2019 COSIA LAND EPA

In Situ Research Report

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INTRODUCTION

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

Canadian Natural Resources Limited (Canadian Natural)*
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Imperial Oil Resources Limited (Imperial)
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COSIA publishes two reports, 2019 COSIA Land EPA – Mine Research Report and 2019 COSIA Land EPA – In Situ Research Report. This report summarizes progress for projects related to in situ reclamation of the COSIA Land EPA.

The project summaries included in this report do not include all projects completed under the Land EPA. Please contact the Industry Champion identified for each research project if any additional information is needed.

2019 COSIA Land EPA – In Situ Research Report. Calgary, AB: COSIA Land EPA.

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

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WETLANDS

H38 Wetland Carbon Flux Research Project

COSIA Project Number: LJ0290

Research Provider: University of Waterloo, Northern Alberta Institute of Technology (NAIT)

Industry Champion: Imperial

Status: Year 3 of 4

PROJECT SUMMARY

Imperial's Cold Lake Operations commenced a wetland reclamation trial in 2008 at Mahihkan H38 pad. The pad was constructed in 2002 with 38,800 m^3 of borrow fill material on a treed rich fen that had an average depth of 148 cm of organic material (peat). This wetland reclamation trial included partial and complete pad removal (Figure 1). The reclaimed fen wetland was allowed to naturally revegetate.

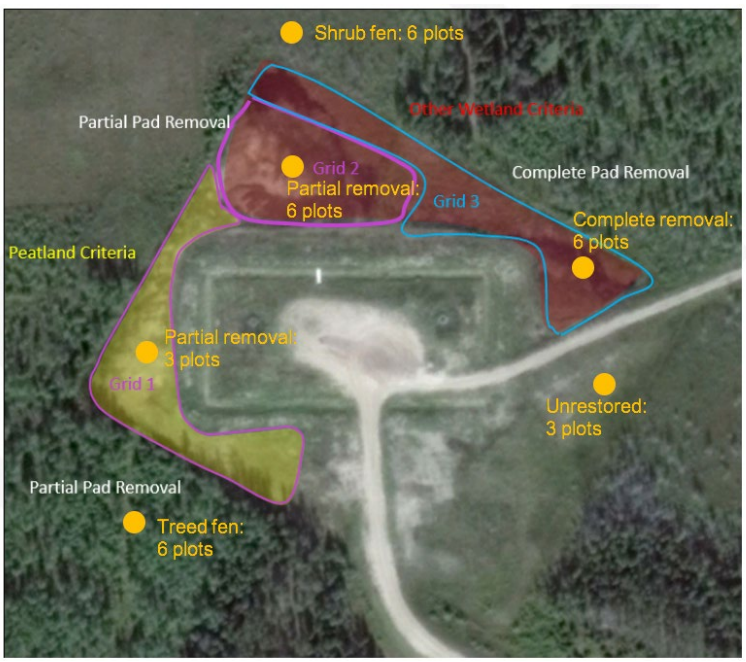

Figure 1: Diagram study site including the three grids surveyed for vegetation in 2018. Orange circles indicate approximate positions of plots used for carbon flux measurements and indicate the number of replicate plots in each zone. Considering vegetation assessment, the yellow area passed the peatland criteria while alternative wetland criteria are recommended for red areas.

Water chemistry, vegetation and wildlife use was monitored annually at this site from 2010 to 2015. Given that greenhouse gas (GHG) exchange is an important peatland ecosystem function, a study was initiated in 2016 to understand how reclamation activities (partial and complete pad removal) impact these GHG fluxes. Only preliminary measurements were conducted in 2016, with expanded sampling in summer 2017 and 2018. In 2019, final measurements of vegetation biomass and litter decomposition were collected, but analysis of this data is ongoing.

The well pad has sections where the clay fill has been completely removed, partially removed (treatment sites) and left in place (control site). Sampling of vegetation and GHG exchange at dominant vegetation communities within each treatment is being conducted. These results will be compared to adjacent, undisturbed peatlands (reference sites) with plots in both a forested and shrubby fen.

The specific objectives of the project are to:

1. Determine the growing season flux of CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide) on a well pad, reclaimed four to five years prior to the study, under various civil earthwork treatments (complete removal, partial removal) compared to adjacent undisturbed peatland and unreclaimed (i.e., no removal) control sites.
2. Evaluate ecohydrological controls (e.g., plant cover and type, water table position, C/N ratio) on the rate of GHG flux and how these vary between treatments, and between the reclaimed and undisturbed peatland.
3. Determine aboveground and belowground net primary production and organic matter accumulation at the same treatments where GHG fluxes are determined.
4. Evaluate differences in dissolved organic carbon concentration and chemistry, microbial community structure and nutrient availability between treatments on the reclaimed pad and the natural peatland, and links between these variables and GHG fluxes.
5. Evaluate how well plant community composition, as evaluated under the peatland wellsite reclamation criteria, correspond to biogeochemical function and GHG flux.
6. Correlate site history, construction methods and reclamation techniques with current site progress and carbon status and develop best management practices (BMPs) for future sites.

PROGRESS AND ACHIEVEMENTS

Measurements have been made to address all objectives. All data has been collected and a manuscript investigating CO_2 and CH_4 flux will be completed by March 2020. Biomass and Net Primary Production (NPP) samples were collected in autumn 2019, coinciding with removal of litterbags installed for litter decomposition. Biomass and NPP data analysis will be completed this spring. A laboratory incubation experiment was conducted to measure soil respiration rates in vitro for samples from H38: where no pad removal was completed (control); where the pad was completely removed; and in areas with partial pad removal (i.e., grade reduction to meet the elevation of the adjacent peatland). Respiration rates were compared to those measured in reference peatlands and other well pads reclaimed with partial removal (SKEG as described in Vitt et al., 2011) and inversion techniques (IPAD, Sobze et al., 2012). Results indicate the function of the microbial community.

In 2019, progress made towards achieving objectives 1, 2, 3, 5 and 6 is outlined below.

Carbon Dioxide and Methane Exchange

As part of a broader understanding of carbon exchange on reclaimed well pads, H38 was compared to a well pad reclaimed with partial fill removal located near Peace River, AB (SKEG).

Sites located at H38 are clearly marked in all figures and tables below.

Under full-light conditions, the net ecosystem exchange of CO_2 (NEE) in reclaimed areas of H38 were similar to natural reference fen rates, with greater uptake than the understory of the reference bog (Figure 2). Most treatments had CO_2 uptake (noted as a negative to indicate removal from the atmosphere), with generally greater uptake at reclaimed plots than at the unreclaimed areas (control) where no pad removal occurred. The exception was the flooded area within the complete pad removal zone (CR) and the wettest areas of the partial removal zone (PR-0-W) – these plots were sources of CO_2 to the atmosphere, likely due to the low vegetation cover (see Vegetation Recovery section below).

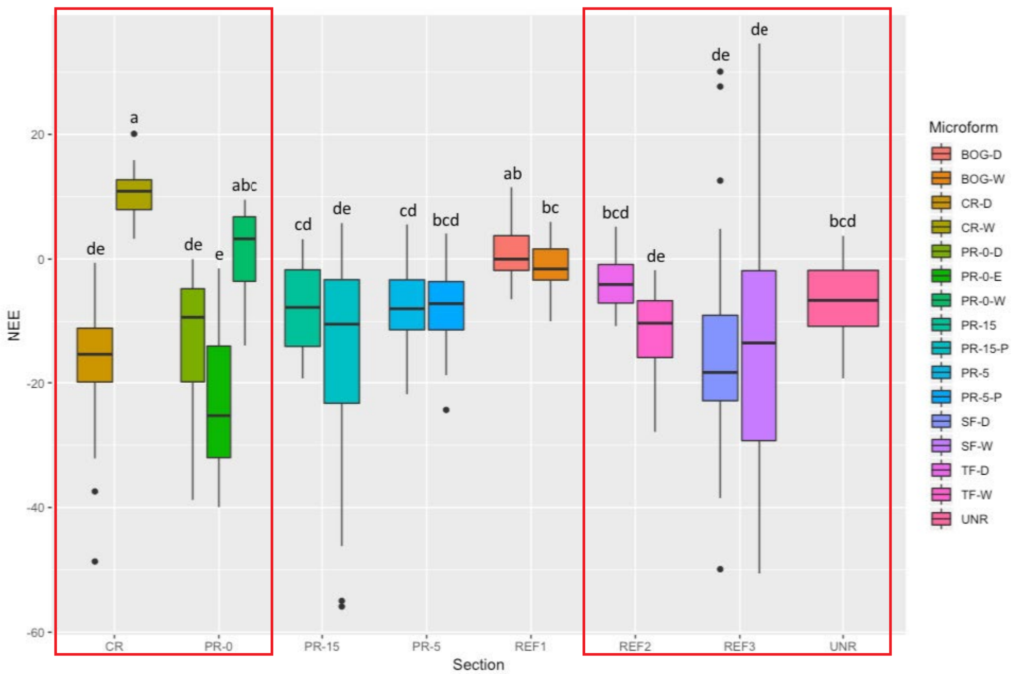

Figure 2: Net ecosystem exchange (NEE) of CO_2 during the monitoring season of 2018 at a photosynthetically active radiation (PAR) photon flux density of ≥ 1000 µmol m^{-2} s^{-1}. Negative NEE values indicate uptake of CO_2 from the atmosphere (carbon sink). Groups with the same letters are not significantly different. Sites at the H38 study site are indicated by red boxes.

Treatments are:
PR-15: Partial removal of mineral soil (MS) to 15 cm above seasonal water table
PR-5: Partial removal of MS to 4-6 cm above seasonal water table
PR-0-D/W: Partial removal of MS to surface elevation of surrounding fen reference ecosystem (uneven ground relief)
PR-0-E: Partial removal of MS to same surface elevation of surrounding fen reference ecosystem (even ground relief)
CR: Complete removal of MS
UNR: Unrestored
BOG-D and BOG-W: Reference bog dry and wet microsites, **REF1**
SF-D and SF-W: Shrubby fen dry and wet microsites, **REF2**
TF-D and TF-W: Treed fen dry and wet microsites, **REF3**

Methane emissions from the reclaimed sections of H38 were often similar or slightly lower than the adjacent reference fens, and lower than the reference bog measured in Peace River, although differences were not significant (Figure 3). Very high emissions were measured at the flooded area of the complete removal treatment. The unreclaimed pad at H38 had very low CH_4 flux.

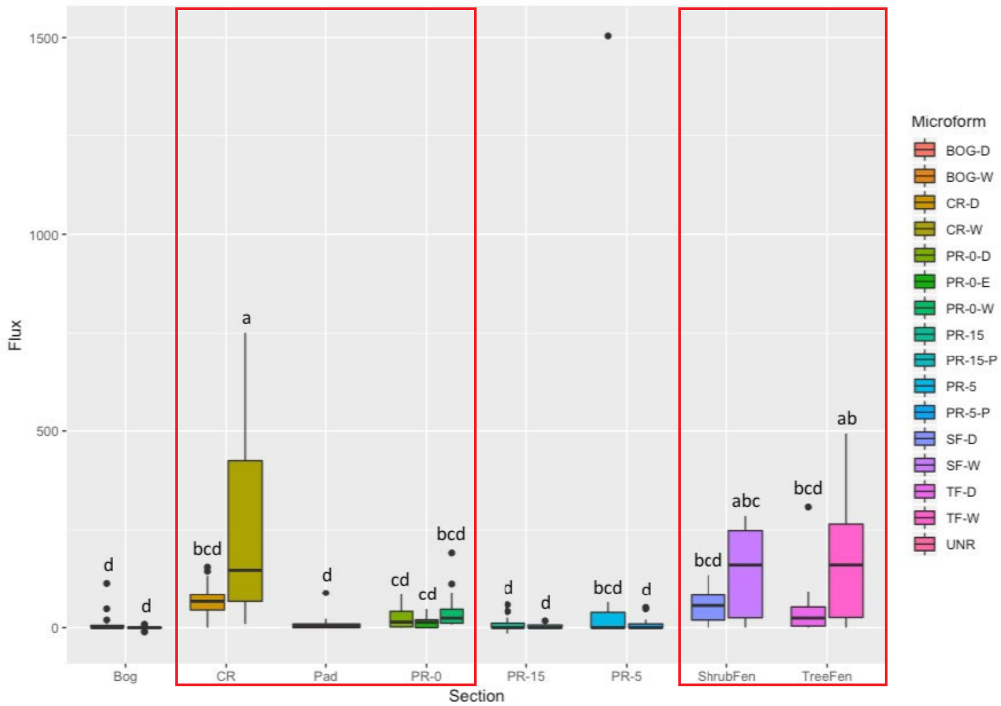

Figure 3: Methane fluxes in 2018 (mg CH_4 m^{-2} d^{-1}). Sites at the H38 study site are indicated by red boxes.

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PR-15: Partial removal of mineral soil (MS) to 15 cm above seasonal water table
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CR: Complete removal of MS
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BOG-D and BOG-W: Reference bog dry and wet microsites
SF-D and SF-W: Shrub fen dry and wet microsites
TF-D and TF-W: Treed fen dry and wet microsites

Empirical models were developed to estimate gross ecosystem photosynthesis, ecosystem respiration and CH_4 fluxes based on photosynthetically active radiation, soil temperature and water table position according to Baird et al. (2019). Combining these models with local meteorological conditions measured at the station installed on site allowed us to estimate seasonal carbon exchange. Seasonal carbon balances across reclamation treatments at H38 ranged from mean values of -423 g C m^{-2} (net C uptake) to 723 g C m^{-2} (net C emission) over a 107-day period (Table 1). Plots within both complete pad removal and partial pad removal areas were net carbon sinks. However, the greatest loss of carbon to the atmosphere occurred at sites with shallow to deep inundation, where plant establishment was poor. The unreclaimed site was a source of carbon in both 2017 (225 g C m^{-2}) and 2018 (175 g C m^{-2}). Rates of C exchange on the reclaimed pad were within the range of those measured at the Peace River site, and in the reference bog and fens. However, it should be noted that the reference site overstory productivity, which would increase the C uptake at these sites, has not yet been included in these calculations.

Table 1: Cumulative seasonal carbon fluxes of methane (CH_4), and net ecosystem exchange of CO_2 (NEE) as a sum of gross ecosystem production (GEP) and ecosystem respiration (R_{eco}), for all monitoring sectors* in 2017 and 2018. Both seasonal calculations were done for a time period of 107 days (May 17 – August 31, 2017 and May 22 – September 9, 2018). Sites located at H38 are shown in bold.

Microform sector*	May – September 2017					May – August 2018				
	GEP	R_{eco}	NEE	CH_4	Total	GEP	R_{eco}	NEE	CH_4	Total
	(g C m^{-2})					(g C m^{-2})				
Unreclaimed	**-394**	**506**	**112**	**0.7**	**225**	**-487**	**574**	**87**	**0.8**	**175**
Partial removal to 15 cm above WT	-322	368	47	1.4	95	-348	368	21	0.7	42
Partial removal to 15 cm above WT + planting	-525	559	34	0.2	69	-512	499	-13	0.2	-26
Partial removal to 5 cm above WT	-339	285	-54	3.5	-105	-416	346	-70	6.1	-133
Partial removal to 5 cm above WT + planting	-329	282	-47	0.6	-94	-342	224	-118	0.7	-235
Partial removal to 0 cm above WT (dry microsites)	**-417**	**314**	**-103**	**3.9**	**-202**	**-323**	**110**	**-213**	**1.8**	**-423**
Partial removal to 0 cm above WT (wet microsites)	**-160**	**206**	**46**	**6.6**	**99**	**-216**	**580**	**365**	**3.3**	**732**
Partial removal to 0 cm above WT (uneven ground)	**-421**	**420**	**-2**	**3.3**	**0**	**-443**	**409**	**-34**	**1.1**	**-67**
Complete removal (dry microsites)	**-475**	**348**	**-127**	**7.2**	**-246**	**-375**	**284**	**-91**	**5.8**	**-177**
Complete removal (wet microsites)	**-39**	**333**	**294**	**31.9**	**621**	**-27**	**225**	**198**	**21.7**	**418**
REF-Shrubby Fen (dry microsites)	**-606**	**715**	**109**	**16**	**234**	**-407**	**638**	**231**	**4.6**	**466**
REF-Shrubby Fen (wet microsites)	**-652**	**671**	**19**	**28.4**	**66**	**-606**	**561**	**-45**	**11.9**	**-79**
REF-Treed Fen (dry microsites)	**-219**	**299**	**81**	**2.7**	**164**	**-150**	**334**	**184**	**3.7**	**371**
REF-Treed Fen (wet microsites)	**-578**	**418**	**-160**	**33.4**	**-286**	**-454**	**283**	**-171**	**14.3**	**-328**
REF-Bog (dry microsites)	**-204**	**358**	**155**	**0.6**	**310**	**-283**	**377**	**94**	**0.8**	**190**
REF-Bog (wet microsites)	**-184**	**262**	**77**	**0.1**	**155**	**-337**	**248**	**-88**	**0**	**-177**

*Partial or complete removal refers to mineral fill present for the well pad. REF indicates reference, undisturbed peatlands.

Soil Respiration and Chemical Conditions

Remnant mineral soil fill on areas of reclaimed well pads in peatlands (i.e., partial removal) had elevated electrical conductivity in soil compared to complete removal plots and reference peatlands (Table 2). However, this was not linked to higher concentrations of extractable dissolved organic carbon (DOC) or plant-available nutrients. The specific chemistry of the fill used in pad construction appears important to post-reclamation soil chemistry conditions. This is illustrated by the high sulphate concentrations at the Peace River, Alberta reclaimed pad (PR-5 and PR-15 treatments) compared to treatments at H38.

Table 2: Soil pH and electric conductivity (EC), as well as mean dissolved organic carbon (DOC in mg L^{-1}) and plant available soil nutrient supply rates (in mg L^{-1}) of ammonium, iron, phosphorus and sulfur, in all monitoring sectors*. BDL stands for values below detection limit (detection limit for Fe 0.12 µg L^{-1}).

Sector*	Mean pH	±SD	Mean EC [µS/cm]	±SD	DOC	Iron (Fe)	Ammonium (N/NH_4^+)	Phosphorus (P/PO_4)	Sulfur (S/SO_4^{2-})
Unreclaimed	8	0.2	290	27.6	n.a.	BDL	14.4	44.5	24.8
Partial removal of mineral soil (MS) to 15 cm above WT	4.8	0.2	1109.8	870.8	5	BDL	33.6	85.6	5608.2
Partial removal of MS to 4-6 cm above WT	4.2	0.3	1442	753.3	6.3	BDL	21	113.7	1638.2
Partial removal of MS to surface elevation of surrounding fen REF ecosystem (uneven ground relief – dry microsite)	3.2	0.4	378.7	17.2	5.8	2.43	15.9	58.2	12.2
Partial removal of MS to surface elevation of surrounding fen REF ecosystem (uneven ground relief – wet microsite)	3.3	0.4	344.3	26.9	6.5	BDL	28.8	88.6	80.8
Partial removal of MS to surface elevation of surrounding fen REF ecosystem (even ground relief)	5	2.1	348.7	11.5	10.8	BDL	11	76.4	9.7
Complete removal (dry microsites)	4.8	0.3	106.3	13.3	8.6	0.55	168.6	267.5	32.5
REF-Shrubby Fen (dry microsites)	4.9	0.3	122.5	27.8	24.5	5.43	364.9	330.6	95.7
REF-Shrubby Fen (wet microsites)	4.6	0.2	76.1	32.9	15.5	2.97	332.7	296.5	69.2
REF-Treed Fen (dry microsites)	5	0.1	86.7	58.5	n.a.	1.76	213	182.2	88.9
REF-Treed Fen (wet microsites)	4.9	0.2	68.7	20.2	n.a.	1.47	356.6	355.7	81.5
REF-Bog (dry microsites)	4	0.2	34.7	10.9	35	2.19	109	117.1	100.2
REF-Bog (wet microsites)	2.9	0.6	38.9	3.6	28.8	0.90	126.8	85.2	95.2

*Partial or complete removal refers to mineral fill present for the well pad. REF indicates reference, undisturbed peatlands.

Soil respiration was measured in vitro using soil collected in the top 10 cm of each natural site and reclaimed well pad. At H38, soil respiration was lower for the well pad compared to the adjacent natural fen and similar to, or lower than, other reclaimed well pads (SKEG and IPAD) in the Peace River region (Figure 4). There were also no significant differences in soil respiration between the complete removal and partial removal sections of H38. This suggests that maintaining mineral soil near the surface of the wetland profile does not enhance carbon losses through soil respiration. Higher respiration at the natural reference fen near H38 is likely linked to fresh litter inputs as illustrated in dissolved organic carbon composition that indicated low molecular weight.

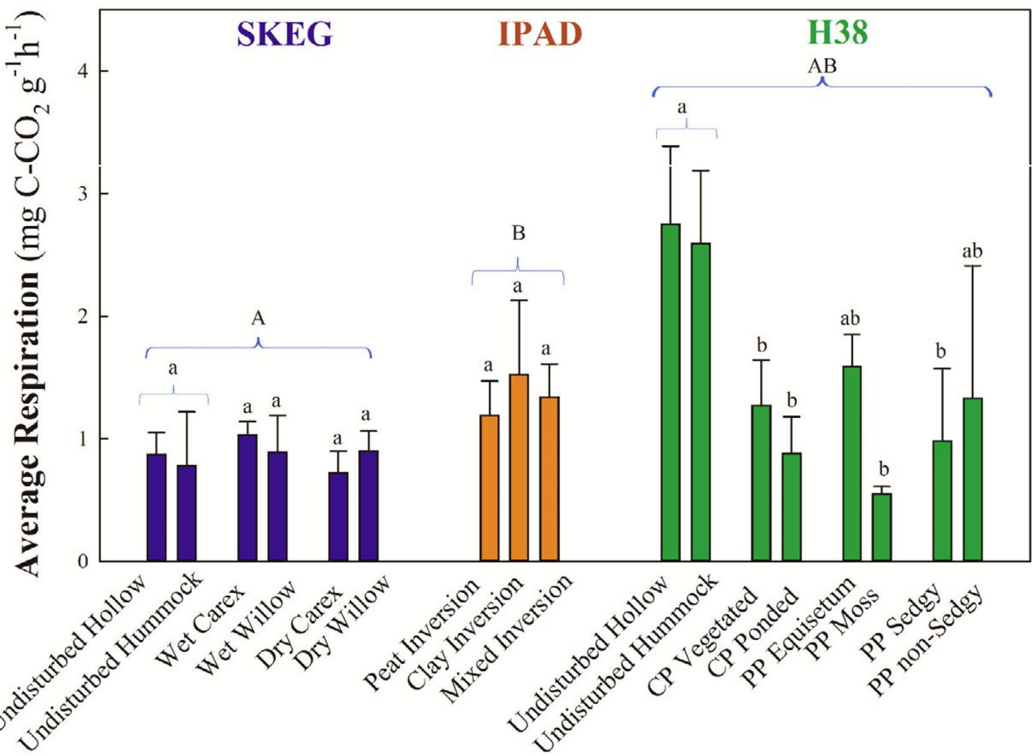

Figure 4: Soil respiration rates measured in vitro representing a series of reference peatlands (undisturbed) and reclaimed well pads. The well pads include: **H38**, the focus of the present report, with sections where the well pad has been completely removed (CP) or partially removed (PP); **SKEG,** where pad material was partially removed to a different elevation resulting in either wet or dry conditions; and **IPAD,** where pad material was completely removed and underlying peat decompacted (peat inversion), or pad removal was carefully buried under peat (clay inversion), or quickly buried resulting in some mixing (mixed inversion). The undisturbed site at SKEG is a treed bog and the undisturbed site at H38 is a shrubby rich fen. Uppercase letters indicate significant differences between study sites, and lowercase letters between specific treatments. Treatments are significantly different from each other if they share no letters in common.

Vegetation Recovery

Vegetation surveys were completed in reclaimed areas of the pad in three grids, using the Alberta Peatland Criteria (Figure 1). Although 100% of species surveyed were hydrophytes, three distinct wetland communities have formed. Applying the peatland criteria to all, only Grid 1 would be certifiable, although Grid 2 was reclaimed using the same method (partial pad removal). Both Grid 2 and Grid 3 failed for landscape, desirable species cover and woody stem counts, due to the presence of large open-water areas. Grid 3 also failed due to high undesirable species cover (Table 3). It should be noted that while Grid 3 was assessed using the peatland criteria, the complete pad removal treatment resulted in a shallow water body and use of this criteria is not appropriate.

Grid 2 can be divided into sections (open water versus vegetated) and the shallow open-water area may be able to pass mineral wetland criteria in the future. In practice, this is how this reclaimed site would be assessed. Delineate different areas and use appropriate criteria to assess each.

Table 3: 2018 Peatland Criteria assessment results

	Grid 1	Grid 2	Grid 3
Landscape Parameter	Pass	Fail	Fail
Species Richness	Pass	Pass	Pass
Desirable Species Percent Cover	Pass	Fail	Fail
Undesirable Percent Cover	Pass	Pass	Fail
Woody Stems	Pass	Fail	Fail
Site Performance Using Peatland Criteria	**Pass**	**Fail**	**Fail**
Reclamation Technique	Partial Removal	Partial Removal	Complete Removal
Wetland Classification	Fen	Emergent Marsh	Shallow Open Water Wetland
Criteria Should Assess With	Peatland	Other Wetland	Other Wetland

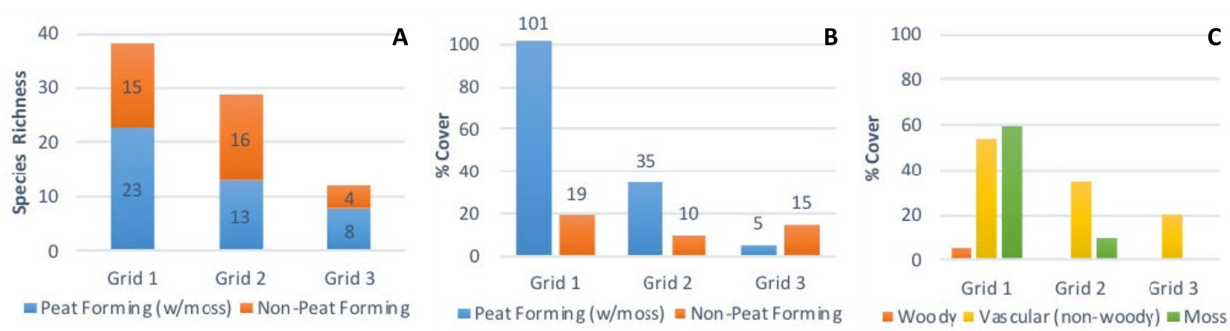

Figure 5: 2018 Vegetation survey summary by each grid, showing A) species richness of peat and non-peat forming species, B) cover of peat and non-peat forming species and C) cover of vegetation strata.

Grid 1 had the highest species richness (38) and highest number of peatland species (23), while Grid 3 had the lowest number of species (12) (Figure 5). Grid 1 also had the highest cover by peat forming species, while Grid 3 had only 5% peat forming species cover. Grid 1 was the only area with significant woody species cover and had almost 60% moss cover, while Grid 3 lacks both moss and woody species cover.

2019 Updates

In 2019, vegetation surveys were conducted using a 50 cm quadrat that was randomly tossed 20 times each in Grid 1, Grid 2, and the Natural Fen area to the north of the pad (natural) (Figure 1). Plants were identified to the species level whenever possible, and later grouped into bryophyte, herb, grass, horsetail, sedge and shrub (including small trees) categories. Within each 50 cm x 50 cm plot, litter and open water were also recorded. Finally, plants were grouped into peatland and non-peatland species, and then total plant cover was calculated by adding the two groups.

In Grid 1 and Grid 2 , depth of newly accumulated organic matter over mineral clay soil (Figure 6) was measured using a measuring tape in the center of the quadrat.

Figure 6: Close view of Grid 1 (and the growing moss carpet), Grid 2, and the Natural Fen.

Community composition was compared by carrying out a redundancy analysis (RDA) with relativized species cover in the main matrix. Mean peat depth in Grid 2 is 3.8 cm, significantly lower than the 13.5 cm in Grid 1 ($F_{(1,38)} = 44.67$, $P < 0.001$, data not shown). Vegetation in the Natural Fen, Grid 1 and Grid 2 were all different from each other (Figure 7).

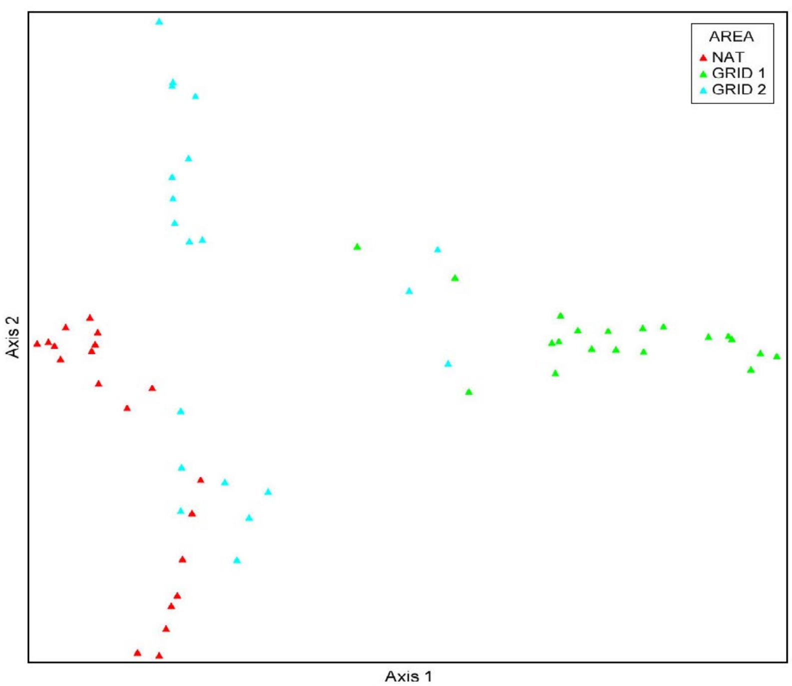

Figure 7: Redundancy analysis (RDA) of 2019 vegetation survey.

