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Restoration Innovation Roadmap Phase 1

A Synthesis of Lessons Learned to Date

Prepared for:
Regional Industry Caribou Collaboration (RICC)

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Report Date:
May 3, 2019

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Executive Summary

Restoration within woodland caribou habitat has become a common tool in the conservation and range planning toolbox for woodland caribou in western Canada. Current programs have successfully moved restoration from an experimental concept to one that is now being applied within large portions of woodland caribou ranges. Despite this ongoing work, organizations delivering programs have indicated that a clear summary of the current state-of-knowledge related to restoration does not exist. Such a synthesis is a key tool for facilitating adaptive management within restoration programs and for expediting learnings and efficiencies in future projects.

To address this gap, this first phase of a Restoration Innovation Roadmap was initiated by the Regional Industry Caribou Collaboration (RICC). This report aims to synthesize key learnings related to research, implementation, and monitoring of existing restoration programs. The intent of summarizing these key learnings is to provide a clear state of knowledge related to restoration in western Canada and to facilitate the use and adoption of these key learnings by consultants, environmental advisors and policy makers. Following this report, a second phase of the Restoration Innovation Roadmap will focus on identifying future opportunities to significantly reduce the costs of restoration while maintaining or improving the effectiveness of these treatments.

Core Opportunities to Reduce Costs and Improve Effectiveness

This project focused on summarizing the key learnings related to planning, implementation and monitoring of restoration programs. Through this synthesis, the following eight recommendations for opportunities to reduce restoration costs and improve effectiveness emerged. Additional opportunities will be highlighted in the second phase of the Restoration Innovation Roadmap project.

1) Studies from both north-east Alberta and west-central Alberta have shown that vegetation on linear features is a key deterrent to wolf use and movement along these lines. **Re-establishing vegetation trajectories to sufficient densities on linear features appears to be a key tool for reducing wolf movement efficiency on the landscape**.
2) **Achieving the 65% undisturbed habitat target is possible in many ranges when the impacts of fire are excluded**, and modelling has been completed to guide a prioritization process. However, key decisions will need to be made to achieve this target. Leaving lines open for active dispositions (e.g., gas wells and associated pipelines), not restoring these other types of dispositions during legacy seismic line restoration programs and leaving high densities of lines open for trappers will likely compromise the effectiveness and efficiency of restoration efforts. Negotiations with disposition holders and exploring creative ways to maintain trapper access while effectively restoring linear features should be explored.
3) **Restricting restoration activities to winter is a major constraint and ongoing uncertainty for restoration programs**. Sometimes programs are encountering too much frost, other times too little frost, and frozen ground conditions leave little room for error and put operator safety at

risk. Numerous contractors and consultants stated that a focus on solely winter operations leads to high uncertainty and this uncertainty is likely to increase with climate change.

4) **Creating more time and space for planning is critical**. Restoration planning takes time and was noted by all interviewees as a key stage for reducing costs for programs. Planning reduces risks, improves efficiency of equipment, and creates space to plan treatments to be most effective. However, restoration contracts are still often awarded with short timelines for delivery. In some cases, contracts have been awarded in November with expected delivery in January (i.e., two months later). Evaluating the feasibility of extending these timelines, and specifically targeting the award of contracts a minimum of one year prior to expected treatments is suggested. While this may be logistically challenging for funding organizations, rushed planning has been shown to lead to higher costs and less effective outcomes – both of which pose a real risk to restoration programs within woodland caribou habitat. Considering longer term planning opportunities, such as planning out a restoration area with a five-year timeline, could also provide opportunities for companies with non-producing gas wells and other dispositions to consider including these in a restoration program.

5) **Operator training and availability is a major constraint.** Organizations regularly stated there is a shortage of workforce capacity to deliver restoration treatments, and those contractors that are available have limited to no experience in restoration. This increases safety risks on programs and can compromise effectiveness of treatments. Hosting training workshops, encouraging use of the COSIA/NRCan Silviculture Toolkit and Virtual Tours for restoration, and retaining workers for subsequent programs is a necessity for improving restoration efficiency and effectiveness.

6) **Investing in new equipment is expensive and carries high risk.** Through our interviews, we heard that many companies would be willing to invest in new equipment, but the high uncertainties related to awarding contracts means that most will use existing equipment (e.g., standard excavators) and restoration specialists may not emerge. Developing a small pool of companies that are specifically selected to deliver restoration work over the next 10 years could provide the necessary stability for contractors to invest in new equipment. Such a process could see companies apply to be added to the list and to be provided a higher likelihood of work once selected. A high standard of quality and cost competitiveness would then be required to remain a preferred contractor. Such an approach would clearly need to be carefully balanced with the need for innovation and competitiveness.

7) **There is a need to explore new innovations for creating microsites in restoration.** Studies to date have shown that mounding, tree planting, and applications of woody materials/stem bending are key tools in the restoration toolbox which are working to re-establish vegetation and reduce predator use of lines. However, operators are still using conventional approaches to create these microsites (e.g., through the use of excavators). Focused studies on how to innovatively create these microsites using new equipment and/or new techniques could significantly improve the effectiveness and efficiency of restoration programs.

8) **Drones and Unmanned Aerial Vehicles (UAVs) are on the cusp of incredible efficiency.** Through interviews with leading scientists, we heard that drones and UAVs have enormous potential to

contribute to both efficient planning and monitoring. For example, solar powered drones already exist that could survey entire programs to a high standard of quality. The limitation is not the technology available; rather, it is the current regulatory requirements for line of sight operation of drones. Once regulations are established, many more opportunities will present themselves for efficient data collection to guide planning, implementation and monitoring.

Cost Reporting

Through interviews with contractors and company representatives, we found there was considerable consistency between the perceived relative cost breakdowns for restoration programs. Individuals reported with reasonable consistency the following allocations of costs for the various stages of a restoration program:

Total Restoration Costs = Planning (20-30%) + Implementation (65-75%) + Monitoring (3-5%)

We suggest that a cost metric should break implementation costs into treatment costs and incidental costs. While this adds a layer of complexity to the cost metric, by breaking costs into these categories, organizations will be better able to understand how access costs, treatment efficiencies, and other variables drive the total cost of restoration. We suggest here that the extra effort required to establish this breakdown will pay off by providing more opportunities to learn across programs and identify efficiencies that can be modelled in future programs.

$$\text{Linear Cost} = \frac{\text{Planning (\$)} + \text{Treatment Costs (\$)} + \text{Incidental Costs (\$)} + \text{Monitoring (\$)}}{\text{Total KM in Project – Advanced Regeneration}}$$

$$\text{Adjusted Linear Cost} = \frac{\text{Planning (\$)} + \text{Treatment Costs (\$)} + \text{Incidental Costs (\$)} + \text{Monitoring (\$)}}{\text{Total KM in Project (Including Advanced Regeneration)}}$$

Acknowledgements

This project was made possible by funding from the Regional Industry Caribou Collaboration (RICC). Imperial Oil, Devon Canada, and CNOOC provided funding for the work. The project was administered by the Alberta Biodiversity Monitoring Institute.

We would like to express our thanks to the individuals who participated in interviews with us as part of this project. Their perspectives contributed greatly to the insights and synthesis contained within this report. Specifically, we would like to thank: Kristen Foxcroft (Cenovus), Rochelle Harding (CNOOC Limited), Jon Gareau (CNRL), Caroline Hann (Meg Energy), Andrew Vandenbroeck (Silvacom), Brian Coupal (Independent), Bruce Nielsen (Woodlands North), Geoff Sherman (Woodlands North) and Paula Bentham (Golder Associates).

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1. Introduction

The Case For an Innovation Roadmap

Restoration within woodland caribou habitat has become a common tool in the caribou conservation and range planning toolbox in western Canada. Current programs have successfully moved restoration from an experimental concept to one that is now being applied within large portions of woodland caribou ranges within Alberta (e.g., Cenovus LiDea program). From 2016–2017 alone, restoration commitments from various organizations totaled at least 7,500 km of linear restoration. Restoration has also emerged as a key tool in range planning efforts within Alberta, with current large-scale projects focused on planning and delivering restoration projects within the Cold Lake, East-Side Athabasca River, Little Smoky, A La Peche, Bischto, and Yates caribou ranges (Figure 1).

Despite this ongoing work, organizations and consultants delivering programs have cited that a clear summary of the current state-of-knowledge related to restoration does not exist. Such a synthesis is a key tool for facilitating adaptive management within restoration programs and for expediting learnings and efficiencies in future restoration programs. To address this gap, the Regional Industry Caribou Collaboration (RICC) and Fuse Consulting Ltd. have identified that a clear opportunity exists to develop a multi-phase innovation roadmap to guide restoration programs for years to come.

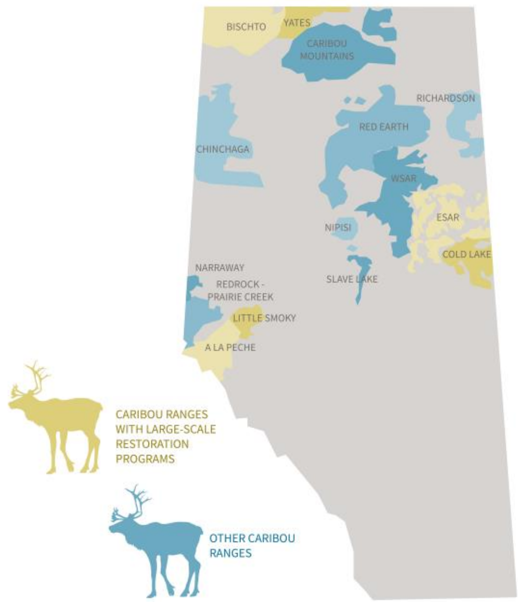

Figure 1. Alberta woodland caribou ranges with large scale restoration projects.

The first phase of this Restoration Innovation Roadmap (this report) seeks to synthesize key learnings related to research, implementation, and monitoring of existing restoration programs. By summarizing these key learnings, the intent is to provide a clear state of knowledge related to restoration in western Canada, and to facilitate the use and adoption of these key learnings by restoration funders, consultants, environmental advisors and policy makers. A second phase of the Restoration Innovation Roadmap Project will then identify up to 30 key innovations that could drive significant improvements in ecological effectiveness and economic efficiency of restoration programs.

The goal of this roadmap is to establish an ambitious, far-reaching vision for significantly reducing restoration costs while maintaining or improving the ecological effectiveness of treatments. This synthesis, however, is not intended to be an introduction to restoration programs. Readers that are new to the topic are encouraged to review additional documents that introduce key concepts related to linear restoration (Pyper et al. 2014, Dabros et al. 2018).

The case for restoration

Significant resources have been invested in woodland caribou conservation over the last 15 years in western Canada. Much of the discussion and implementation has circled around both population management and restoration objectives. For example, studies have recently documented the positive short-term effects of population management for woodland caribou. Specifically, studies have demonstrated that wolf control has been successful in reducing the rate of woodland caribou population decline and stabilizing the population (Hervieux et al. 2014). Similarly, a recent analysis has shown that using individual population control measures such as maternity penning and alternate prey management, or preferably combinations of these, can lead to short-term increases in caribou populations (Serrouya et al. 2019).

These studies highlight the critical role that population management fills in the woodland caribou conservation toolbox. However, in order to translate positive outcomes from population management approaches into long-term population growth for woodland caribou, restoration within high quality habitats must be considered a key priority (Hervieux et al. 2014). Similarly, population control measures, such as wolf control, will likely need to be paired with progressive approaches to conserve and restore habitat in order to maintain public support for these aggressive management techniques (Hervieux et al. 2014, Serrouya et al. 2019).

Restoration of linear features has long been considered a key requirement for addressing wolf movement efficiency concerns on the landscape (James et al. 2004, Latham et al. 2011, Athabasca Landscape Team 2009) and fragmentation that benefits alternate prey (James et al. 2004). Recent studies have shown that with increasing vegetation heights along seismic lines, wolf movement efficiency is reduced (Dickie et al. 2017) and wolf selection for seismic lines decreases (Finnegan et al. 2018). As on-the-ground restoration continues to expand in western Canada, monitoring programs have helped raise awareness about what works, and what doesn't, in terms of restoration activities. These key learnings are captured through this report.

