2018 COSIA LAND EPA

Mine Research Report

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INTRODUCTION

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

Canadian Natural Resources Limited
Cenovus Energy Inc.
ConocoPhillips Canada Resources Corp.
Devon Canada Corporation
Imperial Oil Resources Limited
Nexen Energy ULC
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COSIA publishes two reports, 2018 COSIA Land EPA - Mine Research Report and 2018 COSIA Land EPA - In Situ Research Report. This report summarizes progress for projects related to mine site reclamation of the COSIA Land EPA.

The project summaries included in this report do not include all projects completed under the Land EPA.

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

2018 COSIA Land EPA - Mine Research Report. Calgary, AB: COSIA Land EPA.

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INSTRUMENTED WATERSHED

Aurora Soil Capping Study: Program Overview

COSIA Project Number: LJ0201

Research Provider: University of Alberta, University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

The Aurora Soil Capping Study (ASCS) is a study to address the following issues for oil sands mine operators in the Athabasca Oil Sands Region: 1) the effect of naturally-occurring petroleum hydrocarbons (PHCs) in soil reclamation materials and overburden on environmental receptors (e.g., plants, surface water and groundwater), 2) the appropriate use of coarse-textured reclamation materials to create soil moisture and nutrient conditions similar to the predevelopment upland forest conditions in the area, and 3) the appropriate tree species and revegetation strategy for quick establishment of a forest stand and promote development of the understory community. The ASCS is designed specifically for the purpose of addressing these issues, consisting of several, replicated soil cover design treatments with vegetation subplots. Learnings from this work 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% to 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 boulders. The oil sand materials present in the soil reclamation material have measurable PHC concentrations; however, their total concentration within the entire soil reclamation matrix is significantly lower than the PHC concentration present in LOS.

The ASCS tests a number of soil reclamation cover designs and capping depths on LOS. There are a total of 12 treatments that are replicated in triplicate in one-hectare (ha) cells, resulting in a total study area of approximately 36 ha. Each cell has been vegetated to a mix of trembling aspen, white spruce and jack pine to a standard density of 1,800 stems/ha; a mix of understory species was also included in the planting. Within each cell there are 25 m by 25 m vegetation subplots. These subplots have individual tree species (trembling aspen, white spruce and jack pine) and a mix of the tree species in a standard density of 2,000 stems/ha, as well as a higher density of 10,000 stems/ha. Within the cells and vegetation subplots, an array of instruments has been installed to measure parameters such as soil moisture, temperature, groundwater presence and water quality. Other individual research programs have also installed a number of instruments to conduct their research within the study area. A meteorological station has been installed at the site to capture 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 projects Water and Carbon Isotope Methods Development and Hydrocarbon Degradation and Mobility were completed in 2015 and 2017, respectively.

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., Canadian Natural Resources Limited, Imperial Oil Resources Limited, Total E&P Canada Ltd.

Status: Year 7 of 7

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 containing oil sand materials (aggregated oil sand material [AOSM]) overlying lean oil sand overburden;
2. determine optimal soil cover design options and placement thickness(es) of peat-mineral mix and upland surface soil for soil-moisture, which will result in reclamation soil cover designs equivalent to natural a/b ecosites of the region;
3. evaluate the possibility of separate placement of mineral soil layers (Bm, deeper subsoil lifts) containing AOSM 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 soils containing AOSM over lean oil sand overburden.

PROGRESS AND ACHIEVEMENTS

Below is a summary of the progress and achievements completed in 2018. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for earlier work completed.

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

Eric Neil completed and defended his M.Sc. thesis in 2018 that studied water repellency and hydraulic properties of aggregated oil sand materials (AOSM) collected at the Aurora North Mine. He also published a paper from this thesis in 2018.

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

Ivanna Lee Faucher (M.Sc. candidate) is currently writing her thesis which is studying 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 internally store water within their elastic and inelastic tissues. Knowledge from this study may help in understanding how transplanted jack pine forests on reclamation sites with coarse textured soils utilize limited plant-available water.

LESSONS LEARNED

Water Repellency and Hydraulic Properties of Aggregated Oil Sand Materials

- Water repellency (WR) of AOSM collected at the Aurora North Mine operation is prevalent, but water infiltration into AOSM still occurs within 60 s of contact, albeit at a reduced rate compared to the surrounding soil. This implies that AOSMs in subsoil may slow down soil water flow, but it is unlikely that it will create preferential flow as is the case in many hydrophobic soils.
- AOSMs in soil layers placed directly below the root zone may increase water retention time in the root zone, by decreasing the infiltration rates below the root zone.

See previous COSIA Land EPA Mine Site Reclamation Research Reports for additional summaries of lessons learned over the course of this seven-year study.

LITERATURE CITED

COSIA Land EPA 2017 Mine Site Reclamation Research Report. Calgary, AB: Canadian Natural Resources Limited*; Imperial Oil Resources Limited; Suncor Energy Inc.; Syncrude Canada Ltd.; Teck Resources Limited. Available at: https://www.cosia.ca/sites/default/files/attachments/COSIA%20Annual%20Report%202017_MAR26_FINAL.pdf

PRESENTATIONS AND PUBLICATIONS

Published Theses

Neil, E.J. 2018. Hydraulic properties of aggregated oil sand material from the Athabasca deposit. M.Sc. Thesis. Department of Soil Science, University of Saskatchewan. 117 pp.

Journal Publications

Neil, E.J. and Si, B.C. 2018. Exposure to weathering reduces the water repellency of aggregated oil sand material from subsoils of the Athabasca region. Can. J. Soil Sci. 98:1-13 (2018).

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	2018
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	2017

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, Imperial Oil Resources Limited, Total E&P Canada Ltd.

Status: Year 6 of 6

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 in the natural and reclaimed environment.

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 successfully defended her M.Sc. thesis in 2018, which studied the effects of different soil reclamation materials and placement techniques at the Aurora Soil Capping Study on early tree growth (2012-2014). Her study, a collaborative effort with TransAlta Corp., as part of the NSERC Industrial Research Chair in Forest Land Reclamation (LE0012), also examined the effect of soil fertilization and biochar on soil properties and establishment of tree species.

Shauna Stack (M.Sc. candidate) has continued her study examining the effect of fertilization on tree growth at the Aurora Soil Capping Study. Shauna continued to analyze data from her field program and is currently writing her thesis. Her study is part of the NSERC Industrial Research Chair in Forest Land Reclamation (LE0012) and future results and lessons learned will be reported in that program.

LESSONS LEARNED

Below are some key outcomes from the study work completed in 2018.

- Topsoil material type was the key factor influencing early seedling growth, with seedlings performing better when growing on forest floor material than peat at the Aurora Soil Capping Study. Lower soil temperature appeared to be the main factor restricting seedling growth in the peat, although phosphorus nutrient limitation might have also played a role. It is uncertain if similar results can be expected across the range of peat materials that are used in oil sands reclamation. However, results do suggest that there may be a risk of placing too much (too thick) peat coversoil when there is minimal to no mineral component contained in the peat material. Further studies are required to explore these mechanisms in more detail.
- Subsoil material type and total capping thickness had little effect on early seedling growth, with only faster-growing aspen responding to different subsoil conditions. It appears that the performance of aspen in these subsoils might have been driven by differences in resource availability (nutrients and water). Since aspen had the greatest above-ground growth rates of all tree species of the study, its root system was likely the most extensive and with that was able to explore deeper soil layers. Potential responses of the other tree species can be expected in the future once plants and their associated root systems expand deeper into the soil profile.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Bockstette, J. 2018. The role of soil reconstruction and soil amendments in forest reclamation. MSc Thesis, 95 pages, Department of Renewable Resources, 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	2017
Jana Bockstette	University of Alberta	M.Sc.	2013	2018
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	2018
Shauna Stack	University of Alberta	M.Sc.	2016	Ongoing*
Greg Pec	University of Alberta	Post-Doctoral Fellow	2016	2018
Jake Gaster	University of Alberta	M.Sc.	2012	2015
Shanon Hankin	University of Alberta	M.Sc.	2012	2015
Brittany Hynes	University of Alberta	Summer Assistant		
Emily Reich	University of Alberta	Summer Assistant		
Daniel Doyon	University of Alberta	Summer Assistant		
Fran Leishman	University of Alberta	Field Technician		
Caren Jones	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.

Industry Collaborators: Alberta Innovates

Status: Year 5 of 5

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

Below is a summary of the progress and achievements from the 2018 work conducted under Objectives 2 and 3. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for previous activities.

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

Microbial biomass phospho-lipid fatty analysis (PLFA) was measured for four material types prior to and after addition of either glucose (enriched in 13C, with δ13C=362.1 permil), or nitrogen (N), phosphorus (P), and potassium (K). The soil materials consisted of the two coversoils of the Aurora Soil Capping Study: 1) Forest Floor-Mineral [FFM] which upland surface soil consisting of the LFH, A and potentially a portion of the B horizon, and 2) Peat from bogs or fens [PM], compared to two native forest floor materials from soils in the area. Four replicates were measured prior to incubation, then incubated for five days.

Prior to incubation, total Phospho-lipid fatty analysis (PLFA) biomass varied greatly among the different materials. Native forest floors had higher microbial biomass (means of 1,170 nmol g-1 and 2,710 nmol g-1 for FF1 and FF2, respectively), while for the reclaimed soils, PM and FFM were significantly lower (967 nmol g-1 and 275 nmol g-1, respectively). The fungi to bacteria ratios varied between 0.07 and 0.16 in the four materials, and were significantly lower in the PM material compared to the rest, indicating that proportionally less fungi were present in PM.

Following glucose or NPK addition, all soils respired more carbon, indicating both additions increased carbon mineralization. However, the increase was greater with the glucose addition, particularly for the FFM and PM soils. Glucose made up the majority of mineralized carbon in the case of FFM, but did not induce a priming effect. For PM, however, the proportion of glucose mineralized increased with time showing a positive priming effect throughout the incubation, which means that the addition of glucose triggered an increase in soil organic matter (SOM) mineralization.

Microbial community composition was assessed after glucose addition and all soils were significantly different from their respective controls (p-value <0.05), although the difference was smaller in the case of FF1, and particularly FF2. The FFM microbial community composition tended to be more similar to FF2 once glucose was added, while the PM microbial community remained different from both natural forest floor soils. Microbial composition also showed differences following NPK additions, but differences were much smaller than following glucose addition.

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

A laboratory column study was conducted, constructed from coversoil (PM and FFM) and sand-textured subsoil reclamation materials from the Aurora Soil Capping Study, with and without sand-textured tailings sand and sandy loam-textured lean oil sand overburden substrate. These were compared to two control soil profiles from two native soils in the area. The experiment was conducted in triplicate. Soil physical and chemical properties were characterized for all materials prior to the column experiment. A continuous intense rainfall (50 mm) was applied simultaneously at the top of each column, corresponding to the average maximal rainfall observed each summer in Fort McMurray (AB, Canada), from 2001 to 2015. After five days, the columns were dismantled, and a representative soil sample was taken for analysis from each 10-cm segment (to a total column depth of 120 cm).

The difference between the initial soil water content and the water content five days after the intense rainfall showed how each reclamation material retained water and limited its transport down the profile. The water present in the 0 cm to 20 cm of FMM significantly increased after the rainfall, while it remained the same in PM. Regardless of the coversoil material in the 0 cm to 20 cm layer, an increase in water content was observed in all segments from 20 cm to 100 cm in the columns containing LOS from 50 cm to 120 cm, and from 20 to the bottom of the column in columns containing subsoil or tailings sand from 50 cm to 120 cm. In the columns containing LOS, more water accumulated in the 40 cm to 50 cm layer compared to treatments without LOS.

Ammonium-N (^{15}N-labelled) fertilizer was introduced into the columns and after five days the first 0 cm to 10 cm and 10 cm to 20 cm of FFM and PM were similar and comparable to the initial (pre-fertilizer addition) amount of extractable mineral N in the 10 cm to 20 cm layer. Isotopic analysis of the mineral N in the soil confirmed that most of the ammonium-N had been converted to nitrate-N. However, a significant fraction of the fertilizer-N was not recovered in either form (9% in PM and 25% in FFM), suggesting some N may have been lost from the columns in gaseous form. The remaining amount of extractable mineral N in the 0 cm to 20 cm topsoil horizon after five days was increased by a factor of 2.3 in PM coversoil and five in FFM coversoil with the fertilizer addition. Interestingly, no difference in the mineral N profile below 20 cm was seen at the end of the experiment between the fertilizer treatments and the control treatments. The measurement of the isotopic composition of nitrate-N enabled the calculation of the fraction of nitrate-N derived from the 15N-labelled ammonium at each investigated soil depth. These calculations show that the fertilizer-derived N had not been leached out of the first 20 cm at the end of the leaching experiment.

Using the assumption that the first 50 cm of the soil is the average rooting zone for boreal forest trees, the amount of extractable mineral N present in the 0 cm to 50 cm zone before and after the leaching experiment was measured. Profiles with PM coversoil contained a higher amount of extractable mineral N compared to FFM, prior to and after fertilizer addition. When comparing the underlying reclamation materials, coarse-textured columns (e.g., subsoil or tailings sand) below 50 cm led to the highest loss of mineral N from the profiles having FFM coversoil, relative to the columns containing LOS. However, tailings sand and lean oil sand resulted in an increase in mineral N in the 0 cm to 50 cm at the end of the experiment. When PM was present in the 0 cm to 20 cm, its combination with LOS as the underlying substrate led to the smallest loss of mineral N from the 0 cm to 50 cm zone.

The results suggest that following an intense summer rainfall (50 mm), the input of water is homogeneously distributed over the whole soil profile when sandy substrates are present below 50 cm. Following the intense rainfall, a large part of the initial nitrate-N can be leached out from the first 20 cm of organic capping materials, especially when FFM is used. However, when LOS is used below 50 cm, the movement of mineral N is slowed down and N is accumulated above 60 cm depth.

LESSONS LEARNED

Frédéric Rees is in the process of finalizing two manuscripts, from the results of Objectives 2 and 3. Below are the key outcomes of these manuscripts.

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

- Glucose addition (priming) in PM triggered SOM mineralization which confirms that the organic carbon component in PM is primarily unavailable to the soil microbial community. The observed priming effect resulted in a shift in the overall microbial community structure, although composition still remained distinct from the two forest floor materials sampled from natural soils.
- FFM coversoil did not show any enhanced SOM mineralization linked to glucose addition, similar to the two natural soil forest floor materials. Nonetheless, the overall microbial community structure in the FFM became more similar to that of the natural soil forest floor material following glucose addition.

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

- Depending on the combination of materials used for land reclamation, reclaimed soil profiles may provide equal or higher amounts of available N in the rooting zone compared to natural coarse-textured soils in the oil sands region. The available N will provide an opportunity for revegetation establishment.
- Column tests found the PM as coversoil was able to retain more mineral N within the top 20 cm of a reclaimed soil profile after an intense rainfall compared to FFM, from which a significant part of the mineral N was leached out. The retention of N within the root zone will increase the opportunity for plant uptake, rather than leaching (and loss) from the root zone.
- Compared to the redistribution of water with depth, the flow of N down the soil profiles was slower and more restricted by the presence of textural discontinuities between the sandy subsoil and the overlying material, (e.g., when lean oil sands were used). Soil water retention resulting from textural discontinuities has the potential to retain more soil-water and nutrients within the root zone for plant uptake, rather than leaching (and loss) from the root zone.

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	Post-Doctoral Fellow	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	2017
Shelby Buckley	University of Alberta	B.Sc.	2017	2018
Justine Lejoly	University of Alberta	Technician		

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 6 of 6

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 are being investigated at the Aurora Soil Capping Study (ASCS) 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 containing naturally occurring hydrocarbon 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 subsoil 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., tree harvesting). This study will seek to 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

Sebastian Dietrich studied soil spatial heterogeneity and soil quality of coversoil material at the Aurora Soil Capping Study as part of Studies 3 and 4. He successfully completed his PhD thesis and published two papers from his thesis in 2018.

LESSONS LEARNED

The following are key outcomes of the activities completed in 2018. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for other project outcomes.

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

Soil respiration in the first two years after soil placement at the ASCS found seasonal patterns similar to natural reference sites on the forest floor material (FFM) coversoil treatments, suggesting that some belowground function remains after soil reclamation salvage and placement activities. However, soil respiration of entirely Peat treatments at the ASCS did not have a similar seasonal pattern like those of natural reference sites. Soil microbial biomass and heterogeneity increased with time since disturbance, potentially indicating stages of site recovery for coarse-textured sites (e.g., a/b ecosites).

Study 4 – Effect of mixing peat and subsoil on nutrient and microbial dynamics

Soil nutrient status of Peat from the ASCS differs from upland reference type a/b ecosite surface soil; FFM coversoil retains some of its nutrient and microbial characteristics and is more like type a/b ecosite surface soil. The primary significant differences observed were in phosphorus (P) availability, which was extremely low on this peat coversoil material. It's uncertain if the ASCS peat coversoil material is consistent or unique with the range of peat coversoil materials used in reclamation. Therefore, early revegetation may be more successful with FFM than Peat coversoil at the ASCS.

Greenhouse trials using soil reclamation materials at the ASCS found seedling growth improved with admixing subsoil. This improvement is believed to be due to the mineral admixing resulting in a more similar biogeochemical characteristics (e.g., nutrient availability) and increased soil C mineralization. Some further increases in tree growth were measured with biochar addition, likely related to an increase soil nutrient availability (e.g., potassium and phosphorus), which are low with the peat at the ASCS, and increased soil C mineralization. Peat coversoil can be improved with admixing of subsoil, or amendments such as biochar or fertilizer.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Dietrich, S.T. 2018. Characterization of Soil Spatial Heterogeneity and Improvement of Capping Materials for Oil Sands Mine Reclamation. PhD Thesis. Department of Renewable Resources, University of Alberta. 195 pp.

Journal Publications

Dietrich, S.T. and M.D. MacKenzie. 2018. Biochar affects aspen seedling growth and reclaimed soil properties in the Athabasca oil sands region. Can. J. Soil Sci. 98:519-530.

Dietrich, S.T. and M.D. MacKenzie. 2018. Comparing Spatial Heterogeneity of Bioavailable Nutrients and Soil Respiration in Boreal Sites Recovering From Natural and Anthropogenic Disturbance. Frontiers in Environmental Science. Volume 6, Article 126.

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		
Nicole Filipow	University of Alberta	Field Technician		
Arezoo Amini	University of Alberta	Lab Technician		
Maksat Igdyrov	University of Alberta	Field Technician		
Mark Howell	University of Alberta	M.Sc.	2012	2015
Sebastian Dietrich	University of Alberta	PhD	2014	2018
Nduka Ikpo	University of Alberta	Lab manager		
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		
Sylyanne Foo	University of Alberta	Lab Technician		
Patrick Neuberger	University of Alberta	Lab Technician		
Jhon Enterina	University of Alberta	Lab manager		
Jeff Battigelli	University of Alberta	Research Associate		

Research Collaborators: Brad Pinno, University of Alberta; Brian Lanoil, University of Alberta; Sylvie Quideau, University of Alberta

Evaluating the Success of Fen Creation (Phase II)

COSIA Project Number: LJ0098

Research Provider: University of Waterloo

Industry Champion: Suncor Energy Inc.

Industry Collaborators: Imperial Oil Resources Limited, Teck Resources Limited

Status: Year 1 of 5 years

PROJECT SUMMARY

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

Phase II has three objectives:

1. **Ongoing assessment of ecosystems functions:** Under a range of climatic conditions, judge the NFW performance relative to natural reference ecosystems, and provide a database to demonstrate its suitability for reclamation certification.
2. **Assess how changes to soil and vegetation form and function affect system trajectory:** To project the trajectory of NFW it is important to understand how placed materials have evolved over the first five to 10 years (per above objective), and how they have developed over longer time-frames (10-30 years) at other reclaimed sites. The rates and processes observed over time are needed to parameterize the numerical modelling of hydrology and solute transport, the output of which is needed to apply conceptual models of biogeochemical and ecological functions including carbon dynamics and plant community development.
3. **Use numerical and conceptual models to evaluate alternative design applicability to closure landscape scales:** Numerical models of NFW hydrology and solute transport validated using field data will be used to understand how design modifications to the closure landscape can improve system function and performance. Design optimization will involve consideration of improvements to contaminant management and water use by different landscape elements.

PROGRESS AND ACHIEVEMENTS

Objective 1: Assessment of Nikanotee Fen ecosystem functions

Annual piezometer and well monitoring measurements in 2018 revealed no significant change in saturated hydraulic conductivity compared to previous years' values. Despite a lack of statistically significant difference, the NFW peat illustrates a generally decreasing saturated hydraulic conductivity with depth, which is typical of natural peatlands and of the reference fens studied in the region.

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

Within the NFW Upland, in the first five years post-construction, weathering processes have increased the hydraulic conductivity by over an order of magnitude and are progressively decreasing the hydraulic conductivity of deeper soils within the upland every year.

Total annual net ecosystem productivity (gross ecosystem productivity minus respiration) of the Nikanotee Fen in 2018 was in line with the previous three years (2015-2017). The fen was planted in 2013. Vegetation and carbon data for 2013 and 2014 show that the system has increasing vegetation growth as well as carbon accumulation rates each year (after initially being a carbon source), until 2015 when the system reached a relative equilibrium. Water-use efficiency (WUE) for the fen portion of the NFW follows the same trend as net ecosystem productivity, gross ecosystem productivity, and respiration.

Carbon dynamics of the upland are slowly trending towards a carbon sink as upland vegetation continues to develop and gross ecosystem productivity rates continue to "decrease or increase". However, the estimated timeline for the upland to transition to a carbon sink is unknown. Increased carbon accumulation and water-use efficiency in the upland suggests that the vegetation is still developing and has not yet reached equilibrium, which is to be expected until a mature upland forest has been established.

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

Modelling efforts in 2018 have shown that recharge basins that are not adjacent to hillslopes and do not receive surface runoff are still highly effective recharge features on the landscape, particularly in the late post-construction period. In contrast, slope-adjacent basins are critical to the initial 'wetting up' of the aquifer and experience a rapid decrease in efficacy. Isolated basins away from slopes will remain focused recharge features indefinitely due to the lack of sediment infill from adjacent slopes that can inhibit soil structure and spontaneous plant establishment.

LESSONS LEARNED

- LFH site comparisons show that one of the most hydrologically significant hydraulic properties, infiltration, plateaus seven to eight years after reclamation, in line with values seen in reclamation literature at other locations across the North American continent.

- 3D modelling efforts using multi-decadal time-series datasets demonstrated that isolated basins will be important features for promoting recharge in uplands over long time-scales as the upland becomes more vegetated and the slope-adjacent basins fill with sediment and receive decreasing quantities of surface runoff.
- Due to the role of uplands as both water storage and water conveyance features, coversoils should be applied thicker in areas designated to support forests and should be stripped entirely from areas designated as recharge features. This minimizes water stress to plants and maximizes potential groundwater recharge in these areas respectively.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Elmes, M.C., 2018. Hydrology of a moderate-rich fen watershed prior to, and following wildfire in the Western Boreal Plain, Northern Alberta, Canada, Ph.D. Thesis, University of Waterloo, Waterloo, Canada, 131 pp.

Osman, F., 2018. Sulfur biogeochemistry in a constructed fen peatland in the Athabasca Oil Sands Region, Alberta, Canada, M.Sc. Thesis, University of Waterloo, Waterloo, Canada, 121 pp.

Volik, O., 2018. Environmental controls on carbon sequestration in a saline, boreal, peat-forming wetland in the Athabasca Oil Sands Region, Ph.D. Thesis, University of Waterloo, Waterloo, Canada, 146 pp.

Journal Publications

Borkenhagen, A., Cooper, D.J. 2018. Tolerance of fen mosses to submergence, and the influence on moss community composition and ecosystem resilience. *Journal of Vegetation Science*, 29(2), 127-135

Daté, V., Nwaishi, F.C., Price, J.S., and Andersen, R. 2018. Short-term exposure to Oil Sand Process-Affected Water does not reduce microbial potential activity in three contrasting peatland types. *Wetlands*, 1-10

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Gingras-Hill, T., Nwaishi, F.C., Macrae, M.L., Price, J.S., Petrone, R.M. 2018. Ecohydrological functioning of an upland undergoing reclamation on post-mining landscape of the Athabasca oil sands region, Canada. *Ecohydrology*, 11:e1941

Kessel, E.D., Ketcheson, S.J., Price, J.S. 2018. The distribution and migration of sodium from a reclaimed upland to a constructed fen peatland in a post-mined oil sands landscape. *Science of the Total Environment*, *630*, 1553-1564.

Simhayov, R.B., Weber, T.K.D., Price, J.S. 2018. Saturated and unsaturated salt transport in peat from a constructed fen. *Soil*, 4(1), 63-81

Volik, O., Petrone, R.M., Hall, R.I., Macrae, M.L., Wells, C.M., Price, J.S. 2018. Organic matter accumulation and salinity change in open water areas within a saline boreal fen in the Athabasca Oil Sands Region, Canada. *Catena*, 165, 425-433.

Conference Presentations/Posters

Coulas, M. and Strack, M. 2018. The 'Priming Effect' of Carex aquatilis and Juncus balticus during fen reclamation. Poster. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Coulas, M., Sarawati, S. and Strack, M. 2018. Soil organic matter decomposition: Tea and litter bag analysis, and the inhibitory effects of phenolic compounds. Oral Presentation. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Davidson, S.J., Rogers, H., Zang, J., Van Beest, C., Petrone, R.M. and Strack, M. 2018. Impact of wildfire on methane emissions and dissolved organic carbon at a boreal fen, Alberta, Canada. Poster *in* The resilience and vulnerability of Arctic and Boreal ecosystems to climate change VI: Biogeosciences Section - *American Geophysical Union (AGU) Fall Meeting. December 10-14, Washington D.C., United States of America.*

Elmes, M.C. and Price, J.S. 2018. Hydrologic function of a moderate-rich fen watershed in the Athabasca Oil Sands Region of the Western Boreal Plain, northern Alberta. Poster. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Elmes, M.C., Thompson, D.K. and Price, J.S. 2018. Changes to the hydrophysical properties of upland soils in the Athabasca Oil Sands Region following wildfire. Oral presentation. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Popovic, N. and Petrone, R.M. 2018. the role of vascular vegetation on carbon and water dynamics in a constructed peatland. Poster. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Popović, N., Green, A., Kessel, E.D. and Petrone, R.M. 2018. Carbon and water dynamics during the early development of a reclaimed, post- oilsands landscape in northern Alberta, Canada. Poster *in* Biogeochemical and functional consequences of vegetation changes in the Anthropocene I: Biogeosciences Section - *American Geophysical Union (AGU) Fall Meeting. December 10-14, Washington D.C., United States of America.*

Van Beest, C.E.S, Petrone, R., Nwaishi, F. and Waddington, J.M. 2018. Nutrient cycling in a fen peatland one-year post-wildfire. Poster. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Van Huizen, B.S. and Petrone, R.M. 2018. Conceptualizing the role of seasonal ground ice in a Western Boreal Plains peatland. Oral presentation. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Van Huizen, B.S., Petrone, R.M. and Pomeroy, J.W. 2018. Modelling seasonal ground ice and evapotranspiration in a Western Boreal Plains peatland using the Cold Regions Hydrological Model (CRHM). Poster. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

Volik, O., Petrone, R., Quanz, M., Macrae, M., Rooney, R. and Price, J. 2018. Environmental controls on CO2 exchange along a salinity gradient in a saline boreal fen in the Athabasca Oil Sands Region. Oral presentation. *Joint meeting of Canadian Geophysical Union (CGU); Canadian Soil Science Society (CSSS); Computational Infrastructure in Geodynamics (CIG); Eastern Section of Seismological Society of America (ES-SSA) and Canadian Society for Agricultural and Forest Meteorology (CSAFM). June 10-14, Niagara Falls, Ontario, Canada.*

RESEARCH TEAM AND COLLABORATORS

Institution: University of Waterloo; Colorado State University

Principal Investigator: Dr. Jonathan Price

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Richard Petrone	University of Waterloo	Co-Investigator		
Dr. Maria Strack	University of Waterloo	Co-Investigator		
Dr. David Cooper	Colorado State University	Co-Investigator		
Scott Davidson	University of Waterloo	Post-Doctoral Fellow		
John Hribljan	Colorado State University	Post-Doctoral Fellow		
Matthew Elmes	University of Waterloo	Ph.D.	2014	Completed 2018
Natasa Popovic	University of Waterloo	Ph.D.	2017	2021
Owen Sutton	University of Waterloo	Ph.D.	2015	2020
Brandon Van Huizen	University of Waterloo	Ph.D.	2015	2020
Christine Van Beest	University of Waterloo	M.Sc.	2016	2018
Hilary Irving	University of Waterloo	M.Sc.	2017	2019
Sarah Fettah	University of Waterloo	M.Sc.	2018	2020
Tyler Prentice	University of Waterloo	M.Sc.	2017	2019
Gabriel Dube	University of Waterloo	M.Sc.	2018	2020
Suyuan Yang	University of Waterloo	M.Sc.	2018	2020
Rebecca Cameron	University of Waterloo	M.Sc.	2018	2020

Emily Prystupa	University of Waterloo	M.Sc.	2018	2020
Karisa Tyler	University of Waterloo	M.Sc.	2018	2020
Lewis Messner	Colorado State University	M.Sc.	2015	2019
Adam Green	University of Waterloo	Technician		
Eric Kessel	University of Waterloo	Data Manager		
James Sherwood	University of Waterloo	Project Manager		

Research Collaborators: Colorado State University

Sandhill Fen Research Watershed Program Overview

COSIA Project Number: LJ0204

Research Provider: Multi researchers and institutions

Industry Champion: Syncrude Canada Ltd.

Status: Multi-year project

PROJECT SUMMARY

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

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

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

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

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

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

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

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

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

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

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

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

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

RESEARCH TEAM AND COLLABORATORS

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

- The Early Development of Sandhill Fen: Plant Establishment, Community Stabilization, and Ecosystem Development (completed in 2016)
- Influence of Peat Depth, Hydrology and Planting Material on Reclamation Success Within a Created Fen-like Setting (completed in 2016)
- Early Community Development of Invertebrates in Sandhill and Reference Fens - Local Effects of Vegetation, Substrate, and Water Quality (completed in 2016)
- Sandhill Fen Geospatial Metadata System (completed in 2016)
- Assessing the Sodium Buffering Capacity of Reclamation Materials in Sandhill Fen (completed in 2016)

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

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 7 of 7

PROJECT SUMMARY

Sandhill Fen Research Watershed (SFRW) is designed to assess the ability to re-establish fen wetlands. As part of a program to measure the water and carbon balance of SFRW, McMaster University and Carleton University researchers have undertaken detailed measurements of ecosystem water and carbon fluxes since 2013. This includes documenting the rate, timing and pathways of water and carbon movement in the SFRW ecosystem while also collecting comprehensive data on water quality and biogeochemical cycling.

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 five year period (2012–2017) 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 (2012–2018);
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 (2012–2018);
4. Monitor changes in DOC and POC quantity and quality across a range of hydrological conditions (2012–2018);
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;
6. Assess Mercury output from the fen and compare it to reference fens in the area;
7. Assess soil nutrients using plant root simulator 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; and
8. Use stable isotopes and hydrochemistry to better understand the linkage between runoff flow pathways and sources of water.

PROGRESS AND ACHIEVEMENTS

Considerable progress has been made towards the objective of measuring and understanding the water and carbon balance of the Sandhill Fen Research Watershed. Continuous year-over-year measurements have been taken 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, and also in response to annual climate variability.

Water fluxes are being quantified for each year using; three meteorological stations, two to three eddy covariance systems, approximately 25 near-surface water wells, and snow surveys. In the early years of the project, active pumping occurred both in and out of the watershed, this caused challenges in understanding the water balance. However, since 2014, the pumping has been limited to outflows.

Water Balance

Snowmelt period

Snow water equivalence (SWE) is measured at three sites at the SFRW and supplemented by annual snow surveys.

In 2018, additional extensive winter research was conducted to understand the impact of cold season processes on the SFRW hydrology. Several hundred points were monitored multiple times over the melt season and two runoff collectors were installed to assess whether overland flow occurred on the hummocks (Figure 1).

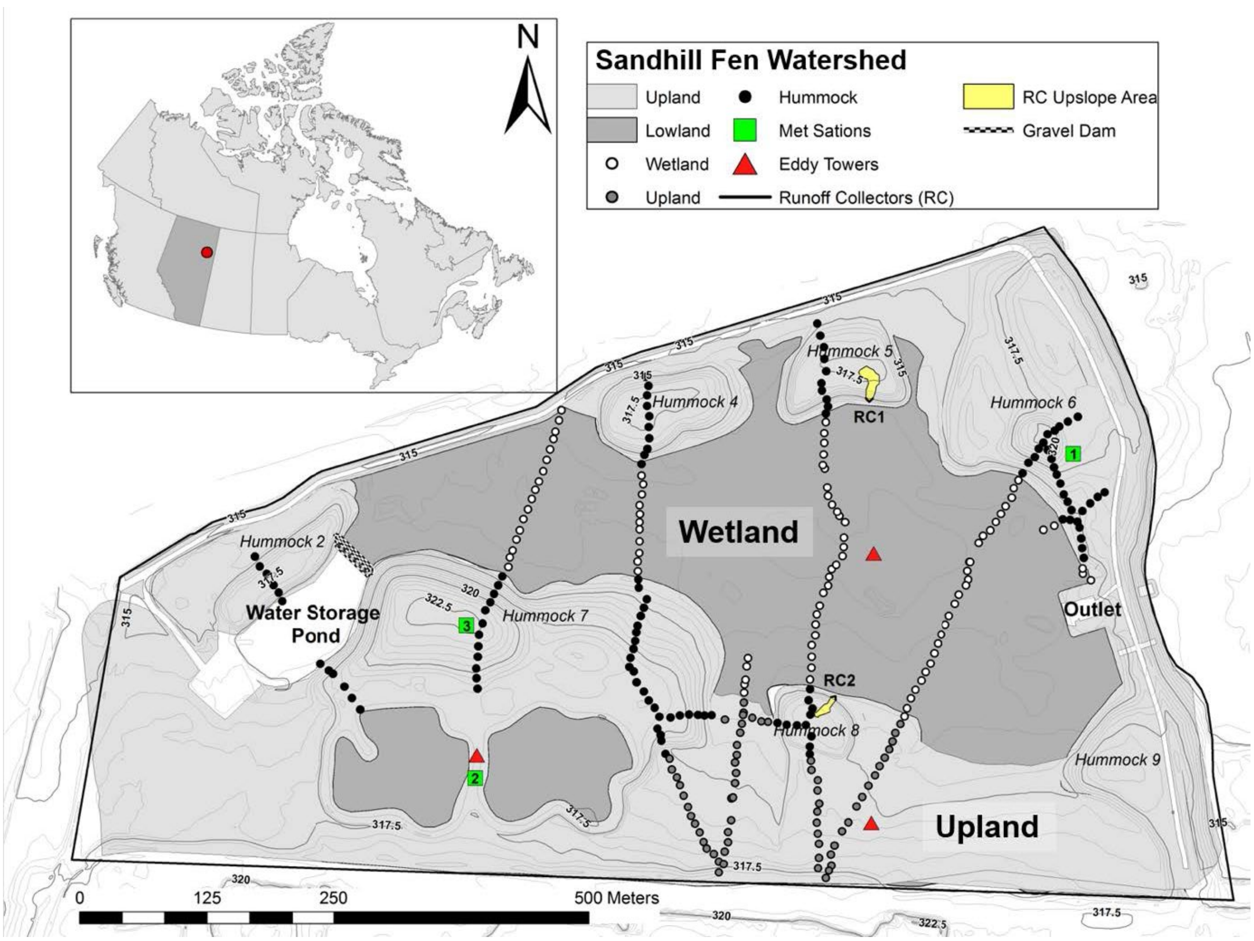

Figure 1. Map of SFRW with location of snow survey transects, runoff collectors and other instrumentation. Circles represent snow survey locations.

Winter 2018 had the greatest snowfall since 2013 (Figure 2) with snowfall approximating the long-term Fort McMurray climate average of approximately 105 mm (data not shown). Snow variability was measured across the fen. Wetlands received on average greater snow than uplands and hummocks, although the differences were small (Figure 3a).

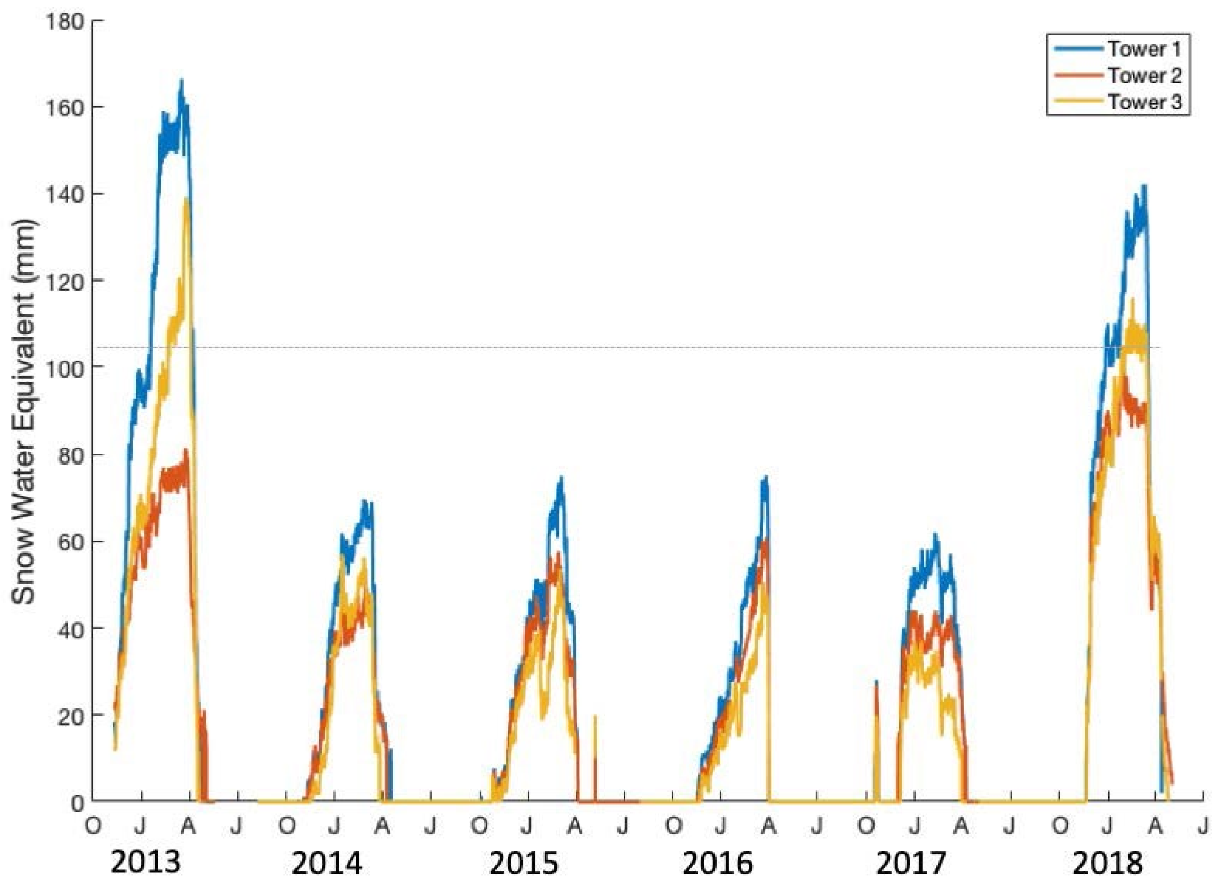

Figure 2. Snow water equivalent at the three Sandhill Watershed meteorological stations.

