent population declines in the Boreal MAPS region, we are able to discern which species appear to be driven by low productivity on the breeding grounds, and which species appear to have been driven by low adult survivorship during migration or on the winter grounds.
- Least flycatcher, myrtle warbler and clay-colored sparrow wing lengths do not differ among populations of birds captured and measured in the oil sands region, the Lesser Slave Lake area, or as described in Pyle (1997) based on measurements taken across North America (French et al. 2016). Birds with longer migrations have been noted to have longer wings, potentially separating the populations we are measuring from those that are captured elsewhere. At least for these three species, the individuals we are capturing in the oil sands region do not appear to differ from those captured and measured elsewhere, removing a potential confounding factor from consideration.

LITERATURE CITED

Albert SK, DeSante DF, Kaschube DR, Saracco JF (2016) MAPS (Monitoring Avian Productivity and Survivorship) data provide inferences on demographic drivers of population trends for 158 species of North American landbirds. North American Bird Bander 41:133-140

DeSante DF, Burton KM, Velez P, Froehlich D, Kaschube D (2015) MAPS Manual, 2015 Protocol. Point Reyes Station, CA: The Institute for Bird Populations; 49 pp

DeSante DF, Kaschube DR, Saracco JF (2016) Vital Rates of North American Landbirds. The Institute for Bird Populations, Point Reyes Station: www.VitalRatesOfNorthAmericanLandbirds.org

Foster KR, Godwin CM, Pyle P, Saracco J (2016) Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada. Restoration Ecology (Open Access): doi: 10.1111/rec.12478

Lebreton J-D, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67-118

Newton I (2004) Population limitation in migrants. Ibis 146:197-226

Pollock KH, Nichols JD, Brownie C, Hines JE (1990) Statistical inference for capture-recapture experiments. Wildlife Monographs, No. 107

Pyle P (1997) Identification guide to North American birds. Part 1. Slate Creek Press, Bolinas, CA.

Rosenberg KV, Kennedy JA, Dettmers R, Ford RP, Reynolds D, Alexander JD, Beardmore CJ, Blancher PJ, Bogart RE, Butcher GS, Camfield AF, Couturier A, Demarest DW, Easton WE, Giocomo JJ, Keller RH, Mini AE, Panjabi AO, Pashley DN, Rich TD, Ruth JM, Stabins H, Stanton J, Will T (2016) Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 63 pp.

Thompson ID (2006) Monitoring of biodiversity indicators in boreal forests: a need for improved focus. Environmental Monitoring and Assessment 121:263-273

Wells JV (2011) Boreal birds of North America: a hemispheric view of their conservation links and significance. University of California Press, Berkeley, CA

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Foster KR, Godwin CM and Pyle P (2012) Monitoring Avian Productivity and Survivorship in the Oil Sands Region of Northeastern Alberta. In: A.B. Fourie, M. Tibbett (Eds) Mine Closure 2012, Proceedings of the Seventh International Conference on Mine Closure, Brisbane Australia. Australian Centre for Geomechanics, Nedlands Australia. pp 563-571.

Foster KR, Godwin CM, Pyle P, Saracco J (2016) Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada. Restoration Ecology (Open Access): doi: 10.1111/rec.12478.

French RLK, Roberto-Charron A, Foster KR (2016) The accuracy of wing chord ranges in Pyle (1997) as indicators of sex in North-Central Alberta populations of Least Flycatcher, Myrtle Warbler, and Clay-colored Sparrow. North American Bird Bander 41:116-125.

Nordell CJ, Haché S, Bayne EM, Sólymos P, Foster KR, Godwin CM, Krikun R, Pyle P, Hobson KA (2016) Within-site variation in feather stable hydrogen isotope (δ^2Hf) values of boreal songbirds: implications for assignment to molt origin. PLoS ONE 11: e0163957. doi:10.1371/journal.pone.0163957.

Conference Presentations/Posters

Pyle P, Foster KR, Godwin CM, Kaschube DR, Saracco JF (2016) Use of Yearling Probability Estimates (reflecting SY:ASY ratios) from Capture-Station Data to Investigate Landbird Demographic Variables and Habitat Quality. Western Bird Banding Association Conference, Point Reyes Station, California. October 10 & 11 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Owl Moon Environmental Inc.

