EMISSIONS REDUCTION ALBERTA (ERA) NON-CONFIDENTIAL FINAL OUTCOMES REPORT (FOR)

Linear Restoration Equipment Modernization and Deployment

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cenovus ENERGY

Project Details

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Name and information of Recipient contact:	Jason Barrie
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Additional Multimedia

A brief video developed by Fuse Consulting Ltd., which showcases the technology tested in this trial, is also available to support the content presented in this report.

Project Description for ERA Website:

Hundreds of thousands of kilometres of legacy seismic lines criss-cross Alberta's boreal forest, with important implications for carbon sequestration and species-at-risk. Over half of these lines have failed to regenerate naturally and require active restoration efforts including mechanical site preparation and tree planting to address site-limiting factors and allow trees to grow. However, standard site preparation methods using excavators are prohibitively expensive and time-consuming, making large-scale restoration efforts economically unfeasible. Treating sites may release carbon, often in the form of methane, or may stimulate long-term carbon sequestration through increased productivity within ecosystems. The combined opportunities for increased production efficiency, and carbon uptake within treated ecosystems, present an important opportunity for research and innovation in the context of emissions reduction.

The purpose of this project was to rapidly innovate novel restoration techniques by adapting forestry and farming technologies to the site conditions encountered during a restoration program. Our goal was to test the operational feasibility of these technologies and monitor the ecological efficacy of the treatments they delivered. In parallel, carbon monitoring of short-term and long-term ecosystem responses is enabling the full quantification of the carbon outcomes of restoration treatments, with a focus on lowland environments. The project culminated in the development of a purpose-built amphibious base mounted with a Bracke three-row mounder, which was able to access wetland sites, safely navigate water crossings, and treat lines in approximately 10–15% of the time of an excavator while producing mounds of near-comparable height.

The results of this trial have shown that several pull-behind farming implements can perform well on upland and mesic sites, while the Bracke has the versatility needed to successfully treat a wide range of site types. While the amphibious Bracke was only tested in lowland sites and in frozen conditions due to delays in obtaining the necessary equipment, preliminary results are extremely promising. Initial vegetation responses illustrate that all treatments were effective in stimulating vegetation recovery responses on lowland and upland site types and addressing moisture conditions on sites, which is often a key site limiting factor. Most treated sites are also showing increased leader growth of trees compared to untreated controls.

By opening the door to larger-scale restoration programs, the technology developed as part of this trial has the potential to dramatically improve environmental and greenhouse gas (GHG) outcomes in Alberta by accelerating the pace of linear restoration. Reforesting lines improves carbon sequestration, and the rapid treatment speed of the Bracke and other implements, including drawn or pull-behind implements, would directly result in a fraction of the emissions per kilometer than conventional methods. Such pull-behind methods are particularly promising as they use less fuel, cause less disturbance and create microsites for trees. Rapid and effective linear restoration could additionally benefit caribou conservation efforts in the long term by decreasing predation risk to this federally listed species.

While commercialization and mass-production of the technologies developed as part of this trial are not currently planned, the low awareness by industry highlights the need for incentives to increase demand for technological advancements. Nevertheless, the amphibious Bracke that was developed and trialed is currently slated for operational implementation by Cenovus in spring 2024. First Nations communities have also expressed an interest in adopting this technology to further their own restoration efforts, as have parties in the United States.

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1 Executive Summary

The historical construction of seismic lines in western boreal ecosystems of Canada has left a lasting imprint, disrupting soil, vegetation and typical forest succession pathways on a wide range of sites. While some mesic sites may recover naturally, the linear footprints have nevertheless increased forest fragmentation and altered wildlife dynamics, with important implications for many species of concern including boreal caribou. Although some sites may recover on their own, it is essential to acknowledge that active restoration efforts are necessary on certain sites to resolve site limiting factors and enable linear features to return to a forested state over time.

The restoration of legacy seismic lines represents a substantial conservation challenge, as there are many hundreds of thousands of kilometers requiring restoration, yet existing restoration methods are costly and extremely time-consuming. Restoring these lines not only addresses ecological constraints but may also help to conserve or increase carbon stocks by facilitating the growth of both planted and naturally regenerating trees in treated areas. This process also presents the opportunity to mitigate greenhouse gas (GHG) emissions through more efficient restoration methods and technology. In response to the challenge of restoring linear features in forested peatlands, mesic forests and upland forests, Cenovus initiated trials funded by Emissions Reduction Alberta (ERA) to explore innovative equipment and technologies to improve restoration efficiency and effectiveness.

This project identifies and compares the operational efficiency and feasibility of a variety of restoration techniques to create microsites capable of addressing site limiting factors. A fail-fast system was employed to assess restoration techniques, focusing on digging implements, tow-behind farming implements and the Bracke mounder. Tools that demonstrated effectiveness in addressing site limiting factors were retained and tested further. Promising initial performance of the Bracke mounder prompted the innovation of an amphibious Bracke, which emerged as a strong performer by significantly enhancing operational efficiency while maintaining ecological efficacy. This amphibious Bracke will now be further tested and implemented at an operational scale in 2024, an outcome that would not have been possible without the ERA funding support for this trial.

The performance of restoration treatments was evaluated in the field from 2021 to 2023 using key parameters including treatment speed, microsite persistence and quality, vegetation responses and GHG implications. The results revealed notable findings: accelerated treatment speeds for novel equipment, high microsite persistence and quality from the Bracke mounder, promising initial vegetation responses across a range of treated sites and implements and significant potential for mitigation of GHG emissions through improved treatment efficiency.

Researchers from the Northern Alberta Institute of Technology (NAIT) also completed greenhouse gas monitoring research at the site. Their research aims to quantify initial direct and indirect greenhouse gas (GHG) emissions associated with restoration treatments, comparing the effectiveness of standard (inverted) and upright mounds. Short-term results indicate that upright mounds have not reduced emissions as much as anticipated due to dry field conditions, and direct emissions from restoration equipment are relatively insignificant compared to indirect emissions resulting from peat decomposition and methane release from wetlands. This research serves as a catalyst for longer-term studies which will provide deeper insights into the effectiveness of these treatments in reducing emissions as vegetation continues to recover.

1.1 Treatment Speed

The **Bracke technology exhibited remarkable speed compared to traditional methods**, significantly accelerating restoration while maintaining high microsite quality. This was true of both the Bracke attached to a skidder and the amphibious Bracke, the latter of which produced a comparable number of microsites in lowland plots in 10–15% of the time required by standard mound techniques. The amphibious Bracke also compared well to other tow-behind implements in terms of speed, treating 100 m in the lowlands in approximately 6 min on average (and 3-3.5 min for a single pass) compared to the approximately 4–17 minutes taken by the tow-behinds. Other tow-behind implements also demonstrated commendable speed, including the disc, cultivator, ripper shank and potato plow, however, their treatment qualities varied across site types and were particularly compromised in lowland sites. Outside of the Bracke mounder tow-behind, the overall observation from this trial is that while some tow-behind implements, in particular a two-row disc, could have potential, further testing is required. Standard mounds and upright mounds had similar treatment times and were far slower than the Bracke mounder, ranging from 43–54 minutes in lowlands and 30–33 minutes in uplands.

1.2 Microsite Quality and Persistence

We compared microsite height at implementation (2021) with microsite height during the most recent sampling period (August 2023) to evaluate each treatment's persistence over time. Assessing microsite quantity and quality is important for evaluating the effectiveness of restoration techniques, especially in challenging terrains like lowland sites. This study revealed that **the standard Bracke produced microsites that had not lost height after two years in lowland areas,** whereas standard mounds shrank by 7.5 cm on average. Upright mounds (both bucket and tree scoop) and the two-row disc treatment also did not lose height in the lowlands over two years. Indeed, most treatments performed well including in mesic and upland sites, with some notable exceptions (box blade in mesic sites and two-row disc in uplands).

Considering the Bracke's rapid treatment speed, it demonstrated high microsite quality and integrity (particularly in lowland sites), making it stand out as a strong contender for quicker restoration efforts. A key outstanding question is whether the height of the microsite created by the Bracke in lowlands is high enough to enable long-term forest recovery, and how this compares to the standard mounds. Upright mounds also show promising potential as they showed less shrinkage over time compared to standard mounds. Future monitoring will be important in assessing the long-term success of these microsites compared to other treatments.

1.3 Ecological Efficacy

Many treatments successfully addressed site-limiting factors such as soil moisture, though vegetation responses differed across restoration treatments. While **Bracke-treated sites showed lower natural regeneration compared to standard mounds**, positive tree growth dynamics were observed. The difference in natural regeneration between Bracke and standard mound treatments is possibly linked to stress-induced seed responses due to the way that trees are tipped (standard mound) versus cut (Bracke and other treatments). By 2023, some differences in leader length were observed. All treatments other than the Bracke showed greater leader lengths than in control plots. Planted trees in Bracke plots had slightly shorter leader lengths than the controls, although this difference was not statistically significant. We believe that longer-term data will help inform interpretations about leader length in relation to the various treatments applied.

1.4 GHG Implications

Initial findings from research conducted by the Northern Alberta Institute of Technology (NAIT) indicates that **while upright mounds had less carbon uptake** than anticipated due to dry conditions two years post-treatment, **they exhibited greater variability in plant productivity and respiration** compared to standard mounds. Both upright and standard mounds showed increased methane emissions compared to untreated areas in the first two years post-treatment. As vegetation continues to grow and establish on upright mounds, this may lead to decreased CH_4 emissions and higher CO_2 uptake compared to standard mounds in the long-term. Direct emissions from restoration equipment were relatively insignificant compared to the indirect emissions from treated areas. Continued monitoring planned for 2024 and beyond is essential to fully understand the long-term GHG implications of these restoration treatments as vegetation recovers on treated seismic lines.

2 Project Description

2.1 Introduction

Summary:

- *Seismic line restoration presents an important opportunity to reduce carbon emissions, increase carbon sequestration, and improve environmental outcomes in Alberta.*
- *Conventional methods for restoring seismic lines are extremely costly and time-consuming. The focus of this trial was on adapting existing technology to make it a viable option for preparing seismic lines for tree planting quickly and effectively, thus reducing carbon emissions per km treated and increasing efficiency of GHG mitigation.*
- *Using a phased testing approach, we adjusted and innovated the technology being tested, ultimately developing an amphibious Bracke that has demonstrated the ability to access and treat lowland sites even under challenging conditions.*

Seismic line restoration in the boreal forest of northeastern Alberta presents a critical opportunity to enhance ecosystem health and mitigate greenhouse gas (GHG) emissions. In response to this challenge, Cenovus acquired funding from Emissions Reduction Alberta (ERA) to initiate a series of trials to explore innovative equipment and technologies aimed at improving restoration efficiency and effectiveness. A key underlying goal was to seek efficiencies in treatment to reduce carbon emissions in Alberta (Pyper and Tigner, 2021). Trials initiated in the fall of 2021, spring of 2022 and fall of 2023 have revealed promising tools and techniques for delivering restoration treatments at rapid speeds and high quality.

The focus of this project was to evaluate a range of restoration equipment, including tow-behind and conventional machinery, to determine their feasibility and efficacy in restoring seismic lines. Additionally, the project aimed to assess the ecological impact of these treatments and their potential to accelerate recovery of forest cover on linear features. Key objectives included refining existing equipment and developing innovations to address site limiting factors and improve caribou conservation outcomes within their boreal forest habitats.

The trials evaluated the quality and immediate effects of restoration treatments across different land cover types, including forested peatlands, mesic forests and upland forests. A fail-fast system was implemented to quickly identify and eliminate approaches unlikely to perform as desired at larger scales while retaining tools and methods that showed promise in delivering restoration treatments.

Ultimately, we retained a series of tools and methods that appeared to reasonably deliver restoration treatments as desired to address site limiting factors. This led to the innovation of the amphibious Bracke attached to a KMC prime mover in the second trial, which performed well but had limited ability to traverse lowland sites. This led to further innovation and the custom-build of a highly engineered and designed amphibious Bracke attached to a pontoon undercarriage and other modifications to the cab and frame in the third phase of the project. The advancements in technology throughout the project have proven to enhance the operational efficiency of restoration methods, directly reducing emissions by being able to treat comparable stretches of line in the fraction of the time of conventional methods. Additionally, the project is expected to contribute to increased carbon storage by planting trees in treated areas and creating the necessary microsites for both planted and naturally regenerating trees to survive and grow.

The ecological efficacy of treatments (with the exception of the amphibious prime mover, which was not trialed until 2023) was assessed both one and two growing seasons after treatment, revealing the effectiveness of various treatment methods in restoring seismic lines in Alberta. Detailed results on the outcomes of each technology trialed are presented throughout this report.