The role of slope position and aspect was further evaluated. East slopes were found to have slightly greater accumulation of snow and west facing slopes the least (Figure 3b). Furthermore, there was less accumulation at the crest of hillslopes than at their base (Figure 3b).

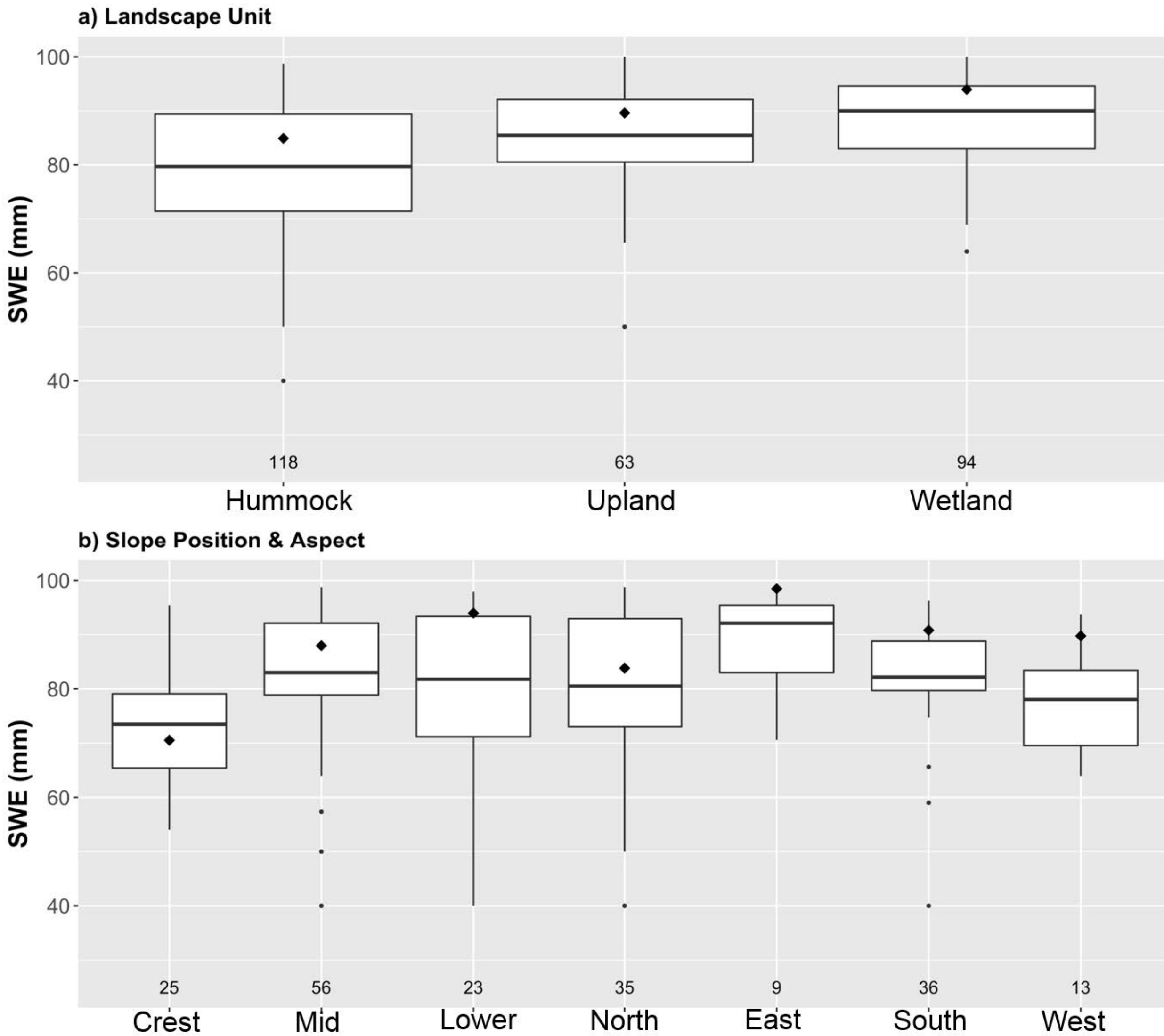

Figure 3a,b. Maximum measured snow water equivalent (SWE) in February 2018 as represented by (a) landscape position and (b) slope position and aspect.

In terms of melt rate, the south and west slopes began their main melt period several weeks in advance of the north and east slopes. Yet the slopes all became snow free in approximately mid-May, with rapid melt observed at the north-facing slope (Figure 4).

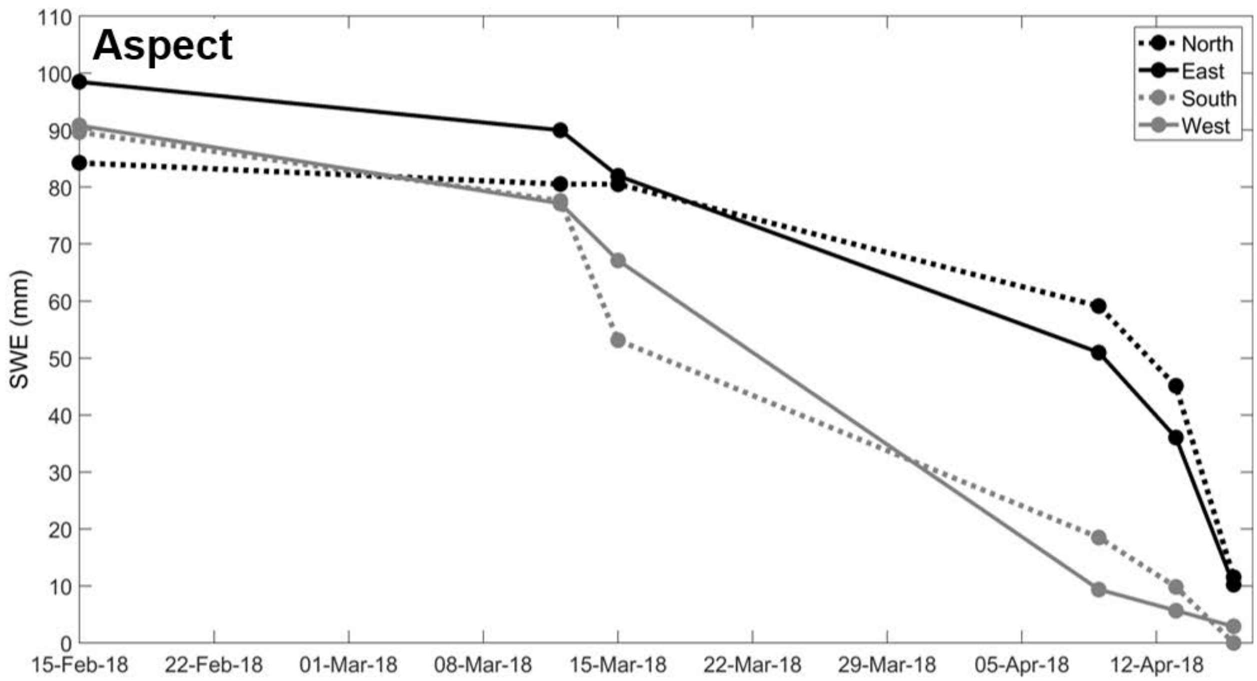

Figure 4. Snow Water Equivalent (SWE) progression with time as represented by aspect.

Direct overland runoff was observed on both north and south facing slopes in 2018. South facing slopes had runoff beginning approximately four weeks before runoff on the north slopes (Figure 5). Runoff was 18 mm (30% of the snowpack) at the south slope, and it was 23 mm (40% of the snowpack) for the north facing slope.

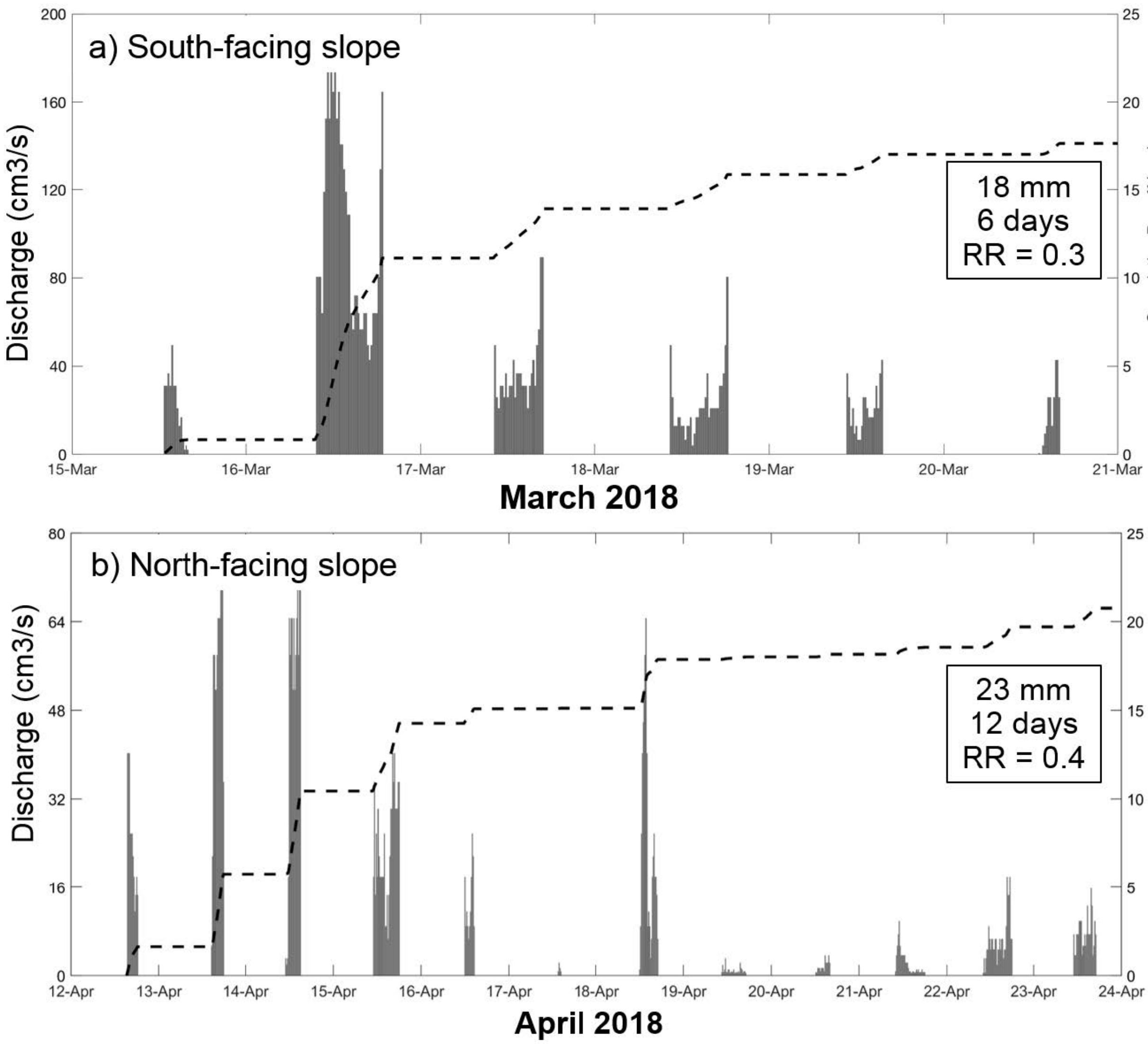

Figure 5. Runoff as measured on the south and north facing runoff collectors. The grey bars represent tips and flowin cm^3/s and the right axes and dashed line is the total runoff during snowmelt.

Growing Season

Rainfall is measured at four sites at SFRW, and is not highly variable among gauges. 2018 was very wet during June and July, and rainfall in 2018 was approximately 100 mm greater than the annual average of ~ 300 mm. It is notable that in one 24-hour period in July ~ 100 mm of rain fell. A large rain year resulted in high water tables, which are reported below.

Pumping data for 2018 is not yet available. However, it is known that on at least two occasions in July, pumps removed considerable volumes of water from the lowland, resulting in a 30 cm drop in the water table over a week, demonstrating their efficiency. Note that the water table is virtually always above the surface. At present, there remains no formal policy for managing water levels in the SFRW.

Evapotranspiration (ET) was measured for the lowland, upland and perched areas, using the eddy covariance technique, and continues for the lowland and upland areas. Evapotranspiration varied among years, responding most strongly to climate forcing (Figure 6). The variability was greater in the lowland than the upland among the years. Notably, 2018 had very low ET rates in the lowland compared with the upland. Lower ET rates in the lowland exacerbates the issue of the high water table.

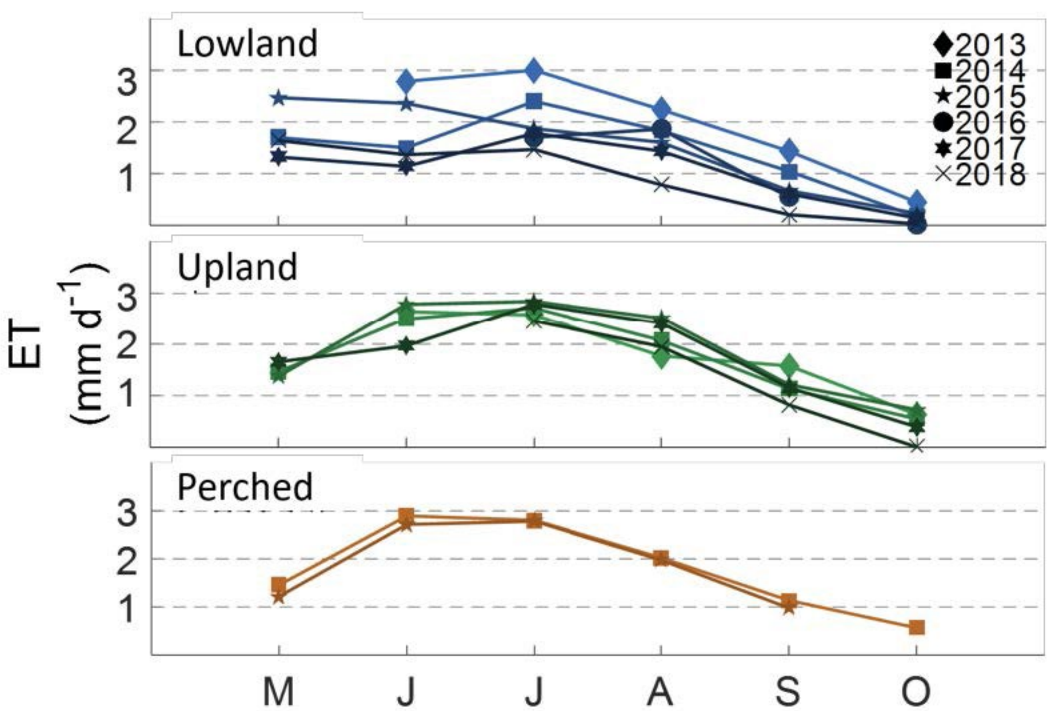

Figure 6. Monthly average evapotranspiration in mm/d for the eddy covariance towers (2013-2017).

Carbon Balance

Carbon Dioxide

Vertical carbon dioxide (CO_2) balances were computed for the fen and terrestrial eddy covariance towers over multiple growing seasons (Figure 7) and annual totals for the lowland tower (Figure 8).

During summer, the fen is a seasonal carbon sink since gross ecosystem production (GEP, i.e., photosynthesis) is greater than ecosystem respiration (ER). There are notable patterns that have occurred at both the lowland and the upland since measurements and reclamation began.

For the lowland growing season, carbon accumulation occurred quickly following vegetation establishment and growth (2014). Net ecosystem exchange (NEE), which is the difference between GEP and ER, increased rapidly in 2015 and 2016, yet measurements in 2017 and 2018 suggest rates are declining. While there is no single reason for this decline, both 2017 and 2018 had very wet conditions, which reduce productivity in the lowland. We are unsure what role the increase in salinity is having, although salinity concentration values are not that high in the lowland compared to OSPW or natural saline fens.

In contrast, NEE at the upland site continues to increase as vegetation establishes. There were instrument problems through June at the uplands site. However, once the system was repaired, high rates of NEE were recorded indicating vigorous growth and carbon accrual. Carbon fluxes at the perched fen are no longer monitored.

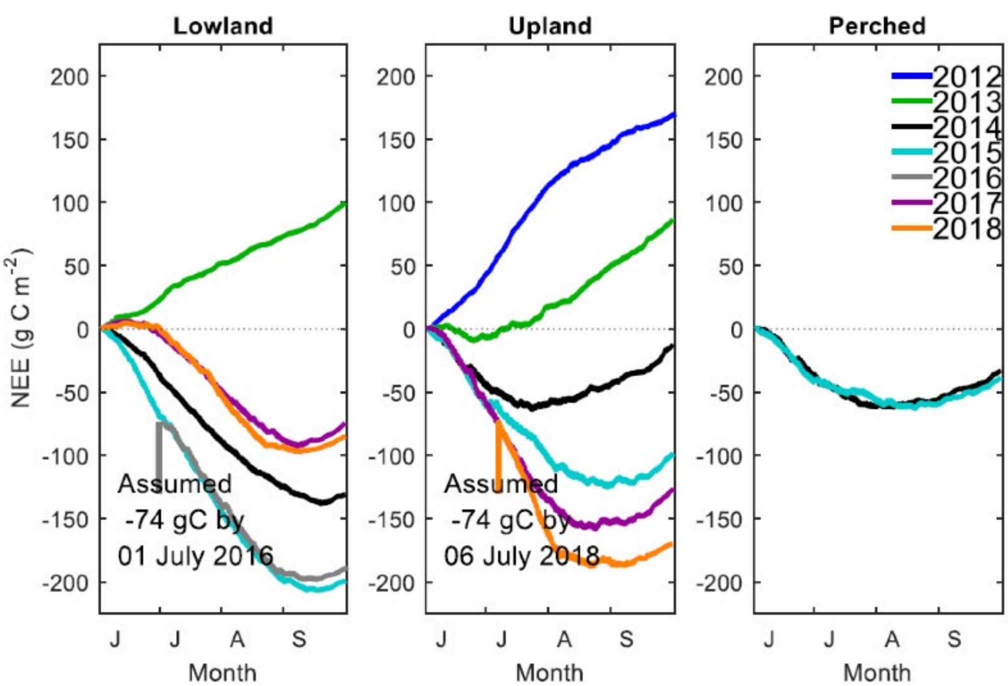

Figure 7. Growing season net ecosystem exchange (NEE). Negative values indicate uptake of carbon

On an annual basis, we only report Carbon balances for the lowland (Figure 8, 9).

Note that there is considerable inter-annual variability in photosynthesis compared to respiration, which reflect the growing season conditions and the health/uptake of the plant community. While there is some uncertainty in the measurements, the fen area quickly became an annual carbon sink by year three and four (estimated). In the last two years, gross ecosystem productivity has declined, and the fen has become a carbon source as respiration exceeds production. We presume this is due to the wet conditions at the site.

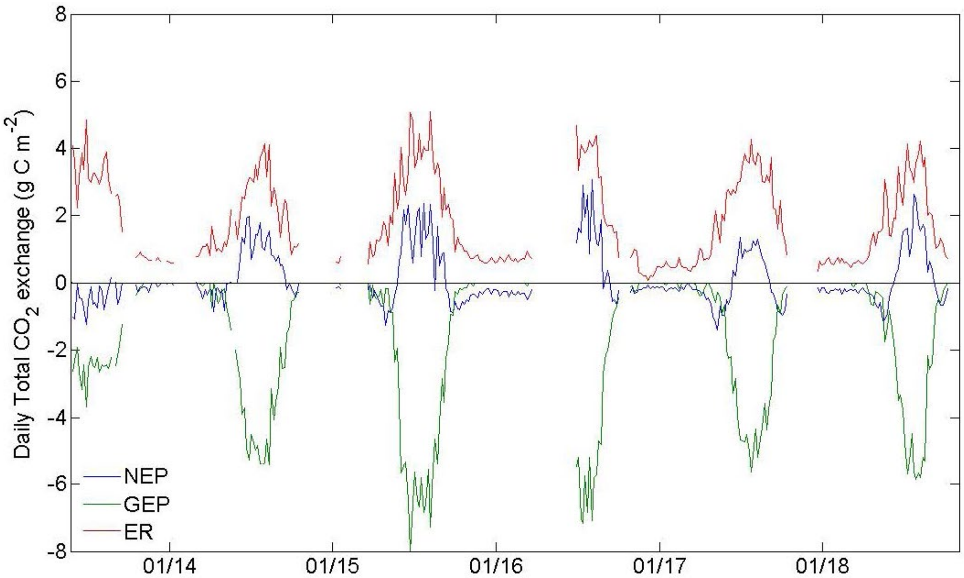

Figure 8. Ecosystem Exchange (NEE) of CO_2 along with Gross Ecosystem Exchange (photosynthesis) and Ecosystem Respiration.

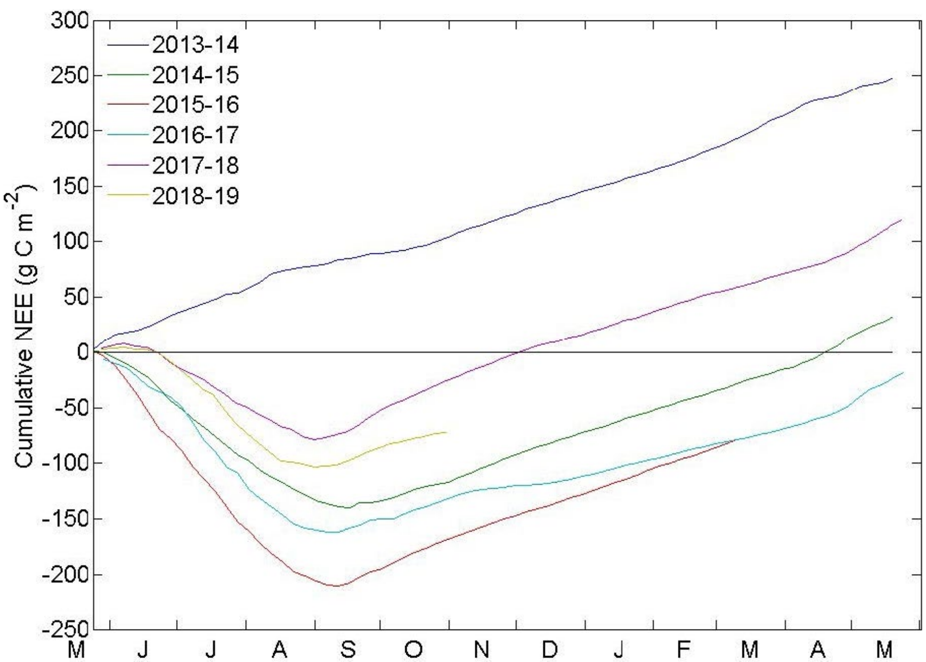

Figure 9. Annual cumulative NEE for growing years beginning 2013/14. Note that the fen oscillates between a weak sink and more recently a weak source of CO_2.

Methane (CH_4)

Methane fluxes continue to be very low at the SFRW, although some evidence suggests that they are increasing over time, and in 2018, there was an apparent larger emission event in July (Figure 10).

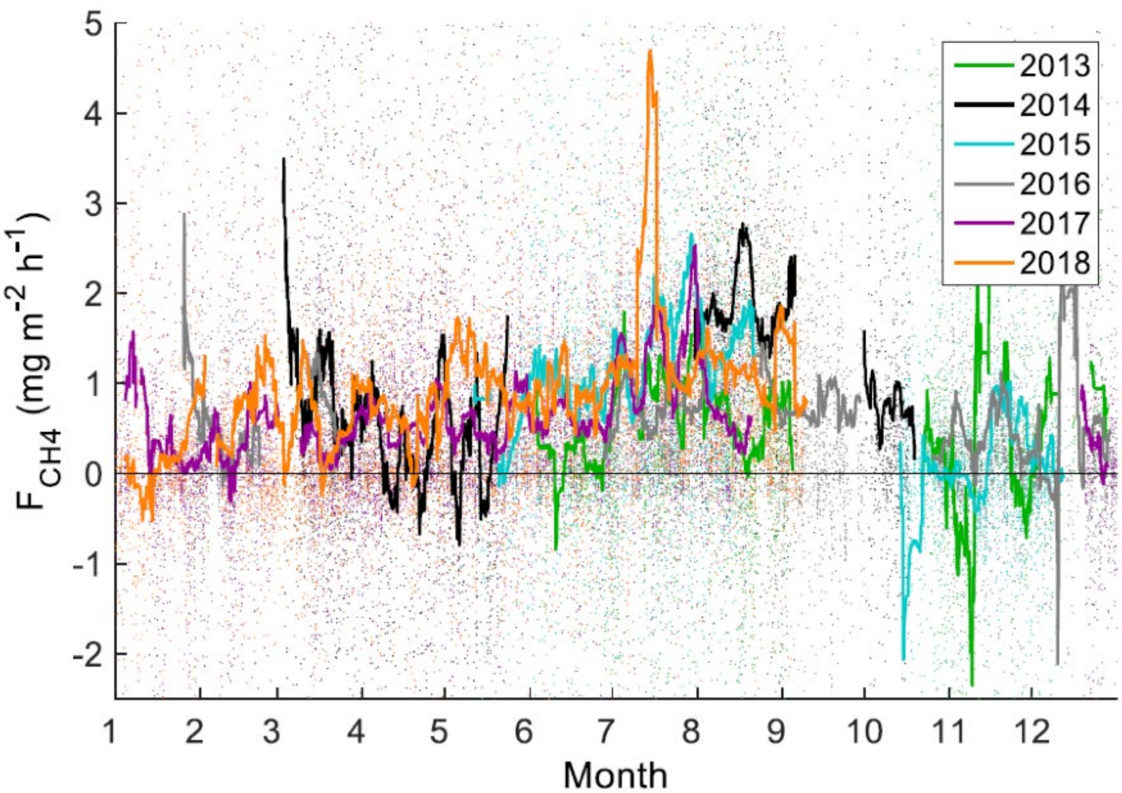

Figure 10. Seven day running averages of methane flux for years since 2013.

Salinity and Water Chemistry

Through 2018, salt concentrations in the fen continue to increase year-over-year. This has also been noted by other researchers. The increased salinity is particularly evident along the margins of the wetlands and uplands. Figure 11 shows interpolated fen salinity maps throughout the duration of the study.

Note that not all samples are the same, although a general trend of increasing salinity is evident, particularly among the margins where values are in excess of 5000 µS/cm^{-1} in 2018. Water in the central part of the fen typically remains around 2000 µS/cm^{-1}. Note that there is some bias in the trends due to the method of interpolation. Water chemical composition has changed as well during this period, but 2018 data has not been analyzed.

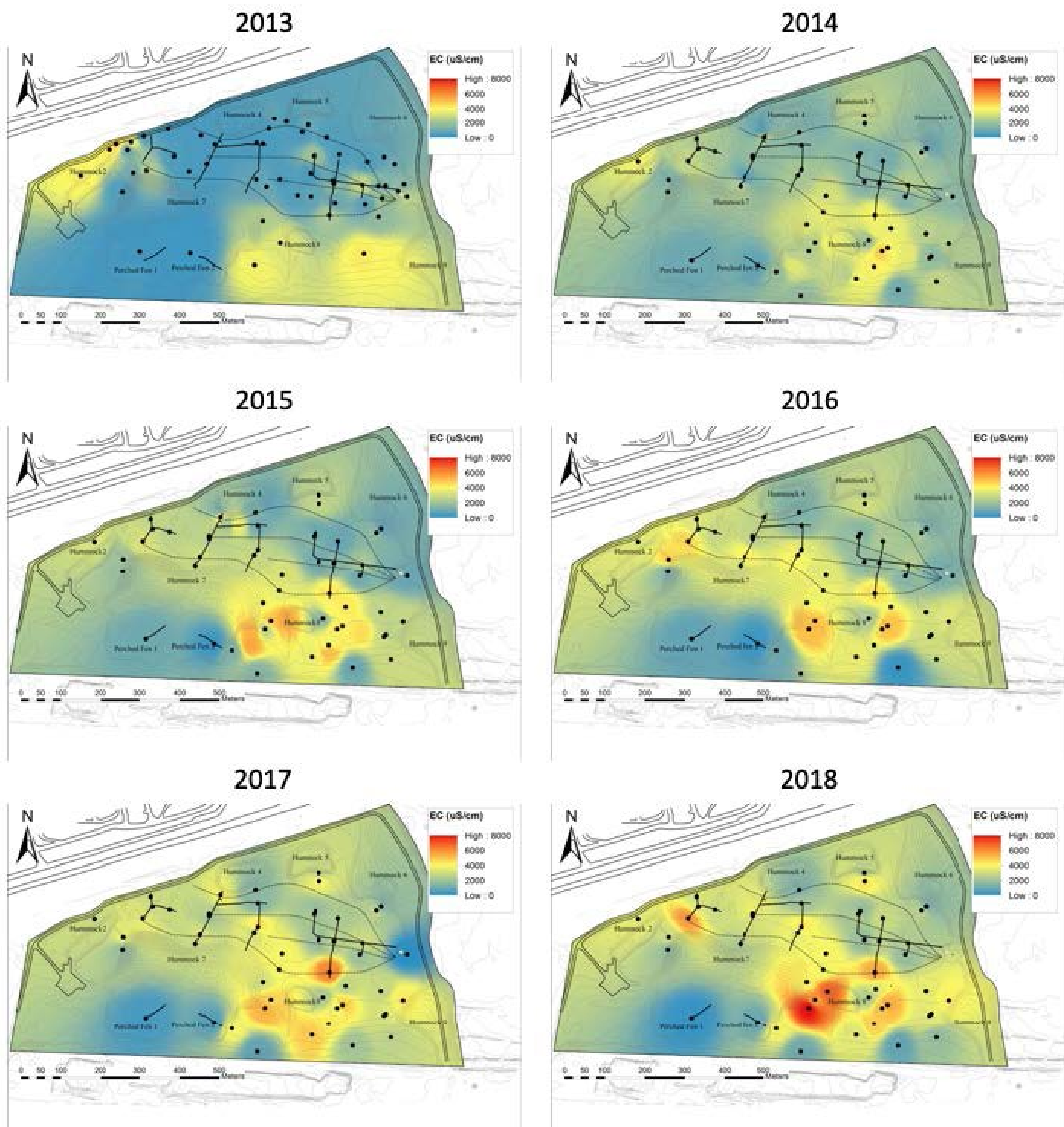

Figure 11. Salinity maps of SFRW from 2013-2018

LESSONS LEARNED

1. Measure the ecosystem-scale annual water/energy and carbon (C) balance for the reclaimed fen over a five year period (2012–2017) based on complete year measurements of all the major inputs and outputs to the system

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, balanced by snow and rain inputs and with important pumping events to dewater the lowland during most years. The general precipitation regime has been slightly drier than normal since commissioning with the bulk of the inputs being in the form of rain, often during intense summer storms. 2018 had a particularly high summer rainfall event – providing approximately one third of the normal summer rainfall in 24 hours. The timing of rainfall during the year is considered particularly important.

Evapotranspiration (ET) has been relatively conservative among the years, with some increase in the uplands as vegetation develops, yet some decline in the lowland, particularly in 2018. One of the most notable changes occurring in the watershed is ongoing salinization in certain lowland and transition/margin areas, presumably where tailings water originating from the underlying tailings disposal area is reporting to the surface.

Carbon balances indicate that the watershed moved toward a carbon sink in the first few years, but now is a weak source, likely because of the saturated lowland conditions. Overall, the climate was warmer during the past six years compared with the thirty year-climate normal for this region. The water table was high in 2018 for most of the year compared with previous years.

Wet vegetated surfaces typically evaporate at a rate greater than wetlands due to transpiration streams, increased roughness and turbulence. It is assumed that the wet and lower radiation recorded in 2018 resulted in lower rates, although research is ongoing.

2. Use stable isotopes and hydrochemistry to better understand the linkage between runoff flow pathways and sources of water

Data suggests most of the snow water infiltrates the hummock soils. This was an unexpected result, and suggests that in certain years, perhaps in years with sufficient snow pack, that runoff is generated at the uplands to supply water to the lowland. It is notable that these runoff ratios are much less (0.3 to 0.4) than 0.7 to 0.9 reported by Ketcheson and Price (2016) for the Nikanotee watershed. At present, we are testing a model to predict thresholds for runoff generation.

3. 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 (2012–2018)

Methane fluxes remain very low although they are increasing. The continuously saturated conditions provide ideal conditions for methanotrophs, but high sulphate conditions are known to suppress CH_4 fluxes, yet only for a period of time. It is anticipated that CH_4 fluxes will increase.

A final report on the first six years of the SFW is under prepartation.

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PRESENTATIONS AND PUBLICATIONS

Published Theses

M. Graham Clark. PhD thesis. 2018. The initial biometeorology of the constructed Sandhill Fen Watershed in Alberta, Canada. 192 pp. Carleton University.

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Spennato HM, Ketcheson SJ, Mendoza CA, Carey SK. 2018 Water table dynamics in a constructed wetland, Fort McMurray, Alberta. Hydrological Processes. 32: 3824-3836. doi:10.1002/hyp.13308

Biagi KM, Oslwald CJ, Nicholls EM, Carey SK. 2019. Increases in salinity following a shift in hydrologic regime in a constructed wetland watershed in a post-mining oil sands landscape. Science of the Total Environment, 653, 1445-1457. doi: 10.1016/j.scitotenv.2018.10.341

Conference Presentations/Posters

Biagi K, Clark MG, Humphreys ER, Carey SK. The influence of winter processes on the hydrology of a constructed wetland in the Athabasca Oil Sands Region, Alberta, Canada: six years after construction. Presented at the American Geophysical Union meeting, Washington DC, December 2018.

Biagi K, Clark MG, Humphreys ER, Carey SK. The influence of winter processes on the hydrology of a constructed wetland in the Athabasca Oil Sands Region, Alberta, Canada: six years after construction. Presented at CGU Annual General Meeting, June 2018.

Clark MG, Humphreys ER, Carey SK. The initial biometeorology of a constructed watershed. Presented at CGU Annual General Meeting, June 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: McMaster University / Carleton University

Principal Investigator: Dr. Sean Carey

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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Michael Treberg	McMaster University	Research Technician		
Gordon Drewitt	McMaster University	Research Technician		
Graham Clark	Carleton University	PhD Student	2014	2018
Kelly Biagi	McMaster University	PhD Student	2016	2019
Chelsea Thorne	McMaster University	MSc Student	2013	2015
Erin Nicholls	McMaster University	MSc Student	2013	2015
Kelly Biagi	McMaster University	MSc Student	2013	2015
Jessica Rastelli	McMaster University	MSc Student	2014	2016
Haley Spennato	McMaster University	MSc Student	2014	2016
Arthur Szybalski	McMaster University	BSc Student	2014	2015
Hannah Ponsonby	McMaster University	BSc Student	2017	2018

Research Collaborators: Carl Mendoza, University of Alberta; Kevin Devito, University of Alberta; Lee Barbour, University of Saskatchewan; Matt Lindsay, University of Saskatchewan; Simon Landhäusser, University of Alberta; O'Kane Consultants

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 7 of 7

PROJECT SUMMARY

Oil sands mining temporarily disturbs lands. Once mining is complete, the process to reclaim lands begins. A priority in the reclamation and certification of disturbed lands is the redevelopment of forested landscapes, including the rapid re-establishment of tree cover. Planting trees remains one of the most effective strategies in rehabilitating boreal forests affected by industrial disturbance to functioning forest ecosystems. The quick development of a continuous tree canopy on a site helps suppress establishment of weedy forb and grass species, which can significantly hinder tree survival and growth. One approach to speed up forest canopy development is to increase the planting density of trees.

The overall goal of this research project is to examine the inter-relationships among tree species and density, understory development and potential water use on different reclamation ecosites on the seven hummocks found on the Sandhill Fen Research Watershed.

Objective 1: Evaluate tree seedling establishment, early growth and canopy development in response to planting density of jack pine, trembling aspen, and white spruce on substrates salvaged from a/b ecosite or d ecosites, guided by questions including:

- What is the impact of soil type (a/b and d ecosites) and microsite parameters (e.g., coarse woody debris (CWD), soil temperature, soil moisture, soil nutrient availability) on the growth of planted seedlings?
- How does individual tree biomass allocation aboveground (stem and leaves) and belowground (fine and coarse roots) differ between tree species, ecosite and stem density treatments?
- What is the initial leaf area development of jack pine and aspen seedlings in relation to other growth parameters (e.g., height and diameter) on reclamation sites?

Objective 2: Investigate understory vegetation development in response to different site conditions and forest floor substrates salvaged from a/b ecosite or d ecosites, based on questions including:

- How do overstory density, coarse woody debris (CWD), and resource (nutrient and water) availability affect understory vegetation development on the two different ecosites?
- How does the initial soil seedbank contribute to understory vegetation development in d ecosites and how do different environmental conditions (aspect) affect its expression?

- What is the potential for natural (unassisted) tree regeneration on upland sites and what microsite conditions promote establishment?

Stand level leaf area development and potential water use is a key driver of the water cycle in natural forests and forests on reclaimed land. The three major components of water use at the stand level are tree transpiration, understory transpiration and evaporation from the soil. However, very little is known about how these water use components in upland reclamation environments interact and respond to environmental conditions such as soil water potential, tree density or tree species composition.

Objective 3: Gain a better understanding of the water balance in reclamation landscapes by determining how much water (as estimated by leaf area) is potentially used by vegetation (trees and understory) over time, with different planting densities and on soil types that have different abilities to store water, guided by questions including:

- How does planting density affect stand level leaf area development of jack pine and trembling aspen?
- How does planting density affect understory leaf area development on the differing ecosites?
- What is the potential water use of tree seedlings and how does that relate to planting density, species and soil moisture availability?

PROGRESS AND ACHIEVEMENTS

This season was devoted to processing and interpretation of data and producing a program final report which has been submitted to Syncrude Canada Ltd.

LESSONS LEARNED

Objective 1: Evaluate tree seedling establishment, early growth and canopy development in response to planting density of jack pine, trembling aspen and white spruce on substrates salvaged from a/b ecosite or d ecosites.

- All planted tree seedlings grew much taller on the hummocks capped with fine-textured coversoil compared to hummocks capped with the coarse-textured coversoil. However, the hummocks with fine-textured coversoils experienced much greater soil moisture loss during dry years (i.e., 2015) compared to the areas capped with coarse-textured coversoil. The likely difference in the depleted soil water is believed to be related to the stark differences in leaf area development on these two different site types. To explore these responses in more detail, the leaf area-soil water relationship will require further attention as forest stands and their associated leaf area develop on the hummocks.
- Overall, planted tree seedling survival was high across the site, regardless of coversoil material. Some reduced survival was seen in trembling aspen (potentially related to stock quality), while survival in white spruce and pine was consistently high. The variation in survival among species could be related to seedling quality, indicating that planted tree seedlings are capable of establishing on upland reclamation sites over a wide range of site conditions, with early growth rates reflecting the site conditions. Of the three planted tree species, white

spruce lacked a strong response to most site conditions and planting regimes, while aspen and pine were much more responsive.

- Within the first five years after site construction, soil available nutrients (i.e., coversoil material) and woody debris placement drove early aspen and pine growth responses across the site.
- Although variables such as topography and planting density appear to play a minor role at this point in time, aspen and pine seedlings responded only to different planting densities and aspects when site conditions were more extreme (e.g., less growth on coarse textured soils on south-facing slopes).
- Structural Equation Modeling (SEM) was used to explore this complex data set of biotic and abiotic variables. This modeling approach allowed for a more detailed exploration of the data, exposing relationships and interactions that linear modeling alone would not be able to detect and potentially identifying indirect causal pathways. Due to a lack of plots in some of our treatments, we were able to do this only for planted jack pine seedlings on the coarse coversoils. Using this analysis we uncovered temporal shifts in the variables that governed seedling performance, indicating a pronounced shift from seedling stock quality variables early in the recovery to biotic (competition), edaphic (soil nutrients), and climatic variables (water availability) later in the development.