Principal Investigator: Kenneth R. Foster

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Christine Godwin	Owl Moon Environmental Inc.	Co-Principal Investigator		
Peter Pyle	The Institute for Bird Populations	Staff Biologist		
Ron Taylor	The Institute for Bird Populations	Staff Biologist		
Danielle Kaschube	The Institute for Bird Populations	MAPS Coordinator		
James Saracco	The Institute for Bird Populations	Research Ecologist		
Lauren Helton	The Institute for Bird Populations	Staff Biologist		
Steve Albert	The Institute for Bird Populations	Assistant Director for MAPS and MoSI		

Research Collaborators:

Examinations of the isotopic composition of feathers as related to the continental deuterium gradient
Collaborators: Dr. Erin Bayne, University of Alberta; Dr. Samuel Haché, Canadian Wildlife Service, Yellowknife

The Boreal MAPS program provides feather samples for analyses; these data are integrated with data from samples provided by researchers across Canada.

Bison Research, Mitigation and Monitoring

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck Resources Ltd.

Industry Collaborators: Shell Canada Energy

Status: Year 2 of 5

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 Government of Alberta 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?

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?

1 The Ronald Lake Bison Herd Technical Team is a multi-stakeholder group (i.e., Aboriginal communities, government, and industry) with a mandate to identify and address information needs that will inform regulatory and 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.

Teck and Shell are providing funding for this project and 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

The study began in August 2015 and is expected to run through 2020. Initially, this project was expected to be two years in duration and completed in 2016. However, after the first year, the Ronald Lake Bison Herd Technical Team and the University of Alberta developed a plan for an additional four year-research program. Progress that occurred in 2016 that supports achieving the stated objectives included:

1) What is the spatial distribution of male and female bison on an annual and seasonal basis?

a) What is the spatial distribution of male and female bison on an annual and seasonal basis?

Global Positioning System (GPS) collar data collected in 2013, 2014, and 2015 were compiled to assess potential inter-annual and gender-specific variation in space use. To inform landscape-level planning in the region, predictive seasonal maps of bison habitat selection were generated. Over the two and a half year monitoring period, Ronald Lake bison demonstrated relatively high fidelity to seasonal ranges, particularly by females during the calving season.

b) What are the patterns of habitat selection?

GPS collar data collected in 2013, 2014, and 2015 were compiled to assess potential inter-annual and gender-specific variation in habitat selection. Males and females differed in their patterns of habitat selection. Females showed high selection for meadow marshes across all seasons while males were more variable and season-dependent in their selection of land cover types. These differences may be due to gender-specific differences in forage requirements and/or behavioural segregation of forage resources to minimize inter-gender competition.

c) What is the influence of natural and anthropogenic disturbances on habitat selection?

Recent forest fires (≤ 10 years old) had variable influence on bison selection of land cover types with weak overall trends evident. In general, selection for burnt areas was strongest during the spring, areas with higher severity burns were weakly selected over lower severity burns, and selection of burnt areas was stronger by males than females. The dominant fire disturbance within the Ronald Lake range was the 2011 Richardson Fire; thus, most inferences on bison response to fire are in relation to this specific fire and bison responses immediately post-fire (≤2 years old) are unknown. Because bison responses are likely strongest in the first 1-2 years post-fire, the weak and variable response of bison to burnt areas reported here may be due to variations in successional trajectories within the Richardson Fire.

Bison demonstrated more distinct responses to anthropogenic disturbances (primarily linear features such as roads and seismic lines) than they did to the Richardson Fire. In general, both genders selected for anthropogenic disturbance across all seasons except for females in winter. The positive response of bison to these features may indicate their use as travel corridors, or bison may be selecting these features as feeding patches if the created forest gaps contain potentially higher forage abundances than the surrounding forest. Effects of disturbance age were more pronounced for males as they demonstrated a stronger selection for more recent disturbances (≥ 2006).

Evaluating bison response to human activity was restricted to females during the winter of 2014. Human activity during the winter significantly impacted female responses to disturbance with the odds of a female selecting an active disturbance feature being 29 times lower than the odds of selecting an inactive disturbance feature.

2) What bottom-up (forage & habitat supply) or top-down (predation) factors limit the Ronald Lake wood bison herd?

b) Does insect harassment and ground firmness affect summer forage availability?