2.2 Project Background

Summary of project background:

- *Legacy seismic lines are widespread in Alberta and do not grow back well, with long-term negative impacts to carbon stocks, ecosystem integrity and boreal caribou.*
- *Mechanical site preparation (mounding) followed by tree planting is a standard restoration practice that promotes the return of forest cover on treated lines. However, standard site preparation methods using an excavator are prohibitively expensive.*
- *This trial was conducted from 2021–23 with the goal of innovating and adapting alternative technologies and assessing their operational efficiency and ecological efficacy in treating legacy seismic lines.*
- *The overarching goal of this work is to identify and operationalize technology that will enable larger-scale restoration projects and the economic, environmental, and carbon benefits they will produce.*

The restoration of legacy seismic lines plays a pivotal role in the recovery of boreal caribou habitat and increased carbon stocks. Historically, bulldozer construction of these lines disrupted soil substrate and microtopography, impeding tree recruitment and hindering forest cover recovery across Canada's western boreal ecosystems (Dabros et al. 2018). Resulting impacts on soil temperature, moisture gradients and water table depth created site-limiting factors that favored aggressive early successional species (Lee and Boutin 2006; van Rensen et al, 2015; and Finnegan et al. 2018).

This disturbance persists as non-treed features along the seismic lines, resulting in ecological ramifications that have prompted a shift towards linear feature restoration (Dabros et al. 2018). Some impacts of non-treed features include reducing spatial separation between wolves and caribou, which increases wolf movement speed within caribou habitat, leading to increased hunting efficiency, larger wolf populations, and smaller wolf home ranges within areas with dense linear features (Dickie et al. 2022).

Commonly employed restoration methods involve the use of excavators to create mounds and surface microtopography. This approach has shown efficacy in redirecting recovery trajectories toward tree cover (Tattersall et al. 2020; Beirne et al. 2021). Further, mechanical site preparation (mounding) followed by tree planting and/or hummock and tree transplanting have been documented to increase carbon storage. Tree planting alone has been found to increase boreal forest stand carbon totals by 20 tonnes per hectare, equating to approximately 0.44 tonnes of carbon per hectare per year (Colombo et al. 2005).

Despite these benefits, the mounding process remains slow and expensive with an average pace of approximately 1 km per day per excavator accompanied by costs ranging from $8,000 to $16,000 per 1 km (Pyper et al. 2014). The large expanse of linear features requiring restoration within caribou ranges in western Canada highlights the urgency of addressing this challenge. The key to success lies in integrating operational efficiency and ecological efficacy, with treatments needing to be both feasible in the field and successful in resetting recovery trajectories and creating favourable microsites for tree planting.

Initiated in 2021, this ERA funded trial is a long-term experiment designed to compare the operational efficiency and ecological efficacy of various restoration methods in the Cold Lake Caribou Range. Three broad categories of treatment delivery were assessed: amphibious prime movers, tow-behind implements, and a Bracke three-row mounder. This trial aimed to evaluate the effectiveness of these treatments in terms of speed, quality and immediate effects on site limiting factors. Partnerships with Cenovus and Great Excavations Inc. involved the implementation and operation of fourteen machines. The trial's ecological monitoring (conducted by Fuse Consulting Ltd.) and GHG/carbon dynamics research (conducted by the Northern Alberta Institute of Technology (NAIT)) spanned from the initial implementation in 2021 to winter 2023. This collaborative effort aimed to not only restore seismic lines and caribou habitat but also to mitigate the environmental impacts of legacy oil and gas disturbances in Alberta forests.

The significance of this project extends beyond immediate ecological benefits to greenhouse gas (GHG) reduction strategies. Legacy oil and gas disturbances in Alberta forests not returning to forest cover result in reduced terrestrial carbon stocks and increased methane emissions. The project aimed to answer key questions about treatment efficiency, which could contribute to the broader understanding of GHG benefits associated with improved landscape-scale restoration. Overall, this project supports the broader goals of enhancing boreal forest carbon storage, mitigating GHG emissions from restoration machinery and restoring the habitat of species like the boreal caribou.

2.3 Project Objectives

Summary of project objectives:

- *Assess the performance of a range of treatment methods in a variety of forest types.*
- *Develop and assess the performance of a purpose-built amphibious Bracke following promising preliminary results of a KMC prime mover-mounted Bracke.*
- *Assess the performance of standard versus upright mounds.*
- *Evaluate ecological outcomes including tree growth and carbon emissions.*

The project's overarching objectives, as outlined in the original Contribution Agreement, aimed to rigorously test and evaluate the operational efficiency and ecological efficacy of a range of restoration technologies seismic line restoration in Alberta's oil sands operations. The focus was on identifying the most efficient and effective machines to facilitate caribou habitat restoration.

2.3.1 Assessing a range of treatment methods

A key objective was to assess a variety of different treatment methods in a variety of forest types including upland and lowland forests. This included evaluating lower-cost and locally available dragged implements such as the box blade and harrows, pulled behind a Morooka (ultra-low ground pressure tracked vehicle), to determine treatment speed and effectiveness. Another objective was to manufacture and trial a low-cost restoration drum pulled by the Morooka to evaluate its effectiveness and explore cost-effective alternatives for line restoration. The project also set out to modify commercially available tree scoops, attaching them to amphibious arms to facilitate the live transplant of trees from adjacent forests onto the seismic line.

2.3.2 Adaptation and Innovation

An objective of this project was to develop and assess a unique adaptation of an advanced mechanical site preparation implement with a low-ground pressure carrier, capable of efficiently treating both lowland and upland site types in Alberta's boreal forest. Pilot scale testing of amphibious prime movers with alternative implements and seeking innovations based on initial findings led to the development of a purpose-built amphibious Bracke using the most promising machine identified during the trial. The objective evolved to design a machine specifically for use in wetlands to address challenges posed by lowland sites and enhance the versatility of the equipment. This outcome aligns with the original project objective to conduct a commercial-scale test of existing European restoration equipment, specifically evaluating a three-row Bracke Forest AB mounder. The main objective is to integrate state-of-the-art site preparation equipment from Europe with Alberta-based equipment providers' knowledge, resulting in a unique purpose-built solution for linear restoration made in Alberta.

Another project objective is to leverage advancements in technology to date, including remote-control operations developed by project partner Great Excavations Inc. to further develop equipment for efficient and safe excavator operation.

2.3.3 Upright versus standard mounds

An additional objective of this work was to evaluate the performance of standard inverted mounds against upright mounds, both in terms of regeneration success and GHG emissions mitigation. Typically, mounds are created using a digging bucket attached to an excavator to invert and pile peat to simultaneously address site limiting factors of waterlogged and cold soils and low available nutrient supply in lowland sites (Natural Resources Canada, 2019). A recently developed alternative to constructing mounds is transplanting whole, intact hummocks onto target sites. The goal of hummock transplanting is to create desirable site conditions that in some cases already support live trees, while also retaining live bryophyte cover and the ecological processes inherent to live hummocks. An additional expected benefit of upright mounds is reducing GHG emissions compared with standard mounds, which expose old peat to the air and can release methane and "old carbon".

Overall, the project objectives reflect the project's adaptability and commitment to exploring innovative solutions to address the challenges of restoring seismic lines in Alberta's boreal ecosystem.

2.4 Performance/Success Metrics Identified in the Contribution Agreement

Equipment performance for all three trials was assessed for productivity, treatment quality and restoration effectiveness based on a set of metrics outlined in Table 1.

In evaluating restoration effectiveness, comparisons were made with standard winter restoration programs that use conventional equipment, providing insights into treatment speed, cost and short-term quality. The short-term effectiveness of restoration efforts was monitored one- and two-years post-treatment, with continued assessments planned for years five and ten to further assess restoration impacts.

Table 1. Performance Parameters

Treatment speed		
Treatment Speed	km/hr	Cycle time
Transit Speed to Site	km/hr	
Daily Commuting Time	H/day	
Treatment Quality - Near Term		
Mound/Microsite Height	cm	
Mound/Microsite Density	#/ha	
Microsite Seedbed Quality	Good/Fair/Poor	
Tree/Moss Transplant Quality	Good/Fair/Poor	
Treatment Effectiveness - 1-, 2-, 5- and 10-Years Post Treatment		
Tree Stocking Density	Stems/ha	
Natural Regeneration of Acceptable Tree Species	Stems/ha	
Tree Vigor	Good/Fair/Poor	
Tree Height	Max Height cm	Average Height cm
Tree Leader Length	Average Leader Length cm	

2.5 Changes during the Project Lifecycle

Changes during the project lifecycle primarily stemmed from unforeseen challenges encountered during the various phases of the trial. Initially, the Bracke equipment was not ready for the scheduled fall trial in 2021. During the second phase of the trial, the Bracke was attached to a KMC prime mover. This trial enabled us to successfully prove the value of the Bracke on uplands; however, the machine was too heavy to operate effectively on wetland sites. During the third phase of the trial, a custom amphibious Bracke prototype was developed. Delays in the arrival of parts for the machine resulted in the trial being postponed several weeks, and the trial was successfully completed in November of 2024.

As a result, no formal amendments were made to the ERA agreement. However, a minor was implemented within the contract to address the delay with the KMC prime mover in Milestone 1. Additionally, a minor change was made to extend the project completion date by 60 days. This extension was required due to delays in the GHG analysis from NAIT.

2.6 Technology Risks

Technology risks identified at the start of the project along with associated risk mitigation and response strategies are outlined in Table 2.

Table 2. Summary of technology risks, mitigation strategies, effectiveness and challenges encountered throughout the duration of the project.

Risk	Mitigation Strategy	Mitigation Effectiveness
Identified Risks		
Implements may not be able to create targeted microsites	Anticipate and implement design modifications as needed prior to the trial. Conduct minor design modifications as needed during the trial (i.e., in the field).	Most implements were able to produce suitable microsites. Implements that did not were modified and re-tested in spring 2022 or were abandoned as part of the planned "fail fast" approach.
Watercourse crossings	A procedure for watercourse crossings was developed based on previous experience with amphibious excavators. Watercourse crossings were reviewed before the trial using imagery, LiDAR and scouting in advance of field work.	Measures outlined in the procedure were successfully implemented, including amendments for tracked carriers and temporary log fills. Advance scouting identified hazards associated with water crossings, strategies for avoiding hazards, and limiting crossings where possible. Remote control was utilized where possible for water hazard crossings.
Range of terrain conditions at the project site	Morooka and KMC were adapted with amphibious attachments. The technology was adapted to manipulate weight distribution by adding or removing water from the line drum to make it lighter or heavier.	Machines were able to access sites but the KMC Bracke was too heavy for ideal operations on wetlands. Amphibious Bracke was developed to address the shortcomings of the KMC. Being able to adjust the center of gravity was particularly important for the Morooka due to its heavy weight and helped prevent it from sinking and getting stuck.
Take existing technologies in the market and adapting them to work in specific project settings	Working with manufacturer engineers to ensure products are compatible, reliable and safe.	Engineered drawing and technical analyses were successfully used to inform all design and manufacturing work, prior to manufacturing being undertaken.
Challenges Encountered		
Frozen ground conditions due to trial delays	Minor modifications made in the field allowing operators to adjust settings to conditions in real time.	The amphibious Bracke was able to create suitable microsites on a range of sites despite frozen conditions.

3 Project Work Scope

3.1 Experimental Methodology

Summary of methodology:

- *The trial was conducted in the Canoe Lake Restoration Area with a focus on legacy seismic lines.*
- *We tested a range of implements mounted to an amphibious prime mover, Morooka or KMC skidder. Field trials occurred in three phases, culminating in the development of a purpose-built amphibious Bracke.*
- *We collected results on operational efficiency during implementation (e.g., treatment speed, microsite density and height) and ecological efficacy during two post-treatment sampling periods (e.g., soil moisture, natural regeneration, leader length, etc.).*

3.1.1 Study Site

The project occurred in the Canoe Lake Restoration Area, part of Cenovus's Foster Creek steam-assisted gravity drainage (SAGD) oil sands project area on the Cold Lake Air Weapons Range (CLAWR) in northeast Alberta (Figure 1). The restoration focus within the CLAWR is mostly on legacy seismic lines, which was the focus of this project.

We categorized forest covers in the study area into the following three classes typical of the southern portions of the Ecozone that have similar site limiting factors and restoration needs for industrial disturbances: 1) forested peatlands (e.g., bogs and fens) dominated by open, mixed stands of short black spruce and tamarack (≤ 3 m tall), 2) mesic forests dominated by stands of tall and dense canopy black spruce or mixed species of black and white spruce, aspen, and pine, with a dense understory of tall shrubs including willow, alder, rose, and highbush cranberry and 3) pine forests on sandy soils and eskers, with lichen ground cover and a sparse, low ericaceous shrub layer.

Figure 1. Map of the study region near Cold Lake, AB.

3.1.2 Site Selection

We selected a set of candidate linear features for this trial that were no longer needed for SAGD operations. Using GIS, we partitioned features into segments of peatland, mesic, and upland forest types. We then visited all sites in the field to visually confirm vegetation community and recovery status. Ultimately, we clustered all trial sites along a total of approximately seven kilometers between eight legacy seismic lines to control for variation in past line construction methods and impacts, and industrial use.