- Achieving early canopy closure (within five growing seasons) by planting higher seedling density was only achieved on the hummocks that were capped with fine textured soils. Planting at 10000 stems/ha vs. 5000 did not result in much greater benefits to seedling performance and understory development in the short-term; however, more monitoring is required to explore longer-term impacts of planting densities on other forest ecosystem functions such as understory development and water-use.
- Although not studied in detail across the Sandhill fen watershed, the measured and documented variability in topography, coversoils, tree density and species composition, and coarse woody debris placement provided significant spatial variability and complexity across this reconstructed landscape feature. This variability is expected to be reflected in greater ecosystem heterogeneity and related ecosystem functions such as hydrological and soil edaphic processes and successional patterns, which in the long-term is expected to have positive effects on ecosystem responses and recovery to disturbances in these reconstructed landscapes.

Project 1: Evaluating jack pine and trembling aspen seedling characteristics to water availability impact of aspect and hydrogel amendment

- It appears that a larger pine seedling stock type was more suitable for reclamation sites, this planting stock grew taller in height while developing larger root systems. There was some indication that shorter pine seedling stock with higher root to shoot ratios (RSR) may also be suitable, particularly in coarse-textured reclamation coversoils, where the threat from above- and below-ground competition is low.
- Aspen seedling stock with high root to shoot ratios (RSR) established and demonstrated increased growth regardless of field conditions. It appears that higher non-structural carbon reserve (NSC) concentrations in the roots may also have been beneficial to outplanting success. High NSC reserve content (i.e., the reserve pool size, which is related to initial seedling size) did not appear to directly improve growth or outplanting success. Tall aspen seedlings, which have higher NSC content, but often have low RSR, appear to have reduced growth, leaf area and root development, particularly on stressed sites.

- Amending coarse textured soils exposed to a high heat load index (i.e., coarse soils on a south facing aspect) with materials that hold water (i.e., hydrogel) could be beneficial for establishing trees; however, in our study hydrogel did not increase the soil water availability or improve seedling water status, most likely the result of a wet growing season during our experiment. Despite the lack of drought conditions, the potential for hydrogel to help retain soil moisture during less favourable conditions should not be ignored, as aspen seedling height and root growth was increased with hydrogel amendment. This response might be driven by other edaphic conditions that indicated increased phosphorous and potassium availability in soils amended with hydrogel.

Objective 2: Investigate understory vegetation development in response to different site conditions and forest floor substrates salvaged from a/b ecosite or d ecosites,

- As was expected the cover soils salvaged from two very different forest types resulted in the development of two very different plant communities early in site development. The early response of the colonizing vegetation was most strongly driven by coversoil characteristics and the propagule bank contained within. In areas capped with coversoil salvaged from a poor-xeric forest site, vegetation communities included a greater proportion of native species, graminoids and shrubs, while in areas capped with coversoil salvaged from a rich-mesic forest site, vegetation communities were composed of proportionally more introduced species and forbs.
- After five growing seasons, the colonizing vegetation on the hummocks capped with the two different cover soils (poor-xeric and rich-mesic) continue to be different from each other. However, over the course of the study, vegetation communities on the two different cover soil types became more similar to each other. It is not clear from our study whether this trend of convergence will continue. It is possible that on longer timescales, topographical position, density of planted tree seedlings and coarse woody debris will be more important drivers of vegetation community development than initial coversoil source.
- Regardless of coversoil, vegetation diversity was primarily influenced by seedling planting density (canopy cover) and topographical aspect. In both coversoils, metrics of diversity were highest in areas with north facing aspects and higher tree density. North facing aspects, which typically experience less heat and moisture stress, and treatments with higher densities of tree seedlings may have created an environment that was more favourable for the emergence and growth of the largely forest adapted species present in the propagule banks of the coversoils, leading to a more diverse community. Complex interactions between planting density, aspect and coarse woody debris (CWD) impacted metrics of diversity in both coversoils.
- In areas capped with the coarse coversoil from the poor-xeric forest site, the effect of aspect on diversity was modified by CWD abundance, suggesting that CWD may have moderated the harsher environmental conditions present on south facing slopes in areas capped with the poor-xeric material, where water may have been limiting. This confirms that CWD has a beneficial effect on colonizing vegetation and seedling growth. Varying the volumes of CWD at different scales appears to encourage variation in colonizing vegetation cover and with that heterogeneity of plant communities at different spatial scales (see also Projects 2 and 3).
- Changes of the colonizing vegetation community were rapid early on (first two growing seasons) and dominated by few non-native, annual and biannual ruderal species, while plant communities appear to become more stable (perennial species driven) in the subsequent years, where changes are more subtle.

- Over the whole site we found 196 different plant species in the upland areas of the Sandhill Watershed and we believe that the increased spatial variability, a result of topographical variation, differences in coversoil materials, and placement of CWD played a significant role in the high species richness, community diversity and heterogeneity across this reclaimed landscape.

Projects 2 and 3: Role of slope aspect and coarse woody debris in plant colonization; and spatial variation, seedbank and soil type driving vegetation colonization on reclaimed upland sites

- Variation in topography at different scales ranging from the microtopographical (one metre or less in height) scale to the landscape level has significant effects on colonizing vegetation and the expression of the legacy seedbank contained in the coversoil material. At the microscale, CWD enhanced the expression of the seedbank allowing more forest specific species to establish. At the hummock scale, slope and aspect impact seedling growth and plant community development. Providing variability at different scales is expected to further enhance microsite availability for colonizing vegetation and with that future species richness and diversity.
- Increasing tree planting density above 2,000 stems per hectare which is the current operational standard (aspen and pine) had a positive effect on maintaining the initial diversity of native and forest associated species contained in the salvaged forest floor material. As stated above, the differences between 5,000 and 10,000 are not great in these early stages, this suggests the optimum density is above 2,000, but less then 10,000. This optimum value can be further refined as the vegetation community matures
- Coarse woody debris (CWD) can help ameliorate harsh conditions (such as the high heat load index on south-facing slopes capped with coarse-textured cover soils) and increase diversity and cover of native and forest associated vegetation. However, there is a trade-off with space occupied by CWD and site availability for plant establishment and growth. This points to a need for potentially prioritizing deployment of CWD, particularly when supply is limited.

As spatial patterns of the vegetation on reclamation sites change over time, the importance of introduced annual and biannual species currently considered weedy species in the community may decline. However, the long-term effects of canopy development on both native and non-native, non-forest perennial grasses and forbs and their effect on forest-associated species are not clear. Therefore, until the effects of these species types on forest-associated species are better understood, management interventions such as non-selective herbicide use to control introduced vegetation should be viewed with caution, as with closing tree canopy conditions further shifts in plant communities can be expected.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Merlin, M, Leishman, F, Errington, RC, Pinno, BD & Landhäusser SM. 2018. Exploring drivers and dynamics of early boreal forest recovery of heavily disturbed mine sites: a case study from a reconstructed landscape [online]. New Forests. doi: .10.1007/s11056-018-9649-1.

Conference Presentations/Posters

Mendoza, C., M. Lukenbach, P. Twerdy, S. Carey, K. Devito and S. Landhäusser, 2018. Mitigation of environmental impacts through construction of a reclaimed upland-wetland system on soft tailings at an oil-sand mine, NE Alberta, Canada. *Resources for Future Generations 2018,* Vancouver, BC, June, Abstract 2053. (Invited; Session Keynote)

Lukenbach, M.C., C.J. Spencer, C.A. Mendoza, K.J. Devito, S.M. Landhäusser and S.K. Carey, 2018. Groundwater recharge in a reclaimed watershed following oil sands mining: Implications for groundwater flow in reconstructed landscapes. Proceedings, *GeoEdmonton, 71st Canadian Geotechnical and 13th Joint CGS/IAH-CNC Groundwater Conference*, Edmonton, September.

Lukenbach, M., C. Mendoza, K. Devito, K. Hokanson, P. Twerdy and S. Landhäusser, 2018. Landform design influences groundwater recharge and local-scale flow when re-establishing Boreal ecosystems on soft tailings deposits. *Resources for Future Generations 2018,* Vancouver, June, Abstract 1641.

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RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Simon Landhäusser

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Ruth Errington	Natural Resources Canada	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
Frances Leishman	University of Alberta	Research Technician		
Ellen Macdonald	University of Alberta	Professor		
Katherine Melnik	University of Alberta	M.Sc.	2008 2013	2013 2017
Morgane Merlin	University of Alberta	PhD	2015	2020
Brad Pinno	University of Alberta	Assistant Professor		

Research Collaborators: Natural Resources Canada

Our Forest Reconstruction research is closely tied to a number of research programs including:

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

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

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 7 of 8

PROJECT SUMMARY

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

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

This program will address the following objectives:

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

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

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

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

PROGRESS AND ACHIEVEMENTS

This season was devoted to processing and interpretation of data. Pamela Twerdy's M.Sc. thesis and refereed journal articles are in the final stages of preparation.

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

LESSONS LEARNED

Overarching Program Learnings

Planning progressive reclamation should consider changes in landform scale water movement with time. The effectiveness of hummocks (hydraulic flow pathways and general hydrology of the system) are impacted by land management necessary for operations (i.e., in many instances, final closure drainage cannot be established in early stages of reclamation).

Groundwater flow to the north in the SFWR area is affected by a buried gravel channel. The buried gravel channel is influencing the groundwater and surface-water system in the northwest area of the lowland.

The current recharge area appears to be sufficient to sustain the SFWR wetland with an appreciable area of open water. Recharge likely comes from a legacy berm on the site (318 Berm), a topographic high distinct from the wetland and southern hummocks, as well as the hummocks. As wetland vegetation and peat become further established, less external water will be required to maintain the wetland.

Objectives 1: Test the configuration, height and size of coarse grained hummocks required to maintain wetland and forest ecosystems on reconstructed landscapes and Objective 2: Test soil layering in perched fens and role of storage in layers of different types and thicknesses on generating moisture surplus for wetland and adjacent forestland water demands

Detailed soil-moisture data and corresponding numerical modelling results indicate that the degree of recharge and subsequent mounding beneath hummocks is largely controlled by vegetation, and reclamation material texture and thickness.

The following general comments can be made about groundwater flow:

- Recharge for the watershed occurs on the hummocks and the 318 Berm (upland areas) this confirms the effectiveness of intentional design of the uplands to provide recharge;
- Some flow reversals appear to occur at the toes of hillslopes; this mimics natural sites and confirms the wetland/upland areas are responding to meteoric weather events.
- Water flows towards the Kingfisher wetland area, which is expected, but flow rates may be enhanced by water management or construction activities;
- Some groundwater flows to the north, past hummock four, into a buried channel;
- Very little snowmelt reaches the water table below hummocks; and
- Following precipitation events, water discharges near the toe of the SE swale and other ephemeral draws, coinciding with small increases in water table elevation as water is added to the capillary fringe.

It is too early to tell which direction water will eventually flow between the uplands and lowlands (e.g., forest to wetland vs. wetland to forest, or frequent water reversals). Vegetation and reclamation material texture and thickness influence recharge rates below hummocks; however, overall recharge is more areally extensive than simply the hummocks.

The electrical conductivity (EC) at depth (within 10 m of the ground surface) is 2000 µS/cm to 3000+ µS/cm. However, it tends to be lower, yet highly variable, in shallow piezometers and wells. At depth, higher EC is correlated to elevated sodium concentrations. Elevated electrical conductivities are observed along the toe of the SE swale following precipitation events.

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

A preliminary and very general synthesis of the results indicates that hydraulically effective hummocks might be more subdued than those constructed for the sandhill fen study, but more distinct than the shallow hummock represented by the SE swale.

The SE slope/swale acts as a very low hummock with a wide forestland-upland transition zone. Preliminary analysis suggests the potential ability of small topographic changes to provide water table separation and surface water recharge. Defining the specifications needed to achieve those functions will be a focus of this programs final report.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Mendoza, C., M. Lukenbach, P. Twerdy, S. Carey, K. Devito and S. Landhäusser, 2018. Mitigation of environmental impacts through construction of a reclaimed upland-wetland system on soft tailings at an oil-sand mine, NE Alberta, Canada. *Resources for Future Generations 2018,* Vancouver, BC, June, Abstract 2053. (Invited; Session Keynote)

Twerdy, P.A., M.C. Lukenbach and C.A. Mendoza, 2018. Hydrogeological considerations for landscape reclamation on soft tailings deposits in the Athabasca Oil Sands Region. Proceedings, *GeoEdmonton, 71st Canadian Geotechnical and 13th Joint CGS/IAH-CNC Groundwater Conference*, Edmonton, September.

Lukenbach, M.C., C.J. Spencer, C.A. Mendoza, K.J. Devito, S.M. Landhäusser and S.K. Carey, 2018. Groundwater recharge in a reclaimed watershed following oil sands mining: Implications for groundwater flow in reconstructed landscapes. Proceedings, *GeoEdmonton, 71st Canadian Geotechnical and 13th Joint CGS/IAH-CNC Groundwater Conference*, Edmonton, September.

Lukenbach, M., C. Mendoza, K. Devito, K. Hokanson, P. Twerdy and S. Landhäusser, 2018. Landform design influences groundwater recharge and local-scale flow when re-establishing Boreal ecosystems on soft tailings deposits. *Resources for Future Generations 2018,* Vancouver, June, Abstract 1641.

Mendoza, C., M. Lukenbach, P. Twerdy, S. Carey, K. Devito and S. Landhäusser, 2018. Ecohydrological development of a reclaimed upland-wetland system constructed on soft tailings at an oil-sand mine, NE Alberta, Canada. *Geophysical Research Abstracts,* Vol. 20, EGU2018-11843.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Carl Mendoza

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

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

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

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

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

NSERC – Syncrude Industrial Research Chair in Mine Closure Geochemistry

COSIA Project Number: LJ0292

Research Provider: University of Saskatchewan

Industry Champion: Syncrude Canada Ltd.

Status: Year 5 of 5

PROJECT SUMMARY

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

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

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

Objective 2: Identify processes and conditions controlling water quality.

Objective 3: Constrain geochemical implications of potential closure scenarios.

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

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

PROGRESS AND ACHIEVEMENTS

Strong progress was again made in 2018 toward meeting the proposed research objectives. Specific details of this progress are outlined below.

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

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

Activity 1.1 – Characterization of existing centrifuge cake deposits

Centrifuged cake is a thickened tailings material produced by amending fluid fine tailings (FFT) with a coagulant (i.e., gypsum) and flocculent (i.e., polyacrylamide) and then centrifuging. Research activities associated with this objective were completed in April 2016. Although two manuscripts were originally planned, these data are more amenable to a single comprehensive manuscript that remains in preparation.

Activity 1.2 – Characterization of existing petroleum coke deposits

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

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

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

Objective 2: Identify processes and conditions controlling water quality

This objective includes two principal activities that aim to improve the understanding of relationships between biogeochemical and physical processes influencing water quality in cake and coke deposits. This research is dependent upon the findings of the initial field studies outlined above (*Activity 1.1*, *Activity 1.2*) and was initiated in December 2016. Research activities associated with Objective 2 are ongoing, with all activities nearing completion as of December 2018. The expected completion date is expected to coincide with the end of the first IRC term on March 31, 2019.

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

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

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

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

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

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

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

Objective 3: Constrain geochemical implications of potential closure scenarios

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

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

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

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

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

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

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

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

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 integrates field measurements, laboratory observations, and modeling by Ph.D., M.Sc., and B.Sc. students into a guidance document that will support ongoing mine closure planning. This data synthesis will be written up as a chapter for an upcoming book co-edited by Lindsay (IRC). The chapter will include key information on geochemical characteristics and behaviour of materials examined through this IRC, plus additional oil sands mine materials research conducted by Lindsay or published by others.

LESSONS LEARNED

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

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

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

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

PRESENTATIONS AND PUBLICATIONS

Published Theses

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

Journal Publications

Submitted:

Lindsay, M.B.J., Vessey, C.J., Robertson, J.M., In Revision. Mineralogy and geochemistry of oil sands froth treatment tailings: Implications for acid generation and metal(loid) release. *Applied Geochemistry* Manuscript Ref. No: APGEO-D-18-00735.

Published:

Robertson, J.M., Nesbitt, J.A., Lindsay, M.B.J., 2019. Aqueous- and solid-phase molybdenum geochemistry of oil sands fluid petroleum coke deposits, Alberta, Canada. *Chemosphere* 217, 715–723. doi:10.1016/j.chemosphere.2018.11.064.

Vessey, C.J., Lindsay, M.B.J., Barbour, S.L., 2019. Sodium transport and attenuation in soil cover materials for oil sands mine reclamation. *Applied Geochemistry* 100, 42–54. doi:10.1016/j.apgeochem.2018.10.023.

Nesbitt, J.A., Robertson, J.M., Swerhone, L.A., Lindsay, M.B.J., 2018. Nickel geochemistry of oil sands fluid petroleum coke deposits, Alberta, Canada. *FACETS* 3, 469–481. doi:10.1139/facets-2017-0115

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	2017
Mattea Cowell	University of Saskatchewan	B.Sc.	2015	2016
Colton Vessey	University of Saskatchewan	B.Sc.	2015	2016
Lawrence Swerhone	University of Saskatchewan	M.Sc.	2016	2019
Mattea Cowell	University of Saskatchewan	M.Sc.	2016	2019
Mojtaba Abdolahnezhad	University of Saskatchewan	M.Sc.	2016	2019
Dr. Jared Robertson	University of Saskatchewan	Post-Doctoral Fellow	2017	2018
Colton Vessey	University of Saskatchewan	M.Sc.	2017	2019
Drake Meili	University of Saskatchewan	B.Sc.	2018	2018
Dr. Lee Barbour	University of Saskatchewan	Professor Emeritus		
Dr. Joyce McBeth	University of Saskatchewan	Assistant Professor		
Dr. Ning Chen	Canadian Light Source	Staff Scientist		

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 4 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 19 years (e.g., TROLS, HEAD, HEAD2, SFMN projects, etc.) that are informing the oil-sands mining industry on the natural functioning of aquatic, peatland and forestland systems with heterogeneity in vegetation and geology representative of the Ft. McMurray region (Devito et al. 2012). The wildfire burn in May 2011 of the Utikuma region encompassed much of the URSA transect, providing a natural analogue for a range of future reclaimed oil-sands landscapes in the initial years post construction, when the risk of landscape failure is greatest (Devito et al. 2016). Knowledge gained from this research will direct future management, and catchment design and planning, by providing the foundation for the development of resilient catchments and self-sustaining ecosystems in the next generation of reclaimed oil-sands environments.

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

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

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

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

- whether BP ecosystems (wetlands-forestlands) develop and interact to minimize overall water use or develop to maximize productivity;

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

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

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

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

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

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

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

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

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

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

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

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

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

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

a) Determine how surface and groundwater flow and hydro-chemistry vary across the landscape in response to seasonal and climate forcing and succession (post-wildfire) and b) Determine how forest biomass relates to the spatial weighting and configuration of wetland-forestland interfaces on different HRAs and during early succession (post-wildfire).

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

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

PROGRESS AND ACHIEVEMENTS

For all projects listed in objectives or deliverables in Scope 1, the fieldwork has been completed and final analyses continue. All projects for Scope 2 & 3 have been initiated and results are presented in the outcomes section and scientific publications listed below for 2018.

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

All fieldwork was completed by end of summer 2017. Final analyses of the hydro-meteorological, ecohydrological and hydrogeological data continued during 2018 to answer the questions associated with Objectives 1 to 6.

Objective 1: ***Wetland substrate and ice layering.***

This objective focuses on examining the role of soil layering and ice formation in peatlands and mineral margin swamps on water storage, evapotranspiration rates and moisture conservation. Addressing the questions listed below will help assess the relative role and effectiveness of potential soil capping strategies on reclaimed land in providing sufficient water yield in a cost-efficient manner.

The work to address both research questions (Q1.1 and Q1.2) associated with this objective has been initiated, with approximately 80% of the work completed and completion of work for both questions expected in 2019.

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

- In addition to the previous work listed in the COSIA Land EPA 2017 Mine Site Reclamation Research Report, S. Wilkinson (PhD) along with P. Deane (M.Sc.), conducted field-based hydrophobicity tests on burned peat one and two years post-fire and found strong to severe water repellency in some locations, supporting previous work by N. Kettridge. Greater levels of peat-water repellency were associated with reduced evapotranspiration rates, as tested using a mobile chamber. Specifically, the latter successional species feathermoss, in a "singed" state, was found to exhibit the greatest water repellency and lowest evapotranspiration rates. Moreover, unburned feathermoss also exhibits water repellency when dry. This suggests that hydrophobic layers in peat could reduce evapotranspiration rates and improve water conservation, especially in dry peatlands.

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

- M. Braakhekke (Y. van der Velde) is currently modelling forest vs peatland bi-stability states over the past 1,000 years, with mineral vs peat covered soils as initial conditions. Results indicate that in the present climate, mineral soils isolated or connected to external water sources can provide the moisture conditions required to initiate wetland formation and further peatland development. This supports early fieldwork reported by K. Devito and modelling by N. Kettridge.

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

This research examines ecosystem recovery following wildfire and the role of succession on ET and water conservation of wetlands, specifically peatlands. Knowledge from this objective will aid in estimating timelines for ecosystem development and anticipating future water balance of HUs on closure landscapes as constructed ecosystems (wetlands-forestlands) grow and mature with time.

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

- S. Wilkinson (PhD) is analyzing the moisture retention properties of hummock, hollow and margin peat, with time since fire, and also accounting for HRA. Current analyses find that, hollow and margin peat surface moisture retention increases due to fire and then decreases again with the recovery of new moss. Hummock moisture retention is mainly unaffected by fire, due to the common occurrence of low/negligible burn severity. Margin peat is generally most dense and has moisture retention properties that show less depth dependence than peatland middles (hummocks and hollows). HRA (Coarse, Moraine, Fine) has no significant effect on peat moisture retention properties in bog systems, although there may be some interaction with margin peat depth and properties. Analyses are continuing.

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?

- Analyses by R. Leonard (PhD) demonstrate the impact of different layers of ecosystem complexity that form during the succession of a wetland on peatland surface temperatures and associated evapotranspiration. This highlights the important role of trees on thermal heterogeneity and thus evaporation.
- P. Moore (Post-Doctoral Fellow) is continuing development of the PHI-BETA-THETA combined numerical models that simulate peatland radiation and energy balance components, including soil thermal dynamics.

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

Development and analysis of numerical models, based on conceptual understanding from earlier work continued in 2018 (P. Moore, R. Leonard and M. Braakhekke). The models will be used to determine the range of peatland hydrological trajectories and vegetation moisture stress with different soil layering, climate cycle and vegetation succession to model and assess peatland sustainability.

Objective 4: ***Ephemeral draws.***

The controls on ephemeral draw wetland formation and their role in generating moisture surplus and delivering water to downstream wetlands and adjacent forests, are being examined. Such small forested wetlands occur throughout upland forests (Devito et al., 2012). A better understanding of where and how frequent runoff is generated within the forest ecosystem will aid in establishing future design criteria. This information will be used to better anticipate and utilize the amount and persistence of water yield from constructed forest in closure landscapes vital for maintaining downstream and adjacent ecosystems.

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

Analyses by A. Hurley (PhD) are assessing the magnitude and frequency of runoff from ephemeral draws to downstream locations. Results indicate that runoff occurs irregularly and is linked to cumulative departures of annual precipitation early in the growing season and/or the frequency and magnitude of precipitation throughout the year (rather than seasonal or annual totals). Further, analyses of shallow groundwater dynamics and gradients indicate:

1. recharge to deeper ground water (yet at negligible rates, as conductivity of confining layer is low); and
2. subsurface flow into hillslopes (i.e., water loss from the ephemeral draw) occurs during and directly after spring melt due to wet conditions and/or after successive precipitation events that satisfy storage within the ephemeral draw.

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

- Analyses by A. Hurley (PhD) have shown that the variability of available storage capacity (as defined by soil characteristics and antecedent moisture) is fairly large within the ephemeral draw, and is considerable in contrast to the adjacent, forested uplands. This results in two important dynamics:
    1. hillslopes of adjacent uplands are generally uncoupled (i.e., not hydrologically connected) from the ephemeral draw, and will rarely contribute to runoff at the catchment outlet (i.e., they buffer storm responses); and
    2. the morphology of the soil surface, as well as the confining layer (in conjunction with soil texture), control not only available soil and depression storage, but also the connectivity within ephemeral draws.

  Hence, the areas of largest storage capacity will control the overall geometry and extent of areas contributing to, and transmitting lateral flows to, the catchment outlet via ephemeral draws. Analogously, flows toward adjacent uplands are generated by the formation of saturated areas. While still dependent on the absolute extent of such saturated areas, water table gradients across wetland interfaces are more decisive in controlling the magnitude of lateral flows.

- Near-surface solid ice can decrease available storage, and hence promote the generation of lateral flows, but this capacity is determined by its spatial continuity and persistence in time. Since snow accumulation within the ephemeral draw is generally low, and most precipitation occurs during growing season months with high evapotranspirative demand, ice formation is especially important in redistributing water early in the growing season before demand peaks.

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

- Fieldwork exploring growth dynamics and water use of forest trees adjacent to an ephemeral draw has been completed. A. Hurley (PhD) is currently deciphering the interplay of ephemeral draw geometry and water export, focusing on lateral flow generation as well as forestland water use and growth responses.

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

This research attempts to 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. An understanding of the role of interfaces between forestlands and wetlands, and the relative gain (runoff generation) or loss (vegetation uptake) of water, can be utilized to determine the impact of the spatial orientation and configuration of different HUs, on the moisture distribution and water yield of closure landscapes.

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

- K. Hokanson (PhD) has shown how the scale of flow, surficial geology, and local substrate layer control water table configurations and responses to climate. Water tables controlled by regional flow systems are less sensitive to short-term climate, but will be susceptible to long-term drying or wetting. Local flow systems (fine-textured landforms) and intermediately positioned coarse-textured landforms are generally sensitive to short-term climate changes. Analyses of water table responses to wet and dry climate cycles observed at URSA illustrated the sensitivity of forestland and wetlands to long-term climate change. K. Hokanson (PhD) found that wetting and drying at the hummock scale, and thus the WFI, is out of sync with annual precipitation. However, water table position and hydraulic gradient data collected during a mesic year (mesic regarding annual precipitation compared with both long-term deficits and three-year cumulative deficits) show that in subhumid climates, peatlands are the predominant source of water across the WFI. The majority of hydraulic gradients across the WFI (coarse-textured HRAs and low-relief fine-textured hummocks) show water being sourced from wetlands into hummocks. However, the magnitudes and total fluxes are small relative to those seen in humid or high-relief landscapes. Large, extensive fine-textured hummocks develop water tables that follow topography and create a gradient into neighboring wetlands. However, extremely low hydraulic conductivities, result in little actual movement of water across the interface from the actual hummock.

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?

- Based on short-term tree responses to water availability and use (cf. Objective 4), A. Hurley (PhD) is further employing detailed wood anatomical analyses (on individual cell basis).to gain insight into within-year growth dynamics for both target species (aspen, white spruce). The analyses will allow the inference of links between climate and growth at higher temporal resolution. Additional analyses on delineating the impact of ephemeral draw water export, are underway. For example: Identification of water sources along a transect in the same wetland-upland complex is still outstanding but will employ stable water isotopes as tracers.

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

The limits of water use and distribution on constructed oil-sand landscapes are key issues in initial and final closure plan developments. In Objectives 7 and 8, the proportion and configuration of wetlands (including ephemeral draws) to forestland required in different HRAs is quantified. The basis for this work is to provide adequate surface water inputs and/or groundwater discharge during the range of climate conditions for larger wetlands or aquatic systems (i.e., end pit lakes), and how this may change with succession of the AOS landscape.

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

The overall objective of this 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 at natural analogue landscapes (Devito et al. 2012).

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

S. Leader (PhD) is compiling pond stage data across URSA to further understand the interactions between climate, texture, and land cover, and their controls on pond response to wetting and drying cycles. Initial data exploration shows differing pond memory of antecedent conditions, which can be explained by varying multi-year cumulative departures from the long-term precipitation mean. This highlights the need to consider responses to the short-term climate within the context of the long-term climatic conditions.

S. Leader (PhD) has merged empirical data into a reduced-complexity numerical model with the capability to simulate a wide array of landscape configurations (HRA, HU proportions, landscape position) in order to investigate the influence of BP catchment characteristics on the dynamics and thresholds of water storage, connectivity and AET over the long-term (100 year). Initial simulations demonstrate the important role of HU proportion on storage and runoff, whereby higher peatland proportions result in wetter, more connected catchments. Further simulations will investigate pond-peatland-forest interactions and system dynamics, which will aid in understanding the influence of catchment characteristics and long-term climate cycles on runoff generation, recharge and evaporation.

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

We continued the long-term monitoring of natural systems at URSA in 2018 to examine;

1. how processes may vary following large-scale disturbance (i.e., wildfire); and
2. to further interpret long-term water yield from larger catchments in Objective 7.

This information can be used to set baselines and acceptable ranges in hydrology and chemistry of surface and subsurface waters, and biomass responses for use in developing goals for short and long-term performance of closure landscapes and assessments of these landscapes.

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)?

Regression analyses using landscape scale synoptic sampling of dissolved organic carbon (DOC) and specific ultra-violet absorbance (SUVA) from 34 shallow lakes (SLs) with a range of climate scenarios (P-PET) ranging from three months to two years were undertaken in 2018 by E.Pugh (PhD). The analysis shows that the greatest variation in SL chemistry (DOC and SUVA) occurs in short-term (three month) and long-term (24 month) climate scenarios. This indicates that the variability of DOC and SUVA responses in SLs is broadly controlled by climate. The analysis also indicates that there is a threshold within the range of climate scenarios analyzed (approximately between eight to 10 months) whereby the mechanistic reasoning for variability of SL DOC and SUVA switches from external mechanisms to internal mechanisms. Further analyses show that interactions between short-term and long-term climate scenarios and landscape characteristics, such as landform, cause lag times in SL chemistry responses depending on which landform SLs are located in. This further indicates that the variability of DOC and SUVA responses in SLs is broadly controlled by the interactions between climate cycles and watershed characteristics.

LESSONS LEARNED

For activities that occurred in 2018:

Can layering soils in peatlands (including hydrophobicity and frost formation) be used to reduce evapotranspiration (ET), to behave as an effective capping material, and to generate surplus fresh water and surface runoff in various Alberta Oil Sands (AOS) landscapes?

- Hydrophobic layers in peat could reduce evapotranspiration rates and improve water conservation, especially in dry peatlands.

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

- Ephermal draws dynamics and gradients indicate:
  1. recharge to deeper ground water (yet at negligible rates, as conductivity of confining layer is low); and
  2. subsurface flow into hillslopes (i.e., water loss from the ephemeral draw) occurs during and directly after spring melt due to wet conditions and/or after successive precipitation events that satisfy storage within the ephemeral draw.
     - The areas of largest storage capacity will control the overall geometry and extent of areas contributing to, and transmitting lateral flows to, the catchment outlet via ephemeral draws. Analogously, flows toward adjacent uplands are generated by the formation of saturated areas. While still dependent on the absolute extent of such saturated areas, water table gradients across wetland interfaces are more decisive in controlling the magnitude of lateral flows.

How does HRA and texture control the magnitude and direction of water across the WFI?

- The scale of flow, surficial geology, and local substrate layer control water table configurations and responses to climate.

- Water table position and hydraulic gradient data collected during a mesic year (mesic regarding annual precipitation compared with both long-term deficits and three year cumulative deficits) show that in sub-humid climates, peatlands are the predominant source of water across the WFI.

Overall summary lesson:

- Modelling results show that in the present climate, mineral soils isolated or connected to external water sources can provide moisture conditions sufficient to initiate wetlands and to promote further peatland development. This has positive implications for landscape design both in terms of material budget requirements (reducing the demand for peat) and for conceptualizing the multiple possible roles (i.e., water receivers and/or generators) of wetlands and peatlands.

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RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Kevin J. Devito

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Mike Waddington	McMaster University	Professor		
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Jessica Ritz	University of Alberta	Technician	2014	2018
Matthew Morrison	University of Waterloo	Technician	2017	In Progress
Erik Peterson	University of Alberta	Technician	2018	2019
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WETLANDS

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 4 of 4 (final year)

PROJECT SUMMARY

In March 2005, Suncor Energy Inc. (Suncor) 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 ongoing 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 and function over time to the natural, undisturbed 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 exist 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" project 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

Note: Results of the 2017 monitoring program became available in 2018 after the publication of the 2017 COSIA Land EPA Mine Site Reclamation Research Report, and are therefore presented in this report.

Monitoring continued in 2017; a summary of the 2017 assessment (Hatfield and MEMS, 2018) is provided below:

Long term monitoring and assessment results indicate that the hydrologic, chemical and biological conditions of McLean Creek and the STP Wetlands Complex are representative of functioning and healthy ecosystems.

Results of the hydrologic monitoring showed that discharge during the 2017 open-water season was highly variable due to natural events such as rainfall and beaver activities. Discharge patterns at lotic stations within and downstream of the STP Wetlands Complex were similar to the discharge pattern at the upstream reference station.

Continuous water quality monitoring of McLean Creek indicated that fluctuations observed in water quality variables during the open-water season (i.e., temperature, dissolved oxygen (DO), conductivity, and pH) were generally due to rainfall events (changes in conductivity) and seasonal variability (changes in dissolved oxygen and water temperature).

In 2017, the vegetation communities of the STP Wetlands Complex were comparable to the reference wetland of upper McLean Creek. Mean plot species diversity was not significantly different between any stations of the STP Wetland Complex and reference wetland. The results of the vegetation assessment showed that vegetation vigour has increased over time at all stations, indicating that plants are becoming more robust as these wetlands continue to mature. Results from 2017 were consistent with those from 2014 to 2016, indicating that nitrogen and phosphorus levels in plant tissue are stabilizing at a level similar to the reference wetland MC-9A. All stations were within the performance standard for self-sustaining plant communities.

Benthic invertebrate community monitoring in 2017 indicated that the STP Wetlands Complex are mirroring natural conditions observed in the upper portion of the watershed. Benthic invertebrate communities at all stations in the McLean Creek watershed were dominated by chironomids or co-dominated by chironomids and tiny crustaceans (Daphniidae). In general, benthic invertebrate community indices (i.e., taxa richness, abundance, diversity, and evenness) at all stations were within, or greater than, the range of variability observed at the reference stations. The benthic invertebrate communities appear to indicate that all exposure stations are reflecting the habitats of, and functioning similarly to, the reference wetlands.

LESSONS LEARNED

Results of the 2006 - 2017 monitoring programs indicated that since their construction, there has been a positive progression in the development of benthos, 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. 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.

The performance indicators developed in 2013 have now been applied to five years of monitoring data. DFO reviewed the 2017 monitoring program report for the effectiveness of the wetlands as required to avoid and mitigate potential impacts to fish and fish habitat. Based on the information provided, DFO advised Suncor that the conditions of Authorization 03-HCAA-CA1-0345 have been satisfied.

PRESENTATIONS AND PUBLICATIONS

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RESEARCH TEAM AND COLLABORATORS

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Ecohydrologic Investigations 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 3 of 3

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 and vegetative 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 or observable from aerial or satellite images, they are currently difficult to predict or account for during the closure planning process. However, 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 investigates the conditions under which these small-scale opportunistic wetlands develop. Understanding these conditions will help predict their performance through future climate cycles. The results from this research will allow improved prediction of the occurrence and performance of these wetlands, and ultimately provide guidance or designs for enhancing opportunities for wetlands to develop. The results of this work will also be crucial in accounting for the full spectrum of wetlands that exist on the closure landscape.

PROGRESS AND ACHIEVEMENTS

During 2018, field work was completed and efforts were focused on documentation of wetland assessment protocols, data base management, paper submission and final report composition.

LESSONS LEARNED

Results indicate opportunistic wetlands are common in greater frequency than previously catalogued on all reclaimed landforms. Wetland density is approximately 0.8 wetlands/ha and approximately 8% cover. Wetland types are predominantly willow swamps, sedge marshes and, to a minor extent, cattail open water marshes. Many wetlands are generally characterized by a near-surface confining layer.

Wetlands are not restricted to lower landscape positions. There is no relationship observed with potential cumulative water source, nor landform aspect and its associated shading potential, although sheltering from predominant winds does impact formation or development. Wetlands form in different locations depending on the landform substrate texture.

Some wetlands form at the toes of slopes or where groundwater intersects the ground surface on coarse-textured landforms. These wetlands are generally large, elongated in shape, and follow the base of the landform. This indicates that external sources of water (groundwater discharge, upstream runoff) are required for formation of these wetlands.

Many additional wetlands form on the flat top, mid-slope, and base of landforms with fine-textured substrates, including areas perched above the water table. These wetlands are variable in size and shape, although most are circular or convoluted. Wetlands on fine-textured landforms appear to form on flat areas or depressions that are protected and have less soil water storage, promoting frequent soil saturation. These results indicate that site characteristics and internal feedbacks influence wetland formation. This has large implications for design of landforms and potential wetland construction on lease sites.

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PRESENTATIONS AND PUBLICATIONS

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RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Dr. Kevin Devito and Dr. Carl Mendoza

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Peatland Reclamation Markers of Success

COSIA Project Number: LJ2073

Research Provider: Southern Illinois University Carbondale

Industry Champion: Syncrude Canada Ltd.

Status: Year 3 of 5

PROJECT SUMMARY

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

Project 1: Tracking key ecosystem variables. After three years of data collection at the Sandhill Fen Research Watershed (SFRW) 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 sandhill fen outside of existing wetland research plots. Each of these variables plays a key role in the success of the wetland, and continued monitoring of these factors will supply valuable information for understanding wetland performance and function.

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

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

PROGRESS AND ACHIEVEMENTS

The following progress was made towards achieving the stated objectives in 2018:

- During the 2018 field season water samples were collected in May, July, and August to assess chemistry and changes throughout the growing season. These water samples are needed for understanding sodium concentrations and tracking ecosystem variables (Projects 1 and 2).

- In July, a vegetation survey from 84 plots across the SFRW was completed. This continuous vegetation survey allows study of plant community development.
- Community analysis, diversity, and species abundance statistics have been completed. This also contributes to understanding plant community development and allows for a comparison between the community on the Sandhill fen and natural communities at reference sites.
- *Carex aquatilis* leaf tissue and soil samples were collected from the vegetation plots for sodium extraction - to begin January 2019. This sodium extraction contributes to understanding plant response to sodium concentration (Project 2)
- Winter resin tubes and summer resin tubes from the past year were removed. The resin tubes will be extracted for nitrogen and sulphur deposition this spring.
- Water chemistry analysis for Sandhill Fen was completed, and reference site water chemistry is in progress (some results presented).
- Sandhill Fen water table position was monitored and compared to reference sites.
- Preliminary vegetation comparisons between Sandhill Fen and reference sites have been compiled; detailed analysis will be completed in spring of 2019.
- Decomposition rates and peat quality for Sandhill Fen and reference sites will be analyzed in 2019 as well. In spring 2019, lab analysis of 2018 samples will be completed.

In addition to the analysis of data and samples collected during the field season, a greenhouse experiment is currently running to determine the response of *Carex aquatilis* seeds collected from a variety of sites to a sodium gradient. This experiment will conclude in March 2019, and a manuscript detailing the results will be written.