The challenge, as with many complex ecological questions, is to determine the key drivers of success and to focus on carefully replicating these in future restoration programs to maximize the efficiency and effectiveness of restoration work within woodland caribou ranges. Rather than seeing restoration and population management approaches as competing techniques, academics, planners and policy makers must recognize the importance of both tools to achieve caribou conservation objectives.

Restoration treatments: a focus on vegetation recovery and functional goals

While there has been considerable debate about the intended goals of restoration work (Pyper et al. 2014, Golder Associates 2014, Dabros et al. 2018), there is growing awareness that to maximize the value and impact of restoration, treatments must focus on addressing site limiting factors and promoting vegetation recovery on linear features. Similarly, these studies acknowledge the importance of pairing these long-term vegetation recovery goals with short-term goals of reducing wolf and human movement efficiency along linear features. For example, the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta 2017) sets the long-term goal of restoration as the return of vegetation cover with species capable of reaching the canopy. However, they also highlight the importance of functional restoration approaches such as woody materials, stem bending etc. Evidence of success for techniques such as fencing, which are strictly focused on wolf movement objectives, is also weak (Bohm et al. 2015). This growing focus on restoration that achieves both wolf movement objectives and vegetation recovery objectives serve as a key guidepost for future restoration programs.

An example of a restoration treatment delivered within the Cold Lake Caribou Range.

The cost of restoration

Despite the potential benefits of restoration for woodland caribou populations, there is no denying the considerable costs of this technique. Pyper et al. (2014) documented an average range of restoration costs of $8,000-$12,000 per linear km of restored line. More recent implementation experience suggests this cost range is robust, however some programs have cited costs as low as $6,000 per km and as high as $34,000 per km. These costs are considerable, especially when multiplied by the approximately 270,000 km of linear features which may require restoration within woodland caribou ranges in Alberta. This statistic alone points to the need to innovate and reduce restoration costs while maintaining or improving ecological effectiveness.

Part of the challenge of interpreting these cost metrics, however, is that there has been no standard reporting metric for restoration programs. As an example, some programs have included considerable winter access costs within their cost metrics, while others have not as they have been able to leverage adjacent reclamation programs to cost-share key winter road costs. Use of a consistent cost metric could provide significant value for comparing and sharing learnings across programs.

Structure of this report

This report is designed to synthesize the key learnings related to restoration of linear features from the past five years (2014-2019). The goal is to inform the adaptive management cycle by synthesizing key learnings to date which can be used to improve future implementation and learning. This report is therefore broken into planning, implementation and monitoring sections. Within each section of the report, key opportunities to apply learnings to improve efficiency and effectiveness of restoration programs are identified. **These brief summaries can be found at the end of each sub-section of the report.** The document then concludes with a proposal for a standardized cost metric, and a summary of key learnings and future knowledge gaps to guide restoration programs.

2. Planning

Planning is arguably one of the most important steps in delivering restoration programs to achieve efficient and effective implementation. Organizations regularly state that more time spent on planning leads to more efficient operations and more effective treatments to achieve ecological objectives. Planning also ensures that restoration treatments have the best potential to make a meaningful contribution to woodland caribou conservation (Government of Alberta 2017). This section synthesizes key learnings related to planning restoration programs. The insights in this section of the report are captured from academic papers, restoration implementation reports, and company interviews. The following topics are covered:

1. Setting restoration goals with a focus on vegetation heights.
2. Natural regeneration – how to detect it and when to expect it.
3. Streamlining the prioritization process for more efficient planning.
4. Novel tools and techniques can enable flexible scheduling.
5. Lessons learned through operations.

Setting Restoration Treatment Goals With a Focus on Vegetation Heights

Setting a restoration goal is a key step in restoration planning and informs the required treatments. Numerous studies have recently improved knowledge related to wildlife and human use of linear features, and this information can be used to develop science-based objectives in restoration planning.

Wolf movement can be slowed by relatively short vegetation

It is now well accepted that linear features afford a movement advantage to wolves, allowing them to travel faster and farther as they search the landscape for prey (Dickie et al. 2016). Wolf movement rates in northeastern Alberta were found to be 2-3 times faster when traveling on linear features (Dickie et al. 2016). However, these movement rates were dependent on the height of vegetation on linear features. Dickie et al. (2017) found that increasing vegetation height was associated with reduced wolf selection of linear features and reduced wolf movement speed. A threshold of ~0.50 m in vegetation height was associated with a substantial drop in wolf movement rates. Compared to surrounding forest, a linear feature with minimal vegetation resulted in a 4.4 Km/h increase in wolf travel speed, whereas a linear feature with 0.50 m vegetation only offered a 1.5 Km/h increase in wolf travel speed. This effect of even slightly higher levels of vegetation was particularly significant in upland sites (Figure 2).

In western Alberta, within the Little Smoky and A La Peche ranges, Finnegan et al. (2018) also found that wolf movement was deterred in the summer on linear features with vegetation heights greater than 0.7 m (Figure 2). However, they also noted that higher vegetation heights were associated with higher wolf use in the spring. While the study did not explicitly test why, the authors suggest this could have been attraction to areas due to higher densities of alternative prey (Finnegan et al. 2018). Grizzly bears, meanwhile, selected for linear features with lower vegetation heights in the spring and summer, but did not appear to have higher movement rates along these features.

Figure 2. Wolf movement rates can be reduced considerably with relatively short vegetation. Taller vegetation is required to slow wolf movement such that it matches the surrounding forest.

These studies provide support to the idea that re-establishing vegetation along seismic lines provides resistance to wolf travel and use, particularly in the summer months. It is particularly noteworthy that two studies from different research teams (i.e., Dickie et al. 2017, Finnegan et al. 2018), using independent methods, have arrived at a similar threshold for initial impacts of vegetation height on wolf movement of 0.5-0.7m. This vegetation height is also listed as the minimum height threshold for re-vegetation within the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta 2017).

A key takeaway, therefore, is that re-establishing vegetation along seismic lines at sufficient densities does appear to be a viable strategy for reducing wolf movement efficiencies. While both studies focused specifically on vegetation heights, one area for future research is whether functional restoration approaches, such as applying stem bending or other woody materials to treated lines, might result in similar wildlife responses at similar treatment heights. At the very least, operators should seek to elevate woody materials on lines to increase the likelihood of creating a movement obstacle for wolves and other species.

In order to achieve more complete changes to wildlife use of linear features, higher vegetation heights are required. For example, Dickie et al. (2017) found that wolf movement rates did not match the adjacent forest until 33% of the vegetation on a linear feature had exceeded 4.86 m (Figure 2). This study provides important perspective to the goals of restoration and to determining appropriate metrics for the evaluation of restoration success. In order to block wolf movement on lines, vegetation re-established through restoration treatments should be allowed to reach a minimum height of ~5.0 m and to achieve sufficient densities along linear features.

This 5.0 m threshold has been incorporated into the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta 2017), alongside requirements for tree species to be capable of reaching the forest canopy over time. Such recommendations are in line with evidence in the literature and should provide better clarity to what the long-term goal is for achieving restoration. As a point of caution, **programs that seek to achieve lower vegetation thresholds, densities, or compositions than those cited here are likely to prove ineffective and may compromise the credibility of restoration as a viable tool in the caribou conservation toolbox.**

Off-Highway Vehicle (OHV) use of linear features is also reduced by taller vegetation

While Dickie et al. (2017) showed that vegetation height reduced wildlife movement, Pigeon et al. (2016) have also demonstrated that higher vegetation heights serve as a key deterrent to OHV use of linear features in west-central Alberta. Off-highway vehicle (OHV) use is a significant challenge for restoration planners, as OHVs can damage regenerating vegetation and keep linear features open for predators like wolves (Van Rensen et al. 2015). Establishing restoration goals at heights and densities that deter OHV use is likely to further improve the long-term value and effectiveness of restoration treatments.

Example of a seismic line where OHV use has impeded recovery. Photo credit: Woodlands North.

Pigeon et al. (2016) found that OHV use was most associated with dry seismic lines with low vegetation, with ease-of-travel being the main factor determining OHV use. OHV use was minimal on lines with vegetation exceeding 2.4 m - 4.3 m. Beyond this height threshold, lines were no longer found to be at high risk of OHV use (Figure 3).

Figure 3. Relatively tall vegetation is needed to prevent OHV use on linear features.

These conclusions from Pigeon et al. (2016) point to an important implication: treatments that won't reach a height of 2.4 m - 4.3 m height in the short-term will likely require additional functional treatments, such as woody materials, mounding, stem bending etc., in order to further deter human use. These findings also further emphasize the importance of focusing long-term restoration goals on establishing tall vegetation heights to maximize deterrents for future OHV use. Finally, without a comprehensive engagement strategy that outlines where trails will be maintained, restoration programs are unlikely to realize their objectives as treatments may be re-disturbed by continued OHV traffic.

Recommendations for restoration

- Planners should recognize the critical importance of long-term vegetation heights and densities to achieving restoration goals. Treatments that do not achieve high enough vegetation density, or that do not promote vegetation with the potential to reach above 5.0 m, may compromise the success and credibility of restoration approaches. In these cases re-treatment may be needed, which will significantly increase costs.
- While shorter (i.e., 0.5 m) vegetation heights appear to effectively reduce wolf travel speed, using a taller height threshold (i.e., 2.4 m - 5.0 m) as a restoration objective, and as a criterion for identifying advanced regeneration, will provide a more accurate reflection of whether the movement advantage afforded to both wolves and OHVs has been addressed.
- When restoration treatments are delivered in areas with high OHV use, treatments that do not immediately achieve a vegetation height of 2.4 m - 4.3 m should be paired with functional approaches to reduce mobility along lines (e.g., mounding, stem bending) in an effort to avoid having to re-treat these features.
- Restoration work that occurs in regions with high OHV use should develop comprehensive plans to balance the needs of OHV users and the woodland caribou conservation goals. Zonation approaches for OHV access and caribou conservation, identifying trails to leave open, or other forms of engagement are likely necessary as restoration work continues to expand in scope.

Advanced Regeneration – How to Detect It and When to Expect It

Advanced regeneration presents both an opportunity and a challenge for restoration programs. Linear features with existing advanced regeneration present an opportunity for cost savings, as active restoration efforts like mounding or planting may not be needed. Recent research has improved the ability to predict where advanced regeneration is most likely to occur.

Advanced regeneration is less likely in very wet and very dry ecotypes

Not all linear features will have the same regeneration trajectory over time. Van Rensen et al. (2015) found regeneration is least likely in especially wet ecotypes, on wider linear features, and close to roads.

Using LiDAR-derived canopy data and a 3 m threshold for regeneration (consistent with the minimum green-up rule in Alberta forestry regulations), Van Rensen et al. (2015) found that site characteristics had a dramatic effect on the presence of advanced regeneration. Mesic sites with 2 m - 3 m depth-to-water were likely to have advanced regeneration, whereas disturbed fens were unlikely to reach the 3 m vegetation height threshold even after 50 years from the initial disturbance. In general, particularly dry or wet sites were least likely to have advanced regeneration. Lines that were wetter, wider, closer to roads, and in lowland ecosites were the least likely to have advanced regeneration (Figure 4).

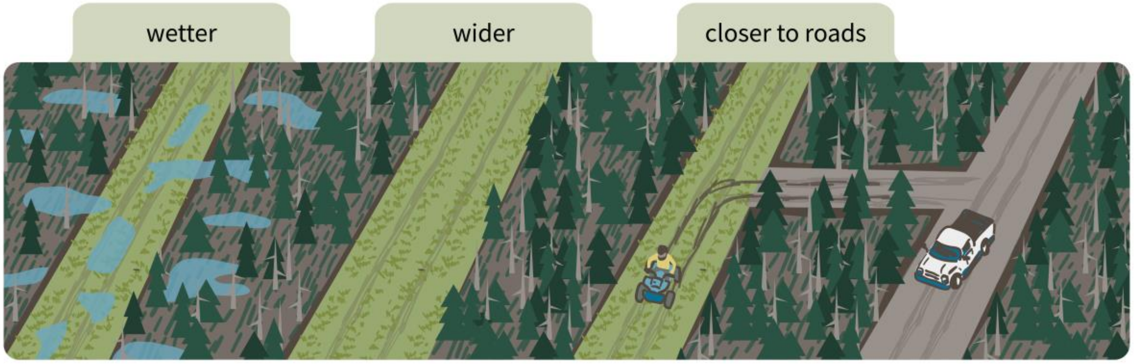

Figure 4. The site limiting factors that decrease the amount of advanced regeneration on a linear feature.