3.1.3 Experimental Treatments

Our goal for this trial was to identify and compare the feasibility, speed and outcomes of different techniques to expedite the implementation of restoration treatments along linear features. We designed a series of restoration treatments using a hierarchical approach to quickly abandon failing methods in the field (i.e., a fail-fast system).

Ultimately, we retained a series of tools and methods that appeared to reasonably deliver restoration treatments as desired to address site limiting factors (Table 3). In all cases, mechanical treatments were complemented by tree planting as per normal restoration operations. We conducted trials during vegetation dormancy in fall 2021 and in spring 2022, and tree seedlings were planted in July 2022 after treatments were completed. We monitored ecological responses in summer 2022 and 2023. Results from the initial 2021 trial led to the innovation of an additional machine type, the amphibious Bracke, which was developed to address the Bracke's inability to traverse lowlands. This innovative machine was trialed in fall 2023, marking the completion of the current project.

Table 3. Summary of plots that were implemented in 2021/22 and subsequently re-surveyed in 2022 and 2023, by site and treatment type. Treatments that were not re-surveyed following implementation were considered "fail fast" treatments that were either not operationally feasible or very clearly did not adequately address site limiting factors.

	Site Type								
	Lowland			Mesic			Upland		
Implement Type	**2021/22**	**2022**	**2023**	**2021/22**	**2022**	**2023**	**2021/22**	**2022**	**2023**
Tow-behind Marooka									
Bottom Plow	3			2	2	2			
Box Blade	1			3	3	3	3	3	3
Cultivator				2	2	2			
Disc21	3	3	3	4	3	3	3	3	3
Disc22	3			3	3	3			
Drum							3	3	3
Harrows							1	1	
Potato Plow	3			2	2	2			
Ripper Shank				2	2	2			
Excavator									
Standard Mound	6	6	6						
Upright Bucket	8	8	6				1	1	
Upright Tree Scoop	8	8	6	1			3		
KMC-Bracke									
Bracke	3	3	3	9	9	9	3	3	3
Control									

	Site Type								
	Lowland			Mesic			Upland		
Implement Type	**2021/22**	**2022**	**2023**	**2021/22**	**2022**	**2023**	**2021/22**	**2022**	**2023**
Control	3	6	7	4	4	3	5	4	3

Amphibious Prime Mover

We used a prime mover equipped first with a standard 46” digging bucket and cutting teeth, and next with a tree scoop, to deliver standard mounds and to transplant whole hummocks (Figure 2). A tree scoop is a specialized, arrow-shaped implement often affixed to a skid-steer to transport, remove, and dig holes for planting large trees and shrubbery. We used the standard bucket to create mounds (hereafter “standard mounds”) and the bucket and tree scoop to transplant hummocks (hereafter “upright bucket” and “upright scoop” respectively) in forested peatlands in fall 2021 and spring 2022. We also tested tree scoops to create a version of a standard mound in uplands in fall 2021.

Figure 2. An amphibious prime mover with conventional bucket (left) and a tree scoop modified to work with an excavator quick attach (right).

Tow-behind Implements

In fall 2021 we tested a purpose-built, weighted drum designed to create microsites and increase surface roughness; small harrows; a box blade; and a two-row disc (Figure 3). All implements, except for the drum, were designed for use as acreage implements and widely available at local equipment stores. The drum was tested in uplands and the other implements were tested in uplands, mesic forests and in some cases lowlands. Experimental use of the tow-behind implements during fall 2021 indicated that enlarging and strengthening the implement frame and three-point hitch designs and using different implement types may improve restoration performance focused on creating small scarifications in the soil to create variable microsites for recovery. In spring 2022 we also tested a larger single-row disc; a bottom plow; a cultivator with sweeps; a cultivator with potato plow shoes; and a single row of subsoil shanks/ripper teeth (Figure 4, Figure 5 and Figure 6). Implements tested in the spring of 2022 were trialed in all three land cover types (upland, mesic and lowland). All tow-behind implements were attached to a modified Morooka MST 800.

Figure 3. Tow-behind implements tested in this project: line restoration drum, a small acreage disc (left), small acreage harrows (center) and small acreage box blade with tines (right).

Figure 4. Tow-behind implements tested in this project: ripper shanks (left) and single row disc (right).

Figure 5. Tow-behind implements tested in this project: cultivator with sweeps (left) and cultivator with potato plow shoes (right).

Figure 6. Tow-behind bottom plow tested in this project.

Bracke Mounder

A Bracke three-row mounder ("Bracke") is a forestry implement designed and manufactured in Sweden to create a mounded planting location to reforest harvested areas. The Bracke consists of a spinning spool with large protruding plates affixed to an articulated arm (Figure 7). We used a three-armed, three plate design (other designs are available) where the outer two arms were adjustable to achieve different treatment widths. The Bracke creates microsites as it is dragged by a prime mover. We used a tracked LGP Prime Mover manufactured by KMC. The speed of rotation of the plates, the depth and pitch the plates dig into the ground, and resistance of inserted plates are all programmable and communicable between the Bracke and operator in the prime mover via sensors and an in-cab computer interface. Our intent was to use three different factory pre-set combinations to evaluate the efficacy of mimicking a standard mound. We tested the Bracke in spring 2022 in all land cover types. In fall 2023, an amphibious Bracke was purpose-built with a pontoon undercarriage highly engineered and designed for optimal operation in wetland sites. The amphibious Bracke was trialed in the field in fall 2023 (Figure 7).

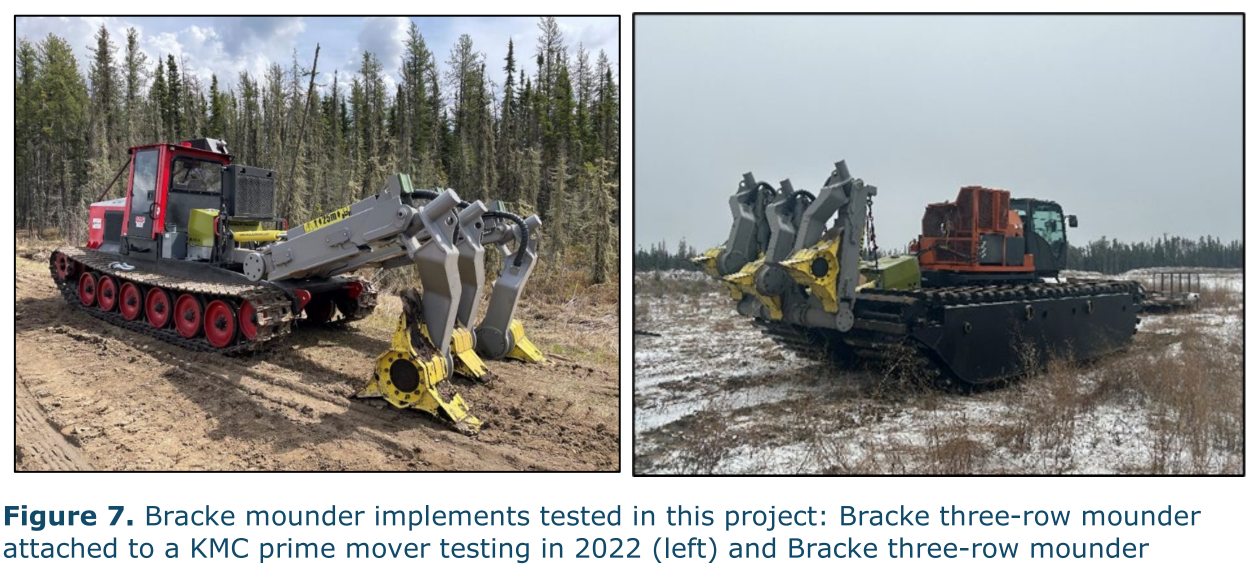

Figure 7. Bracke mounder implements tested in this project: Bracke three-row mounder attached to a KMC prime mover testing in 2022 (left) and Bracke three-row mounder attached to an amphibious pontoon tested in 2023 (right).

Tree Planting

After all initial treatments were delivered, tree seedlings were planted at all sites in July 2022. Tree planters were directed to plant appropriate species at appropriate densities into available microsites at all plots. Planters were allowed flexibility to meet logistical constraints of helicopter access planting efforts (e.g., species mixes per planting bag, and spacing relative to seedling drops), but were expected to broadly plant into created microsites as follows: pine in xeric uplands at 1,400–1,800 stems per ha; pine or black spruce in mesic forests at 1,800–2,200 stems per ha; and black spruce or tamarack in forested peatlands at 1,600–2,200 stems per ha. In spring 2024, trees will be planted on additional microsites created by the amphibious Bracke during its trial in fall 2023.

3.1.4 Experimental Design and Data Collection

For each restoration treatment and land cover type combination we established treatment and control plots using a before-after-impact-control design. For each combination, we interspersed three treatment line segments and one to three control plots along a sampled seismic line. Within each treatment segment, we nested three 50 m^2 sampling plots (either 3.99 m circular or 5 × 10 m rectangular plots) to collect data on post treatment microsite density and quality.

Operational efficiency

To evaluate operational efficiency, we measured both the timing of treatment delivery and quality of delivered microsites. To measure timing, we recorded the elapsed time, in seconds, from the start to the end of the treatment segment. To measure treatment quality, we counted microsite density and recorded the size of created microsites. Microsite persistence was evaluated by testing for loss of microsite height between implementation and 2023.

Ecological efficacy

To evaluate ecological efficacy, we measured the short-term (i.e., two growing seasons) responses of microsite quality, vegetation, soil moisture and soil temperature to delivered treatments. We also evaluated the outcomes of trees that were planted in July 2022.

Five planted seedlings per plot were tagged during the initial sampling period and revisited during each sampling period. We measured soil volumetric water content and temperature at the base of each tree, and tree seedling characteristics including height, leader length, collar diameter and tree vigour.

At all plots we counted the total number of naturally occurring and planted tree stems, and the total number of shrub stems. We also recorded the height of three representative shrubs. Additional measurements included the heights of provincially acceptable tree species for linear restoration and the composition of ground cover (e.g., surface water, dead material, woody, exposed soil) and vegetations (grasses and sedges, herbs, bryophytes, and lichen).

3.2 Technology Development, Installation and Commissioning

The technology development and installation process for the various pieces of equipment and the Bracke system involved an evaluation of bids from equipment providers. After an engineering assessment was completed with Bracke engineers, a solution was awarded to Great Excavations Inc.

For phase 1 of the project, existing farming attachments were adapted to deliver restoration treatments (i.e., mounding). Purpose-built tow-behinds were subsequently developed for phases 2 and 3, reflecting the innovative nature of this project's technology development process.

The customization process included adjusting the Bracke to improve its performance in wetlands. The Bracke was initially installed on a KMC skidder and tested during phase 2, but the equipment was too heavy to operate reliably in wetlands. In response to this challenge, an engineering assessment was conducted for the adaptation of the Bracke mounted to an amphibious prime mover. The amphibious Bracke was then built and trialed in fall/winter 2023 (phase 3). Currently, the technology is being further developed to determine how it can be applied at a larger operational scale.

3.3 Results

Summary of results:

- *The Bracke and pull-behind implements treated lines in a fraction of the time required by excavator treatments.*
- *The Bracke delivered a comparable number of microsites/ha to the excavator treatments, while many of the pull-behind implements created a more continuous disturbance.*
- *The Bracke and amphibious Bracke were able to produce mounds that approached the heights of excavator-produced mounds in lowland sites. The Bracke also had adjustable settings, allowing it to be adjusted to produce the smaller mounds desired in upland sites.*
- *Most treatments had a positive effect on soil moisture, but the Bracke stood out for not only reducing soil moisture in the lowlands but also increasing soil moisture in the uplands.*
- *The standard mound outperformed all other treatments for natural regeneration in lowland sites because the excavator is used to tip trees (rather than trees being cut by a felling crew). Continued innovation may be necessary to achieve comparable outcomes using novel technologies.*

This section summarizes the cumulative results of this project since 2021. The time of project completion marks two years after treatments were originally implemented and one year after trees were planted on associated microsites. The trial in its entirety is the first of its kind comparing methods for restoring habitats along linear features, a critical component of delivering the most effective habitat restoration for caribou. The addition of the paired monitoring of carbon outcomes from treatments helps to further evaluate the trade-offs involved in these treatments. Initial results from NAIT's GHG emission study indicate that both direct and indirect emissions from restoration treatments are not showing significant carbon outcomes in the short-term, two years post-treatment. As a result, no significant changes in practice can be drawn from these preliminary results at this stage. Longer-term studies are necessary to provide deeper insights into the effectiveness of different treatments, including standard mounds versus upright mounds, in reducing GHG emissions.