Key findings for 2018 are summarized below:

Reference Site Comparisons to Sandhill Fen

The locations of the reference sites are shown in Figure 1, sites include Sandhill Fen (SHF), one extreme rich fen, three saline fens, two treed moderate rich fens, two marshes, one open moderate rich fen, and three poor fens. In 2018, these sites were sampled for chemical indicators of reclamation success, including porewater pH, electrical conductivity (EC), and porewater nutrients and base cation concentrations. Organic matter decomposition rates, a functional indicator, was monitored. Lastly, structural indicators we sampled included plant community composition, key vascular plant and moss species, peat quality, and fen water table position. Highlights to date are included.

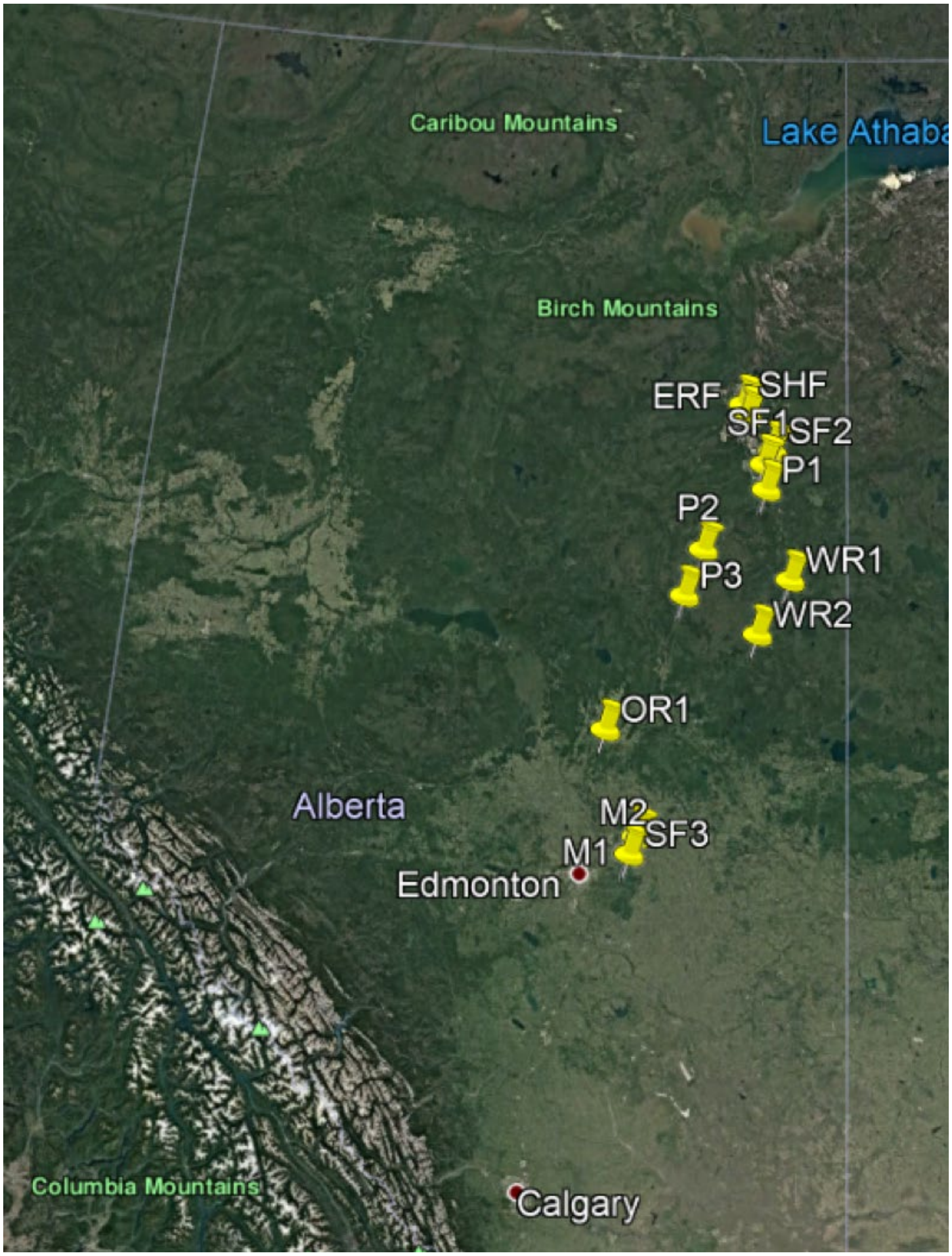

Figure 1. Reference site locations (Google Earth). Site abbreviations: SHF is Sandhill Fen Research Watershed; ERF is an extreme rich fen; P1, P2, and P3 are poor fens; OR1 is an open rich fen; M1 and M2 are marshes; WR1 and WR2 are wooded rich fens, and SF1, SF2, and SF3 are saline fens.

Water chemistry of Sandhill Fen is most comparable to marshes rather than the fens that were sampled. pH is basic (Sandhill Fen range: 8.01 – 8.91) and within the range of marshes, while electrical conductivity (EC) is high (Sandhill Fen range: 1263 – 5140 µS/cm) and more variable than at reference sites (except for the saline fens).

Sandhill Fen nutrient levels are low. Ammonium and nitrate from Sandhill Fen are similar to the low end of values measured in marshes, and phosphate values are lower than most of the reference sites.

Base cation concentrations are comparable between Sandhill Fen and the marsh sites, but anions at Sandhill Fen are more similar to saline fens.

The water table at SFRW in 2017 was much higher and more variable (SFRW 2017 range: -22 cm to +73 cm) than any of the reference sites including the marshes. In 2018, the water table is much closer to that of the marsh sites (SFRW 2018 range: -45 cm to +51 cm). Some of the variability can be attributed to the water pumping at the SFRW site. Due to intense summer storms the sandhill fen wetland area had unmanageably high-water tables so pumping occurred in July to drastically drop the water table. In the long-term, if water table stability could be maintained, it would reduce stress on the plants at the site.

In comparison to the reference sites, plant communities at Sandhill Fen were quite dissimilar from the fens and most similar to the marshes. Although Sandhill Fen shared many common species with the fen sites, high abundances of *Carex aquatilis*, *Typha latifolia*, and *Calamagrostis canadensis* coupled with large open water areas and low moss cover explain the similarity with the marsh plots. Vegetation plots localized across dry zones at Sandhill Fen are dissimilar from both fens and marshes due to the presence of several upland plant species. Plots localized in wet areas at Sandhill Fen are only slightly similar to the marshes due to the species poor nature of these plots and areas of open water.

Sandhill Fen Monitoring and Analyses

Water Chemistry

Sodium concentrations in water (0 cm to 50 cm below soil surface) continue to rise with a 2018 mean of 573.0 mg/L ± 22.8 mg/L compared to 488.6 mg/L ± 20.4 mg/L in 2017; but areas with concentrations over 1500 mg/L were found and a maximum of 2391 mg/L. Calcium concentrations were higher in 2018 (348.2 mg/L ± 19.3 mg/L) than in 2017 (304.9 mg/L ± 5.2 mg/L). There is spatial variability for all base cations.

Diversity and Status of Sandhill Fen Species

There was a marked decrease in diversity and plant cover for both vascular and bryophyte species in 2017 as a result of standing water flooding out bryophyte and forb species that occupy the area under sedges and shrubs. In 2018, the bryophytes have not recovered, and some of the desirable species have not returned. The effect of the flood was not as severe for undesirable species nor the dominant species of Sandhill Fen. *Typha latifolia*, *Carex aquatilis,* and *Calamagrostis canadensis* show resilience to the flooding. Continued monitoring of desirable species diversity and bryophyte cover should be carried out.

Carex aquatilis response along to the sodium gradient at SFRW was measured using a SPAD chlorophyll meter, and there was no difference between areas of the fen with higher soil sodium than areas with low soil sodium (2017 data). However, there was a higher reading in all areas during the earliest measurement in the season.

LESSONS LEARNED

Project 1: Tracking key ecosystem variables

Sandhill Fen Monitoring and Analyses

Higher water tables from 2017 continued to have an effect on SFRW vegetation in 2018, particularly a reduction in bryophyte occurrences. Diversity of desirable vascular species and bryophytes have not rebounded to pre-flood values. Changes in species diversity observed show that the plant community is very responsive to water table elevation fluctuations. In cases where reclaimed areas are still connected to operational areas and the overall engineered drainage is linked, the water management plan will have significant impacts on the wetland vegetation community. The ability of the Sandhill Fen vegetation to respond to water table fluctuations indicates promising resilience.

Project 2: Plant response to sodium concentration

Sodium concentrations in water (0cm to 50 cm below the surface) continue to increase, and spatial variability is noteworthy. Several samples had over 1500 mg/L sodium, and a maximum value of 2391.4 mg/L was found.

Project 3: Development of peatland markers of success

Reference Site Comparisons to Sandhill Fen

Porewater electrical conductivity is high at Sandhill Fen but falls between the expected EC of a natural sub-saline marsh and a saline fen. Base cation concentrations at Sandhill Fen are most similar to marshes. Anion concentrations at Sandhill Fen are most similar to saline fens.

Six years post plant introduction, community composition at SFRW is most similar to marsh communities and quite dissimilar to reference fens. Reclaimed wetland plant communities are very dynamic. Over the six years of examination, depending on the year, the SFRW wetland could be classified differently. This highlights how conventional wetland classification may not be appropriate or even applicable as a tool for studying, evaluating or comparing wetland performance in early years of reclamation.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Hartsock, J.A., and Bremer, E. 2018. Nutrient supply rates in a boreal extreme-rich fen using ion exchange membranes. Ecohydrology 11(7): 8. doi: 10.1002/eco.1995.

RESEARCH TEAM AND COLLABORATORS

Institution: Southern Illinois University Carbondale

Principal Investigator: Dr. Dale Vitt

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

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 3 of 3

PROJECT SUMMARY

Although large-scale engineered fens have been constructed and are currently monitored by the oil sands 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 for the Cumulative Environmental Management Association (CEMA) 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. 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.

The objectives of Dr. Bayley's study were to: 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 developed 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]). 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; water amplitude; percent 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 (SAV) metric and a Wet Meadow Vegetation (WMV) 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).

The objective of this project is to implement Dr. Bayley's monitoring procedures on five voluntary shallow open water wetlands located within reclaimed land on the Horizon lease. Wetlands will be assessed annually in order to understand how they are developing in early seral stages. This study will provide a means to understand the developmental trajectory of shallow open water wetlands on reclamation areas.

PROGRESS AND ACHIEVEMENTS

All five wetlands were once again measured in 2018 for all parameters, including submerged aquatic vegetation, abiotic stress and wet meadow composition. As well, continuing from last year, monthly ionic composition samples were taken at each wetland (dissolved calcium and magnesium), in order to understand how this may change over the season. This data can be used for future wetland research initiatives. Complete datasets have now been collected for three sampling seasons.

The calculated wetland metrics show strong variability between sample years, and it is difficult to ascertain the reasons for this. It is evident that environmental factors may have changed within the wetlands over time, however the exact cause and extent of these changes in terms of their influence on these metrics is unknown and complex. Moreover, it is difficult to determine management options, or their rationale, in response to these changes or "failing" scores.

LESSONS LEARNED

The Wetland IBI protocols represent a clear, teachable, and relatively easy means to assess marsh wetland conditions. Procedures are easy to follow, and the data is simple to process, as the calculation spreadsheets are included with the procedure. As most of the procedures and collections methods were already practiced in the third year, the program in 2018 was easily completed by two students with minimal supervision.

While the original program developed "pass/fail" criteria as part of the tool's genesis, these criteria are not relevant to reclamation wetlands because they are not directly tied to either certification criteria or provincial wetland policies (the IBI program pre-dating the current Alberta Wetland Policy), but instead represent +/- one standard deviation from the mean of the natural reference wetlands. While this threshold is a logical way to understand how a reclaimed wetland's health theoretically compares to those found in natural wetland areas, the characteristic differences between these two wetland types are too large to ignore, and represent a severe bias in comparison. All in all, this program is effective in empowering operators with tools and knowledge to evaluate certain aspects of their reclamation wetlands, and may well be used, in part, in future monitoring efforts that are designed within a more appropriate regulatory and operational context.

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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 2018.

RESEARCH TEAM AND COLLABORATORS

All research provided by Canadian Natural Resources Limited, Horizon.

COMPENSATION LAKES AND AQUATICS

Horizon Lake Monitoring Program

COSIA Project Number: LJ0011

Research Provider: Canadian Natural Resources Limited, Hatfield Consultants

Industry Champion: Canadian Natural Resources Limited

Status: Year 11 - Ongoing

PROJECT SUMMARY

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

The measure of success for Horizon Lake is based on satisfying conditions identified in Canadian Natural's Fisheries Act Authorization for Horizon, 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 2017 monitoring program became available in 2018 after the publication of the 2017 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. They consist of Arctic grayling, brook stickleback, burbot, finescale dace, fathead minnow, lake chub, longnose sucker, slimy sculpin, trout-perch, and white sucker.

There were 1,575 fish caught from Horizon Lake during the 2017 fall sampling program, including 20 recaptures of fish tagged between 2011 and 2018. An additional 316 passive integrated transponder (PIT) tags were deployed during the 2017 sampling period. Fishing was conducted using a variety of techniques, including gill netting, minnow trapping, electrofishing, and fyke netting. The assemblages of fish species caught by the different fishing methods have been relatively consistent from 2012 to 2017, though the relative proportions of each species have varied over time. Similar to 2015 and 2016, fathead minnow and white sucker were the dominant forage and large-bodied fish species in 2017. The relative proportion of each species captured in 2017 was within the range of previous observations (2009 to 2016), with the exception of lake chub, which comprised a lower proportion of the population than all previous years, and trout-perch, which comprised a higher proportion of the population than all previous years. Arctic grayling captures continued to be low (13 in total), and no finescale dace, burbot, or slimy sculpin were captured during the 2017 fall sampling program.

Total mercury and methyl mercury concentrations in fathead minnow (FTMN) and lake chub (LKCH) tissues collected from Horizon Lake have shown a declining trend since annual monitoring commenced in 2009, with 2017 representing the lowest concentrations observed to date. 2017 was also the first year that total and methyl mercury concentrations in FTMN collected from Horizon Lake were lower than those observed in fish collected from the Calumet reference watershed. As in previous years, all of the forage fish tissues were below the Health Canada (2007a) guidelines for subsistence fishers (0.2 mg/kg) and general consumers (0.5 mg/kg) in 2017.

Total and methyl mercury concentrations in juvenile white sucker composite samples collected from Horizon Lake in 2017 were slightly higher than 2016, but within the range of previous observations. All nine white sucker muscle tissue samples collected in 2017 contained concentrations of total mercury above the 0.2 mg/kg Health Canada (2007a) guideline for subsistence fisheries, while no fish contained concentrations above the 0.5 mg/kg guideline for general consumers.

Concentrations of total metals in fish tissue samples were below human health consumption guidelines in 2017, with the exception of arsenic, which exceeded in all samples, and aluminum and copper, which exceeded in some samples. Fish tissue samples collected from the Calumet reference watershed also exceeded the consumption guidelines for these three metals.

Fish Abundance and Production Estimate

A hydroacoustic survey was conducted in 2017 to measure abundance and production of four target species in Horizon Lake (fathead minnow, lake chub, longnose sucker, and white sucker). Total production for these four species was 701 kg in 2017, with the two sucker species comprising 93% of the total production biomass. Although the 2017 fish production estimate for Horizon Lake was lower than the estimates for the previous three years, the hydroacoustic surveys showed robust and consistent overall abundances of fish.

Water Quality

Seasonal in situ profile data from Horizon Lake reflected the influences of regionally warm temperatures and low precipitation in 2017, with surface temperatures near or above the maximum historical observations in spring, summer, and fall. Continuous water temperature data from the thermistor strings showed a thermocline was established in mid-May and persisted until after the dataloggers were removed in early-September.

Vertical profiles of pH showed moderate variability through the water column, with values ranging from 6.97 to 8.43. The pH remained within the protection of aquatic life guideline range (CCME 2007) at all depths in 2017.

Discretely sampled dissolved oxygen (DO) profiles identified a decline in pelagic zone DO, with concentrations falling below 5.5 mg/L (the lowest acceptable concentration to support all life-stages of all species of fish; CCME 1999) at depths greater than 5 m in July, greater than 9 m in early-September, greater than 16 m in late-September, and greater than 11 m in February. However, there was abundant access to well-oxygenated water in the lake throughout the year, and fish would be expected to simply avoid the low oxygen areas of the lake until turnover occurred.

Seasonal and inter-annual variability in key 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 spring freshet and lake turnover, although inter-annual variability has also been observed in response to specific climatic events, such as flood conditions during the spring of 2013 and a very dry period that occurred during the spring of 2015. There were no substantial increases in metal concentrations identified from the data collected during the bi-annual (fall and winter) water quality sampling programs, with concentrations of most analytes within the historical ranges. The only exception was total dissolved phosphorous in winter 2018 (0.056 mg/L), which was higher than previous years (0.005 mg/L to 0.032 mg/L). All analytes except sulphide were within water quality guidelines for the protection of aquatic life (CCME 2007) in September 2017 and February 2018. Sulphide exceedances have been observed in the lake in previous years and have been historically common in the Tar River (1998 to 2016; www.ramp-alberta.org), including exceedance observations before Horizon Mine was present on the landscape.

Trophic status of Horizon Lake was evaluated using the production-based trophic state index (TSI) presented in Wetzel (2001). Historically, the lake has generally been classified as an eutrophic system. In 2016, the lake was oligotrophic in winter and mesotrophic in spring; this was the first time the trophic status indicated an oligotrophic state since monitoring began in 2008. The trophic status returned to eutrophic in summer 2017 and remained there through the winter 2018 sampling program.

Aquatic Macrophytes

Macrophytes play an important role in nutrient cycling, provide a food source for aquatic organisms, and provide physical structure that increases habitat complexity for a number of invertebrates and fish species (Wetzel 2001). Similar to results in previous monitoring years, macrophytes were comprised predominately of submergent species in 2017. Total macrophyte cover was approximately 28%, which was slightly below the 33% cover predicted in the Horizon No Net Loss Plan (NNLP). Overall, macrophytes appear to be well-established in the littoral zone of Horizon Lake.

Plankton

Phytoplankton abundance and biomass in 2017 were both within the ranges observed in previous years. 2017 was the second consecutive year that the highest annual richness was observed in fall; prior to 2016, the highest annual richness was always recorded in summer. Species richness in the fall has gradually increased since 2013 and was higher in 2017 than all previous years. Simpson's diversity has been relatively consistent since monitoring commenced in 2008. Overall, Horizon Lake currently supports a highly diverse phytoplankton community.

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 from 2008 to 2013, and diatoms contributing a larger proportion of the biomass from 2014 to 2017. 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).

Similar to previous years, seasonal peaks in phytoplankton abundance occurred in the summer; phytoplankton biomass has historically been highest in summer, with the exception of 2010 , when biomass peaked in fall.

Zooplankton abundance and biomass were higher in 2017 than previous monitoring years with the exception of abundance in 2012. 2017 was the first year that ciliophora made up the largest portion of abundance in summer and fall; rotifers have generally been the most abundant group in all seasons since monitoring commenced. The presence of ciliophora has not been consistent from year-to-year, with observations in all three seasons only occurring in 2012, 2015, and 2017. Similar to previous years, the dominant zooplankton group by biomass was Rotifera. Overall, Horizon Lake supports a low to moderately diverse and moderately variable zooplankton community. Low evenness indicates that the abundance of individual zooplankton taxa is not equal within Horizon Lake and the community is dominated by high abundance of a few taxa.

Phytoplankton and zooplankton communities are naturally dynamic, fluctuating both seasonally and temporally (Findlay and Kling 1979 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, zooplankton can influence phytoplankton biomass, abundance, and community composition through top-down control (Carpenter and Kitchell 1984).

Benthic Invertebrates

In 2017, Diptera (true flies, midges, and mosquitoes) were the most abundant taxa by density in Horizon Lake, followed by Oligochaeta (worms). Diptera and Oligochaeta have been the most abundant taxa in the mid-lake and littoral sites since 2008. Similar to previous years, average benthic invertebrate density and richness were highest in the near-shore area, followed by the littoral area, and the mid-lake area in 2017. This was expected given shallower lake regions generally have greater amounts of oxygen and primary production, higher habitat heterogeneity, and greater food resources available. It is also known that habitats that receive limited light exposure (i.e., deeper waters) are known to deter colonization by many benthic invertebrate species. Benthic invertebrate communities have generally been dominated by collector-gatherers at all areas in all years. Near-shore benthic invertebrate communities have generally contained a higher number of functional feeding groups, including macrophyte herbivores, omnivores, scrapers, and shredders. This is indicative of a greater number of food sources available closer to shore, such as assorted aquatic vegetation, terrestrial inputs from the riparian zone, and nutrients and light conditions that encourage periphyton and phytoplankton to flourish. The percent ETO (percentage of fauna as Ephemeroptera, Trichoptera, and Odonata) has generally been low (less than 1%) at all areas in all years. Overall, the benthic invertebrate community assessments for Horizon Lake suggest that habitat quality has improved over time, which may be a result of more diversity in primary production and food sources for invertebrates, and more available habitat niches. Community fluctuations are likely reflecting seasonal variation in temperature and water quality, as increasing diversity and evenness are creating robustness within the benthic invertebrate populations in Horizon Lake.

LESSONS LEARNED

The monitoring strategy for Horizon Lake was to evaluate the establishment of various ecological attributes 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 resident fish species. Fish production was 701 kg in 2017, which was lower than the compensation target of 2,543 kg/year in the DFO Authorization for the Horizon Project. Although the 2017 fish production estimates for Horizon Lake were lower than the previous three years (2014 to 2016), the hydroacoustic surveys indicated robust and consistent fish populations are still present in the lake.

The hydroacoustic surveys also showed consistent distribution of fish sizes. The approved fish production method has returned consistent estimates over multiple years, and there is evidence that the 2017 results were the anomalous result of a combination of factors, including: low capture rates of large-bodied species; high minnow trapping capture rates of fathead minnow; and possible size selection bias in the fish capture program. The production and biomass calculations carried these unusual results through to the final production estimates, and consequently these results should be interpreted with some caution, as they may not accurately represent actual fish production in 2017. Further investigation into this reported decline will be presented in the 2018 annual report, in conjunction with the results of a fall 2018 repeat of the hydroacoustic survey. Overall, the continued capture of a broad range of ages of both longnose and white sucker indicate that adult populations continue to grow in Horizon Lake and that recruitment of young fish continues to occur.

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PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Hatfield Consultants. 2018. Horizon Lake Monitoring Program – 2017 Technical Report. Prepared for Canadian Natural Resources Limited. North Vancouver, BC: Hatfield Consultants. p. 237.

RESEARCH TEAM AND COLLABORATORS

Institution: Hatfield Consultants

Principal Investigator: Daniel Moats

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Meghan Isaacs	Hatfield Consultants	Environmental Specialist		
Tim Poulton	Hatfield Consultants	Senior Environmental Specialist & Manager		
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Compensation Lake Studies

COSIA Project Number: LJ0260

Research Provider: Golder Associates

Industry Champion: Imperial Oil Resources Limited

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 invertebrates in littoral and pelagic habitats
- Aquatic vegetation establishment
- Phytoplankton and zooplankton

PROGRESS AND ACHIEVEMENTS

Water Quality

Results show that Muskeg Lake was well oxygenated and slightly alkaline in 2018. Concentrations of total suspended solids (TSS), total dissolved solids (TDS), total alkalinity, and nutrients were within the ranges measured in previous monitoring years, with the exception of total alkalinity and nitrate in March, which were higher than the previous ranges. Major ion concentrations were generally in the ranges measured in previous years, with the exception of sodium in March, which was higher than the previous range. Concentrations of magnesium and sulphate were lower than the previous range in September. Concentrations of total and dissolved metals were generally within the range of concentrations documented in previous years – when concentrations did deviate from the previous ranges, they were usually higher than the range in March (e.g., arsenic and boron), and lower than the range in May and September (e.g., sulphur and uranium).

Fish And Fish Habitat

Fish sampling, via minnow trapping and gill netting, was conducted in May (spring) and August/September (late summer) in 2018. A total of eight fish species were captured in 2018. The total number captured (in spring and summer) and average weight (spring) is summarized below:

- Northern pike (*Esox lucius*): 80 (average weight 1938.7 g)
- Longnose sucker (*Catostomus cacatostomus*): 2 (average weight 251.9)
- White sucker (*Catostomus commersonii*): 53 (average weight 737.2 g)
- Brook stickleback (*Culaea inconstans*): 3,005 (average weight 1.3 g)
- Fathead minnow (*Pimephales promelas*): 4,960 (average weight 2.4 g)
- Finescale dace (*Phoxinus neogaeus*): 5,180 (average weight 1.7 g)
- Northern redbelly dace (*Chrosomus eos*): 439 (average weight 1.6 g)
- Pearl dace (*Margariscus margarita*): 2,834 (average weight 3.7 g)

Habitat data recorded in 2018 included: continuous water temperature, dissolved oxygen, pH and specific conductivity in the pelagic zone. While both littoral and pelagic data-loggers were deployed in late May, the littoral logger malfunctioned a few days after deployment and no data was collected for the littoral zone for 2018.

Aquatic Vegetation

In 2018, the distribution of the aquatic macrophytes in the littoral zone was mapped. A total of 100 areas of aquatic macrophytes were identified along the shoreline, showing continuous expansion of vegetation relative to distributions mapped in 2016 and 2017. The vegetation identified included sedges (*Cyperaceae*), sago pondweed (*Potamogeton pectinatus*), cattails (*Typh*a), coon tail (*Ceratophyllum demersum*), northern water milfoil (*Myriophyllum exalbescens*), floating leaf pondweed (*Pontamogeton natans*) and floating aquatic vegetation mats.

Benthic Invertebrates

Data were collected in late summer/fall 2017 but sample analysis was not completed at the time of the COSIA Land EPA 2017 Mine Site Reclamation Research Report, so this summarizes the results of the 2017 sampling. Samples were collected from both deep (pelagic) and shallow (littoral) sampling locations. Mean total density of benthic invertebrates was moderate (i.e., in the range of 5,000 to 50,000 organisms/m^2) at the littoral sampling location and similar to densities recorded in 2016, while density increased from low (i.e., <5,000 organisms/m^2) to moderate at the pelagic sampling location compared to previous years. Taxonomic richness was moderate (i.e., in the range of 10 to 40 taxa) at both the littoral and pelagic sampling locations. At both locations, diversity indices were high and evenness was moderate, indicating diverse communities with fairly even abundance between the different taxa.

At the littoral sampling location, the benthic invertebrate community was dominated by non-biting midges (*Parakiefferiella sp.*, *Tanytarsus sp*. and *Cryptochironomus sp.*) and seed shrimp (Ostracoda). They comprised approximately 48% and 16% of the community, respectively.

At the pelagic sampling location, the benthic invertebrate community was dominated by non-biting midges (*Chironomus sp., Procladius sp.*and *Tanytarsus sp.*) and seed shrimp (Ostracoda). They comprised approximately 49% and 32% of the community, respectively.

Benthic invertebrate samples were also collected in late summer/fall 2018, but sample analysis is not available for this report.

Plankton

Data were collected in late summer/fall 2017 but sample analysis was not completed at the time of the COSIA Land EPA 2017 Mine Site Reclamation Research Report, so this summarizes the results of the 2017 sampling. Mean taxonomic richness of zooplankton was found to be 15 ± 1.2; while that for phytoplankton was found to be 36.7 ± 1.5. Total and percent abundance and biomass as well as dominant taxa by biomass were also determined for both phytoplankton and zooplankton.

Comparisons of results to date have shown that zooplankton mean abundance and biomass steadily increased year over year to 2016, followed by a relatively large increase in 2017. Phytoplankton mean abundance and biomass has varied year over year but has generally been similar between years, until 2017 when a relatively large increase occurred.

Plankton samples were also collected in late summer/fall 2018, but sample analysis is not available for this report.

LESSONS LEARNED

A summary of the current level of development and trends for the biological components of the Muskeg Lake based on the monitoring data for the period 2013 to 2018 is highlighted below:

Aquatic Macrophytes:

- Success of planted pondweed stands was low to moderate for shallow plantings and nil for deep plantings.
- Bulrush plantings were completely successful (high survival and moderate to high vigor with evidence of spreading).
- Natural colonization of other aquatic vegetation has been observed in the littoral zone and mapping of aquatic vegetation indicates continuing expansion of aquatic macrophytes in the lake.

Plankton (indicator of lake productivity):

- Zooplankton biomass has increased annually in Muskeg Lake, with a relatively large increase in 2017.
- Muskeg Lake zooplankton biomass was initially much lower than that of Kearl Lake, but in 2016 reached the minimum level found in Kearl Lake and in 2017 exceeded levels found in Kearl Lake.
- Recent Zooplankton taxonomic richness in Muskeg Lake is within the range recorded for Kearl Lake.
- Phytoplankton biomass and richness developed rapidly (unlike zooplankton), followed by variable levels from year to year. By completion of filling of Muskeg Lake in 2013, phytoplankton biomass and richness had already achieved levels similar to the lower ranges of Kearl Lake.

- Recent phytoplankton biomass has exceeded the levels recorded in Kearl Lake and richness is within the range of Kearl Lake.

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

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

Fish Populations:

- The number of fish species captured in Muskeg Lake steadily increased over the monitoring years and all fish species present in Kearl Lake colonized Muskeg Lake by 2017.
- Muskeg Lake is providing secure overwintering habitat for both Muskeg and Kearl Lake fish populations as well as year-round habitat for forage fish, suckers and sport fish.
- Muskeg Lake is providing suitable habitat for large-bodied fish.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2018.

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: Suncor Energy Inc.

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

Status: Year 6 of 6 (final year with 3-year extension)

PROJECT SUMMARY

Development of large mining projects can require temporary or permanent removal of fish habitat. To offset fish habitat losses as per Fisheries Act Authorization requirements, 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 refinement of existing HSI models to quantify fish habitat in the Athabasca oil sands region. 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. This provided a synopsis of the information collected to date, which allowed data gaps to be assessed. Further, this work 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 although individual operators had obtained substantial data for several fish species additional data was required for a number of key fish 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 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. The key objectives of Phase 2 were to:

- Collect fish habitat-use observations to address the data gaps identified in Phase 1.
- Develop a method 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 validated with empirical data.
- Satisfy HSI model validation conditions in a number of operator Fisheries Act Authorizations.

PROGRESS AND ACHIEVEMENTS

The third and final year of Phase 2 data collections, analysis, modeling and report writing was completed in 2015. Sampling activities in 2015 included 192 mesohabitat units and 180 fish and fish habitat records for five priority fish species (Arctic grayling, burbot, northern pike, walleye, and longnose dace). In 2015, 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 modeling was completed in the spring of 2016 to provide information to refine the HSI models for 14 fish species from the Athabasca oil sands region. The fish species include the five priority fish species noted above, two sucker species (longnose sucker and white sucker) and a number of small-bodied fish species (brook stickleback, finescale dace, fathead minnow, lake chub, pearl dace, slimy sculpin, and troutperch). The analysis used a model selection and weight-of-evidence approach to identify habitat variables that limit fish abundance, which were then incorporated into revised HSI models for each species. The report was finalized during a two day workshop in February 2018.

OUTCOMES AND LESSONS LEARNED

Study outcomes were as follows:

- regional HSI's were validated for species where sufficient data was available;
- model validation could not be completed for data-poor species including walleye, Arctic grayling, northern pike, and yellow perch; and
- modified and new regional SI's were developed.

The final report is complete and has been reviewed. Planning is ongoing for potential conference presentations and/or primary publications.

LITERATURE CITED

Golder Associates Ltd. (Golder). 2008. Fish species habitat suitability index models for the Alberta oil sands region. Version 2.0. October, 2008.

PRESENTATIONS AND PUBLICATIONS

Hatfield and Ecofish, 2018. Refinement of Fish Habitat Pre-Disturbance Models: Phase 2. In Preparation. Prepared for: CANADA'S OIL SANDS INNOVATION ALLIANCE (COSIA), FISHERIES SUSTAINABLE HABITAT (FiSH) COMMITTEE. 338p.

RESEARCH TEAM AND COLLABORATORS

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

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

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	Modeling Specialist		

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 4 of 5 duration

PROJECT SUMMARY

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

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

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

This project is a collaboration with COSIA Project LJO071, Assessing the Productive Capacity of Compensation Lakes. The specific objective of this project is to relate habitat to growth relationships of fish.

PROGRESS AND ACHIEVEMENTS

Sampling

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

Laboratory Analysis

- Otiliths (all species) and cleithra (Northern Pike) were extracted and analyzed from four species: Northern Pike (NRPK), White Sucker (WHSC), Lake Whitefish (LKWH) and Yellow Perch (YLPR) from six lakes in the Lower Athabasca region.

Table 1 – Sample sizes of age structures extracted from four species of fish from lakes in the Lower Athabasca region. Species codes are: Northern Pike (NRPK), White Sucker (WHSC), Lake Whitefish (LKWH) and Yellow Perch (YLPR).

Lake	NRPK	WHSC	LKWH	YLPR
Steepbank	30	17	NA	NA
Unnamed 1	30	13	NA	NA
Unnamed 2	24	17	NA	NA
Goodwin	30	11	30	30
Kirby	30	8	16	30
Wappau	30	17	NA	28
Total	**174**	**83**	**46**	**88**

LESSONS LEARNED

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

PRESENTATIONS AND PUBLICATIONS

Journal Publications

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

Conference Presentations/Posters

Theis, S., Roberts, K., and M.S. Poesch. Does habitat offsetting work: a cross continental meta-analysis of North American and European freshwaters. North American Congress for Conservation Biology, Toronto, ON, July 2018 (Poster).

Roberts, K.N., Ruppert, J.L.W., and M.S. Poesch. The Long-Term Dynamics of Fish Community Structure in Northern Lakes. CANFORWEST, Banff AB, April 2018. Oral Presentation (reviewed).

Theis, S., Roberts, K., and M.S. Poesch. Offsetting in aquatic ecosystems, a meta-analysis. Alberta Chapter of the Wildlife Society Annual General Meeting, Lethbridge, AB, March 2018.

Roberts, K.N., Ruppert, J.A., and M.S. Poesch. Fish assemblage structure and dynamics in novel ecosystems. Canadian Conference for Fisheries Research, Edmonton, AB, January 2018.

Terry, M.W., Ruppert, J.L.W. and M.S. Poesch. Hydroacoustic based estimates of fisheries productivity in the Athabasca oil sands: Implications for offsetting. Canadian Conference for Fisheries Research, Edmonton, AB, January 2018.

Theis, S., Roberts, K., and M.S. Poesch. Offsetting in aquatic ecosystems, a meta-analysis. Canadian Conference for Fisheries Research, Edmonton, AB, January 2018 (Poster).

Reports & Other Publications

Theis, S., Ruppert, J.L.W., Minns, K., Koops, M., and M.S. Poesch. (In Review) Does habitat offsetting work? A cross-continental synthesis assessing compliance and ecosystem function in North American and European freshwaters. Conservation Biology.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark S. Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	M.Sc.	2016	2018
Karling Roberts	University of Alberta	PhD	2016	2020
Sebastian Theis	University of Alberta	PhD	2017	2022

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

Assessing the Productive Capacity of Compensation Lakes

COSIA Project Number: LJ0171

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 4 of 5

PROJECT SUMMARY

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

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

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

The key objectives of the project are:

1. Assess methods for measuring fisheries productivity across compensation lakes and natural systems
2. Assess how habitat influences fisheries productivity
3. Assess the use of artificial structures to enhance habitat for species of concern
4. Assess functional diversity in compensation lakes
5. Compare food-web structure (e.g., stable isotopes, fatty acids) of compensation lakes as compared to pristine, minimally impacted, and highly disturbed lakes and rivers

PROGRESS AND ACHIEVEMENTS

Sampling

- Four lakes, Steepbank, Goodwin, Unnamed Lake (near Conklin), and Horizon Lake (CNRL mine site), were sampled for fish, invertebrates, and basal resources in winter 2018

- Invertebrates and basal resources sampled in three lakes (Steepbank, Goodwin, and Unnamed Lake (Conklin) in summer 2018

Laboratory Analysis

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

Hydroacoustics Surveys

- 14 Hydro acoustic surveys – day and night
- Sampled fish species (N = 244) – Pike, White Sucker, Perch, Lake Whitefish, Spottail Shiner, Ninespine Stickleback
  - Otoliths, length, weight, sex, stomach, gonads, liver, tissue, scales, fin clip

Habitat Enhancements

- Implementation of 2 different habitat enhancement treatment sites
  - Collection of habitat data – to be analyzed
  - Invert data
  - Fish counts – to be analyzed
  - Mark and recapture for pike VIE (N = 23)
  - Mark and recapture Spottail Shiners Fin CLIP (N = 77)

LESSONS LEARNED

Analysis of hydroacoustic data showed a broad range in biomass and productive capacity/fisheries productivity within the Lower Athabasca region. For example, analysis of hydroacoustic data collected in fall 2017, across five lakes revealed a mean fish density of between 0.04 fish/m^3 to 1.50 fish/m^3, with an average lake density of 0.55 fish/m^3. Preliminary analysis clearly illustrates fish density was variable across each lake and observed distribution patterns are consistent with what would be expected given the life histories characteristics of the species present. For example, lakes containing lake whitefish and yellow perch exhibited significantly higher fish densities at lower depths compared to lakes where the only sport fish was northern pike. These species regularly inhabit deeper regions of the lake typically not visited by northern pike, which are generally observed at depths less than five metres.

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

In the global synthesis provided by Theis et al. (In Review), they show that in general, offsetting in aquatic systems has high compliance and that compliance does not necessarily mean increased ecosystem function. Compliance was generally low in offsetting projects that required new structures.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

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

Conference Presentations/Posters

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Terry, M.W., Ruppert, J.L.W. and M.S. Poesch. Hydroacoustic based estimates of fisheries productivity in the Athabasca oil sands: Implications for offsetting. Canadian Conference for Fisheries Research, Edmonton, AB, January 2018.

Theis, S., Roberts, K., and M.S. Poesch. Offsetting in aquatic ecosystems, a meta-analysis. Canadian Conference for Fisheries Research, Edmonton, AB, January 2018 (Poster).

Reports & Other Publications:

Theis, S., Ruppert, J.L.W., Minns, K., Koops, M., and M.S. Poesch. (In Review) Does habitat offsetting work? A cross-continental synthesis assessing compliance and ecosystem function in North American and European freshwaters. Conservation Biology.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta

Principal Investigator: Dr. Mark Poesch

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Michael Terry	University of Alberta	M.Sc.	2016	2018
Karling Roberts	University of Alberta	PhD	2016	2020
Sebastian Theis	University of Alberta	PhD	2017	2022

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

SOILS AND RECLAMATION MATERIALS

Surface Soil Stockpiling Research

COSIA Project Number: LJ0264

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial Oil Resources Limited

Status: Year 3 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.

Mine operators are required to minimize mixing of markedly different soil textures, and in some cases may be required to segregate upland surface soil by ecosite (Alberta Environment and Water 2012; Beckingham and Archibald 1996) to preserve soil texture and other soil qualities, and to maintain separate and distinct seed banks. Research, however, suggests that viability of plant propagules significantly diminishes with depth in soils that are stockpiled for long periods of time. (MacKenzie 2013). Storing different textured soils 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 coarse textured soils (a/b surface soil) can be co-mixed with moderate/fine textured soils (d/other surface soil) in the same pile without negatively affecting soil chemical and physical properties or potential vegetation community (specifically a/b ecosite vegetation) establishment.