Factors influencing bison habitat selection are not well understood; therefore, the effects of forage availability, ground firmness and insect biting activity on bison habitat selection are being examined. Upland pine forest, deciduous forest and marsh / emergent sedge meadow and an esker were sampled for insects, vegetation and ground firmness during June, July and August 2016.

OUTCOMES AND LESSONS LEARNED

This reporting period did not alter the emerging outcomes or lessons learned in the previous reporting period, which were:

- Bison bull collaring was not successful. Bull monitoring periods were short, presumably due to collar failures.
- Home range can be affected by sample size. Continued monitoring will help delineate annual and seasonal home ranges.
- Utilization Distributions provide more conservative estimates of home range than Minimum Convex Polygons.
- Current data indicate that the Ronald Lake bison herd does not use the area east of the Athabasca River.

LITERATURE CITED

Belanger, R, S. L.N. Carbyn, M.A. Edwards and S.E. Nielsen. 2016. Where do the Wood Bison Roam? Habitat Selection of the Ronald Lake Herd. 5th American Bison Society Meeting and Workshop, September 26-29, Banff, Alberta, Canada.

Candler, C., S. Leech, C. Whittaker, and The Firelight Group with Mikisew Cree First Nation. 2015. Sakâw Mostos: Mikisew Cree First Nation Indigenous Knowledge Study. Mikisew Cree First Nation and The Firelight Group Research Cooperative, Victoria, BC. 64 pp.

COSEWIC. 2013. COSEWIC assessment and status report on the Plains Bison (*Bison bison bison*) and the Wood Bison (*Bison bison athabascae*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xv + 109 pp. (GOA 2014).

DeMars, C., S. Nielsen and M. Edwards. 2016. Range Use, Habitat Selection, and the Influence of Natural and Human Disturbance on Wood Bison (*Bison bison athabascae*) in the Ronald Lake Area of Northeastern Alberta. 49 pp + appendices.

Government of Alberta (GOA). 2014. Managing Disease Risk in Northern Alberta Wood Bison – Outside of Wood Buffalo National Park. 2013-2014 Progress report. September 2014. Downloaded 1 October 2015. http://esrd.alberta.ca/fish-wildlife/wildlife-diseases/documents/ManagingBisonDiseaseWoodBuffalo-Sep2014.pdf

Joly, D. O., and F. Messier. 2004. Factors affecting apparent prevalence of tuberculosis and brucellosis in wood bison. Journal of Animal Ecology 73:623-631.

Nielsen, S. 2016. Ecology of wood bison and their response to natural and anthropogenic disturbances in the oil sands region of northeast Alberta. Form 101 Application for Natural Sciences and Engineering Research Council of Canada Collaborative and Development Grant. 46 pp.

PRESENTATIONS AND PUBLICATIONS

Conference Posters

Belanger, R, S. L.N. Carbyn, M.A. Edwards and S.E. Nielsen. 2016. Where do the Wood Bison Roam? Habitat Selection of the Ronald Lake Herd. 5th American Bison Society Meeting and Workshop, September 26-29, Banff, Alberta, Canada.

Reports & Other Publications

A report (citation provided below) was provided to the Ronald Lake Bison Herd Technical Team in April 2016. Because the report delineates important seasonal habitat and the Ronald Lake bison are pressured by hunting, particularly in the winter, a redacted report will be made public, in mid-2017, in the interest of protecting the herd from further hunting.

DeMars, C., S. Nielsen and M. Edwards. 2016. Range Use, Habitat Selection, and the Influence of Natural and Human Disturbance on Wood Bison (*Bison bison athabascae*) in the Ronald Lake Area of Northeastern Alberta. 49 pp + appendices.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Scott Nielsen

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Scott Nielsen	University of Alberta	Alberta Associate Professor		
Mark Edwards	University of Alberta	Adjunct Professor		
Robert Belanger	University of Alberta	M.Sc. candidate	2015	2018

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, Mikisew Cree First Nation

Human & Wildlife Risk Assessment of Oil Sands Reclamation & Closure Landscape Scenarios

COSIA Project Number: LJ0272

Research Provider: Golder Associates Ltd. and Intrinsik Corp.

Industry Champion: Suncor Energy Inc.