3.3.1 Fail Fast Learnings

A key part of phase 1 of this project was to test a range of methods and push ideas to failure quickly to eliminate the techniques that showed low promise in delivering effective and efficient restoration treatments. Using this 'fail fast' approach, we identified the methods that showed the most promise in 2021 and advanced them to more trial time and higher numbers of replicated plots in 2022. In the spring of 2022, we also tested a series of new tow-behind implements with the goal of fully assessing which implements could help advance more efficient and effective restoration. The techniques that showed low promise were eliminated from the trial before advancing to subsequent phases. Techniques that were eliminated include harrows, cultivators with sweeps and the ripper plow (Table 4).

Table 4. List of implements eliminated from the trial due to poor performance and the fail fast rationale for each.

Implement	Fail Fast Rational
Harrows	While initially appealing, the harrows created almost no noticeable disturbance to the **upland** soils at the test plot. After 100 m of testing, the implement was eliminated from further testing. A variation on the harrows would be heavy harrows, though this is also unlikely to create a large enough disturbance.
Cultivator with sweeps	The cultivator with sweeps was severely prone to accumulating roots and organic material, to the point the machine became unusable in **upland and lowland** sites due to the inability to clear the accumulated material without hand clearing. A variation on this was chisel tips on the front row followed by potato plow shoes, which performed better.
Ripper plow	The three-pronged ripper plow was also prone to accumulating roots and organic material in **upland and lowland** sites, requiring clearing by hand. The ripper teeth also created long linear channels that were considered a risk for erosion. A heavy ripper or one with fewer shanks may have performed better.

3.3.2 Treatment Efficiency

Treatment Speed

The assessment of treatment speed serves as an effective metric in determining the efficiency of various implements, offering insights into their productivity both on an hourly and daily basis.

The amphibious prime movers delivered treatments (standard mound, upright bucket and upright tree scoop) much slower than the pull-behind and Bracke implements, taking five to seven times longer on average to treat 100 meters (Figure 8). These differences were most striking in the lowland sites, where tow-behind implements were able to deliver treatments in approximately 4–17 minutes on average, despite the challenges inherent to treating wetter sites. This was in comparison to an average of 45-55 minutes per 100 meters for the amphibious prime mover.

Notably, the amphibious Bracke was able to deliver treatments with an average speed of six minutes in lowland sites (two passes to completely treat the width of most lines), with a single pass taking 3–3.5 minutes on average. This efficiency occurred despite being trialed under frozen conditions. This result highlights the success of the amphibious Bracke in enabling rapid treatments in sites that are otherwise highly difficult to access and treat, and the potential for even greater efficiencies under non-frozen conditions and/or with further operational refinement to achieve outcomes in a single pass.

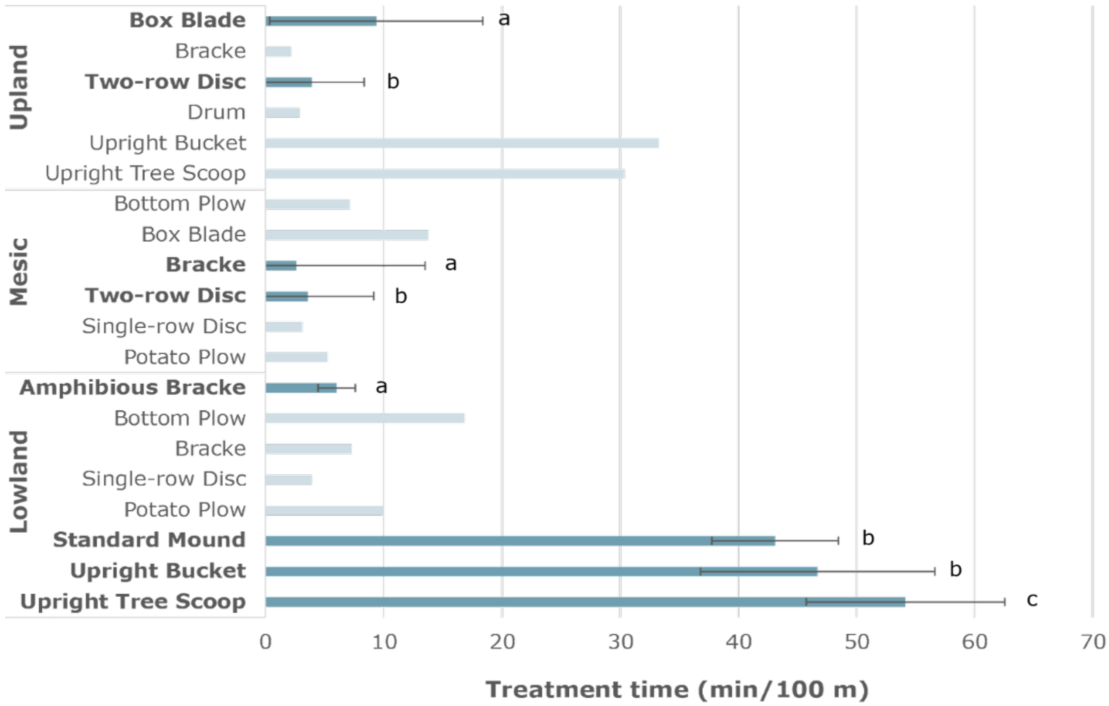

Figure 8. Average time in minutes to treat 100 m of line. Light-coloured bars indicate treatments that were trialed but had too few replicates for statistical testing (i.e., a sample size of 1–2). Whiskers indicate 95% confidence intervals for treatments with three or more replicates. Different letters indicate statistically significant differences among treatments within each site type.

Microsite density

While treatment speed is a crucial metric in assessing the efficiency of restoration technologies, it's important to consider the effectiveness of treatment factors, like microsite density and quality, to determine overall efficiency. As a reference point, lines are typically planted to a density of approximately 1,400–2,200 stems per hectare.

Many of the tow-behind implements (e.g., box blade, disc, etc.) produced a high density of microsites, particularly on mesic and upland sites. In some cases, the high microsite density reflects the tendency of some pull-behinds to “rough up” the ground and create a nearly continuous disturbance. Given the target planting density described above, treatments that deliver well more than 5,000 microsites/ha (e.g., the box blade, two-row disc and drum in the uplands) do not necessarily indicate proportionally greater treatment success. However, should longer-term monitoring indicate high tree regeneration success on these treatments, their ability to create a continuous disturbance may provide useful benefits for the secondary objective of reducing human and wildlife travel.

In lowland sites, several of the tow-behind implements and both of the Bracke treatments produced as many or more microsites compared with the excavator treatments, which delivered approximately 1,900–2,750 microsites/ha on average. Notably, the amphibious Bracke delivered nearly 3,000 microsites/ha in less than 15% of the time of excavator treatments and did so under frozen conditions. These comparisons are not intended to diminish the role of amphibious prime movers or standard mounds, rather the standard mounding technique was used as the baseline upon which success was being evaluated, considering it is the standard practice used currently.

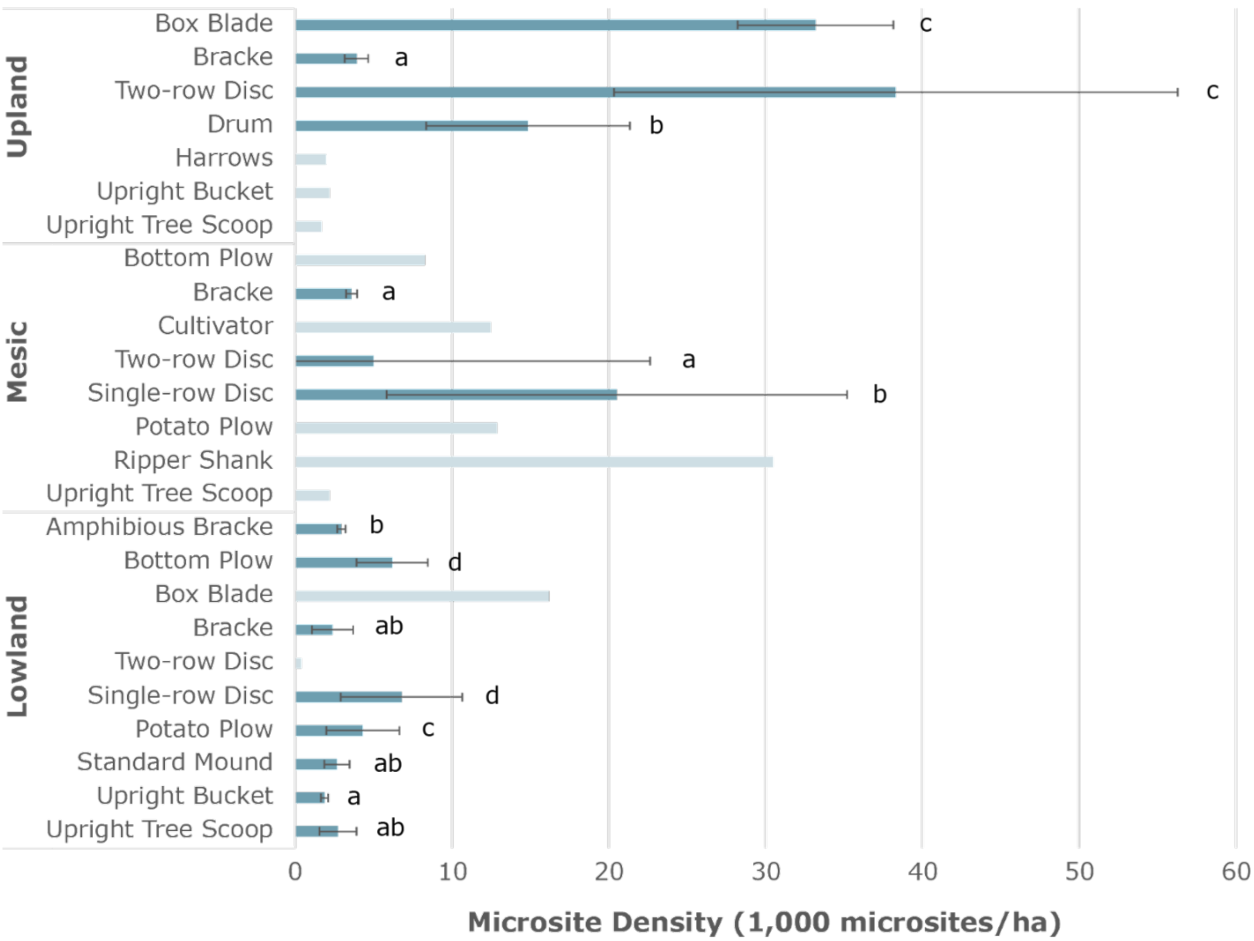

Figure 9. Average microsite density (thousands of microsites per hectare). Light-coloured bars indicate treatments that were trialed but showed poor performance in the field, leading to too few replicates for statistical testing (i.e., a sample size of 1–2). Whiskers indicate 95% confidence intervals for treatments with three or more replicates. Different letters indicate statistically significant differences among treatments within each site type.

3.3.3 Microsite Quality and Persistence

Microsite height

Microsite height is an important indicator of treatment quality. In upland sites, microsites help to elevate planting sites above competing vegetation. In lowland sites, tall microsites that elevate growing sites above the water table are particularly crucial for tree survival.

Across different site types, microsite heights were tallest in lowland areas and shortest in upland areas, consistent with objectives for treating site-limiting factors. The Bracke is unique in that it can customize microsite height based on site conditions, favoring taller mounds in wetter areas. On upland and mesic sites, the Bracke consistently produced taller microsites compared to pull-behind implements, supporting optimal tree growth (Figure 10). Excavator treatments, particularly the upright bucket and tree scoop, showed similar efficacy in microsite height to the standard mounder (Figure 10). Initial measurements in the fall of 2023 indicate promising results for the amphibious Bracke, which achieved tall microsites (29.2 cm on average) despite being hindered by frozen conditions.