The following treatments are being evaluated:

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

In 2016 six stockpiles were constructed (two ABSS, two OSS and two MIXED) at the Kearl Oil Sands Operation. Each stockpile is approximately 3,000 m^3 in volume, with a maximum height of 5 m and a footprint of approximately 38 m x 38 m. The average grade for all slopes on each stockpile is 3H:1V (Horizontal:Vertical). To mimic operational procedures as closely as possible, mixing of the ABSS + OSS stockpiles was not perfectly homogenous. Mixing was accomplished by dumping alternating loads of ABSS and OSS; a support dozer was used to achieve further mixing. Stockpile surfaces were rough-textured to reduce erosion.

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

PROGRESS AND ACHIEVEMENTS

Soil Monitoring:

Soil monitoring for Year 2 (2018) was conducted in October for the six stockpiles. A summary of the sampling protocol is provided below.

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

For 2018, most of the measured parameters in the MIXED stockpiles were still similar to the ABSS or OSS stockpiles. A summary is shown below (Figure 1). The electrical conductivity (EC) increase and sodium adsorption ratio (SAR) decrease with depth is believed to be related to the leaching of soluble ions from the surface to deeper layers.

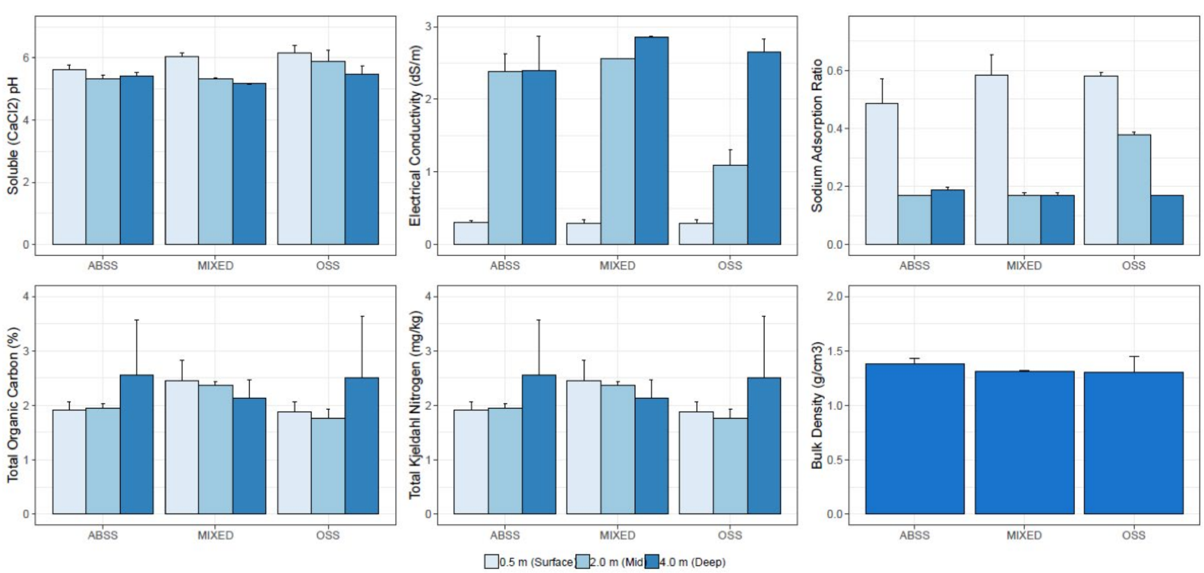

Figure 1: Soil Parameter results for 2018

Vegetation Monitoring:

To capture a representative sample of established vegetation on the stockpiles in 2018, three plots (0.5 m x 1.0 m) were established on the north slope and three plots were established on the south slope (lower, mid, and upper slope) on each stockpile. In 2017, vegetation was only monitored in plots along the plateau of the stockpiles. Since vegetation establishment in these plots was very poor, likely due to compaction during the intense monthly soil sampling, these plateau plots were deemed not representative of the stockpile so the vegetation monitoring plots were adjusted in 2018.

Percent cover of vegetation, leaf litter, and bare ground were recorded and used to calculate key vegetation performance parameters. A larger survey of each stockpile was also completed; any species observed on the six stockpiles that were not captured in the vegetation plots were recorded, resulting in a value of true species richness on each stockpile.

Total vegetative cover and evenness in the plots were not significantly affected by stockpile type in 2018. Species richness in the plots was, however, significantly affected by stockpile type (OSS was higher than the MIXED or ABSS stockpiles). Species richness when assessed on the stockpiles as a whole (determined by total number of species observed on each stockpile) was, however, not significantly affected by stockpile type. The MIXED and OSS stockpiles had significantly greater diversity compared to the ABSS stockpiles. A summary of the vegetation performance parameter results as measured in 2018 are presented in Figure 2.

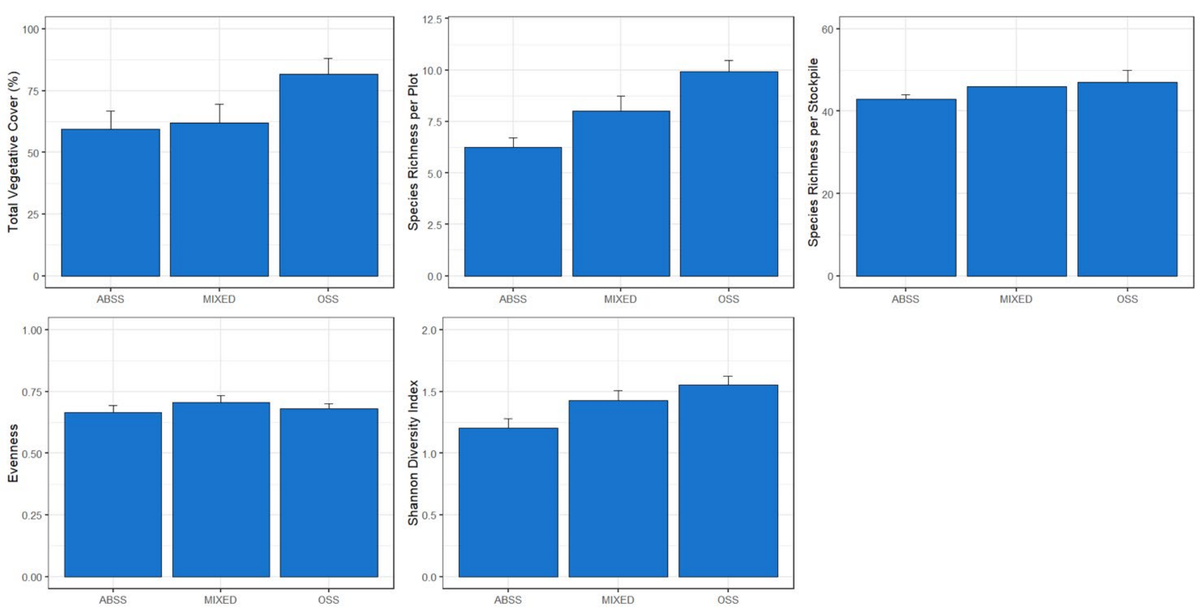

Figure 2: Vegetation Parameter results for 2018

LESSONS LEARNED

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

LITERATURE CITED

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

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

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

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released in 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and & Environmental Consulting Inc.

Principal Investigator: Brittany Flemming, PhD.

Nutrient Biogeochemisty 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 Oil Resources Limited, Suncor Energy Inc., Total E&P Canada Ltd.

Status: Year 8 of 8

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 with peat or peat-mineral mix coversoil 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 with peat or peat-mineral mix coversoil. 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 peat or peat-mineral mix coversoil, 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

Below is a summary of the progress and achievements from the work conducted under Objective 7. Please refer to previous COSIA Land EPA Mine Site Reclamation Research Reports for outcomes of other objectives.

Objective 7: Modelling the effects of soil cover depth on tree growth and productivity in reclaimed saline-sodic overburden landscapes

Nilusha Welegedara completed a PhD thesis which used *ecosys*, a process based ecosystem model, to forecast short and long-term effects of plant productivity on different soil cover depth treatments of Syncrude Canada Ltd.'s South Bison Hill research trial. The South Bison Hill research trial consists of three capping treatment designs: 1) 15 cm of Peat coversoil over 20 cm clay loam to clay textured, Pleistocene till and glaciolacustrine mineral subsoil (35 cm total cover cap); 2) 20 cm Peat over 30 mineral subsoil (50 cm total cover cap); and 3) 20 cm Peat over 80 cm mineral subsoil (100 cm total cover cap). The South Bison Hill research study is a long-term study site assessing vegetation response, soil-water availability and salt movement on reclaimed saline-sodic overburden (Clearwater Formation). Previous studies have modelled water availability and salt movement (physical and chemical processes), but *ecosys* also simulates biological and nutrient cycling processes. In addition, the study has provided detailed descriptions for processes and field measurements in reclaimed covers using basic fundamental theories, and an integrated assessment of water, salinity, nutrient and carbon cycling, and their interactions, for different reclamation cover depths constructed on a reclaimed landform.

The study used *ecosys* to evaluate the effect of different soil cover depths on: a) soil-water availability and plant water-use efficiency, b) salt-redistribution, and c) nitrogen mineralization and plant nitrogen uptake. The study also assessed the effect of soil cover depth on forest regeneration under different climate conditions, the current climate and a warming climate scenario.

The modelled changes in soil moisture, rooting depth, tree water-use, salt redistribution, soil and foliar nitrogen (N) concentration and aboveground tree biomass with soil cover depth followed the same trends as independent measurements. Greater soil moisture content (θ), plant water-use, N mineralization, N uptake and consequently greater biomass were modelled in 100 cm cover vs. 35 cm and 50 cm covers particularly during dry and intermediate years, after the sites had reached over-story crown closure (2011 - 2015). However, a clear relationship between root zone salt concentrations, driven by upward salt migration from underlying overburden, and biomass growth was not apparent. Also a clear topographical effect was not found for salinity in the reclamation covers during the study period. Upward salt diffusion into the covers equilibrated with salt removal from the covers through convection with downslope water movement over time, maintaining stable salt concentrations in the root zone. This equilibration indicated that long term plant growth in the covers may not be affected by the salinity in the overburden. However, modeling found salt removal and consequent discharge with downslope water flow from the covers, indicating a risk of salinization in downslope areas.

Modelled net primary productivity (NPP) increased linearly with modelled transpiration (R2 > 0.9) and N uptake (R2 > 0.8) that increased with available water holding capacity (AWHC) and total soil nitrogen (TN) that in turn increased linearly with cover depth. However, there were non-linear relationships between transpiration and AWHC and between tree N uptake and total N. After running *ecosys* with seven hypothetical covers in addition to constructed landforms (35 cm, 50 cm and 100 cm), results also indicated that there is little effect of cover depths greater than 100 cm on forest regeneration. The 100 cm cover achieved NPP similar to that of natural boreal mixed-wood forests of the region earlier than did the 35 cm and 50 cm covers. However, the long-term (100 yrs.) modelling without any ecosystem disturbances indicated that all the reclamation covers reached a similar NPP (~400 g C m-2 y-1) during wet years after approximately 25 years from start of reclamation, comparable to the NPP modelled for a similar age regenerating natural site after stand replacing fire within the region.

Long-term modelling (1999 - 2099) with climate change (Representative Concentration Pathway [RCP] 8.5) increased NPP in the 100 cm cover (22%) more than in the 50 cm cover (15%) and the 35 cm cover (14%) because NPP in the shallower covers declined during dry years due to lower AWHC. Also aspen vs. white spruce growth tended to increase with increasing soil cover depth and warming due to improved water and N uptake associated with greater AWHC and total soil nitrogen. However, the NPP gains modelled in all the reclaimed sites under warming climate were lower than that of the regenerating natural site (45%) due to decreased soil nutrient availability of peat coversoil, particularly phosphorus, over time. Thus, P fertilization may be needed to achieve a productivity gain in reclaimed areas similar to natural sites under climate change.

LESSONS LEARNED

Below are some key outcomes derived from the work conducted under Objective 7. Please see previous COSIA Land EPA Mine Site Reclamation Research Reports for outcomes under other objectives.

Some key outcomes of *ecosys* modelling of saline-sodic overburden reclamation at the South Bison Hill Research were the following:

- *Ecosys* model outputs in the study were closely aligned with results from other independent modelling and field studies conducted at South Bison Hill, adding confidence to the findings of these studies.
- Greater θ, plant water-use, N mineralization, N uptake and consequently greater biomass were modelled in 100 cm cover vs. 35 cm and 50 cm covers, particularly during dry and intermediate years.
- A clear relationship between root zone salt concentration and biomass growth was not apparent.
- After running ecosys with a range of cover depths, results indicated that there is little effect of cover depths greater than 100 cm on forest regeneration, as further increases in AWHC and total N would have little effect on NPP.
- Long-term (100 yrs.) modelling indicated that all the reclamation covers reached a similar NPP (~400 g C m-2 y-1) after approximately 25 years from start of reclamation, comparable to the NPP modelled for a similar age regenerating natural site after stand replacing fire within the region.
- Long-term modelling (1999 - 2099) with climate change (RCP 8.5) increased NPP in the 100 cm cover (22%) more than in the 50 cm cover (15%) and the 35 cm cover (14%) because NPP in the shallower covers declined during dry years due to lower AWHC.

- Long-term modelling using *ecosys* of the South Bison Hill research trial (Peat [or peat-mineral mix] over finer-textured mineral subsoil) with a RCP 8.5 climate change scenario indicated that nutrients in peat coversoil, particularly phosphorous, would limit an increase in plant growth in reclaimed areas compared to that in regenerating natural sites.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Welegedara, N.P.Y. 2019. Modelling Short and Long-term Effects of Soil Cover Depth on Tree Growth and Productivity in Reclaimed Landscapes of Northern Alberta. Ph.D. Thesis. Department of Renewable Resources, University of Alberta.

Journal Publications

McAdams, B.N., Quideau, S.A., Swallow, M.J.B., and Lumley, L.M. 2018. Orbatid mite recovery along a chronosequence of afforested boreal sites following oil sands mining. Forest Ecology and Management. 422 (2018) 281-293.

Norris, C.E., Quideau, S.A., Landhäusser, S.M., Drozdowski, B., Hogg, K.E. and Oh, S.-W. 2018. Assessing structural and functional indicators of soil nitrogen availability in reclaimed forest ecosystems using 15N-labelled aspen litter. Can. J. Soil Sci. 98: 357-368 (2018).

RESEARCH TEAM AND COLLABORATORS

Institution: 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	Post-Doctoral Fellow	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	Post-Doctoral Fellow	2012	2014

Jacynthe Masse	University of British Columbia	PhD	2011	2016
Nilusha Welegedara	University of Alberta	PhD	2013	2018
Brittany McAdams	University of Alberta	M.Sc.	2015	2017
Cassandra McKenzie	University of Alberta	M.Sc.	2015	2017

Limitations of Stockpiled Soil

COSIA Project Number: LJ0300

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 1 of 2

PROJECT SUMMARY

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

Some of the specific questions to be answered include:

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

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

PROGRESS AND ACHIEVEMENTS

There is no progress to report for 2018. The Principal Investigator left the Canadian Forest Service (CFS) and was no longer available to lead this project. However, personnel at CFS have now been assigned and it is expected to resume in 2019.

LESSONS LEARNED

No lessons learned at this time.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service, University of Alberta

Principal Investigator: Brad Pinno

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Edith Li	Canadian Forest Service	Research Technician		
Sophia Yang	Canadian Forest Services/ University of British Columbia	Student Intern (BSc)		2020
Chris Wohl	Canadian Forest Services/ University of British Columbia	Student Intern (BSc)		2018

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

COSIA Project Number: LJ0299

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 2 of 3

PROJECT SUMMARY

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

This project seeks to answer two main research questions:

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

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

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

The primary value of this work is the confidence that it could give operators in understanding how to approach their stockpiled assets in the future, and the development of tools for assessing soil health that are more directly relevant to reclamation practices than current methods.

PROGRESS AND ACHIEVEMENTS

In 2017, soil samples for chemistry, microbiology, and seed bank analysis were obtained, along with aboveground plant assessment, for one stockpile showing three different broad aboveground plant categories (dominated by wheatgrass; dominated by sow thistle and sweet clover; or mixed). Aboveground species abundance, richness, evenness, and coverage were assessed, and seedbank quantity and quality was determined at each depth (Table 1). The primary findings for this unseeded stockpile were that the aboveground species observed were natives (sow thistle, sweet clover, wheatgrass), that the viability of seeds decreased dramatically with depth in the stockpile, and that the seedbank was strongly impacted by aboveground vegetation (Buss and Pinno, in press). It is currently unclear whether these findings are broadly applicable as they were done on only a single site; the 2018 sampling should address these concerns. Also, for the 2017 samples, community level physiology profiling, broad chemical analyses (as listed in Table 1) and DNA extraction were completed and are currently undergoing analysis.

In 2018, eight stockpiles were sampled; four at Wolf Lake (an *in situ* oil sands site in Central Alberta) and four at Horizon (an oil sands surface mine in Northern Alberta). Each stockpile was a different age and was sampled in three locations. Horizon stockpiles consisted of ages six months, 1.5 years, five years and seven years, and Wolf Lake stockpiles were two years, six years, 11 years and >28 years of age. There were eight stockpiles and six natural sites sampled, each with three plots, for a total of 42 sampling plots in the study. Seed bank samples were taken from five different depths for the stockpiles and six different depths for the natural sites (Table 1). Samples were also taken from below one metre for seven of the stockpile locations (Table 1). One of the stockpiles did not have a deep sample because it did not extend much deeper than one metre.

There were a total of 235 soil samples taken from both study locations, with 99 from Horizon and 136 from Wolf Lake. In addition to the soil samples, above ground vegetation cover was also sampled at each of the 42 plot locations in June/July 2018. The vegetation data has been processed and entered and will be analyzed with the seed bank data. Initial analysis has started on these data sets.

The seed bank samples were processed in September/October and are currently in the greenhouse as part of a seedling emergence study. The greenhouse experiment began in November 2018 and will run until the end of February. Once the greenhouse work is completed, data analysis will begin. The greenhouse results will be used to compare seed bank communities with the above ground plant communities.

Basic soil parameters, such as gravimetric water content, pH, electrical conductivity, and soil texture have been measured for both the stockpile and natural reference sites at every depth. Total carbon and nitrogen, as well as aggregate size distributions, of the bulk soil samples collected have also been measured for all sites, though on a subset of depths. For these variables, the data is currently being entered and organized in preparation for future statistical analysis. Bulk densities are being calculated and water retention curves generated on soil cores collected for all sites and the same subset of depths mentioned above, with the lab work expected to be completed in the coming months.

For the 2018 samples, CLPP (Community Level Physiological Profiling) studies are underway for all 0 cm to 10 cm and deep samples. Once the 2018 CLPP data has been completed, ordination analyses for both 2017 and 2018 samples will be undertaken in combination with plant, seedbank, and chemistry data to determine the impact of stockpiling on these features, and any possible correlations between these factors. Similarly, deoxyribonucleic acid (DNA) extraction has been completed for all samples collected in 2017, and DNA extraction is currently underway for 0 cm to 10 cm and deep samples collected in 2018. Extraction is expected to be completed by March, and DNA sequencing of 16S rRNA genes will be undertaken immediately. Once the sequences are obtained, the ordination data mentioned above will be used as a guide to evaluate whether microbial community structure is related to soil functioning and health, as determined by the ordination described above.

Table 1: Timeline and sampling strategy.

	2017*	2018**	2019
Main goal	Protocol development; site identification	Primary sampling; above-ground and below-ground analyses	Complete analyses; follow up sampling; model development
Sampling Depths	0-10 cm; 10-30 cm; 30-100 cm	0-5 cm; 5-10 cm; 10-20 cm; 20-30 cm; 80-90 cm	N/A
Sites	1	8 stockpile + 6 natural	0
Samples per site	9	15 stockpile + 18 natural + 7 deep stockpile	0
Soil parameters	• Microbial community analyses (functional diversity, community richness, community evenness, community composition) • General soil parameters (pH, EC, total C, total N, nutrients, CEC, texture) • Organic matter quality • Bulk density • Field capacity	• Microbial community analyses • General soil parameters • Organic matter quality • Residual organic matter stability • Release of bioavailable nutrients • Bulk density • Field capacity • In situ soil temperature profiles • Pore size distribution	• Complete analysis • Biodiversity intactness modelling
Plant Parameters	• Species abundance • Community richness • Community evenness • Coverage	• Species abundance • Community richness • Community evenness • Coverage • Seed bank quantity and quality • Aboveground and root biomass	• Complete analysis • Biodiversity intactness modelling

*Completed
**Sampling completed; analyses underway.

LESSONS LEARNED

The lessons learned at this point are minimal as the process of analyzing samples collected in 2017 and 2018 is ongoing and the data has not yet been integrated. However, based on the 2017 plant survey and seedbank germination data, it has been found that the plants in the stockpiles tend to be native species (primarily forbs and grasses); that the seed viability decreases with depth; and that the aboveground species make the largest contributions (and therefore impact) to seedbank composition throughout the stockpiles (Buss and Pinno, in press).

There are two major management implications from these observations:

1. Weed control is critical on soil stockpiles to prevent weed establishment following placement as a reclamation material; and
2. As stockpile depth affects seedbank viability, shallower stockpiles are preferred.

Note that these findings are preliminary and are subject to modification once complete data has been obtained and analyzed from the more rigorously sampled 2018 samples.

LITERATURE CITED

Alberta Environment and Water. 2012. Best Management Practices for Conservation of Reclamation Materials in the Mineable Oil Sands Region of Alberta. Prepared by MacKenzie, D. for the Terrestrial Subgroup, Best Management Practices Task Group of the Reclamation.

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

Buss, J. and B. Pinno. (2019 in press) Soil stockpile seed viability declines with depth and is impacted by surface vegetation. J. Amer. Soc. Mining Reclam.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

Buss, J. and B. Pinno. (2019 in press) Soil stockpile seed viability declines with depth and is impacted by surface vegetation. J. Amer. Soc. Mining Reclam.

Conference Presentations/Posters

J. Buss and B. Pinno, 2018. Soil stockpile seed viability is affected by depth and current surface vegetation. American Society of Mining and Reclamation Conference. St. Louis, MO, USA. (20 min oral presentation)

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)
Brad Pinno	University of Alberta	Assistant Professor		
Sylvie Quideau	University of Alberta	Professor		
Miles Dyck	University of Alberta	Professor		
M. Derek MacKenzie	University of Alberta	Associate Professor		
Helena Magaldi-Ribiero	University of Alberta	Ph.D.	2016	2020
Jennifer Buss	University of Alberta	M.Sc.	2017	2020
Kyle Stratechuk	University of Alberta	M.Sc.	2018	2020

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 2

PROJECT SUMMARY

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

The objective of this study is:

1. Examine the biological implications of soil chemistry in 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 and on reclamation areas. 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 sodicity, or perhaps other chemical parameters.
   - Using these data to develop a Soils Index of Biological Integrity (if possible) that may be used to further understand how soil health can be measured and understood in the context of reclamation. The Soils IBI will be further refined and tested with data as new reclamation comes online, and will be used as a tool to monitor reclamation progress and success.

PROGRESS AND ACHIEVEMENTS

During the summer of 2018, 50 new sites were sampled, all located on reclamation polygons constructed during the previous winter. The final ecosite target for the reclamation treatments that were sampled are d-ecosites (Beckingham & Archibald, 1996), which matches the previously sampled natural and disturbed sample locations. These samples will provide a baseline for the biological communities in reclamation polygons.

The mesofauna in the samples collected over the past three summers have been identified, counted, and categorized into relative abundances and densities of arthropods in both coarse and fine textured soils (Figures 1 and 2). Statistical analyses determined if any relationships exist between the natural, cleared, and reclaimed treatment sites. There are some distinct relationships that have emerged between the treatment types and the arthropod communities. For example, arthropod densities were often considerably lower in the reclaimed sites, compared to natural or disturbed sites. As well, certain families of arthropods showed differences in relative abundance between soil types, but the Acari and Collembola did not.

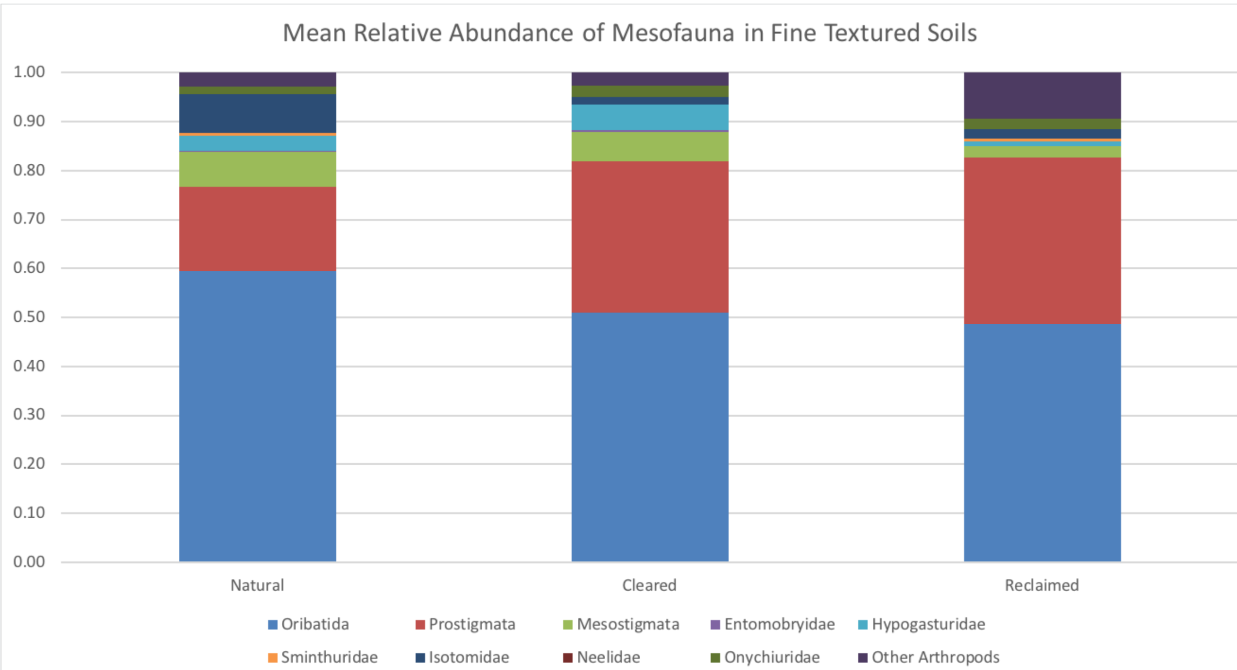

Figure 1- Mean Relative Abundance of Mesofauna in Fine Textured Soils.

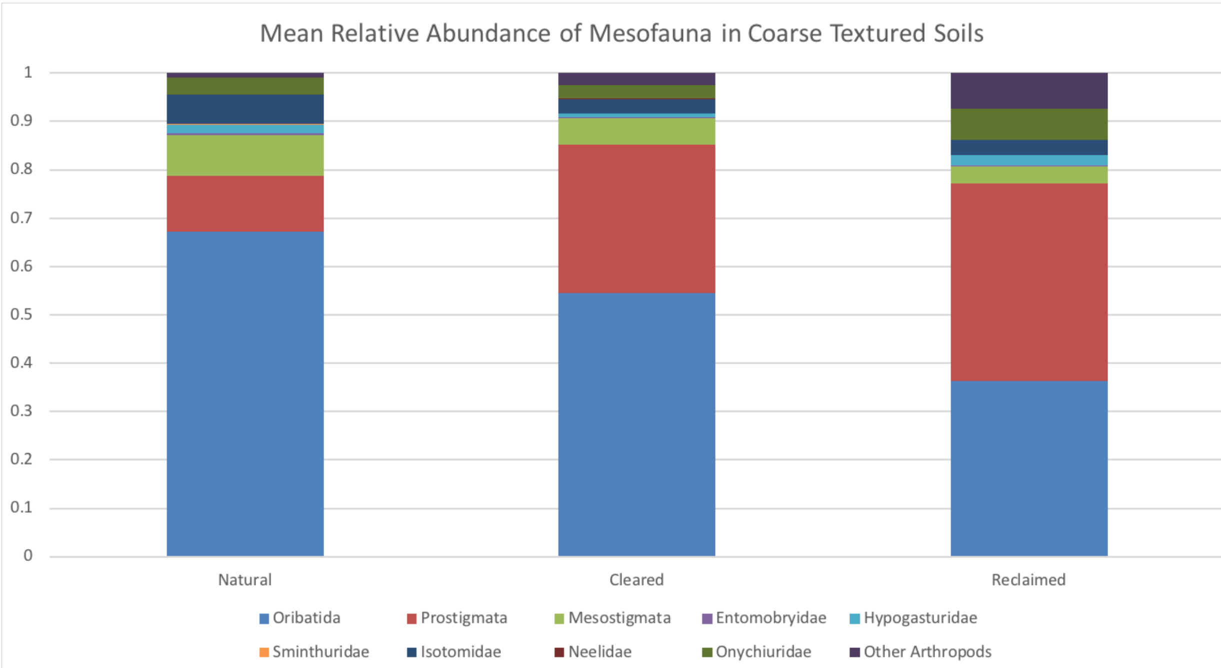

Figure 2- Mean Relative Abundance of Mesofauna in Coarse Textured Soils.

LESSONS LEARNED

This study is in early stages and so there are no lessons learned to report for 2018.

LITERATURE CITED

Beckingham, J. D., Archibald, J. H., & Northern Forestry Centre (Canada). (1996). Field guide to ecosites of northern Alberta. Edmonton: Northern Forestry Centre.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2018.

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. Jeff Batigelli	University of Alberta	Researcher		
Dr. Derek MacKenzie	University of Alberta	Assistant Professor		
Helena Ribeiro	University of Alberta	PhD		
Gregory Hook	Canadian Natural Resources Limited	Reclamation Specialist	2016	2019
Ira Sherr	Canadian Natural Resources Limited	Reclamation Specialist		

REVEGETATION

NSERC – Industrial Research Chair in Forest Land Reclamation

COSIA Project Number: LE0012

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 5 of 6

PROJECT SUMMARY

Oil sands extraction is a major component of the Alberta and Canadian economy, and the associated surface mining temporarily disrupts forest ecosystems. A pressing objective of land reclamation in the boreal forest region is to return disturbed sites to functioning and self-sustaining ecosystems. Early in the recovery of forests, the main challenge is rapid 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, competition and limited soil nutrients, during stand initiation and development. In addition, it is exploring the use of different topographical features to promote more spatially diverse site conditions resulting in more diverse plant communities.

The Chair is addressing three general topic areas and associated research questions:

Accelerating Forest Establishment

- How does the application of organic amendments (e.g., salvaged peat or forest floor material) influence tree and vegetation establishment on undeveloped subsoil mineral surface substrates?
- Can a fast-growing herbaceous cover crop be used as a deep soil amendment to improve growing conditions on nutrient poor sites?
- What is the impact of specific fertilization prescriptions on newly planted trees across different capping materials and what is its effect on understory vegetation and competition?
- What is the impact of increased surface roughness on environmental gradients and microsite variability? How do these gradients affect the establishment of tree and understory species and community development in reclamation sites?

Influencing Forest Stand Trajectories

- Can aspen stem density and performance be increased in older reclamation sites by cutting to promote vegetative reproduction (suckering), coupled with reducing competition?
- Can tall aspen stock with high root-to-shoot ratios be developed? How feasible is it to use tall aspen seedling stock on high competition sites?
- Is infill planting of seedlings on low density forest reclamation sites a viable option for forest canopy development and competition control?

Assessing Trajectories of Forest Reclamation

- What role does rooting space play in root water uptake, leaf area, and stand productivity for aspen, jack pine and white spruce in reclaimed oilsands sites?
- What role 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

Below is a summary of the progress and achievements from the work conducted under accelerating forest establishment, influencing forest stand trajectories, and assessing trajectories of forest reclamation objectives. Please refer to previous COSIA Land EPA Mine Site Reclamation Research Reports for outcomes of other objectives.

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.

A study that tests the arrangement and usage of municipal compost as an organic amendment for successful tree establishment on nutrient limited sites was completed in 2018, with Erika Valek successfully defending her M.Sc. thesis.

To study questions related to the feasibility of enhancing micro- and meso-topography for natural establishment of vegetation and trees, monitoring of early vegetation establishment and tree performance on an operational scale study site was implemented on the Canadian Natural Albian Sands lease. Sophie Aasberg (recruited in 2018) continued the work that was started by Kate Melnik (M.Sc. 2017) and Trevor de Zeeuw (M.Sc. candidate) who studied the early tree and vegetation establishment. Trevor continued to summarize results from his studies and is in the final stages of compiling his thesis. Sophie re-measured all the plots (trees and vegetation) and she will be summarizing the longer-term results of this field study over the next year.

Shauna Stack (M.Sc. candidate) continued to explore nutrient limitations (in particular phosphorous and potassium) as a driver of reduced growth on peat dominated cover soils. In 2016, she applied different fertilizer regimes to plots planted with different tree species and has been monitoring their growth and nutrient uptake. These plots were re-measured in 2018 and Shauna is in the process of summarizing her data and preparing it for a manuscript to be submitted in 2019.

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 adverse effects on stand development. Stand management strategies (e.g., intervention practices) are being explored that could facilitate and improve forest canopy and understory development on older reclamation sites with sparse canopies. In a controlled study, the feasibility of cutting juvenile (8 to 12 years) aspen of seedling origin to increase stem density through root suckering was explored. This study was initially led by Carolyn King (M.Sc.) who finished her projects and successfully defended her thesis in 2017. To explore this topic further, Caren Jones (Research Technician) selected operational reclamation sites in the SAGD and mining region in 2017, which were subsequently cut in 2018, and measured in the late summer of 2018. Summarizing the data and preparing it for publication in 2019 is ongoing.

Assessing Trajectories Of Forest Reclamation:

There has been over 30 years of forest land reclamation in the oil sands area. Assessments 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 drivers of forest stand performance on reclamation sites.

Morgane Merlin (PhD candidate) has successfully analyzed a complex data set that explores how leaf area, rooting depth, and climatic and edaphic variables can be linked to water-use, and how those linkages change with different species. She prepared a manuscript that was submitted in December 2018. In the same context, Morgane and Ashley Hart (M.Sc. candidate) executed a controlled greenhouse study that explored the ability of lateral water movement (hydraulic redistribution) in soils through aspen root systems. Results have been compiled and Ashley is in the process of summarizing her results for her thesis and has also prepared a manuscript for publication. To explore in more depth the accuracy of sap flow measurements to estimate tree water-use, an additional study was executed to validate the Heat Ratio Method for Sap Flow estimation using the cut tree method (whole tree lysimeter). For that study, the stem of a mature aspen (21 m tall) was cut under water and maintained in an upright position using a support tower. Measurements and comparisons of in-situ actual water-uptake, with sap flow measurements, were taken at various locations along the stem. This study was led by Morgane and in 2018 she started to summarize these data. More detailed results are expected in 2019.

LESSONS LEARNED

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

- Plant species diversity can be enhanced considerably by increasing localized variation in microsites for seed germination or enhanced budding from rhizomes, roots and stem fragments in reclamation soils.
    - A greater range in microsite diversity achieved through increased surface roughness and spatial variation in surface soil materials (e.g., relative amounts of mineral and organic soil components) will result in; (i) localized variation in soil moisture and temperature regimes; and (ii) increased opportunities for lodgement and germination of a wide variety of seeds, likely contributing to beneficial increases in boreal forest plant species diversity.
    - Planted tree seedlings also showed a positive response to increased site variability.
- Placing salvaged forest floor material in patches on a reclamation landscape can improve the spread of native boreal forest species. However, it appears that this spread might be relatively slow, as the early colonization of these species into new areas is dominantly through vegetative means such as belowground rhizomes.
- Cutting of juvenile seedling-origin aspen stands (10 to 20 years) can be used to promote suckering and can lead to improved stocking; however, responses are closely related to aspen performance and site conditions of the original stand.
- High Root-Shoot ratios for aspen seedlings are more important than seedling size to promote above- and below-ground competitiveness with existing vegetation on out-planting sites.
- Organic amendments, such as municipal compost, are suitable materials to increase the organic component in reclamation surface soils lacking organic matter. However, caution needs to be taken as these amendments (depending on the source materials) can also produce negative effects such as increased competition and higher salinity in the reclamation surface soils.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Bockstette J. 2018. The role of soil reconstruction and soil amendments in forest reclamation. M.Sc. thesis, University of Alberta, 95 pages.

Valek ER. 2018. Challenges of utilizing municipal compost as an amendment in boreal forest reclamation subsoil material. M.Sc. thesis, University of Alberta, 104 pages.

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

Howe A. 2018. Assessment of a seedling-based approach to aspen restoration in the intermountain west. M.Sc. thesis, Utah State University, 72 pages.

Journal Publications

Bockstette, S.W., Pinno, B.D., and S.M. Landhäusser. 2018. Responses of planted Populus tremuloides seedlings to grass competition during early establishment [online]. Trees. doi: 10.1007/s00468-018-1710-3.

Jones, C.E. and S.M. Landhäusser. 2018. Plant recolonization of reclamation areas from patches of salvaged forest floor material. Applied Vegetation Science 21: 94-103.

Jones, C.E., Bachmann, S., Lieffers, V.J., and S.M. Landhäusser. 2018. Rapid understory plant recovery following forest floor protection on temporary drilling pads. Restoration Ecology 26: 48-55.

King, C.M. and S.M. Landhäusser. 2018. Regeneration dynamics of planted seedling-origin aspen (Populus tremuloides Michx.). New Forests 49: 215-229.

Melnik, K., Landhäusser, S.M., and K. Devito. 2018. Role of microtopography in the expression of soil propagule banks on reclamation sites. Restoration Ecology 26(S2): S200-S210.

Merlin, M., Leishman, F., Errington, R.C., Pinno, B.D. and S.M. Landhäusser. 2018. Exploring drivers and dynamics of early boreal forest recovery of heavily disturbed mine sites: a case study from a reconstructed landscape [online]. New Forests. doi: .10.1007/s11056-018-9649-1.

Norris, C.E., Quideau. S.A., Landhäusser, S.M., Drozdowski, B., Hogg, K.E., and S. Oh. 2018. Assessing structural and functional indicators of soil nitrogen availability in reclaimed forest ecosystems using 15N-labelled aspen litter. Canadian Journal of Soil Science 98: 357-368.

Refereed publications supported by the chair position, with research funding from other sources

Cobb, R.C., Ruthrof K.X., Breshears, D.D., Lloret, F, Aakala, T, Adams, H.D., Anderegg, W.L., Ewers, B.E., Galiano, L., Grünzweig, J.M., Hartmann, H., Huang, C., Klein, T., Kunert, N., Kitzberger, T., Landhäusser, S.M., Levick, S., Preisler, Y., Suarez, M.L., Trotsiuk, V., Zeppel M.J.B. (2017). Ecosystem dynamics and management after forest die-off: a global synthesis with conceptual state-and-transition models. Ecosphere, doi:10.1002/ecs2.2034.

Hartmann, H., Adams, H.D., Hammond, W.M., Hoch, G., Landhäusser., S.M., Wiley, E., and S. Zaehle. 2018. Identifying differences in carbohydrate dynamics of seedlings and mature trees to improve carbon allocation in models for trees and forests. Environmental and Experimental Botany 152: 7-18.

Kokkonen, N.A., Macdonald, S.E., Curran, I., Landhäusser, S.M. and V.J. Lieffers. 2018. Effects of substrate availability and competing vegetation on natural regeneration of white spruce on logged boreal mixedwood sites. Canadian Journal of Forest Research 48: 324-332.