Status: Year 1 of 2

PROJECT SUMMARY

Golder Associates Ltd. (Golder) and Intrinsik Corp. (Intrinsik) have been retained by Suncor Energy Inc. (Suncor) to conduct a Human and Ecological Risk Assessment of Suncor's Reclamation and Closure Landscapes planned for operational oil sands sites (hereafter referred to as the Environmental Risk Assessment). The Environmental Risk Assessment and supporting tasks will be conducted for four sites: the Suncor Base Mine; the Fort Hills Oil Sands Mine Project; the Firebag In Situ Oil Sands; and the MacKay River and Dover In Situ Oil Sands. In addition to potential risks to human health, the Environmental Risk Assessment will focus on aquatic and terrestrial wildlife risk receptors (an aquatic health risk assessment was conducted previously for consolidated tailings; Golder 2009). The overall aim of the Environmental Risk Assessment is to provide guidance to Suncor's closure and reclamation planning.

Specific objectives for the Environmental Risk Assessment are provided below:

- Review background documents, including recent closure plans, risk assessments, and data collected as part of previous studies.
- Compile historical environmental data (e.g., soil, water, and tissue chemistry).
- Conduct a gap analysis based on the results of data review and compilation.
- Conduct a field sampling program to address data gaps and supplement existing data.
- Identify key wildlife receptors and determine if they require further assessment.
- Integrate the above information in a problem formulation that sets the scope for the wildlife and human health risk assessment in support of reclamation for various ecosystem and substrate types.
- Conduct a quantitative human and wildlife health risk assessment (including exposure calculations) applicable to the various ecosystem types, considering the ranges of substrates that will need to be placed/managed as part of reclamation over various time periods.
- Summarize the risk assessment findings in a knowledge transfer document (including a risk matrix/registry) to guide engineering/reclamation planning.

PROGRESS AND ACHIEVEMENTS

Data collected to date by Suncor were compiled and reviewed as part of a data gap assessment. Identification of key wildlife receptors was also completed subsequent to the data gap assessment. Based on the data gap assessment, Golder and Intrinsik recommended the collection of additional environmental samples (i.e., sediment, soil, water, and tissue) to support the Environmental Risk Assessment. The September 2016 field program targeted the following five landform-substrate combinations:

- Structural Fill – coke and sand capped consolidated tailings (aquatic and terrestrial samples).

- Structural Fill – consolidated tailings (terrestrial samples). Aquatic samples for this substrate-landform combination have already been collected as part of the previous Golder (2009) risk assessment.
- Structural Fill – regular tailings (aquatic and terrestrial samples).
- End Pit Lake – mature fine tailings (MFT; aquatic and terrestrial samples).
- Non-structural Fill – dried Mature Fine Tailings (dMFT; aquatic samples). Terrestrial vegetation was not observed in the targeted dMFT sampling locations during the 2016 program; therefore, only aquatic samples were collected for this substrate.

Chemistry data for the samples collected as part of the 2016 field program were received at the end of November 2016. Data screening to identify chemicals of potential concern for further evaluation in the Environmental Risk Assessment was completed at the end of December 2016. The data screening was conducted by comparing maximum concentrations of chemicals measured in various media in the environment to applicable environmental quality guidelines. The chemicals of potential concern identified will be included in the Environmental Risk Assessment. It is expected that the overall Environmental Risk Assessment will be completed in late 2018 or early 2019 depending on the timing of the additional field programs; a first draft based on the results of the data collected in 2016 will be available in 2017.

OUTCOMES AND LESSONS LEARNED

Preliminary analyses are being evaluated for incorporation into the Environmental Risk Assessment.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: Golder Associates Ltd. and Intrinsik Corp.

Principal Investigators: Audrey Wagenaar (Golder) and Bart Koppe (Intrinsik)

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Audrey Wagenaar	Golder Associates Ltd.	Associate/Senior Environmental Scientist		
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Lizanne Meloche	Golder Associates Ltd.	Senior Environmental Scientist		
Andrew Graham	Golder Associates Ltd.	Project Manager		
Emily-Jane Costa	Golder Associates Ltd.	Environmental Scientist		
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Christine McFarland	Intrinsik Corp.	Senior Scientist		
Karl Bresee	Intrinsik Corp.	Senior Scientist		

Early Successional Wildlife Dynamics Program

COSIA Project Number: LJ0013

Research Provider: LGL Limited Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Shell Canada Energy, Suncor Energy Oil Sands Limited Partnership

Status: Year 2 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 under-studied.