A one-way ANOVA (analysis of variance) was carried out to compare the percent cover of different functional groups among the three areas and mean peat depth between Grid 1 and Grid 2, followed by Tukey's pairwise comparisons of means. Whenever data were not normally distributed, a Kruskal-Wallis test was carried out instead, followed by a post hoc Dunn's test among groups. Grid 2 had the lowest mean peatland species cover (37.4 ± 6%), which is dominated by sedges (21.4 ± 3.7%). More than half of Grid 2 is open water (51.3 ± 7%) (Figures 8 and 9). Grid 1 had the highest bryophyte cover (61.5 ± 5.9%), horsetail cover (6 ± 1%) and the lowest shrub cover (1.2 ± 0.6%). Open water covers 28.8 ± 6.1% in Grid 1, similar to the Natural Fen (27.8 ± 6.4%). The natural area had the highest peatland vegetation (86.5 ± 7.5%) and total vegetation cover (91.7 ± 7.5%). It also has the highest herb (34.8 ± 7.6%) and shrub cover (16.9 ± 3.3%).

The 2019 survey confirmed our 2018 observation that Grid 1 is in fact accumulating peat through the growth of bryophytes. All three areas are very wet and they differ from each other in terms of vegetation composition. In many areas of Grid 1, extensive moss carpet, dominated by *Brachythecium acutum*, has formed. Larch and willow individuals are starting to grow but they are still a small component compared to other areas. In contrast, bryophytes such as *Aulacomnium palustre* and *Tomenthypnum nitens* grow in isolated mounds in the natural fen. The high water table between the mounds led to the dominance of herbaceous species such as *Menyanthes trifoliata*.

Grid 2 is more similar to a marsh than the surrounding fen due to the substantial open-water area, substantial sedge and minimal bryophyte cover. Aquatic species such as *Lemna minor* are dominant in many areas. Peat formation is limited to small areas where there is bryophyte growth.

Grid 1 shows that the partial removal of mineral fill and the creation of a flat, saturated mineral substrate can foster the growth, over time, of many peat-forming species, particularly true mosses. No planting or donor introduction was applied, so peat-forming vegetation establishment was through natural ingress. The surrounding flow-through fen probably facilitated the transport of spores, rhizomes and seeds onto the reclaimed surface, contributing to the overall success of the site. It is still recommended that donor moss is transferred after the partial removal of mineral fill in future trials. Early introduction of donors can accelerate the recovery of vegetation, especially in drier areas such as a poor fen or a bog.

Achieving the right soil surface elevation after mineral pad removal can be tricky, as observed in Grid 2. This area is closest to the main flow path of the natural fen and the soil surface elevation is slightly lower than that in Grid 1, resulting in a marsh-like community different from both Grid 1 and the natural fen area.

Complete removal of the mineral pad (Grid 3) led to the creation of a shallow open water. The buried peat was unable to rebound after the weight of the mineral pad was removed. Although floating mats of moss are emerging and emergent marsh plants are growing along the sides, the majority of the area is still open water.

Researchers maintained the conclusion that Grid 1 can pass the peatland criteria as of 2018 while the rest of the pad should be assessed as freshwater wetlands instead. None of the areas are failing as wetlands, but peat formation is limited to areas where shallow water covers the mineral surface.

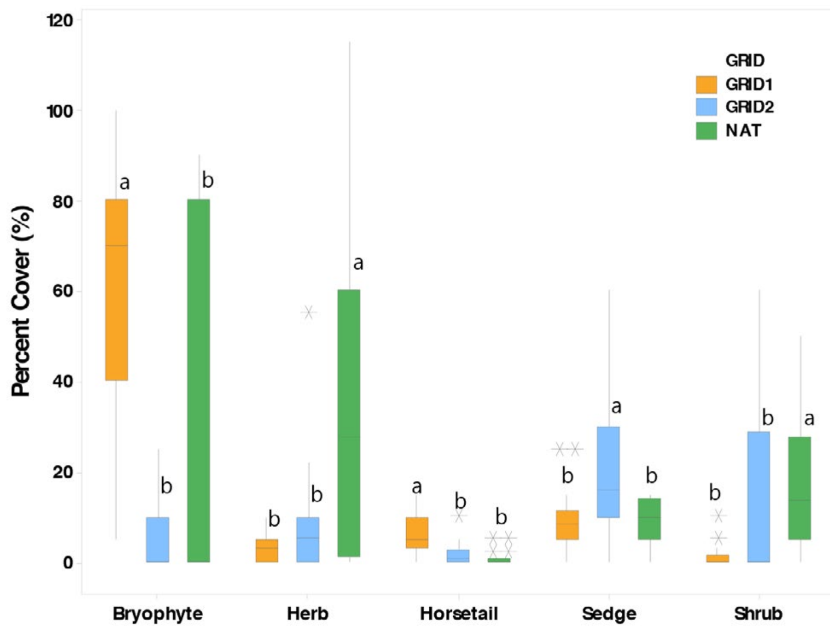

Figure 8: Results of Kruskal-Wallis tests of percent cover of vegetation groups by area. Different letters indicate significant differences ($p < 0.05$) between groups by Dunn's test. Whiskers represent the 95th percentile. Horizontal lines are medians.

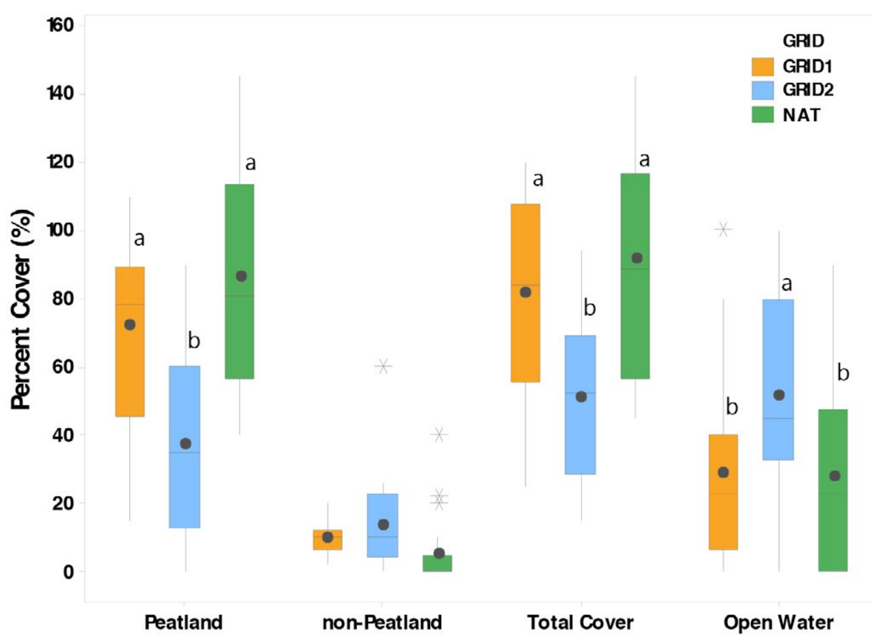

Figure 9: One-way ANOVA results of percent cover by area. Different letters indicate significant differences ($p < 0.05$) between groups by Tukey's test. Whiskers represent the 95th percentile. Horizontal lines are medians and dots are means.

LESSONS LEARNED

Almost all treatments measured on the reclaimed well pad had net CO_2 exchange (under full-light conditions) and CH_4 emissions that were similar to the adjacent undisturbed fen. A return of net carbon accumulation was observed at many treatments over the summer study period and at rates similar to the understory of reference bogs and fens in the region. Complete pad removal (leading to deep inundation), or partial pad removal (to a grade that allows frequent shallow inundation), prevents the recovery of plant cover which results in these plots remaining sources of CO_2 to the atmosphere. Treatments that result in persistent inundation (flooded conditions) should be avoided in order to more rapidly return carbon sink functionality to the site after reclamation.

Remnant fill left during well pad reclamation to peatland increases local electrical conductivity of peat above that of reference peatlands, but does not appear to result in large nutrient pools. However, local differences in fill chemistry do impact resulting post-reclamation soil chemistry and should be measured to determine the potential impact on reclamation outcomes.

It was observed that remnant fill did not increase soil respiration rates compared to those in adjacent natural peatlands. This suggests that leaving remnant fill in place will not hinder peat accumulation through enhanced decomposition and also indicates that partial pad removal is likely a viable reclamation option considering biogeochemical function.

Partial pad removal by leaving remnant fill in place does not hinder the development of peatland vegetation, particularly moss, if the surface is suitably saturated. Pad H38 borders a wet fen to the north. Water flows freely around the reclaimed areas, bringing propagules for natural revegetation. Open water areas are too deep for most wetland species to establish, although floating moss mats start to occur along the edges in some areas. Achieving proper soil surface elevation and restoring hydrological connectivity is critical in order to reclaim mineral material well pads like H38. Deep open water should be avoided as much as possible.

Industry can use stratified approaches when assessing a reclaimed site with different amounts of vegetation cover. Large areas of open water with non-peat forming wetland species failed the peatland criteria but may be able to pass a mineral wetland criteria assessment instead.

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PRESENTATIONS AND PUBLICATIONS

Dixit A, Munir T, Strack M. 2019. Evaluation of soil respiration rates across a range of well pad peatland restoration treatments in the Alberta oil sands region. Society of Wetland Scientists Webinar Series, April 18.

RESEARCH TEAM AND COLLABORATORS

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Martin Brummell	University of Waterloo	Post-Doctoral Fellow	2017	2017
Meike Lemmer	Laval University	PhD Student	2017	2021
Arohi Dixit	University of Calgary	Visiting Student	2018	2018

Removing the Wellsite Footprint (iFROG)

COSIA Project Number: LJ0216

Research Provider: Circle-T Consulting Inc.

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: AOC Lesimer Corner Partnership, Canadian Natural, CNOOC Petroleum North America ULC, Devon Canada Corporation, Harvest Operations Corp., Husky Oil Operations Ltd., Imperial, Japan Canada Oil Sands Limited, MEG Energy Inc.

Status: Year 3 of 6

PROJECT SUMMARY

The purpose of the industrial Footprint Reduction Options Group (iFROG) is to develop, fund and implement a balanced portfolio of boreal wetlands research projects that:

- Follow the fundamental guiding principles of land stewardship, intelligent research, and collaboration;
- Demonstrate iFROG members are meeting the intent of the applicable wetland research conditions in their respective Environmental Protection and Enhancement Act (EPEA) Approvals (for oil sands in situ projects);
- Contribute to mitigating impacts to wetlands during operations; and
- Increase the knowledge base for, and confidence in, wetland reclamation efforts.

In 2019, three projects were supported: Japan Canada Oil Sands Limited (JACOS) Road Reclamation, From Dirt to Peat, and Pad TT Road Construction Best Practice.

JACOS Road Reclamation Study (Year 2 of 3)

The JACOS Road Reclamation Study involves the continuation of reclamation work initiated in 2010. The reclamation work involved the partial removal of fill material from a road constructed through a peatland.

Three treatment blocks were established and approximately 80 cm of fill was removed from each block. This was followed by the establishment of study plots where a number of revegetation treatments were applied. Vegetation recovery was assessed in 2012 and 2013. In addition, offsite hydrology, vegetation, greenhouse gas (GHG) dynamics and nutrient dynamics were studied from 2010 through 2014.

Two of the treatment blocks were prone to prolonged flooding, while the third showed some promise for the establishment of natural revegetation. Therefore, the follow-up reclamation work plan included reworking the two flood-prone treatment blocks along with the remainder of the road.

The road was divided into two study areas one for the study of revegetation on a peat substrate and the other for revegetation on a mineral substrate. The peat substrate study will examine revegetation treatment response on varying depths of peat substrate. The mineral substrate study evaluates revegetation response to surface treatments aimed at moderating surface moisture. Both treatment types are intended to inform reclamation practices regarding amendment application and substrate type. Hydrologic responses to the reclamation treatments, as well as to drainage structures installed to facilitate hydrologic connectivity across the road, will also be evaluated.

From Dirt to Peat (Year 1 of 3)

This study is a three-year, multi-site, meta-analysis examining ecological recovery in response to a range of reclamation practices over a range of conditions, including both partial and complete removal of fill from roads and pads constructed within wetlands. Seven pads and two linear features will be studied, including the iFROG Canadian Natural pad and the JACOS road study sites.

The study objective is to characterize each site in terms of its functioning, or potential to function, as a healthy peatland based on peat accumulation potential and GHG balance. Ecological response variables that will be used include vegetation composition, accumulation of organic matter ("peat thickness"), above and below ground biomass productivity, biomass decomposition, peat accumulation potential (calculated) and GHG balance. Explanatory variables include the site-specific treatments, as well as environmental conditions such as local climatic indicators, soil and water chemistry, soil moisture and soil temperature. Reclamation site response variables will be compared with similar variables on reference peatlands within the oil sands areas in which the study sites are located.

Pad TT Road Construction Best Practice (Year 2 of 3)

Devon Canada constructed a road at their Jackfish 2 project (now Canadian Natural Jackfish 2) bisecting several areas of deep fen peat that are each approximately 180 m long. Timber corduroy was used as road foundation over the soft peat sections in conjunction with several culverts that were closely spaced within each section. High-density polyethylene (HDPE) pipe culverts or log bundles were installed among the culverts to facilitate additional drainage. Seventeen culverts and seven bundles were installed along the 1.5 km length of road.

Study objectives are to:

- Determine whether or not the road allows water to pass through effectively as a result of the corduroy and drainage conduit installations;
- Characterize flow rates and patterns in the vicinity and through the road to assess the effectiveness of the type and number of conduits; and
- Assess road performance in the corduroy sections as indicated by progressive road settlement over time, and identify any problem areas.

PROGRESS AND ACHIEVEMENTS

JACOS Road Reclamation

Reclamation earthworks for the study were completed in 2018. In addition, revegetation treatments were applied and study plots were established and instrumented in 2019. Analyses of 2019 data are ongoing, therefore no results are available to report at this juncture. However, desirable vegetation has been establishing within the applied revegetation treatments, particularly on the organic substrate, indicating promise for successful long-term establishment.

From Dirt to Peat

In the first year of this study (2019), all study plots were successfully established and instrumented. Soil and plant tissue samples were collected and frozen, and are awaiting lab analysis. No results are presently reportable.

Pad TT Road Construction Best Practice

Results of the road elevation survey in 2019 indicate the road has settled in the range of 20 cm to 30 cm along the corduroy foundation sections, including over drainage conduits. Settlement is greater adjacent to conduits than directly over them, which has resulted in undulations in the road. Road settlement has caused bowing of drainage conduits and upward deflection of inlets and outlets. All conduits continue to pass water despite the settlement-induced distortion and bowing of the conduits.

On average, the water table measurements did not differ in depth between sides of the road, indicating that the road does not impede water flow overall. However, when water well transects were examined individually, water table depths did differ between the upstream and downstream sides of the road in some locations. The water table was higher on the upstream side of the road near the end of the road (i.e., entrance to the pad) where the ground elevation of the crossed fen is lowest and water flow through the fen appears to be highest.

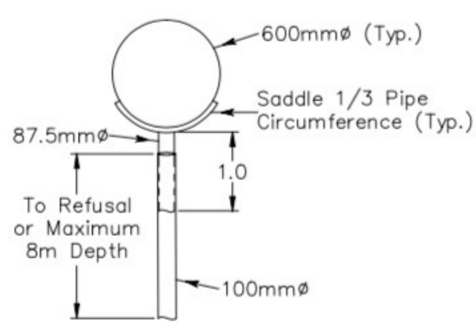

Figure 1: Culvert resting on piles at target embedment elevation. A trench was dug prior to installing the piles so that the culvert's elevation could be set to the desired post-construction embedment elevation. Right: Saddle design detail. (Drawing produced by All-Can Engineering & Surveys (1976) Ltd.)

Figure 2: Pre-embedded solid steel culvert covered with mineral fill and abutted with logs. Centre: HDPE pipe bundle being installed among corduroy logs. Right: Log bundle wrapped in a geotextile placed among corduroy logs.

LESSONS LEARNED

JACOS Road Reclamation Study

Analyses have not yet been completed, therefore no lessons learned to report for this study in 2019.

From Dirt to Peat

Establishment year of the study. No lessons learned to report in 2019.

Pad TT Road Construction Best Practice

When compared to resource roads constructed in similar conditions but using more conventional culvert spacing, the timber corduroy foundation that was built with an increased number of closely spaced conduits has improved the flow of water beneath the road and minimized flow impediment.

The value of this study will be increased by assessing which conduit types and locations are contributing most to water flow, particularly in the highest-flow area of the road. This information will aid future road construction projects by identifying which conduits (and depth of placement) are advantageous, and which might be redundant and less necessary.

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

No presentations or publications are available for 2019.

RESEARCH TEAM AND COLLABORATORS

Institution: Circle-T Consulting, Inc.

Principal Investigator: Terry Osko

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Line Rochefort	Université Laval	Professor of Peatland Ecology		
Bin Xu	NAIT Boreal Research Centre	NSERC Industrial Research Chair in Peatland Restoration		
Clayton Gillies	FPInnovations	Senior Researcher		
Christine Isabel	Université Laval	MSc	2019	2021
Pascal Guérin	Université Laval	MSc	2019	2021

Research Collaborators: Dr. Maria Strack, University of Waterloo

Assessment of Relevant Indicators for the Monitoring of Reclaimed Sites in Peatlands

COSIA Project Number: LJ0328

Research Providers: LOOKNorth, NAIT Centre for Boreal Research, InnoTech Alberta, Natural Resources Canada (Canadian Forest Services), and Rankine Geospatial

Industry Champion: Canadian Natural

Status: Year 1 of 2

PROJECT SUMMARY

The peatland monitoring framework will help industry develop cost-efficient, relevant and effective monitoring and reporting programs that support reclamation objectives. Understanding reclaimed peatland recovery in comparison to natural peatland areas will help identify whether current reclamation practices are successful at achieving reclamation targets both on regional and site levels. It also allows for adaptive management approaches that will address problems in a timely manner for long-term ecosystem sustainability. Identifying indicators that are relevant for monitoring recovery, as well as those that replace conventional methods, may reduce the labour requirements for monitoring footprint disturbances and the financial burden of annual monitoring programs.

Four of Canada's Oil Sands Innovation Alliance (COSIA) associate members (AMs) have teamed up to bring together the right expertise to achieve a whole-ecosystem approach to wetland monitoring and assessment. Together, the AMs will develop an integrated, scientifically robust and financially sustainable monitoring pilot program to assess the ecological recovery of physical, chemical and biological indicators for air, vegetation, soil, hydrogeology, water and biodiversity at reclaimed and natural peatland sites across the Athabasca oil sands region.

The intent of the monitoring framework is to: increase the feasibility and efficiency of in-field monitoring; identify indicators that are the most relevant (in terms of peatland recovery); identify technologies that can streamline and remove labour-intensive conventional sampling; and increase the consistency of sampling across sites. LOOKNorth anticipates that this will provide industry with the ability to communicate and report more efficiently with regulators on peatland recovery and compare results between sites (within company and between companies, if warranted) for landscape integration planning. The early identification of indicators that are not performing well will also allow for early intervention to help ensure reclamation success. The expected benefit from the project is more efficient allocation of reclamation budgets and resources (i.e., more area monitored with less or equivalent effort), which will eventually lead to a better performance of the aggregate total reclaimed areas.

The project scope includes several in situ oil and gas sites (well pads and linear features) reclaimed to peatland status in the last decade or so. A series of natural and reclaimed sites have been set up to establish benchmarks for monitoring and to assess site progress towards meeting provincial criteria. Observations on regional hydrology, soil, vegetation – particularly ground layer bryophytes – and soil/water chemistry were collected at multiple spatial scales using field-based methods, unmanned airborne vehicles (UAV) and satellite remote sensing. The multi-scale

data will be analyzed and evaluated for contributions and insights related to progress from disturbed areas towards fully functional boreal wetlands. While wildlife surveys are not within the scope of the activity, the project will consider wildlife use of the study areas as a habitat value indicator.

The main objectives of this project are to:

1. Consolidate ground-truthed field data from a series of reclaimed in-situ peatland sites;
2. Identify key indicators for field monitoring;
3. Pilot and field test ground based and remote sensing techniques appropriate for monitoring peatland indicators; and
4. Ultimately develop a monitoring framework integrating indicators across temporal and spatial scales to inform planning and reclamation decision making.

Achieving the goals listed above will require execution of the following major tasks over two years (2020-2021):

1. Selection of peatland indicators through survey and consultation, involving industry, consultants, government, and academia;
2. Design of a two-year pilot monitoring plan. Use of existing field sites with options to add additional sites, both field and conducting remote sensing monitoring; and
3. Execution and analysis of the two-year pilot plan, with annual review and updates.

The project aims to advance and optimize the manner in which wetland reclamation is monitored. This project builds on the existing state of knowledge regarding reclamation of wetlands in the oil sands region, as gathered and established through multi-stakeholder discussions and presented in 2007 as reclamation guidance by the province of Alberta. The guidelines presented to the province through the Reclamation Working Group under the now defunct Cumulative Environmental Management Association do not consider recent advancements in harmonization of wetland monitoring by industry via COSIA and by Alberta Environment and Parks (AEP). The recent advancements have created an opportunity to establish a framework for assessing reclamation success against these indicators. In addition to producing the reclamation monitoring framework, which is missing from the developed monitoring system, this project provides an opportunity to advance best practices by utilizing novel methods to quantify changes in indicators diagnostic of wetland function. Assessing these indicators efficiently can significantly reduce monitoring costs related to the assessment of reclamation success beyond the operational phase of assets. The envisioned framework is expected to leverage data generated by provincial policies and frameworks to support planning, design, construction and monitoring of reclaimed wetlands in an integrated approach as outlined by existing provincial wetland policies and objectives.

PROGRESS AND ACHIEVEMENTS

Activities completed towards achieving project goals in 2019 included:

1. Selection of peatland indicators through survey and consultation, involving industry, consultants, government and academia

NAIT Centre for Boreal Research (NAIT CBR) has been working with InnoTech Alberta on a project funded by Petroleum Technology Alliance Canada (PTAC) to evaluate conditions and scenarios where a well pad or a road can be left in place in a peatland without the need to reclaim back to a peatland. The project team has conducted surveys with industry and government representatives since January 2019. Key indicators relevant to meeting reclamation criteria and the recovery of ecosystem functions have been highlighted in the survey. Dr. Xu and the project team are drafting the summary report based on survey responses. The project team met with Canadian Natural and other COSIA members several times since January 2019 to discuss project scope and the selection of indicators. The PTAC surveys and direct consultation with industry have been used to guide the selection of indicators and the design of experiments for the project through knowledge sharing between PTAC and COSIA members.

2. Design of a two-year pilot monitoring plan. Use of existing field sites with options to add additional sites, both field and conducting remote sensing monitoring.

The project team met several times in April and May 2019 to finalize project scope, identify team member roles and responsibilities, hire UAV vendors, and to design field experiments and plans for UAV and remote sensing data acquisition. Four regions have been identified in the Peace River area. These areas range from bogs to treed fens, to open-sedge dominated marshes. They represent major types of wetlands and peatlands commonly found in northern Alberta. These are sites that NAIT CBR has been studying and monitoring since 2011.

3. Execution and analysis of the two-year pilot plan, with annual review and updates

With site selection finalized, NAIT CBR: began installing field sensors and ground control points (GCPs); set up vegetation, hydrology and topography plots within each study area; and worked with the remote sensing team to prepare the flight in July 2019 during the period of peak plant biomass (leaf-on). A second flight was completed in October 2019 in the same areas (leaf-off condition). Water table position, soil temperature, moisture, surface topography and vegetation surveys were completed during the summer of 2019. Soil/water samples and greenhouse gas samples were analyzed in the fall of 2019. An annual progress report will be prepared by early 2020, and results will be presented at professional meetings and conferences in 2020.

In 2020, the project team will select another region to apply the draft indicator framework. The goal is to test and validate the methodology developed in 2019. Additional indicators/parameters may be added to those evaluated in 2019. NAIT CBR will lead the field measurements and facilitate site access and UAV data acquisition. A progress report will be prepared after samples and data have been processed by the end of December 2020. Water table position, soil temperature, moisture, surface topography and vegetation surveys will be completed during the summer of 2020. Soil/water samples will be analyzed in the fall of 2020. A peatland monitoring framework will be developed that aligns with provincial wetland policy and reclamation guidelines.

2019 Field Updates and Preliminary Results

Site Selection

At the beginning of the 2019 field season, four areas of interest (AOI) were chosen for detailed study. The four AOIs, located in the Peace River Region, contain a combination of reclaimed features, linear impacts and surrounding natural peatland reference types. In total, five reclaimed well pads, one reclaimed airstrip and two reclaimed winter roads are present within the four AOIs.

Following site selection, each AOI was instrumented for field survey and UAV imagery collection. This included the fabrication and installation of five ground control points (GCPs) within each AOI to act as reference points for UAV survey data collection (Figure 1). Within each AOI, a GCP was placed near the middle of the area and near each of the four corners. Corner GCPs were placed a minimum of 60 m from the AOI boundaries, and all GCPs were at least 40 m from vegetation plots to avoid contamination of the plots' spectral signature.

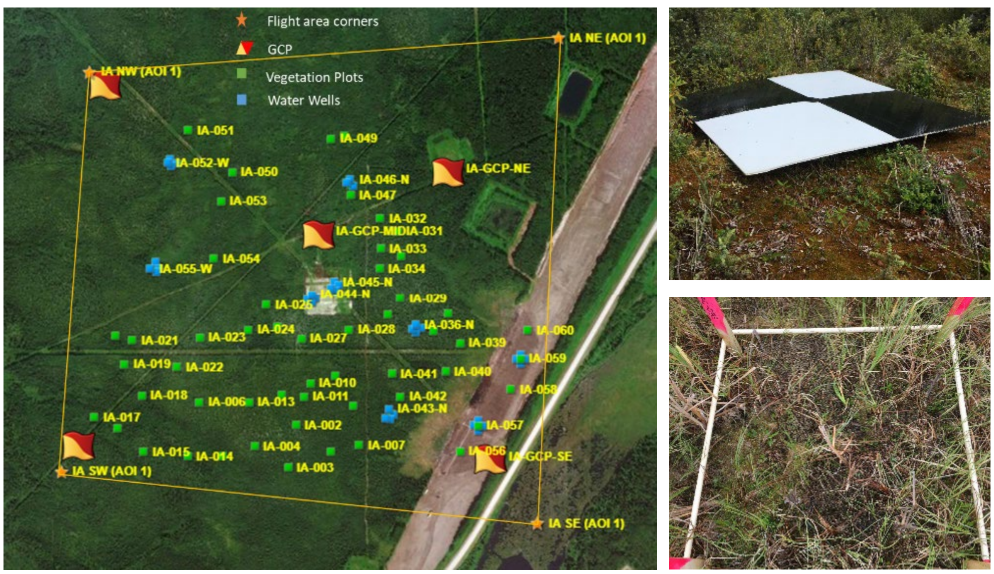

Figure 1: Aerial view of AOI 1 and close-up views of a 1 m x 1 m vegetation plot and a ground control point (GCP).

Vegetation

Sixty random locations within each AOI were chosen to act as ground-truth plots for vegetation identification. Plots were marked on the ground using wooden stakes placed at each of the four corners of a 1 m x 1 m plot. Each stake was fabricated with a 3.5 cm x 3.5 cm square top and was spray-painted pink for visibility (Figure 1). Stakes were installed with the intent of being visible from above during the UAV flights so that the location and elevation of each plot could be obtained from the collected imagery. Vegetation plots were set up on the reclaimed features present within each AOI, as well as within the surrounding natural reference peatlands.

During the growing season (specifically during July to early August 2019), vegetation surveys were conducted at each of the installed vegetation plots, wherein the percent cover of all vegetation species present was measured and recorded. Trees, shrubs and herbaceous plants were measured at the 1 m x 1 m plot scale. Bryophytes, lichens and liverworts were measured within five 25 cm x 25 cm quadrats located at the north, east, south and west corners of each 1 m x 1 m plot, as well as in the centre of each plot.

Observed vegetation species have been divided into vegetation categories which will potentially be distinguishable in the collected imagery. These categories include peatland moss (*Sphagnum* moss and true moss), weedy moss (those which grow primarily on disturbed sites), lichen, liverwort, aquatic herb, broad leaved herb, narrow leaved herb, grass, deciduous shrub, evergreen shrub, deciduous tree and conifer tree. There is a greater focus on ground layer bryophytes because they are the most important components in boreal peatland ecosystems and particularly challenging to identify using existing remote sensing and UAV technologies.

Preliminary analysis of the vegetation percent cover data collected within each AOI shows that the moss cover at the majority of the reclaimed sites is predominantly true moss, while the reclaimed pad in AOI 1 (IPAD) has a greater proportion of *Sphagnum* moss than true moss (Figure 2). Ground layer cover within the IPAD/Airstrip, Skeg/822, and Aspen Natural Reference areas (AOI 1-3) is quite similar, while the Chip Road Natural Reference area (AOI 4) is unique in its proportion of true moss cover.

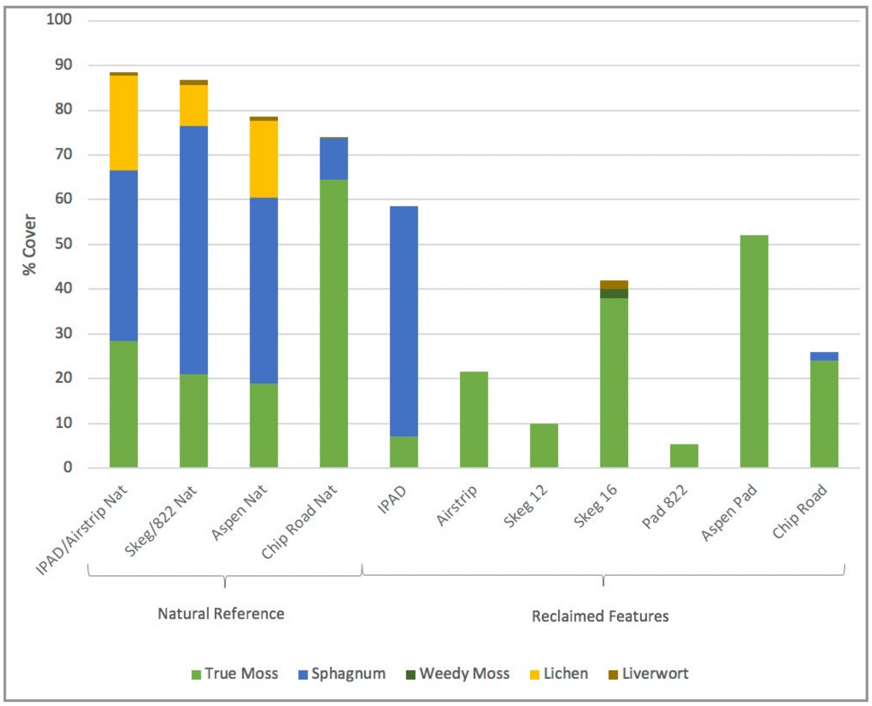

Figure 2: Observed ground layer vegetation average percent cover by site.