Pigeon et al. (2016) also found that OHV use was most associated with dry seismic lines that had low levels of advanced regeneration.

Taken together, these studies suggest growing awareness of key variables that can be used to inform modelling approaches for detecting advanced regeneration areas. To our knowledge, no efficient and reliable approach to predicting this advanced regeneration is currently available. This is largely because recent, publicly available LiDAR data are not available for most of the woodland caribou ranges. The most recent data at a large scale, purchased by the Government of Alberta, were captured in 2007, in most cases. This means that significant regeneration could have occurred since the data was captured. Alternatively, it could also mean that areas that previously showed sufficient regeneration may have been re-explored through recent seismic programs (Figure 5).

While field-based reconnaissance can help determine whether advanced regeneration does in fact occur on lines, as restoration programs expand in size the possibility to visually or aerially inspect all line segments becomes logistically challenging. Future studies that focus on building a robust modelling approach for predicting advanced regeneration, with subsequent field testing, would provide significant opportunities to more effectively plan out restoration programs. Such planning could then potentially reduce costs by understanding where advanced regeneration currently exists. Restoration planners could start by exploring opportunities to merge the methods developed by Hornseth et al. (2018), Pigeon et al. (2016), and Van Rensen et al. (2015). We suggest that agencies could explore the cost/benefit of purchasing recent LiDAR data for woodland caribou ranges to facilitate more efficient modeling and planning.

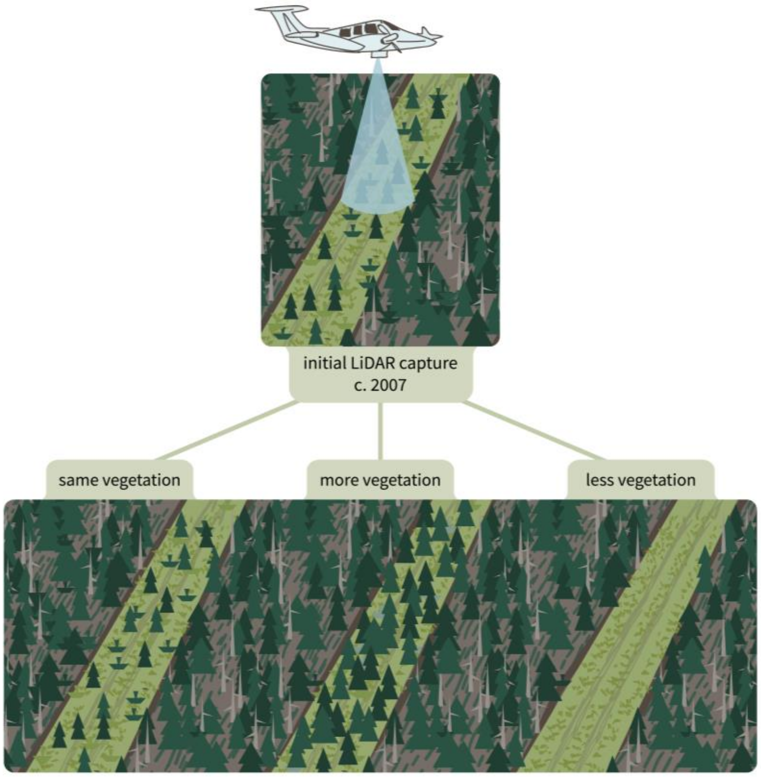

Figure 5. In the years following the initial capture of LiDAR data, a given site may have remained largely the same, it may have regenerated considerably, or it may have been re-explored (less vegetation).

Recommendations for restoration

- Age of a seismic line is a poor predictor of seismic line recovery and more sophisticated modelling techniques are required for predicting advanced regeneration. New models that can accurately predict advanced regeneration without new LiDAR acquisition should be explored.
- Alternatively, investing in new LiDAR data within woodland caribou ranges with active restoration planning could significantly reduce the planning costs associated with restoration. This data would make widespread modelling of vegetation recovery on lines more accessible and accurate. It would also provide accurate pre-treatment data which could reduce monitoring costs. A cost/benefit analysis should be completed for LiDAR acquisition.
- Linear features that are wetter, wider, and closer to roads are less likely to exhibit advanced regeneration. Planners should expect to prescribe restoration treatments on these features.
- OHV use can hinder advanced regeneration on linear features otherwise amenable to vegetation growth. Planners should model the factors associated with OHV use in their study area and seek ways to limit OHV use to reduce future costs associated with retreatments.

Streamlining the Prioritization Process for More Efficient Planning

With thousands of kilometres of linear features available for restoration, selecting landscapes that will provide the most benefit to woodland caribou is a key step in the planning process. In recent years, research has produced numerous recommendations for linear feature prioritization. These prioritization exercises have the potential to stretch restoration dollars further by maximizing the caribou conservation benefits gained from each linear feature restored. However, different studies on linear feature prioritization have focused on different spatial scales, which are difficult to compare. These various recommendations are combined here into a framework, from the coarsest scale to the finest scale. Using this framework, restoration planners can streamline the planning process and confidently identify high-priority areas in which to begin restoration. Such prioritization is likely to help manage costs and improve ecological effectiveness of restoration treatments.

Prioritization at the township level – get the most bang for your buck

Caribou broadly avoid anthropogenic disturbances (MacNearney et al. 2016); therefore, creating large, contiguous areas of undisturbed habitat should be a primary goal. This is best achieved if prioritization begins from a coarse landscape perspective. Two COSIA-led prioritization exercises have explored ways of maximizing gains in undisturbed habitat for minimal cost at the township level (ABMI 2016, ABMI 2017). The process is relatively straightforward and accounts for the possibility of future resource extraction on the landscape.

Each township across five caribou ranges (Cold Lake, West-side Athabasca River, East-side Athabasca River, Richardson and Red Earth) were first evaluated for how much new undisturbed habitat would be gained if all features were restored (the “bang”). This is then divided by the density of seismic lines in each township, which represents the cost of restoration (the “buck”). Dividing habitat gained by cost gives a “bang-for-buck” for each township. This metric is then weighted by a resource valuation layer, which reflects the likelihood that the township would be subject to future resource extraction activities. Townships are then distributed equally into five “zones” according to priority level (ABMI 2016). A second iteration of this prioritization process has also been developed which made several adjustments to the initial prioritization layer and stratified the analysis across each caribou range (ABMI 2017).

$$\frac{(\text{\% disturbed habitat} - \text{\% disturbed habitat remaining if restored})}{(km \text{ seismic lines}/km^2)} = \frac{\text{BANG}}{\text{BUCK}}$$

$$\frac{\text{BANG}}{\text{BUCK}} \times \text{resource valuation layer}$$

Simulating restoration using this method reveals some key considerations for restoration planners to maximize efficiency and ecological outcomes. While seismic lines are the greatest factor affecting the amount of disturbed habitat, restoring both seismic and other dispositions at the same time is often a substantial improvement over restoring seismic lines alone (ABMI 2017). Essentially, seismic lines should guide the prioritization process, but other features should be considered when restoration efforts are planned out for that township (Figure 6). Within the study area for this prioritization exercise, if seismic lines and other dispositions are restored in the three highest priority zones, and fire is excluded, the federal target of 35% undisturbed will be reached in all caribou ranges (using the Environment Canada metric). If only seismic lines are restored, up to 56.3% of the caribou range area will remain disturbed.

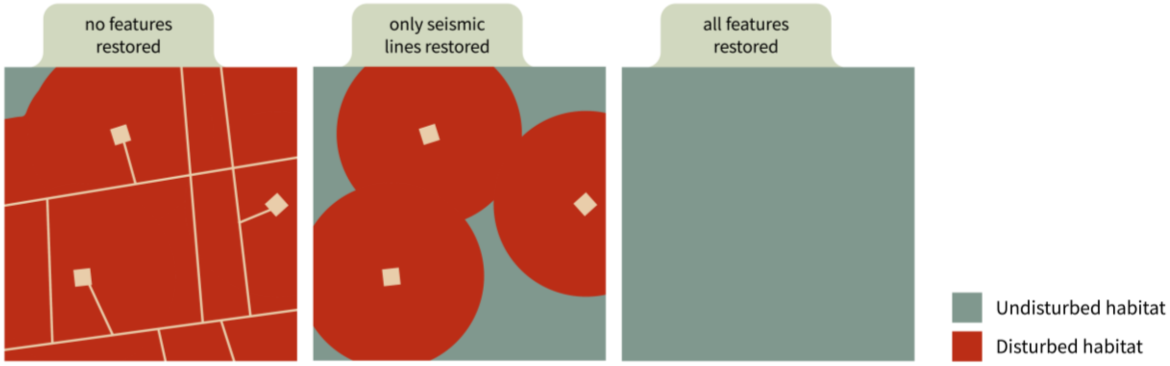

Figure 6. Restoring both seismic lines and other dispositions (e.g., gas wells) significantly improves opportunities to achieve the disturbance threshold in the federal recovery strategy.

The main strategic advantage of prioritizing restoration by township is that it can help maximize the economic investments in restoration over the long term. It achieves this by attempting to avoid future development areas and keeping the focus on identifying and restoring features within large, contiguous areas of woodland caribou ranges.

Create intact caribou refugia by treating lowlands first

Once a township has been selected for restoration, planners should identify habitat areas that are most essential to woodland caribou recovery. Woodland caribou traditionally use lowlands as refugia from predators during calving. However, linear features have compromised the integrity of these refugia by allowing predators increased access (DeMars and Boutin 2017). Wolves strongly select for linear features in lowlands and avoid lowlands without linear features (DeMars and Boutin 2017). Because female caribou using linear features are more likely to lose their calf, and wolves likely need only a few linear features to effectively search lowland areas, restoration efforts should aim for these lowland areas to be fully intact (DeMars and Boutin 2017). Thus, restoration planners should focus on creating intact caribou refugia within lowlands before addressing drier upland areas of the township.

Logistical constraints and efficiencies with moving equipment into and among lowland areas require more thought. Once equipment is into an area it may simply make sense to treat all lines in that area. However, it appears that there is at the very least significant merit in scientifically testing the impact of fully restoring only lowlands, versus restoring both lowlands and uplands in an area. Similarly, there may be opportunities for more intensive treatment in lowlands (e.g., mounding) with lower intensity treatments on uplands (e.g., ripping, scalping etc.) depending on site limiting factors.

Focus on linear features that are least likely to regenerate on their own

When deciding which candidate linear features should receive restoration treatments planners should first, where logistically feasible, eliminate those which have sufficient advanced regeneration. Of the remaining features that do not meet advanced regeneration height thresholds, those with characteristics least associated with successful regeneration should be highest priority. Focusing first on peatland refugia serves a dual benefit, as lowlands are already more likely to contain the linear features least amenable to natural regeneration. In general, wetter features are least likely to regenerate on their own, with disturbed fens unlikely to meet a three-metre height threshold even 50 years post-disturbance (Van Rensen et al. 2015). Xeric sites appear to exhibit lower regeneration rates than mesic sites, so these should be higher priority when restoring upland areas. However, more research is needed to make a definitive recommendation.

Consider preventing OHV access to linear features waiting for treatment

OHVs can act as a limiting factor preventing natural regeneration. OHV use is most likely to occur on upland lines (Pigeon et al. 2016, Hornseth et al. 2018), which are coincidentally less likely to be represented in high-priority lowland refugia. Upland linear features would also be the most amenable to natural regeneration if not for the presence of OHVs. If OHV access to these lines could be prevented early in the restoration program, it is possible that some would undergo natural regeneration while active restoration efforts are undertaken in higher-priority peatland refugia. By the time restoration efforts are directed towards these lower-priority areas within the township, more lines may have reached the vegetation height threshold for advanced regeneration and no longer need active restoration treatments, thus saving costs.