To address this deficiency, a 5-year program is underway to fulfil various objectives including:
(1) addressing the requirements for reclamation certification;
(2) evaluating wildlife use of reclaimed habitats and areas adjacent to the development;
(3) assessing the return and re-establishment of wildlife on reclamation areas; and
(4) evaluating the effectiveness of practices and principles applied in reclamation areas to improve biodiversity.

Focal taxa representing aquatic, semi-aquatic, terrestrial, and avian species were selected for annual monitoring from reclaimed habitats, mature forest, cleared, burned, and logged juvenile stands on leases operated by Canadian Natural Resources Limited (Canadian Natural), Suncor Energy Inc., Shell Canada Energy and Fort Hills Partnership. Annual sampling is underway to generate a 5-year 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 and to other sites recovering from other human or natural disturbance (logging, clearing, forest fire). The 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 each operating footprint. These data will also be used to ensure that oil sands operators are in compliance with the terms and conditions of their Environmental Protection and Enhancement Act (EPEA) approvals. The design of the program is flexible enough to ensure expandability and adaptability over time. The 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 to adapt to changing goals and objectives.

Wildlife sampling occurs from habitats representing several distinct types of sites: (1) reclaimed upland habitats, (2) burned, logged, and cleared sites regenerating naturally or via planting, (3) compensation lakes, and (4) mature forested stands. A standardized sample unit is used that includes a small mammal trapping grid, songbird point count stations, and winter-active animal transects or modified Finnish triangles depending on the size and shape of the reclamation area. Focal taxa include amphibians (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 ([songbirds, waterfowl, owls, and raptors [diurnal and forest-nesting]), specific species of birds (ruffed grouse [*Bonasa umbellus*],

yellow rail [*Coturnicops noveboracensis*], pileated woodpecker [*Dryocopus melanoleucus*]), small mammals (deer mouse [*Peromyscus maniculatus*], meadow vole [*Microtus pennsylvanicus*], and southern red-backed vole [*Myodes gapperi*]), bats, and winter-active animals. All other wildlife observed on each lease that are not the focus of systematic surveys are recorded as incidental observations. These data can often provide important insights regarding the use of an area by all wildlife species.

Annual sampling will occur in most months with the majority of work occurring during the snow-free period. Survey methods include the use of qualified and proficient biologists to (1) document songbird presence, (2) conduct waterfowl surveys, (3) capture and identify amphibians, (4) live trap small mammals, and (4) assess vegetation species composition, cover, and height at all sample sites, and (5) 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) is produced for each year of the Early Successional Wildlife Dynamics (ESWD)program.

PROGRESS AND ACHIEVEMENTS

This project started in 2015 with a projected completion of Phase 1 in 2020 (a 5 year program). Sampling in 2016 occurred from 34 sites on Canadian Natural's Horizon Oil Sands (n=12 sites), Suncor Energy's Base Lease (n=11 sites), Fort Hills (n=4 sites), and Shell Albian Sands Muskeg River and Jackpine Mines (n=7 sites). The 34 sites were distributed among six main habitat types:

Site Type	Canadian Natural	Suncor (Base)	Shell Albian Sands	Fort Hills	Total
Reclaimed	5	7	1		13
Comp Lake	3		1	1	5
Cleared	–	2	–	1	3
Logged	–	–	3	–	3
Burned	2	–	–	1	3
Mature Forest	2	2	2	1	7
Total	12	11	7	5	34

Site Type defined: Reclaimed sites represent those reclaimed to upland habitats (with the year of reclamation ranging from 1984 to 2015), comp lake sites are habitat adjacent to compensation lakes, cleared represents areas that were cleared (vegetation removed) and left to regenerate on their own, logged are sites that were planted with tree species following clear cut logging, burned sites are sites that were burned to mineral soil in 2011 (part of the Richardson fire), and 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.

The following data were collected from each site in 2016:

- Small mammal live trapping: spring and fall sampling; no spring sampling occurred on the Shell or Suncor Lease;
- 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 and Fort Hills; and

- Winter-active animal surveys occurred in early 2016 on the Canadian Natural Resources lease, Shell Albian Sands, and Suncor Energy Base Lease.

Data collection occurred in all months of the year with most occurring during the snow-free period (May to October). The data collected in 2016 contribute 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 2016 data constitute year 2 of the 5 year phase 1 dataset.