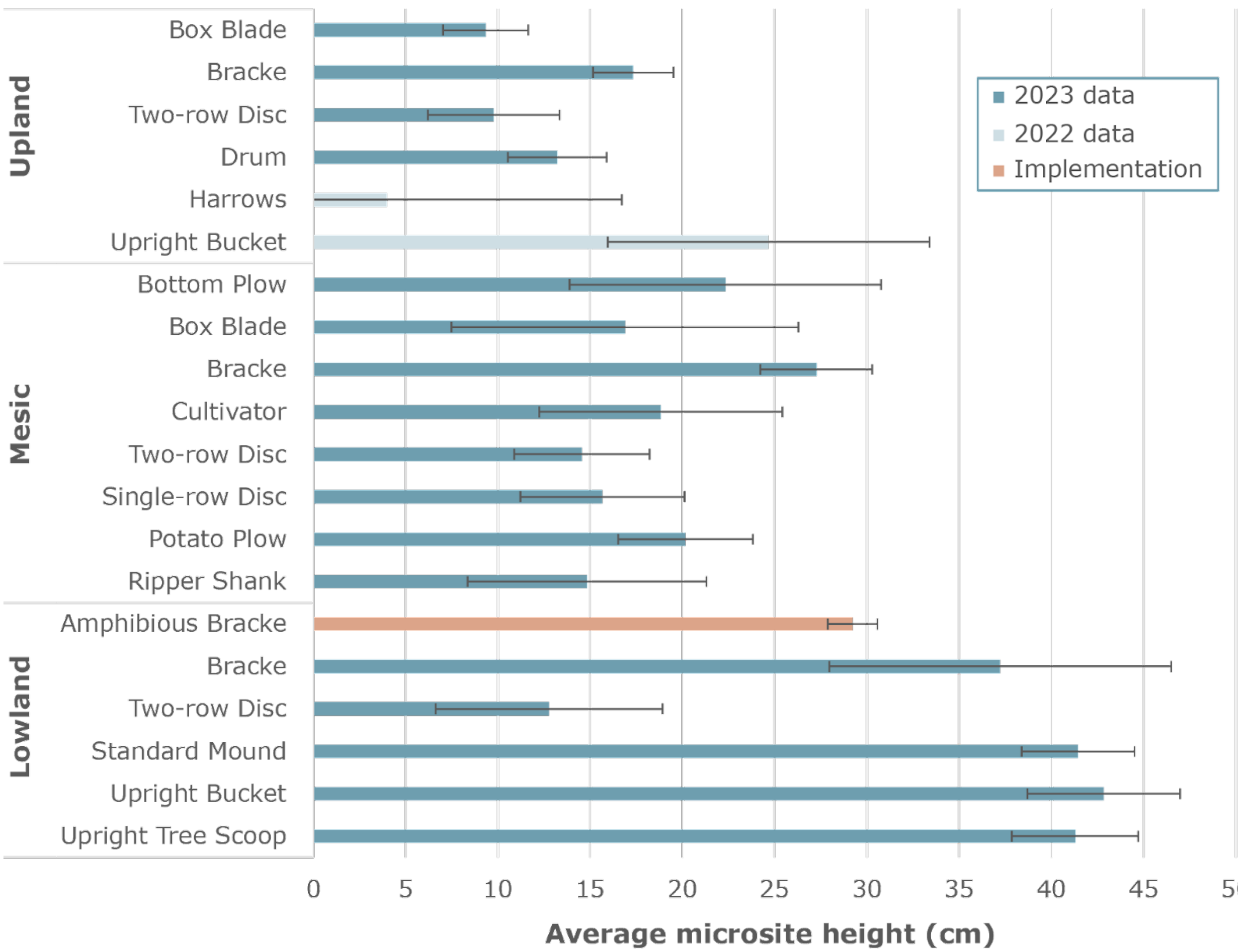

Figure 10. Microsite height measured in 2023 and 2022 for a range of restoration equipment innovations in upland, mesic and lowland ecosites. Initial (i.e., at implementation) results are included for the amphibious Bracke. Whiskers represent 95% confidence intervals.

Microsite persistence

We compared microsite height at implementation (fall 2021 and spring 2022) with microsite height during the most recent sampling period (August 2023) to evaluate each treatment's persistence over time. The ability of a microsite to persist is another critical factor for successful restoration efforts, ensuring that treated areas remain intact to allow for a tree to grow. In upland sites, both the Bracke and two-row disc treatments showed declines in microsite height; however, changes in height for the Bracke treatment were very small (2.5 cm decline). Microsite height declined more significantly for two-row disc (7.6 cm decline, representing over 40% height loss). Box blade and upright bucket treatment microsites showed no declines in height. In mesic sites, no significant declines in microsite height were observed except for the box blade, which declined by over half from 37.4 cm at implementation to 16.9 cm in 2023. In lowland sites, the standard mound declined from 48.9 cm at implementation to 41.4 cm in 2023, while upright mounds (bucket and tree scoop), Bracke and two-row disc did not show these declines in height over time.

Considering the speed of the Bracke, it proved its ability to maintain microsite quality and integrity, particularly in lowland sites. Re-measurement of the microsites created using the amphibious Bracke will be invaluable for assessing this novel treatment's long-term success, as its results to date make it stand out as a potential solution for quicker restoration efforts. Future monitoring will be important in assessing the long-term success of trees growing on these microsites compared to other treatments.

3.3.4 Ecological Efficacy

Assessing vegetation responses two years post-treatment provides valuable insights into the ecological effectiveness of restoration efforts across different land types. While long-term vegetation response data is not yet available, observations from 2022 and 2023 offer preliminary indications of treatment efficacy.

Soil Temperature and Moisture Dynamics

Soil temperature and moisture dynamics are important for seedling establishment and success. Within dry upland sites, moisture is often a site limiting factor and treatments that can improve access to moisture are desirable. In lowland sites, the water table is often high and too much moisture is a site limiting factor and treatments that can reduce soil moisture are desirable.

In upland sites, the Bracke was the only treatment to significantly increase soil moisture, with 25.6% soil moisture on average compared with 19.4% in the controls. This finding is notable because the Bracke was the only treatment to clearly enhance moisture conditions for seedling growth. In lowland sites, all treatments significantly reduced soil moisture, which was extremely high in the controls. The upright tree scoop and Bracke achieved the driest microsites in lowlands (Figure 11).

Soil moisture is not typically considered a limiting factor in mesic sites, so it is neither surprising nor concerning that almost no treatments resulted in significantly different soil moisture conditions than the controls. Most treated plots were slightly but not significantly drier than the controls, while one treatment (single-row disc) had significantly higher soil moisture.

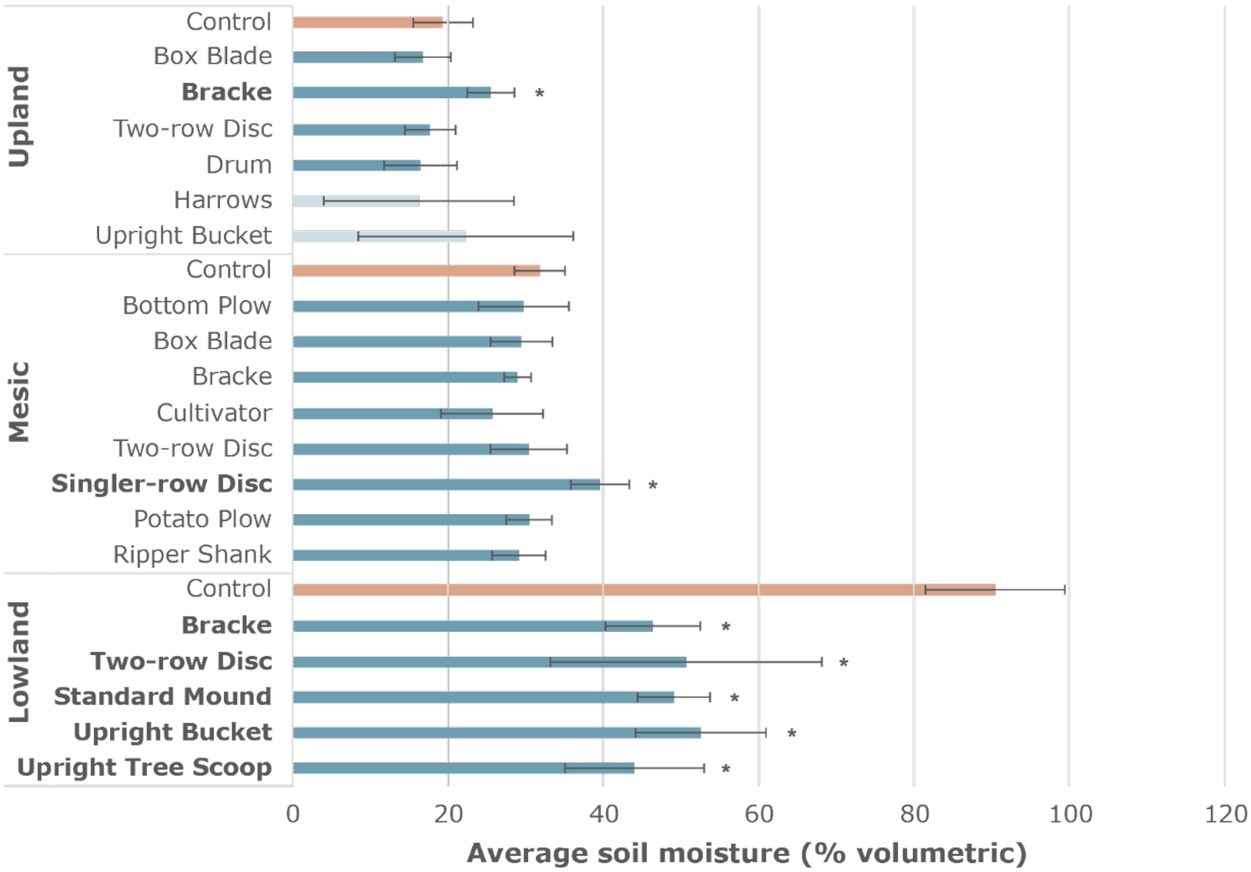

Figure 11. Average soil moisture as measured by a moisture meter at the base of five measured trees per plot in 2023 (light-coloured bars indicate values measured in 2022 for treatments that were not resampled in 2023). Asterisks represent significant differences from the control plots and whiskers represent 95% confidence intervals.

In mesic and lowland sites, treatments generally resulted in warmer soils compared to controls. Notably, the Bracke treatment in lowland sites exhibited cooler temperature, warranting further investigation.

Shrub density and height

Shrub density and height are early indicators of ecological responses to treatments, with findings from the most recent sampling period (i.e., the most growing seasons since treatment) reported here.

The most notable differences in shrub density between untreated controls and treated plots were observed in mesic sites, where the control plots had higher shrub densities than the treated plots, with statistically significant differences found for the box blade, two-row disc and single-row disc (Figure 12). In uplands, the plots treated using the box blade, two-row disc, drum, harrows and upright bucket had higher shrub densities than the controls, while the plots treated with the Bracke had markedly fewer, but none of these findings were statistically significant. In the lowlands, shrub densities were not significantly different on treated plots compared with the controls.

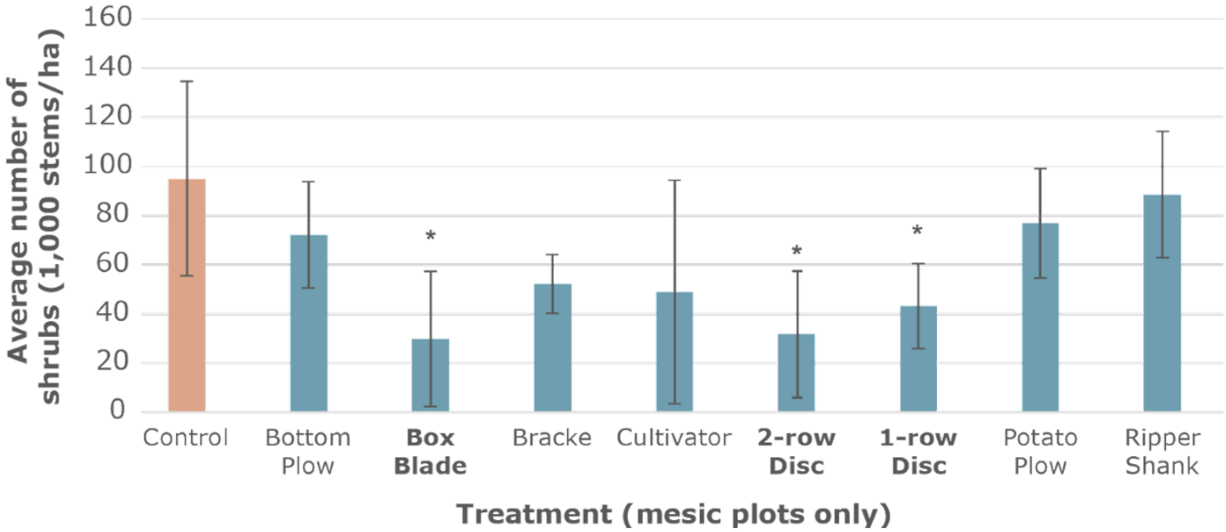

Figure 12. Shrub density measured at mesic sites in 2023 at treated plots and untreated control plots. Asterisks represent significant differences from the control plots and whiskers represent 95% confidence intervals.

Shrub heights varied across site types, with shorter shrubs in upland sites and taller shrubs in lowland areas. In lowland sites, treated plots generally exhibited taller shrubs compared to controls, while the opposite trend was observed in upland sites. In lowland sites, differences in shrub height were observed among excavator treatments, with the upright bucket plots containing significantly taller shrubs compared to standard mounds (Figure 13).