The field, shrub and tree layer at the Chip Road Natural Reference (AOI 4) is also unique from the AOI 1 to 3 natural reference areas in terms of the proportion of narrow leaved herbaceous vegetation, deciduous shrubs and evergreen shrubs (Figure 3). With the exception of the reclaimed pad in AOI 1 (IPAD), the reclaimed features appear to be dominated by narrow leaved herbaceous vegetation and grasses. Deciduous shrubs – and in the case of the IPAD reclaimed pad, evergreen shrubs – are also present on several of the reclaimed features.

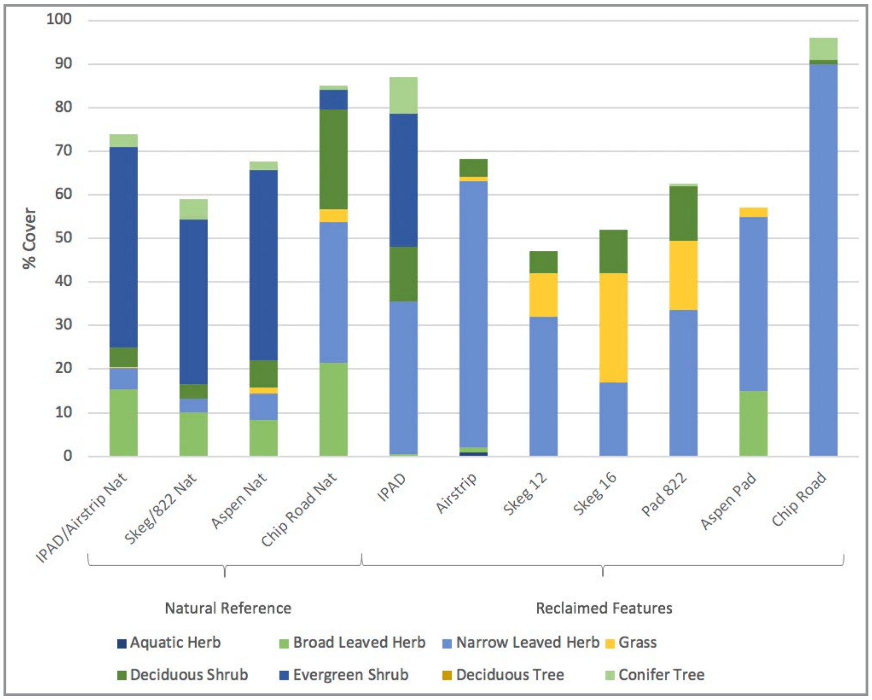

Figure 3: Observed field, shrub and tree layer average percent cover by site.

Further statistical analyses will be conducted on the collected vegetation percent cover data in the late winter and early spring of 2020.

Hydrology

In order to obtain water level data across each AOI in locations where surface water bodies were not visible, a subset of vegetation plots across each site were chosen for the installation of water monitoring wells. Between seven and 11 vegetation plots spread across each AOI were selected, at which four water wells were installed. Wells were located approximately 10 m from the plot corners in each of the four cardinal directions (north, east, south and west) and were installed to a depth of between approximately 0.5 m and 1.0 m below ground surface. Due to the presence of permafrost at some locations, a small number of wells were not installed.

Water level was measured within all wells twice over the course of the 2019 field season. Measurements occurred in July/August and October following the UAV flights. Water table measurements (as metres below ground surface) have been calculated for each well. As a next step, well elevations (metres above sea level [masl]) will need to be identified from the collected UAV data, at which time they will be used to calculate water table elevation (masl) across each AOI. Measured water table elevation will in turn be used to validate the UAV data analysis model's estimation of depth to water table based on visible surface water bodies.

In addition to manual water level measurements, two automated continuous water level data loggers were installed at each AOI. Collected data from these loggers will be analyzed in spring 2020.

Chemistry

At the time of water level measurements, a water sample was collected from each well. At locations where wells could not be installed due to permafrost, a water sample was taken from nearby ponded water. A peat sample was also collected adjacent to each well at this time. Measurements of soil moisture content, soil temperature and pore water electrical conductivity (EC) were taken from the location of each peat sample immediately prior to or following collection of the sample.

All water and peat samples were analyzed for pH and EC in a laboratory setting. Based on the average pH of all collected water samples within each AOI, and pH ranges indicative of specific peatland types, the natural areas and reclaimed sites within each AOI can be classified by peatland type (Figure 4).

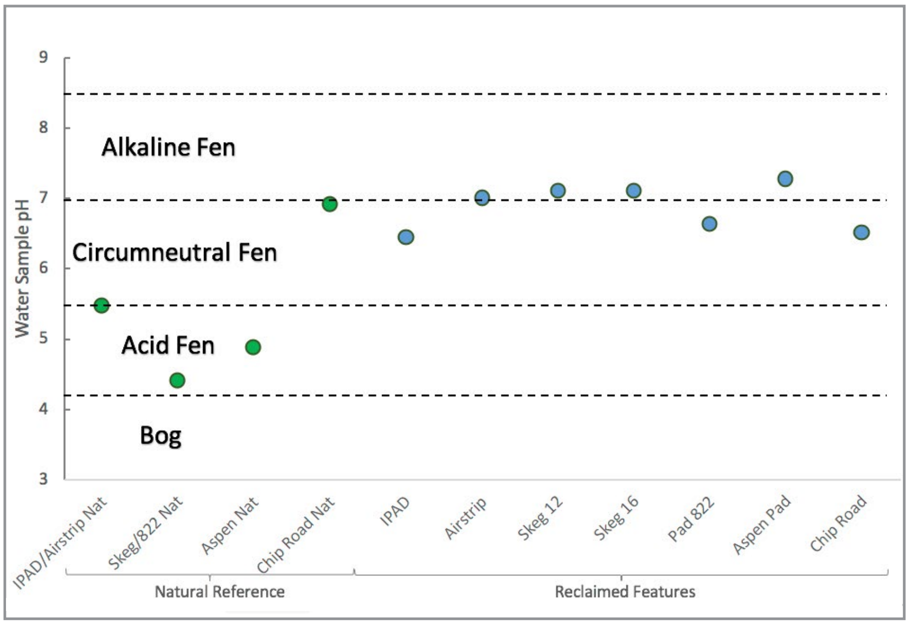

Figure 4: Peatland class based on average water sample pH. Shaded boxes indicate the range of pH indicative of each peatland type, based on the Reclamation Criteria for Wellsites and Associated Facilities for Peatlands (Alberta Environment and Parks, 2017).

Water samples from the IPAD/Airstrip, Skeg/822 and Aspen Natural Reference areas (AOI 1 to 3) had, on average, a lower pH than samples taken from the Chip Road Natural Reference area (AOI 4) and the reclaimed features. Based on the average water sample pH, these three natural reference areas (AOI 1 to 3) are classified as acid fens, while the Chip Road Natural Reference area is classified as a circumneutral fen. All reclaimed sites fall within the pH ranges which would typically be found in circumneutral fens and alkaline/saline fens in the natural environment.

Results of electrical conductivity testing are expected in early Spring 2020. Average electrical conductivity of all water samples collected from each site area within the AOIs is shown in Figure 5.

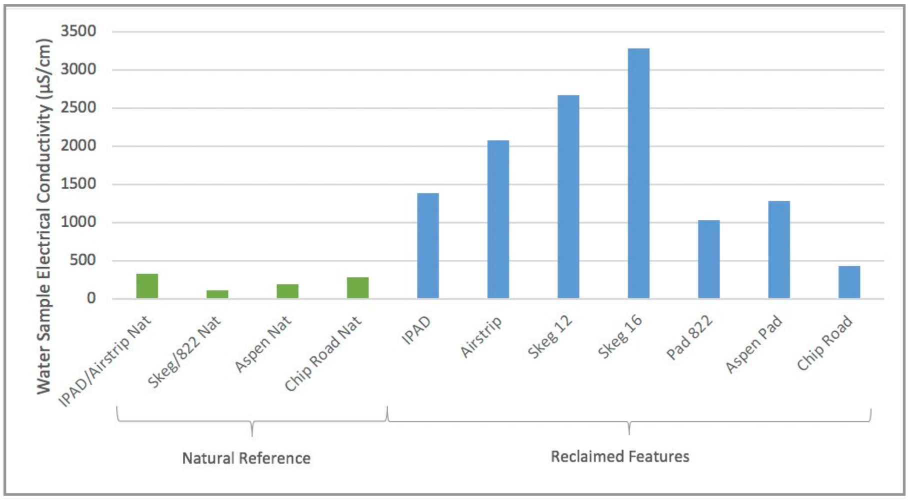

Figure 5: Average electrical conductivity of collected water samples.

Average electrical conductivity measured from samples taken within the natural reference areas of the four AOIs is in general much lower than that measured from the reclaimed features, with the exception of the reclaimed Chip Road. In the case of Airstrip, Skeg 12 and Skeg 16 reclaimed features, the high measurements of electrical conductivity are likely due to the influence of remnant mineral soil.

Water samples have been submitted for further laboratory testing of nutrients (specifically total sodium, calcium, potassium, chloride, magnesium, nitrogen, ammonium-nitrogen, nitrate-nitrogen, total phosphorus and total dissolved phosphorus).

Microtopography

In order to provide reference and testing data for the UAV imagery elevation measurements, ground surface microtopography measurements were taken within the natural reference area and on the reclaimed features present within each AOI. Ground surface along a straight line between each corner post and the corresponding well in that cardinal direction (i.e., between the north corner post and the north well, and so on for each cardinal direction) was measured relative to the height of the corner post. This was accomplished through measurement of the distance down to the ground surface from a level string tied between the corner post and corresponding well at 0.5 m intervals horizontally along the string. Elevation of each corner post from the UAV data will be used to convert the distance measurements to ground surface elevations.

UAV Imagery Collection and Processing

Spectral imagery was collected by Osprey Integrity Ltd. during July 2019 and October 2019. The UAV was equipped with an Altum sensor. Some of the data specifications for both the UAV and the sensor are given below in Table 1 and Table 2.

Table 1: Altum Sensor Specifications

Spectral Bands:	Blue, green, red, red edge, near infrared (NIR)
Wavelength (nm):	Blue (475 nm center, 20 nm bandwidth), green (560 nm center, 20 nm bandwidth), red (668 nm center, 10 nm bandwidth), red edge (717 nm center, 10 nm bandwidth), near-IR (840 nm center, 40 nm bandwidth)
RGB Colour Output:	High-resolution, global shutter aligned with all bands. 12 bit RAW
Thermal:	LWIR thermal infrared 8-14 um. Radiometrically calibrated
Sensor Resolution:	2064 x 1544 (3.2 MP per EO band) at 120 m (400 ft) AGL 81 cm per pixel (thermal) at 120 m
Ground Sample Distance (GSD):	5.2 cm per pixel (per EO band) at 120 m (~400 ft) AGL 81 cm per pixel (thermal) at 120 m

Table 2: Fixed Wing RTK/PPK UAV Platform Specifications

Drone Model	WingtraOne / Tailsitter VTOL
Max. Payload Weight	800 g
Wingspan	125 cm
Battery Capacity	98 Wh
Radio Link	8 km
Max. Flight Time	55 min
Wind Resistance	Up to 45 km/hr
Onboard GPS	Double redundancy, using GPS, Glonass and ready for Galileo and Beidou
Camera Model	Sony RX1R II (42 MP)
Ground Coverage at 400 ft (120 m)	750 ac
Max Ground Sample DIstance (100 ft)	0.7 cm / pixel
Absolute accuracy (RMS): **Without GCPs**	Horizontal = 1 cm Vertical = 2 cm

The timing of the first flight was intended to capture vegetation leaf-on conditions during the growing season, while the second flight was timed to capture leaf-off conditions. This imagery is undergoing analysis by LOOKNorth. Field vegetation data collected by NAIT CBR are currently being used to train the UAV data analysis model.

Two methods of classification were selected to map the distribution of the peatland vegetation in the area of interest: pixel based classification and Object Based Image Analysis (OBIA).

Based on the collected bands, and in order to highlight differences among classes, the following indexes were selected as inputs for the pixel based classification:

- Normalized Difference Vegetation Index (NDVI) (Tucker, 1979);
- Soil Adjusted Vegetation Index (Huete, 1988);
- Modified Soil Adjusted Vegetation Index (MSAVI2) (Qi, Chehbouni, Huete, Kerr and Sorooshian, 1994);
- Enhanced Vegetation Index (EVI) (Main et al., 2011), Red Edge (Cloutis, Connery, Major and Dover, 1996);
- Chlorophyll Index Red Edge (CIRE) (Gitelson et al., 2003); and
- Texture values of entropy, contrast and Geary's C (Haralick, 1973).

LOOKNorth also included Slope produced using the WingtraOne – Sony RX1R II images. The OBIA classification method was implemented using a Simple Non-Iterative Clustering (SNIC) (Achanta & Süsstrunk, 2017) to create semantic objects using geometrical features in addition to the same channels used in the pixel based method. In both cases the algorithm selected to predict the class values is random forest.

Training Data Collection

Training and testing data were collected using a combination of ground truth data and image interpretation techniques. Only visible plots from ground truth were used and additional training data was selected through visual interpretation. Initially, class development started with 14 classes: peatland moss (*Sphagnum* moss and true moss), weedy moss (those which grow primarily on disturbed sites), lichen, liverwort, aquatic herb, broad leaved herb, narrow leaved herb, grass, deciduous shrub, evergreen shrub, deciduous tree, conifer tree, urban and water. LOOKNorth selected this complex classification in order to reduce confusion (errors of omission and commission) between important classes. The number of training/testing data points within each class is not equal but roughly proportional to the expected proportions of each class (Millard and Richardson, 2015). Forty percent of all training sites are saved for independent validation of the classification model.

LESSONS LEARNED

This study is in its early stages and so there are no lessons learned to report for 2019.

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PRESENTATIONS AND PUBLICATIONS

No presentation or publications in 2019.

RESEARCH TEAM AND COLLABORATORS

Institutions: LOOKNorth / NAIT Centre for Boreal Research / C-CORE

Principal Investigators: Mark Kapfer / Bin Xu / Garrett Parsons

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Meyra Fuentes	C-CORE	Remote Sensing Engineer		
Rebekah Ingram	NAIT Centre for Boreal Research	Research Associate		
Melanie Bird	NAIT Centre for Boreal Research	Research Officer		
Frankie NcCorchuk	NAIT Centre for Boreal Research	Research Assistant		
Dani Degenhart	Natural Resources Canada	Research Scientist		
Jaime Pinzon	Natural Resources Canada	Restoration Ecology Scientist		
Neal Tanna	Innotech Alberta	Research Scientist		
Cassidy Rankine	Rankine Geospatial	Owner		

SOILS AND RECLAMATION MATERIAL

Cold Lake Topsoil Depth Experiment

COSIA Project Number: LJ0208

Research Provider: Paragon Soil & Environmental Inc.

Industry Champion: Imperial

Status: Year 5 of 7

PROJECT SUMMARY

Many older wellsites in northern Alberta do not have sufficient salvaged topsoil (A horizon material + LFH) to meet the minimum 80% replacement criteria as specified in the *2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands* (ESRD 2013). This is due to a combination of factors including loss of topsoil during salvage and placement in early wellsite establishment, as well as compaction of LFH during soil handling. This project was initiated to determine whether less than 80% of an original ground topsoil replacement depth allows for successful reclamation to an equivalent land capability.

The primary goal of the project is to evaluate the progression and success of research plots through vegetation response to topsoil depth treatments at 80% (Control) and 50% of reclamation replacement depth as well as response to peat or biochar amendment on the 50% replacement depths.

Reclamation research plots were established in 2015 at a site at Imperial's Cold Lake Operations and includes three replicates of four treatments (12 plots total, each 20 m X 20 m) incorporating two topsoil replacement depths (TSRD) and two soil amendments. Each plot was divided into four equal quadrants of 10 m x 10 m.

The treatments established were:

1. 80% TSRD (Control);
2. 50% TSRD;
3. 50% TSRD with a peat amendment (50% TSRD + peat); and
4. 50% TSRD with a biochar amendment (50% TSRD + biochar).

Baseline soil sampling of each plot was conducted. Tree (trembling aspen [*Populus tremuloides*], balsam poplar [*Populus balsamifera*], white spruce [*Picea glauca*], white birch [*Betula papyrifera*]) and shrub (saskatoon [*Amelanchier alnifolia*], green alder [*Alnus veridis*], red osier dogwood [*Cornus sericea*]) planting in the plots occurred following plot construction and treatment application. Following planting, the seedlings were mapped and tagged.

The key annual objectives for this study are as follows:

- Evaluate topsoil chemical and physical properties in each plot;
- Assess vegetation composition (per quadrant) and planted tree growth/survival (per plot) to determine if treatments have an effect on vegetation establishment and performance; and
- Compare soil and vegetation parameters from the previous monitoring years.

PROGRESS AND ACHIEVEMENTS

Topsoil composite samples were collected from each of the plots from 12 discrete locations to obtain an overall representative composite sample for each plot. Topsoil samples were analyzed for soil nutrient parameters of total Kjeldahl nitrogen (TKN), total organic carbon (TOC), and available nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). Duplicate samples for bulk density analyses were also taken. The soil profile (topsoil, upper subsoil, and lower subsoil) was also sampled for acidity (pH), electrical conductivity (EC) and sodium adsorption ratio (SAR). In 2019, Plant Root Simulator (PRS®) probes were also deployed to determine the rate of flux of key topsoil nutrients.

Vegetation cover assessments and planted tree/shrub measurements were completed in all four quadrants for each of the 12 plots. Seedling performance in each treatment was evaluated in the form of seedling height, health and percent survival. Vegetation parameters recorded in the field were used to calculate species and weed richness, Shannon Diversity Index (SDI) and evenness.

Preliminary results of the 2019 soil and vegetation monitoring program are summarized below, as final interpretations of results were not available at the time this report was prepared. Final results will be included in the 2020 report.

Soil Parameters

As in previous years, several soil nutrient parameters were measured in topsoil samples collected from the trial plots in 2019. Based on preliminary results, topsoil nutrient parameter differences appear to be dependent on assessment year with few treatment differences observed and no consistent trends of increasing or decreasing concentrations over time. Higher concentrations of soil nutrient parameters were generally observed in the 2016 assessment year.

Salinity parameters (EC and SAR) and acidity (pH) were measured from soil samples collected from the topsoil, upper subsoil, and lower subsoil on alternate trial years (2015, 2017 and 2019). All parameters were independent of treatment and pH and EC were also independent of assessment year. All EC and SAR values for all horizons and all treatments were low.

Vegetation Parameters

Vegetation community metrics (vegetative cover, weed cover, richness, weed richness, SDI and evenness) were calculated for all treatment plots. Community metrics were significantly lower in the 50% TSRD + biochar treatment for vegetative cover, richness and weed richness. Treatment had no effect on weed cover, SDI or evenness.

Vegetative cover, weed cover and richness were significantly affected by assessment year. Consistent trends of increases or decreases over time were not observed. However, data suggests an increase in cover, weed cover and richness between 2015 and 2016 which was followed by decreases in following years. This suggests that vegetation began to establish and increase in the second year of the trial (dominated by pioneer and weedy species) and gradually decreased over time as the desired vegetation community began to establish.

In addition to community metrics, the height, health and survival of planted woody seedlings were also assessed in 2019. Significant increases in height over the course of the trial were observed for all planted species. Several species-specific trends were observed, but most notably, balsam poplar, red-osier dogwood, saskatoon, aspen and white spruce were significantly taller in the 80% TSRD (Control) treatment than in the 50% TSRD + biochar treatment.

Seedling health (measured as a score from 0 [dead] to 4 [excellent]) has generally decreased over time; significant decreases were observed for balsam poplar, saskatoon and aspen. Trends in seedling health by treatment varied, but significantly higher health was observed in the 80% TSRD (Control) treatment for balsam poplar, saskatoon, white birch and white spruce. Aspen and balsam poplar were also healthy in 50% TSRD + biochar treatment plots.

Similar to seedling health, seedling survival has generally decreased over time, with significant decreases observed for balsam poplar, green alder, saskatoon, aspen, white birch and white spruce. Survival of red-osier dogwood was not dependent on assessment year. The effect of treatment was also varied; high survival was observed in the 80% TSRD (Control) for balsam poplar, white birch and white spruce. Aspen survival was significantly lower in the 50% TSRD treatment than any other treatment. Survival of green alder, red-osier dogwood and saskatoon was not dependent on treatment.

Changes in seedling height, health and survival are presented in Figures 1 through 3.

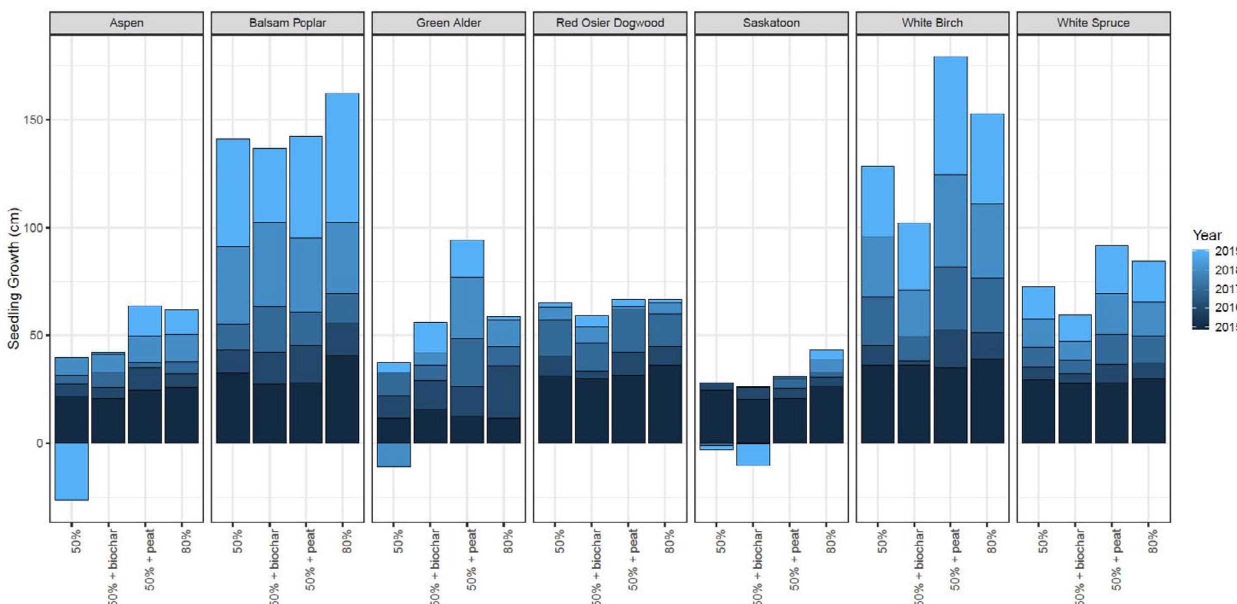


Figure 1: Average growth (cm) of surviving planted tree and shrub seedlings (2015 to 2019).

Note: Individual stacked bars represent initial height (2015) and growth for each assessment year thereafter (2016 to 2019). Bars below the zero line indicate an average loss of height for that year. The total height of a stack is equivalent to the average seedling height (cm) at Year 5 (2019).

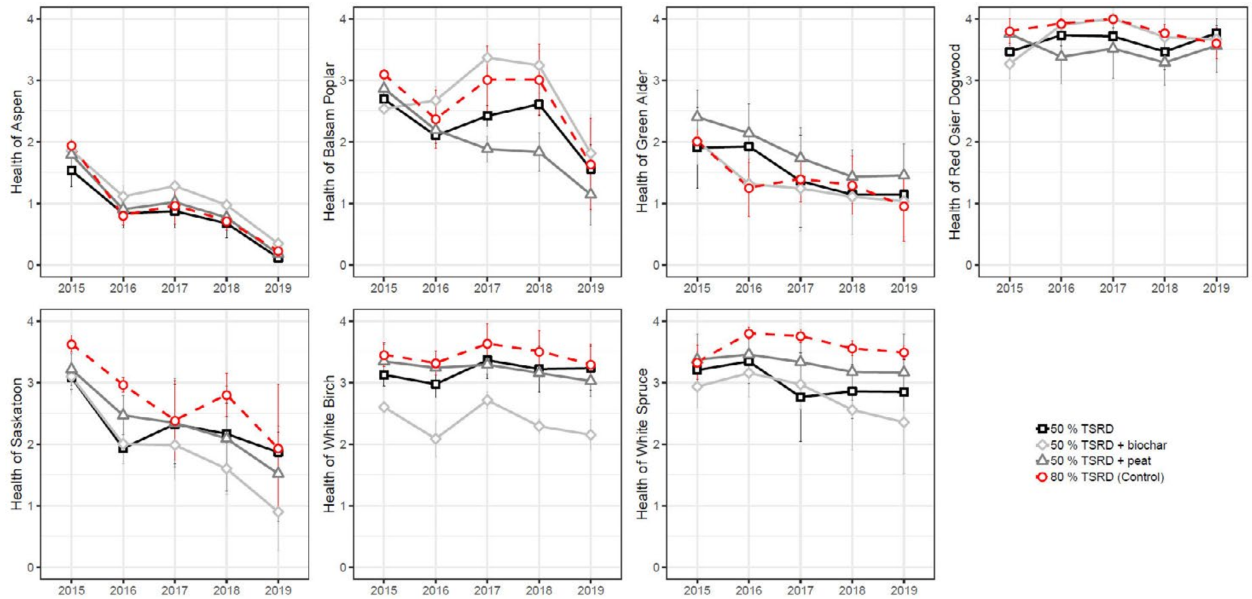


Figure 2: Average health of surviving planted tree and shrub seedlings (2015 to 2019).

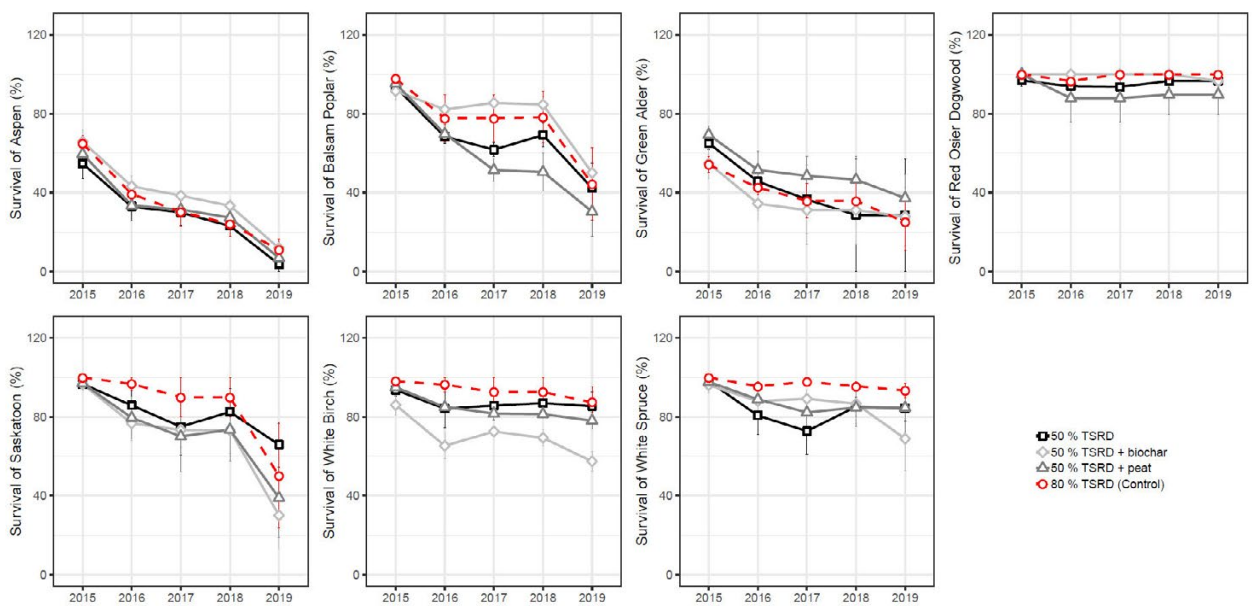


Figure 3: Average percent survival of planted tree and shrub seedlings (2015 to 2019).

LESSONS LEARNED

Once results have been synthesized in the final year of the study (2021), lessons learned will be shared.

LITERATURE CITED

Environment & Sustainable Resource Development (ESRD). 2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands (Updated July 2013). Edmonton, Alberta. 81 pp

PRESENTATIONS AND PUBLICATIONS

Poster (*Can a Well Pad be Reclaimed with Less Topsoil*?) presented at 2019 Oil Sands Innovation Summit (June 3 - 4), Calgary, Alberta.

RESEARCH TEAM AND COLLABORATORS

Institution: Paragon Soil & Environmental Inc.

Principal Investigators: Brittany Flemming, PhD and Katelyn van den Tillaart

DNA-Based Technologies to Evaluate Successful Reclamation

COSIA Project Number: LJ0294

Research Provider: Imperial

Industry Champion: Imperial

Industry Collaborators: ExxonMobil

Status: Year 3 of 5

PROJECT SUMMARY

Over the years, different reclamation practices have been implemented at Imperial's Cold Lake in situ operations in northern Alberta. Old practices often resulted in compacted soils and included the planting of non-native grasses and monocultures. Current (new) practices are focused on planting target ecosite tree and shrub species with the application of woody debris and the use of rough and loose soils.

Cost-effective tools to monitor reclamation trajectories are lacking. Genomic tools, which are DNA-based, can be used to obtain comprehensive biological information from soil and potentially assess progress and trajectory in sites that have been reclaimed. Soil biology is a fundamental soil component because soil biological communities are involved in important ecological functions such as cycling of nutrients, decomposition of organic matter, toxicity tolerance/resistance and degradation of pollutants.[1, 2] The presence or abundance of certain species or communities within the soil can reflect the status of the environment in which they are found.[3]

The main goal of this project is to explore the application of genomics to assess the ecological status of reclaimed sites by monitoring biological communities in soil from different ecological levels including plants, fungi and microorganisms. Next-generation sequencing technologies will be used to characterize the soil communities of selected reclamation sites over time.