Various means of temporarily preventing OHV access should be explored, such as restoring or blocking portions of lines at intersections with roads. A potential opportunity for an adaptive management experiment would be applying access management treatments to upland areas only while fully treating lowlands. Camera traps or ARUs could be used to detect human use of linear features. Discovering what treatments will deter OHV users is a key knowledge gap, and previous authors have suggested that full restoration will be required to address this issue (Vinge and Pyper 2012). If the only viable method to deter use is complete restoration along the length of the linear feature, then these areas should not serve as a distraction from restoration of high-priority lowlands which serve as key refugia for woodland caribou.

Seek opportunities for adaptive management

While this framework for prioritizing linear features can act as a starting point for restoration programs, planners should seek to remain flexible and take advantage of learning opportunities when choosing where and when to apply restoration techniques. Experiments conducted at a broad landscape scale can help fill knowledge gaps and identify potential cost savings for future restoration programs.

For example, an experiment could be conducted comparing three landscape-level treatments: treating only lowlands, treating only the transition from uplands to lowlands, and treating only uplands. The degree to which these treatments affect predator use of lowlands areas could be assessed using camera traps and/or collar data. Such experiments can help reveal the relative importance of the spatial overlap vs numerical effects of caribou predators. Whatever the objective, such studies should be conducted using a robust, adaptive management approach in order to provide value to future restoration programs.

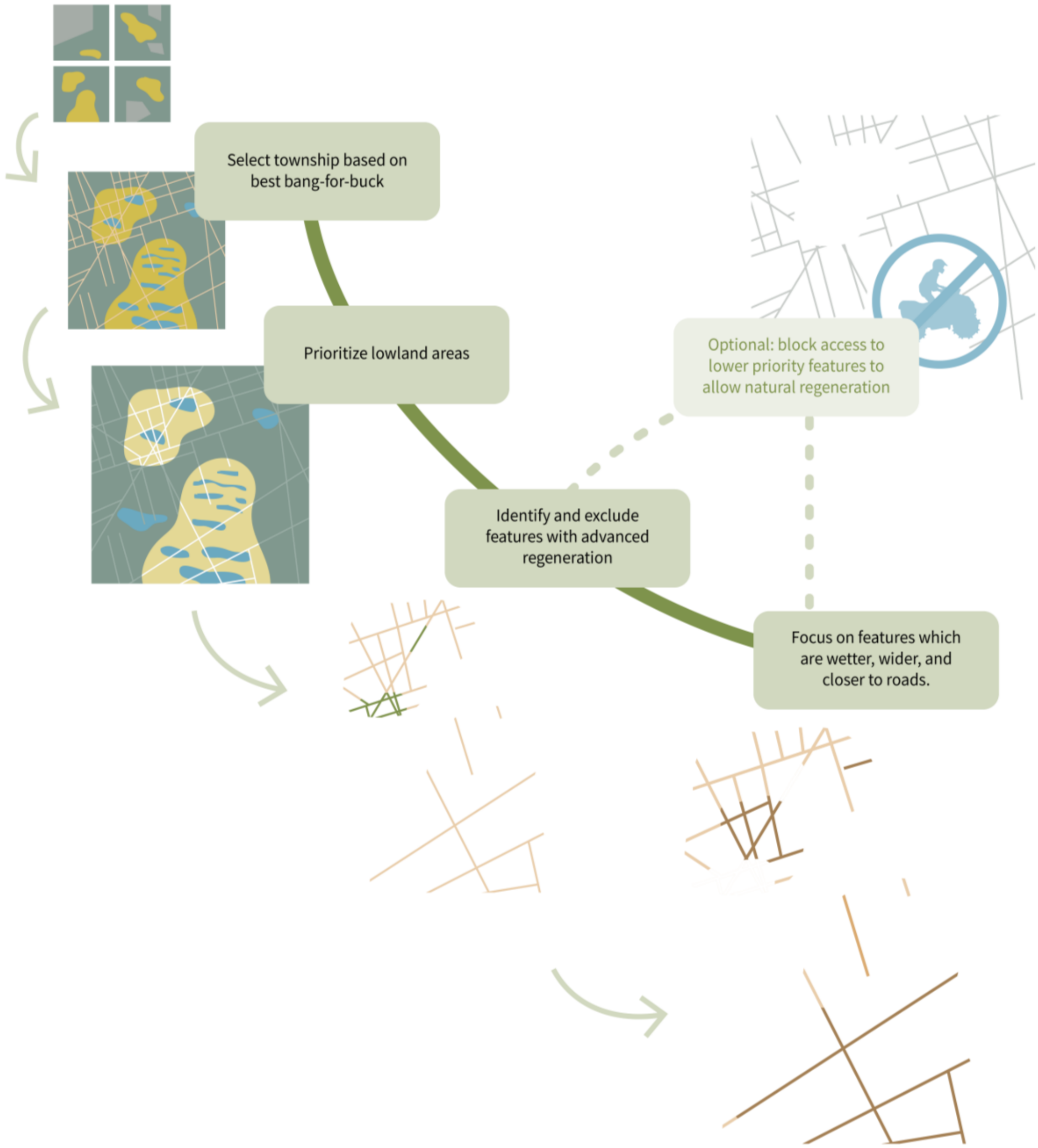

Figure 7. A streamlined approach for prioritizing restoration efforts.

Recommendations for restoration:

- High priority linear features should be identified by starting from a broad, township level before working down to individual features (Figure 7). Once identified, these features should guide mobilization planning so that they are treated as early as possible in the restoration program.
- While the prioritization process can help expedite benefits to caribou, it should not be considered overly prescriptive. Planners should also consider opportunities for adaptive management experiments at various scales.
- In order to achieve disturbance threshold objectives outlined in the federal recovery strategy, organizations should seek opportunities to restore non-producing or non-productive gas well sites and other disturbances, where possible, to expedite the efficiency of restoration and the anticipated ecological effectiveness.

Novel Tools and Techniques Can Enable Flexible Scheduling

Seasonal constraints can be a source of significant expense for restoration programs. When excavators and other heavy machines are dependent on frozen conditions, a delay in frost establishment can set back a restoration program by several weeks. Greater flexibility in scheduling a field season would allow restoration planners to find efficiencies in their restoration programs. Over the past few years, novel tools and techniques have been tested to remove some of the seasonal constraints facing restoration planners.

Winter planting is a viable option

Traditionally tree planting has been restricted to the summer months, consistent with approaches used in forestry. However, due to the remote nature of linear restoration programs and the fact that many areas are in difficult lowland areas, there has been considerable focus placed on finding more flexible timing for planting programs. Winter planting is a technique that allows for greater flexibility in logistical planning and potentially savings on mobilization costs (i.e., the same crew performing mounding or other treatments could plant at the same time, as opposed to mobilizing a new crew in the spring). So far, studies have seen favourable outcomes for winter-planted seedlings.

In a trial at the Evergreen Center near Grande Prairie, Alberta, nearly 500 black spruce seedlings were planted in a pilot study (Tan and Vinge 2012). Planting occurred immediately after mound creation. Two seedlings were planted on each mound at depths of 4 and 8 cm deep. A second group of seedlings from the same stock were spring-planted to offer a comparison. Good survival rates (>94%) were seen in all planting treatments, though seedlings winter-planted to 4 cm experienced 4-5% lower survival (Tan and Vinge 2012). No difference in survival was seen between the seedlings that were winter planted to 8 cm depth and the spring-planted seedlings. Winter-planted seedlings did exhibit greater damage to terminal buds and branches (46% and 58-86%, respectively) (Tan and Vinge 2012). Planting to a depth of 8 cm resulted in less damage compared to the seedlings planted to 4 cm deep. Vertical growth was good across all seedlings (10-20 cm) although spring-planted seedlings grew 4-7 cm taller (Tan and Vinge 2012).

A more recent trial by CNRL found similar success (Golder Associates Ltd. 2017). Both tamarack and black spruce seedlings were winter-planted (tamarack were exclusively planted in winter, so no seasonal comparison was possible). Tamarack seedlings did particularly well (99% survivorship) and are recommended for inclusion in future planting treatments, especially in treed fens (Golder Associates Ltd. 2017). Overall, summer and winter-planted black spruce were comparable in terms of growth and survival. While black spruce survivorship was somewhat higher on summer-planted lines, winter-planted black spruce tended to be taller and have greater leader growth compared to summer-planted seedlings (Golder Associates Ltd. 2017). Winter planting conducted as part of the Algar Caribou Habitat Restoration Project was also successful with excellent survival rates. Like the Evergreen trial, planting depth appeared to be an important factor, along with microsite selection and larger seedling size (Silvacom 2018).

Cracking of mounds is one issue planners should be mindful of. In the Evergreen trial, high mounds with straight sides were found to erode more easily and may have contributed to some seedling mortality (Tan and Vinge 2012). The CNRL study found that seedlings seemed to grow better when planted higher up on mounds and when mounds did not substantially settle and crack (Golder Associates Ltd. 2017). They detected no seedlings on cracked mounds, suggesting they may have slipped into the cracks and died (Golder Associates Ltd. 2017). Similarly, documentation of lessons learned at the Algar site indicated that compressing mounds slightly at the time of creation helped reduce settlement and mound deterioration (Silvacom 2018).

Based on these monitoring programs, winter planting appears to be a robust treatment that can be used on linear restoration programs. While a detailed cost comparison to summer planting has not been completed, the efficiency afforded to programs by planting at the time of treatment is anticipated to reduce costs. However, continued monitoring is required to better understand how timing of winter planting, and conditions after planting, affect winter survival. For example, with increasing variability in winter conditions, warm spells that thaw the ground could pose specific risks to recently planted seedlings. More research and monitoring are recommended to better understand these specific drivers of survival and performance. Long-term monitoring is also required to ensure short-term success results in long-term performance.

Amphibious restoration can support summer work, but further testing is needed

Restoration work has traditionally been carried out in winter months in order to ensure enough frost establishment to support equipment on lowland sites. However, expanding restoration opportunities to include the summer and fall seasons could offer several benefits to restoration operations, including a reduced need for ice road construction (Pyper and Larsen 2016a, 2016b). Mounding rates in non-frozen conditions are also likely to be more predictable since the machines are not contending with frost conditions. Smaller machines can also be used as less force is required to break through the peat layers in non-frozen conditions. Finally, the extended working season (28-32 weeks vs 6-10 weeks) and longer daylight hours could also increase efficiency and productivity of restoration programs (Pyper and Larsen 2016a, 2016b). It is estimated that a summer restoration program using amphibious excavators could be delivered for 45-60% the cost of a similar winter program (Pyper and Larsen 2016a). However, specialized tools will be necessary to safely operate on non-frozen terrain. Specifically, specialized equipment is needed to safely mobilize crews to and from active treatment areas.

Amphibious excavators are one such tool that would allow linear restoration work to be performed in non-frozen conditions. Such machines use specially modified undercarriages to apply ultra-low ground pressure, meaning they do not require the same ground support as traditional excavators (Pyper and Larsen 2016a, 2016b). COSIA member companies have performed several pilot studies to determine the viability of amphibious equipment for linear restoration in Alberta.

An example amphibious excavator.

In a brief trial, a large Trax 200 machine and small Bobcat E50 machine were tested in peatland conditions in north-eastern Alberta. Both machines crossed peatland and upland sites with ease and no soil rutting was observed as a result of the equipment (Pyper and Larsen 2016a). Creek crossings were also executed with minimal disturbance (i.e., no stirring up of the sediment) other than some flattening of vegetation beside the creek. No limitations on restoration techniques were observed, as both machines could perform mounding, stem bending, tree transplanting, etc. It is estimated that the amphibious excavators could treat 0.9-1.8 km per day compared to the 0.8 km per day typical for winter programs (Pyper and Larsen 2016a).

In a follow-up trial, an amphibious excavator and a low ground-pressure (i.e., Nodwell) excavator were tested in non-frozen conditions. Both excavators performed well at conducting restoration activities and travelling over upland and lowland sites (Pyper and Larsen 2016b). However, the transit speed of the amphibious excavator was noted as a limitation (Pyper and Larsen 2016b). The Nodwell excavator, while able to transit at a faster pace, exhibited a significant "wobble" during treatment delivery which could result in significant operator fatigue and nausea (Pyper and Larsen 2016b). Modifications to the machine could reduce the wobble issue and increase the transit speed (from 2 km/h observed in the trial to an estimated 5.2-6.2 km/h) (Pyper and Larsen 2016b).