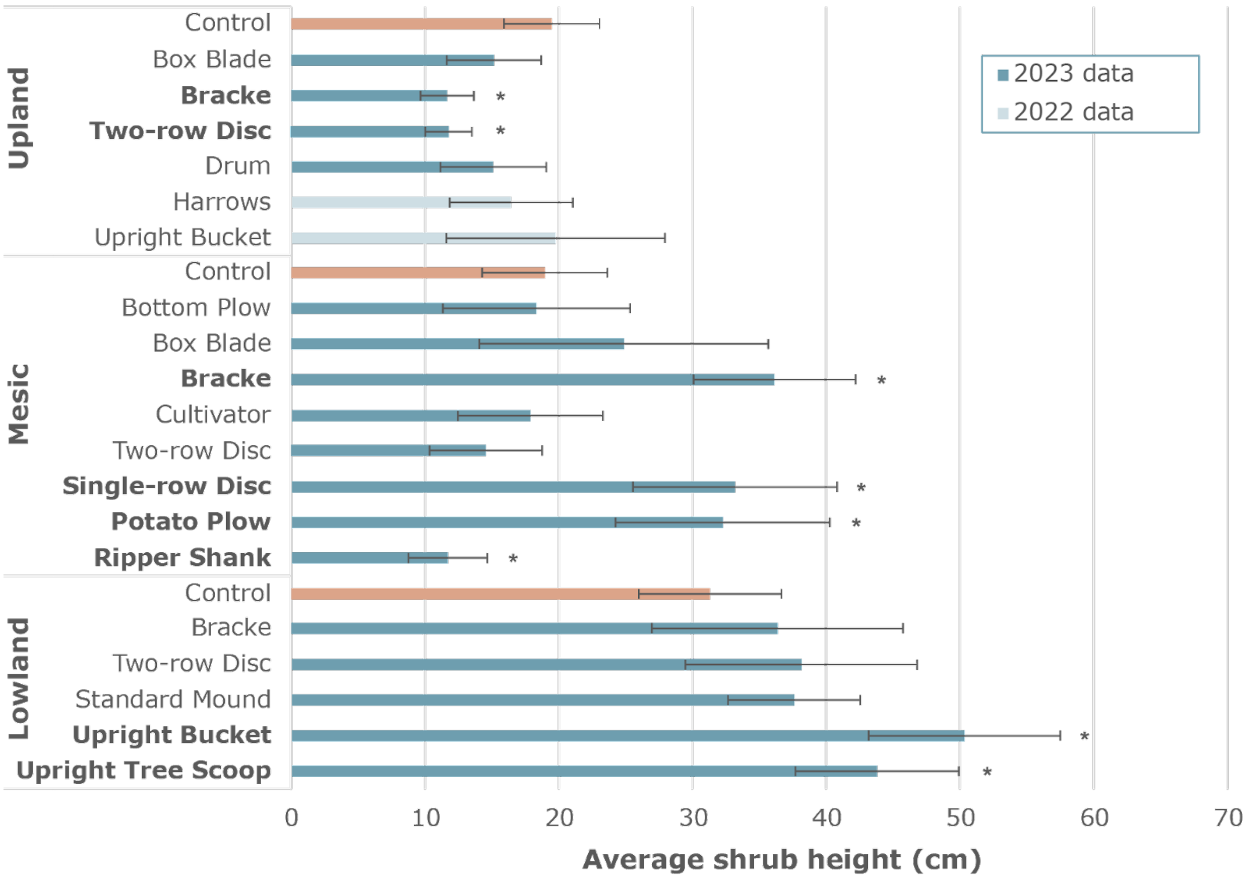

Figure 13. Shrub heights measured in 2023 at treated plots and untreated control plots (light-coloured bars indicate values measured in 2022 for treatments that were not resampled in 2023, and for which only one plot was sampled). Asterisks represent significant differences from the control plots and whiskers represent 95% confidence intervals.

Treatment impacts on shrub height and density can influence ecosystem dynamics and tree performance. The shorter shrubs observed in Bracke plots in upland sites may indicate reduced competition for seedlings and thus improved conditions for tree growth. However, greater shrub densities and taller shrubs may help to reduce elk, moose, deer and wolf movement, an important goal of linear restoration for caribou recovery.

Natural Regeneration

Control plots generally exhibited low natural regeneration, while treated sites showed varying degrees of natural regeneration. In upland sites, treatments like the drum and Bracke significantly outperformed controls in promoting natural regeneration. In mesic sites, control plots displayed higher natural regeneration and treatments exhibited greater variability in natural regeneration. In lowland sites, the standard mound treatment stood out with higher natural regeneration compared to controls. This may be attributed to increased surface area and stress-induced seed response from tree-tipping during excavation (Kleinke et al. 2022). Comparing excavator treatments in lowlands revealed the standard mound's superior ability to promote natural regeneration. While upright bucket and the upright tree scoop treatments had less natural regeneration than the standard mound, it is important to recall these mounds are often transferred from the adjacent forest, and therefore include many shrubs and trees already within the microsite. These results about natural regeneration are important; however, long-term data will better clarify the long-term survival of these germinates and help to clarify longer-term responses from these treatments.

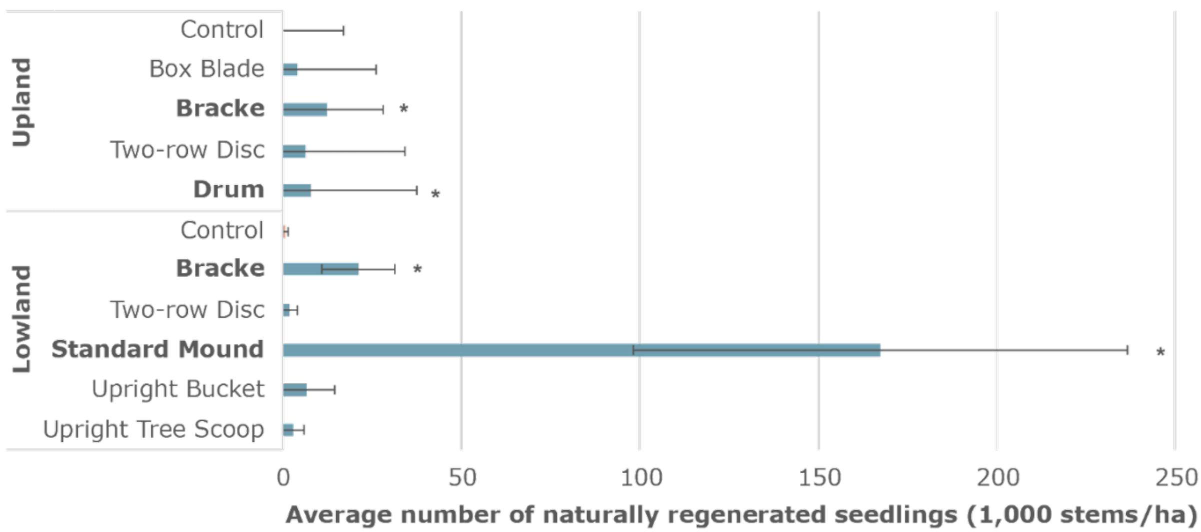

Figure 14. The number of naturally regenerated trees counted in a 3.99 m subplot for each treatment sampled in 2023 (uplands and lowlands shown). Whiskers indicate 95% confidence intervals.

Leader Length of Planted Trees

By 2023, some differences in leader length of planted trees had become evident, despite being only one full growing season since planting. To evaluate treatment effects on leader length, we compared treatments against leader length in control plots for each site type. Differences may be early indicators of treatment quality; however, longer term data will provide more reliable indications of lasting treatment benefits to tree growth. The most statistically significant differences in leader length were evident in lowland sites. All treatments other than the Bracke had significantly greater leader lengths than in the controls (Figure 15). Planted trees in Bracke plots, in contrast, had slightly shorter leader length than the controls, although this difference was not significant.

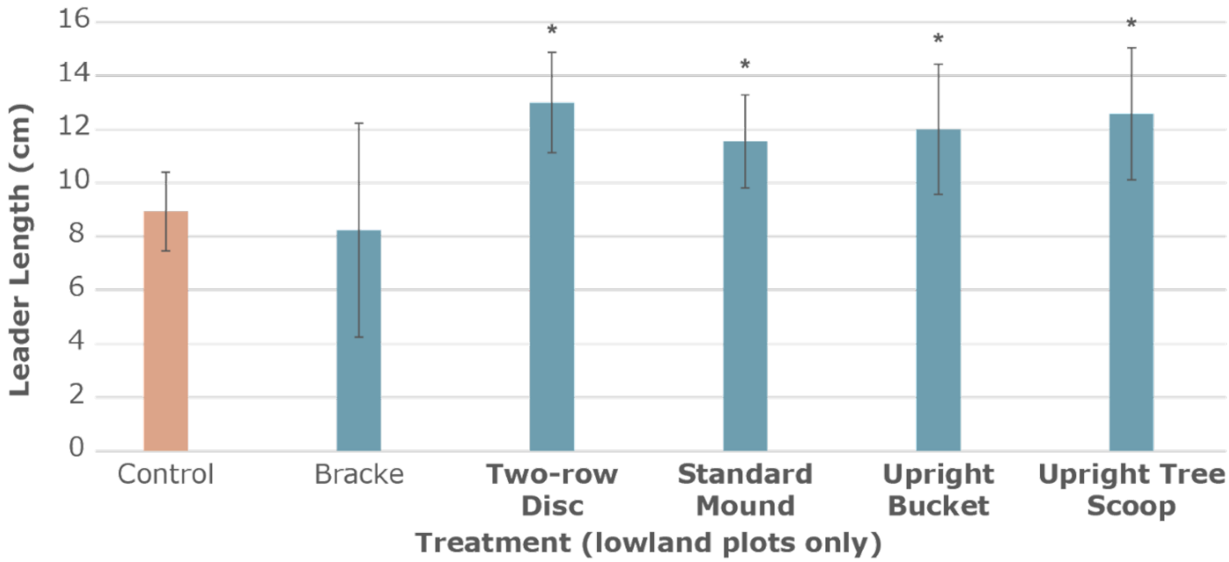

Figure 15. Average leader length measured at treatment plots in lowland sites in 2023.

In mesic sites, average leader length in the control plots was higher than in treatment plots However, none of the differences were statistically significant, indicating that the variability was so high among treatments and/or the sample size was too low to draw any firm conclusions regarding treatment quality at this time. In upland sites, average leader length in the control plots was comparatively low. Only the two-row disc treatment saw statistically greater leader lengths.

4 Commercialization

Summary of commercialization progress:

- *We made significant technological advancements during this trial. While commercialization of the technology is dependent on demand, the amphibious Bracke was considered a success and is planned for operational scale implementation by Cenovus. Other organizations requiring restoration support are also keenly interested in the technology advancements made in this trial.*
- *Barriers to commercialization include a highly specialized market and high start-up costs, lack of interest and incentive among industry with respect to broader restoration beyond Cenovus, and lack of clarity within industry around how to implement these innovations.*
- *However, organizations in the U.S. and First Nations groups have expressed a strong interest in upscaling the technology in local communities.*
- *Iterative technological advancements saw the Bracke technology advance from TRL 7 to TRL 8, progressing toward TRL 9 in 2024.*

Throughout the project, the technology has advanced significantly. During the first trial phase, the Bracke implement was initially tested on a KMC skidder. We quickly found that the KMC Bracke was not ideal for treating wet lowland sites due to its high weight and high overall ground pressure. We then adapted the Bracke attachment to fit on an amphibious pontoon undercarriage during the third phase of the trial to address these site-limiting challenges. This highly engineered and designed adaptation allowed for the successful treatment of lowland sites with impressive speed. Cenovus moved from pilot testing of amphibious equipment to commercial deployment in one year. While there are no plans to begin mass producing the amphibious Bracke frame attachment and selling it to competitors at this time, there are discussions underway with plans to put this technology to use at a larger operational scale in late spring 2024 for Cenovus' Underwood Lake Restoration program. Fuse Consulting and Swamp Donkey Solutions are also speaking to a range of clients about the potential of this technology, and future interest is high at this stage in conversations.

Barriers to commercialization include a lack of knowledge and interest among other industry partners in undertaking large scale restoration programs like Cenovus has undertaken. However, interest has been expressed by organizations in the U.S. and several First Nations groups with a strong interest in upscaling the technology in local communities. Another barrier to commercialization is the lack of clear guidelines and parameters within the restoration industry on how to conduct restoration activities using newly innovated technologies. No clear framework exists for this type of technology within the forest industry, and no government regulations or frameworks exist for these types of technologies within the forest and oil and gas industry. As a result, industry partners have no incentive to seek out innovative restoration technologies on top of already significant costs. High costs and the lack of government regulations for implementing restoration work make it challenging to fully scale and commercialize this equipment. However, this may change with the implementation of government caribou range plans and new opportunities for significant restoration work emerging in B.C.