All data collected in 2016 are undergoing QA/QC and integration with previous data (into a relational and fully-documented SQL database). An annual report will be prepared for March 2017.

OUTCOMES AND LESSONS LEARNED

Due to the recent initiation of this project there are no outcomes or lessons learned to document at this time.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: LGL Limited Environmental Research Associates

Principal Investigator: Virgil C. Hawkes

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Virgil Hawkes	LGL Limited	MSc., Senior Wildlife Biologist, Vice-President		
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Charlene Wood	LGL Limited	MSc., Wildlife Biologist		
Naira Johnston	LGL Limited	MSc., Wildlife Biologist		
Michael Miller	LGL Limited	PhD., Vegetation Ecologist		
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Environmental Research and Monitoring

Shell Albian Sands Mine Reclamation Monitoring Using High Resolution Data from Unmanned Aerial Systems

COSIA Project Number: LJ0193

Research Provider: PrecisionHawk Ltd.

Industry Champion: Shell Canada Energy

Status: Year 2 of 3

PROJECT SUMMARY

The overall goal of this project is to investigate the ability of Unmanned Aerial Systems (UAS) to monitor vegetation and reclamation stockpiles at the Shell Albian Sands mine site. In the first year, 2015, PrecisionHawk collected very high-resolution imagery over a reclamation site using the Unmanned Aerial Vehicle (UAV) Lancaster, a 5lb, fixed wing UAE to calculate the position and height of trees, and to use data for measuring stockpile volumes. During 2016, efforts were focused to constrain the positional accuracy of the UAV to a point where yearly monitoring of trees approached accuracies achieved in traditional ground based techniques. The team used a combination of improved technology from 2015, as well as a number of Ground Control Points (GCP's).

The project objectives for 2016 were to:

1) Collect high quality LiDAR scans using dual-frequency differential GPS.
2) Improve on the method to measure the position, canopy cover, and height of trees within reclaimed and natural areas.
3) Generate volumetric stock assessments of three stockpile areas using drone-generated 3D data products within PrecisionHawk's data processing and analytics software.

PROGRESS AND ACHIEVEMENTS

Objective 1: LiDAR surveys were acquired by the PrecisionHawk platform over two locations at the Albian Sands Mine Reclamation Site. These surveys provided 3D information of the sites at a resolution 0.2 m, with elevation information to within ± 0.19 m at one location and ± 0.79 m at the other.

Objective 2: By using an image classification method on the orthomosaics, PrecisionHawk, was able to estimate canopy cover percentage on a 10 m by 10 m grid over the entire study site. This image classification has a reported overall accuracy of 82%. This delivers an areal extent of the canopy of planted trees. Additionally, the LiDAR surveys were used to measure the position and height of the planted trees using a local maxima processing method. Lastly, since the surveys covered naturally forested areas, we were able to directly compare the reclaimed locations' tree measurements to ones made by the same method within the natural area.

Objective 3: Structure from motion technology for UAS surveys has improved considerably which enables stockpile volume assessment within mine reclamation sites. We generated volume estimates using structure from motion derived 3D information, and compared it with previously collected aerial LiDAR surveys to generate a time series of volume estimates at the site. While traditional ground based surveying methods provide a greater precision on a per point basis, the coverage of the drone surveys over the entire stockpile area makes it comparable in accuracy. Additionally, the time spent to get a calculation is less than in traditional survey methods.

OUTCOMES AND LESSONS LEARNED

Research into the efficacy of UAS surveys to improve the monitoring of reclaimed mine sites has shown potential for a more efficient and safe retrieval of relevant monitoring measurements. The technology is advancing rapidly, and as a result the products derived using PrecisionHawk's platform stand to improve significantly in the near future.

Tree stand measurement: Tree positioning from LiDAR point clouds remains an active area of research, with only a single method currently readily available for processing. Additionally, the results of this method are constrained by the added noise inherent in a drone platform for collecting points. LiDAR surveys from drone platforms are in their infancy, and so currently the method developed for tree stand measurement is mostly constrained by the ability of the drone to collect LiDAR over varying topographies. Currently the ability of UAVs to deal with variable topographies increases the difficulty of collection, and limits the possible precision of vegetation measurements that come from the surveys. This limitation, however, will soon be overcome as the technology becomes available.