The testing and performance of these amphibious machines is an important area of work that could significantly improve restoration work and reduce costs over time. Amphibious excavators have the potential to permit almost year-round restoration work, which could significantly improve the flexibility of restoration programs and offer equipment operators more stable employment throughout the year.

Recommendations for restoration

- Multiple monitoring programs have shown that winter planting is a viable option for restoration, and planners can take advantage of opportunities for planting during mounding operations. Caution should however be taken as there is not yet sufficient knowledge about how seedlings respond to variable winter conditions (i.e., planting during an uncharacteristically warm or cold period).

- Mounds should be formed with sloped sides to prevent cracking, and winter-planted seedlings should be placed deeper into mounds to ensure survival and optimal growth.
- Tamarack seedlings appear to be a good candidate for winter-planting, especially in treed fens.
- Heavy-equipment designed for performing restoration in non-frozen conditions should be explored in more large-scale trials. While amphibious excavators travel more slowly, the advantages of a longer operating season, longer daylight hours, and more predictable weather conditions may offer significant opportunities for cost savings (Figure 8).

Figure 8. Traditional versus alternative program scheduling and deployment opportunities.

Planning: Lessons Learned From Active Programs

An effective plan can set a program up for success but figuring out how to make that plan and what road bumps to expect in the execution of that plan can be challenging. We interviewed several experienced restoration planners and asked them to share some of their key lessons learned. Here, we cover some common themes that impact the success of the planning process.

Lessons Learned	Rationale	Key Considerations
Start earlier than you think	- Organizing a program involves frequent delays and approvals. - Approvals and permits must be secured early, and trees must be ordered up to 18 months in advance.	- Starting planning as early as possible will help minimize impacts of delays on program delivery. - Securing experienced operators and contractors may expedite the approval process.
Take the time to do it right	- A well thought out plan that includes opportunities to restore a range of dispositions can improve restoration outcomes.	- Provide enough time to consult stakeholders and build a well thought out plan. - Consider reaching out to stakeholders whose involvement can improve restoration outcomes (e.g., other disposition holders).

There is no current substitute for ground-truthing	- LiDAR and other data sets may be out of date and will require ground verification.	- Taking the time to plan and ground truth areas of the treatment plan during snow free conditions will help reduce the number of surprises and delays during field implementation.
Streamline communication with contractors	- Programs involve diverse professionals.	- Creating a single communication point of contact will help streamline clarity and communications. - Regular feedback about quality control to operators improves efficiency and effectiveness of restoration.
Stay flexible	- A well-planned schedule can always be thrown off by unexpected events. - On the ground treatments will always need to be adapted on the ground – to some degree.	- Establishing clear goals and decision processes will help ensure field-based decisions still help achieve the broader goals of the restoration program.

3. Implementation

Now that several restoration programs have been implemented, the opportunities to capture insights and lessons learned through this implementation is significant. This section synthesizes the key learnings to date. The insights in this section of the report are captured from interviews with consultants and industry managers, review of implementation reports, and academic papers. The section covers the following topics:

1. Choosing a Holistic Approach Rather than Strictly Functional Techniques
2. Innovative Implements Can Help Expedite Treatments
3. Lessons Learned from Industry Operations

Choosing a Holistic Approach Rather than Strictly Functional Techniques

Caribou recovery has been a central focus in discussions about linear feature restoration. Because increased predator movement and access have been identified as a key mechanism by which linear features impact caribou (Dickie et al. 2016, DeMars and Boutin 2017), techniques that prevent features from acting as movement channels have been of interest (Dabros et al. 2018). Such treatments (i.e., those that obstruct predator movement) are referred to as “functional restoration.” While functional restoration techniques have received past attention, restoration planners are encouraged to consider more holistic silvicultural methods aimed at habitat restoration for the reasons described below.

Fences are difficult to maintain effectively

Fencing is one technique that focuses solely on functional aspects of restoration, but there is poor evidence for their effectiveness. In a pilot study, Bohm et al. (2015) deployed snow fences at 15 treatment sites near Fort Nelson, BC. Camera traps were used to measure predator use, baited with a lure at the centre of the linear feature intersections. Snow fencing appeared ineffective at preventing predators from accessing line intersections. Snow tended to bury or damage fences, which compromised their effectiveness as a barrier in the following snow-free season, and wolves appeared to simply move around the fencing while still using treated linear features (Bohm et al. 2015).

Because of these durability issues, wire mesh has been suggested as a better option (DeMars and Benesh 2016). However, wire mesh fences require stakes for structural support, which come with increased costs (DeMars and Benesh 2016). Hydrogeophysical features of the area and the degree of disturbance to the soil (DeMars and Benesh 2016) can also increase the cost of installing the treatment, and any cost-benefit analysis should include the expenses of repeated repairs to the fencing on an annual basis (Bohm et al. 2015). Given their inherent reliability issues and apparent ineffectiveness, fences are not recommended as a restoration technique.

High woody material volumes work, but are impractical at larger scales

Woody materials applied to linear features have been acknowledged as a tool for reducing predator use of lines. For example, by applying large amounts of woody materials, the Statoil Kai Kos Dehseh Caribou Pilot Project reduced wolf use year round (>50%) and essentially eliminated OHV use of linear features

(Pyper et al. 2014). However, the treatment intensity of 200 m^3/ha is unrealistic at a larger program scale and introduces other hazards to landscapes such as increased fire risks. While this study is unlikely to be replicated at large scales, it does emphasize the relative value of applying high enough densities of woody materials to lines to function as a movement barrier. Future studies should keep this in mind when selecting woody material densities for their programs as very low levels of woody materials may not achieve restoration objectives (e.g., Tattersall et al. *in prep*).

Recommendations for Restoration

- Fencing as a restoration technique has poor evidence for efficacy and will incur repeated costs through annual maintenance and eventual removal. Alternative techniques, such as tree felling, mounding, and coarse woody debris may provide similar functional benefits while having the benefit of being applied alongside silvicultural techniques such as mounding that can expedite the recovery of trees and vegetation on the site.
- Holistic restoration techniques that encourage a return to forest cover will leave organizations less exposed to risks associated with re-treating lines and will have an added benefit of providing value to other species on the landscape that may respond negatively to linear features.
- Organizations implementing restoration techniques can learn from these functional studies and should be aware that more woody material on a linear feature creates a more effective movement barrier. Studies should seek to help determine ideal levels of woody materials that balance fire risks, costs, and changes to movement of predators on linear features.
- Organizations should also acknowledge that too low of levels of woody materials are not likely to be effective for reducing predator movement efficiency.

Innovative Implements Can Help Expedite Treatments

Using excavators to treat linear features is a slow, methodical process that requires a highly skilled operator. New tools offer opportunities to automate and expedite the restoration process, which could result in significant cost savings. Here, we profile some of the work COSIA member companies have done to test new specialized tools and identify some important considerations planners should make to ensure robust testing of their effectiveness.

Examples of microsites resulting from the tow-behind shark-fin drum.

New tools can speed up treatments, but organizations need to ensure ecological goals are still met

Along with amphibious excavators, COSIA member companies have conducted trials of other specially-designed implements for operating in non-frozen conditions, including a pull-behind implement for creating microsites (the Shark Fin Drum), and a conventional tree spade. While the tree spade performed poorly in lowland habitats, it may have specific applications in upland areas or in areas where rapid closure of lines is required (e.g., to reduce OHV access). The pull behind Shark Fin Drum remained a promising option for summer restoration (Pyper and Larsen 2016b).

The Shark Fin Drum was effective at creating a high number of microsites at an impressive rate of 1500 m/h (Pyper and Larsen 2016b). However, to be used effectively in a restoration program, considerations will need to be made to provide a seed source or physical seeding and to conduct tree felling or stem bending with different equipment (Pyper and Larsen 2016b). This tool is also limited to upland habitats and the long-term viability of the created microsites is unknown. Planners should consider opportunities for testing the effectiveness of this site preparation treatment, such as comparing predator use and seedling growth on linear features treated with the Shark Fin Drum versus those treated with a traditional excavator.

A trial comparing the effect of mound size on seedling growth was initiated at the Evergreen Centre by Natural Resources Canada in late 2018. One issue with smaller mounds is that as they settle over time, seedlings may no longer be sufficiently raised above the water table. Determining a minimum effective mound height in different ecotypes should be a research goal of future restoration programs, and seedling survival should be carefully monitored at sites using implements like the Shark Fin Drum.

Recommendations for restoration

- Tow behind implements have the potential to transform the efficiency of treating upland sites, especially in areas where creation of microsites and opportunities for natural regeneration exist (e.g., mesic sites).
- The Shark Fin Drum, or other tow behind implements, are a promising option for creating microsites, and restoration planners should consider testing its long-term effectiveness.
- Restoration plans that incorporate the use of pull behind devices like the Shark Fin Drum may need to use complimentary equipment (i.e., tree fellers) to adequately treat a site.
- Considering the potential increases in treatment speed, there appears to be significant innovation opportunities related to equipment that could significantly improve the efficiency of restoration programs, particularly those located on upland sites.

Implementation: Lessons Learned from Industry Operations

While a good plan can anticipate many of the needs and challenges of a program, some lessons only become clear during the execution. We interviewed restoration planners from several RICC member companies and asked them to share their major lessons learned from conducting restoration programs. Here, we summarize the key recurring themes that emerged from these interviews.

Lesson Learned	Rationale	Key Considerations
Experienced operators are essential	- Operators must understand proper treatments and how treatments will change over time. - Costs are driven down significantly as operators become more confident.	- Train and retain good operators. - Finding experienced operators and consultants can be difficult and training programs are needed to expand workforce capability. - Capitalize on recent training tools like the COSIA/NRCan silviculture toolkit and virtual tours.
Working off-lease leads to unexpected challenges, but often has more value for woodland caribou	- On-lease programs have more control over restoration areas. - Off-lease programs have experienced challenges with camp vandalism, and development over restoration areas.	- Remote programs incur higher access and safety costs. - In-demand operators may struggle with remote camp situations. - Restoration in areas close to active programs can find cost efficiencies by sharing costs for roads etc.
Winter planting appears effective	- Several companies have been satisfied with winter planting results. - Typical treatment paces are 1-1.5 km/day for planters and mounding operations.	- Cracking of mounds poses risks for seedlings. Slightly compressing mounds may aid in reducing cracking. - Larger seedlings may perform better but should be tested. - Mound size is important to prevent seedling drowning over time. - Tamarack trees could be used in wetter areas and performed well in one winter planting application.
Variable winter conditions affect program schedules	- Changes in weather are a key factor contributing to restoration complexity and costs. - Conventional equipment requires frozen ground conditions. - Late onset of frost, cold temperatures with no snow, or too much snow can all greatly impact programs.	- Exploring options for expanding restoration beyond winter seasons would result in less weather dependency. - Contingencies may be required for winter programs as weather changes can result in significant additional costs.
Plans must remain flexible during implementation	- Planning is critical, but all programs change once applied on the ground.	- Having full clarity on restoration goals can guide on-site decision making and ensure restoration treatments deliver on the intended goals built into the planning process.
Scales of economy matter	- Programs often note that it takes up to two weeks for operators to fully understand and apply treatments efficiently.	- Establish larger programs that span longer time periods to capitalize on efficiencies. - Seek opportunities to find and retain good talent for future years and/or programs.
Regular communication with operators is key	- By providing operators with regular, timely feedback, better outcomes are observed.	- Establish a system of quality control and feedback that is timely and respected by operators.

4. Monitoring

Monitoring is a critical component of any restoration program. There are two types of monitoring: implementation monitoring (did crews do what they were supposed to?) and effectiveness monitoring (are the ecological objectives of the program being met?) (Bunnell and Dunsworth 2009). Implementation monitoring acts as a form of quality control, ensuring that any future conclusions made regarding effectiveness are not based on flawed implementation of treatments. Effectiveness monitoring is what allows organizations and researchers to gain new insights, discover better ways to achieve restoration, and generate new research questions.

Without robust, scientifically credible monitoring, organizations can be left in the dark on which treatments are most effective. By valuing and prioritizing a robust monitoring program, organizations can not only be scientific leaders, but can identify efficiencies for their own programs more quickly. Monitoring programs may include vegetation plots, survival assessments, or wildlife monitoring.