Pinno, B.D. and S.M. Landhäusser. 2018. Linking basic and applied research in North American forest ecosystems – The 11th North American Forest Ecology Workshop. Forest Ecology and Management 421: 1-2.

Weber, R., Schwendener, A., Schmid, S., Lambert, S., Wiley, E., Landhäusser, S.M., Hartmann, H., and G. Hoch. 2018. Living on next to nothing: tree seedlings can survive weeks with very low carbohydrate concentrations. New Phytologist 218: 107-118.

Wiley. E., Rogers, B.J., Griesbauer, H.P. and S.M. Landhäusser. 2018. Spruce shows greater sensitivity to recent warming than Douglas-fir in central British Columbia. Ecosphere 9(5): e02221.

Conference Presentations/Posters: Supported by the chair position, with research funding from COSIA and/or other sources (* indicates presenter)

Mendoza C*, Lukenbach M, Twerdy P, Carey SK, Devito K, Landhäusser SM. 2018. Ecohydrological development of a reclaimed upland-wetland system constructed on soft tailings at an oil-sand mine, NE Alberta, Canada. EGU General Assembly 2018, 8–13 April 2018, Vienna, Austria.

Welegedara N*, Grant RF, Quideau S, Landhäusser SM, Merlin MA, Lloret E. 2018. Modelling tree water uptake and water use efficiency as affected by cover thickness in reclaimed open pit mining landforms. AGU 2018, Washington, DC Dec. 10-14, 2018. Abstract available here: https://agu.confex.com/agu/fm18/meetingapp.cgi/Paper/364818

Stack S*, Landhäusser SM. 2018. Challenges in reconstructing soils: building the foundation for forest restoration in mine reclamation areas. Atlantic Reclamation Conference (ARC2018), Miramichi, NB, Oct. 15-18, 2018. Abstract available here: http://atlanticclra.ca/wp-content/uploads/2018/10/Shauna-Stack-sstack_CLRAabstract2018.pdf

de Zeeuw, T*, Melnik, K, Landhäusser, SM. 2018. The role of microtopographical surface soil variation in boreal forest reclamation. Society of Ecological Restoration Europe Conference 2018. Restoration in the Era of Climate Change, Reykjavik, Iceland Sep. 9-13, 2018. Abstract available here: https://sere2018.org/wp-content/uploads/2018/09/Abstract-bok-oral-poster-workshop-symp_10-9-1.pdf

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	2018
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	2020
Carolyn King	University of Alberta	M.Sc.	2015	2017
Erika Valek	University of Alberta	M.Sc.	2015	2018
Shauna Stack	University of Alberta	M.Sc.	2016	2018
Trevor de Zeeuw	University of Alberta	M.Sc.	2016	2019
Ashley Hart	University of Alberta	M.Sc.	2016	2019
Sophie Aasberg	University of Alberta	M.Sc.	2018	2020
Coral Fermaniuk	University of Alberta	M.Sc.	2018	2020

Kevin Solarik	University of Alberta	Post-Doctoral Fellow	2017	2018
Emily Reich	University of Alberta	Research Assistant		
Brittany Hynes	TU Munich, Germany	Research Assistant		
Daniel Doyon	University of Alberta	Research Assistant		
Caren Jones	University of Alberta	Technician		
Fran Leishman	University of Alberta	Technician		
Pak Chow	University of Alberta	Technician		

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

NSERC–Industrial Research Chair in Terrestrial Restoration Ecology

COSIA Project Number: LE0034

Research Provider: University of Alberta

Industry Champion: Syncrude Canada Ltd.

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

Status: Year 3 of 6

PROJECT SUMMARY

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

The focus of this research program is to increase the scientific understanding of how belowground features interact with self-sustaining forests. The overarching research question is whether LOS acts as a barrier or medium to 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 question:

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

PROGRESS AND ACHIEVEMENTS

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

As the bulk of the research under the Industrial Research Chair (IRC) requires identification of roots, the first task was to refine and develop existing molecular tools designed for this purpose. A reference data base of DNA markers for ~ 200 plant species occurring in the region was created. This database is used to identify individual root samples to species.

Understanding the ecological factors influencing root distribution of target plant species desired in revegetation of reclaimed sites is an important step in designing cover soils. Together, two M.Sc. students are investigating how abiotic and biotic factors influence root distributions of boreal forest communities. Specifically, one project focuses on characterizing root distributions in soils that differ in texture (M.Sc. student, Brown), and a second project focuses on how root profiles change with stand age (M.Sc. student, Wasyliw). The former project was carried out in aspen stands occurring on fine and coarse textured soils, and samples are being processed now. For the latter project, roots were sampled that were present up to 90 cm below the soil surface along transects in pine stands of varying age. Associated aboveground characteristics (tree age, leaf area, tree height and size) were recorded. Samples are being processed.

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

Shallow oil sand deposits (<50 cm) occur naturally in the Mineable Oil Sands Region and forests have been growing on these deposits since the last ice age. These natural deposits are generally well weathered and can be variable in form, presenting as either bitumen masses (commonly referred to as tar balls) or bands through the soil profile. This allows for the possibility that a tree could directly interact with or simply avoid the bitumen present in the deposits. Understanding how tree roots respond to natural bituminous deposits may help predict root behaviour, and ultimately forest establishment, on reclaimed landforms containing LOS in the rooting zone (soil covers). However, locating roots of individual trees is an arduous, time-consuming and destructive activity.

M.Sc. student La Flèche used dendrochemical analysis of aboveground tree tissue to determine whether roots interact with these shallow oil sand deposits. Dendrochemistry, using tree rings to monitor changes in soil and atmospheric chemistry over time, is a growing branch of science that has been used largely to study environmental contamination from nearby industrial practices. La Flèche used this technique to determine the potential of trace metals vanadium (V), molybdenum (Mo), nickel (Ni) and rhenium (Re) to act as indicators of tree rooting behavior in bituminous soils.

Five sites presenting shallow natural bituminous deposits and two sites free of bitumen (all confirmed with tests of soil hydrocarbons) were sampled for trace metals in boles of jack pine trees and soils. Along with this project, La Flèche also characterized root growth and presence of trace metals in tree seedlings growing on a recently reclaimed LOS landform at the Canadian Natural Horizon mine site.

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

Some species or populations of root microbes may be restricted to sites with oil sand present, while others may be found only on sites free of oil sand; these patterns would suggest specialization. This premise is the basis for screening plants and microbes as candidates for phytoremediation of hydrocarbon contaminated soils. James Franklin, a PhD student who started September 2017, will build his research around this particular focus. To date, he has conducted a broad survey of natural bituminous sites, and sampled fungi from these sites in addition to soils of several bitumen-free forests. Using Illumina next generation sequencing, he will characterize arbuscular and ectomycorrhizal fungi occurring in the samples. Franklin will develop this project over the next year to include experiments that test for the importance of these symbionts in mediating tree survival in oil sands.

LESSONS LEARNED

Currently, the key outcome and contribution from this project is a set of refined molecular methods for identifying plant species based on root fragments, along with a comprehensive library of DNA markers by species. These outcomes will support future work on understanding how various plant species are utilizing (or being limited by) reclamation soils or any other soil environments in the boreal forest.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Metzler, P. 2018. Molecular Identification of Boreal Forest Roots: An Expansion of Techniques and Investigation of Limitations and Biases. M.Sc. thesis, Department of Renewable Resources, University of Alberta

Journal Publications

Metzler, P., La Flèche M., Karst, J. Expanding and testing fluorescent amplified fragment length polymorphisms for identifying roots of boreal forest plant species. In revision for Applications in Plant Sciences.

Conference Presentations/Posters

La Flèche, M., Shotyk, W., Karst J. 2018. Trace metals as indicators of rooting behaviour in bituminous soils. International Conference on Heavy Metals, Athens, Georgia, USA July 22-July 26. Abstract included in Conference Program. Available here: https://img1.wsimg.com/blobby/go/88952f9a-7856-428d-8dfb-fa50527081c3/downloads/1cpabe9ho_738953.pdf

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.	2016	2018
James Franklin	University of Alberta	PhD	2017	2021
Marc La Flèche	University of Alberta	M.Sc.	2017	2019
Josh Wasyliw	University of Alberta	M.Sc.	2017	2019
Ariel Brown	University of Alberta	M.Sc.	2017	2019
Nicholas Brown	University of Alberta	M.Sc.	2018	2020
Brea Burton	University of Alberta	Summer Undergraduate Technician		

Andrea Simeon	University of Alberta	Summer Undergraduate Technician		
Jason Eerkes	University of Alberta	Summer Undergraduate Technician		
Christine Simard	University of Alberta	Lab Technician		
Serena Farrugia	University of Alberta	Summer Undergraduate Technician		
Pak Chow	University of Alberta	Lab Technician	2016	

Research Collaborators: Pedro Antunes, Algoma University; Willima Shotyk, University of Alberta; Brian Lanoil, University of Alberta

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 6 of 6

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 internal and external (certification) evaluation 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 evaluation 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 focused on measurement and interpretation of ecosystem fluxes using the eddy-covariance technique, and is being undertaken by McMaster and Waterloo universities. WP2 is focused on biometric covariates to ecosystem fluxes, and is being completed by Integral Ecology Group. WP3 is a knowledge synthesis that draws together elements of the first two package along with other sources of relevant information. WP3 is a cooperative effort between all organizations.

PROGRESS AND ACHIEVEMENTS

Eddy covariance monitoring in 2018 provided an additional seven site-years of water and carbon flux data beyond the sixty site-years previously acquired. Two meetings were held with Industry Collaborators to present and discuss findings, and to evaluate the best options for presenting the final synthesis of learnings. A final Knowledge Synthesis report is nearing completion.

LESSONS LEARNED

Key learnings from this project include:

1. Fluxes of water and carbon, as measured by eddy covariance techniques, are valuable integrative indicators of ecosystem function and performance for reclaimed sites, and for contrasting reclaimed and natural sites.
2. Reclaimed soils on the study sites have a similar capacity as surrounding natural soils to provide water to ecosystems in support of vegetation growth and other ecosystem processes.
3. Reclaimed ecosystems within the study have similar levels of Actual Evapotranspiration (AET) and Net Ecosystem Productivity (NPP) as ecosystems on surrounding undisturbed sites, with similar rates of development following either reclamation or natural disturbance.
4. Development of leaf area following reclamation follows similar patterns and at similar rates as on natural ecosystems following natural or logging-based disturbances.
5. Several easy-to-measure biometrics, and most particularly leaf area index (LAI), correlate well with eddy covariance measures of AET and NPP, offering the possibility of extrapolating these functional metrics of ecosystem performance to non-instrumented sites where the simpler biometric values are available. Potential applications include site-wide quantification and prediction of, (i) ecosystem water yield contributing to landform recharge, wetland water supply and streamflows, (ii) developing reclaimed ecosystems as carbon sinks for carbon balance modeling, and (iii) overall terrestrial ecosystem productivity as supporting evidence for reclamation certification and evaluation of equivalent land capability at mine closure.

PRESENTATIONS AND PUBLICATIONS

Published Theses

Strilesky SL. 2019. Functioning of reclaimed oilsands ecosystems and the implications for reclamation certification. PhD Dissertation, Carleton University, 156 pp.

Journal Publications

Chasmer L, Baker T, Carey SK, Straker J, Strilesky S, Petrone R. 2018. Monitoring ecosystem reclamation recovery using optical remote sensing: Comparison with field measurements and eddy covariance. Science of the Total Environment, 652, 436-446. doi: 10.1016/j.scitotenv.2018.06.039

Conference Presentations/Posters

J. Straker, T. Baker, S. Carey, R. Petrone. 2018. Using ecosystem water and carbon fluxes as integrated measures of reclamation success. *Northern Latitude Mining Reclamation Workshop.* Whitehorse, Canada. September 10-13, 2018. [Oral, invited] Available here: https://www.yukonminers.org/index.php/presentations/63-straker-justin-using-ecosystem-water-and-carbon-fluxes/file

RESEARCH TEAM AND COLLABORATORS

Institutions: McMaster University / University of Waterloo / Integral Ecology Group

Principal Investigators: Sean Carey / Richard Petrone / Justin Straker

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Stacey Strilesky	McMaster / Carleton	PhD	2014	2019
Gordon Drewitt	McMaster University	Research Associate		
Erin Nicholls	McMaster University	MSc	2013	2015
Chelsea Thorne	McMaster University	MSc	2013	2015
Felix Nwaishi	University of Waterloo	Partial Post-Doctoral Fellow	2015	In progress
George Sutherland	University of Waterloo	Research Associate	2015	In progress
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	In progress
Jeff Anderson	Integral Ecology Group	Restoration Ecologist		
Trevor Baker	Integral Ecology Group	Soil Scientist		
Meghan Laidlaw	Integral Ecology Group	Terrestrial Ecologist		

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 5 of 6

PROJECT SUMMARY

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

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

A total of 35 clones selected from Al-Pac's CPP-PB1 registered clonal population were included in this field study based on the results from previously completed salt screening. Twenty-five of these clones were the top performing clones in the 50% OSPW treatment (high salt treatment) and were chosen as the 'salt tolerant treatment group' (Treatment 1) and 10 of the remaining clones that did not exhibit salt tolerance in the 50% process affected water treatment were chosen as a control group (Treatment 2). The Syncrude Stream I cuttings (Treatment 3) were included as a second control to compare the Al-Pac CPP clones to a local unscreened population.

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

PROGRESS AND ACHIEVEMENTS

The work completed on this project in 2018 consisted of annual tree measurements at the end of the growing season. Variance in site factors at the different trial locations appears to be having a major impact on the growth of the poplars. The locations in Sandhill Wetland are struggling while the trial at Base Mine Lake is thriving, with order-of-magnitude differences in growth being observed. At this time, high water tables and associated low soil oxygen levels at the Sandhill Wetland sites are suspected as the primary cause of poor growth rather than high salinity. High tree mortality associated with flooding after a severe rain event in August 2018 has negatively impacted sites in the Sandhill Watershed, and these sites may need to be abandoned.

Trial completion is expected in the fall of 2019.

LESSONS LEARNED

There are no lessons learned to be reported for 2018 since clonal trends for salt tolerance have not yet been evaluated

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		

Oil Sands Vegetation Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting, Inc.

Industry Champion: Canadian Natural Resources Limited

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

Status: Ongoing

PROJECT SUMMARY

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

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

PROGRESS AND ACHIEVEMENTS

In 2018, the OSVC continued its efforts to direct research applicable to the efficient use of seed and alternative propagules as well as successful native plant community establishment.

Additional activities supporting OSVC initiatives included:

1. Annual reporting on OSVC seed collection and banking activities.
2. Preparing and maintaining research needs documents and tracking current research initiatives.
3. Completing a literature review regarding vegetative propagation of boreal shrub species.
4. Continuing to pursue the establishment of stooling beds for beaked hazelnut (*Corylus cornuta*), and seed orchards for red-osier dogwood (*Cornus sericea*).
5. Initiating a pilot study for vegetative propagation of beaked hazelnut (*Corylus cornuta*) and lowbush cranberry (*Viburnum edule*).

6. Providing seeds for the Alberta Government to further their research on shrub seed viability, germination, and longevity.
7. Liaising with the Alberta Government to improve seed collection methods on public lands.
8. Entering into discussions regarding seed banking and collection to support related projects such as provincial caribou conservation, and revegetation of conventional oil and gas sites provincially.

In 2018, the OSVC harvested 2,665 litres (L) of seed from five seed zones in northeastern Alberta. The following were extracted and registered:

COLK – 900 L of tamarack seed from a single lot in seed zone CM 3.1.
SAOS – 1,330 L of tamarack seed from four seed lots from seed zones CM 2.1, CM 2.4, CM 3.1 and LBH 1.5.
NAOS – 435 L of seed from 33 seed lots representing 21 species from seed zones CM2.1 and CM 2.2.

Table 1. Species harvested

NAOS	
Alnus viridis (green alder)	*Larix laricina* (tamarack)
Amelanchier alnifolia (Saskatoon)	*Linnaea borealis* (twinflower)
Arctostaphylos uva-ursi (bearberry)	*Populus balsamifera* (balsam poplar)
Betula papyrifera (paper birch)	*Populus tremuloides* (trembling aspen)
Caltha palustris (marsh marigold)	*Prunus pensylvanica* (pin cherry)
Chamerion angustifoilum (fireweed)	*Prunus virginiana* (chokecherry)
Cornus canadensis (bunchberry)	*Rhododendron groenlandicum* (Labrador tea)
*Cornus sericea (*red-osier dogwood)	*Shepherdia canadensis* (buffaloberry)
Corylus cornuta (beaked hazelnut)	*Vaccinium myrtilloides* (blueberry)
Dasiphora fruticosa (shrubby cinquefoil)	*Viburnum edule* (lowbush cranberry)
Empetrum nigrum (crowberry)	

LESSONS LEARNED

The OSVC continues to explore research opportunities that were identified in the earlier knowledge gap analysis. There has been a particular focus on shrub establishment on oil sands reclamation sites, including shrub mortality monitoring and plant material quality, vegetative propagation of boreal shrubs, and increasing the efficiency of seed harvest for key species such as aspen (*Populus tremuloides*). The long-term goal of establishing production units (stooling beds and/or seed orchards) for characteristic shrub species is ongoing and requires collaboration among several stakeholders – industry, nursery producers and the Government of Alberta.

PRESENTATIONS AND PUBLICATIONS

Newsletters

Wild Rose Consulting, Inc. 2018. Oil Sands Vegetation Cooperative Newsletter. May 3(1). 3 pages. https://www.cosia.ca/sites/default/files/attachments/OSVC%20Newsletter%20-%20May%202018.pdf

Wild Rose Consulting, Inc. 2018. Oil Sands Vegetation Cooperative Newsletter. December 3(2). 3 pages. https://www.cosia.ca/sites/default/files/attachments/OSVC%20Newsletter%203%282%29.pdf

Reports

Wild Rose Consulting, Inc. 2018. Vegetative Propagation of Native Shrubs: A Literature Review. 50 pages

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

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

Research Collaborators: Dr. Jean-Marie Sobze, NAIT Centre for Boreal Research; Lindsay Robb, Alberta Tree Improvement and Seed Centre (Government of Alberta)

Jack Pine Establishment

COSIA Project Number: LJ0263

Research Provider: Paragon Soil & Environmental Consulting Inc.

Industry Champion: Imperial Oil Resources Limited

Status: Year 3 of 5

PROJECT SUMMARY

Following surface mining, oil sands operators are required to reclaim the disturbed land such that reclaimed soils and landforms are capable of supporting a self-sustaining, locally common boreal forest regardless of the end land use, and to ensure that the reclaimed land is integrated with the surrounding areas. Establishment of jack pine (*Pinus banksiana* Lamb.) stands on sandy materials (a1 ecosites) is often challenging.

During a 2013 site visit to the Kearl River Water Intake (RWI), substantial ingress of weeds and erosion were noted on sandy reclaimed soils. Dense stands of jack pine were also establishing along the RWI Right-of-Way (RoW) south of the RWI access road. At the time, it was assumed that the jack pine establishment was due to the Richardson Fire that burned the area in May 2011. As with nearby reclaimed areas, the RoW appeared to be colonized by weeds, grasses, and early successional herbaceous species through natural regeneration and/or ingress prior to the fire; jack pine seedlings were not planted.

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

Specific objectives of the trial include: evaluating jack pine revegetation success (via seeding) based on establishment of desired plant communities and trajectory towards the target a1 ecosite phase; comparing 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 indications that alternative revegetation strategies (e.g., other than via seedling planting) are possible.

PROGRESS AND ACHIEVEMENTS

Year 3 (2018) vegetation monitoring for the Jack Pine Revegetation Trial, took place in mid-July 2018. Year 3 monitoring captures the third growing season for the treatment plots, and Year 7 post-fire for the natural burned area. Each subplot was assessed for percent cover of trees, shrubs, forbs, graminoids, bryophytes and lichens, leaf litter and bare ground. Vegetation species were identified with reference to the Flora of Alberta (Moss 1983) and Plants of the Western Boreal Forest and Aspen Parkland (Johnson et al. 1995).

As recommended in the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (the Revegetation Guidelines; AENV 2010), information collected from the vegetation quadrats was used to calculate species abundance, richness, evenness, and diversity, using the Shannon Diversity Index. These vegetation metrics from the three years were compared using analysis of variance. The number of established seedlings in each height class (<5 cm, 6 cm to 15 cm, and >100 cm) was too low to perform statistical analysis.

Jack pine seedlings were present in all treatment plots (100 m^2) at the Bouchier laydown area, and in none of the

treatment plots at the Willbros Laydown (Figure 1). In 2017, seedling emergence at the Willbros Laydown area was minimal. The failure of seedling emergence at the Wilbros laydown was attributed to competition with graminoids at the site. By 2018, no jack pine seedlings had survived at the Willbros Laydown. Jack pine seedlings in plots that established at the natural burned site in 2016 (Year 5) were present in higher numbers than in the treatment plots in 2018 (Year 3). While statistical analyses were not possible, it appears that the number of emerged seedlings in the broadcast seeding treatment at the Bouchier Laydown is similar to the number of seedlings in the natural burned sites. Several seedlings from the heat-treated cones also emerged at the Bouchier Laydown. Very few seedlings emerged from the untreated cones.

Seedling emergence and growth in the treatment plots has been slower than in the natural burn area. By Year 5 (2016) in the natural burn area, most seedlings were taller than 1.0 m. By Year 3 in the treatment plots, seedlings remained shorter than 10 cm.

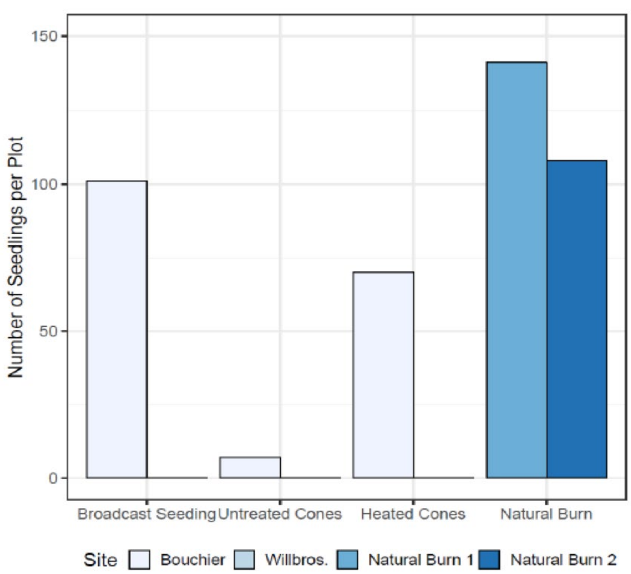

Figure 1. Average number of jack pine seedlings in Year 3 Treatment plots (2018) compared to Year 5 (2016) Natural Burn plots.

None of the community metrics calculated were dependent on seeding treatment in 2018. Most metrics did not change significantly between Year 1 (2016) and Year 3 (2018), except for community evenness, which increased between Year 1 (2016) and Year 2. Values for diversity, species richness, and evenness in subplots were comparable between treatment and natural burned plots in all assessment years (2016 to 2018), with the exception of subplot species richness, which was greater in the natural burn area than in treatment plots in 2016. Percent vegetative cover was generally greater in treatment plots than in the natural burn area, suggesting that shade from jack pine seedlings in the natural burn area has precluded the persistence of early-successional forb and graminoid species in the natural burn area. These early successional species still dominate the treatment plots, particularly graminoid species in the Willbros Laydown. The number of characteristic species was higher in the natural burn area (two to three species) than the treatment plots (zero to one species). The threshold as presented in the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (AENV 2010) for the Dry site type (a1 ecosite phase, pure jack pine dominated) is two species.

LESSONS LEARNED

At this stage in the Trial, broadcast seeding is the most effective treatment for establishing jack pine from seed; however, the treatment is ineffective if there is a high abundance of graminoid present (i.e., if the site has been heavily seeded to grass). Some performance metrics were similar to, or approaching, those in the natural burn area, but a shift away from early successional species was observed for the natural burn area by Year 7 (2018). The treatment plots are still dominated by early successional graminoids and forbs by Year 3 (2018).

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.

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

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

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications were released.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil and & Environmental Consulting Inc.

Principal Investigator: Paragon Soil and & Environmental Consulting Inc.

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

COSIA Project Number: LJ0128

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Imperial Oil Resources Limited

Status: Year 3 of 4

PROJECT SUMMARY

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

Specific objectives are to:

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

The project consists of four studies that include both field and environmentally controlled experimental conditions.

PROGRESS AND ACHIEVEMENTS

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

In 2018, we primarily focused on the data collection and analysis from previous plant growth experiments. The results showed that in both upland and lowland blueberry populations, seedlings inoculated with four ERM fungi (*Pezicula ericae*, isolate #38; *Rhizocyphus ericae*, #50; *Meliniomyces variabilis,* #81; *Oidiodendron maius*, #96) had higher biomass (shoot, root, total dry weight) and gas exchange parameters (net photosynthesis and transpiration rates) compared with the non-inoculated control. Among the four ERM fungi, plants inoculated with #38 had the highest shoot and root biomass in both drought and non-drought treatment experiments, with an increase of about double compared to the control. The water potential in the seedlings inoculated with ERM fungi was also higher than the control seedlings under drought stress. This indicates ERM association improved water absorption capability of blueberry plants under dry soil conditions. The net photosynthesis and transpiration rates in both lowland and upland blueberry inoculated with mycorrhizal #38 were significantly higher than the control under drought and non-drought treatment.

We also amplified six putative blueberry aquaporins (AQPs) from leaf and root samples. Two PIP1 and four PIP2 AQPs were amplified from leaf samples: PIP2;1, PIP2;2, PIP1;3, PIP2;5, PIP1;1, PIP2;8, and one PIP1 and three PIP2 AQPs were amplified from root samples: PIP2;1 PIP2;2 PIP1;1 PIP2;8.

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

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

Six plants of blueberry and six plants of Labrador tea from all three soil treatments (non-autoclaved fresh topsoil, non-autoclaved one-year stockpiled topsoil and autoclaved one-year stockpiled topsoil) were included in the analyses. Roots of each experimental plant were pulverized, and DNA was extracted using the cetyltrimethylammonium bromide (CTAB) method. Subsequent polymerase chain reactions (PCR) were performed using fungal specific ITS1F and ITS4 primers. Thermocycling conditions were as follows: 95 C for two minutes; 33 cycles of 95 C for 30 seconds, 56 C for 30 seconds, 72 C for one minute and final elongation oar 10 minutes at 72C. PCR products were purified using the GeneJET PCR Purification Kit (Thermofisher, Crawley, UK), and cloned into the pCR2.1-TOPO vector (Invitrogen, Paisley, UK). From each experimental group, 25 to 30 positive colonies were selected and stored. Colonies were PCR amplified using M13 sequencing primers. Sequencing of 20 to 30 clones per experimental group was performed using the Sanger DNA Sequencing (MBSU, University of Alberta). Molecular identification of isolated fungi conducted using BLASTn searches of the ITS region at the NCBI website.

Leohumicola verrucose fungus were found in the roots of blueberry and Labrador tea plants grown in autoclaved one-year stockpiled topsoil.

In order to identify fungi species in plant roots of other soil treatments (non-autoclaved fresh topsoil, non-autoclaved one-year stockpiled topsoil), six blueberry and Labrador tea plants were randomly selected from both fresh and non-autoclaved one-year stockpiled topsoils. Molecular analyses showed that *Leohumicola verrucosa* and *Serendipita herbamans* fungi respectively from *Ascomycota* and *Basidiomycota* divisions are common in both plant species in both soil treatments. *Clavaria citrinorubra* were common in both Labrador Tea and Blueberry plants grown only in one-year stockpiled topsoil. *Pezoloma ericae* is considered as prominent ericoid mycorrhizal fungus and was observed in plant roots grown only on fresh topsoil treatments. Other fungi including *Phacidium grevilleae*, *Mycosymbioces mycenaphila*, *Acremonium dichromosporum*, *Micarea soralifera* and *Xenopolyscytalum pinea* from Ascomycota division were found on these ericaceous plant species roots on both fresh and non-autoclaved stockpiled topsoil treatments.

In the present study according to cloning data, out of 20 to 30 selected colonies from each plant root in each soil treatment, we obtained six, one and three ERM fungi from Labrador tea plant roots grown, respectively, in fresh, autoclaved stockpiled, and non-autoclaved stockpiled topsoil. For blueberry plant roots, we obtained, one and five different ERM fungi, respectively, from fresh, autoclaved stockpiled, and non-autoclaved stockpiled topsoil.

2.2 Effect of Ericoid Mycorrhizal Fungi on Ericaceous Plants under Salt Stress

The seeds of blueberry, cranberry and Labrador tea were sterilized and grown on PDA medium (potato dextrose agar) and then transferred to the autoclaved potting mix soils. After four months of growth, we inoculated the plants with two ericoid mycorrhizal fungi *Oidiodendron maius* (#96 isolate) and *Meliniomyces variabilis* (#81 isolate). In this study, 20 seedlings of each plant species were inoculated with *Oidiodendron maius* and another 20 were inoculated with *Meliniomyces variabilis*. Twenty other seedlings of each species remained non-inoculated. NaCl treatment (30 mM) was applied to the plants two months after the inoculation. Ten seedlings from each group of the mycorrhizal and non-mycorrhizal plants for each species were treated by 30 mM NaCl and another 10 were considered as untreated control.

At the end of the experiment in 2018, several physiological parameters including gas exchange, dry weights, chlorophyll concentrations, and mycorrhizal colonization intensity were measured. Overall, the ERM inoculated blueberry, Labrador tea and cranberry showed higher net photosynthesis rate, shoot and root dry biomass, and chlorophyll concentrations compared with non-inoculated plants under both 0 mM and 30 mM sodium chloride (NaCl) treatments. For blueberry, plants inoculated with #96 ERM fungi had better growth and physiological performance compared with those inoculated with ERM fungi strain #81. The NaCl treatment reduced root mycorrhizal colonization percentage in blueberry, Labrador tea and cranberry; however, the mycorrhizal colonization rate of #96 and #81 ERM inoculated plants were still higher than 50%.

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

In June 2018, the roots of blueberry seedlings were immersed in #38 and #96 fungal isolate culture for one week for mycorrhizal inoculation. Then, the seedlings were planted in two blocks at the Horizon reclamation site and one block at the Albian reclamation site. There were three plots in each block with 30 seedlings planted in each plot. In August 2018, 50 ml of #38 and #96 fungi culture were injected in the root zone of each plant for the second mycorrhizal inoculation. We also measured the shoot heights and monitored the survival rate. Two months after planting, about 90% of seedlings were alive in all blocks. We will measure the growth and physiological parameters of the plants again in the summer of 2019 to examine the effects of ERM associations.

LESSONS LEARNED

Study 1

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

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

Study 2

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

Study 3

The results for this study will be available in 2019.

LITERATURE CITED

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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 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta, Department of Renewable Resources,

Principal Investigator: Janusz J. Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Wenqing Zhang	University of Alberta	Post-Doctoral Fellow		
Deyu Mu	University of Alberta	Ph.D.	2016	2019
Sepideh Fadaei	University of Alberta	M.Sc.	2016	2019

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

COSIA Project Number: LJ0303

Research Provider: University of Alberta

Industry Champion: Canadian Natural Resources Limited

Status: Year 3 of 4

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 CNRL Horizon lease must be reclaimed: capped with suitable overburden, subsoils, coversoils, and revegetated. However, there are significant knowledge gaps as to the potential success of NST reclamation, such as how vegetation will tolerate the potentially limited nutrient supply, high pH, elevated salt concentrations, or the presence of phytotoxic substances such as fluoride and naphthenic acids present in the NST substrate. These factors can adversely affect water and nutrient uptake of the plants used for reclamation, as well as microbial activities and community structures, particularly of mycorrhizae, in the reconstructed soils. It is therefore crucial to understand how species that are used in reclamation revegetation and are representative of the locally-common Boreal forest, will respond in the reclamation of NST deposits.

Several plant species used in reclamation are of special significance to Aboriginal communities living in the area. Therefore, an important part of the investigation of NST reclamation will be to understand if potential contaminants from within the NST in reconstructed soils could greatly reduce establishment or 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. In addition, elemental sulfur is an important by-product of oil sands mining industry, and it is commonly used to lower soil pH in agricultural practices. Therefore, elemental sulfur has potential benefits to be used for mitigating high pH stress of reclamation soil on vegetation.

The objectives of the project are:

1. To examine growth and physiological parameters in 20 native boreal forest plant species growing in six types of growth media containing a combination of NST and/or coke, capped with reclamation cover soils.
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, phosphorus and sulfur supplies on plants growing in NST-amended soil.

PROGRESS AND ACHIEVEMENTS

Study 1: Design and Progress

One-year-old seedlings were obtained from the tree nursery and grown in PVC pipes of 50-cm length and 10-cm diameter in a controlled-environment growth room.

The PVC pipes were filled with six types of growth media:

A: 40-cm topsoil (upland forest floor-mineral mix, control);

B: 40-cm peat-mineral mix (PMM, control);

C: 40-cm NST (non-segregating tailings, control);

D: 30-cm NST capped with 10-cm topsoil;

E: 30-cm NST capped with 10-cm PMM; and

F: 30-cm NST capped with 10-cm coke and 10-cm topsoil.

Eight seedlings per species were grown in each growth medium for three months. Plants were watered every two days and fertilized weekly with 50% modified Hoagland's mineral. Seedling shoot heights were measured at the beginning and end of treatment period. At the end of each experiment, leaf gas exchange parameters (net photosynthesis and transpiration rates) were measured with a LICOR-6400 infrared gas analyzer, leaves were sampled for chlorophyll and elemental analysis, and shoots and roots were harvested and oven-dried for biomass measurements.

Species Selected For Each Study:

Experiment 1 (April to June 2018): trembling aspen (*Populus tremuloides*), sandbar willow (*Salix exigua*), lowbush cranberry (*Viburnum edule*), and white spruce (*Picea glauca*).

Experiment 2 (July to September 2018): beaked hazelnut (*Corylus cornuta*), beaked willow (*Salix bebbiana*), and saskatoon (*Amelanchier alnifolia*).

The samples from an earlier study (September to November 2017) were also processed and data analyzed. These included red-osier dogwood (*Cornus sericea*), paper birch (*Betula papyrifera*), green alder (*Alnus viridis*), and Schubert chokecherry (*Prunus virginiana*),

Study 1: Results

Of the 11 studied species, only dogwood and sandbar willow showed no mortality in all treatments. However, these two species showed reduced dry weights in treatment C (NST control). Schubert chokecherry and lowbush cranberry showed greater than 50% mortality in treatment E (NST with PMM cap) and C (NST control). Overall, plants had higher mortality rates in the treatments with media containing NST compared with the control treatments containing only topsoil or peat mineral mix (Treatment A or B).

Only paper birch and green alder plants had significantly higher relative shoot height growth (RSHG) in treatments A and B compared with media containing NST. Paper birch and beaked hazelnut showed the greatest difference of total dry weights between treatment B (PMM control) and treatment C (NST control). White spruce and beaked hazelnut had lower shoot to root dry weight ratios in treatments A, B and F compared with treatments C, D and E. Lowbush cranberry and beaked hazelnut showed the largest reduction of net photosynthesis rate in treatment C compared with treatments A and B. Paper birch demonstrated higher photosynthesis and transpiration rates in treatments A and B compared with other treatments involving NST. Dogwood showed significantly higher transpiration rates in treatment A compared with the remaining treatments. Paper birch and green alder had higher leaf chlorophyll concentrations in treatments A and B compared with other treatments containing NST. White spruce had significantly higher chlorophyll concentrations in treatments A, B and F compared with treatments C, D and E. Beaked hazelnut showed significantly lower chlorophyll concentrations in treatment C compared with the remaining treatments.

For green alder, sandbar willow, lowbush cranberry and beaked hazelnut, the foliar Na concentrations in treatment C (NST control) was significantly higher than for other treatments. For white spruce, the foliar Na concentration in treatment C was significantly higher than for treatments A, B and F. For paper birch, Schubert chokecherry, dogwood and saskatoon, the mean value of foliar Na (sodium) concentration in treatments containing NST was considerably higher than for treatments A and B, however, due to the large variation, the differences were not statistically significant. This indicates that the plants of these species growing in NST-containing media differed strongly in how they were able to control Na uptake. Overall, there was no large difference in foliar Mg, P, K and Cu (magnesium, phosphorus, potassium and copper) concentrations between treatments A or B, compared with other treatments containing NST (C, D, E, F). For lowbush cranberry, white spruce, beaked hazelnut and saskatoon, the foliar Ca (calcium) concentration of treatment B was higher than the treatments containing NST. Fe and Mn (iron and manganese) deficiencies are commonly found in plants growing in high pH soils (George et al. 2012). Among the examined species, in paper birch the foliar Fe concentration in treatment D was significantly higher than in the other treatments; in bebbs willow, foliar Fe concentration in treatment A was significantly higher compared with the other treatments. For paper birch, Schubert chokecherry, sandbar willow, and bebbs willow, the foliar Mn concentration in treatment A (topsoil control) was significantly higher than for other treatments. For white spruce, the foliar Zn (zinc) concentrations in treatment A, B and F were significantly higher than in treatments C, D and E.

Study 2: Design and Progress

The effects of elemental sulphur on growth and physiological responses were studied in beaked hazelnut (*Corylus cornuta*) and saskatoon (*Amelanchier alnifolia*) growing in soil of high pH. The pH of a Boreal topsoil was adjusted to 8.0 with calcium hydroxide using three rates of supplemental sulphur: 0 (control) 5 and 25 g kg^{-1} soil. One-year-old beaked hazelnut (*Corylus cornuta*) and Saskatoon berry (*Amelanchier alnifolia*) were grown in the six soil treatments for two months. Soil pH was monitored weekly. The shoot growth in height, shoot and root dry weights, net photosynthesis, and transpiration rates were measured at the end of experiment. Leaf chlorophyll and element concentrations are currently being analyzed.

Study 2: Results

For pH 8.0 soil, the 25 g S Kg^{-1} soil supplement could effectively reduce soil pH from 8 to 4, while the effect of 5 g S Kg^{-1} soil supplement was relatively small. For pH 6.0 soil, 5 g and 25 g S Kg^{-1} soil supplement reduced soil pH by one and two units, respectively. For beaked hazelnut, the dry weights of plants at pH 8, 5 g/Kg S were significantly higher compared with pH 6, 25 g/Kg S. For saskatoon, the dry weights of plants at pH 8, 0 g/Kg S were significantly higher compared with the plants at pH 6, 25 g/Kg S. For beaked hazelnut, the net photosynthesis rate at pH 6, 0 g/kg S was significantly higher than pH 8, 0 and 5 g/kg S; however, the transpiration rate was lower at pH 6, 5 and 25 g/Kg S treatments. For saskatoon, both photosynthesis and transpiration rates were lower at pH 6, 5 g/Kg S and pH 8, 25 g/Kg S treatments.

LESSONS LEARNED

Study 1

As the permeability of NST is quite low, the plants growing solely on NST were likely under hypoxic stress that aggravated their physiological responses. However, it was shown that capping NST with either topsoil or peat-mineral mix helped to mitigate these physiological stresses. Overall, capping NST with coke resulted in minimal effects on plant growth, the notable exception being white spruce, which showed a decrease in foliar Na concentrations, but increase in foliar Zn concentrations. Importantly, the growth of paper birch, green alder and beaked hazelnut on the NST control was severely inhibited, so the revegetation of these species in NST reclamation will require special consideration. Although there were no severe nutrient deficiencies within the plants during the short experimental period, it is unclear if this trend would continue in a longer-term study period. Therefore, longer-term controlled environment and field studies should be conducted to monitor nutrient uptake in plants growing in NST reclamation areas.

