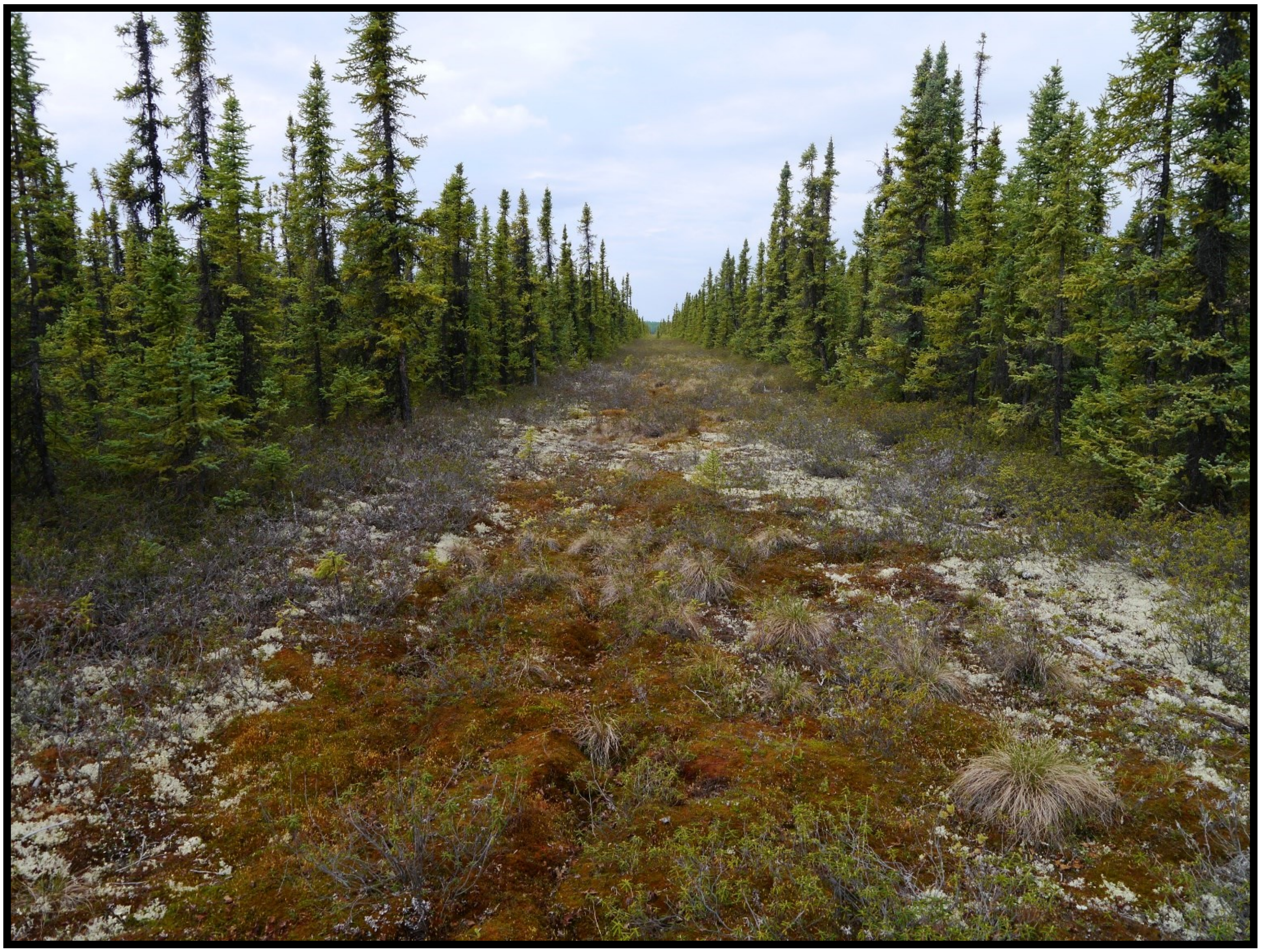
TESTING FUNCTIONAL RESTORATION OF LINEAR FEATURES WITHIN BOREAL CARIBOU RANGE

JANUARY 2016



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EXECUTIVE SUMMARY

The boreal ecotype of woodland caribou (*Rangifer tarandus caribou*) is provincially *Red-listed* in British Columbia and federally listed as *Threatened.* Population declines of boreal caribou have been attributed to direct and indirect effects of landscape disturbance within and adjacent to caribou range. In western ranges, linear features such as seismic lines, pipelines and roads are a prominent form of disturbance. These features are hypothesized to increase caribou predation rates – the proximate cause of population declines – by facilitating predator movement into caribou range and by increasing predator hunting efficiency. Because of these mechanistic links, limiting predator movement on linear features has become a management priority for stabilizing caribou populations in the long-term.

In this report, we outline a multi-year framework for developing and testing techniques for functionally restoring linear features within caribou range. Functional restoration refers to techniques that aim to limit predator use of linear features to ultimately restore historic caribou-predator encounter rates but that do not necessarily result in the restoration of lined areas to their pre-disturbance structural state (i.e. ecological restoration). Perceived benefits of functional restoration over ecological restoration include more immediate impacts on the targeted biological process, cost-effectiveness and speed of treatment.

The primary objective of our three-year framework is to develop effective techniques that can be deployed in a cost-effective, logistically feasible manner and applied over a biologically meaningful area, which we define as a wolf (*Canis lupus*) pack's territory. In the first year, techniques are tested at a small scale to determine their efficacy in excluding predator use of lines. By conducting a literature review and gathering expert opinion at a project scoping meeting, we identified tree felling and fencing as promising techniques to be tested in this phase. In the second year, effective techniques are evaluated on their efficacy in excluding predators from defined areas. Finally, in the third year techniques are deployed over > 50% of a wolf pack's territory to determine their efficacy in limiting wolf movement rates, kill rates and productivity.