The key objectives for this project in 2019 were as follows:

- Conduct genomic analyses (from sequencing to bioinformatics) on previously collected soil samples to develop standardized best practices and approaches that can be applied to soil samples in subsequent years;
- Identify trends and potential biological indicators that can be used to infer reclamation progress and trajectory at selected sites; and
- Assess physicochemical parameters in soils from selected reclaimed and control sites.

PROGRESS AND ACHIEVEMENTS

Soil samples were collected in 2016 and 2018 at several "old" and "new" reclamation sites at Cold Lake Operations, as well as at undisturbed (natural) sites around the area. In 2019, additional soil samples were collected at the same locations to assess physicochemical properties including nutrients, total organic carbon (TOC), organic matter (OM), pH, Total Kjeldahl nitrogen (TKN), sulfate, soil saturation and soluble chloride. In addition, bioinformatics and data analysis was progressed with sequencing data from samples collected in 2016, to identify trends and potential bioindicator taxa. Bioinformatics analyses done in this study are based on taxonomic abundance, biodiversity and dissimilarity metrics using R v3.5.1[4] packages including *vegan 2.5.5*, *phyloseq 1.26.1* and *indicspecies 1.7.6*.[5,6,7]

Key preliminary results for 2019 are summarized below:

- Based on community similarity in a non-metric multi-dimensional scale analysis (NMDS), the natural and reclaimed sites (old/new) are separated along the axis 1 (NMDS 1), especially for the microbes and fungi communities (Figure 1). Within the plant communities, along the axis 2 (NMDS 2), sites that have undergone newer reclamation practices are grouping together with natural sites, suggesting the newer practices have resulted in vegetation that is more similar to the vegetation observed in natural sites (Figure 1). However, more sampling over time is necessary to confirm whether this is a significant trend.
- The communities of microbes were driven by some physicochemical properties in the different reclamation practices and natural sites (Figure 2). For example, TOC and OM were driving communities of natural sites and communities of one of the new reclamation sites, while communities in the old reclamation sites were driven by soil saturation and pH. Soluble chloride, TKN and sulfate were also driving the community of sites undergoing new reclamation practices (Figure 2).

Taxa associated with the different reclamation practices and natural sites were identified based on abundance and they will continue to be monitored over time. Within the plant community, the main taxa associated with natural sites were from the family Pinaceae, which are affiliated with boreal trees from the coniferous family including spruce, fir and some flowering plants. Different taxa were associated with the old and new reclamation sites within the plant community. For the fungi community, taxa mainly from the families Basidiomycota and Ascomycota were associated to all natural and reclaimed sites. Members of these families are known to form ectomycorrhizal associations (symbiotic relationships) in boreal forests with certain species of trees including within Pinaceae. For the microbes group, identified taxa in both reclaimed and natural sites were mainly members of the phylum Nematoda that comprise a range of organisms that have been identified as soil bioindicators based on their specific trophic functions (e.g., plant or bacterial feeders).

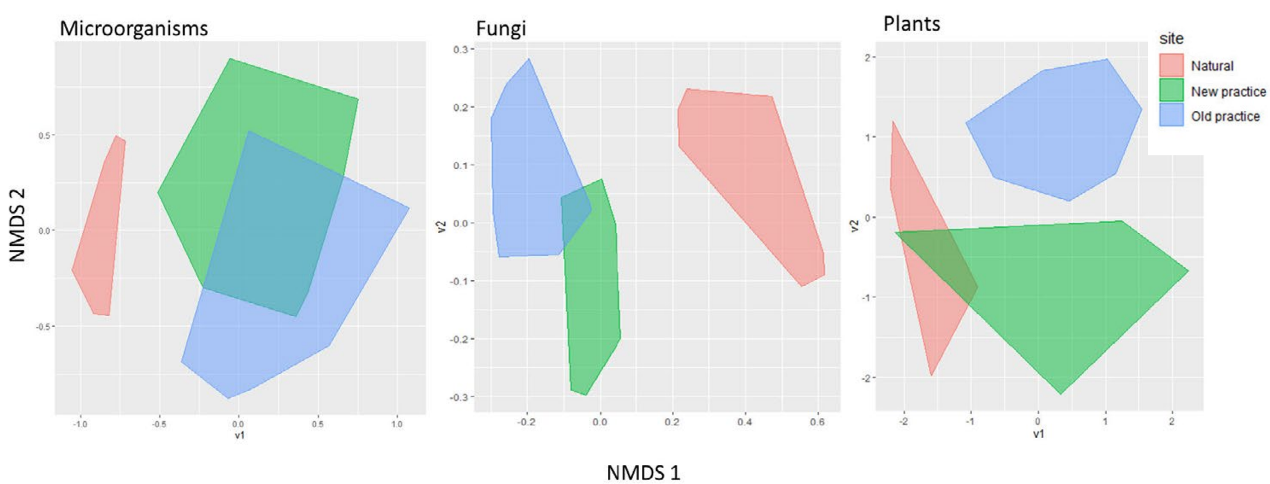


Figure 1: Community assemblage for the old and new reclamation sites and control sites. NMDS plot based on the dissimilarity index (Bray-Curtis).

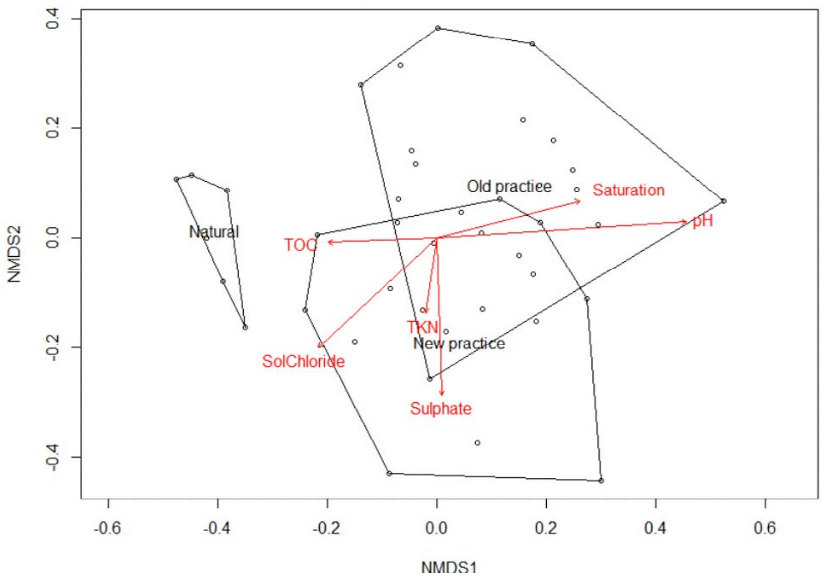


Figure 2: Physicochemical parameters driving the community assemblage within the microorganisms.

LESSONS LEARNED

There are no lessons learned to report for 2019.

LITERATURE CITED

[1]Bentham, H., Harris, J.A., Birch, P., Short, K.C. (1992). Habitat classification and soil restoration assessment using analysis of soil microbiological and physicochemical characteristics. J. Appl. Ecol. 29, 711-718

[2]Schloter, M., Nannipieri, P., Sørensen, S.J., Van Elsas, J.D. (2018). Microbial indicators for soil quality. Biol Fert Soils, 54, pp. 1-10

[3]Stork, N.E. and Samways, M.J. (1995). Inventorying and monitoring of biodiversity, in Global Biodiversity Assessment (Heywood, V.H., ed.), pp. 453–543, Cambridge. University Press

[4]R Core Team (2013). R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. URL http://www.R-project.org/

[5]Oksanen, Jari. (2015). Multivariate analysis of ecological communities in R: vegan tutorial

[6]McMurdie PJ, Holmes S (2013) phyloseq: An R Package for Reproducible Interactive Analysis and Graphics of Microbiome Census Data. PLOS ONE 8(4): e61217

[7]De Cáceres, M. and Legendre, P. (2009). Associations between species and groups of sites: indices and statistical inference. Ecology, 90: 3566-3574

PRESENTATIONS AND PUBLICATIONS

There were no public publications or presentations in 2019.

RESEARCH TEAM AND COLLABORATORS

Institution: Imperial

Principal Investigator: Carolina Berdugo-Clavijo

Research Collaborators: Dr. Mehrdad Hajibabaei (CEGA), Dr. Greg Singer (CEGA), Dr. Jordan Angle (ExxonMobil) and Dr. Lucie N'Guessan (ExxonMobil).

REVEGETATION

Cluster Planting

COSIA Project Number: LJ0314

Research Provider: Northern Alberta Institute of Technology: Centre for Boreal Research (NAIT-CBR)

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: CNOOC Petroleum North America ULC

Status: Year 3 of 4

PROJECT SUMMARY

Most of the current knowledge and best practices for tree establishment in Alberta are founded on practices developed in the forest industry that optimize productivity of commercial forest tree species intended for merchantable harvest. However, the goal of many reclamation operations, as directed by current regulatory criteria, is less focused on merchantable timber (though this is often still an objective) and rather more on whether a functional, resilient, native vegetation community becomes established on the reclaimed site. Regeneration of deciduous tree species after other commonly occurring disturbances, such as fires and forest harvesting, is often patchy with uneven distribution of trees. Establishing these species in a similar manner on disturbed industrial sites will likely lead to a more natural, heterogeneous landscape with diversity in vegetation structure. This diversity in structure may allow other native species to ingress, leading to faster site recovery and vegetation resilience. Due to slower growth rates of nursery stock deciduous seedlings, non-native and fast-growing ruderal species may achieve site occupancy first and compromise reclamation success. Using cluster planting (i.e., the overwhelming of portions of a site with native tree species) may therefore be a viable alternative approach that could preclude the development of ruderal species and enhance regeneration capacity of other native species ingressing over time.

The concept and evaluation of cluster planting is being tested within two recently reclaimed industrial sites. Comparisons of tree establishment, early growth and surrounding vegetation development around uniformly planted (non-clustered) seedlings and cluster-planted seedlings are being undertaken.

This trial will evaluate two factors to answer questions related to the size of a cluster and spacing of deciduous tree seedlings within clustered planted arrangements: Three sizes (dimensions) of clusters were used where tree seedlings were planted at 0.75 m spacing, in clusters of 3 m x 3 m, 5 m x 5 m or 7.5 m x 7.5 m. The performance of the seedlings in the clusters is compared against seedlings planted individually at a conventional spacing of ~1.4 m. The effect of seedling spacing within a cluster is tested by spacing seedlings at 0.5 m, 0.75 m or 1.0 m in the same size cluster of 5 m x 5 m. The layout of each treatment combination was spaced in order to achieve a density of 5,000 stems ha^{-1}. The following three deciduous tree species were combined within all cluster treatment types noted above:

- Aspen (*Populus tremuloides*), 25% composition
- Paper birch (*Betula papyrifera*), 50% composition
- Balsam poplar (*Populus balsamifera*), 25% composition

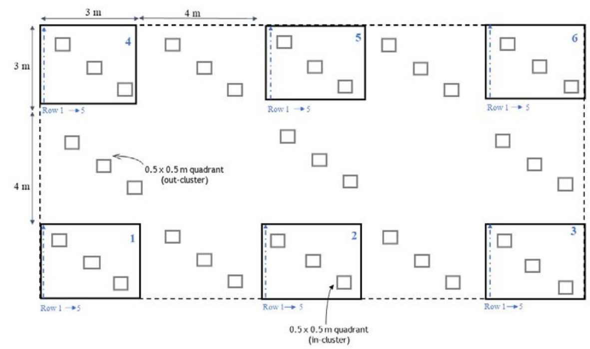
Different cluster sizes and within-cluster plant spacing is evaluated based on the following:

1. Does the physical size (dimensions) of a cluster of deciduous trees impact the early growth and development of individual trees? Is there a difference in understory vegetation development within and adjacent to differently sized clusters?
2. Is it better to create clusters with tighter plant spacing (shortening time to canopy closure but increasing space between clusters)?
3. Does the clustering of deciduous woody species improve the growth and survival of those trees compared to single seedlings?
4. Does cluster planting support the establishment, maintenance and ingress of desirable native plant species?
5. Does cluster planting prevent or reduce the dominance of undesirable non-native plant species?

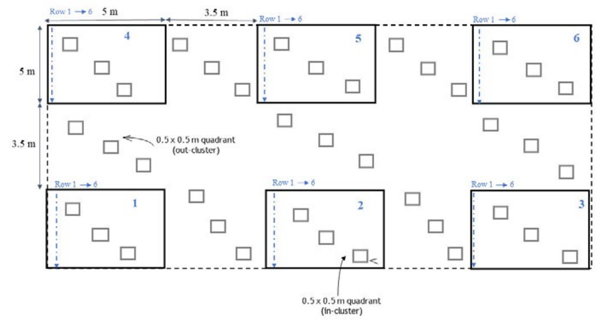
This project is replicated at two operating in-situ facilities: ConocoPhillips Canada's Surmont facility (Conoco) and the CNOOC Long Lake facility (CNOOC). These operations are within 15 km of each other and approximately 1 hour southeast of Fort McMurray. The Conoco site is comprised of two recently reclaimed borrow pits: # 1, reclaimed in the summer 2016; and #5, reclaimed in November 2016. The second study location, CNOOC, which is a 2.5 ha reclaimed sump, was reclaimed in November 2017. At the Conoco site, each treatment was replicated seven times for the cluster size factor and four times for the seedling spacing factor, while at the CNOOC site, each cluster size factor and seedling spacing factor was replicated five times. Treatment factors were randomly assigned within replicate blocks (where each block contained six clusters of each treatment combination) across each of the two study locations (refer to Figure 1 for examples of layout of a replicate block of each treatment combination).

Similar reclamation instructions were given to the earthworks crews at all three sites, to reclaim as per the site-specific reclamation commitments associated with each disposition with the additional request to make the sites rough and loose. Earthworks at borrow pit #1 occurred under wet conditions leading to a smoother and perhaps more compacted site than desired, whereas borrow pit #5 was completed under drier conditions which achieved slightly better surface roughness. At the CNOOC site, a dozer with a six-way blade furrowed the entire site where the individual furrows were spaced approximately two to three metres apart. The objective of furrowing was to create greater surface heterogeneity. Field establishment of seedlings occurred at the Conoco site in spring 2017 and at the CNOOC site in spring 2018. In addition, a pre-emergent herbicide was incorporated into the study design at the CNOOC site based on concerns regarding vegetation competition observed at the Conoco location.

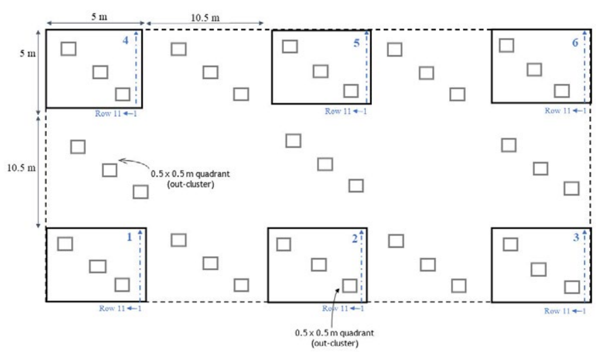
(a) 3x3 m cluster size, 0.75 m spacing between plants within cluster



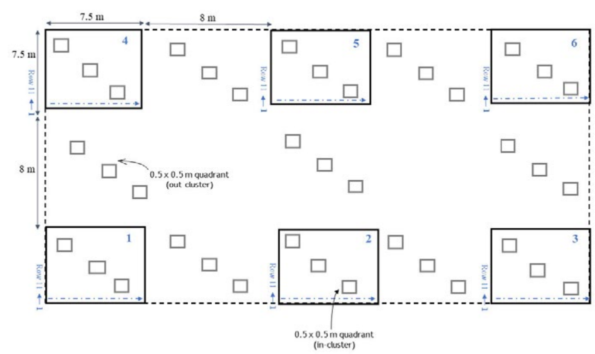
(d) 5x5 m cluster size, 1.0 m spacing between plants within cluster



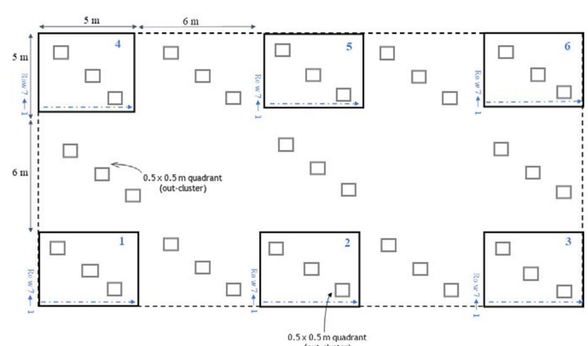
(b) 5x5 m cluster size, 0.5 m spacing between plants within cluster



(e) 7.5x7.5 m cluster size, 0.75 m spacing between plants within cluster



(c) 5x5 m cluster size, 0.75 m spacing between plants within cluster



(f) Control, 1.4 m spacing between plants

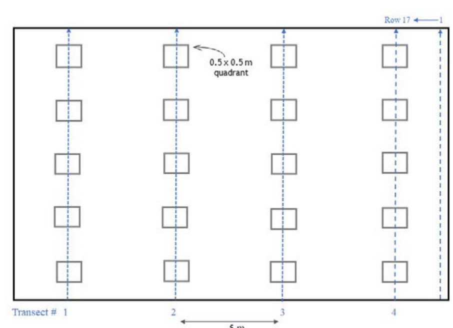


Figure 1: Diagram of an experimental plot. Example shows one experimental block representing each cluster size factor (individual clusters of seedlings are shown in black squares) and spacing factor. **(a)**, 3 m x 3 m with 0.75 m spacing, **(b)** 5 m x 5 m plot with 0.5 m spacing, **(c)** 5 m x 5 m plot with 0.75 spacing, **(d)** 5 m x 5 m plot with 1 m spacing, **(e)** 7.5 m x 7.5 m plot with 0.75 m spacing **(f)** control, conventionally planted seedlings (1.4 m between plants). Presence and total height of all seedlings within the treatment blocks were measured and this diagram illustrates individual vegetation survey points (0.5 m x 0.5 m quadrat) by grey squares.

PROGRESS AND ACHIEVEMENTS

In 2019, we continued to conduct vegetation surveys and track the growth and survival of over 25,000 deciduous tree seedlings. Although this field study is in the early stages of development (two to three growing seasons now), some initial observations related to seedling establishment have been made. The greatest differences associated with growth and survival were between the deciduous tree species planted at each site. Across sites, total height and survival of seedlings is similar for paper birch (*Betula papyrifera*) and balsam poplar (*Populus balsamifera*), but consistently lowest in aspen (*Populus tremuloides*). Secondly, likely due to differences in herbaceous plant competition between the study sites, there are substantive differences in growth rates between these locations.

For both study sites, there was no difference in seedling survival rate or plant height for clusters of varying size. Changing the spacing between tree seedlings (0.5 m, 0.75 m or 1.0 m spacing) did not result in a significant difference in total height or survival rate at either site. Interestingly, we continue to observe that total height of the paper birch and balsam poplar seedlings at the CNOOC site have exceeded those at the Conoco site despite the one-year head start. These study sites were located less than 15 km apart, within the same seed zone (CM 3.1), and soil preparation activities and the timelines between site reclamation and planting were similar between the study sites. Assuming "similar enough" soil conditions, we hypothesize that this marked difference is most likely due to reduced initial herbaceous plant competition (as the CNOOC site had a pre-emergent herbicide applied immediately prior to planting). (Study 2 of Project LJ0226 Interim Reclamation)

LESSONS LEARNED

At this stage of the project, it is too early to draw any conclusions or make recommendations regarding efficacy of cluster planting as a forest reclamation tool.

PRESENTATIONS AND PUBLICATIONS

No public presentations or publications in 2019.

RESEARCH TEAM AND COLLABORATORS

Institution: Northern Alberta Institute of Technology | Centre for Boreal Research

Principal Investigator: Dr. Amanda Schoonmaker

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Mark Baah-Acheamfour	Northern Alberta Institute of Technology, Centre for Boreal Research	Research Associate		
Kaela Walton-Sather	Northern Alberta Institute of Technology, Centre for Boreal Research	Research Assistant		

Emma Glinny	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2018	2020
Gabriel Bitar	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2018	2020
Carlee Ikert	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2016	2018
Brandi Charette	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2016	2018
Sofia Toledo	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2017	2019
Matt Engleder	Northern Alberta Institute of Technology, Centre for Boreal Research	Student Research Assistant	2017	2020
Kera Yucel, MSc	Northern Alberta Institute of Technology, Centre for Boreal Research	Research Officer		

Research Collaborators: Dr. Brad Pinno, University of Alberta (formerly Canadian Forest Service); Dr Simon Landhäusser, University of Alberta

Improving Establishment Success and Early Growth of Trembling Aspen

COSIA Project Number: LJ0255

Research Provider: Canadian Forest Service, Natural Resources Canada

Industry Champion: Imperial

Status: Year 5 of 6

PROJECT SUMMARY

The purpose of this project is to address field observations that trembling aspen (*Populus tremuloides* Michx.) seedlings planted on newly reclaimed in situ oil sands sites often have poor survival after outplanting, and when they do survive, exhibit poor growth and form. It is hypothesized that the lack of appropriate soil fungi (mycorrhizae) could be contributing to these observations.

In the fall of 2015, the community of fungi associated with aspen roots at undisturbed (natural) and reclaimed sites (NN-Borrow and D-East Borrow) at Imperial's Cold Lake Operations was assessed using traditional culturing techniques, greenhouse studies and next-generation DNA sequencing. A total of 28 taxa of root associated fungi were cultured from aspen root systems, the majority of which were saprophytes (including seven species with known mycorrhizal properties). Ectomycorrhizal fungi were observed on the roots.

In 2016, a year following reclamation, the fungal communities present at the D-East Borrow site were studied along three transects that started 10 m inside the interior of undisturbed forest, crossed the forest edge and ended 40 m into the reclaimed area. Differences in fungal communities were observed at different points along the transects using Illumina DNA sequencing. Within the interior of the forest, ectomycorrhizal fungi were more common, while in the reclaimed areas arbuscular mycorrhizae and saprophytes were more common. These field assessments have demonstrated that soil fungal communities do exist within the root systems of aspen growing in reclaimed areas, that they may improve aspen survival, and that natural areas of adjacent undisturbed forest can act as a source of ectomycorrhizal fungi that can disperse into reclaimed areas.

In 2017, two greenhouse studies were conducted at the Northern Forestry Centre (NoFC) in Edmonton, Alberta. In each study, root-associated fungi that were collected at the Imperial Cold Lake site, as well as isolates from the NoFC culture collection, were inoculated onto aspen seedlings. In both studies the growth responses were highly variable, resulting in no statistically significant difference between treatments. However, during the experiment, it was observed that the uninoculated controls did not grow as well, or survive, compared with the aspen that were inoculated.

In 2018, a field trial was established at the D-East borrow site to assess the effect of root-associated fungi on aspen growth and survival. A total of 360 aspen seedlings were planted into three blocks of 120 seedlings, with 20 replicate aspen seedlings for each of the five different root-associated fungi plus 20 replicates of the uninoculated control. The seedlings were measured twice in 2018.

PROGRESS AND ACHIEVEMENTS

The focus of our 2019 research was the assessment of aspen growth and survival following field trial establishment in 2018. Aspen height, diameter at the root collar and survival were measured in May and September of 2019. Overall, aspen mortality was low as 29 of 360 replicates, or eight percent of the aspen seedlings, were dead at the September assessment. Mortality was spread relatively evenly across the treatments and the three blocks. Average growth of aspen seedlings that were inoculated by all five of the different fungal species was higher than the uninoculated control. The treatment that provided the best growth resulted in an average increase in aspen height of 26 cm and diameter of 3.4 mm, compared with the control treatment which resulted in average height increase of 16 cm and diameter of 2.8 mm. However, variability was high which resulted in no statistically significant difference between treatments in height or diameter growth. The results are encouraging and as the trial progresses statistically significant results may emerge. Monitoring and measurement of the trial will continue in 2020.

LESSONS LEARNED

When the trial was established, each of the aspen seedlings was enclosed within a tubular, biodegradable, mesh tree guard. These tree guards reduced deer browse and provided excellent protection to the aspen seedlings. The tree guards are expected to last for up to five years and will continue to protect the trees as long as they remain intact. The tree guards are likely a contributing factor to the low mortality that was observed and a formal trial to compare the survival of seedlings enclosed within tree guards versus unprotected seedlings would provide valuable data.

It is too early to provide a robust recommendation on the best fungi to use to enhance aspen establishment and growth.

PRESENTATIONS AND PUBLICATIONS

There were no reports or publications released in this reporting year.

RESEARCH TEAM AND COLLABORATORS

Institution: Canadian Forest Service, Northern Forestry Centre

Principal Investigator: Tod Ramsfield and Richard Krygier

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Restoration of Native Tree and Shrub Species on Reclaimed Grassy Sites

COSIA Project Number: LJ0291

Research Provider: Natural Resources Canada, Canadian Forest Service

Industry Champion: Imperial

Status: Year 4 of 6

PROJECT SUMMARY

The objective of the study is to determine the most effective site treatment for oil sands legacy sites (20 to 30 years old) in the boreal forest that were reclaimed using non-native grass and herbaceous species. These sites were reclaimed to the standards of the day (standards in place at the time the reclamation was completed) and have grass as the only or predominant vegetation growing on the site. The intent is to establish desirable boreal tree and shrub species so that these sites can be placed on trajectory to becoming fully functioning forest ecosystems. Restoration of forest ecosystems on these sites will reduce the area of disturbed forest and forest fragmentation impacting woodland caribou and other wildlife species.

In the spring of 2016, a field study was designed to test a range of mechanical and chemical site preparation treatments on the establishment and growth of tree and shrub seedlings. The field study was established at D63 Borrow which is located at Imperial's Cold Lake Operations. The soil is a compacted sandy clay loam with a 2 cm to 5 cm thick LFH layer. pH ranged between 6.4 and 7.8 and SAR between 0.5 and 1.1. Soil nutrient concentration was approximately 4 ppm of nitrogen, <4 ppm of phosphorus and 77 ppm to 110 ppm of potassium. The site was divided into forty, 9 m x 30 m plots in two rows of twenty and oriented north/south along the short axis of the site. Treatments were assigned randomly to each plot.

The treatments (four site preparation techniques and an untreated control) being tested are:

1. Non-selective herbicide (glyphosate) 1 m x 2 m spot spray followed by planting the next year, installation of a 40 cm tall biodegradable waxed paper tree shelter supported by a wooden stake after planting, and an additional application of a non-selective herbicide (glyphosate) around the tree shelter if required;
2 Excavator mounding of soil (mounds 30 cm wide by 25 cm long), followed by planting;
3. Excavator mounding of soil followed by the application of a non-selective herbicide (glyphosate) only over the mound area in the year of treatment, followed by herbicide before planting if needed;
4. High-speed soil mixing (160 cm wide x 140 cm long patches) followed by the application of a non-selective herbicide (glyphosate) only over the mixed area in the year of treatment, followed by herbicide before planting if needed; and
5. Untreated control.

Prior to the establishment of the research trial, a soil chemical analysis was conducted to determine nutrient status of soils at the site. The analysis showed that available nitrogen and phosphorus was less than 4 ppm while available potassium ranged between 70 ppm and 120 ppm. Given the poor nutrient availability, fertilizer tablets (Forestry Suppliers 20-10-5, 21 gram) were placed by each seedling/cutting in half of the plots (randomly selected) on each site treatment. There were four replications of each site treatment/fertilizer combination.

Eighteen seedlings of white spruce (*Picea glauca* Moench Voss.) and green alder (*Alnus viridis* [Chaix] DC.), and eighteen 20 cm long balsam poplar cuttings (*Populus balsamifera* L.) were planted in June of 2017 in each of the treatments. Seedlings/cuttings were planted on the top of the mounds or in the middle of the mixed bed. The planting spot was randomly assigned to each seedling.

In 2018, two additional study sites were developed at Cold Lake Operations (J10, P3). Treatments at these sites incorporated learnings from the D63 Borrow. In J10 and P3, the pre-emergent herbicide Torpedo™ was added to the tank mix with glyphosate in the treatments where herbicides were used. In addition, the fertilizer application protocol was modified. The fertilizer tablets were placed no closer than 10 cm from the stem of the seedling/cutting. Plants were site prepared in 2018 and planted in the spring of 2019.

PROGRESS AND ACHIEVEMENTS

The third-year assessment of the D63 site was completed in the fall of 2019. In most treatments, the application of fertilizer significantly reduced survival of all species. The only treatments with no significant difference in survival ($p \leq 0.05$) was control for alder and the mixing + herbicide treatment for spruce and poplar. Necrosis of the leaf margins of alder was observed in the second year in the fertilizer treatments. Within treatments, the application of fertilizer did not significantly increase height and stem diameter growth for all species.

Survival was significantly greater ($p \leq 0.05$) than the controls for mounding (no fertilizer), mounding + herbicide (no fertilizer), herbicide + shelters (no fertilizer) for all species.

Height increment of alder and poplar was significantly greater ($p \leq 0.05$) than the controls for the herbicide + shelter (with and without fertilizer). There was no significant difference ($p \leq 0.05$) from the control for all the other treatments.

Grass was controlled well by both the mechanical and herbicide treatments in D63 when compared to the control. However, the same cannot be said for Canada thistle. The amount of Canada thistle is similar between the control and all treatments, with the exceptions of mixing with no fertilizer and both herbicide with shelters treatments. The extensive root system of Canada thistle makes it difficult to control with a single non-selective herbicide application.

Despite the use of glyphosate in the mixing and mounding treatments, Dutch white clover became a major problem on these two treatments, with cover between 30% and 60% in a 30 cm x 30 cm plot around the seedlings. Dutch white clover also began to develop on the herbicide + shelters and mounding + herbicide treatments, but not to the same extent by the end of the first year. The last herbicide treatment occurred in the late summer of 2016 on all but the herbicide + shelters treatment.

Because glyphosate is a contact herbicide, it only killed perennial plants and clover seedlings that were present at the time of application. There were no clover seedlings present at the time of planting so no glyphosate was applied. We were able to apply herbicide to the herbicide + shelters treatment well after planting because the seedlings were protected from spray drift by the shelters. This additional herbicide application after the clover seed had germinated significantly reduced clover competition on this treatment.