To address these barriers and accelerate the future commercialization of these restoration technologies and techniques, videos, reports and data will be shared with the oil sands industry partners, the Government of Alberta and academics within the BERA program (Boreal Ecosystem Recovery and Assessment). Results will also be shared with members of the Pathways Alliance who will share the information with related organizations and member companies. Efforts to raise awareness of this technology to broader restoration markets including Indigenous Nations implementing restoration work in B.C. will also be made. Overall, the key aspects of addressing barriers to commercialization are sharing the knowledge gained through this restoration program by bringing the right people into the room who can adopt the technology and generate demand for commercialization.

Phase 1 of the project involved prototyping different technologies at a technology readiness level (TRL) of 7. Some of the technologies tested in phase 1 remained at a TRL 7 by project completion. However, after adapting the technology based on the results of phase 1, the KMC adapted with the Bracke attachment and ended phase 2 at a level 8 TRL. The third phase involved adapting the equipment further to perform in lowland site types, which led to the development of the amphibious Bracke in phase 3. The amphibious Bracke ended the trial at a level 8 TRL. The amphibious Bracke is progressing toward a level 9 TRL with restoration work at a larger industry scale planned for spring 2024. None of these advancements would have likely been possible without the support of the ERA program for this trial.

5 Lessons Learned

Summary of key learnings:

- *The Bracke performed extremely well, exceeding our highest expectations. The Bracke's speed, and that of other tow-behind implements, represents a significant potential advancement in delivering high quality restoration treatments with unprecedented efficiency.*
- *GHG implications of inverted versus upright mounds.*
- *Equipment acquisition challenges leading to delays.*

Many treatments were successful, with the Bracke standing out overall.

An exciting key learning arising from this ERA-funded trial was the high success of many of the tested implements in rapidly delivering quality microsites across a range of sites. While continued monitoring will be important for evaluating the growth and success of planted trees and naturally regenerating germinants, initial results are generally promising. Taken as a whole, this trial demonstrates that when 'good disturbances' are applied to the landscape, we can address site limiting factors on upland and lowland site types, particularly soil moisture. While more growing seasons will be needed to gain a clear understanding of tree regeneration, early indicators of natural regeneration and leader growth provide early evidence that treatments are helping to reset the successional trajectory of these legacy seismic lines.

The Bracke was a treatment of particular interest, and the successful development of the amphibious Bracke stands out as an important accomplishment and advancement of the trial. During the earlier phases of the trial the KMC skidder-mounted Bracke performed well on upland sites, standing out for its rapid treatment speed, customizability to site conditions, and ability to improve soil moisture for planted seedlings. The further development of the amphibious Bracke in response to the challenges encountered on lowland sites resulted in a new technology that delivered microsites that were almost as tall as those produced using an excavator in a fraction of the time. While soil moisture has not yet been measured for the amphibious Bracke treatments, microsites created in lowlands using the standard Bracke successfully reduced soil moisture compared with untreated plots.

While other treatments such as the two-row disc showed promise initially, follow-up microsite height measurements revealed substantial microsite height loss over time. Standard mounds also lost height over time, likely because of the inverted peat compressing under its own weight. These findings contrast with the Bracke, which compressed mounds as it created them, potentially resulting in less change over time compared with other treatments, including standard mounds.

Natural regeneration of treated microsites remains an interesting question that emphasizes the importance of continued monitoring. An interesting finding was the very high number of naturally regenerating germinant on the standard mound treatment. This result was attributed to the effect of tipping trees using the excavator to close the line, which triggers a strong seed production response. However, while there are many germinant on these microsites, their survival rate is typically low, and these densities are expected to be a poor predictor of natural regeneration success. Additionally, while it did not achieve the same natural regeneration levels as the standard mound, the Bracke was the only treatment to lead to germinant densities that were statistically higher than the controls on both upland and lowland sites, which each had negligible natural regeneration in the untreated controls.

GHG findings will help clarify the relative emissions implications of upright and standard mounds.

Further, initial GHG results are proving to be key for understanding the benefits and functionality of upright mounds versus standard mounds in an emissions context. Standard mounds create microsites by inverting ("flipping") the soil onto itself, exposing material that was previously belowground. Most other equipment, including the Bracke and the pull-behind implements testing during this trial, also create inverted microsites. In peatlands, inverted mounds expose peat to the air, which causes them to release methane and "old carbon" that had previously been sequestered underground. An important question of this trial is whether upright treatments (i.e., upright bucket or upright tree scoop) mitigate these GHG emissions by preserving the surface peat rather than inverting it.

Early results indicate that while upright mounds had less carbon uptake than anticipated compared to standard inverted peat mounds, primarily due to drier conditions two years post-treatment, they also showed greater variability in plant productivity and respiration. This suggests that upright mound's emissions and carbon uptake can be influenced by environmental conditions. As vegetation continues to establish on microsites, upright mounds may exhibit enhanced carbon uptake and increased resilience to varying environmental conditions over time. Continued monitoring will help identify the short and long-term GHG implications of these alternative treatments as vegetation continues to recover.

Technological innovations of this nature can face procurement and timing challenges.

Several challenges led to important learnings regarding technology development. There are limitations around the suppliers and the types of innovations that can be incorporated into existing machinery. Acquiring equipment parts made in Alberta and Canada proved challenging due to 1) a lack of government regulations for building machines of this caliber and 2) extremely high costs to produce locally. These challenges can force manufacturers to acquire the necessary parts from overseas, where they have less control over the type and quality of the equipment, in order to meet timelines. International shipments commonly face logistical issues, leading to delays and inconsistencies with parts that sometimes require additional analysis and engineering.

In the case of the amphibious Bracke, delays in the shipment of parts from overseas resulted in a delay in the development of the machine due to additional analysis and redesign needed. This led to a delayed start to the final trial of the project. This delay pushed the trial to the end of the field season, which introduced two key limitations:

1. **Frozen conditions:** While the amphibious Bracke was able to perform well overall despite frozen conditions, logistical challenges on very frozen sites resulted in the delivery of suboptimal mounds. This resulted in fewer plots being set up for the trial than originally planned.
2. **Shorter trial window:** Because of the lateness of the trial, we focused formal testing on lowland plots alone. While trials were also planned for mesic and upland sites, more time was required at the start of the trial to test the machine and determine appropriate settings and configurations before formal plots could be implemented in these sites. Testing complications in frozen conditions also limited time available to formally trial upland and mesic sites. Field observations in upland and mesic sites were documented, however no formal data was recorded. Future testing will be necessary on a full range of sites to fully understand the versatility of the amphibious Bracke.

6 Environmental Benefits

6.1 Emissions Reduction Impacts

Summary of emissions reduction impact:

- *Restoration of legacy seismic lines using site preparation and tree planting presents an important carbon storage opportunity in Alberta.*
- *Preliminary estimates indicate that treated wetland areas capture two tonnes of carbon per year.*
- *While upright mounds had less carbon uptake than anticipated compared to standard (inverted) peat mounds in lowlands two years post-treatment, they exhibited greater variability in plant productivity and respiration compared to standard mounds.*
- *The impressive treatment speed of the amphibious Bracke means it can treat lines in 10–15% of the time of conventional methods.*

Forests are the largest terrestrial carbon sink on earth and enhanced growth via reforestation is increasingly acknowledged as a cornerstone in increasing carbon storage and mitigating the impacts of climate change (Domke et al. 2020; Griscom et al. 2017). The Government of Alberta estimates that 60% of legacy seismic lines have not regenerated to forest cover (GOA, 2017), and Cenovus estimates that two thirds of the legacy lines on the Cold Lake Air Weapons Range require active treatment for forest regrowth. Within Alberta's forests, there is a significant area where investment in forest regrowth is possible, which contributes to overall increased carbon storage and emissions reduction.

This trial has demonstrated that when active restoration occurs, site limiting factors on upland and lowland sites are addressed and we see increased tree and shrub growth post-treatment. This is an important finding. From previous research it is well known that upland and lowland sites have the hardest time regenerating naturally post-disturbance. This study provides clear evidence, through changes in moisture regimes, shrub growth response, and tree leader height response, that when 'good disturbances' are introduced into ecologically stagnant sites, we can accelerate growth and recovery of trees and shrubs on these sites. This serves to provide important information to inform future restoration within Alberta's boreal forest.

A second core environmental benefit from this study is the potential for more rapid treatments across upland, mesic and lowland sites. The Bracke was able to treat sites in 10-15% of the time of excavator-based treatments. If these treatments also provide a long-term ecological response that promotes recovery, this could enable restoration programs to cover vastly more area in a shorter amount of time. This could result in direct benefits for species like woodland caribou and could enable larger areas to be treated in far more efficient ways than current practices. This shift in efficiency still remains to be tested at an operational scale, but this trial is providing evidence that such changes in efficiency are possible.

While much of the focus of this study was on testing the Bracke mounder, a key finding of this study is the potential role of upright mounds as well. Upright mounds rapidly increase the rate of recovery by bringing trees and shrubs that are already established onto the lines. From a visual perspective, lines appear as though they are recovered within minutes of the treatments being applied. Our data also shows that upright mounds appear to be addressing high moisture issues by reducing moisture within the microsites, and we are also seeing positive growth of planted tree seedlings on these mounds. Continual monitoring of these upright mounds will help to further inform their potential role in the restoration toolbox.

From a carbon perspective, the baseline scenario for comparison is one that assumes no restoration occurs and legacy seismic lines not currently on track to achieve forest cover remain open and unforested. An additional point of comparison is a scenario by which restoration occurs but is implemented entirely using standard methods (i.e., standard mounds using an excavator). Both points of comparison serve to illustrate the emissions reduction and carbon storage potential of 1) increased restoration efforts and effectiveness and 2) technological improvements over the status quo.

Tree planting increases boreal forest stand carbon totals by 20 tonnes per hectare, equating to about 0.44 tonnes of carbon per hectare per year (Colombo et al. 2005). Mechanical site preparation techniques like mounding, hummock transplanting and tree transplanting may further increase carbon storage. Combining mounding site preparation with tree planting increases carbon storage via improved tree growth. Mounding is the current preferred method due to the small area of the site that is disturbed as compared to traditional methods. Previous studies have found no reduction in soil carbon stocks associated with mechanical site preparation and mounding was shown to increase carbon stocks by more than 20 tonnes per hectare on sites with upland characteristics (Mjofors et al. 2017).

Throughout this project, research and continuous monitoring is ongoing to quantify how much carbon is being stored within upland, mesic and lowland sites. An important consideration when it comes to estimating the amount of carbon stored is that standard mounds can contribute to the release of methane or ‘old carbon’ by exposing old carbon-rich peat when mounds are inverted in peatland sites (Schmidt et al. 2022). Both standard mounds and Bracke mounds invert peat. However, upright mounds have been proposed in response to these concerns as a method that reduces the amount of old exposed peat by exposing less surface area.

NAIT’s research aimed to quantity the carbon impacts of upright mounds versus standard mounds in wetland sites, focussing on both direct and indirect emissions associated with the restoration treatments in this trial. Results revealed insights into emissions released during site preparation and restoration activities (direct emissions) as well as understory GHG cycling during the initial recovery phase, two years post-treatment. It is important to note that the Bracke had not been deployed in wetland areas at the beginning of the NAIT trial, therefore the GHG emission analysis focused on conventional inverted mounding (standard mounds), upright mounding using a tree scoop attachment and upright mounding using a conventional bucket attachment.

Direct Emissions

Direct emissions primarily arose from transporting and operating heavy machinery, with a generic machine efficiency rating of 10-12 litres of diesel per hour used to calculate emissions. The upright tree scoop treatment consumed the most fuel due to its slower speed and longer treatment duration compared to the standard bucket treatment (Bird and Xu, 2024). When averaged per kilometer of treated seismic line, the upright bucket treatment had the lowest emissions due to its faster application rate, although it emitted more when standardized for mound density (Bird and Xu, 2024). The amphibious Bracke tested later in the trial proved significantly faster, with the potential for reducing emissions by performing the work of multiple excavators in a single pass. Overall, direct carbon emissions resulting from the operation of restoration equipment were insignificant compared to the emissions from the treated lines (indirect emissions) for the first two years after restoration (Bird and Xu, 2024). **The results of this ERA restoration project will help to further advance low-carbon restoration strategies by directly reducing the per-km emissions of restoration programs and by reducing barriers to widespread restoration efforts, which have to date been cost-prohibitive**.

Indirect Emissions

Indirect emissions were assessed by NAIT using the closed chamber method to measure CO_2 and CH_4 fluxes in different treatment areas. Restoration treatments like mounding and tree planting can offset direct emissions by promoting vegetation growth, which varies among treatment types. While both upright and standard mounds had similar net ecosystem exchange, the sum of understory plant productivity and understory ecosystem respiration, the upright mounds showed more variability in plant productivity and respiration (Bird and Xu, 2024). This variability suggests that as vegetation continues to establish and grow, upright mounds may exhibit greater carbon uptake and resilience to environmental conditions that inhibited carbon uptake in the short-term. Standard mounds showed limited CO_2 exchange, whereas upright mounds had higher CO_2 exchange due to greater ecosystem respiration rates (Bird and Xu, 2024). Both treatments emitted more CH_4 than untreated areas, driven by emissions from pools created by the restoration treatment (Bird and Xu, 2024).