Study 2

This study found that supplementing soil with elemental sulfur effectively mitigated high soil pH effects. In beaked hazelnut, the 25 g/Kg sulfur treatment enhanced the photosynthesis rate for plants growing in pH 8.0 soils, and in contrast the 25 g/Kg sulfur supplement reduced both photosynthesis and transpiration rates in saskatoon at pH 8.0. Future elemental analyses work will provide a better understanding of the potential effects of sulfur supplementation on leaf nutrient balance.

LITERATURE CITED

George E, Horst WJ, Neumann E. Adaptation of plants to adverse chemical soil conditions. In Marschner's Mineral Nutrition of Higher Plants (Third Edition) 2012 (pp. 409-472).

PRESENTATIONS AND PUBLICATIONS

There were no presentations or publications in 2018.

RESEARCH TEAM AND COLLABORATORS

Institution: University of Alberta, Department of Renewable Resources

Principal Investigator: Janusz J. Zwiazek

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Wenqing Zhang	University of Alberta	Post-Doctoral Fellow		
Xuehui (Chris) Sun	University of Alberta	M.Sc.	2018	2020

The Long-Term Plot Network

COSIA Project Number: LJ0295

Research Provider: Forestry Corp (FORCORP), Paragon Soil and Environmental Consulting Inc.

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Imperial Oil Resources Limited, Teck Resources Limited, Suncor Energy Inc., Syncrude Canada Ltd.

Status: Ongoing

PROJECT SUMMARY

The Long-Term Plot Network (LTPN) is a large-scale monitoring and research program of reclaimed mine sites in the Athabasca oil sands region. The LTPN collects data on vegetation and soil dynamics, as well as growth rates of commercial timber species, on plots established on reclamation areas. By tracking the progress of reclaimed sites over the long-term, the project can assess outcomes of different reclamation techniques, which in turn supports achieving regulatory requirements for monitoring and certification, as well as providing rich, contextual reclamation datasets for applied research initiatives.

The goals of the LTPN are:

1. Develop and maintain a longitudinal sampling program for upland reclamation sites across the oilsands mineable region in order to provide a comprehensive repeated-measures dataset that quantifies vegetation outcomes of a wide range of reclamation practices, and supports related applied research.
2. Develop an understanding of vegetation dynamics, tree growth, and soil dynamics in the period following reclamation treatments, in order to guide reclamation planning in the short term.
3. Develop an understanding of plant community structure and composition, reclaimed soil properties, and potential for commercial forest stands to support assertions of achieving Equivalent Land Capability over the long term.
4. Produce clear, easy to understand reports that can be used to effectively communicate insights from the program to reclamation practitioners, regulatory bodies, and concerned stakeholders.

The collaborative nature of the program benefits the mining industry as a whole through multiple avenues: cost-sharing of monitoring activities; strategizing methods to meet regulatory reporting and potential certification requirements; developing an understanding of reclamation trends over a range of mine site conditions; and effective knowledge exchange between companies.

The program is made up of two components: 1) annual field work (including plot establishment, sampling, and maintenance across oil sands leases); and 2) longer-term project management, program development, and database maintenance. Each component is carried out by a different service provider. As the program continues, the goal is to create a comprehensive network of reclamation sampling plots that are representative of the different reclamation treatments across the mineable oil sands.

PROGRESS AND ACHIEVEMENTS

Program Development

In 2018, biweekly project status reports were initiated, summarizing activities from both program management and field sampling. These reports enhanced communication between the funding partners and service providers, improving the ability to make logistical and strategic decisions on the program as the year unfolded.

A draft 2019-2023 tactical plan was created, outlining the projected program management, development, and sampling activities to occur within this five-year window. A key part of ongoing program development will be determining future plot establishment needs as more reclamation comes online. Additionally, a rationale document was developed in 2018 to further develop and refine the LTPN's goals, objectives, assumptions, questions, and its sampling matrix, which will solidify the program's purpose and structure in the future.

Field Sampling

No new plots were established in 2018. Five existing plots were sampled in 2018 for soils measurements, vegetation measurements, tree mensuration, site index, and foliar analysis sampling. Reclamation plots are to be sampled every five years. In 2019 and beyond, new reclamation plots will be established, and processes will be developed to determine availability of plots for sampling and maintenance requirements.

LESSONS LEARNED

The issue of plot maintenance proved to be significant in 2018, as in 2017. A lesson learned is that plot maintenance should be scheduled and prioritized along with re-measurements so that the maintenance timelines do not lag and become overwhelming.

As a considerable amount of time was invested in 2018 developing questions that partners would like to answer with the LTPN data, it is crucial that any monitoring program be developed according to feasible questions the data can answer.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2018.

RESEARCH TEAM AND COLLABORATORS

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Becky Doherty	ForCorp	Program Coordinator		
Kerry Nice	ForCorp	Application Development Manager		
Vincent Futoranski	Paragon Soil and Environmental Consulting	Field Coordinator		

Optimizing Weed Control

COSIA Project Number: LE0044

Research Provider: NAIT Centre for Boreal Research, InnoTech Alberta

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: Canadian Natural Resources Limited, Cenovus Energy Inc., Devon Canada Corporation, Imperial Oil Resources Limited, Nexen Energy ULC, Suncor Energy Inc., Syndrude Canada Ltd., Teck Resources Limited

Status: Year 1 of 1

PROJECT SUMMARY

In Alberta, there are 75 regulated weed species (46 prohibited noxious and 29 noxious) listed in the *Weed Control Regulation* (Government of Alberta, 2010a) under the *Weed Control Act* (Government of Alberta, 2008). These weeds need to be destroyed (prohibited noxious) or controlled (noxious), as undesirable species. The concern with having weeds establish is that they can; (1) out-compete and displace local native grasses, forbs, shrub and tree seedlings; (2) alter natural habitats and reduce local biological diversity; (3) hybridize with native species; and (4) change local nutrient cycling, water chemistry and hydrological regimes.

Alberta Environment and Sustainable Resource Development (2012) describes the concern with weeds on industrial developments as:

1. Fire hazards in non-vegetated areas
2. Competition with desirable plant species
3. Economic challenges of controlling the weeds both onsite and offsite
4. Non-compliant with the *Weed Control Act*

Some of these concerns are more pertinent for the settled portions of Alberta (White area) and may be less of a risk for the forested portion (Green area). However, there is currently no comprehensive documentation to support or refute this. Observations from years of field work on disturbed and reclaimed forested sites have indicated that, at least some of the weeds currently regulated by the *Weed Control Act* may pose less risk to native plant establishment, succession and ultimately reclamation success in a boreal ecosystem. The issues with continuing to manage regulated weeds, which are interpreted to be of low risk, while aiming to achieve reclamation closure include the following: increased time and resources spent on weed management; increased herbicide application into the environment; unintentional mortality of desirable native species from accidental herbicide overspray; and a delay in reclamation certification application by at least one growing season (Government of Alberta, 2013).

The overall goal of this project was to attempt to assess whether noxious weeds in the boreal forest are significantly impacting boreal succession. The assessment was performed using publicly available literature, available vegetation survey data and field experience of oil sands operations practitioners.

Current regulations require operators to control or eradicate noxious or prohibited noxious weeds, respectively. Presently, this is accomplished through the use of herbicides and manual labour (e.g., hand-pulling). This project aimed to demonstrate whether, under certain site conditions, there is a third (potentially more cost effective) alternative – utilizing successional processes and forest vegetation development to better address some of the issues raised above.

Project objectives were:

1. To compile current information on weed status and management programs in the boreal ecosystem, for both mining and in-situ oil sands operations.
2. To determine the risk factors of the regulated weeds that have been observed in the boreal ecosystem, with this objective being addressed by:
    a. Developing fact sheets summarizing key characteristics that have historically made these species problematic: their known distribution in Alberta and tolerance, known impacts to environment, and current management options.
    b. Completing a retrospective case study on available data sets where vegetation monitoring had occurred for at least three years to examine whether noxious weeds appeared to influence the development of woody vegetation and if these species were persistent over time.
    c. Developing a risk analysis framework based on the results from the literature review and retrospective case study and with consideration of a risk analysis tool - that was developed by Alberta Agriculture and Forestry. (Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm13262)
3. To determine whether the current approach to weed management (i.e., active control and eradication) of these regulated weed species is necessary in boreal reclaimed sites or if other methods could be used (i.e., monitoring).
4. To identify whether there is enough evidence to reduce the number of weeds requiring active management in the boreal ecosystem.

PROGRESS AND ACHIEVEMENTS

Current Information on Weed Status and Management

Noxious weeds are more prevalent within in situ and mineable oil sands sites than prohibited noxious weeds. Of those designated in the 2010 *Weed Control Regulation*, the top four noxious weeds managed by oil sands operations include perennial sow thistle, scentless chamomile, Canada thistle and common tansy. These species are predominantly transported to sites via equipment and machinery. The movement of salvaged or stockpiled soil infested with noxious weed populations, is the major cause of spreading infestations over large areas.

A retrospective case study was conducted to quantitatively examine patterns in forest vegetation and non-native development using six oil sands data sets provided by the industry participants and existing research data managed by the authors, and included data sets where vegetation monitoring had occurred for at least three years. Correlation analyses completed across the six reclamation sites did not find strong evidence of a negative association between woody cover and noxious weeds (by group or by species); this was measured across multiple years of measurement. The only significant correlations between these parameters were in fact positive associations between woody cover and noxious weeds (by group and by species including perennial sow thistle and Canada thistle). This analysis was supported by changes in relative dominance favouring woody vegetation as individual sites aged. However, the relative dominance of noxious weeds varied over time and there was no consistent trend amongst the sites.

Risk Factors

A risk analysis framework was developed based on the results from the retrospective case study and with consideration of a currently available risk analysis tool that was developed by Alberta Agriculture and Forestry. The risk analysis tool was not useful for determining effects thresholds, though it has utility for its core purpose which is to effectively triage and prioritize invasive species in terms of management considerations. The authors developed a conceptual risk analysis framework using the risk analysis tool as a starting point but using a more quantitative approach to evaluation.

The proposed Reclamation Risk Analysis Tool is a two-part evaluation:

1. First, the user provides data on relative dominance by vegetation category, site age, tree and shrub height, as well as management risk. It would then calculate an exposure risk (risk of site not becoming a forest) showing thresholds in relative dominance between vegetation cover types and stand age.
2. The second part of the evaluation includes a short questionnaire that rated aspects of environmental risk to generate a single number score. The exposure and environmental risk could then be plotted, and conceptually the combined value would be expressed in the standard way risk-analysis are shown (green, yellow or red). Considerable research is required to support both components of the Reclamation Risk Analysis Tool.

Native Vegetation as Weed Management Approach

The correlations in this study, based on multiple datasets from oil sands operators, showed relative density of woody species increased through time on reclaimed sites. The effect on noxious weeds was inconclusive. More work is required to determine if native vegetation and boreal succession processes are an effective control of weeds in a boreal reclamation context.

LESSONS LEARNED

While the correlations in this study showed relative density of woody species increased through time on reclaimed sites in all data sets, the effect on noxious weeds was inconclusive. To determine the conditions under which native plants outcompete noxious weeds on reclaimed sites, and how long that might take, will require longer-term studies designed specifically for this purpose.

LITERATURE CITED

Alberta Environment and Sustainable Resource Development. 2012. Weed Management on Industrial Sites. Alberta Environment and Sustainable Resource Development, Edmonton, Alberta. Alberta Environment and Sustainable Resource Development R&R/12-01. 7 pp. https://open.alberta.ca/dataset/4f56c8ed-e0de-4378-90d7-887c927784b0/resource/71847f4b-f9d7-4822-aaba-6f680b366cf8/download/weedmanagementindustrialsites-fs-jul2012.pdf

Government of Alberta. 2013. *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands (Updated July 2013).* Government of Alberta, Edmonton, Alberta. 65 pp. Available at: https://open.alberta.ca/dataset/9df9a066-27a9-450e-85c7-1d56290f3044/resource/09415142-686a-4cfd-94bf-5d6371638354/download/2013-2010-Reclamation-Criteria-Wellsites-Forested-Lands-2013-07.pdf.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Small, C., D. Degenhardt, B. Drozdowski, S. Thacker, C.B. Powter, A. Schoonmaker and S. Schreiber. 2018. Optimizing Weed Control for Progressive Reclamation: Literature Review. InnoTech Alberta, Edmonton, Alberta. 48 pp.

A. Schoonmaker, S. Schreiber, C.B. Powter, and B. Drozdowski. 2018. Optimizing Weed Control for Progressive Reclamation: Retrospective Case Study and Risk Framework. InnoTech Alberta, Edmonton, Alberta. 69 pp.

RESEARCH TEAM AND COLLABORATORS

Institution: InnoTech Alberta / NAIT Centre for Boreal Research

Principal Investigator: Bonnie Drozdowski / Amanda Schoonmaker

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Stefan Schreiber	NAIT Centre for Boreal Research	Research Associate		
Chris Powter	Enviro Q&A Services	Senior Environmental Advisor		
Christina Small	InnoTech Alberta	Researcher		
Dani Degenhardt	Canadian Forest Service	Researcher		
Sarah Thacker	InnoTech Alberta	Junior Researcher		

Bioengineering and Conventional Erosion and Sediment Control

COSIA Project Number: LE0041

Research Provider: Associated Environmental Consultants Inc.

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: Canadian Natural Resources Limited, Cenovus Energy Inc., Devon Canada Corporation, Imperial Oil Resources Limited, Nexen Energy ULC, Suncor Energy Inc., Syncrude Canada Ltd., Teck Resources Limited

Status: Year 1 of 1

PROJECT SUMMARY

A key component of the, Bioengineering and Conventional Erosion and Sediment Control Solutions for Oil Sands Operations Study, was to document erosion and sediment control (ESC) approaches currently used by in situ and mining companies in northern Alberta. The study also included some coal and forestry companies where their ESC experiences would be relevant to the geographic and ecological conditions encountered by oil sands companies.

Information was collected through, interviews with eleven companies, and documents acquired from operational personnel. Successes, and lessons learned from failures, of bioengineering ESC and of conventional engineered ESC were evaluated. In this study, conventional approaches are defined as techniques to control ESC using concrete, riprap, aggregate, nylon, geotextiles (commonly polypropylene or polyester), and gabion baskets (i.e., wire baskets and/or cages filled with riprap). Bioengineering, is the use of living plant materials to perform some engineering function of ESC (e.g., live pole drains, wattle fences, live staking etc.).

Bioengineering may improve environmental performance at oil sands operations and help meet the COSIA Land EPA goals of reducing footprint, more rapid reclamation, and optimizing biodiversity. These ESC techniques may:

- Reduce footprint intensity, in some cases, as vegetation can be re-established more rapidly and permanently during either operations or phased closure;
- Provide biodiversity benefits, as the bioengineered structures will lead to early successional ecosystems that will succeed to more mature ecosystems and provide a diversity of habitats, especially with phased reclamation;
- Support reclamation objectives for closure by helping create self-maintaining, self-healing ecosystems that mimic natural creeks, wetlands, and other landforms; and
- Result in cost savings during operations, due to lower cost materials and lower maintenance needs, with no requirement to remove synthetic materials/structures at closure.

PROGRESS AND ACHIEVEMENTS

A final report documenting the benefits and limitations of bioengineering and conventional ESC approaches, as identified by operations personnel, was prepared and published in 2018.

LESSONS LEARNED

The final report was published in 2018. Some of the key findings are summarized below:

- Bioengineering techniques have been implemented in field operations for at least the past 10 to 15 years at a variety of mining and in situ facilities.
- Bioengineering techniques can be used successfully alone and in combination with conventional erosion and sediment control in a variety of settings.
- The use of rough and loose soil management with coarse woody material and the planting of shrub and tree seedlings, is being used more commonly at some of the oil sands and coal mines for rapid, natural revegetation. The use of the rough and loose technique will allow oil sand operators to move away from the practice of hydroseeding. Grasses and legumes reduce the survival of tree and shrub seedlings, and reduce the potential for ingress of native plant species from surrounding areas.
- Bioengineering techniques to establish vegetation are discouraged at higher-risk operational sites where: encroaching wildlife could increase human-wildlife conflicts; or where rapid or certain ESC is required to manage safety risks; or where vegetation would obscure visual integrity inspections.
- Bioengineering techniques using live plants are considered permanent ESC methods that require little maintenance once established. They are particularly successful along streambanks, drainways, and near groundwater seeps. The vegetation helps manage the water sources that can cause erosion and helps to stabilize the slopes with its root masses. These techniques are particularly useful for operational projects away from high ESC risk areas, such as, at well pads, soil stock piles, bridges, roads and for the closure landscape.
- Bioengineering techniques may be challenging to implement for larger scale, landscape-level projects, due to the intense labour required for installation, and due to the limited availability of live cuttings. Live plant cuttings could be grown in stooling beds (cultivated in fields) or rooted in nurseries.
- Although erosion and control matting is used at several oil sands and coal operations, it can be challenging to install, maintain and remove at final reclamation, and can inhibit plant species diversity.

Ten factors to be considered when determining the suitability of specific erosion control practices for a project were identified:

1. Risks or consequences of failure,
2. Need for immediacy,
3. Water flow and velocity,
4. Topography/slopes,
5. Soil characteristics and moisture,
6. Accessibility,
7. Weather and season,
8. Permanency of techniques,
9. Availability of materials, and
10. Cost.

Three recommendations are proposed to encourage the use of bioengineering as a more common ESC practice in the oil sands region:

1. Increase training on bioengineering techniques and installation
2. Coordinate live plant production for bioengineering installations
3. Coordinate and expand research on bioengineering techniques

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

INTEGRATED REPORT Canada's Oil Sands Innovation Alliance (COSIA). Bioengineering and Conventional Erosion and Sediment Control Solutions for Oil Sands Operations. Associated Environmental Consultants Inc. May 2018. Available at: https://www.cosia.ca/sites/default/files/attachments/Bioengineering%20and%20Conventional%20Erosion%20and%20Sediment%20Control%20Solutions%20for%20Oil%20Sands%20Operations.pdf

RESEARCH TEAM AND COLLABORATORS

Institution: Associated Environmental Consultants Inc.

Principal Investigator: Judy Smith

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Stephanie Findlay	Associated Environmental Consultants Inc.	Environmental Scientist		
Kristin Andersen	Associated Environmental Consultants Inc.	Senior Environmental Scientist		
Dave Polster	Polster Environmental Services Ltd.	Plant Ecologist		

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 13 - Ongoing

PROJECT SUMMARY

Remote wildlife cameras are a useful tool for assessing and monitoring various aspects of terrestrial wildlife, especially the return of wildlife to and subsequent use of anthropogenically altered habitats (Hawkes, et al. 2016). The proper implementation of wildlife cameras 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 lease consistently since 2006. Cameras are currently deployed in a number of areas for regulatory requirements and are also used in other 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 time of 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 not only 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). Canadian Natural Resources Limited (Canadian Natural) is also interested in the success of 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

During 2018, wildlife camera data was collected and reviewed. The complete spatial and temporal patterns of wildlife occurrence and use (occupancy) is completed on a three-year cycle with the next analysis to occur at the end of 2019.

LESSONS LEARNED

Data analysis for 2018 will not occur until the end of 2019. No new lessons learned to report at this time.

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.

PRESENTATIONS AND PUBLICATIONS

No presentations or publications in 2018.

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)
Wendell Challenger	LGL Limited	Biostatistician		
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Christine Dennis	Canadian Natural Resources Limited	Environmental Coordinator		
Jamie-Lynn Greter	Canadian Natural Resources Limited	Environmental Coordinator		
Madison Walsh	Canadian Natural Resources Limited	BSc	2014	2018
Emma King	Canadian Natural Resources Limited	BSc	2015	2019
Gregg Hamilton	Canadian Natural Resources Limited	BSc	2015	2019
Austin Bruan	Canadian Natural Resources Limited	BSc	2015	2019

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

COSIA Project Number: LJ0214

Research Provider: Owl Moon Environmental Inc.

Industry Champion: Syncrude Canada Ltd.

Industry Collaborators: ConocoPhillips Canada Resources Corp., Hammerstone Corporation, Husky Oil Operations Ltd., Suncor Energy Inc., Devon Canada Corporation, Nexen Energy ULC

Status: 2011 – Present (annual participation)

PROJECT SUMMARY

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

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

The industry-specific value from this program is twofold:

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

The Monitoring Avian Productivity and Survivorship in Oil Sands Region Program (Boreal MAPS Program) has been established to address two 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; and
2. To acquire data for use in estimating population vital rates for bird species nesting in the boreal forest.

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

In 2011, six MAPS stations were established in the oil sands region and the program was expanded to include 38 stations by 2015, although not all stations were operated in each year due to safety concerns related to the Horse River wildfire in 2016, and due to funding constraints. A total of 35 stations have operated over enough years to be included in the analytical dataset. These include 15 natural or reference stations (>90% of habitat unaffected by disturbance), five reclaimed stations (>55% of habitat reclaimed), and 15 disturbance-affected stations (<90% natural, <55% reclaimed; e.g., cutlines, exploration well pads, roads). Since 2011, six stations have been affected by natural disturbance; one station was flooded in 2013, and five stations burned in 2016.

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

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

Computer entry, data proofing, and verification of banding, mist-net effort, and breeding status data 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. A minimum of 2.5 adult captures per 600 net-hours is required to derive adult population size and productivity index estimates. Survival estimates require an average adult capture rate of ≥2.5 adults per year and at least two between-year recaptures over a minimum of four, and preferably five consecutive years of collected data. More years of data improves the precision of the survival estimate, and up to 10 years may be required to collect sufficient data for some species. For species with sufficient capture and recapture data, survivorship was estimated using Modified Cormack-Jolly-Seber capture-mark-recapture models (Pollock et al. 1990; Lebreton et al. 1992). Recruitment is being evaluated as an additional vital rate metric. As estimate of recruitment of breeding birds into the adult population is obtained from the number of young (HY) that survive and reproduce, as determined by the capture rate of second-year (SY) birds or through capture-mark-recapture analyses. Recruitment may include birds that immigrate into the area.

PROGRESS AND ACHIEVEMENTS

Quality assurance review and analyses of the 2018 data are ongoing, and the numbers presented here are preliminary and may change as the data are validated. In 2018, field work comprised 11,648 net-hours of operation at 33 stations, resulting in 3,789 birds newly banded, 55 released unbanded, and 1,339 recaptures of previously banded birds, for a total of 5,183 captures (267 total captures per 600 net-hours). Captures were higher than those recorded in 2017 (4,701; 246 total captures per 600 net-hours), and similar to those recorded in 2016 (5,087; 279 total captures per 600 net-hours), and much lower than in 2015 (8,315; 393 total captures per 600 net-hours). A statistically-significant (p=0.001) downward trend of -4.4% in adult population size (all species pooled) is apparent from 2011 to 2018 (Figure 1). Preliminary analyses estimate 123.4 adults per 600 net-hours in 2018, compared to 115.9 adults capture per 600 net-hours in 2017. Productivity (the number of young relative to adult captures for all species, normalized for effort) has also decreased significantly (p=0.001) with a slope of -0.070 since 2011 (Figure 1). The preliminary productivity estimate for 2018 appears to be 0.71, compared to 0.68 in 2017.

With the data collected under the MAPS program, we are able to examine possible explanations for these trends on per species basis, such as effects of the forest fire in 2016, natural cycles in local populations, regional resource development, a reflection of the general decline in landbird populations continent-wide, or a combination of factors. The population trends we are observing are consistent with continental findings and the general decline in bird populations.

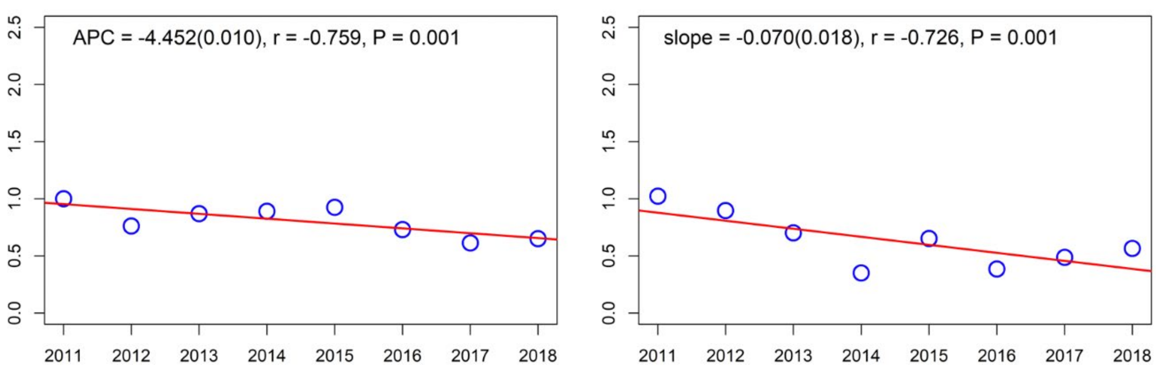

Figure 1. Regional landbird adult population size (left panel; APC is annual percent change [±SE of the slope]) and productivity (right panel; slope of the regression line is the annual change in productivity index [±SE of the slope]), from 2011 to 2018, with the correlation coefficient (r) and significance of the correlation coefficient (P) shown in each graph. The index of population size was arbitrarily defined as 1.0 in 2011, while productivity was defined as the actual productivity index value. A correlation coefficient close to 1.0 indicates a close fit of the data to the regression line.

Objective 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 eight years, 42,642 bird captures of 96 species have been recorded, of which 32,042 were newly banded, 658 were released unbanded, and 9,942 were recaptures of birds banded earlier in the same season or in previous seasons. As reclaimed habitats reach 30 years old, species richness approaches that of predominantly undisturbed habitat (Figure 2), as measured by species presence determined by point counts (10-minute), species captured during MAPS banding, and species observed at the station during the banding process, including those captured (MAPS breeding status). Point counts represent the total number of territorial males detected calling as compared to both males and females captured and their breeding condition, and males and females exhibiting auditory or visual breeding behaviour (breeding status) during the MAPS banding program. Species richness varies by method, with richness as measured by the MAPS breeding status procedure resulting in the highest level of observed species richness, consistent across all MAPS stations. The MAPS procedures show a substantial difference in the number of species detected compared to point counts from newly reclaimed through to older (e.g., mature forest) habitats, allowing greater understanding of changes in performance over time as station habitats mature.

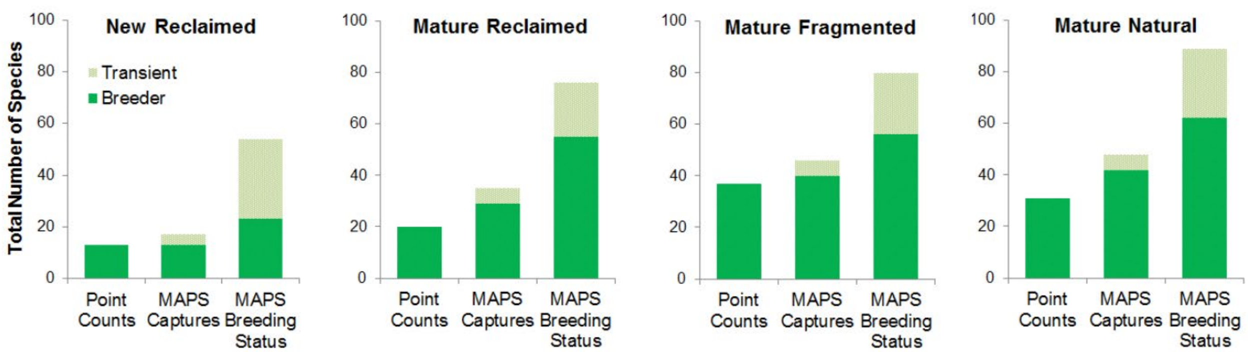

Figure 2. Cumulative species richness (across all years) at representative Boreal MAPS stations as measured using 10-minute point count, MAPS capture, and MAPS breeding status procedures.

Monitoring at the five stations at which the habitat burned in the 2016 Horse River wildfire provides an opportunity to track avian community recovery in a natural disturbance area and compare it to that observed in habitats recovering from anthropogenic disturbances. In 2018 (two-years post-fire), early colonizing sparrow species continued to predominate in the recovering burn habitats. A few species present before the fire, including a Canada warbler, were recaptured in 2018. It is expected that as the burned habitats grow and mature, a broader range of species will occur, although the timing of colonization is not known.

A habitat structure assessment was completed in 2018 at all operating MAPS stations. This represents the second assessment conducted to-date, with the first habitat structure assessments completed in 2012 and 2013. With these data we will be able to compare the habitat changes among undisturbed natural habitats, natural habitats recovering from the 2016 wildfire, disturbed (anthropogenic) habitats, and reclaimed habitats.

The potential use of the age-class structure of breeding landbirds in the evaluation of habitat quality, in reclaimed, disturbed and natural areas is being examined. Preliminary analyses indicate that lower quality habitats support an overall younger bird age-class structure (higher proportion of first-time breeding individuals) relative to higher quality habitats, which tend to be occupied by a proportionately higher number of older, experienced birds. This effect appears to be habitat and species-specific, potentially making it an indicator of habitat quality, adding to the indicators represented by adult population size, productivity, survivorship, and species richness.

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

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

Data from 2018 are currently being integrated into the trend analyses and updating of population size, productivity, and survivorship estimates. Data from MAPS banding programs outside of the oil sands region have been acquired (through data-sharing and use agreements), allowing derivation of vital rate estimates for these same species nesting elsewhere in the boreal forest. These analyses will provide insight into the contribution of regional stresses on the population trends for these species, and identify the species that may benefit from regional efforts (e.g., productivity effects indicate breeding ground stresses) and those that would not (e.g., survivorship effects indicate stresses outside the breeding grounds). This analysis is core to the question of whether or not changes in bird populations in the region reflect relatively local stresses or are an expression of changes in these populations at a continental level.

This Boreal MAPS dataset now contains more than half of the Canada warbler continent-wide MAPS data upon which vital rate estimates may be obtained. Using this integrated database, we have published an account of the complex relationships among habitat quality (breeding, wintering, migratory), human footprints, and Canada warbler populations (Wilson et al. 2018). Breeding density declines were greater in the eastern than in the western and central portions of the breeding range, productivity did not significantly decline in any of these three regions, recruitment declined in all regions, and both juvenile and adult survival appeared low in the east and west and was declining in the east. Abundance also declined in relation to increasing habitat disturbance, most of which was occurring on wintering grounds, where the human footprint index increased by 14% between 1993 and 2009, compared with an increase of only 0.1% within the breeding range. These demographic trends and correlations suggest that habitat disturbance on the wintering grounds are negatively affecting survival (particularly that of juvenile birds), and is the primary driver of Canada warbler declines. The population of Canada warbler in the oil sands region is declining at a lower rate than in populations to the east. The western population wintering grounds have been affected to a lesser extent. Canada warbler adults showed significant correlations with habitat-specific covariates responding to mature forested habitats (Foster et al. 2016), and recently Krikun et al. (2018) presented the results of a study of vegetation species preferred by Canada warbler, suggesting that measures can be taken to identify and protect Canada warbler habitat on the breeding grounds.

We have conducted preliminary vital rates analyses for least flycatcher and yellow warbler, for comparison to the vital rates derived for Canada warbler. Adult population and productivity analyses are presented in Figure 3. The declining population of least flycatcher coupled with increasing productivity and a low adult survivorship (0.27) indicates that effects outside of the breeding grounds are likely driving the population trend. For yellow warbler, decreasing productivity and a reasonably high survivorship (0.48) suggests that effects on the breeding grounds are driving the declining population of this species. For Canada warbler, declining populations and a non-significant productivity trend and a reasonably high adult survivorship rate (0.53) suggests the absence of a breeding ground effect, and that adult survivorship is not affected. Although not analyzed solely using Boreal MAPS data, inclusion of our data in the continental analyses (Wilson et al. 2018) resulted in the identification of juvenile survivorship as the primary driver for declining populations, including those in northeastern Alberta.

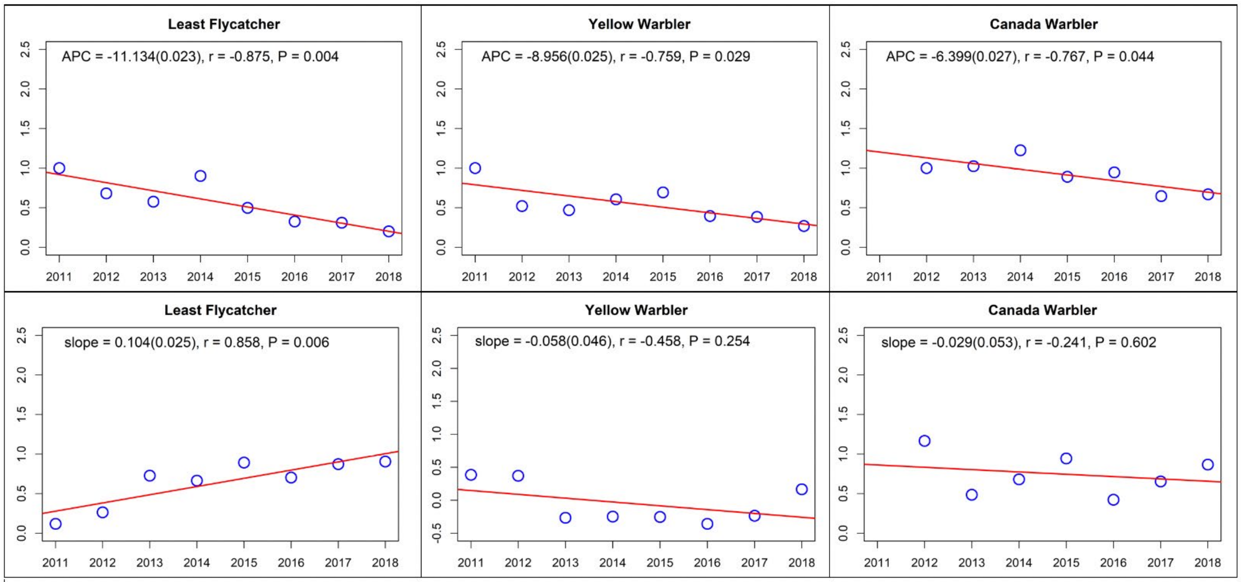

Figure 3. Adult population size (top panels; APC is annual percent change [±SE of the slope]) and productivity (bottom panels; slope of the regression line is the annual change in productivity index [±SE of the slope]) for least flycatcher (left), yellow warbler (centre) and Canada warbler (right), from 2011 to 2018, with the correlation coefficient (r) and significance of the correlation coefficient (P) shown in each graph.

These analyses, on a species by species basis, are supportive of reclamation and disturbance recovery planning, as species experiencing breeding ground stresses are those that would benefit from habitat improvements. Investment into efforts to reverse the decline of Canada warbler (6.4% per year as of 2018 data) would be generally limited to protection of Canada warbler breeding habitats (as required under SARA), although inclusion of preferred vegetation species (e.g., choke cherry, Canada buffaloberry, green alder) in planting prescriptions in habitats with suitable canopy species (aspen was not preferred by Canada warbler) would benefit this (Krikun et al. 2018) and potentially other species. Since the primary driver of declining (at 11.1% per year) least flycatcher (Sensitive in Alberta) populations appears to be outside of the breeding grounds, specific reclamation or disturbance restoration practices focused on this species are unlikely to have a measurable population-level effect. Yellow warbler, on the other hand, has a reasonably high adult survivorship value with a significantly declining productivity, indicating that effects primarily on the breeding grounds are driving yellow warbler population decline (currently 8.9% per year) in the region. Inclusion of yellow warbler habitat in reclamation and disturbance recovery programs is likely to have a direct benefit on yellow warbler populations.

Although not an objective of this program, collaboration with other researchers is actively being sought. Our collaborations in 2018 included publication of the Canada warbler paper containing our data to-date (Wilson et al. 2018), and with researchers from the University of California, Los Angeles, on the *Bird Genoscape Project, Mapping the Flyways of the Americas* project. The Boreal MAPS program has provided blood and feather samples for genetic analyses (Canada warbler, American robin, American redstart); these data will be integrated with data from samples provided by researchers across North America. The goal of the Bird Genoscape Project is to use genomic sequencing to map the migratory connections between breeding, wintering and migratory stop-over areas linking critical bird habitats across geographic boundaries. For migratory birds, knowledge of these connections is essential for the development of effective conservation strategies.

Owl Moon Environmental Inc. is also collaborating with other MAPS operators through database integration and analyses to provide a broad perspective on the reasons for landbird population changes and the potential contribution of oil sands regional resource development to these changes.

LESSONS LEARNED

Understanding regional landbird population trends and their underlying vital rates provides necessary context for the interpretation of population trends of species in reclaimed habitats, in areas recovering from anthropogenic disturbance, and in areas subjected to natural disturbances. The MAPS protocol is a robust protocol that can be applied across a large range of species and habitats and is capable of providing evidence of avian habitat use and the proximal causes of population change for individual species. Data collected using other methods such as bird point counts and automated recording units can be put into context by comparing against MAPS vital rate data. Demographic data are more robust than presence/absence data, and although data from point counts and automated recording units can identify increasing or decreasing trends, MAPS vital rate data can suggest why populations are changing.

- Work is continuing to determine which of the species showing a consistent, regional population decline are driven by low productivity on the breeding grounds, and which species appear to be driven by low adult survivorship during migration or on the winter grounds:
    - Low or declining productivity would indicate that effects are occurring on the breeding grounds.
    - Low or declining adult and/or juvenile survivorship would indicate that the effects are occurring on the wintering grounds or during migration, as demonstrated for Canada warbler (Wilson et al. 2018). Canada warbler recruitment declined in western, central and eastern regions, and both juvenile and adult survival appeared low. Demographic trends were correlated with habitat disturbance on the wintering grounds, which is negatively affecting juvenile Canada warbler survival, and is the primary driver of Canada warbler declines.
- Species-by-species demographic analyses, correlated with habitat structure data, can directly inform reclamation planning by targeting species that are at risk for which effects are occurring on the breeding grounds:
    - Our data show that regional Canada warbler populations are declining by 6.7%/year, but productivity is relatively stable. Survival of juvenile and adult birds is affected by wintering habitat disturbance. Canada warblers are semi-colonial, and avoiding disturbing known Canada warbler habitat on the breeding grounds would mitigate declines, but is likely to have limited effectiveness in enhancing population growth.
    - Regional least flycatcher (Sensitive in Alberta) populations are decreasing by 11.1%/year, while productivity is increasing. Low survival on the wintering grounds is suggested, providing limited local opportunities to reverse this trend.
    - Regional yellow warbler populations are declining by 8.7%/year, and productivity is decreasing in the oil sands region. Stress on the breeding grounds is suggested, and habitat requirements for this species are understood and are likely to be easily incorporated into reclamation and restoration plans.
- This program is measuring the substantial short-term (annual) variability, superimposed on population cycles that operate on long term (i.e., decadal) time scales. Long-term monitoring is important in understanding the

contribution of resource development and human activity in the region to avian population changes, in the context of natural variability and population cycles.

- Understanding vital rates for species of conservation concern (e.g., Canada warbler, yellow warbler) is a critical requirement in being able to prepare and implement effective recovery strategies and will help to focus efforts on reducing the more substantial stresses in the life cycle for these species.
- The SY:ASY (age class ratio) appears to be an indicator of habitat quality, with lower ratios in more highly structured habitats suggesting the potential presence of source habitat (analyses in progress)
- Species richness increases with stand age, and this is directly related to increasing habitat structure complexity.
- Species diversity indices (preliminary analysis only, data not shown) based on point counts appears to be more variable than diversity based on MAPS captures, and point counts appear to overestimate diversity in young habitats.