Two new sites (J10, P3) were planted and data collected in 2019. At site J10 we observed that the use of pre-emergent herbicide in the tank mix made a difference in the amount of grass and clover development at the end of the first growing season for all treatments containing herbicide. However, the same cannot be said for P3, where clover development was higher on the mixing + herbicides site than the control site and the mounding only site. This difference in performance between sites was attributed to the recalculation by the contractor of the application volume of herbicide mix between the two sites. P3 received a little more than half the volume of mix per treatment compared to J10.

Preliminary analysis shows that the differences in herbicide effectiveness resulted in greater alder and poplar survival for most treatments in J10 than P3.

Seedling growth data for 2019 is currently being analyzed.

LESSONS LEARNED

Study findings to date are:

- It appears that any soil disturbance (e.g., mounding, mixing) on legacy sites will disturb the weed seedbank (e.g., Dutch white clover) resulting in high numbers of weed seedlings and unwelcome vegetative competition with planted seedlings. Weed control in the form of post-emergence herbicide application after weed germination and before tree planting, or pre-emergent herbicide application after tree planting, is likely required.
- When using individual tree fertilization systems such as tablets, placing the tablet too close to the stem will cause seedling mortality of alder and poplar. White spruce is not affected to the same extent.
- Herbicides must be a key component in any site treatment to reclaim legacy sites where non-native grass/ herbaceous seed mixes were used in reclamation. Mechanical treatment alone is not sufficient to control seed banking species like Dutch white clover.
- The timing of the application of non-selective herbicides like glyphosate is critical to controlling clover seedlings. The addition of a pre-emergent herbicide made a significant difference in clover growth at the end of the first growing season after planting. This had a significant effect on first year alder and poplar seedling survival.

PRESENTATIONS AND PUBLICATIONS

There are no presentations or publications as this study is still in the early stages.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Richard Krygier

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Interim Reclamation

COSIA Project Number: LJ0226

Research Provider: Northern Alberta Institute of Technology: Centre for Boreal Research (NAIT-CBR)

Industry Champion: ConocoPhillips Canada Resources Corp.

Status: Year 6 of 10

PROJECT SUMMARY

This program of research encompasses study topics of: (1) interim reclamation (also known as temporary reclamation); as well as (2) final reclamation. Although, it should be recognized that much of the interim reclamation research is applicable to final reclamation. Each study (and projects therein) is described below:

Study 1: Interim Reclamation of a Facility Soil Stockpile

Industrial site disturbances, whether in the mining or oil and gas sector, typically result in the clearing of forests and stockpiling of surface soils during the development and operational phases. Ongoing management of these stockpiles is required until the site is decommissioned and final reclamation is undertaken. This is where the facilities are removed, the site is recontoured and stockpiled soils are spread. Historical and current practices include seeding stockpiled soils with grasses and the use of chemical herbicides to eradicate or control prohibited and noxious weeds. In principle, the temporary reforestation of soil stockpiles will provide: root and seed propagules; coarse woody materials; long-term soil erosion control; reduced noxious weed management; and increase biodiversity. Temporary reforestation of soil stockpiles is an alternative, though not widely utilized, practice that may better fit the fundamental long-term final reclamation goals in forested settings, which is to re-establish a functional forest.

This temporary (or interim) reclamation project is situated on an eight-hectare topsoil and subsoil stockpile that is anticipated to be in place for more than 40 years. The intent of this study is to advance interim reclamation a step beyond historical recontouring and seeding practices to include the establishment of woody species on nonactive areas of an in situ project (e.g., soil stockpiles) during the life of the facility. It is hypothesized that this will speed establishment of forest cover and reduce the need for ongoing and repeated weed management. To date, this practice is not something that has been commonly implemented at in situ facilities in the oil sands region. This project provides an on-site demonstration of the effect of site preparation (dozer to create furrows and backhoe to mound on steeper slopes), varying planting densities (0, 2,500, 5,000 and 10,000 stems per hectare), and the use of coarse woody material as a reclamation material (present or absent). Rather than assessing one combination of interim reclamation techniques, the experimental trials have been structured to support the development of best practices that will have a high probability of success at final in situ specific reclamation and will be cost effective to implement.

This project is also designed to question assumptions about species suitability for use (in terms of the outplanting of different nursery stock species) in a reclamation context. Industrial disturbances do not necessarily follow the same early vegetation dynamics patterns found after fires or forest harvesting. Industrial disturbances require soil to be moved during construction and again during reclamation prior to the final revegetation. This "unnatural" soil handling forces the system into being a largely seed-based regeneration/revegetation system rather than root based. This has consequences for the native species being established and will actually favour those species that are able to tolerate competition as young seedlings. The project is situated on a big hill with soil and aspect variability which should help inform tolerance ranges for each of the planted species in a reclamation context.

While the long-term goal of this project is to initiate forest development, in the short term, three separate projects were initiated at this site in order to ask specific questions related to initial planting density, how to include desirable native herbaceous species, and alternative methods of planting deciduous trees.

Specific objectives and study questions for these projects are further described below.

Project 1: Site preparation and establishment density

1. Compare three densities of container stock planting (2,500, 5,000 and 10,000 stems per hectare) and monitor natural regeneration (within unplanted controls).
    a. Which native tree and shrub species will provide speedy establishment, produce viable seed within the time frame of facility life and have capacity to regenerate aggressively through root fragments following reclamation activities?
    b. Which species are best suited to different combinations of slope position and aspect on reclamation soils?
    c. Is natural regeneration a viable approach for forest plant establishment?
    d. How does the speed of canopy development and structure compare with different densities over time?
    e. Does the overstory density impact development of understory vegetation?
    f. Does aspect or slope position interact with plant establishment through these methods?
2. Compare use of soil adjustment to create a rough and heterogeneous soil surface against track-packed "smooth" reclamation approach.
    a. Does soil adjustment impact the growth and production of planted woody species?
    b. Does soil adjustment improve natural ingress and regeneration of desirable woody species?
3. Demonstrate the utility of coarse woody material in conjunction with soil treatments to create a rough and heterogeneous soil surface.
    a. Does coarse woody material impact growth and production of planted woody species?
    b. Does coarse woody material increase the stability of sloped soils and reduce erosion?
    c. Does coarse woody material improve the natural ingress and regeneration of desirable woody species?
4. Examine the impact of wildlife browsing (and presence) on establishment and development of planted woody species.
    a. Which species are preferentially browsed?
    b. What is the impact of browsing on plant performance?
    c. Does browsing significantly impact canopy development?

Project 2: Cover crop establishment through planting

5. Evaluate two methods of planting native forbs including: individual planting of container stock and co-planting native forbs with a woody species (produce plants in same plug).
   a. Does the forb develop (increase in vegetation cover) equally well with both approaches?
   b. Is there a positive, neutral or negative impact for the woody species which shares the plug initially?

6. Compare the effect of the addition of native forbs during the early phase of forest development.
   a. Do they facilitate ingress of other desirable species?
   b. Do they reduce ingress of undesirable species?
   c. Do they aid in soil stabilization?
   d. What is incremental cost of planting native forbs?

7. Optimize production of mixed-species container stock for three different woody species (green alder, willow and paper birch) each co-grown with fireweed.
   a. What is the best time to sow the forb into container with woody species?
   b. Is mixed-species container stock appropriate for all woody species or only for specific species?

Project 3: Aspen establishment through container stock, optimizing plant deployment through grouped planting

This study was conducted as a pilot project to further the concept of cluster planting of deciduous trees (see project Cluster Planting (page 18), 2018 COSIA Land EPA – In Situ Report).

8. The objective of this project was to compare localized cluster planting of aspen with conventional planting at uniform spacing. In this project, the question of how many plants are required for a "cluster" to positively impact survival and growth of aspen container stock will be addressed.

Study 2: Vegetation Management Solutions for Final Reclamation

Site occupancy with native plant species is a key objective of reclamation and reforestation of industrial sites. However, noxious weeds and other undesirable vegetation (e.g., sweet clover [*Melilotus* sp.], alsike clover [*Trifolium hybridum*], creeping red fescue [*Festuca rubra*], timothy [*Phleum pretense*] and smooth brome [*Bromus inermis*]) are transported to reclamation sites by a variety of mechanisms. These include historical presence in the soil seed bank from previous decades of utilization in cover crop mixes, contaminated equipment, wind, wildlife and in some cases intentional broadcasting. Collectively, these undesirable species present challenges to the development of forest plant communities. In northern Alberta, management of aggressive agronomic species is a significant issue to forest development and the certification of reclaimed wellsites (Bressler, 2008). Regulatory criteria and legislation clearly define the need to control and eradicate noxious weed species (Weed Control Act, 2010; Environment and Sustainable Resource Development, 2013), as well as undesirable species (Environment and Sustainable Resource Development, 2013). Site preparation, cultural control (cover crop establishment) and chemical management represent a range of approaches to control or eradicate undesirable species.

The objective of this study was to examine the ability of combinations of native plant cultural controls (cover crop) and herbicide-based approaches to reduce and eliminate undesirable plant ingress. In this study, approaches that are appropriate for use in the early stages of revegetation development following soil replacement will be evaluated.

Each of these approaches was initiated in the first year following reclamation with plans to monitor the study for three growing seasons. At the completion of the study, the following questions will be answered:

1. Which approaches are most effective at reducing the initial establishment of undesirable species?
2. By controlling ingress of undesirable plants, are there also differences in native plant establishment through natural ingress?
3. Is there a reduction in the growth and productivity of desirable native woody species when utilizing a treatment that is aimed at reducing undesirable plant development (i.e., a trade-off)?
4. What is the potential return on investment of the vegetation management approaches considering relative benefit/success at managing undesirable species?

PROGRESS AND ACHIEVEMENTS

Study 1: Interim Reclamation of a Facility Soil Stockpile

Overall this study is progressing well. Creating surface heterogeneity either through furrowing, or rough and loose mounding (on steeper parts of the stockpile), has stimulated the emergence of a wide range of plant species (70 plus species) from the soil seed and propagule bank. Experiment-wide there has been a steady increase in woody vegetation development, and this year woody plants represented nearly 30% of all vegetation cover across the study area. Forty volumetric water content sensor stations were installed across the study area in 2016-2017. Based on spatial mapping of the monthly averages at these stations, it was observed that furrowing has also resulted in greater evenness of soil moisture along the slopes of the site. This moisture will promote growth of planted seedlings as well as facilitate seed-based establishment from wind-dispersed seeds over time.

Project 1: Site preparation and establishment density

Three planting densities (2,500, 5,000 or 10,000 stems per hectare [sph]) and an unplanted control treatment were initiated in this trial in a randomized block design with fixed effect for planting density treatment and random effect for block. After four growing seasons, there is a clear gradient in tree density with up to 5,000 sph associated with the 10,000 sph treatment, while there were < 1,200 sph of trees in the unplanted treatment (natural recovery, Figure 1). Substantial natural recovery of shrubs (largely willows and raspberries, ~16,000 sph) have blurred the differences between the planting density treatments (no significant difference in shrub densities experiment-wide) though all planting treatments still maintained higher mean total woody densities (shrubs + trees) than the unplanted control ($p < 0.05$). Despite the similarity in the density of shrubs, all planting treatments demonstrated a significant ($p < 0.05$) lead in woody vegetation cover compared with the unplanted treatment. The woody vegetation cover was only 3% on average for the unplanted treatment as compared to 13% to 14% in the 2,500 sph and 5,000 sph treatments, and 18% in the 10,000 sph treatment. For the 10,000 sph treatment, this represents close to half of the 42% total vegetation cover observed.

A B

Figure 1: Examples of planting treatments in Project 1 from August 2019. (a) 2,500 and (b) 10,000 sph.

Project 2: Cover crop establishment through planting

The forest industry has planted tree plugs (small trees grown in nurseries) in commercial reforestation efforts for decades. Traditionally, these were commercial tree species containing one plant per plug. NAIT is developing "hitchhiker" plugs that in addition to the tree include a herbaceous species such as fireweed. The hitchhiker plant provides shelter for the slower-growing tree and may prevent invasive weedy species, such as scentless chamomile, from taking hold. Adding a second species doubles the number of plants delivered to site, at much less than double the cost, and increases the plant diversity of the planted stock.

Creating hitchhiker nursery stock composed of a fast-growing forb (in this case fireweed) and a fast-growing deciduous species (green alder, paper birch or Bebb's willow) was not an easy task. For each of these mixtures, there were consistent growth and survival trade-offs if the timing of fireweed introduction into the nursery cavity was either too early or too late (as illustrated in Figure 2). Observations from the third growing season in the field indicate that for green alder and paper birch, sowing fireweed into the nursery container two weeks after sowing the woody species resulted in suitable development of the woody and forb species. However, for Bebb's willow, fireweed should be sown concurrent with the willow as this particular species was extremely fast-growing; later sow dates with fireweed led to poor establishment (though the willow grew well).

Figure 2: Examples of (a-b) early sowing of fireweed with paper birch where both species were sown at the same time in the nursery cavity versus later sowing where the paper birch seedling was sown (c) two weeks or (d) four weeks prior to sowing the fireweed. Photo was taken in August 2019, three growing seasons after stock establishment in September 2016. Red arrows indicate location of fireweed plants.

Project 3: Aspen establishment through container stock, optimizing plant deployment through grouped planting

Aspen seedlings were clustered in groups of 4, 10 or 20 plants (spaced ~ 25 cm apart within the cluster) or planted singly at a total density of 2,500 stems per hectare. Although preliminary, some emerging qualitative trends are noted for the Year 4 height and survival of these aspen seedlings:

1. In general, survival of individual aspen seedlings appears to be more tightly tied to site conditions (degree of herbaceous competition) rather than clustering. Although the singly planted treatment was not different from any of the clustered treatments, there appears to be higher survival associated with the lowest cluster group (4 plants) compared with groups of 10 or 20 plants. This may be attributable to self-thinning as individual seedlings are averaging 1.2 m to 1.5 m in height.
2. Aspen seedlings tended to be taller when grown in clusters rather than singly. However, this trend is more pronounced for seedlings growing in subsoil and less clear when grown in topsoil. This may be at least partly attributable to the increased competition of the topsoil pushing the aspen to focus growth in height (perhaps at the expense of lateral branch development).

Study 2: Vegetation Management Solutions for Final Reclamation

The key findings after the third growing season were that:

1. Pre-emergent herbicide applications did not significantly ($p < 0.05$) impair the growth and development of the deployed target species; in fact, three-year-old seedlings of green alder, balsam poplar and paper birch were greatest with pre-emergent herbicide treatments. However, the post-emergent herbicide was associated with shorter plants and lower survival of planted nursery stock seedlings.
2. Both pre- and post-emergent herbicide treatments were successful in decreasing total vegetation cover relative to other treatments. The pre-emergent herbicide has resulted in significantly lower ($p < 0.05$) grass cover and slightly less non-native forb cover while the decline in vegetation cover for the post-emergent treatment was almost wholly attributable to a lack of non-native forb and limited woody cover.

LESSONS LEARNED

Study 1: Interim Reclamation of a Facility Soil Stockpile

As only four seasons of growth have been completed, we are far from making final conclusions about these studies and the overall approach of temporary reforestation. However, this study has clearly demonstrated that creating surface heterogeneity (in this case using a dozer to create furrows and backhoe to mound on steeper slopes) can have a stimulating effect on native plant regeneration.

Hitchhiking fireweed with deciduous woody species has proved challenging and the evidence thus far suggests that there is a very narrow window with which both species can be successfully introduced into the same nursery container. Sowing fireweed too early or too late has resulted in either comprised growth of the deciduous species or limited emergence of the fireweed.

There are few differences in terms of plant growth or vegetation development to suggest there is any short-term benefit to tight (25 cm spacing) clustering of aspen seedlings. However, continued monitoring of this study is required to quantify the potential effects of this alternate planting approach as perennial forest species are slow to develop and it is anticipated that there may be other factors that become important as this project ages (such as changes in vegetation development around aspen clusters).

Study 2: Vegetation Management Solutions for Final Reclamation

The third growing season of data collection for this study has been completed and though findings are preliminary, strong evidence has been observed that pre-emergent herbicides were both highly effective at controlling undesirable non-native herbaceous species (largely in the first two years with some maintenance of this effect into the third year) and that they have not negatively affected the survival and growth of planted woody species.

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PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

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Reports & Other Publications

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Kera Yucel, MSc	NAIT Centre for Boreal Research	Research Officer		

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Faster Forests

COSIA Project Number: LJ0019

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: Canadian Natural, Cenovus Energy Inc., CNOOC Petroleum North America ULC, Devon Canada Corporation, Husky Oil Operations Limited, MEG Energy Corp. and Suncor Energy Oil Sands Limited Partnership

Status: Year 3 of 5

PROJECT SUMMARY

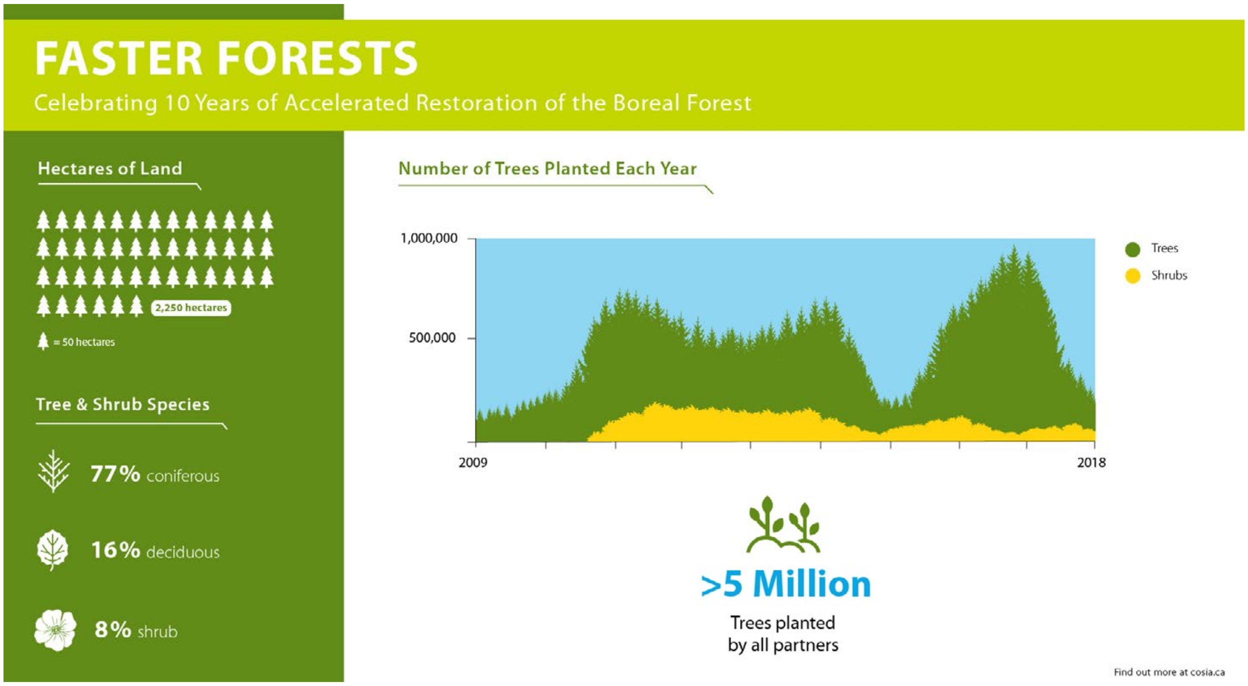
Exploration activities required to locate subsurface energy resources result in the clearing of vegetation on exploratory wellsites prior to development. Returning land to a functioning boreal ecosystem can take decades. Historic reclamation practices typically involved seeding disturbances with grass and allowing trees and shrubs to grow back on their own. Often these sites became ecologically stagnant with grasses impeding the establishment of shrubs and trees. The Faster Forests program has led to wider adoption of planting sites soon after disturbance, improved reclamation practices and the planting of local native trees and shrubs to accelerate site recovery.

A number of studies out of the University of Alberta have focused on understanding the factors affecting site recovery and recommended practices for construction and reclamation. ConocoPhillips Canada Resources Corp., with Nexen Energy ULC., Statoil Canada, Suncor Energy Inc. and Total E&P Canada Ltd. implemented recommendations from these studies to create Faster Forests in 2009.

Reclamation of in situ oil sands exploration (OSE) wells and access trails may include planting of tree and shrub seedlings (although some sites are able to recover naturally) in an effort to reduce the time it takes for these disturbances to recover. While the amount of land directly disturbed through OSE programs is a relatively small percentage of the total area, large contiguous patches of wildlife habitat are fragmented when the trees on these sites and associated access routes are cleared. There is a need to restore ecological structure and ecosystem functions at these sites within a shorter period of time. Construction practices (e.g., low or minimal disturbance, rough and loose surface soil placement in uplands, microtopography conservation in peatlands, etc.) have a strong influence on the reclamation outcomes on OSE sites.

The objective of Faster Forests is to accelerate OSE sites along a trajectory towards self-sustaining boreal forest ecosystems. This will be accomplished through promoting the best practices gained through research and knowledge sharing.

PROGRESS AND ACHIEVEMENTS



Knowledge Sharing Achievements

Three knowledge sharing initiatives were progressed in 2019: field tour, visual guide to planting and a remote sensing based efficacy assessment.

Field Tour

The annual field tour was implemented in 2019 with participation from industry, Alberta Energy Regulator (AER), Alberta Environment and Parks (AEP), and academia. As with previous years, the attendance was capped at 25 people to ensure discussions routinely involved the entire group and were as candid and open as possible.

Field tours to visit OSE reclamation sites started in the autumn of 2011 as an initiative of the Oil Sands Leadership Initiative Land Stewardship Working Group (OSLI-LSWG) to share information in an informal and open manner with each other and the Province of Alberta regulators. This field tour consistently provides the industry participants with a progressive and non-binding dialogue with the regulators as a basis upon which to build trust and promote positive change to define a shared vision of success and achieve desirable outcomes. Participants recognize that fostering a culture of openness creates opportunities to challenge the status quo and the freedom to explore and develop innovative solutions to accelerate environmental performance. As a result of these tours, all participants find great value in sharing ideas, collaborating for innovative solutions and growing relationships.

The purpose of the Faster Forests field tour is to display the "fruits of the program's labour" and provide a forum for people to collaborate, advance research and development, and promote the use of the best new practices. The lessons learned as part of the Faster Forests program need to be shared between companies as well as departments within companies. Furthermore, the field tour allows invited external guests from academia, regulatory agencies and reclamation consultants to view the results firsthand and offer feedback for continued innovation and accelerated environmental performance. In 2019 the Field Tour was attended by a mix of construction personnel, environmental advisors, reclamation managers, regulatory representatives from both AER and AEP, and reclamation consultants.

The theme for 2019 was to visit sites that are struggling or demonstrate difficult issues. As with previous years, several non-OSE sites were also visited, specifically borrow pits and the surrounding upland, as the same construction and reclamation practices that have been developed and implemented by the Faster Forests program are commonly used at these locations.

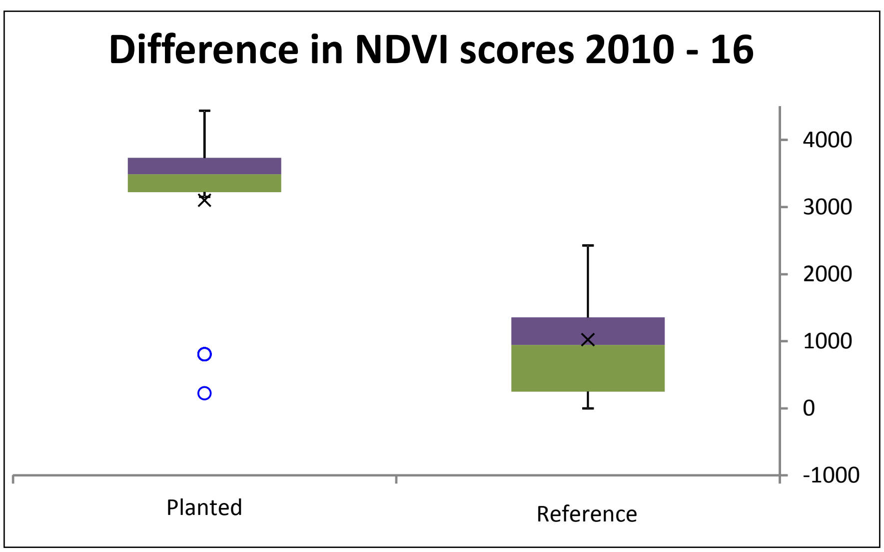
A Visual Guide to Planting

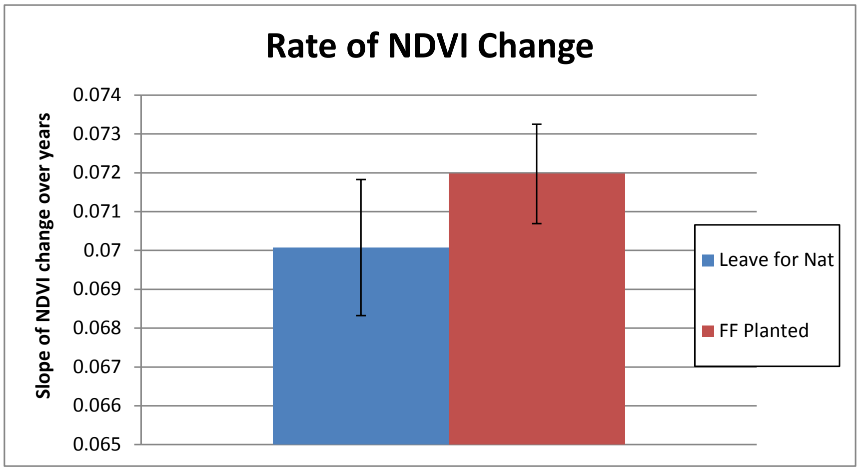
Building on the success of the technical and visual guides previously published, which focused on improved OSE reclamation performance through construction and reclamation practices (Osko & Pyper, 2018, Osko, Pyper & Odsen, 2018), the concept was extended to the planting component of the Faster Forests program to capture the accumulated experiences and learnings over the past ten years.

The guide *Faster Forests: A Visual guide to planting* is aimed at equipping treeplanters and their supervisors with the rationale and technical guidance to maximize the success of plant establishment on reclaimed sites.

Efficacy Assessment

The remote sensing based pilot initiated in 2018 to measure the productivity of Faster Forests planted OSE sites and unplanted (natural recovery) OSE sites was expanded to include more than 450 locations in 2019. Preliminary results suggest that planting significantly increases the amount of vegetation on the planted sites as compared to unplanted sites, as measured with multispectral satellite imagery.





The multispectral satellite image analysis used Normalized Difference Vegetation Index (NDVI) as the metric for analysis. Due to the overlap between trees, shrubs and ground vegetation, it has been deemed that this method of analysis can be improved. As such, the Faster Forests program is considering first completing a landcover assessment with the same multispectral imagery.

LESSONS LEARNED

While developing, *A Visual Guide to improved construction and reclamation practices on oil sands exploration sites (2018*), it became apparent that site construction and reclamation practices are not consistent across the industry. There is an opportunity to align the industry along multiple best management practices for OSE construction as well as other aspects of the Faster Forests program such as treeplanting. Based on feedback from the construction guide, efforts were focused on producing a visual guide. An accompanying technical document was not developed as the visual guide provides the information to the intended target audience in sufficient detail.

LITERATURE CITED

Improving OSE reclamation performance through enhanced construction and reclamation practices (Prepared by: Terry Osko Ph.D., P.Ag., Circle T Consulting Ltd. and Matthew Pyper MSc, Fuse Consulting Ltd. Report Date: November 13, 2018)

A Visual Guide to improved construction and reclamation practices on oil sands exploration sites. (Prepared by: Terry Osko Ph.D., P.Ag., Circle T Consulting Ltd., Matthew Pyper MSc and Sonya Odsen MSc, Fuse Consulting Ltd. Report Date: November 13, 2018)

PRESENTATIONS AND PUBLICATIONS

Reports & Other Publications

Faster Forests: A visual guide to planting (Prepared by: Terry Osko Ph.D., P.Ag., Circle T Consulting Ltd. & Matthew Pyper MSc, Fuse Consulting Ltd. Report Date: December 2019). (In preparation) Will be available at: COSIA.ca

CAPP Context story: https://context.capp.ca/articles/2019/feature_faster-forests

Conference Presentations

PTAC Ecological Issues Forum, December 5, 2019. Keynote address; "Faster Forests: A Decade later" Available at: https://www.ptac.org/

Videos

Video: ConocoPhillips "10 years and 5 million trees" 2019-09-25, "Faster Forests" retrieved from: http://www.conocophillips.ca/sustainable-development/environment/land-and-biodiversity/faster-forests/

COSIA Faster Forests webpage: https://www.cosia.ca/initiatives/land/projects/faster-forests

RESEARCH TEAM AND COLLABORATORS

Principal Investigator: Jon Hornung

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Dr. Terry Osko	Circle T Consulting Ltd.	Principal		
Matthew Pyper	Fuse Consulting Ltd.	Principal		

Research Collaborators: Simon Landhäusser, University of Alberta; Kevin Ball, Alberta Energy Regulator

Oil Sands Vegetation Cooperative

COSIA Project Number: LE0014

Research Provider: Wild Rose Consulting, Inc.

Industry Champion: Canadian Natural

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

Status: Ongoing

PROJECT SUMMARY

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

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

PROGRESS AND ACHIEVEMENTS

In 2019, activities supporting the OSVC initiatives included:

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

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

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

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

Table 1: Species harvested

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

LESSONS LEARNED

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

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

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

LITERATURE CITED

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

PRESENTATIONS AND PUBLICATIONS

Newsletters

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

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

RESEARCH TEAM AND COLLABORATORS

Institution: Wild Rose Consulting, Inc.

Principal Investigator: Ann Smreciu

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

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

WIILDLIFE RESEARCH AND MONITORING

Regional Industry Caribou Collaboration (RICC)

COSIA Project Number: LJ0155

Research Provider: Alberta Biodiversity Monitoring Institute (ABMI)

Industry Champion: Canadian Natural

Industry Collaborators: Cenovus Energy Inc., Imperial, Suncor Energy Inc., CNOOC Petroleum North America ULC, Athabasca Oil Corporation, MEG Energy, Alberta-Pacific Forest Industries

Status: Year 4 of 5

PROJECT SUMMARY

The main cause of caribou declines across most of their ranges is excessive predation, mostly by wolves. The current high predation rates are a result of many complex and interacting factors, including landscape level habitat changes (both natural and human caused). For any caribou recovery program to be successful, it has to address the full range of habitat and population factors impacting caribou, and it must be implemented at the broad-range scale to ultimately spur caribou population growth over time.