Despite long-term benefits for tree productivity and carbon uptake, upright mounds showed less carbon uptake in the short-term due to drier conditions leading to moisture stress for vegetation (Bird and Xu, 2024). The 2022 and 2023 seasons were drier than average, which affected moss cover and photosynthetic activity, particularly in upright mounds that were adapted to wetter conditions (Bird and Xu, 2024). Longer-term GHG monitoring is required to capture further results as the recovering vegetation continues to grow and establish. As a result, NAIT and Cenovus plan to continue monitoring GHG emissions from this project in the 2024 field season.

6.2 Other Environmental Impacts

Summary of other environmental impacts:

- *Restoration of linear features provides important benefits to the health of forest ecosystems by reducing habitat fragmentation, improving air and water quality and more.*
- *A crucial benefit of linear restoration is advancing boreal caribou recovery, whose critical habitat is severely restricted by linear features in many parts of Alberta.*
- *A key uncertainty of the restoration innovations to date is long-term vegetation recovery, including how well planted trees grow and whether treatments that promote natural regeneration (i.e., standard mounds with tree-tipping) produce better outcomes.*

This restoration program promotes the recovery of intact forests by using various restoration techniques to restore linear features, allowing them to recover to a forest canopy. Restoration of linear features provides many immediate and future environmental benefits, including but not limited to:

- Improved air and water quality
- Increased carbon sequestration
- Reduced habitat fragmentation
- Increased biodiversity arising from:
    - Increased structural complexity (i.e., vegetation layers)
    - Increased habitat features including nesting sites, dead wood and moist areas
- Reducing the amount of "edge" habitat and associated characteristics (more direct sunlight, higher soil temperatures, less humidity, more invasive species)

A key benefit of linear restoration and an important objective for forest managers is boreal caribou recovery. Linear features put caribou at increased risk by reducing the remoteness of their preferred habitats, attracting other ungulates (deer, elk and moose) and attracting shared predators (wolves and bears). The federal recovery strategy for boreal caribou considers linear disturbances *plus a 500-m buffer* as disturbed habitat, meaning linear features have a disproportionate impact on Alberta's ability to achieve caribou habitat objectives. **Widespread, effective linear restoration programs are thus a key tool for advancing caribou recovery objectives**.

The advancement of the amphibious Bracke in terms of its significant treatment speed and ability to deliver high-quality treatments could allow for more area to be treated quickly, leading to positive outcomes for caribou. Likewise, the ability of upright mounds to directly improve habitat conditions on linear features by bringing established trees and shrubs onto lines, could reduce recovery timelines by decades on these linear features. While initial vegetation responses are positive, long-term vegetation recovery post-treatment requires continued monitoring after project completion. As time goes on, the role of tree tipping versus cutting trees onto lines as a method of closing out the line requires additional study to further understand implications for natural regeneration.

7 Economic and Social Impacts

Summary of economic and social impacts:

- *By increasing the economic feasibility of large-scale restoration programs, the technology innovations developed during this trial present important opportunities for job creation and economic diversification.*
- *Continued caribou declines present a threat to the oil and gas and forestry sectors, as failure to make recovery progress may trigger a moratorium on industrial activity, with massive economic implications.*
- *By reducing barriers to restoration programs, the technology innovations may create important job and training opportunities for Indigenous communities, including opportunities for Indigenous-led restoration programs.*

The successful development of a more efficient and effective restoration technology during this trial has important economic and social impacts that extend beyond the completion of the project. In Alberta, there are hundreds of thousands of kilometres of seismic lines that require restoration treatment to be converted back to productive forest cover.

Direct Economic Benefits and Opportunities

By substantially reducing the cost, time and emissions of site preparation per km of line, the innovations we have advanced — particularly, the development of the amphibious Bracke — have strong potential for increasing the scale of restoration programs and the jobs they create. Expanding the "restoration economy" of Alberta represents a form of diversification that supports both economic and environmental goals at once.

Direct economic benefits of planned restoration trials within the next five years following this project include employing Albertans for mechanical treatment, tree planting, program planning and businesses for tree nursery seedling stock, and purchasing equipment. Seismic line restoration in this capacity is estimated to provide significant benefits to the broader society in the form of jobs, business revenue, and stimulation of new economic opportunities in remote communities.

This project has supported entrepreneurship and innovation through local businesses in Alberta. The innovative amphibious Bracke was developed by Great Excavations Inc. and many other local project partners and employees supported the outcomes of the project including Fuse Consulting Ltd, a growing consulting company in western-Canada. The project has supported restoration and carbon sequestration research in Alberta through post-secondary partnerships with NAIT. Knowledge development has gained traction with other Alberta organizations including the Forest Resource Improvement Association of Alberta (FRIAA) and the Government of Alberta.

These technologies have opportunities for deployment across North America and beyond. There has already been expressed interest in the amphibious Bracke in the U.S. The Bracke Forest company that manufactures the Bracke attachment is based in Sweden, creating a potential for possible knowledge sharing and innovation. They likewise are exploring this new market and adoption of their technology as a potential business opportunity for their equipment.

Mitigating Economic Risk

Habitat fragmentation and caribou decline are not unique to Alberta but rather occur across the boreal forest from British Columbia to Newfoundland. The evolution of technology and Alberta-based testing of the technology throughout this project have provided important restoration learnings and knowledge contributing to more effective habitat restoration nationwide. Efforts to improve caribou habitat and restore caribou populations are important for the future of oil and gas development in Alberta. In British Columbia, the decline in boreal caribou populations led the BC Oil and Gas Commission to place an interim moratorium on new resource development in Northern BC. If efforts to support and improve caribou populations are not implemented, Alberta could face the same development restrictions which could have greater implications for the $11 billion forest industry contribution to the greater economy of Alberta.

Social and Economic Benefits to Indigenous Peoples

In the boreal forest, the ability of First Nations and Métis peoples to maintain their traditional way of life is often diminished due to oil and gas development. Human footprint, including linear features, impact Indigenous peoples directly by altering the land on which they hunt, trap and forage for traditional foods and medicines. Habitat loss and fragmentation affect caribou and other culturally significant species, affecting communities' ability to harvest and their connection with the land. Linear restoration will work towards 'healing' the land that is vital to the way of life of Indigenous communities and is an important step for reconciliation.

Learnings from this project and future restoration programs will also provide economic benefits to Indigenous communities, for example by:

- Creating training and employment opportunities as part of industry restoration programs.
- Improving the economic feasibility of Indigenous-led restoration programs and the social and economic benefits those would provide. Local First Nations communities have expressed an interest in upscaling the technology in local communities as part of their own restoration efforts.

8 Scientific Achievements

The project has led to several scientific achievements. Two manuscripts by Fuse Consulting Ltd. on vegetation assessment results and equipment performance are in preparation for publication, contributing valuable insights into linear restoration practices. Future publications are also being planned as future monitoring occurs. Matthew Pyper (Fuse Consulting Ltd.) presented at the North American Caribou Workshop on project findings in 2023 and plans to present at future caribou conservation webinar events. Dr. Bin Xu from the Northern Alberta Institute of Technology (NAIT) delivered four presentations on the Cenovus trials. Additionally, multimedia content has been captured to develop training and outreach materials in the form of 360 virtual tours in the future.

More broadly, this trial has created a significant long-term trial that is contributing data and insights that are filling critical gaps in scientific knowledge. By monitoring tree performance on a range of microsites, collecting data on long-term changes in carbon, and directly testing different equipment outcomes through a robust before and after control impact design, we believe there is a significant scientific legacy created by this trial and one that will contribute to numerous scientific publications and scientific insights in the future.

9 Conclusions

The findings from the three field trial phases conducted as part of this project demonstrate significant progress in advancing seismic line restoration practices in Alberta's boreal forest. Through rigorous testing and evaluation of various restoration technologies including mechanical site preparation implements and amphibious prime movers, the project achieved its objectives of assessing treatment methods and promoting adaptation and innovation in restoration techniques.

The project successfully identified and evaluated efficient and effective machines that support the feasibility of large-scale restoration programs, including the development of a purpose-built amphibious Bracke specifically designed for treating wetland sites. The project's emphasis on innovative technologies including the purpose-built amphibious Bracke, has led to direct emissions reductions by improving operational efficiency. This machine treats lines in 10–15% of the time of conventional equipment, even under suboptimal (i.e., frozen) conditions. Additionally, by restoring seismic lines and planting trees on created microsites, the project could potentially contribute to increased carbon storage if new growth takes in more carbon than released.

Further, the ecological efficacy of the treatments assessed in subsequent years post-treatment, provides valuable insights into their performance across different site types. The findings from the trials conducted in 2022 and 2023 showcase the effectiveness of various treatment methods in restoring seismic lines in Alberta's boreal forest. The trials demonstrated that the Bracke mounder surpassed expectations in terms of precision, consistency and speed, implementing treatments quickly while maintaining high-quality microsites across diverse site types. Additionally, tow-behind implements such as the two-row disc showed promise as a potential alternative for restoration treatments. The evaluations of standard mounds and upright mounds provided valuable insights into their performance and ecological impacts. Standard mounds, while effective in creating high quality microsites, raised concerns about the potential release of methane in lowlands due to the exposure of old carbon-rich peat when mounds are inverted. In contrast, upright mounds have been proposed as a method to mitigate this concern by reducing the amount of old exposed peat through less surface area exposure. Initial findings from NAIT indicate that upright mounds do not necessarily lead to reduced CH_4 emissions or higher CO_2 uptake compared to standard mounds in the short-term. Ongoing data collection and longer-term analysis are required to fully understand the emission impacts of upright versus standard mounds as vegetation continues to establish. This research will inform future restoration practices and help optimize the selection of treatment methods. Overall, the amphibious Bracke emerged as the most promising machine in terms of speed and versatility while maintaining microsite quality and integrity, showcasing its potential for widespread adoption in seismic line restoration projects. One major constraint of this machine, however, is the need to fell trees by hand following treatments, as opposed to the ability to perform tree tipping like with standard mounds and upright mounds. The long-term implications of these differences on site recovery and wolf movement efficiency should be closely studied. The ability of upright mounds to directly create live tree and shrub vegetation on a site also has the potential to accelerate recovery timeline by decades.

The project's outcomes highlight the importance of continued innovation and adaptation in restoration practices to address the challenges of restoring seismic lines in Alberta. The outcomes of this project are expected to contribute to increased carbon storage, emissions reduction and ecological resilience in forest ecosystems in Alberta and beyond.

10 Next Steps

The next steps for the technology include plans for another restoration trail in the spring of 2024 to implement the developed technology in partnership between Great Excavations Inc. and Cenovus.

While there are no further plans by Great Excavations to rapidly commercialize the amphibious Bracke, sharing the knowledge and results of this project by bringing the right people into the room who can adopt the technology and generate demand for commercialization is an identified next step. The innovation cycle throughout the project involved the creation of new ideas based on existing commercialized equipment which led to the creation of new products combining various aspects of the technologies, which in turn inspired further innovation.

At this stage, upscaling the technology to the next stage is out of the developer's hands, requiring additional interest from the industry and other partners to provide the capital required to advance the technology. Another potential next step is to partner with First Nations communities who have expressed interest in upscaling the technology in local communities to advance the technology.

Fuse Consulting Ltd. and Swamp Donkey Solutions are also actively working with partners in western Alberta and eastern British Columbia to assess interest in testing this machine on a wider range of site types, including areas primarily dominated by uplands.

Continuing to test and adapt the technology operationally is hoped to increase traction from other industry partners and will continue the partnership between Cenovus and Great Excavations Inc. Ultimately, the most important next step is to continue to share the learnings and knowledge that resulted from this project within the industry to enhance linear restoration practices within Alberta and beyond.

11 Communications Plan

There are a few key aspects of knowledge sharing that are part of a broader communications plan following the completion of this project. Videos, reports and data documenting the restoration technologies and their learnings will be shared with the oil sands industry, the Government of Alberta and academics within the Boreal Ecosystem Recovery and Assessment (BERA) program. Experimental results will also be shared with members of the Pathways Alliance who will share the information with related organizations and member companies.

Additionally, various scientific reports are in progress to publish results which will be shared with the broader scientific restoration community. Presentations will also be given as opportunities to present themselves at conferences, etc. Cenovus will continue to be available to present or share the results of this trial with relevant organizations associated with linear restoration with the hopes that other industry partners will use the results of this study to increase the effectiveness of their restoration programs. Ultimately, the overarching goal of the communications strategy is knowledge sharing of the project results and technology leading to increased business opportunities for existing equipment and implement owners.

12 Literature Review

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