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Wilson S, Saracco JS, Krikun R, Flockhart DTT, Godwin CM, Foster KR (2018) Drivers of demographic decline across the annual cycle of a threatened migratory bird. Scientific Reports, 8:7316 | DOI:10.1038/s41598-018-25633-z

RESEARCH TEAM AND COLLABORATORS

Institution: Owl Moon Environmental Inc.

Principal Investigator: Kenneth R. Foster

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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:

Drivers of demographic decline across the annual cycle of a threatened migratory bird (Canada Warbler vital rates relative to habitat conditions on the breeding and wintering grounds)
Collaborators: Dr. Scott Wilson, Canadian Wildlife Service, Ottawa; Dr. Tyler Flockhart, University of Maryland & Lesser Slave Lake Bird Observatory; Richard Krikun, Lesser Slave Lake Bird Observatory

The Bird Genoscape Project – Mapping the Flyways of the Americas
Collaborators: Ms. Jasmine Rajbhandary and Dr. Thomas B. Smith, Department of Ecology & Evolutionary Biology, University of California, Los Angeles

Bison Research, Mitigation and Monitoring Program

COSIA Project Number: LJ0266

Research Provider: University of Alberta

Industry Champion: Teck Resources Limited

Industry Collaborators: Canadian Natural Resources Limited

Status: Year 4 of 5

PROJECT SUMMARY

The goal of the Bison Research, Mitigation and Monitoring Program 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 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 use of available summer forage?
   c. How do winter conditions and wolf predation risk influence winter habitat use and survival?
   d. What mechanisms promote selection for upland meadow habitat in late spring to early summer and what influence does this have on recruitment and calf survival?

1 The Ronald Lake Bison Herd Technical Team is a multi-stakeholder group (i.e., Indigenous 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 Indigenous communities (Candler et al. 2015). The proposed Frontier Oil Sands Mine Project intersects a portion of the home range of the Ronald Lake wood bison herd.

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

Teck Resources Limited is providing funding for this project and the work is technically directed by the Ronald Lake Bison Herd Technical Team. Canadian Natural Resources Limited also provided funding for years two and three.

PROGRESS AND ACHIEVEMENTS

Progress that occurred in 2018 (Year four of five) that supports achieving the stated objectives included:

1. **What is the spatial distribution of male and female bison in relation to season, habitat type and natural and anthropogenic disturbances?**

    a. What are the patterns of habitat selection?

    To better understand why bison select certain habitats and avoid others, we compared bison foraging, wallowing, and bedding activity between areas recently used by bison and areas available but not recently used by bison. Also, we quantified a variety of environmental factors (e.g., landcover type; canopy cover; tree, shrub and coarse woody debris densities; percent cover of vegetation species; forage quantity and quality; distance to nearest marsh; ground firmness; distance to water; and snow characteristics; etc.) and compared them between areas recently used by bison and areas available but not recently used by bison.

    Analyses of the GPS radio collar data in relation to landcover types suggest the Ronald Lake bison herd's movements northward may be constrained due to landscape features and landcover types that bison avoid (DeMars et al., 2016). We found that bison GPS locations had a significant positive relationship (i.e., selected) with six landcover types (emergent marsh, shrubby poor fen, upland deciduous, graminoid poor fen, conifer swamp and meadow marsh), a significant negative relationship (i.e., avoided) with six other landcover types (mixedwood swamp, upland pine, shrub swamp, tamarack swamp, graminoid rich fen and mudflats), and no significant relationship with the remaining 13 landcover types. Relatively high quantities of avoided landcover types in combination with relatively low selected landcover types in the northern part of the Ronald Lake bison herd's home range may limit the northward movement of the Ronald Lake bison herd (Figure 1).

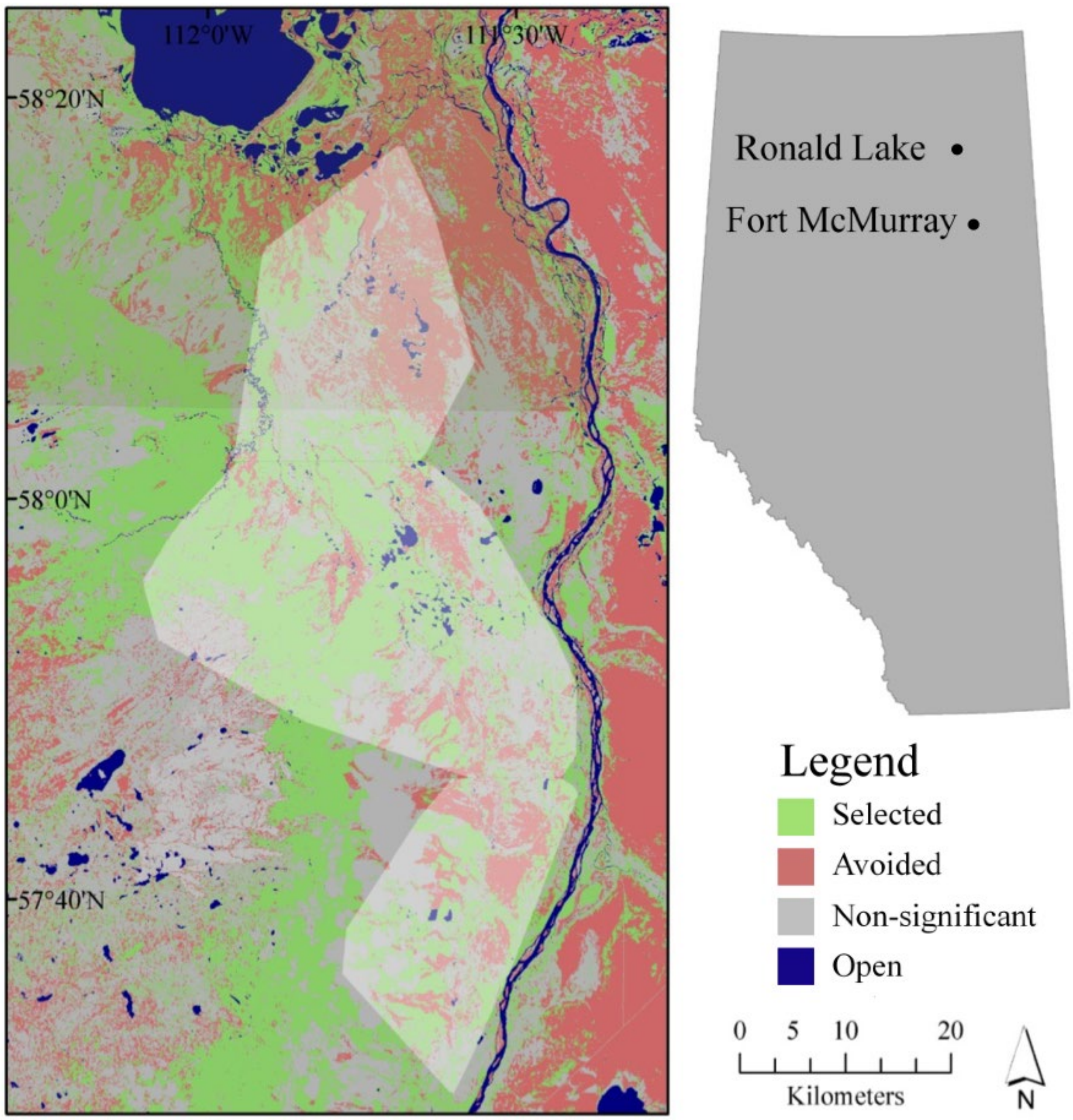

Figure 1. Map showing the distribution of selected and avoided landcover types based on significant negative binomial models of bison GPS locations (n > 350,000) in relation to landcover types.

2. **What bottom-up (forage & habitat supply) or top-down (predation) factors limit the Ronald Lake wood bison herd?**

   c. How do winter conditions and wolf predation risk influence winter habitat use and survival?

   In Year 4 we designed a program to study the effect of wolves, a known predator of bison (Carbyn and Trottier, 1988), on bison survival and habitat selection. To track wolf movements, In Year 5 we will deploy GPS radio-collars programmed at a four-hour acquisition interval, on one or two wolves per pack. First, we will model wolf and bison movements using resource selection functions that will show what habitat characteristics are important to each species and the probability of each being found where those characteristics are present (Boyce et al., 1999). With the combination of location data from both wolf and bison collars, we will determine the spatial extent of habitat that each species uses, as well as when and where they are more likely to interact (Legendre et al.,1989). Second, we will use wolf location data to identify kill sites using GPS cluster analysis (Webb et al., 2008) where we will use available evidence to investigate prey types, collect scat for diet content analysis, and record environmental conditions with an emphasis on snow characteristics such as depth, density and presence of crust.

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?

   To understand more about the forage on natural and anthropogenic disturbances compared to undisturbed area, we quantified forage quantity (biomass) and quality (macronutrient composition) on a variety of land cover and disturbance types within the herd's home range. Biomass estimates revealed high levels of graminoid, particularly sedge, biomass on legacy (> 5 years old) seismic lines through wetlands. Wood bison have been shown to select sedges, likely due to the relatively higher amounts of protein present in this forage plant (Larter and Gates, 1991).

LESSONS LEARNED

This reporting period highlighted the following emerging outcomes:

- Relatively high quantities of avoided landcover types in combination with relatively low selected landcover types in the northern part of the Ronald Lake bison herd's home range may limit the northward movement of the Ronald Lake bison herd. This is an important finding because it helps explain why the Ronald Lake bison herd has not encountered diseased animals from Wood Buffalo Nation Park.
- Forage may be only one of several factors contributing to winter bison habitat use. Other factors to consider include snow depth, density and presence of crust. This is an important finding to consider when calculating winter nutritional carrying capacity.
- High levels of graminoid biomass, particularly sedge, were found on legacy (> 5 years old) seismic lines running through wetlands, This finding will help industry understand how anthropogenic disturbance influences bison habitat use.

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Belanger, R.J., Hecker, L.J., Edwards, M.A., Nielsen, S.E. 2018. Ronald Lake wood bison research program: semi-annual progress report 2018. Report to the Ronald Lake Bison Herd Technical Team, April 30, 2018. University of Alberta, Edmonton, Alberta, Canada T6G 2H1. 16 pp.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigators: Dr. Scott Nielsen / Dr. Mark Edwards

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Rob Belanger	University of Alberta	M.Sc. recipient	2015	2018
Lee Hecker	University of Alberta	PhD candidate	2017	2020
Lindsey Dewart	University of Alberta	M.Sc. candidate	2018	2020

Research Collaborators: Royal Alberta Museum, 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 3 of 4

PROJECT SUMMARY

Golder Associates Ltd. (Golder) and Intrinsik Corp. (Intrinsik) were retained by Suncor Energy Inc. (Suncor) to conduct a Human and Ecological Risk Assessment of Suncor's Reclamation and Closure Landscapes. The ecological risk assessment will focus on aquatic and terrestrial wildlife risk receptors, while the human risk assessment will focus on human risk receptors (the holistic study is hereafter referred to as the Environmental Risk Assessment). The Environmental Risk Assessment and supporting tasks are being conducted for the following sites: Suncor Base Mine; Fort Hills Mine; and MacKay River In Situ Project. The overall aim of the Environmental Risk Assessment is to assess and quantify risk that will be used to inform integrated Mine-Tailings-Closure Planning and Research and Development of technologies that eliminate, reduce or mitigate potential issues.

Specific objectives for the Environmental Risk Assessment are:

- Review background documents, including recent closure plans, risk assessments, and data collected as part of previous studies and compile available historic data.
- Conduct a gap analysis based on the results of data review and compilation.
- Conduct field sampling programs to address data gaps and supplement existing data.
- Conduct a quantitative human and wildlife health risk assessment (including exposure calculations) applicable to the various ecosystem types. This assessment will consider the ranges of substrates that will need to be placed/managed as part of reclamation, and the time period over which exposure will occur.
- Summarize the risk assessment findings in a knowledge transfer document (including a risk matrix/registry).

PROGRESS AND ACHIEVEMENTS

An Environmental Risk Assessment was conducted in 2018 using historical data and field data collected as part of field programs carried out in the summers of 2016 and 2017. Field sampling included collection of surface water, sediment, soil, vegetation and fish tissue samples. The risk assessment targeted ten landform-substrate combinations:

- structural fill (consolidated tailings, sand and coke capped consolidated tailings, regular tailings, froth tailings, fly ash, peat, suitable overburden, and unsuitable overburden);
- end pit lake (mature fine tailings); and
- non-structural fill (dried mature fine tailings).

The landform-substrate field sites that were sampled varied in terms of their state of reclamation, ranging from not fully reclaimed (e.g., structural fill – consolidated tailings structural fill – sand and coke capped consolidated tailings) to fully reclaimed (e.g., structural fill – suitable overburden, structural fill – regular tailings). Surface water, soil, sediment and vegetation samples collected at the partially reclaimed and unreclaimed field sites represented the range of starting conditions for these substrates.

An additional field program was carried out in the summer of 2018 to address data gaps identified in the draft risk assessment. The new data have been compiled and screened and will be incorporated into an updated risk assessment in 2019.

Human Health Risk Assessment

Maximum measured concentrations of contaminants of potential concern (COPCs) in surface water, sediment, soil and fish tissue were compared to screening values protective of human health. The COPCs identified in each landform-substrate were also retained for items for which there are no screening criteria (e.g., vegetation and wild game). Carcinogenic parent and alkylated Polycyclic Aromatic Hydrocarbons (PAHs) were grouped for evaluation in the human health risk assessment. Substances without a screening value but that were of low toxicological hazard were not retained as COPCs (e.g., calcium, magnesium, potassium). Substances with concentrations that exceeded a screening value but lacked robust toxicity information were not retained as COPCs (e.g., zirconium).

The following receptor scenarios were used for the human health risk assessment:

- Indigenous: seasonal (up to 90 days) and year-round use.
- Recreational: hikers and sport fishers & hunters (two days/week).
- Resident Trapper (year-round).

The exposure pathways evaluated in the human health risk assessment included:

- Surface Water: ingestion (as a drinking water source), incidental ingestion (while swimming or bathing), and dermal contact.
- Sediment: incidental ingestion, dermal contact.
- Soil: incidental ingestion, dermal contact, dust inhalation.
- Traditional Foods (berries, traditional plants, wild game, fish): ingestion.

The different receptor scenarios were selected to represent a range of exposure combinations. For example, the recreational hiker was assumed to be exposed to soil, sediment and surface water (swimming or bathing) and to consume berries whereas the Indigenous receptor was assumed to be exposed to all media, including traditional foods (wild game and traditional plants).

Wildlife Health Risk Assessment

Maximum concentrations in surface water, sediment and soil were compared to ecological screening values to identify COPCs for the wildlife health risk assessment (WHRA).

Wildlife receptors of concern were grouped according to feeding environment (i.e., terrestrial and aquatic) and feeding guild (i.e., herbivore, insectivore, piscivore, carnivore and omnivore).

The exposure pathways evaluated in the WHRA included ingestion of the following media:

- Terrestrial: soil, plants, berries, invertebrates, small mammals.
- Aquatic: water, sediment, plants, invertebrates, fish.

LESSONS LEARNED

Once the Environmental Risk Assessment project is completed, it will be used to provide guidance to closure and reclamation planning.

PRESENTATIONS AND PUBLICATIONS

Presentations (Presenting Author)

Koppe, B., Wagenaar, A.K., Bresee, K., Meloche, L.M., Daly, C. 2018. Human health and ecological risk assessment of various reclaimed substrate materials and landform types at oil sands sites. Oil Sands Innovation Summit 2018. June 7 and 8, Calgary, Alberta

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Early Successional Wildlife Dynamics Program

COSIA Project Number: LJ0013

Research Provider: LGL Limited Environmental Research Associates

Industry Champion: Canadian Natural Resources Limited

Industry Collaborators: Suncor Energy Inc., Imperial Oil Resources Limited

Status: Year 4 of 5

PROJECT SUMMARY

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

To address this deficiency, a five-year program 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 reclaimed areas; and
4. Evaluating effectiveness of practices and principles applied in reclaimed areas to improve biodiversity.

Focal taxa representing aquatic, semi-aquatic, terrestrial, and avian species were selected for annual monitoring within reclaimed habitats, mature forest, cleared, burned, and logged juvenile stands on leases operated by Canadian Natural Resources Limited (Canadian Natural's Horizon Oil Sands), Suncor Energy Inc. (Suncor Oil Sands Base), Canadian Natural Upgrading Limited (Canadian Natural's Albian Sands), Fort Hills Operations (Fort Hills), and Imperial Oil Resources Limited (Imperial Kearl Oil Sands). Annual sampling is underway to generate a five-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 are being 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 disturbances (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 operational footprints. These data will also be used to ensure that oil sands operators are in compliance with the terms and conditions of their EPEA Approvals. The design of the program is flexible enough to ensure expandability and adaptability over time. Further, wildlife sampling protocols are aligned with other regionally-relevant and accepted methods and are part of a "living document"; one that will be updated as new information becomes available or revised to reflect changing goals and objectives.

Wildlife sampling is occurring in habitats representing several distinct types of sites: (1) reclaimed (REC); (2) reclaimed habitat adjacent to compensation lakes (COMP); (3) mature forest (MF); (4) cleared habitats (CLR); (5) logged (LOG); and (6) burned (BRN). A standardized sample unit is used that includes a small mammal live-trapping grid, songbird point count stations, and winter-active animal sampling via remotely-triggered cameras. 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 often provide important insights regarding the use of an area by all wildlife species.

Annual sampling occurs in all months, with most work occurring during the snow-free period. Survey methods include the use of qualified and proficient biologists to: (1) document songbird species occurrence and distribution; (2) capture and identify amphibians; (3) live trap and identify small mammal species; (4) deploy remote sensing equipment (remotely triggered cameras and autonomous recording units); (5) assess vegetation species composition, cover, and height at all sample sites; and (6) make reliable observations of all wildlife species during all seasons of the year. Autonomous passive recording devices such as Wildlife Acoustics Song Meters are being used for bats, amphibians, and some species of birds (Yellow Rail, owls). Wildlife cameras are deployed throughout each lease to track the presence and distribution of medium and large-sized mammals. All data are collected in a standardized manner so that appropriate statistical tests can be applied. A comprehensive report (one that pools all data from all operators) was produced in 2016, with the next comprehensive report scheduled for 2020.

PROGRESS AND ACHIEVEMENTS

This project started in 2015, with a projected completion of Phase 1 in 2020 (a five year program). Sampling in 2018 occurred from 38 sites on Canadian Natural's Horizon Oil Sands (n=12 sites), Suncor Energy's Base Lease (n=11 sites), Fort Hills (n=4 sites), Canadian Natural's Albian Sands, Muskeg River and Jackpine Mines (n=7 sites), and Imperial's Kearl Oil Sands (n=4 sites).

The 38 sites were distributed among six main habitat types:

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

Site Type	Canadian Natural Horizon	Suncor Base	Canadian Natural Albian Sands	Fort Hills	Imperial Kearl Oil Sands	Total
Reclaimed	5	7	1	--	1	14
Comp Lake	3	--	1	1	1	6
Cleared	--	2	--	1	--	3
Logged	--	--	3	--	--	3
Burned	2	--	--	1	1	4
Mature Forest	2	2	2	1	1	8
Total	12	11	7	4	4	38

The following data were collected from each site in 2018:

- Small mammal live trapping: spring and fall sampling; no small mammal trapping on Kearl Oil Sands in 2018;
- Songbird point counts: all leases;
- Deployment of autonomous recording units (ARUs): all leases;
- Wildlife camera data collection: all leases;
- Incidental wildlife observations (animals not targeted during systematic surveys): all leases;
- Vegetation sampling: all leases;
- Amphibian surveys: all leases (some via incidental observations);
- Insect sampling (pilot): Canadian Natural's Horizon Oil Sands, Canadian Natural Upgrading Albian Sands, Suncor Base Lease, and Fort Hills; and
- Remotely-triggered cameras were deployed in late-2017 to target winter-active animals. This methodology replaced snow-tracking. Cameras were deployed on all leases in 2017 except for Suncor's Base Lease which were deployed in early 2018.

Data collection occurred in all months of the year, with most occurring during the snow-free period (May to October). Data collected in 2018 contributed to the development of a dataset that will be used to assess the developmental trajectories of reclaimed habitats relative to natural analogs (i.e., the burned, logged, and cleared sites) and to the desired endpoint of reclamation (i.e., the mature forest sites). Because compensation lakes are being constructed 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 2017 data constitute year three of the five year Phase 1 dataset.

All data collected in 2018 are undergoing quality assurance/quality control (QA/QC) and integration with previous data (into a relational and fully-documented SQL database).

Data collected via systematic wildlife surveys (e.g., small mammal live-trapping, songbird point count surveys) are augmented by data collected incidentally (i.e., non-systematic, observer-based data collection). A total of 184 species of wildlife from three taxonomic groups (amphibians [n=1], mammals [n=35], and birds [n=148]) were documented from all sampled oil sands leases. Overall more species were detected on reclaimed habitats [n=135] and those habitats were also associated with the largest number of unique species (n=25). Terrestrial habitats adjacent to compensation lake habitats were associated with 117 species, of which 20 were unique. On burned sites 74 species were observed and only two were unique. Logged and cleared habitats had the least, with 37 and 61 species respectively, and neither treatment was associated with any unique species of wildlife. Finally, 92 species of wildlife were observed in mature forest reference sites, 15 of which were unique. Each of the species associated with a given treatment was expected, based on known patterns of wildlife habitat use, occurrence and distribution. This includes those species unique to a given habitat type. More species were documented incidentally (n=141) than through systematic surveys (n=131) due to the non-rigorous and untargeted nature of data collection associated with incidental data. For example, songbird point count surveys occur during the summer months only, whereas bird species can be recorded incidentally throughout the year. Despite the unstructured nature of observation-based data collection, only one mammal species (Common Muskrat, *Ondatra zibethicus*) was documented solely via incidental observations. As expected, based on detectability and diversity in the three taxonomic groups, bird species were most frequently detected incidentally, followed by mammals and amphibians.

An assessment of key indicator resource species illustrates that some species (e.g., songbirds, bats, Black Bear [*Ursus americanus*]) are widespread and documented from all treatments and leases, while others (e.g., North American River Otter [*Lontra Canadensis*] and North American Beaver [*Castor canadensis*]) are not, having been documented from only one treatment so far. While incidental data help to assess the occurrence and distribution of wildlife species, statistical analyses are not performed on those data for various technical reasons. To rigorously assess certain species and species groups, we use data specific to small mammals, bats, songbirds, wildlife cameras, arthropods, and vegetation to assess the efficacy of upland reclamation relative to our objectives.

The results of small mammal live-trapping revealed a strong seasonal difference in both the relative abundance and number of species captured, with more species and individuals trapped in the fall compared to the spring. Relative abundance of herbivorous species (Deer Mouse [*Peromysucs maniculatus*], Meadow Vole [*Microtus pennsylvanicus*], and Southern Red-backed Vole [*Myodes gapperi*]), increased over time, with an increase in abundance in each subsequent year (2014-2016). Trends in abundance for herbivorous species differed by treatment type depending on species, suggesting general habitat preferences characteristic for these species. For example, Southern Red-backed Vole was more abundant in mature forest, Meadow Vole was more abundant in open habitats with grasses (reclaimed and compensation lake), and Deer Mouse abundance was not associated with any specific habitat type (i.e., habitat generalist). A trends assessment incorporating the 2017 and 2018 data has not occurred, but a preliminary review of the data indicate that total captures of Deer Mouse, Meadow Vole, and Southern Red-back Vole peaked in 2016 and declined thereafter. Total captures in 2017 and 2018 were higher than 2014 and 2015. Once the data are corrected for survey effort, a quantitative comparison over time (by treatment) will be made.

Autonomous bat detectors were deployed for a total of 124,957 hours between 2014 and 2018 (Albian: 19,887 hours; Fort Hills: 11,494; Horizon: 61,173; Kearl: 3,675; and Oil Sands Base: 28,728). All seven species of bat expected to potentially occur in the Athabasca Oil Sands Region based on known or suspected distributional records were documented based on acoustic call signatures. These include five species of provincial conservation concern, including two federally endangered species (Northern Myotis [*Myotis septentrionalis*] and Little Brown Myotis [*Myotis lucifugus*]). All seven species were documented from all treatments in all years, except for the cleared treatment in 2016 where only five species were found. The abundance of calls varied by species in a given treatment, and certain species were more often documented in certain treatments (notably the compensation lake treatment).

In particular, the mature forest has a substantially different detection rate compared to other treatments, likely related to habitat structure. Temporal activity of bats both daily and seasonally was not influenced by treatment.

Songbirds have been surveyed across all treatment types and on all leases. A total of 284 point count stations have been surveyed between 2011 and 2018, resulting in the documentation of 138 species. To increase comparability, this data set was constrained based on several factors, including limiting it to songbirds detected within 75 m of the point count centre for most analyses. Results indicate that songbirds were abundant and widespread across all treatment types; however, the abundance of species varied widely among species and relatively few species made up the majority of detections. Rarefaction techniques suggest that majority of species have been detected within each treatment, and few new species would be added by increasing sample size. However, by increasing sample size at the treatment level (i.e., adding more logged, burned, cleared, and mature forest habitats), more species are likely to be added and the strength of the results increased. Species also differed in their occurrence and abundance among treatments. In particular, the mature forest treatment had relatively low Sørensen Similarity compared to other treatment types. This trend held true when non-metric multidimensional scaling ordinations were plotted. Most other treatments also clustered distinctly, though the cleared treatment had the greatest breadth in ordination space and contained songbird assemblages not different from reclaimed, compensation lake, burned and logged treatments. The dissimilarities in species composition among treatments allowed for the identification of multiple potential indicator species for treatments and groups of treatments. These indicator species are utilizing treatments based on the habitat characteristics of those sites and are selecting habitats consistent with known life-history attributes. The percent similarity of bird communities (species composition and abundance) was contrasted between reclaimed habitats and mature forests (as a proxy for the desired end point of upland reclamation in the AOSR). As time since reclamation increased, so did the similarity of bird communities of reclaimed habitats relative to mature upland forest. There continues to be considerable variation in the percent similarity between reclaimed and mature upland forest (between 13 and 67%), but this is expected given the age of most reclaimed plots (<15). Even the percent similarity oldest reclaimed plot sampled (33 years) varied relative to each mature forest reference points.

With regards to other treatments, plots recovering from logging (aged four to six years) did not group with mature forest plots nor with early reclaimed plots, but with older reclaimed plots aged 10-27 years. Burned plots (aged two to six years) exhibited a similar trend, grouping with reclaimed plots aged 10-18 years. Cleared plots (aged two to four, six to 11, and 16 years) were the most divergent from mature forest plots, and most cleared plots grouped with reclaimed plots aged one to seven years. However, a few older cleared plots (seven to 10 years) grouped with older reclaimed plots, aged seven to 13 years.

Combined, these results provide a good understanding of the current distribution, abundance, and use of various treatments by songbirds in the AOSR, including those of reclamation sites. However, these early-successional habitats are not static, and we expect to see shifts in the distribution, abundance and composition of songbird species as vegetation communities advance.

Wildlife camera data were used to derive usage patterns (i.e., occupancy estimates) of mammals (especially medium to large species) that are otherwise seldom detected by human observers. A minimum of 79 species of wildlife have been observed on wildlife cameras between 2014 and 2018 (minimum indicated because not all 2018 photos have been processed). Standardized sighting rates revealed that wildlife sightings in general increased after 2009 with a peak in 2012, and a subsequent decline to pre-2009 levels. The cause of this peak of activity remains unknown. Analyses into patterns of occurrence focused on the most commonly detected mammals (nine species). Most of these species showed relatively consistent patterns across time and habitat types. However, there were notable differences in usage among treatments. For example, Red Fox, Gray Wolf, and White-tailed Deer use was greatest in compensation lake sites, while Mule Deer, Snowshoe Hare, and Coyote were sighted most frequently in reclaimed habitats. Species had individual patterns to their apparent habitat preferences and intensity, as well as seasons of usage within those habitats. For example, White-tailed Deer, Black Bear, and Moose had consistent sighting rates across years in mature forest and riparian habitats, but appeared to be increasing in reclaimed areas, potentially as habitat succession proceeds. These analyses have provided important data that may help reveal trends that emerge in future years as reclamation advances, that should be associated with shifts in species usage or activity patterns over time. Further (similar) analyses are planned for 2019, at which time data from all years and leases will be assessed relative to occupancy rates by year and habitat type.

Previous (2016) pitfall trap surveys yielded 7,404 arthropods, including 397 spiders and 909 beetles. Spiders were identified to 60 species, while interim beetle identifications yielded 32 species of ground and rove beetles (additional beetle specimens were retained for future identification and analyses). Standardized abundance, richness, and composition of spiders differed among treatment types. The species composition of reclaimed and compensation lake treatments was also significantly different from all other treatments sampled (cleared, burned, and mature forest). The spider species characteristic of the compensation habitat were open-habitat, ground-running species in the family of Wolf Spiders (Lycosidae). The differences in vegetation structure between sites and species-specific habitat requirements is the likely driver of observed compositional differences. Subsequent analyses revealed that certain species of spiders were associated with a given treatment suggesting that spiders could be suitable indicators of ecosystem shift. Following the completion of analyses planned for 2019 we will be better positioned to expand on this line of thinking.

Vegetation is an integral component of forest ecosystems, influencing wildlife use. Wildlife respond to different vegetation characteristics, which in turn differ among different treatments. Previous data (2015-2016) revealed a total of 253 vascular plants. Species richness varied by treatment, with logged sites having the lowest species richness and reclamation and burned sites having the highest. Introduced and invasive species (i.e., weeds) are prevalent in disturbed habitats. The highest number of exotic species was found in reclamation sites, while logged and mature forest sites had the lowest number. We found that while the proportion of vegetation cover by native species was approximately equal among treatments, exotic vegetation was disproportionately prominent in reclamation, compensation lake, and cleared treatments, reflecting the early seral conditions on those sites. Vegetation cover varied by treatment in 2015, with Mature Forest having significantly greater cover than Reclamation and Logged treatments; though this trend did not hold in 2016 when no significant treatment differences were observed. Overall there were significant differences in vegetation communities among treatments. Many plant species were indicative of one or several treatment types. Species with the strongest habitat associations tended to be native species, while several exotic species were indicative of early successional habitat types. We expect changes in vegetation richness and composition over time, and as individual sites continue along revegetation trajectories influenced by characteristics (e.g., time since disturbance, moisture/nutrient profiles, light availability, etc.) particular to each site. As with other taxa, additional analyses are planned for 2019 at which time data from all years, leases, and treatments will be summarized.

Systematic wildlife surveys and remote-sensing technologies (aerial reconnaissance units/drones and remote cameras) each target a group of species located in an area at a particular time (e.g., time of day, season, etc.), or in a particular way (e.g., use of traps, auditory counts, etc.). However, because detectability differs among species and may decrease with decreasing abundance, the effectiveness of a given monitoring approach varies. Further, and perhaps more problematic, is that rare or elusive species may go undetected when systematic survey methods are used. The use of autonomous recording units and remote cameras can mitigate for differential detectability and potential lack of observations of rare and elusive species. Standardized surveys are necessary when assessing trends over time or when comparing wildlife use between treatments or leases. Incidental observations contribute to our understanding of which wildlife species are using reclaimed habitats in the AOSR. The combination of directed and standardized surveys and incidental wildlife observations are providing a thorough understanding of which species are utilizing reclamation areas in comparison to other early successional and mature habitat types.

LESSONS LEARNED

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

1. Commonly used wildlife survey methods, small mammal live-trapping, songbird point counts, use of remote-sensing equipment (autonomous recording units and remotely triggered wildlife cameras), provide a standardized dataset upon which appropriate statistical analyses can be performed. The application of these survey methods contributes to the development of a time-series dataset that can be used in trends assessments and community ecology analyses.
2. Insect sampling (pitfall trapping) is providing data by which ecological shift can be assessed. Preliminary results reveal the presence of species-specific habitat associations with some species occurring in only a single habitat type. With time, it should be possible to use better characterize the species-habitat associations and use the presence and abundance of a suite of species to discuss reclamation efficacy.
3. Winter-tracking surveys (snow-tracking) are a sub-optimal method for documenting the use and occurrence of winter-active animals. Rather, remotely triggered wildlife cameras should be used to ensure that data can be collected in a standardized and consistent manner.
4. The inclusion of incidental data (i.e., data not collected using standardized data collection techniques) provides a more robust understanding of wildlife occurrence and distribution on sites reclaimed to upland habitats when combined with data collected using standardized methods. These incidental observations are an important part of the Early Successional Wildlife Dynamics Program.
5. Following the previous point, we currently record all species of wildlife targeted by standardized surveys. Preliminary analyses suggest that an indicator species approach could be used to focus surveys to a subset of species in each taxonomic group. More data are required to fully test this hypothesis.
6. Our current focus is on developing a baseline against which future comparisons can be made. This necessitates the collection of species occurrence, distribution and abundance data relative to each site sampled. Although informative to the program, species presence and abundance data are only telling us part of the story. In addition to knowing which species occur on upland reclaimed sites relative to the various analogs (burned,

logged, cleared, compensation lake, and mature forest) an understanding of the function and productivity of upland reclaimed habitats is required. It will be necessary to determine if upland reclaimed habitat provides the habitat attributes necessary for wildlife to fulfill their life requisites in a manner consistent (but not necessarily identical to) with exiting mature forest in the region. This will ensure a fulsome assessment and understanding of reclamation efficacy and success.

7. Similarity indices are commonly used to compare species assemblages between treatments types (e.g., reclaimed vs. mature forest). While informative, the degree of similarity might provide misleading data. For example, the percent similarity between two habitat types might overlap, but following the previous point, the productivity and function of the two habitat types may differ substantially with one habitat providing sub-par habitat relative to the other. The use of an index of similarity also poses the risk of setting a threshold against which to proclaim reclamation success. Wildlife communities are non-uniformly distributed across the landscape and can exhibit a high degree of natural variation. The similarity index may be confounded by this natural variation. Using a value of similarity to assess reclamation success only partially supports the requirement to reclaim habitats to a similar (but not identical) pre-disturbance land-capability.
8. Existing mature forests are being used as the reference point for upland reclamation. These habitats provide one possible outcome of upland reclamation; however, it is unknown if reclaimed habitats will develop into mature forests characterized using existing accepted methodology (e.g., Beckingham and Archibald 1996) or if they will simply resemble a currently described mature forest with a different species assemblage. As such, the utility of mature forest points as desired outcomes of upland reclamation may need to be reconsidered or at the very least, put into the context of one of several to many possible outcomes.

LITERATURE CITED

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

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Submitted:

Hawkes, V.C. and T.G. Gerwing. In Review. Wildlife Usage Indicates a Trend Towards Increased Similarity Between Reclaimed Upland Habitat and Mature Boreal Forest in the Athabasca Oil Sands Region of Alberta, Canada. Submitted to PLoS One December 17, 2018. MS Number: PONE-D-18-36024.

In Preparation:

Gerwing, T.G. and V.C. Hawkes. Function from Form: The Problems of Assessing Ecosystem Functionality from Community Similarity Analyses in Restoration Ecology.

Gerwing, T.G. and V.C. Hawkes. Wildlife Usage Trends of Reclaimed Boreal Forest Habitat in Canada's Oil Sands over Three Decades.

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ENVIRONMENTAL RESEARCH AND MONITORING

Reclamation Carbon Life Cycle Analysis

COSIA Project Number: LJ0271

Research Provider: University of Alberta and Natural Resources Canada

Industry Champion: Suncor Energy Inc.

Status: Year 3 of 3

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 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 Energy Inc. (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 system (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 originally known as Pond 1 and was renamed after being reclaimed in 2010. It is the first oil sands tailing pond to undergo surface reclamation work. The initial pre-disturbance ecosystem was examined, which included approximately 198 hectares of wetland and 152 hectares of forest, site preparation and associated energy consumption, carbon 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, the soil carbon return can be predicted and the change in biomass carbon for the 90 years after reclamation.

Further, the carbon balance model from one landform (reclaimed tailings pond) was scaled up to an entire oil sands mine lease, Lease 86/17. The scaled-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). The carbon balance model will support identification of a range of options on how to avoid carbon emissions from various reclamation activities and where and how to plan for enhanced carbon storage during reclamation development and project closure.

A draft report of the work was completed in 2016, but peer review identified deficiencies in some aspects of the model. Consequently, forest and soil carbon modeling experts, at Natural Resources Canada, were identified and added to the existing team in 2017. The enhanced team commenced optimization of the pre-disturbance and reclamation ecosystem model phases in fall 2017.

An enhanced model was developed and utilized to conduct the analysis, and a final draft report was completed in December 2018. The report will be reviewed and finalized in 2019.

The study was conducted during the years 2015-18. Start date: Aug. 1, 2015. End date: 2018.

LESSONS LEARNED

The following are the key lessons identified by this reclamation-focus carbon life cycle assessment:

- Modelling results suggest that planting 1,000 stems/ha of aspen or poplar trees on the soil stockpile would mitigate GHG emissions as trees take up CO_2 and could significantly reduce soil carbon losses during storage as soil carbon is replenished through inputs of litter and other material from the trees. This would also provide a source of coarse woody debris (CWD) and snags for erosion control, creation of microsites for seedlings, and add carbon storage on the landscape.
- Avoid delays in returning reclaimed sites to productive forests. Net primary productivity (NPP) during recovery of the reclaimed forest, being the primary sink for carbon in this analysis, is necessary to the recovery of the ecosystem carbon stock and to off-set emissions from both ecosystem and industrial sources. Although reclaiming sooner will not alter the final ecosystem carbon balance, it will result in a larger ecosystem carbon stock and smaller net carbon source sooner.

- Emissions from disturbance of soil or peat are unavoidable onsite, but additional disturbance emissions off-site can be avoided by harvesting an amount of soil and peat onsite that is sufficient to meet reclamation requirements for soil replacement.
- Avoid the practice of piling and burning woody material (small-sized trees, snags, CWD) that is not removed from the site for harvested wood products because the combustion of wood produces GHG emissions. Mix the woody debris with overburden and bury the material or place it on the reclamation soil surface instead of piling and burning.
- Ensure harvested merchantable timber is converted into long-lived harvested wood products (HWP). This will reduce rates of carbon emissions from merchantable wood, as long-lived HWPs such as dimensional wood used in construction is sequestered for the life of the building, and once land-filled, decays at rates much lower than wood decaying on the forest floor. Current forest wood utilization standards are higher than what was modelled for 1966 (i.e., aspen is the most common species in the area but is believed not to have been harvested in 1966).
- Manage reclaimed sites to avoid natural disturbances (i.e., wildfire) to avoid emissions of CO_2, but also emission of CO and CH_4 from combustion that have higher warming potentials than CO_2.
- Tailings industrial fugitive emissions are a major source of carbon emissions, so capping ponds 10 years earlier than the baseline case could reduce fugitive emissions by 31%.
- Since overburden removal is responsible for 24% of the lease industrial emissions further research should investigate methods to optimize the process to reduce energy consumption.
- The drainage and sand infill pumps consume large amounts of electricity, therefore using cogeneration to reduce the confidence interval of the electricity could decrease sand infill emissions and drainage pump emissions significantly.
- Using coke to cap the ponds results in carbon being buried instead of combusted, therefore reduces industrial emissions.

PRESENTATIONS AND PUBLICATIONS

Di Lullo, G., Zhang, H., Gemechu, E., Kumar, A., Hoffman, D., Shaw, C. and Daly, C. (2018, June). Carbon Life Cycle Assessment of a Suncor Energy Inc. Oil Sands Reclamation Project. Poster presented at the COSIA Innovation Summit, Calgary, AB.

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