The Regional Industry Caribou Collaboration (RICC) is a group of resource companies operating in the oil sands region of northeast Alberta that are working together across their project boundaries to:

- Restore caribou habitat on legacy seismic lines
- Conduct research on caribou ecology and their relationships with other parts of the landscape
- Lead trials on restoration methods, effectiveness and how wildlife respond to restoration

Reversing the decline of caribou requires a focused, science-based strategy that involves multiple partners, including industry, government, academia and non-profit organizations. RICC brings these parties together to contribute to the recovery of boreal woodland caribou and their habitat.

More information about RICC can be found at: www.cosia.ca/initiatives/land/regional-industry-caribou-collaboration

PROGRESS AND ACHIEVEMENTS

RICC is a multi-year program that includes many individual projects that also span multiple years. Achievements in 2019 include the following:

Large-Scale Habitat Restoration

In 2019, RICC members conducted just under 300 km of seismic-line restoration treatments. Work conducted in 2019 brings the cumulative total to over 1,750 km of seismic lines with restoration to date. In addition, RICC developed a restoration treatment plan for three townships in East Side Athabasca River (ESAR) caribou range's Bohn herd.

Evaluating the Efficacy of Video Camera Collars to Measure Ungulate Predation by Black Bears

A pilot project to evaluate the efficacy of video camera collars to measure ungulate predation by black bears was initiated in 2019. In May 2019, these camera-equipped collars were deployed on five black bears in the ESAR range during the caribou calving season (May 1 to July 15). This pilot study demonstrated that this camera-collar technology is suitable for recording potential ungulate kills by black bears, and collar performance (i.e., battery life, video quality, data transmission) generally exceeded expectations.

The pilot program will expand in 2020 to deploy an additional 20 camera-equipped collars on bears within caribou range. This increased sample size should allow for a more robust estimate of kill rates by black bears. By combining this estimated kill rate with an estimate of bear density – derived from an associated remote camera program – the project will provide an estimate of the total number of caribou calves killed by bears.

With population sizes of boreal caribou in this region recently estimated, information from this project will provide the first demographic assessment of bear predation on western populations of boreal woodland caribou.

Ecosystem Monitoring Camera Program

In partnership with the Alberta Biodiversity Monitoring Institute's (ABMI) Caribou Monitoring Unit, the Government of Alberta and the University of Alberta, RICC continued deployment of wildlife cameras in Cold Lake, East Side Athabasca River (ESAR), West Side Athabasca River (WSAR) and Saskatchewan boreal plains caribou ranges. This project monitors mammal (deer, moose, caribou, wolf, bear and mesocarnivores) response to i) wolf reduction program in Cold Lake and ESAR, and ii) the relative influence of anthropogenic habitat alteration and climatic factors. Three clusters of 25 cameras were deployed across ESAR, WSAR and Saskatchewan, for a total of 75 cameras in each range, as well as one cluster within Cenovus Energy Inc.'s Linear Deactivation (LiDea) area in Cold Lake. Cameras collect information year-round and have been collecting data since 2017.

Preliminary data showed that both deer and black bears exhibited a strong latitudinal gradient in the Alberta caribou ranges, with densities an order of magnitude larger in the southern portions of WSAR and ESAR compared to the northern portions. However, this latitudinal trend was not immediately evident in preliminary data from Saskatchewan. Multiple years of monitoring will be required to draw more meaningful conclusions.

LESSONS LEARNED

With the support of RICC, Dickie et al. (2019) evaluated predator (wolf and bear) and prey (moose and caribou) behavioural response to linear features and other anthropogenic disturbances. It was found that wolves and bears both selected linear features and moved faster while on them, suggesting they use them as travel corridors. However, caribou and moose generally avoided these features but moved faster while on them, suggesting they perceive them as risky.

Linear feature restoration is being employed as one mechanism to help reverse caribou declines. However, with the high financial cost to restore seismic lines, theoretical predictions can clarify the efficacy of such actions, and prioritize where or in which order to apply resources. RICC supported two complementary projects that evaluated simulated linear feature restoration to predict the effect of this management action on caribou, moose and wolf populations. In both analyses, restoration was found to have the potential to significantly increase caribou populations, and in some cases could reverse population declines. However, both approaches suggested that to have measurable impacts at the population level, all linear features including permanent railways, roads and highways would have to be restored. This is of course an impossible scenario, and a more realistic scenario is one that includes restoration of temporary disturbances over time, combined with population management tools.

Together, these data can be used to inform future restoration priorities, frameworks and implementation at numerous scales.

LITERATURE CITED

Dickie, M., McNay, R.S., Sutherland, G.D., Cody, M., Avgar, T., 2019. Corridors or risk? Movement along, and the use of, linear features vary predictably among large mammal predator and prey species. J. Ecol. 1–32. https://doi.org/10.2307/2256210

PRESENTATIONS AND PUBLICATIONS

Journal Publications

DeMars, C.A., Serrouya, R., Mumma, M.A., Gillingham, M.P., McNay, R.S., Boutin, S., 2019. Moose, caribou and fire: have we got it right yet? Can. J. Zool. 1–45. https://doi.org/https://doi.org/10.1139/cjz-2018-0319

Dickie, M., McNay, R.S., Sutherland, G.D., Cody, M., Avgar, T., 2019. Corridors or risk? Movement along, and the use of, linear features vary predictably among large mammal predator and prey species. J. Ecol. 1–32. https://doi.org/10.2307/2256210

Serrouya, R., Dickie, M., DeMars, C.A., Boutin, S., 2019a. Predicting the effects of restoring linear features on woodland caribou populations. Ecol. Modell. https://doi.org/10.1016/j.ecolmodel.2019.108891

Spangenberg, M.C., Serrouya, R., Dickie, M., DeMars, C.A., Michelot, T., Boutin, S., Wittmann, M.J., 2019. Slowing down wolves to protect boreal caribou populations: a spatial simulation model of linear feature restoration. Ecosphere 10, 1–17. https://doi.org/10.1002/ecs2.2904

Filicetti, A.T., Cody, M., and Nielsen, S.E. 2019. Caribou conservation: Restoring trees on seismic lines in Alberta, Canada. Forests. doi:10.3390/f10020185

RESEARCH TEAM AND COLLABORATORS

Institution: Alberta Biodiversity Monitoring Institute (ABMI), Caribou Monitoring Unit

Principal Investigator: Rob Serrouya

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Melanie Dickie	Alberta Biodiversity Monitoring Institute (ABMI), Caribou Monitoring Unit	Research Analyst		
Natasha Annisch	Alberta Biodiversity Monitoring Institute (ABMI), Caribou Monitoring Unit	Field Operations Coordinator		
Craig DeMars	Alberta Biodiversity Monitoring Institute (ABMI), Caribou Monitoring Unit	Research Analyst		

Research Collaborators: University of Alberta; Government of Alberta, Department of Environmental Protection; University of Calgary; Wildlife Infometrics Inc.

Migratory Connectivity Project

COSIA Project Number: LJ0276

Research Provider: Migratory Bird Center, Smithsonian's National Zoo and Conservation Biology Institute

Industry Champion: ConocoPhillips Canada Resources Corp.

Status: 2014 - Present (annual participation)

PROJECT SUMMARY

Migration is one of the most engaging phenomena of the animal world and is epitomized by birds. Understanding and tracking animal movements are fundamental components for conserving the habitats that are essential to species survival. And yet, our knowledge about why, how, when and where most of earth's bird species migrate during their lifecycle is rudimentary, at best. Migratory connectivity is the geographic linking of individuals and populations between one life cycle stage and another, such as between breeding and wintering locations for a migratory bird. Without an understanding of migratory connectivity, conservation investments can be ineffective because they are implemented at the wrong place or time, or for the wrong purpose.

Support from ConocoPhillips Global Signature Program for the Smithsonian Migratory Bird Center's Migratory Connectivity Project (MCP, http://www.migratoryconnectivityproject.org/) is enabling important work on the conservation of birds. Considerable overlap exists between MCP and ConocoPhillips Canada Resources Corp.'s (ConocoPhillips) biodiversity stewardship strategies, including:

- Conserving critical habitats where ConocoPhillips does business, ranging from Alaska, through western Canada and the continental United States, and into northern South America (Colombia);
- Strengthening the ability of multiple public and private stakeholders to address and manage biodiversity needs collaboratively; and
- Improving the depth and quality of scientific research related to key environmental challenges that will inform more effective solutions for biodiversity conservation.

Primary objectives include:

1. Signature Electronic Tracking Projects to track the migrations of birds throughout their annual cycles, discover unknown migrations, discover important breeding, stopover and wintering habitats, and make this information available to managers;
2. Testing and advancing new technologies; and
3. Catalyzing research and scientific collaborations around the migratory connectivity of birds throughout North America and across the Western Hemisphere.

PROGRESS AND ACHIEVEMENTS

Signature Tracking Projects

In 2019, efforts were focused on analyzing and recording the results of our electronic tracking studies conducted in previous years. This included an accepted publication about broad-winged hawk migratory connectivity, a paper in revision about drivers of population declines of Connecticut warblers, and a continental scale comparison of migration routes timing, and overwintering habitats of common nighthawks. See publication section, below.

While no new tags were deployed on common nighthawks in 2019, one of the four GPS archival tags deployed in northern Alberta in 2018 (as a trial) was recovered in 2019. This tag contains about 700 GPS points (in contrast to the 60 provided by the previous 3.4 g Argos-pinpoint tags used). Even though this is only a single tag, the increased data provides some really interesting insights into common nighthawk full annual cycle ecology. For example, this male common nighthawk undertook a five-day, ~3,000 km continuous flight from Colombia to central Texas during spring migration, returning to the same breeding territory as the previous year. The bird had a 40 km^2 breeding home range, which emphasizes the complexity of understanding this species on the breeding grounds.

A two-year study of Canada warblers in Colombia was initiated, with a goal of estimating overwinter survival and home range movements. Colombia provides overwintering habitat for Canada warblers that breed in the boreal forest of Alberta. This project aims to identify the causes and locations of mortality for the species. This was done through the use of a tiny coded tag called a nano-tag and an array of four automated telemetry receiver towers (part of the MOTUS Wildlife Tracking System). Thirty-eight Motus tags were attached to Canada warblers to monitor their overwintering movements at four sites.

Testing and Advancing New Technologies

Researchers continued to pioneer the use of new technologies and applications of electronic tags on new species. Eleven new migration paths were transmitted by satellite for common nighthawks in 2019. The total number of migration paths for this species is now 52 of 82 tags deployed. This is a high success rate for new technologies. Researchers on this project were the first to test this new tag for Lotek Wireless (tag manufacturer) and it proved to be an extremely useful new technology for cryptic, hard-to-follow species like common nighthawks.

In Colombia, manual radio tracking was paired with automated tracking in order to determine the success of the automated telemetry array.

Catalyzing Research and Scientific Collaborations

The success of this program, both from a logistical, but also conservation perspective, hinges on successful collaboration with many local and regional partners. Program partners, who have provided local expertise and field personnel, have increased the capacity to execute expeditions, conduct scientific research and disseminate research results.

Research work in 2019 included collaborations with at least 25 organizations and 14 individuals, and these partners all contributed to writing publications. In addition to generous support this program received from ConocoPhillips, other collaborators contributed additional funds and in-kind support for tracking devices, equipment, field time and expenses, and graduate student assistantships. The Migratory Connectivity Project is enabling research at a large scale by catalyzing partnerships across organizations and places.

LESSONS LEARNED

This research is providing the first insights into links between breeding habitats in the boreal forest and overwintering habitats in the South for multiple priority species, including common nighthawk, Connecticut warbler, Canada warbler and broad-winged hawk. Understanding when and where birds migrate is a key first step in learning how and where to manage them effectively to reverse declines.

- In 2019, data show that common nighthawks from multiple populations in North America use a common migratory route, but then they distribute among multiple locations throughout Cerrado and Amazon habitats in Brazil.
- An important finding of research on the Connecticut warbler (still in review/revision) was cumulative forest loss within 50 km of breeding locations in northern Alberta for the Connecticut warbler contributed more to population declines than forest loss on migratory stopover regions or their wintering locations in South America.
- In Colombian overwintering habitat, Canada warblers that were tracked maintained individual territories and overlap of territories among individuals was low. Fewer birds were detected using the automated towers versus the manual tracking; therefore, manual tracking at Colombian overwintering sites is recommended to more accurately distinguish movement from mortality and possible reasons for mortality. Sites were variable in regards to movement: where Canada warblers stayed at a site all winter (rather than moving among sites), five birds were found dead. This information will help estimate the level of mortality for Canada warblers on overwintering habitats.

PRESENTATIONS AND PUBLICATIONS

Journal Publications

One manuscript has been accepted for publication (broad-winged hawk), one is in revision (Connecticut warbler), and one additional will be submitted in early 2020 (common nighthawk).

In Press: McCabe, Rebecca; L. Goodrich, D. Barber, T. Master, J. Watson, E. Bayne, A.L. Harrison, P. Marra, K. Bildstein. 2020. Differences in migratory connectivity and migration ecology among populations of broad-winged hawks (*Buteo platypterus*). *Wilson Journal of Ornithology*

In revision: Hallworth, Michael T., E. Bayne, O. Love; E. McKinnon, J. Trembley, S. Van Wilgenburg, P. P. Marra. Breeding ground habitat loss is the primary driver of population declines for a long-distance migratory shorebird, Connecticut warbler**.** *Proceedings of the Royal Academy B.*

In preparation for *Ecography* (To be submitted by end of January, 2020): Knight, Elly, A.-L. Harrison, A.L. Scarpignato, S.L. Van Wilgenburg, E.M. Bayne, J. Ng, E. Angell, R. Bowman, M. Brigham, W. Easton, T. Forrester, J. Foster, S. Haché, K. Hannah, J. Ibarzabal, T. Imlay, S. MacKenzie, L. McGuire, G. Newberry, D. Newstead, A. Sidler, D. Swanson, P. Sinclair, J. Stephens, J. Tremblay, P.P. Marra. A comprehensive approach to estimating migratory connectivity across the full annual cycle reveals peaks in spatial and temporal connectivity for a declining, long-distance migratory bird.

Conference Presentations/Posters

Knight, Elly, A.L. Harrison, A.L. Scarpignato, S.L. Van Wilgenburg, E.M. Bayne, J. Ng, E. Angell, R. Bowman, M. Brigham, W. Easton, T. Forrester, J. Foster, S. Haché, K. Hannah, J. Ibarzabal, T. Imlay, S. MacKenzie, L. McGuire, G. Newberry, D. Newstead, A. Sidler, D. Swanson, P. Sinclair, J. Stephens, J. Tremblay, P.P. Marra. June 2019. Conservation implications of a migratory network for the common nighthawk**.** American Ornithological Society (137th Annual Meeting). Anchorage, Alaska.

RESEARCH TEAM AND COLLABORATORS

Institution: Migratory Bird Center, Smithsonian's National Zoo and Conservation Biology Institute

Principal Investigator: Peter P. Marra, PhD and Autumn-Lynn Harrison, PhD

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
Amy Scarpignato	Migratory Bird Center, Smithsonian's National Zoo and Conservation Biology Institute	GIS Specialist		

Research Collaborators:

Organizations	**Collaborators**
Primary: University of Alberta	Erin Bayne, Professor
Archbold Biological Station, Florida	Reed Bowman
Bird Studies Canada, Ontario	Stuart MacKenzie
Coastal Bend Bays & Estuaries Coastal Bird Program, Texas	David Newstead
Dalhousie University	Tara Imlay
Durham University, United Kingdom	Luke Powell
Environment Canada, British Columbia	Wendy Easton (BC)
Environment Canada, NWT	Sam Haché
Environment Canada, Quebec	Junior Tremblay
Environment Canada, SK	Steven Van Wilgenburg

Environment Canada, Yukon	Pam Sinclair (YT)
Hawk Mountain Sanctuary	Rebecca McCabe
Hawk Mountain Sanctuary	Laurie J. Goodrich
Hawk Mountain Sanctuary	Keith Bildstein
Independent	Tim Forrester (BC-OK)
Klamath Bird Observatory, Oregon	Jaime Stephens
Lotek Inc. (Tag supplier)	Alan Marsh
Northern Arizona University	Jeff Foster
Smithsonian Migratory Bird Center	Mike Hallworth (Postdoctoral Research Associate)
The Ohio State University	Jay Wright
University of Alberta	Elly Knight, Student (PhD 2021)
University of Alberta	Janet Ng, Student (PhD 2019)
University of South Dakota	Gretchen Newberry
USFWS, Alaska	Jim Johnson
USFWS, Nevada	Chris Nicolai

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

COSIA Project Number: LJ0214

Research Provider: Owl Moon Environmental Inc.

Industry Champion: Syncrude Canada Ltd.

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

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

Status: 2011 – Present (annual participation)

PROJECT SUMMARY

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

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

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

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

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

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

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

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

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

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

PROGRESS AND ACHIEVEMENTS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

LESSONS LEARNED

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

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

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

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

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

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

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

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PRESENTATIONS AND PUBLICATIONS

Pyle P., Foster K. R., Godwin C. M., Kaschube D. R., Saracco J. F. (*in review*) Yearling proportion correlates with habitat structure in a Boreal forest landbird community. Submitted to PeerJ.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Kenneth R. Foster

Name	Institution or Company	Degree or Job Title	Degree Start Date (Students Only)	Degree Completion Date (Students Only)
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James Saracco	The Institute for Bird Populations	Research Ecologist		
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ENVIRONMENTAL RESEARCH AND MONITORING

Boreal Ecosystem Recovery and Assessment (BERA)

COSIA Project Number: LJ0220

Research Provider: University of Calgary

Industry Champion: ConocoPhillips Canada Resources Corp.

Industry Collaborators: Cenovus Energy Inc., Canadian Natural, Devon Canada Corporation, Alberta Pacific Forest Industries Ltd.

Status: Year 5 of 5

PROJECT SUMMARY

The boreal-forest regions of Alberta are under increasing pressure from human development related to natural-resource extraction. Roads, seismic lines, wellsites, cut blocks, mines, pipelines and other elements of human footprint exert cumulative environmental effects that can harm biodiversity, water quality and the habitat of threatened species such as woodland caribou. In order to mitigate these effects, resource-extraction companies and provincial regulators are working to develop monitoring initiatives that track the amount of human footprint present in a given area and measure the rate at which previously disturbed areas are being restored.

The Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) Boreal Ecological Recovery and Assessment project (BERA http://www.bera-project.org) brings researchers, government, stakeholders and industry together to mitigate the effects of non-permanent industrial activities, such as the construction of seismic lines, access roads and well pads, on the boreal forest. The team, led by research experts from the University of Calgary, University of Alberta, Trent University, (Waterloo University added in 2019) and Natural Resources Canada, aims to develop cutting-edge technologies and techniques that can help to measure, monitor and predict the recovery of vegetation and some animal uses after temporary human disturbance by industrial activity.

The Technology

The research program uses advanced geospatial technologies and modelling techniques to aid in the process of measuring, monitoring and predicting vegetation recovery on non-permanent (i.e., to be reclaimed) human footprint features (i.e., seismic lines, roads, etc.).

The BERA project previously included three research areas: remote sensing, sensor networks and ecology. In 2019, a fourth research area was added: soils and ecohydrology.

Objectives

The research project addresses five specific research objectives:

1. Map human footprint features using advanced remote-sensing devices;

2. Assign descriptive attributes to human-footprint features that can be tracked through time in a monitoring program;
3. Develop low-cost ground-sensor networks that can track the physical condition and human or animal use of human-footprint features;
4. Develop statistical models that can predict the rate of vegetation recovery in human-footprint features across the boreal forest; and
5. Deliver a rapid verification protocol designed to assess the reclamation status areas disturbed by humans.

Potential/Actual Environmental Benefits

By discovering new ways to monitor and measure how humans impact the boreal forest and predict how vegetation can return to areas of temporary disturbance, the oil sands and forest industries can improve how they manage reclamation efforts across their areas of operation.

Outcomes

Innovative approaches to mapping the extent and condition of temporary footprint, monitoring vegetation recovery, and the efficacy of habitat restoration activities in the boreal forest are key to effective land reclamation.

Remote sensing technologies offer a credible and defensible way to map and monitor recovery of vegetation on disturbed sites. BERA's research supports industry efforts to develop timely land-reclamation practices. Novel geosensor technology can aid in better understanding the use of recovering temporary disturbances, by both humans and boreal forest dwellers, which is an important factor determining future recovery success.

Arriving at a set of unambiguous scientifically defensible criteria determining vegetation recovery success and future success trajectories will aid in prioritizing areas for treatment as well as inform regulatory requirements for effective boreal forest reclamation.

PROGRESS AND ACHIEVEMENT

Objective 1: Map human footprint features with advanced remote-sensing devices

Gus Lopes Queiroz (MSc, 2019; now serving as a BERA Research Technician) continued the development of the Seismic Line Mapper (SLM), which is a software tool for measuring the path and extent of linear disturbances using least-cost-path analysis of canopy height models. An alpha version of the tool (SLMα) was previously developed within the BERA project.

Lopes Queiroz's work addressed four main goals: (i) solve issues and limitations of the prototype version; (ii) apply an updated version of the SLM to generate line and footprint layers for the three BERA 2017 project areas: Kirby, LiDea I and LiDea II; (iii) conceptualize and implement line-attribution functionalities to the SLM so that the tool output would include attributes which relate to spatial properties, allowing for greater insight on seismic line conditions; and (iv) package the SLM tool as professional software for use by external stakeholders.

While addressing these goals, Lopes Queiroz identified the need to fundamentally change the methods and workflow of the prototype version. The only required data input is a canopy height model map (raster) and a regional-scale digitized linear layer of seismic lines (~1:20,000). This new workflow is more streamlined and allows for much more precise and detailed outputs (footprint polygons and centrelines) at a fine scale (~1:500) including a series of spatial attributes. SLMα was redesigned to adopt a parallel processing method instead, allowing several central processing unit (CPU) cores to work simultaneously. This dramatically reduces the processing time on extensive application areas (i.e., from days to minutes). Finally, to achieve effective parallel processing and allow for multi-licence support (i.e., both ArcMap and ArcGIS Pro) while aiming for effective user experience, SLMα was restructured as stand-alone scripts with its own graphical user interface (GUI), as opposed to ArcGIS script tools. SLMα is operational and ready to be shared as a beta release (SLMβ).

Objective 2: Assign descriptive attributes to human-footprint features that can be tracked through time in a monitoring program

Several BERA researchers from the University of Calgary and Natural Resources Canada (NRCAN) Canadian Forest Service Northern Forestry Centre (CFS) are collaborating on the use of remote-sensing data sets and workflows to perform conifer seedling detection and stocking assessment in line with the Provincial Restoration and Establishment Framework for Legacy Seismic Lines. Greg McDermid (University of Calgary, BERA Principal Investigator) used manual image interpretation (i.e., softcopy interpretation) to document the effects of seedling size (height), species (evergreen versus deciduous), and phenology (leaf on versus leaf off) on seedling detectability. His preliminary findings suggest that good, unshaded imagery commissioned with a piloted aircraft (~5 cm/pixel ground resolution) enabled the detection of more than 80% of evergreen seedlings, with low rates (~2%) of false detection. Further preliminary work by Man Fai Wu (University of Calgary, MSc) and Mustafiz Rahman (University of Calgary, Research Scientist) showed that these softcopy-interpretation results could be largely duplicated by automated workflows (object-based classifications performed on the same imagery), suggesting that large-area production should be possible. However, these techniques rely on a narrow phenological window (spring and fall) where surrounding vegetation was senesced. These workflows are not expected to perform well for small (< 70 cm) or deciduous seedlings.

Michael Fromm (Ludwig-Maximilian University, MSc) assessed the effectiveness of machine-learning algorithms for automatic detection of coniferous seedlings from centimetric drone images of seismic lines. Upon successful completion of his thesis, demonstrating that convolutional neural networks (CNN) can be used as a feature extractor and object detector to classify seedlings, Fromm published his findings in 2019. The best model achieved a mean-average-precision (MAP) value of 0.81, which allowed the detection of eight out of ten seedlings with an error rate of 20%. Michael also found that by using a pretrained CNN, a high MAP (> 0.65) value could be accomplished with as few as 200 training annotations. A combination of leaf-on and leaf-off images produced the best result. Further tests on simulated flying altitude (pixel size) showed that algorithms trained at one resolution could not be applied effectively to imagery at another resolution, but that machine-learning approaches to seedling detection could perform well at a variety of resolutions given adequate training. Predictably, medium and large seedlings can be detected better (large-seedling MAP > 0.99; medium-seedling MAP > 0.85) than small seedlings (MAP > 0.7).

Annette Dietmaier (Ludwig-Maximilian University, MSc) compared airborne laser scanning (LiDAR) and digital aerial photogrammetry for characterizing canopy opening in the boreal forest. Upon successful completion of her thesis, demonstrating that LiDAR data was still best equipped to characterize structural elements of forest canopies (canopy openings mapped with 87% overall accuracy), compared to photogrammetric models (~46 – 47% overall accuracy). Her findings were published in 2019.

Understory vegetation is an important component of the boreal forest as it provides wildlife habitat, influences nutrient cycling, forest succession and fire regimes. However, it often is excluded from forest structure assessment due to the lack of its direct economic significance. As a result, limited research has been conducted on this forest layer. Silvia Losada (University of Calgary, MSc) has taken on the task of advancing the mapping and characterizing of understory vegetation with remote sensing. Using high-density airborne LiDAR and field measurements, Losada was able to collect data across a large spatial extent. Preliminary results show strong correlations between LiDAR and field data. However, some systematic biases were identified. Losada is continuing her analysis to understand the nature of that bias.

Gustavo Lopes Queiroz (University of Calgary, MSc) successfully defended his thesis in the summer of 2019. During his thesis research, he developed novel methods to mapping and estimating the volume of coarse woody material (CWM) both on boreal seismic lines and the surrounding forest. His research tested the effectiveness of a geographical object-based image analysis (GEOBIA) workflow with random forest classification for mapping CWM logs and snags in a 4,300-hectare study area in northeastern Alberta. The models successfully mapped (up to 93.4% completeness and 94.5% correctness) and estimated volume of CWM (0.623 R^2, 0.224 RMSE), with good accuracies. Machine learning proved a valuable tool for detecting CWM on orthophotos. Given a large training sample created by a human interpreter, the artificial intelligence was able to achieve high accuracies with relatively little efforts from the user. CWM estimations in the surrounding forest are more challenging than on disturbances, but good results are achievable through sophisticated statistical modelling.

Kiran Basran (University of Calgary, MGIS) worked on extending an existing depth-to-water mapping technique, originally developed by Rahman et al. (2017). Kiran applied the technique to a large and complex Kirby study site and developed a new strategy for communicating confidence in water-depth estimates over varying conditions. The study concluded that remote sensing can map depth to groundwater table in the low-lying areas with acceptable accuracy (± 30 cm) under the following assumptions: (i) surface water is abundant and visible from the aerial platforms; (ii) surface water is tightly linked with ground water; and (iii) the terrain is flat or gently sloping.

Marko Dejanovic (Ludwig-Maximilian University, Bachelor Honours Student) built on Basran's work by attempting to apply the depth-to-water mapping technique across time using repeated remote-sensing flights. He demonstrated that the technique can serve as a near-real-time monitoring tool, given the same three assumptions.

Cassondra Stevenson (University of Alberta, BSc) used a high-precision altimeter to investigate microtopographic variation on seismic lines compared to adjacent undisturbed forests. After successful completion of her Bachelor's thesis, where she demonstrated that microtopographic complexity on seismic lines was simplified by 20% compared to adjacent stands, she published her findings in 2019. There was no significant change between recently burned and unburned sites, nor between ecosites. Stevenson found that not only were seismic lines simplified, but they were also depressed in elevation by an average of 8 cm compared to adjacent forests due presumably to compaction during the creation of the seismic line and potentially, subsequent use by motorized vehicles. Some minor variation between ecosites was observed, but not with recent wildfires.

In an effort to understand the factors limiting tree recruitment on seismic lines, Caroline Franklin (University of Alberta, Post-Doctoral Fellow) examined the variation in several abiotic conditions – light intensity, air temperature and relative humidity – within and adjacent to seismic lines. Her findings demonstrated that edge effects on the microclimate of seismic lines were most pronounced in wide lines (6.0 m to 8.0 m) and along north forest edges (south-facing exposure) and east forest edges (west-facing exposure). Light intensity on north edges of wide and narrow seismic lines (3.0 m to 3.9 m) was 2.8 times and 1.7 times, respectively, higher than light intensity on south edges (north-facing exposure). Edge effects on light intensity extended up to 5 m into the forests adjacent to wide lines but were restricted to the forest edge for narrow lines. Changes in air temperature and relative humidity extended up to 10 m into the forest edge varying by time of day. The afternoon temperature for north and west (east-facing) edges of wide seismic lines was significantly higher, and relative humidity lower, than in the seismic line centrelines and the interior forest. Meanwhile, evening temperatures were significantly higher at north and east edges and evening relative humidity significantly lower at east edges compared to the interior forest. Wide seismic centrelines were characterized by ≥ 1°C increases in evening temperatures and 2.9% (east-west orientation) and 14% (north-south orientation) lower evening relative humidity than that of narrow seismic centrelines. Tree regeneration was highest where light intensity was highest (the centrelines of wide north-south seismic lines) and a 10-fold increase in light intensity resulted in 5.8 times more regenerating trees.

Kim Kleinke (University of Waterloo, MSc) and Scott Davidson (University of Waterloo, Post-Doctoral Fellow) investigated the impact of seismic lines on physical and chemical soil properties. Field soil samples, measurements of bulk density and soil moisture, and plant data were collected on seismic lines in Kirby and a new area in the Cenovus Energy Inc. lease called Clyde. The sample area included seismic lines restored in varying years, unrestored lines, as well as natural areas. Kleinke further set up a block treatment study design on three seismic lines to test different restoration techniques with the intention of returning next year (in June and October 2020) for sampling. Laboratory analysis of collected plant and peat samples for total carbon, nitrogen and phosphorus, and stable carbon and nitrogen isotopes were started as well as peat bulk density, volumetric water content and organic matter content. Preliminary results to date suggest that removal of vegetation and compacting of soil following seismic line disturbance significantly modifies soil physical and chemical properties including greater bulk density, higher moisture content, greater organic matter loss and changes in nutrient availability. Preliminary results further suggest that total nitrogen in the peat may be higher on seismic lines and changes in stable nitrogen isotopes indicate altered processes. Total phosphorus does not seem to change on seismic lines. Different plant species are responding to these changes in different ways, with conifers responding the most poorly. Potential competitive advantages of species such as Labrador tea may help explain the lack of desired conifer recovery.