Monitoring is a critical component of programs that seek to be verified for restoration actions, such as those implemented as part of Provincial Restoration efforts and evaluated through the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta 2017). Here we summarize key learnings from monitoring programs to date.

How Effective Has Restoration Been So Far?

Several restoration projects have now had several years to respond to treatments. What have we learned from the monitoring of these programs after the initial implementation? This section highlights some key insights from ongoing monitoring work.

Restoration accelerates the road to recovery

Overall, the results of restoration treatments have been very encouraging. While a complete return to forest cover is expected to take many years, there is now evidence that restoration treatments accelerate this trajectory.

Emerging work led by Cenovus (Filicetti et al. 2019) has found that tree planting in peatland sites can significantly alter the rate of regeneration. Planted linear features had 1.6 times more tree stems/ha than untreated lines and 1.5 times more stems/ha than the adjacent undisturbed forest. This is particularly notable considering the treated sites averaged 3.8 years in age since treatment, whereas the untreated sites were 22 years old. Golder Associates (2017) also found success with planting in lowlands: most seedlings appeared healthy and with good survivorship in the immediate years post-treatment. Just one survey plot contained unhealthy black spruce seedlings, and only one survey plot exhibited low survivorship. These mortalities appear to have been due to a stock problem, rather than problems with the treatment. Several studies have found that summer and winter planting are comparable as restoration treatments, with seedlings exhibiting similar growth and survival (Golder Associates 2017, Tan and Vinge 2012). Several years after treatments were applied at the Algar restoration project, seedling survival has been excellent (Silvacom 2018). Mounding appeared to not only benefit the planted seedlings, but also facilitated the growth of additional regenerating vegetation (Silvacom 2018).

Where restoration treatments have failed to establish healthy seedlings, operator expertise has been noted as an important factor. When planting on mounds, the size and shape of the mounds should be carefully considered. High mounds with straight sides are prone to erosion and cracking, which may kill seedlings by exposing their roots (Tan and Vinge 2012). Seedling placement is also critical. On wet sites, seedlings should be placed on the top of mounds to raise them above the water table, whereas on dry sites, seedlings should be placed at the hinge of the mound so that the seedling roots have access to the rich soil located at the base of the mound (see COSIA/NRCan Silviculture Toolkit www.360tours.cosia.ca/toolkit).

Planting locations and seedling species selection also proved to be critical lessons learned from one of the earliest restoration programs in Alberta, the Caribou Range Restoration Program in the Little Smoky range. In a follow-up monitoring assessment, Golder Associates (2015) found that in some cases pine seedlings were planted in shady sites and struggled to establish. Another issue with site selection was that black spruce seedlings were often planted on the top of mounds to try and improve light access, but this created unfavourable moisture conditions. Planting seedlings at the hinge of the mound would have likely produced better results (Golder Associates 2015).

These studies emphasize an important point: restoration techniques are not simple to implement effectively. Effective operator training and close quality control and coaching at the time of treatment implementation are critical aspects of any program. Organizations should seek to leverage two recent COSIA products focused on this goal, the first being a Silviculture Toolkit to educate operators how to apply techniques (www.360tours.cosia.ca/toolkit/), and the second being a virtual tour to help operators see what outcomes they are striving for (www.360tours.cosia.ca).

Restoration can impact predator use from an early stage, but treatment intensity matters

Some emerging research has found that silvicultural restoration treatments can mitigate some of the effects of linear features on wolf movement efficiency. McNay et al. (*In Prep*) found that wolves shifted their use towards less intensely treated linear features within their home range, and wolf travel speed was reduced by a third on heavily treated lines. Similarly, camera trap monitoring from the Algar restoration site suggests that predators may still be using treated lines (Tattersal et al. *In Prep*). While not directly tested, it is possible that the level of woody materials applied to the lines was not enough to serve as a functional movement barrier for predators on lines as low levels of woody materials were applied due to restrictions on project approvals (Andrew Vandenbroeck, Personal Communication).

Carbon benefits of site preparation are also emerging

Approximately 20% of the world's soil carbon is contained in peat (Joosten et al. 2016), and disturbance to lowlands from oil sands exploration (OSE) activity can cause prolonged flooding and a vegetative shift towards sedges, which oxidizes the peat (Murray and Xu 2018). This process can turn the peat from a carbon sink into a carbon source. In Alberta alone, seismic line impacts on peatlands may have caused additional emissions of 4.4-5.1 kt CH4 yr-1 (Strack et al*. In Prep*). Even though mounding creates pools that release methane (CH_4) into the atmosphere, Murray and Xu (2018) found that mounding contributes to greater tree height which can turn a linear feature into a net carbon sink. Organizations seeking opportunities for carbon offsets should consider this benefit of linear restoration and monitor carbon dynamics at their own sites and across different ecotypes.

Recommendations for restoration

- Overall, restoration treatments appear to work well. They can accelerate a site's trajectory towards recovery markedly over untreated sites.
- Adjustments to operational procedures (e.g., differences in mound size) can be critical to the later success of a restoration treatment.
- Emerging effects of restoration treatments are a reduction in wolf travel speed and use of linear features and benefits for carbon storage. These benefits are expected to grow over time.

New Approaches: BERA Imaging Advances For Rapid Data Collection

Traditional field methods for evaluating vegetation can be expensive and time consuming. Rapid advances in imaging technology and analysis have revealed new ways for planners to reduce costs in restoration programs, particularly for monitoring. The BERA project has been particularly productive in testing new imaging tools in real-world applications. Here, we profile some of the recent work from this program. These tools and techniques can be applied both to initial surveys of areas targeted for restoration (e.g., to identify areas with sufficient advanced regeneration) and to the monitoring of vegetation recovery after restoration treatments have been applied.

UAVs are positioned to revolutionize field data collection

Accurately assessing and monitoring vegetation status is important to determine the success of linear restoration efforts. Traditional survey methods that require field crews to assess vegetation manually, however, are time-consuming and difficult to scale. While LiDAR can provide detailed datasets due to its ability to penetrate canopies and produce a complete vertical profile of vegetation, capturing LiDAR data is very expensive, and repeated observations required for monitoring can significantly increase these costs over time.

UAVs present an exciting opportunity to collect detailed vegetation survey data without the high cost of LiDAR or the hassle of traditional ground-based field surveys. Researchers have recognized the need to determine the viability of this technology and have explored operational tests of UAV technology in diverse environments.

The primary restriction preventing widespread deployment of UAVs in restoration programs is not a technological one, but a legislative one. Regulations surrounding the piloting of UAVs has been slow to keep up with the rapid uptake of this technology, and only recently were the rules clarified for operation within line of sight. However, effective application of UAVs over the spatial scales required for linear restoration will require operation beyond line of sight. Once regulations are revised to permit such use, planners can expect already developed technologies will rapidly be commercialized, such as blimps and winged aircraft that can operate using solar power (Dr. Greg McDermid, Personal Communication). Such technologies are already used in military operations and could represent a paradigm shift for industrial monitoring programs.

Cheap, reliable consumer-grade cameras are likely sufficient for UAV-based monitoring

UAVs can be fitted with a variety of sensors for data collection. These include consumer-grade cameras, multispectral sensors, or even miniaturized LiDAR. However, the newer technologies have gone through less real-world testing and are subject to problems like overheating (Dr. Greg McDermid, Personal Communication). Miniaturized sensors (such as LiDAR or multispectral Sensors) for UAVs fail to capture the same quality data as their full-sized counterparts that are used on fixed wing aircraft, making it difficult to justify the extra cost. For current monitoring programs, the humble, reliable, and familiar consumer-grade camera appears to be the best option for consistent results and minimal hiccups.

What can restoration planners learn from the data collected using a UAV mounted camera? The answer is surprisingly broad (Figure 9). There are two general ways the imaging data can be processed. The first is to analyze the spectral data. This 2D data set can be used to assess similarly 2D metrics. For simple counts of seedlings present on linear features, machine learning algorithms can be used to detect seedlings in the UAV-captured images. Using such a setup, Feduck et al. (2018) detected seedlings at a rate of 75.8% and reported very good agreement with estimates from ground surveys. Similarly, Fromme (2018) was able to detect an average of 8 out of every 10 seedlings using consumer grade images. Detection performance depends on the flight height of the UAV; however, the algorithm performed well even on down-sampled images which were similar to what would be captured from a height of 145 metres (Fromme 2018). Ongoing work by Gustavo Lopes Queiroz (BERA 2018) is applying similar techniques to

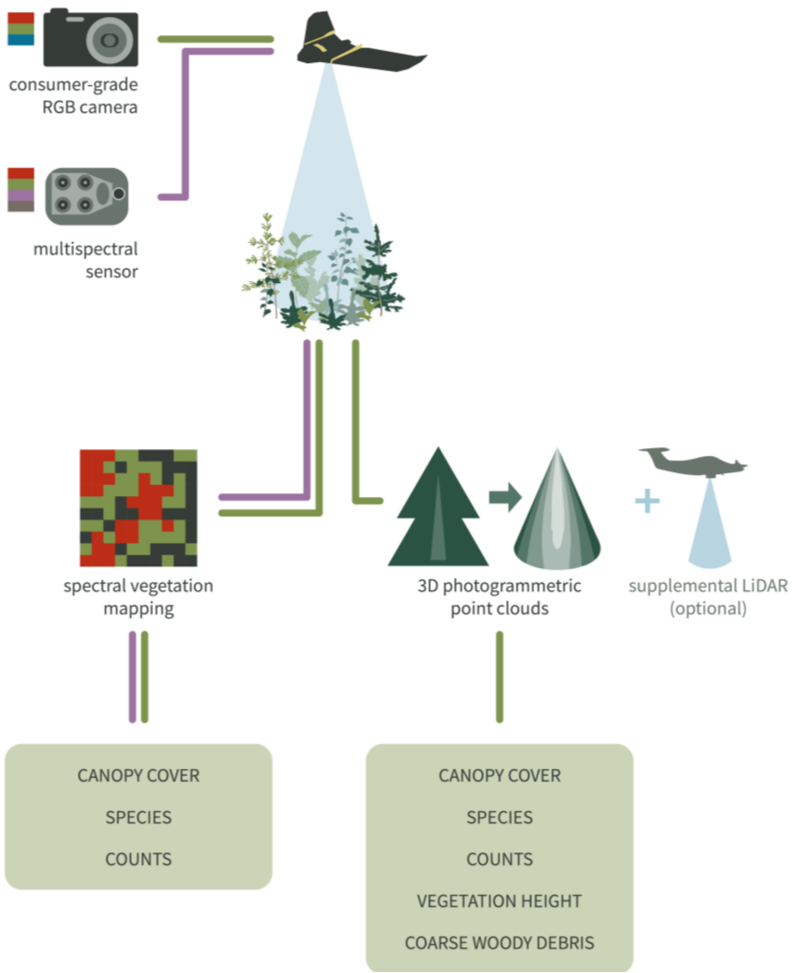

Figure 9. A schematic of options for UAV-based data collection.

the detection of coarse woody debris on and off linear features, with the aim to better prescribe treatment densities in woodland caribou ranges.

UAVs can supplement traditional methods of assessing and monitoring vegetation

For more detailed vegetation surveys, including those of vegetation height, other image processing techniques are available. In a first-ever study characterizing vegetation on linear disturbances, Chen et al. (2017) determined whether 3D structures derived from UAV photogrammetry (so-called "photogrammetric point clouds") could complement or replace traditional ground surveys of vegetation height. Photogrammetric point clouds are made up of many combined photographs taken from different vantage points, and are used to create a detailed, 3D structure of a small area. While complex, photogrammetric point clouds do not require special sensors to produce. As with spectral analyses, a consumer-grade camera can reliably provide the necessary imaging.

UAV photogrammetry alone produced similarly accurate vegetation height estimates as the UAV data supplemented with LiDAR estimates of terrain. Chen et al. (2017) also found that when comparing specific points, there are significant differences between field survey estimates and point clouds from UAV photogrammetry. However, these differences may be less a problem with UAVs, but rather reflect biases of traditional field methods, which are influenced by the subjective judgement of field crews. More recent work has found that the consistency and accuracy of UAV data are comparable or superior to estimates derived from traditional field methods (Alberta Biodiversity and Conservation Chairs 2018).