The use of UAS surveys to monitor vegetation on reclaimed mine sites is dependent on the age of the target species. Though conditions differ site to site, generally the ability of UAS survey methods to differentiate target tree species from surrounding ground vegetation requires the target trees to be taller. The signal of the planted trees must be greater than the noise inherent in the data (~± 0.5 m). In the case of the Shell Albian Sands mine site, a site that was planted 15 years ago produced better results than a site that was plant 5 years ago.

The use of UAS for stockpile volume assessments is an improvement over conventional surveying methods in terms of efficiency and safety. The relative accuracy of these measurements depends on the availability of ground control, as well as the positional accuracy of the UAV platform.

Overall PrecisionHawk found that UAVs have great potential to augment ground-based vegetation monitoring at mine reclamation sites. The trade-off, as is often the case, comes when one must weigh the advantage of greater coverage with the disadvantage of reduced positional accuracy inherent in drone surveys. Therefore, the best strategy for vegetation monitoring at mine reclamation sites is a mixed strategy, where an overview of vegetation conditions is acquired by drones, and a reduced ground effort can fill in the details on a tree by tree basis at a few select sites throughout the area.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were made in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: PrecisionHawk Ltd.

Principal Investigator: Greer Monterastelli

Research Team:

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Greer Monterastelli	PrecisionHawk Ltd.	General Manager – Corporate Accounts & Client Operations		
Scott Hatcher	PrecisionHawk Ltd.	Geospatial Scientist		
Jason San Souci	PrecisionHawk Ltd.	Head of Analytics		

Reclamation GHG Life Cycle Analysis

COSIA Project Number: LJ0271

Research Provider: University of Alberta

Industry Champion: Suncor Energy Inc.

Status: Year 1 of 2

PROJECT SUMMARY

Increased environmental concerns have necessitated the move to more sustainable practices in oil sands reclamation. Ecosystems, including those in the oil sands, contain large amounts of sequestrated carbon. Maintaining carbon storage in the oil sands or returning the land to its similar or equivalent functional capability is an important responsibility for those in energy production sectors. In addition, Alberta's recently announced Climate Change Leadership Plan focuses further attention on greenhouse gas emissions (GHG) from the oil and gas industry.

The goal of this study is to conduct a comprehensive carbon cycle analysis on reclamation-associated activities and to identify opportunities for increasing carbon stock. A Suncor project will be used to conduct a reclamation carbon cycle assessment (LCA) of an oil sands mine.

Key objectives:

- Evaluate carbon balances of energy operations throughout the land use cycle from pre-disturbance to the end of reclamation;
- Develop carbon stock and carbon emission factors applied to boreal forest, wetland, lakes, rivers, and streams ecosystems;
- To scale up a carbon balance model from one small landform to an entire oil sands mine; and
- Provide recommendations to reduce carbon loss from oil sands operations.

This study assessed environmental impacts associated with all the stages of a system from beginning to end use. It followed the four-phase (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation), International Organization for Standardization (ISO) 14040:2006 standard for life cycle assessment.

The following phases were developed for this study:

Phase 1: Determine the goal and scope of the carbon analysis.

Phase 2: Develop the carbon stock and emissions associated with materials and energy.

Phase 3: Focus on a small reclaimed watershed as a case study (Wapisiw Lookout), and, then scale-up to an entire oil sands mine (Suncor 86/17 lease); include both a carbon balance assessment result and an interpretation.

Phase 4: Conduct a detailed interpretation of the results and develop a set of recommendations for future land use and reclamation activities.

PROGRESS AND ACHIEVEMENTS

Wapisiw Lookout was a tailings pond known as Pond 1 and was renamed Wapisiw Lookout after being reclaimed in 2010. It is the first oil sands tailing pond to undergo surface reclamation work. We examined the initial pre-disturbance ecosystem, which included approximately 198 hectares of wetland and 152 hectares of forest, site preparation and associated energy consumption, carbons emissions from tailings during the land forming stage (1966-1995), and carbon return through soil placement and revegetation. With the developed carbon balance model for Wapisiw, we can predict the soil carbon return and the change in biomass carbon for the 90 years after reclamation.

Further, we scaled up the carbon balance model from one landform (a reclaimed tailings pond) to an entire oil sands mine lease, Lease 86/17. The scale-up model includes landform categories that have been used or are in use for reclamation, in some cases since the mid-1960s.