Percy Korsah (University of Waterloo, PhD) continued his research, investigating the impact of seismic lines on peatland vegetation communities and carbon exchange. His long-term goal is to develop a tool to map vegetation communities across a boreal peatland impacted by seismic lines using unmanned aerial vehicle (UAV) imagery and use this to upscale local measurements of carbon flux. Korsah completed his second field season in Peace River measuring carbon dioxide (CO_2) and methane (CH_4) fluxes on seismic lines in peatlands and adjacent undisturbed areas. Preliminary data analysis was started on microbial community function and physical conditions (water table, soil moisture and soil temperature) at each study site. He further collaborated on conducting a laboratory incubation study of peat soil respiration – investigating the effect of soil moisture and temperature from samples on and off the line. Results from this work are anticipated after his final field season in 2020.

Objective 3: Develop low-cost ground-sensor networks that can track the physical condition and human or animal use of human-footprint features

To date, most research on acoustic animals has used relatively coarse measures of abundance to evaluate the success of recovery and restoration. Researchers have shown that such approaches do not have the resolution to accurately represent how animals react to energy sector disturbances. As such, a variety of new techniques using sound triangulation by means of autonomous recording units (ARUs) have been developed. They allow researchers to precisely locate where animals are spending their time and exactly what elements influence whether an animal will or will not use an energy sector footprint.

In particular, limited information exists on how songbirds respond to the regeneration of wellsites following reclamation. Scott Wilson (University of Alberta, MSc) used acoustic localization to determine the assemblage of songbirds on 12 reclaimed wellsites, each covering about 1 ha in size and ranging from 7 to 49 years since reclamation. Wilson also evaluated the similarity of this assemblage to 12 control mature forest sites (greater than 80 years old). Songbird community composition became more similar to mature forest as canopy cover increased on reclaimed wellsites. This suggests that wellsite reclamation practices are allowing for initial suitable vegetation recovery. However, more research on the effectiveness of different strategies at promoting regeneration of wellsites and subsequent impact on songbird communities is required. Ongoing work by Richard Hedley (University of Alberta, Post-Doctoral Fellow) is exploring new, more affordable acoustic methods for surveying the avifauna on reclaimed wellsites. Where before large microphone arrays comprised of 25 microphones were used to examine the spatial distribution of birds on the wellsite (Wilson and Bayne, 2018), Hedley's work shows that it is feasible to survey the birds on a wellsite using a single microphone placed in the center. By measuring the loudness of bird songs, it is possible to determine if a given bird is singing on the wellsite versus in the surrounding forest. Results from this proof-of-concept study are currently under review with the journal Bioacoustics. This new approach has the potential to allow for the development of a scalable, affordable monitoring program to assess the responses of bird communities to wellsite regeneration.

Regarding bird responses to seismic lines, Jocelyn Gregoire (University of Alberta, MSc) is in the process of investigating the behavioural response of the Canada warbler during the different stages of recovery of linear features using sound triangulation techniques. Her objectives are to: (i) determine how Canada warblers use space around seismic lines; and (ii) identify how vegetation regeneration influences this response. Deploying 46 grids of GPS time-synchronized SM3 song meters across seismic lines at different stages of regeneration, Gregoire achieved precise locations of singing events with minimal human disturbance. Vegetation surveys were conducted along the disturbance and in the adjacent forest to assess regeneration. Preliminary insights gained so far suggest that Canada warblers make use of seismic lines once the vegetation reaches a certain height and density.

Research on using autonomous recording units to investigate bird responses to industrial noise is also being pursued by Natalie Sanchez (University of Alberta, PhD). Sanchez is testing whether songbirds avoid noisy areas— taking into account the human disturbance in addition to the noise source. For this work, she is estimating the occupancy of four songbirds breeding in northern Alberta: Lincoln's sparrow, white-throated sparrow, Tennessee warbler and yellow-rumped warbler. Her focus is on abundance responses to industrial noise sites in very different habitats from those previously studied. Preliminary insights suggest that the Lincoln's sparrow (a habitat generalist generally tolerant of physical disturbance) shows some response to noise with evidence suggesting they may adapt their songs slightly to be heard in such environments. However, more analysis is required before conclusions can be drawn.

Lionel Leston (University of Alberta, Post-Doctoral Fellow) has started to investigate the response of forest birds to cumulative effects at multiple spatial scale using data from Big Grids. Recent studies suggest that models of bird abundance are improved by including fine-scale vegetation structural data (e.g., crown height, canopy cover, shrub density). However, fine-scale vegetation data collected from field surveys are time consuming and labour intensive to obtain, even over small extents. In addition, the improvement in model-fit achieved by including fine-scale data may be insufficient relative to the expended effort. Leston is modelling how well abundance of boreal bird species is predicted by different kinds of spatial data, from coarse-scale remotely sensed layers and forest-resource inventory shapefiles, to fine-scale LiDAR point cloud data. It is anticipated that the spatial scale will influence the effect size for most disturbance stressors.

Over the course of the year, Steve Liang and his team (University of Calgary) have continued the development of a new generation of the end-to-end low-cost and low-power IoT (Internet of Things: a network of internet connected objects able to collect and exchange data) sensing system for environmental monitoring including: (i) upgrades to the cloud-based managed services (i.e., Amazon Web Services (AWS) IoT Core) for provisioning sensors and field gateways, that has no single-point-of-failure and is scalable to a very large number of IoT devices; ii) changes to the field LoRA gateway from a lab prototype to a commercial system that is designed to be deployed in the field; (iii) changes to the environmental sensing nodes from a lab prototype PCB-board to a commercial sensor that is designed to be deployed in the field; (iv) development on a new frond-end IoT portal for field data management, visualization, and analysis over the Web; and (v) tests and deployments of the new system for data collection. The team further led and worked with international experts to update the Open Geospatial Consortium (OGC) SensorThings API v1.0 to v1.1., which is fundamental IoT technical architecture for the developments in this research. The advancement of the SensorThings standard has a significant impact for scientists constructing IoT systems for environmental sensing around the world. The team also led and worked with United Nations' ITU-T to define an international standard for IoT data management and processing based on the OGC SensorThings API. This United Nations standard will have a global impact on how nations around the world construct and share IoT sensing data.

Objective 4: Develop statistical models that can predict the rate of vegetation recovery in human-footprint features across the boreal forest

Lack of recovery is common in unproductive forests, such as treed peatlands, due to conditions that limit tree growth such as simplification of microtopography (loss of microsites). The persistence of these features affects biodiversity, including threatened woodland caribou. Although natural regeneration occurs in some places, it is not an effective strategy in treed peatlands, the primary habitat of woodland caribou. This has led to active restoration. However, the current approach to restoration does not consider wildfires that destroy planted trees, yet also initiate early seral conditions that favour natural regeneration. Angelo Filicetti (University of Alberta, PhD) compared tree regeneration on seismic lines and adjacent forests controls for burned (75 sites) and unburned (68 sites) treed peatlands in northeast Alberta. Tree regeneration varied from: 28,500 stems/ha in burned lines; 11,440 stems/ha in unburned lines; 18,210 stems/ha in burned forest; and 9,520 stems/ha in unburned forest. Wildfires promoted natural regeneration in bogs and poor mesic sites, but not in fens where regeneration was negatively related to open water and positively related to cover of bryophyte and woody debris. Finally, tree regeneration was related to microtopography on seismic lines for burned lines, but not unburned lines.

Filicetti also examined the natural and planted recovery of trees in the LiDea restoration site in the Cold Lake Air Weapons Range. He found that, when compared to untreated lines, silvicultural treatments of mounding increased tree density of natural regeneration despite averaging only 3.8 years since treatment (versus 22 years since disturbance for untreated). Specifically, treated lines averaged 12,290 regenerating tree stems/ha. This is 1.6 times more than untreated lines (7,680 stems/ha) and 1.5 times more than the adjacent undisturbed forest (8,240 stems/ha). Treated seismic lines consistently have more regenerating trees across all ecosites. Although, the higher amounts of stems observed on treated poor fens were not significantly different to untreated or adjacent undisturbed reference stands.

Objective 5: Deliver a rapid verification protocol designed to assess the reclamation status areas disturbed by humans

Guillermo Castilla (Canadian Forest Service, BERA Principal Investigator) and his team continued working on automated estimations of conifer seedling heights from high-resolution drone images at 0.35 cm, 0.7 cm and 2.5 cm ground resolutions. The team returned to the field in May 2019 for additional measurements to explain some outliers in their height estimates from the drone photogrammetry. The preliminary analysis results for these drone images indicate that the minimal height error that can be achieved under ideal conditions is approximately 30 cm; meaning that small conifer seedlings (~< 60 cm) cannot currently be reliably measured with high-resolution drone photogrammetry. Final analysis results are expected in spring 2020.

LESSONS LEARNED

Remote Sensing

- Remote sensing is an effective and authoritative source of information for canopy structure and coarse woody material (CWM). Under the correct conditions, remote sensing data can also provide an authoritative source of information for forest understory structure, depth to water, and conifer seedling detection/measurement. Specific lessons include:
  - While digital aerial photogrammetry is a less expensive alternative to map canopy structure, it is unable to compete with the accuracy of LiDAR. This is particularly evident with small structural features such as canopy openings up to 20 m^2, where the photogrammetric technique performs poorly. For now, it is recommended that operational use of digital aerial photogrammetry in forests be limited to mapping large canopy features.
  - Remote sensing can and should be used to study CWM on seismic lines, given that open canopy conditions allow for very accurate and extensive estimations of CWM. The inputs necessary to achieve good accuracies on seismic lines are accessible – an RGBN orthophoto and a training set. Machine learning proved a valuable tool to detect CWM on orthophotos. Given a large training sample created by a human interpreter, the artificial intelligence was able to achieve high accuracies with relatively little efforts from the user. CWM estimations in the surrounding forest are more challenging than on disturbances due to canopy interference, but are achievable through sophisticated modelling. Field measurements become instrumental to achieve good estimates where CWM is invisible from orthographic view.

- High-density LiDAR point clouds show strong correlations with understory structure information collected in the field, suggesting promising future insights. This work is still ongoing, and the source of systematic LiDAR overestimations will need to be understood before any recommendations can be made.
- Depth to groundwater table can be mapped across space and time in low-lying areas with acceptable accuracy (± 30 cm). However only when the following assumptions are met: (i) surface water is abundant and visible from the aerial platforms; (ii) surface water is tightly linked with ground water; and (iii) the terrain is flat or gently sloping. This is a substantial development for groundwater monitoring.
- For remote conifer seedling detection, preliminary findings suggest it is unlikely that survival surveys (two to five years after treatment) will be feasible from piloted aircraft, given current camera technologies. However, establishment surveys (done eight to ten years after treatment) are expected to become feasible given the larger size of seedlings at that age. The preliminary results for automated seedling detection workflows applied on 5 cm/pixel orthoimagery, which constitutes an image resolution that can be feasibly obtained over larger tracts of land using piloted aircraft, suggest good performance on larger conifer seedlings (> 70 cm). However, these results rely on a short phenological window (spring and fall). Further testing is still ongoing.
- The use of artificial intelligence for conifer-seedling detection on centimetric drone imagery indicates reliable results for seedlings with crown diameters greater than 60 cm. More research will be undertaken in this area, but in the future it should be feasible to use convolutional neural networks for automated establishment surveys on sites more than five years after treatment/regeneration, where seedlings are sufficiently large for reliable detection.
- Preliminary analysis on automated height estimation of conifer seedlings suggest that this can be performed with high-resolution (finer than 2.5 cm/pixel resolution) drone imagery with a minimal error of 30 cm, suggesting that seedlings smaller than 60 cm cannot be estimated reliably. More research is needed to assess the accuracy of estimating seedling height at piloted aircraft imagery at resolutions 5 cm/pixel and coarser.

Soils and Ecohydrology

- Simplification of microtopographic complexity and the creation of depressions along seismic lines can persist decades after initial disturbance, with some differences between peatland ecosites. This underscores the need for ecosite-specific restoration of topographic complexity. The importance of microtopography for tree regeneration on seismic lines remains an important question for reforestation of these disturbances and thus long-term recovery of habitat for species dependent on undisturbed peatlands.
- A better understanding of the microclimatic variables affecting tree growth and establishment on seismic lines can help guide restoration efforts. Preliminary findings for poor-mesic conifer forest ecosites suggest that seismic-line width and orientation affect abiotic factors within the linear disturbance, and up to 10 m into the adjacent forest – with patterns in tree regeneration mostly relating to local patterns of light associated with orientation and width of these linear disturbances. This suggests light availability on lines is an important limiting factor for regeneration.
- Preliminary work suggests that the removal of vegetation and the compaction of soil following seismic line disturbance appears to significantly impact soil physical and chemical properties including greater bulk density,

higher moisture content, greater organic matter loss and changes in nutrient availability. Future work will investigate links between changes in soil properties and vegetation recovery.

- Total nitrogen in the peat may be higher on seismic lines, and changes in stable nitrogen isotopes indicate altered processes. Preliminary findings also show that total phosphorus does not seem to change on seismic lines. Different plant species are responding to these changes in different ways with conifers responding the most poorly. Potential competitive advantages of species such as Labrador tea may help explain the lack of desired conifer recovery.
- Preliminary insights deem pristine peatlands still to be the best-case scenario in terms of carbon exchange. Carbon loss from soil and changes to rates of carbon exchange can likely be reduced by minimizing soil disturbance (e.g., reducing compaction through use of lighter machinery or cutting lines by hand).

Sensor Networks

- Low-cost, long-range, low-power IoT networks, such as LoRAWAN, have matured significantly in the past year. Since the first year of the project researchers have pioneered the development of environmental sensing with LoRAWAN. At that time there were no suitable commercial products available for purchasing and testing. However, in 2019 researchers found commercial solutions are much more widely available and mature.
- A serverless solution for IoT devices, such as AWS IoT Core, is more mature. This solution enables the research team to upgrade their architectural design and it is also more scalable and reliable.
- Autonomous recording units (ARUs) can be used to determine wildlife singing locations, based on time of arrival differences of songs to an array of microphones by means of sound triangulation. This allows for precise location of where animals are spending their time and exactly what elements influence whether an animal will or will not use an energy sector footprint.
- Latest insights suggest that “sound truncation” can be used instead of “sound triangulation” to affordably assess how birds react to disturbances.

Ecology

- Forest birds are responding positively to increasing tree and shrub cover growing on well pads and seismic lines in aspen forest. This suggests that practices being implemented to facilitate more rapid growth of trees and shrubs by active restoration are likely to be an effective strategy for recovering these habitats for forest bird species. Which reclamation practices will facilitate the fastest recovery from a bird’s perspective requires more research. As well, most research on recovery of oil sands footprints using birds as indicators has taken place in upland forests dominated by aspen. Work is needed in wetlands and other conifer dominated uplands to confirm the generality of the patterns observed to date.
- Preliminary insights gained so far suggest that Canada warblers make use of seismic lines once the vegetation reaches a certain height and density. Wildfires promoted natural regeneration in bogs and poor mesic sites, but not in fens.
- Mechanical site preparation (mounding and ripping) on seismic lines increased tree density on these treated lines when compared to untreated lines – despite averaging 3.8 years since treatment versus 22 years since disturbance for untreated sites.

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Prioritizing Zones for Caribou Habitat Restoration in the Canada's Oil Sands Innovation Alliance (COSIA) Area. Version 3.0

COSIA Project Number: LE0049

Research Provider: Alberta Biodiversity Monitoring Institute (ABMI)

Industry Champion: Cenovus Energy Inc.

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

Status: Year 1 of 1

PROJECT SUMMARY

Boreal caribou populations are declining across Alberta and much of their Canadian range. A key factor causing this decline is habitat change from industrial exploration and development. Habitat restoration has the potential to play a major role in the recovery of boreal caribou populations. The restoration of linear features associated with industrial development is likely to be a primary component of Range Plans for most caribou ranges in Alberta. Linear features are human footprint features such as seismic lines, trails, roads, pipelines, powerlines, railways and highways. Temporary linear features such as seismic lines and trails are candidates for habitat restoration; empirical evidence from the boreal forest indicates that vegetation recovery on many legacy linear features is unlikely to occur without active restoration.

The overarching goal of this project is to provide a tool to help guide where to prioritize habitat restoration to benefit caribou in a cost-effective manner, while maintaining resource development on a shared landscape. Not all parts of caribou range are equally important to caribou, therefore prioritizing seismic line restoration in areas of higher value habitat may have a greater conservation benefit. While the Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada (Environment Canada 2012) considers all parts of caribou range to be critical habitat, prioritizing restoration in areas of high use provides the most immediate conservation benefit to caribou.

Previous versions of this project incorporated current and future industrial disturbance by precluding caribou habitat restoration within boundaries for operating, approved, applied for and announced projects shown on the Government of Alberta's Oil Sands Information Portal (OSIP) website. Version 3.0 updates OSIP boundaries with more recent information, and explicitly addresses the implications of forest harvest activities and scheduling on habitat restoration.

An objective of this project was to prioritize townships for the restoration of linear features within five caribou ranges in northeast Alberta: Cold Lake, East Side of the Athabasca River (ESAR), Red Earth, Richardson and West Side of the Athabasca River (WSAR). In earlier versions of this work (1.0 and 2.0), each township's priority was based on the potential increase in undisturbed caribou habitat that could be achieved through linear feature restoration while accounting for both the restoration cost and the potential for future resource development. Version 3.0 builds upon this work, introducing four additional objectives:

1. Incorporate caribou habitat value into township-level prioritization.
2. Integrate restoration with predicted future industrial disturbance, including both energy and forestry.
3. Consider decision-support guidance at multiple spatial scales, from regional, to township-level, to individual lines, to specific sites along individual lines, in consideration of operational restoration planning, logistics and treatment requirements.
4. Include additional collaborators and stakeholders to broaden the scope of the analysis and ensure relevance of the project outcomes.

To date, COSIA's prioritization efforts have focused at the township level, which addresses the need for operational economies of scale and creation of relatively large areas of biophysical intactness. However, effective and efficient restoration planning must also incorporate considerations at multiple spatial scales. Prioritization guidance at the landscape, and alternatively the sub-township scale, is therefore included in this iteration.

Lastly, to maximize the relevance and endorsement of the Prioritization 3.0 project outcomes, the technical work was guided by a multi-stakeholder advisory committee comprised of COSIA and its member companies, other energy sector companies, the forestry sector, the Government of Alberta and the research community.

PROGRESS AND ACHIEVEMENTS

Caribou telemetry data obtained from the Government of Alberta was used to create a range-level index of caribou use (Figure 1). Caribou-use intensity was then incorporated into the prioritization method used in Version 2.0 resulting in the zones presented in Figure 2.

For ease of interpretation and conceptual purposes, restoration opportunities were grouped into five priority zones of equivalent area. Restoring all temporary footprint types dramatically improves the disturbance state of all caribou ranges (Table 1). Under this scenario all five caribou ranges meet the 35% disturbance target. This scenario is operationally relevant, as current approaches to restoration require treating all linear features within a project area, whether classified as legacy seismic or not.

Table 1: The change in percent (%) disturbance (excluding fire) as restoration progresses from Zone 1 through Zone 5 resulting from restoring seismic lines and temporary features, reporting both ABMI 2017 and Environment and Climate Change Canada (ECCC)-calibrated disturbance levels. Any area within 2016 OSIP boundaries (operating, approved, applied for and announced projects, buffered by 500 m), are considered disturbed.

	% Disturbance Remaining (Excluding Fire, Including Restoring Temporary Features)											
	Current % Disturbed		Zone 1 Restored		Zones 1-2 Restored		Zones 1-3 Restored		Zones 1-4 Restored		Zones 1-5 Restored	
Range	**ABMI**	**ECCC**	**ABMI**	**ECCC**	**ABMI**	**ECCC**	**ABMI**	**ECCC**	**ABMI**	**ECCC**	**ABMI**	**ECCC**
Red Earth	68.0	47.1	56.1	38.4	41.5	27.7	26.0	16.4	13.4	7.1	8.8	3.8
Richardson	35.9	22.8	30.1	17.7	24.4	12.5	18.4	7.2	8.2	0.0	6.7	0.0
WSAR	85.5	69.8	72.2	57.6	57.8	44.5	45.7	33.4	33.8	22.5	24.6	14.2
ESAR	88.6	77.3	71.7	59.9	57.9	45.6	45.5	32.9	33.0	19.9	27.1	13.9
Cold Lake	86.8	72.3	71.5	55.6	56.6	39.4	46.9	28.8	38.4	19.6	34.7	15.5

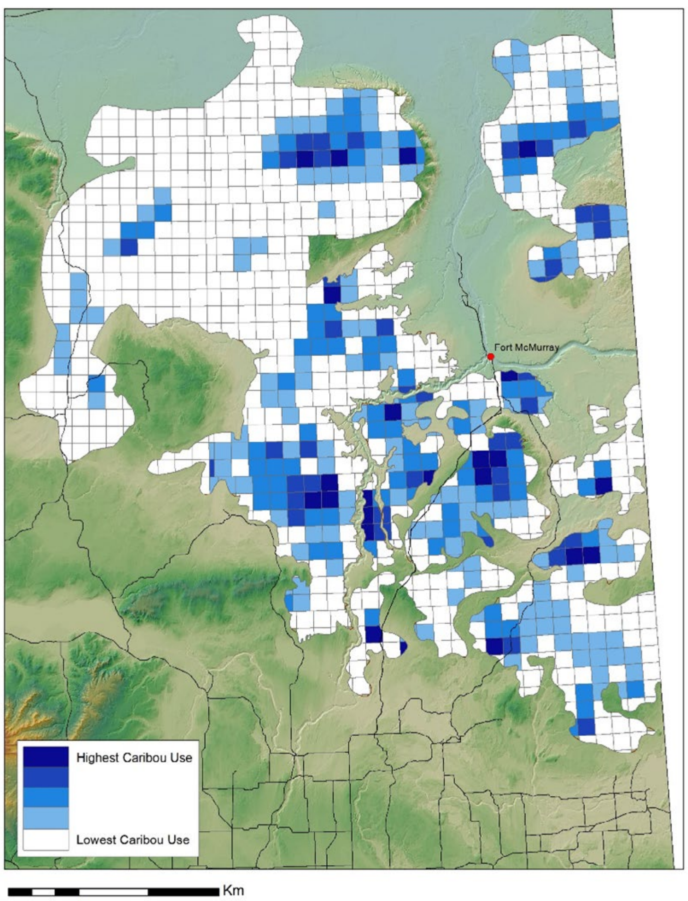

Figure 1: Distribution of caribou-use index at the township level, based on telemetry data from GPS-collared caribou. This map does not provide information regarding other aspects of the prioritization process, and instead focuses on how caribou habitat value will be incorporated into that process.

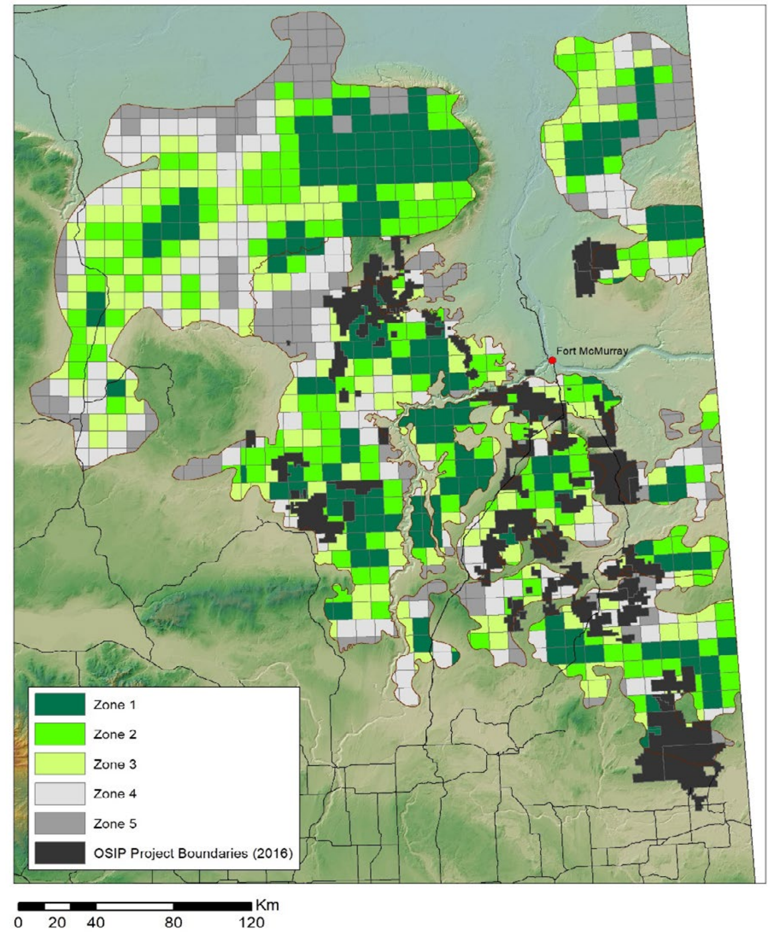

Figure 2: Restoration priority zones incorporating cost-efficiency, potential future resource value and caribou space use. Townships are ranked into priority zones for restoration, with Zone 1 being highest priority and Zone 5 (dark grey) the lowest. Any area within 2016 OSIP boundaries (operating, approved, applied for and announced projects) are considered non-candidate areas for restoration (black).

The development of suggested considerations and operational guidance at various spatial scales was an objective of Version 3.0. Multi-scalar consideration and decision support was developed for the regional, project level and feature scales. In addition, considerations for coordination with forest industry activity were also developed. Multi-scalar considerations are summarized in Figure 3, and sources of information for decision support are summarized in Table 2.

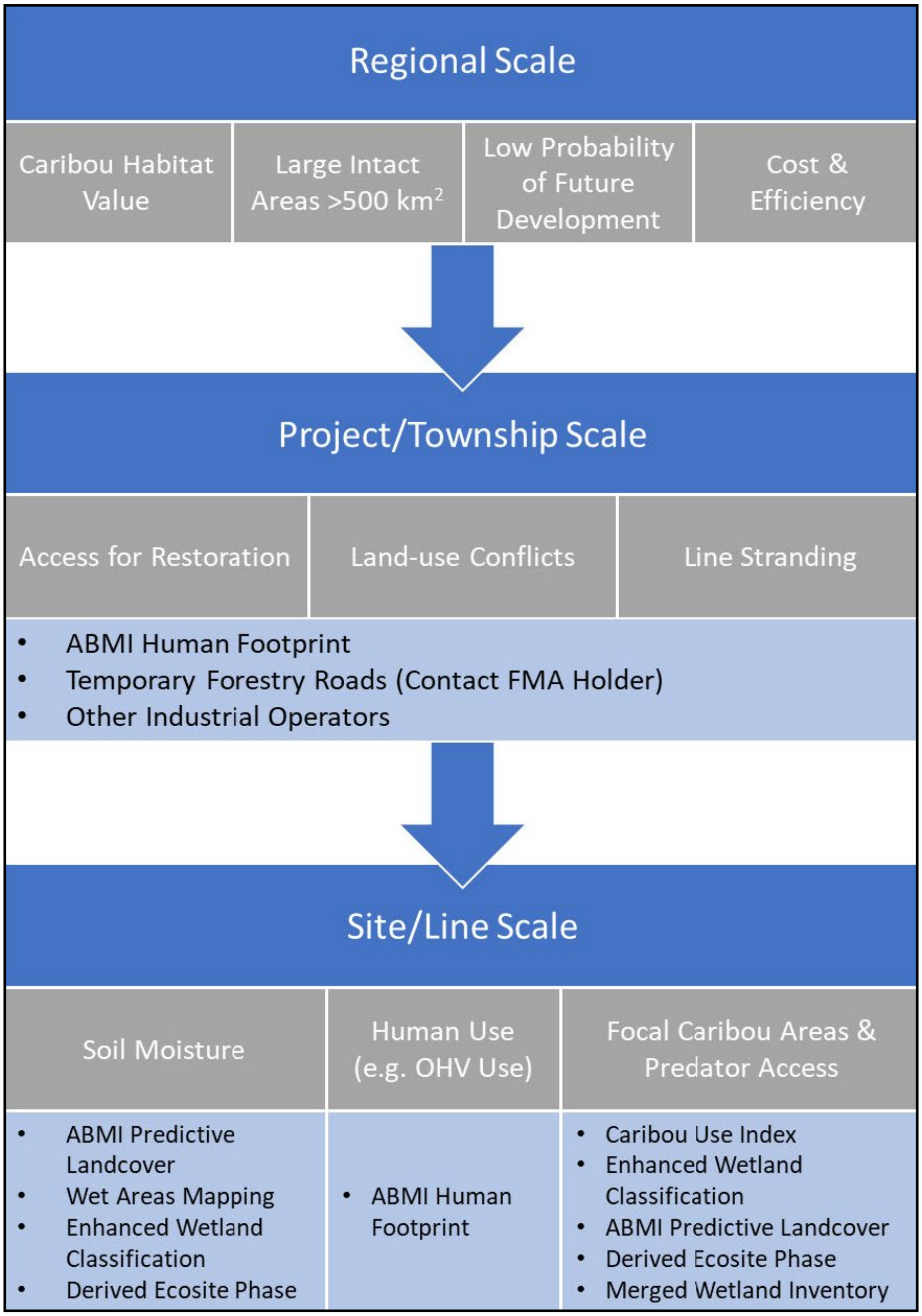

Figure 3: Multi-scale restoration considerations and key data sources for decision support.

Table 2: Potential data sources for multi-scale restoration decision support.