Using UAVs instead of LiDAR or traditional field surveys could result in savings of thousands of dollars. Assuming a survey of thirty 150-metre-long plots, Chen et al. (2017) estimated costs as follows: $16,900 for traditional field surveys, $14,344 for UAV supplemented with LiDAR, and $10,463 for UAV data alone. These estimates include equipment, ancillary data purchase, data collection, and data processing. Considering these costs across a large scale restoration program, the potential cost savings could be significant. Further work by Michelle Filiatrault is currently underway to better determine the data requirements for accurately measuring conifer seedling height (BERA 2018).

This work has clearly shown the potential of UAV imagery, and the potential opportunity of collecting data that is more cost effective than LiDAR. Ongoing engineering improvements in UAV technology will also continue to increase their value, and include improved autonomy, stability, navigation, real-time orientation, battery efficiency, payload capacity, and sensor capability (Franklin and Ahmed 2017). These improvements could help to overcome some of the current constraints such as limited flight times and flight distances.

Species detection is more difficult, but promising advances have been made

With consumer grade cameras, some species detection is possible by analyzing which wavelengths are most reflected by different plants in the image (known as spectral analysis). However, this technique is not at a stage where it can be reliably used for detailed vegetation surveys, and a multispectral sensor (i.e., one that captures green, red, near-infrared, and red edge spectra) may be warranted to improve accuracy (Ahmed et al. 2017a). Highly reflective bands (green and near infrared) are most helpful for species classification (Franklin and Ahmed 2017). Given more extensive training datasets, machine learning approaches can likely improve species detection based on a variety of criteria.

Recommendations for restoration

- UAVs can provide accurate vegetation height data, particularly when only an average height is required, which can result in thousands of dollars in cost savings over traditional field surveys or LiDAR.
- Consumer-grade cameras are often sufficient for capturing UAV-based imaging data, and are affordable and reliable
- UAVs can collect important data on important variables for species identification, such as spectral data. Multispectral sensors can provide a benefit to classification accuracy, but planners should expect hiccups with these relatively new sensors.
- A critical barrier to wide-scale deployment of UAVs are regulations that prevent their operation beyond line of sight. Updated legislation that permits the use of UAVs for this purpose could cause a shift in the data collection paradigm

Monitoring: Lessons Learned from Existing Programs

Lesson Learned	Rationale	Key Considerations
Initial design will determine what can be learned	- Monitoring programs are the best opportunity to inform lessons learned and demonstrate impact, but poorly designed programs eliminate this opportunity. - Ideally, programs would capture vegetation and wildlife monitoring data to assess linkages between vegetation recovery and caribou population health.	- Monitoring programs should have at least a sub-set of plots with matched control plots or ensure that pre-treatment information is captured at a site. Pre-treatment data is particularly valuable for demonstrating treatment effectiveness. - Opportunities to collect wildlife data should be explored. - Developing a consistent approach that can be used across different programs is key for being able to compare results between projects.
Mobilizing field crews can be difficult	- Restored areas, by design, are difficult to access. This can affect monitoring efficiency.	- Monitoring programs can be stratified and can capitalize on lines left open for trapper to access different areas of a program. - More use of UAVs and fixed wing plane-based sensors reduces the need for field access.
Timely updates and reporting provide credibility	- Monitoring data should be updated and reported at regular intervals to maintain the credibility of the program. - Peer-reviewed results lend additional credibility to programs.	- To ensure efficiency for larger projects, planners can consider designating a subset of the treatment area for careful, robust experiments, while treating/monitoring the remaining area more coarsely.
Convincing people of value can be tricky	- Monitoring can often be viewed as a “nice-to-have” rather than a “need-to-have” and funding can be difficult to secure over multiple years.	- Establish funding mechanisms early in the restoration program, and ensure programs provide value such that it bolsters the credibility and effectiveness of the program.

5. Establishing a Common Cost Metric

One challenge that is regularly discussed with respect to restoration programs is the reporting of program costs. Historically, costs per kilometre have been reported in a wide range of ways, and organizations often include different core variables in their cost calculations. In addition, organizations and individuals less familiar with restoration have stated that having a general understanding of cost categories for restoration would be beneficial.

To help inform a more standardized approach to reporting on restoration costs, we surveyed contractors, consultants, and company advisors to understand the core drivers of restoration program costs (see Appendix 1). We also reviewed the cost reporting for the CNRL Kirby project used by Golder Associates and a detailed analysis of costs for the Algar program. The result of this assessment is two different cost metric proposals. The first is a general metric to help understand general cost categories for programs, while the second is a more specific description of a proposed approach to reporting on restoration costs.

Understanding cost allocations in restoration

After completing our review, there was considerable consensus amongst all the interviewees about how much of the relative cost of restoration is attributed to the three categories of planning, implementation, and monitoring. These cost estimates were also consistently verified to be in line with the two detailed cost reviews we completed. The general cost allocations were determined to be the following.

Total Restoration Costs = Planning (20-30%) + Implementation (65-75%) + Monitoring (3-5%)

Proposed standardization system for cost reporting

We propose that the following two standardization metrics could be used to report on costs. By breaking down the program costs into planning, implementation, and monitoring, programs can be more effectively compared and efficiencies in programs identified.

We also suggest two different metrics here to enable reporting of costs with and without advanced regeneration areas included. Including untreated linear features with advanced regeneration in the cost metric is important for capturing the benefit of efficient inventories during the planning stage. If a restoration program has reduced costs by readily identifying areas with advanced regeneration, those kilometres that would otherwise have been treated should still be counted. On the other hand, reporting a cost per treated kilometre allows planners to compare programs that had different existing levels of advanced regeneration. This approach of reporting a linear cost and adjusted linear cost was suggested by Golder Associates in their reporting for CNRL's Kirby project.

Finally, we suggest that a cost metric should break implementation costs into treatment costs and incidental costs (Table 1). While this adds a layer of complexity to the cost metric, by breaking costs into these categories, organizations will be better able to understand how access costs, treatment efficiencies, and other variables drive the total cost of restoration. We suggest here that the extra effort required to establish this breakdown will pay off by providing more opportunities to learn across programs and identify efficiencies that can be modelled in future programs.

$$\text{Linear Cost} = \frac{\text{Planning (\$)} + \text{Treatment Costs (\$)} + \text{Incidental Costs (\$)} + \text{Monitoring (\$)}}{\text{Total KM in Project – Advanced Regeneration}}$$

$$\text{Adjusted Linear Cost} = \frac{\text{Planning (\$)} + \text{Treatment Costs (\$)} + \text{Incidental Costs (\$)} + \text{Monitoring (\$)}}{\text{Total KM in Project (Including Advanced Regeneration)}}$$

Table 1. Suggested variables for inclusion in cost reporting.

Planning	Implementation		Monitoring
	Treatment Costs	**Incidental Costs**	
Imagery analysis	Treatment delivery contracting and equipment	Access and ice roads	Data acquisition
Ground truthing	Quality assurance and quality control	Camp fees	Field data collection
Permitting and approvals	Tree planting	Safety/Medic	Data processing and reporting
Plan development			
Stakeholder meetings			

While we recognize that establishing a cost metric like that described above does imply a more prescriptive approach to cost reporting, we believe this is justified by the added value of having a more standardized metric for reporting and comparison. However, we also identified that if programs are more descriptive in how they report costs this could also facilitate more knowledge transfer.

Through our discussions, some of the key contributors to cost variations and cost uncertainty in programs, which could be more descriptively addressed when reporting on costs, included:

- Amount of frost in the ground (too much = difficult treatments, too little = risk and time to establish frost levels).
- Access costs associated with how remote a program is.
- Camp costs for remote/isolated programs that require in field camps.
- Unpredictability in weather, resulting in variability in frost conditions for equipment.
- Number of stakeholders that require consultation.
- Time provided for completing thorough planning.

To facilitate the descriptive approach to cost reporting identified above, we suggest that along with the reporting of clear costs for restoration programs, programs should also share key drivers of cost variances.

6. Synthesis and Core Conclusions

The following are the core conclusions documented from this phase 1 of the Restoration Innovation Roadmap. These core findings, as well as the others captured in this report, can be used to inform an adaptive management approach and to facilitate continual learning and adaptation of restoration programs. By doing this, programs are likely to realize more cost effectiveness and positive ecological outcomes from their programs.

Planning

- Recent studies from both north-eastern Alberta and west-central Alberta have shown **the importance of vegetation height and vegetation density on wolf movement efficiency along linear features**. These studies show that initial impacts of vegetation regeneration are observed at ~0.5 m, and more complete impacts of vegetation on wolf use of linear features occurs at ~5 m. OHV use has also been shown to be absent at taller vegetation heights. These studies provide scientific confidence to restoration treatments that seek to re-establish vegetation along lines to reduce predator movement efficiencies.
- Recent prioritization work by organizations such as COSIA and the ABMI have helped inform robust approaches for selecting the best locations to achieve long-term restoration goals in woodland caribou ranges. These approaches have also shown that **when linear feature restoration and restoration of other dispositions (e.g., gas wells and associated pipelines) are combined, and wildfires are not considered, federal recovery disturbance thresholds can be met within woodland caribou ranges**.
- New technologies, including UAVs for inventorying lines and equipment for delivering restoration treatments, are creating more flexibility for planning restoration programs. For example, amphibious excavators are providing opportunities to complete restoration under non-frozen conditions, helping provide more options and less seasonality to restoration planners.
- Detection of advanced regeneration represents a key opportunity for restoration programs. Finding techniques that can reliably predict where advanced regeneration may occur, and to integrate this into restoration programs, provides a significant opportunity to improve both the efficiency and effectiveness of restoration treatments. Recent studies from the University of Alberta and from fRI Research have provided key variables to potentially model advanced regeneration and help stratify ground verification programs.

Implementation

- Recent operational trials by COSIA member companies have shown that a range of equipment could be used to achieve restoration goals. For example, tow behind equipment has been shown to treat uplands at up to eight times the rate of current treatments with excavators. These implements may also be used in non-frozen conditions, creating further opportunities for efficiencies. Additional testing and follow-up monitoring of treatment performance are required to continue to operationalize these tools.

- Skilled operators are currently one of the key limiting factors when it comes to effectively delivering restoration trials. Using tools such as the recently completed Silviculture Toolkit and virtual tours of restoration sites to educate operators about why treatments are important as well as the appropriate way to deliver treatments is a key step in restoration implementation. Monitoring studies that have found poor restoration results have been linked to poor operational implementation of restoration treatments. Once operators are trained effectively, they are a valuable asset and should be maintained on projects as much as possible to leverage their knowledge and experience.
- Expecting the unexpected is a key learning from various organizations. Developing a very well-informed plan is a critical aspect of delivering efficient restoration programs, but contractors need to be flexible in how it is delivered, as surprises will arise in the field. The best solution to this is to have clear goals and decisions hierarchies, so that decisions that need to be made in the field are still consistent with the overarching goals developed at the planning stage.
- Treatment intensity matters and is a key driver of restoration success. Establishing sufficient densities of trees on a restored feature and applying woody materials or other movement barriers where possible has been shown to be key to restoration success. Predators have been shown to avoid areas with higher vegetation cover and higher physical barriers such as woody materials. Likewise, areas that received lighter treatment are showing less impact on predator use of lines. Finally, there is no empirical information to inform the use of techniques which skip large sections of lines to improve efficiency, although one study is currently in progress at the Algar Caribou Habitat Restoration site. These techniques are not consistent with the current Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta 2017) and should be tested in a robust way if there is a desire to use them in restoration programs.
- Winter planting of trees has been used in a wide range of projects and has been shown to produce positive outcomes in all cases. Survival of seedlings appears to be on par with summer planting programs, and there are efficiencies that can be realized by planting alongside recently mounded sites in the winter. More research is needed to assess how winter planted seedlings respond to either very warm or very cold planting conditions to help inform the range of positive performance for this technique. A cost analysis comparing winter versus summer planting could also be performed.
- Several recent studies are looking for opportunities to treat upland sites in a more rapid fashion than simply mounding. COSIA member companies tested a tow behind implement that created small microsites, and some programs have tested ripping on uplands as a technique. Further studies of these approaches could significantly improve the efficiency of upland treatments while maintaining or improving the ecological outcomes.