This study looked at forests, wetlands, streams and rivers, and lakes and analyzed carbon flows, carbon stock of materials (i.e., soil, tailings) and carbon emissions from energy consumption through human operations (i.e., site preparation, road construction).

A draft report of the work was completed. Peer review of the draft report was completed. The report will be finalized in 2017 following incorporation of peer review recommendations.

The study was conducted during the year 2015-16. Start date: Aug. 1, 2015. End date: 2017.

OUTCOMES AND LESSONS LEARNED

Outcomes and lessons learned are not currently available for release to the public since incorporation of peer review recommendations is necessary before the model, results and recommendations can be finalized.

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Amit Kumar

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Hao Zhang	University of Alberta	Postdoctoral Fellow	2015	2016
Amit Kumar	University of Alberta	Professor, NSERC/Cenovus/ Alberta Innovates Associate Industrial Research Chair in Energy and Environmental Engineering, Cenovus Energy Endowed Chair in Environmental Engineering		
Christine Daly	Suncor Energy Inc.	Senior Advisor – Land and Reclamation		

Biological Control of Scentless Chamomile

COSIA Project Number: LJ0301

Research Provider: McClay Ecoscience

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 3

PROJECT SUMMARY

Scentless chamomile (*Triplospermum inodorum*) is characterized as a noxious weed within the province of Alberta, and must therefore be controlled. Populations of scentless chamomile exist on the Horizon lease, but until recently, these populations were fairly small and restricted to an area that is not frequently accessed. However, in the past two years, scentless chamomile invasions have increased dramatically in new reclamation areas that were constructed with directly-placed soils from the mine advance. This suggests that these salvaged soils contain a considerable volume of chamomile seed, and that future reclamation areas constructed with soils from this area could be vulnerable to substantial chamomile invasions.

Herbicides have been applied to chamomile populations in non-reclamation areas, however they have been minimally effective. Due to the vulnerability of soil biota and vegetation in early seral stages of reclamation, manual removal is preferred to herbicide application on these areas. However, this option is no longer viable given resource constraints, frequency requirements, and the risk of low-impact injuries it presents. Therefore, controlling scentless chamomile invasions on reclamation areas is increasingly problematic.

A pilot study was established in 2016 to investigate the potential of using specific insects to control populations of scentless chamomile on reclamation areas. Two species of insects that feed exclusively on scentless chamomile – a gall midge (*Rhopalomyia tripleurospermi*) and a seed weevil (*Omphalapion hookeri*) – were sourced from McClay Ecoscience for use in the pilot study. The two insects reduce the reproductive fitness of chamomile by destroying developing seed, or by damaging leaves or flower heads, respectively.

The objectives of the study are to determine: 1) if the biological control agents (insects) are able to colonize chamomile populations and damage plants: and 2) the efficacy of biological control in managing scentless chamomile populations on reclamation areas. The significance of this study is that it will investigate if biological control agents can be used as one effective tool alongside other management options to control scentless chamomile populations on site over the long term.

PROGRESS AND ACHIEVEMENTS

Gall midges (*Rhopalomyia tripleurospermi*) and seed weevils (*Omphalapion hookeri*) were released into scentless chamomile populations at two locations in June 2016: Dedicated Disposal Area 1 (the legacy chamomile population – not a reclamation area), and within an area of the North Toe Berm reclamation area. Monitoring to assess insect damage occurred in August. Monitoring requires brief field surveys to quantify galls formed on young plants to assess gall midge damage, and flower dissection to quantify seed weevils.

Monitoring data has shown that the two biological control agents are able to colonize and damage scentless chamomile plants, fulfilling the first objective. More work will need to be completed to fulfill the second objective. A larger scale release is planned in 2017, and will be informed by a site visit by the contractor to understand logistics and the optimal scale to work with to control reclamation area populations.

OUTCOMES AND LESSONS LEARNED

Both gall midges and seed weevils were shown to infect scentless chamomile plants at both field sites. However, it is not possible to comment on the efficacy of the biocontrol agents with the preliminary data available from one field season. The project is still in its early stages and information is incomplete.

PRESENTATIONS AND PUBLICATIONS

There have been no publications in 2016.

RESEARCH TEAM AND COLLABORATORS

Institution: McClay Ecoscience

Principal Investigators: Alec McClay

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Alec McClay	McClay Ecoscience	Ph.D., P.Biol.		