Dataset	Consideration(s) Addressed	Comments, Advantages and Limitations
ABMI Human Footprint	Access for Restoration Line Stranding Recreational Human Use	Most comprehensive dataset available. Publicly available province-wide. Updated every 1-2 years. Does not include all temporary features such as for temporary forestry roads. Due to a data-sharing issue, current version does not include pipelines. Pipeline layer available from AER until issue is resolved.
Temporary Forestry Roads	Access for Restoration Line Stranding	Contact FMA holder or other forestry operators for availability.
ABMI Predictive Landcover	Soil Moisture Focal Caribou Areas (Peatland Complexes)	Publicly available province-wide (DeLancey et al. 2019). Simplified landcover categories, and soil moisture is not directly estimated. Wet Areas Mapping or Enhanced Wetland Classification are preferred if available.
Enhanced Wetland Classification (EWC)	Soil Moisture Focal Caribou Areas (Peatland Complexes)	Developed by Ducks Unlimited Canada (DUC) in collaboration with forest industry partners. Not available in all areas. Contact DUC for information.
Alberta Merged Wetland Inventory	Focal Caribou Areas (Peatland Complexes)	Wetland inventory maintained by the Government of Alberta, created by merging 35 wetland inventories into a single layer with province-wide coverage.
Derived Ecosite Phase	Soil Moisture Focal Caribou Areas (Peatland Complexes)	Predicted ecosite layer developed by the Government of Alberta, based on Alberta Vegetation Inventory and Light Detection and Ranging (LiDAR)-derived datasets. Available from Government of Alberta.
Wet Areas Mapping (WAM)	Soil Moisture	Not available in all areas. Available from Government of Alberta.

LESSONS LEARNED

Including fire disturbances less than 40 years old (Environment Canada 2012) greatly increases the levels of disturbed habitat observed, such that none of the ranges reach the 35% disturbance threshold even after restoring all five zones. These existing fire disturbances will, by ECCC definition, recover as they reach age 40 and no longer be considered disturbed. However, new fires will continue to occur into the future. Therefore, results presented provide an approximate assessment of the potential effect of restoration and recognize that the amount and distribution of future fires are unknown and will be a major influence on caribou habitat.

Restoring all temporary footprint types dramatically improves the disturbance state of all caribou ranges (Table 1). Under this scenario all five caribou ranges meet the 35% disturbance target. This scenario is operationally relevant since current approaches to restoration treat all linear features within a project area, whether classified as legacy seismic or not. However, when fire is considered, only WSAR reaches the 35% disturbance target.

With respect to multiscalar decision support, a key learning relates to the required size of contiguous restoration areas. Since the ecologically relevant scale for restoring “large tracts” of caribou habitat is the scale of a wolf pack territory, at least 500 km^2 to 1,000 km^2 (Spangenberg et al. 2019), this translates to areas comprising ≥ five townships to 10 townships. Related to the importance of large contiguous areas are the presence of any designated protected areas such as provincial or national parks. Such protected areas may or may not be highly used by caribou, but they do represent areas with near-zero probability of future development.

At the sub-township or project scale, the primary prioritization considerations relate to current and future site access. Access opportunities and restrictions have a significant impact on restoration project cost. Legacy seismic lines serve as important access routes to other seismic lines that require restoration; therefore, a “back to front” approach must be used so as to not strand lines requiring active treatment.

Caribou habitat restoration prioritization has previously taken into consideration current and potential energy development, but this is a shared working landscape with other resource industries, in particular the forestry industry. While forestry operations within high-value caribou habitat (i.e., peatlands) in caribou ranges are limited by the lack of merchantable timber in these areas, there exists a possibility to align linear feature restoration in peatlands adjacent to timber harvest while forestry access is in place. The opportunities for restoration efficiency, and value to caribou, by pairing restoration adjacent to harvest areas will be highly dependent on the overlap of harvest cutblocks, caribou use and seismic lines. No general conclusions or single rule-set can capture this variability, and opportunities for coordinated restoration will need to be assessed on a case-by-case basis.

At the feature or site scale, consideration of forest regeneration limiting factors, caribou ecology and predator-prey dynamics should play a role in determining appropriate treatment types or intensities. In terms of caribou ecology, the largest risk to caribou occurs where upland areas transition into large peat complexes that are highly used by caribou; therefore, these areas may be prioritized for intensive restoration including mechanical treatment for surface roughness or “functional restoration”. Functional restoration measures include line-blocking via bending tree stems across the line, intensive soil preparation by mounding, spreading logs or other woody debris, creating berms or installing fencing. Ideally, reducing movement efficiency can also be combined with reforestation treatments.

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RESEARCH TEAM AND COLLABORATORS

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Amphibious Restoration Equipment Efficacy Assessment

COSIA Project Number: LJ0329

Research Provider: Fuse Consulting Ltd.

Industry Champion: Cenovus Energy Inc.

Industry Collaborators: Canadian Natural, ConocoPhillips Canada Resources Corp., Devon Canada Corporation

Status: Year 3 of 10

PROJECT SUMMARY

Oil and gas activity, and the resultant forest disturbances in northern Alberta, contribute to forest fragmentation and habitat degradation (Environment Canada 2012; Chung 2014; Struzik 2011). Recent disturbance area measurements for the oil sands region total 125,185 ha for seismic lines and 65,919 ha for wellsites (Canada's Oil Sands Innovation Alliance [COSIA] 2013). Legacy exploration sites commonly exhibit arrested succession and require treatment to return to forest cover (Iqbal et al., 2014). These treatments include a focused effort on increasing the survival and growth rate of conifers and utilizing techniques such as soil mounding, which have been shown to be successful.

Linear restoration (or linear deactivation) is a topic of focused investigation with the objective of alleviating successional stagnation, restoring habitat and lessening forest fragmentation. Currently, restoration treatments are primarily applied under frozen conditions using a tracked excavator (track-hoe). The combination of resistance due to frost, as well as the intensive (although proven effective) requirements for mounding and/or screefing techniques, limits productivity. Winter treatment using these techniques is slow and costly (> $10,000 per km), and the industrial capacity for this approach is limited. This is due to the short winter season and the lack of available trained workers relative to the vast number of legacy features that require treatment.

Possible alternatives to winter mounding and screefing, and a description of associated work that has been previously performed, include:

1. Treatment during non-frozen conditions:
    - This was successfully piloted as a COSIA joint industry project in October of 2015 and 2016.
2. Use of a mechanical implement, pulled by a suitable tractor:
    - Amphibious construction equipment was used successfully in a pilot-scale trial (2016) which demonstrated the possibility of a twofold increase in productivity. Similarly, a tow-behind implement was successfully trialled in 2016 on upland sites. While data was collected on the productivity and performance of the equipment, this project revisits these treatment sites to fully evaluate whether the desired ecological outcomes have been achieved. Results will inform upcoming operational implementation work and will help test and verify the effectiveness of more progressive restoration treatments.

3. Use of a device for transplanting trees (a tree spade):
    - Transplanting was tested on a trial basis during the establishment of treatments for the LiDea project (Cenovus 2016), and there was evidence of tree survival in the following season. Due to the reduction of shade created when legacy linear features were created, there is a higher density of juvenile conifers along the edges of lines. Therefore, transplanting may be a defensible means of reversing the impact of the initial disturbance. Successful transplanting of these stems from sources along the line edges of the adjacent forest onto the legacy feature may constitute a restoration treatment with immediate results.

The 2016 amphibious equipment joint industry project tested a tree-spade transplanting implement to evaluate its productivity and operational performance. This trial will evaluate the ecological outcomes since this information is also important for determining the potential utility of this technique for future restoration work.

The objectives of this project are to:

1. Evaluate the ecological outcomes from the use of various amphibious and low-ground pressure excavators on both upland and lowland habitats, including regeneration height, density and health;
2. Assess the ecological outcomes from the use of a tow-behind implement on upland sites, including regeneration height, density and health; and
3. Evaluate the ecological outcomes from the use of a tree-spade implement and the resulting survival and growth of transplanted trees.

PROGRESS AND ACHIEVEMENTS

This monitoring project was designed to assess the performance of restoration treatments three years after application. The monitoring looked at a series of sites treated using a range of alternative restoration equipment:

1. **Lowland Amphibious:** Lowland black spruce/tamarack site, treated by the amphibious excavator (conventional excavator mounted on oversized pontooned tracks)
2. **Upland Dry Amphibious:** Upland dry pine site, treated by the amphibious excavator
3. **Upland Nodwell:** Upland mixedwood site, treated by the Nodwell excavator
4. **Upland Shark Fin Drum:** Upland jack pine mixedwood site, treated with a tow-behind Shark Fin Drum
5. **Lowland Tree Spade:** Lowland black spruce site, treated with a tree spade
6. **Control:** Lowland black spruce and upland pine site, untreated control

Key findings related to restoration performance on this range of sites are outlined below.

Survival Assessment Results

Survival assessment is one of the main criteria used in the Provincial Restoration and Establishment Framework (Government of Alberta 2017). This assessment determines the percent survival of planted or seeded trees within restoration sites. Since the sites in this trial were planted in the summer, they would need to achieve a survival rate of 80% to pass the provincial survival assessment criteria.

Within this study, two out of four treatments met the survival assessment criteria (Upland Shark Fin Drum, Lowland Amphibious). Two sites that did not pass are the Upland Nodwell and the Upland Dry Amphibious sites. At the Upland Nodwell treatment, an average survival of 72% was observed despite there being a significant flush of natural regeneration on the site. In this case, planting on the top of the mounds and significant browsing by local wildlife resulted in lower survival of seedlings on this site. In the case of the Upland Dry Amphibious site: planters selected mounds instead of divots for the planting microsite; species selection was not well suited to the site (e.g., tamarack was planted on an upland pine site); and significant levels of browsing were observed. On a challenging site like the upland dry location, microsite selection and species selection are important to achieve the survival assessment criteria.

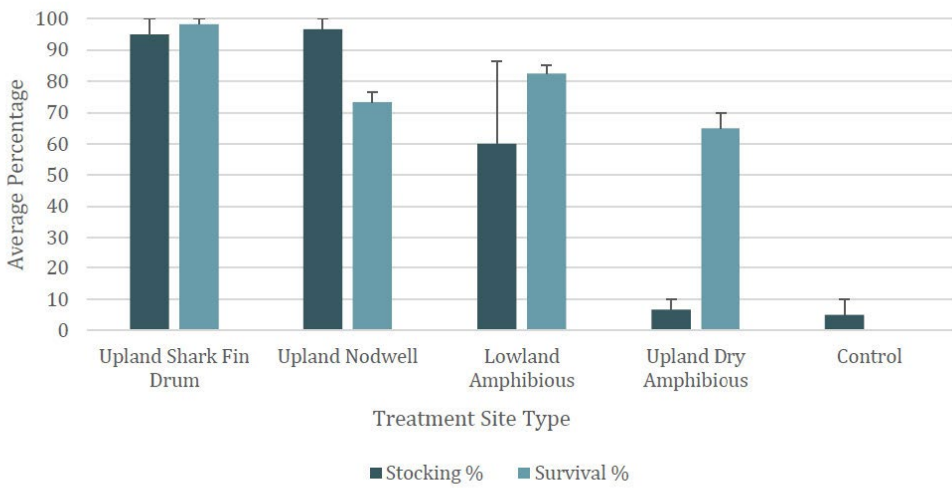

Figure 1: Average percentage stocking and survival within the belt transect for each of the treatment types.

Line-Use Results

Seismic line-use by wildlife is an important metric in evaluating restoration success and can help inform whether treatments have impacted travel efficiency. In the plots within this trial, line-use was either not detected or was restricted to a small game trail at the edge of the lines (two out of five treated sites).

Within all of the treated areas assessed in the monitoring project, there were low to medium amounts of coarse woody material (CWM) applied to the lines. These woody materials remained elevated above the ground surface over the course of three years between initial treatment and this monitoring project. Fuse Consulting observed that sites with applied CWM were difficult to move through and significantly affected worker mobility between plots. While no direct linkage can be made between the presence of woody materials and wildlife use of the lines, the relative absence of signs of use and Fuse Consulting's experience moving on the lines are important indicators that these treatments may be having an impact.

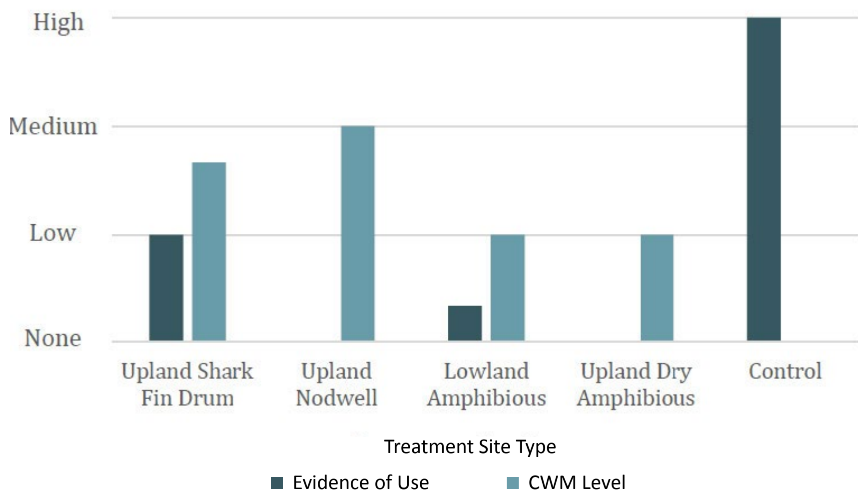

Figure 2: Evidence of wildlife use and coarse woody material (CWM) levels three years after restoration treatment.

Persistence of Tipped Trees Over Lines

A core observation during this monitoring trial was the relative persistence of tipped trees – a restoration treatment where trees were intentionally tipped by either the Nodwell excavator or amphibious excavator – on the seismic lines. Prior winter treatment programs have led to the understanding that trees on these sites quickly become flattened by snow press. All sites monitored for this program had tipped trees which remained significantly elevated above the ground surface, and in some cases trees were still alive and producing vegetation and cone crops. While winter treated sites were not a part of this monitoring program, anecdotal observations suggest that trees tipped during the summer months may have greater persistence and remain elevated for longer periods of time. This may be due to the fact that trees tipped on seismic lines in the summer experience less breakage (more likely to be tipped, than felled).

Figure 3: Upland jack pine site treated with a tow-behind Shark Fin Drum with woody materials applied via a Nodwell excavator. Directly after treatment (left) and three years after treatment (right).

Equipment Specific Observations

Amphibious Excavator

The amphibious excavator was tested on both an upland dry jack pine site (Upland Dry Amphibious) and a lowland black spruce site (Lowland Amphibious). The lowland black spruce site passed the survival assessment, while the upland dry jack pine site did not. However, it is important to note that this failure to reach the survival assessment was not linked to the specific equipment used, but rather the site conditions. The poor survival rate on the site is believed to be a result of a variety of factors including the upland dry jack pine stand having limited natural regeneration on the treated site, incompatible planting site selection and wildlife browsing resulting in significant mortality of planted trees.

All microsites created by the amphibious excavator persisted as expected following treatments and tipped trees in particular were still alive or elevated on the treated sites. Better microsite selection during planting, and the planting of appropriate tree species, likely would have increased the performance on the sites treated by the amphibious excavator. The low observed amounts of natural seeding within the upland dry pine site was surprising and suggests that applying pine seed on these sites to aid in regeneration may be required.

Nodwell Excavator

The upland site that was accessed for the upland Nodwell excavator monitoring (Upland Nodwell) was within a rich aspen spruce mixedwood forest. Not surprisingly, treatments on the seismic line resulted in a significant flush of natural regeneration on the site. While survival of planted seedlings ended up being lower on this site due to browsing and natural senescence, the significant volume of natural regeneration ensured that the lines were well stocked on both sides of the line.

Microsites created by the Nodwell excavator showed good persistence, which was in line with expectations for these site types. Tipped trees on the sites treated by the Nodwell excavator also showed good persistence, with many trees remaining elevated and some of the trees still alive following treatments.

It is clear from the trial that the Nodwell excavator performed as expected and aided in setting the treated site on a path towards restoration.

Shark Fin Drum

The Shark Fin Drum was tested on an upland mixed pine forest with relatively rich soil conditions (Upland Shark Fin Drum). At the time of treatment application, prior concerns about whether the microsites would persist were documented. Instead, strong evidence was found that the microsites persisted and assisted with the regeneration on the treated site. Monitored plots showed that the natural regeneration of trees and shrubs was strongly associated with the microsites created by the Shark Fin Drum.

Tree tipping was also performed by the Nodwell excavator on these sites and many trees remained elevated on the site and in some cases trees were still alive and producing both leaves and needles.

The Shark Fin Drum performed better than was anticipated (based on the previous trial) and warrants consideration for testing on additional site types. The potential treatment efficiency of this implement, combined with the clear ability to create microsites on a richer upland site, shows great promise. A challenge will be to determine whether the implement can perform equivalently on more challenging site types such as a dry upland jack pine site.

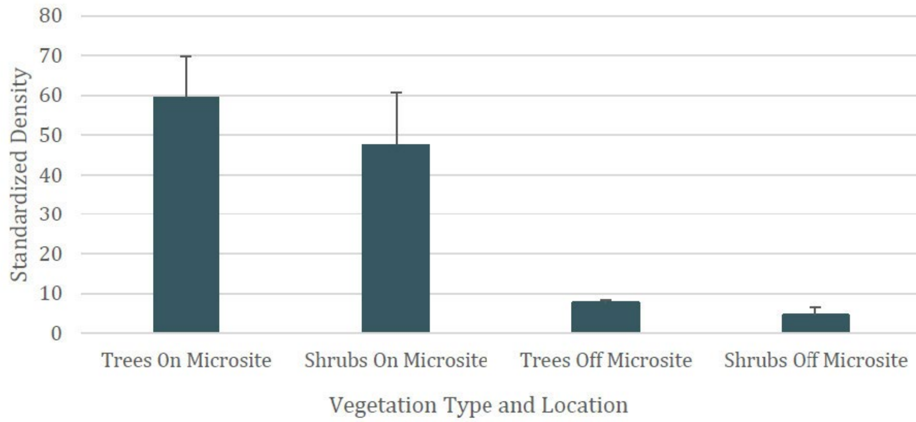

Figure 4: Trees and shrubs found on and off microsites created by the Shark Fin Drum. Data is standardized for area of microsites within a plot (i.e., 14% coverage).

Tree Spade

The tree spade was tested on a lowland black spruce site (Lowland Tree Spade). In a previous study conducted by Fuse Consulting, concerns were noted about the ability of trees to persist on the site and also with the potential drowning of roots within the tree spade plugs.

Three years post-treatment, 45% of the transplanted trees were still alive, 35% were standing but dead and 20% had died and fallen over. Survival of transplanted trees appeared to be higher for smaller trees. There was still a strong visual barrier created on the line immediately following treatment and this visual barrier persisted three years later (Figure 5). While there are still wildlife movement concerns due to the relative lack of woody materials on the treated site, the persistence of trees three years after treatment exceeded expectations.

Figure 5: Lowland black spruce and tamarack site treated using a tree spade. Photos are directly after treatment (left) and three years after treatment (right).

Figure 6: Example of a transplant that contained many smaller trees and showed better survival.

LESSONS LEARNED

1. **There was no obvious difference between equipment in this trial.**

   One of the core objectives of this monitoring assessment was to determine whether there were any noticeable concerns with the restoration outcomes from any of the equipment used in the trials. In all cases, the equipment performed as expected and created conditions that set the sites on a path towards successful restoration over time. While the upland dry jack pine site treated with the amphibious excavator did not perform as well, this was not deemed to be related to the equipment. Instead, this was attributed to the monitoring plots being located on more challenging site types (e.g., upland dry jack pine site).

   With respect to the tree spade tested in this trial, more experimentation should be completed with the objective of improving survival and efficacy of treatments. Application of stem bending on sites treated with the tree spade should be considered to aid in addressing the movement efficiency concerns of caribou predators and primary prey.

2. **Shark Fin Drum created significant regeneration.**

   Results from this monitoring project showed the microsites created by the Shark Fin Drum created a significant flush of natural regeneration on the treated sites. Paired with the tipping of trees with the Nodwell excavator, this site performed better than expected.

   The efficiency of the Shark Fin Drum, paired with its impact on the site, suggests that a larger trial is warranted for this tow-behind implement. Specifically, it will be important to test how well the implement performs on more challenging site types, including upland dry pine sites where regeneration potential may be more limited compared to the site tested in this trial. However, any concerns about microsite persistence were relieved on the specific site types tested in this trial. The use of a Shark Fin Drum, or a similar tow-behind implement, warrants further consideration.

3. **Seed availability appeared limited on some sites.**

   Within some of the trial sites, we noted a relative absence of natural ingress through the natural regeneration of acceptable tree species. This was particularly noticeable on the upland dry jack pine site, where very low natural regeneration densities were observed. On sites such as this, a trial testing the application of seed to these sites, or a higher planting density, may be warranted in order to achieve restoration goals.

4. **Planting microsite and species selection could be improved.**

   While the topic of planting microsites and species selection was not a focus of this trial, it does warrant some discussion as a general observation. Poor species and microsite selection on the upland dry jack pine site was noted in areas where planters selected mounds instead of divots for microsites, and where tamarack was planted in a challenging upland dry site. Although only a small portion of the site types was sampled, and the location of the samples may have corresponded with the end of a planting stretch where species availability was limited, it should be noted that the poor performance on this challenging site type would result in it failing to pass the provincial survival assessment criteria. Heavy wildlife browsing on seedlings in this site type also strongly contributed to some of the survival concerns observed.

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PRESENTATIONS AND PUBLICATIONS

No presentation or publications available for 2019.

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Principal Investigator: Maria Strack

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Restoration Innovation Roadmap Phase 2

COSIA Project Number: LE0059

Research Provider: Fuse Consulting Ltd.

Industry Champion: Imperial

Industry Collaborators: Canadian Natural, Cenovus Energy Inc., ConocoPhillips Canada Resources Corp., Devon Canada Corporation, Suncor Energy Inc., Syncrude Canada Ltd., Teck Resources Limited, Alberta Innovates – Clean Energy

Status: Complete

PROJECT SUMMARY

Restoration of legacy seismic lines within woodland caribou habitat has received considerable attention over the past several years. Restoration programs have successfully transitioned from testing techniques at an experimental scale, to delivering operational scale programs of up to 350 linear kilometres per year. As restoration programs shift in scale, one of the major challenges has been the cost of treatments. Programs regularly cite costs of $8,000 to $16,000 per kilometre.

To help guide the identification of innovative opportunities for linear restoration, a series of organizations came together to fund a two-phase Restoration Innovation Roadmap. The first phase, funded by the Regional Industry Caribou Collaboration (RICC), focused on identifying key learnings to date to facilitate an adaptive management process. The second phase, funded by Canada's Oil Sands Innovation Alliance (COSIA) and Alberta Innovates – Clean Energy, focused on identifying a series of new technologies and techniques that could significantly increase the efficiency of restoration treatments, while maintaining or improving the ecological effectiveness.

Phase 2 of the Restoration Innovation Roadmap project had three core goals:

1. To identify up to 30 innovations that could help improve the efficiency and effectiveness of linear restoration within woodland caribou ranges;
2. To bring together entrepreneurs and innovators to raise awareness about current experience and future opportunities in the field of restoration; and
3. To evaluate whether an innovation ecosystem currently exists for linear restoration, and what is needed in the future to further foster such an ecosystem.

PROGRESS AND ACHIEVEMENTS

This second phase of the Restoration Innovation Roadmap led to the identification of 23 potential technologies or techniques that could reduce the costs of restoration treatment delivery while maintaining or improving ecological effectiveness. To determine which innovations were selected for inclusion in the final report, two key factors were considered: the scale of the potential impact on efficiency, and the likelihood of the innovation realizing a step change in restoration practices. Each technology was summarized using the following subsections:

- Why this innovation should be used;
- Current context/where it is currently applied;
- Considerations and limitations;
- Health and safety; and
- Likelihood to reduce costs.

The innovations range from existing technologies, like alternate excavator bucket designs that could be applied immediately, to forward-looking innovations such as airships which would require considerable time to develop but could transform the way in which restoration programs are delivered.

Of these 23 innovations, the authors determined their top ranked opportunities. Five technologies or techniques that could be applied in the near term included:

1. Implementing virtual simulators to reduce training costs and increase productivity;
2. Using the Hummock Transfer Technique to potentially avoid the costs of tree planting;
3. Developing a multi-function machine to treat wetlands and uplands more efficiently;
4. Planting shrubs within wetlands to potentially avoid the cost of site preparation; and
5. Adopting alternative equipment for treating uplands, such as tow-behind implements or an excavator RipPlow.

Three technologies that are forward-looking, but would require substantially more research and development in order to be applied in the long term, included:

1. Airships to transport people and equipment, and to serve as a mobile camp;
2. Autonomous equipment operations to facilitate increased productivity; and
3. The use of explosives to create surface roughness and apply woody materials.

The final step in the Restoration Innovation Roadmap project was the evaluation of opportunities to create an innovation ecosystem for restoration. Through interviews with innovators and funders, the following opportunities emerged:

- Creating a test site to showcase innovations;
- Increasing communication about funding opportunities;
- Reducing the administrative burden of funding applications; and
- Creating an X-Prize challenge for restoration.

LESSONS LEARNED

One of the key observations from this project was that there are no "silver bullets" that promise to address all of the challenges and opportunities associated with restoration. Rather, the core observation from this study is that the cumulative impact of adopting multiple innovations could lead to a significant change in the way restoration programs could be delivered in the future. For example, adopting the use of virtual simulators to improve training for operators could increase the productivity of treatment delivery, while adopting alternative access vehicles instead of Argos could increase the time available for delivering restoration treatments. In addition, the Hummock Transfer Technique – a process by which intact peat hummocks are placed on treated lines – could eliminate the need to plant trees on difficult wetland sites.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Pyper, M., K. Broadley, L. Neufeld, A. Saxena, R. Harding. 2019. Improving efficiency and effectiveness of caribou habitat restoration through an innovation roadmap. Alberta Chapter of the Wildlife Society Annual General Meeting. Canmore, AB. March 22-24.

Reports & Other Publications

Fuse Consulting Ltd. 2019. Restoration Innovation Roadmap Phase 2: A summary of opportunities to advance innovation for linear restoration within woodland caribou habitat. Prepared for COSIA and Alberta Innovates – Clean Energy. 83 pages.

RESEARCH TEAM AND COLLABORATORS

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Principal Investigator: Matthew Pyper

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Jesse Tigner	SwampDonkey	Owner		
Ken Byrne	FPInnovations	Manager, Resource Management		

Research Collaborators: Alberta Innovates – Clean Energy

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 4 of 4

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 sequestered carbon. Maintaining carbon storage in the oil sands and returning the land to its similar or equivalent functional capability is an important responsibility for the oil sands industry. In addition, Suncor Energy Inc. (Suncor) announced a greenhouse gas (GHG) goal that aims to reduce the emission intensity of the production of its oil and petroleum products by 30% by 2030.

The goal of this study was to conduct a comprehensive carbon cycle analysis on reclamation-associated activities and to identify opportunities for increasing carbon stock. A Suncor project was used to conduct a reclamation carbon cycle assessment (LCA) of an oil sands mine initially and then the scope was extended to include an in situ asset.

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 the environmental impacts associated with all the stages of a system from beginning to end use. It followed the International Organization for Standardization (ISO) 14040:2006 standard (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation) 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), 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.

Phase 5: Apply the methodology and learnings from previous phases to conduct an assessment of an in situ asset.

PROGRESS AND ACHIEVEMENTS

All phases of this study have been completed. Results from Phases 1 through 4 were summarized in the 2018 COSIA Land EPA - Mine Research Report and presented at the COSIA Innovation Summit in 2018 and 2019.

The objective of Phase 5 was to apply the same methodology used in Phases 1 through 4 (at an oil sands mine) to a Suncor in situ asset to assess how carbon (C) stocks and fluxes might be impacted by Suncor's SAGD operations and to help develop a better reclamation and strategic plan to achieve sustainability goals.

A forest carbon (C) life-cycle assessment (LCA) of the disturbance and reclamation of a Suncor in situ asset was conducted in 2019, using the same model developed from Phases 1 through 4.

The majority of areas (90%) within the Suncor in situ asset boundary remain (anthropogenically) "undisturbed", while the areas that are disturbed are divided into two broad categories: "vegetation disturbed" (5%), where trees and other vegetation are cleared, but the soil is left in place; and "soil disturbed" (5%), where trees and other vegetation are cleared and the soil is excavated and stockpiled for later use in reclamation.

Net biome productivity(NBP) – similar to net ecosystem productivity (NEP = NPP [net primary productivity] – Rh [heterotrophic respiration]), but also accounts for emissions originating from disturbances – is expected to be small (negative net emissions of C to the atmosphere, or positive net uptake of C by trees, depending on the scenario) over the lifespan of the project, but in a wildfire scenario a much larger negative NBP is expected.

The base case results show equipment fuel used for the construction of all of the in situ sites' clay pads and subsequent reclamation of the pads contributes 83% of the total operation fuel consumption. Pad removal and contouring during reclamation (38%) and original pad construction and general contouring (32%) are the largest consumers of fuel. Gravel placement and removal contribute another 6% and 7%, respectively.

To assess the impacts of model parameters, Sobol sensitivity analysis was conducted. Results indicated that one key model parameter, pad decompaction dozer productivity, contributed 47% of the fuel consumption uncertainty, and pad thickness accounted for another 23%.

LESSONS LEARNED

- The total estimated GHG released from land-altering activities over the course of the land use cycle at a Suncor in situ asset is equivalent to that of producing steam for six days by the operation of that asset.
- The largest source of GHG emissions from land-altering activities over the course of the land use cycle (does not include the daily in situ operation) comes from the energy expended during the reclamation phase.
- The greatest uncertainty for GHG emission estimates is from reclamation machinery productivity.
- A wildfire scenario is the only event that could cause significant carbon stock reduction on the project site.

LITERATURE CITED

ISO. 2006. ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework. Suncor. 2019. Report on Sustainability. https://sustainability.suncor.com/en/climate-change/ghg-goal (accessed Feb. 20, 2020). Suncor Energy Inc. Calgary, Alberta.

PRESENTATIONS AND PUBLICATIONS

Conference Presentations/Posters

Di Lullo, G. et al. 2018. Carbon Life Cycle Assessment of a Suncor Energy Inc. Oil Sands Reclamation Project. Poster presented at the COSIA Innovation Summit, Calgary, AB.

Di Lullo, G. et al, 2019. Carbon Life Cycle Assessment of a Suncor Energy Inc. Oil Sands Reclamation Project. The Oil Sands Innovation Summit. Calgary, Alberta

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