Monitoring

- Several restoration programs have focused on implementing monitoring programs, which has resulted in clear information about restoration success. Studies looking at vegetation response to restoration treatment have all shown positive outcomes. By actively treating sites and addressing site limiting factors that inhibited vegetation recovery, programs are seeing seedling growth and an influx of natural regeneration on treated sites. While programs would benefit from ensuring they have pre-treatment and post-treatment information, the outcomes of programs have been positive with respect to the benefits of restoration for achieving vegetation growth and recovery on linear features.
- UAVs are seen by the research community as a game changer for restoration monitoring. Research led by Dr. Greg McDermid and colleagues through the BERA program have shown that monitoring vegetation height and, in some cases, detecting individual species is possible with various sensors. This presents an exciting opportunity for maximizing the efficiency of restoration monitoring and reducing the need for invasive ground-based monitoring by field crews. Should future regulations for UAVs enable flying drones beyond line-of-sight, the potential applications of this technology are immense.
- Consumer grade cameras are, surprisingly, one of the most effective sensors that can be used on UAVs and fixed-wing aircraft for restoration monitoring. New approaches enable researchers to convert 2D images into 3D models, and consumer grade cameras have been found to be cheaper and more reliable when capturing field footage. Should line-of-sight regulations be eliminated for drones, the use of consumer grade cameras on UAVs could provide opportunities for detecting species, heights, and densities of vegetation to inform monitoring programs.
- Despite the potential of drones and various sensors attached to fixed-wing aircraft, species level detection remains a core challenge. Deciphering between conifer and deciduous species is currently feasible, but species detection requires more detailed imagery. This imagery is accessible at small scales (i.e., individual lines) but the current methods would not currently be practical at larger scales (i.e., range scales). Future regulations that permit drones to fly beyond line-of-sight could remove this limitation, however.

Core Opportunities to Reduce Costs and Improve Effectiveness

This project focused on summarizing the key learnings related to planning, implementation and monitoring of restoration programs. The project also resulted in the following eight recommendations for opportunities to reduce restoration costs and improve effectiveness. Additional opportunities will be highlighted in the second phase of this Restoration Innovation Roadmap Project.

1) Studies from both north-east Alberta and west-central Alberta have shown that vegetation on linear features is a key deterrent to wolf use and movement along these lines. Focusing

restoration efforts on re-establishing vegetation trajectories at sufficient densities on linear features appears to be a viable tool to reduce wolf movement efficiency on the landscape.

2) Achieving the 65% undisturbed habitat target is possible in many ranges, and modelling has been completed to guide a prioritization process. However, difficult decisions will need to be made to achieve this target. Leaving lines open for active dispositions, not restoring other dispositions (e.g., gas wells and associated pipelines) during legacy seismic line restoration programs and leaving high densities of lines open for trappers will compromise the effectiveness and efficiency of restoration efforts. Discussions with disposition holders and exploring creative ways to maintain trapper access while effectively restoring linear features should be explored.

3) Restricting restoration activities to winter is a major constraint and ongoing uncertainty for restoration programs. Sometimes programs are encountering too much frost, other times too little frost, and frozen ground conditions leave little room for error and put operator safety at risk. Numerous contractors and consultants stated that a focus on solely winter operations leads to high uncertainty and this uncertainty is likely to increase with climate change.

4) Creating more time and space for planning is critical. Restoration planning takes time and was noted by all interviewees as a key stage for reducing costs for programs. Planning reduces risks, improves efficiency of equipment, and creates space to plan treatments to be most effective. However, restoration contracts are still often awarded with short timelines for delivery. In some cases, contracts have been awarded in November with expected delivery in January (i.e., two months later). Evaluating the feasibility of extending these timelines, and specifically targeting the award of contracts a minimum of one year prior to expected treatments is suggested. While this may be logistically challenging for funding organizations, rushed planning has been shown to lead to higher costs and less effective outcomes – both of which pose a real risk to restoration programs within woodland caribou habitat.

5) Operator training and availability is a major constraint. Organizations regularly stated that there is a shortage of workforce capacity to deliver restoration treatments, and those contractors that are available have limited to no experience in restoration. This increases safety risks on programs and can compromise effectiveness of treatments. Hosting training workshops, encouraging use of the COSIA/NRCan Silviculture Toolkit and Virtual Tours for restoration, and retaining workers for subsequent programs is a necessity for improving restoration efficiency and effectiveness.

6) Investing in new equipment is expensive and carries high risk. Through our interviews we heard that many companies would invest in new equipment, but the high uncertainties related to awarding contracts means that most will use existing equipment (e.g., standard excavators). Developing a smaller pool of companies that are specifically selected to deliver restoration work over the next 10 years could provide the necessary stability to contractors to invest in new equipment. Such a process could see companies apply to be added to the list, and once selected a higher likelihood for work could be provided. A high standard of quality and cost competitiveness would then be required to remain a preferred contractor. Such an approach would clearly need to be carefully balanced with the need for innovation and competitiveness.

7) There is a need to explore new innovations for creating microsites in restoration. Studies to date have shown that mounding, tree planting, and applications of woody materials/stem bending are key tools in the restoration toolbox which are working to re-establish vegetation and reduce predator use of lines. However, operators are still using conventional approaches to create these microsites (e.g., through use of excavators). Focused studies on how to innovatively create these microsites using new equipment and or new techniques could significantly improve the effectiveness and efficiency of restoration programs.

8) Drones and UAVs are on the cusp of high efficiency. Through interviews with leading scientists, we heard that drones and UAVs have high potential to contribute to both efficient planning and monitoring. Solar powered drones, for example, already exist that could survey entire programs to a high standard of quality. The limitation is not the technology available. Rather, current regulatory requirements for line of sight operation of drones is significantly limiting these tools. Once regulations are established, many more opportunities will present themselves for efficient data collection.

Key Knowledge Gaps and Future Research Opportunities

After reviewing both the peer reviewed and grey literature, the following list of knowledge gaps and future research opportunities have emerged through this project. These questions could form the foundation for future academic or company monitoring programs. Once answered, they will facilitate further improvements and awareness about restoration outcomes.

Topic	Research Question
Wildlife	
	- How does line width affect predator movement? - How does the height/intensity of stem bending, coarse woody debris, mounding, etc. affect predator movement? - How do alternate prey respond to linear features? How does increased movement and access by predators affect kill rates, and how do these functional aspects of linear features compare to the numerical aspects of increased forage for alternate prey? - Do game trails within areas of advanced regeneration affect restoration performance? - What is the relative effectiveness of: treating only lowlands, treating only uplands, or treating only transitional areas?
Vegetation	
	- How do factors like seedling tolerance, size, planting depth, snow cover, and temperature at time of planting affect seedling success?
Imaging and Sensors	- Can imaging techniques like LiDAR be used to identify OHV use?

	- What is the origin of the mismatch between photogrammetric point cloud estimates of vegetation height and traditional field approaches – does this reflect a limitation of photogrammetric point clouds, or does this reflect the subjective judgement of field crews? - How do image quality, flight and lighting conditions, vegetation density, shadows on lines, and phenological conditions affect the accuracy of UAV-based data? - How can the processing time for photogrammetric point clouds be reduced?
OHV Use and Users	
	- What can be learned from user-specific surveys of OHV users regarding their decisions on which linear feature to use? - Can OHV access be limited through strictly silvicultural treatments?
Equipment	
	- How do amphibious excavators, the Nodwell excavator, and tow-behind implements perform over longer trials (e.g., 10 days/100 hours)?

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Appendix 1. Interview Responses

Person	Key Cost Drivers	Planning Lesson Learned	Implementation Lesson Learned	Monitoring Lesson Learned
Company Rep 1	Consulting, QAQC, Proj mgmt, contractor, access, camps, safety, range control, medics, earthworks	Be flexble, working in mother nature, understanding right amount of frost, tree planting is a hughe undertaking.	No single tool with respect to safety. Scales of economy matter - first two weeks getting used to it but efficiencies come after that. Security can be a concern. Competition for workers can impeded efficiency - need work life balance to keep workers. Lack of consulting capacity	Timelines are important - people want to see outputs/results. Getting itno areas is difficult. People don't want t ocontribute funds unless perr reviewed is published.
Company Rep 2		Take time to do it right. Planning where to access, how to move is tricky. Hard to find areas that won't be disturbed in future. No substitute for ground truthing.	Separate contractor for tree planting asn't needed. Site specific H&S is needed. Wider track machines that can float better desireable. Efficiency improves with time. Efficient b/c close to camp.	Measuring effectiveness requires paired plot design. RICC work has helped monitor animals - showing not using.
Consultant 1	Topography, isolation from access, number of companies for approvals (pipelines LOC etc. Consultation required. Weather conditions, temp, snow volume etc to get the frost right.	Take the time to plan. Need more time (nov contract award Jan implemenetation not feasible). Ground truth in snow free conditions. Planning only as good as imagery data. If don't have time, or imagery, leads to oeprational inefficiencies.	Talk to operators regularly - QC feedback. QC alongside operators. Operators are inexperienced. Convince operators 'why' important, how different from reclamation.	Need strong program, but convincing people to spend money is tricky. Set aside money n advance. Need monitoring to figure out what works and why.
Company Rep 3	Includes everything. Camp costs, travel etc. Big yellow machines. Frost into the ground etc. Safety a big cost.	Cn't rely just on GIS. Do lidar first but also ground truth. Sart early (TFAs and other apporvals take time).	Quality people are key. Management of change is key. One winter low frost cost $50,000. don't pin youself in a corner. Winter planting works well with about 4 hours to get planted.	Using provincial framework. Found restrictive at first, but industry comments adjusted this. Framework a bit restrictive as some lines <1km. Set up helicopter landing spots.
Company Rep 4	Access is huge. Location key as drives stakeholder approvals etc. Remote camps are an enourmous cost. Uncertianty around winter conditions is huge cost.	Annual planning was complicated by having too many contractors. Hiring indigenous contractor form other territory was seen as negative. Start early with regulatory approvals.	Easier if working on your own lease as have more control. Struggled with winter conditions - too warm caused issues. Planning to avoid advanced regen is tricky. Winter planting really worked. Planted larger seedlings which worked well.	Plan program early (befor project). Control lines for research are key. Wolf cull confounding results.
Consultant 2	Number fo crossings can really affect costs. Having this info ahead of time is helpful to plan ahead, get aprpovals. Road access , whether need remote camp etc are key.	Ground assessments go a long ways to planning and talking with operators.	Prescriptions are great but prevailing conditions can change. Focus on desired outcome and not just prescription. Have a strong tactical plan.	Natural regen after treatment is surprising. Haven't tracked naturals. Some seedlings died but overall success is high.
Consultant 3	Frost levels can be a driver of costs. Need to be able to show how climate imapcts treatment efficiency.	Earlier the star the better. Need to plan this work 2-3 years in advance in some cases. Leave enough time for permits, approvals etc.	Have to have the right equipment. Can be an issue with smaller operators. Is equi0pment maintained properly to be resilient? Few point awarded in contracts/bidding rpocesses for innovation.	Need to establish monitoring plots at time of implementation. Monitoring is very valuable and should be prioritized. Without it, hoe do you know what worked?
Consultant 4	Accesibility and access to high grade is a huge cost driver.	Can't do enough planning. Need enough time to go through properly. Need the right data.	A good system of communications and safety. If good communication, operations relatively easy.	Good people and good training are key to get the right data. Follow clear process and goals like outlined in provincial framework.
Consultant 5	Planning should be included. Cost/km should include areas left for natural regen. Cost of imagery should be included. Travel distance a huge factor. Frezzing in access and frost levels are key.	Early engagement with First Nations is important. Think about efficienies with size of projects. Detailed remote sensing data is very valuable. Build decision tress for when to treat.	Be prepared to tweak your plan. Think ahead for permits, crossings etc. Plan will defintiely change once in the field. Stakehodlers who arrive late to the table (once a program is in progress) can be really tricky. Making every staleholder happy results in very little left to treat.	Paired plots are important for testing variables. Needs to cosnider veg growth and caribou response. Need data colelction and plots to be same for every program.