We estimated technique-specific costs and example budgets for each year of the framework. These estimates contain a high degree of uncertainty, primarily related to probable site-specific variation in logistic feasibility, ultimate study design and the adaptive nature of the framework. Nevertheless, cost estimates were below those reported for current ecological restoration initiatives.

Implementation of the framework will require significant financial investment and involvement of all relevant stakeholders, including government, First Nations and industry. Given this and the adaptive nature of the framework, we suggest the formation of an oversight committee as a critical first step toward project initiation.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

Executive Summary ... i

Acknowledgements ... ii

Background ... 1

Scope and Objectives ... 4

Framework Methodology and Timelines ... 4

Estimated Costs and Example Budget ... 15

Summary ... 22

Literature Cited ... 23

Appendix A: Literature Review ... 26

Appendix B: Analyses of Wolf Pack Territories ... 44

Appendix C: Cost Estimate Contacts ... 47

LIST OF TABLES

Table 1: Operational pros and cons of proposed techniques for functionally restoring linear features in northeast British Columbia. ... 7

Table 2: Overview of time line and objectives for developing and testing techniques for functionally restoring linear features. ... 14

Table 3: Per kilometer costs associated with tree felling to functionally restore linear features in northeast British Columbia. Note that these estimate due not include accommodation and meal expenses and assume that suitable trees are available on site. ... 15

Table 4: Per kilometer costs associated with snow or wire mesh fencing to functionally restore linear features in northeast British Columbia. Note that these estimate due not include accommodation and meal expenses. ... 16

Table 5: An example budget for Year 1 in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia ... 17

Table 6: An example budget for Year 2 in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia ... 19

Table 7: An example budget for Year 2 in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia ... 21

LIST OF FIGURES

Figure 1: The hypothesized effects of linear features on space use and movements of alternate prey (e.g. moose) and wolves. By increasing wolf movement rates and facilitating movements of alternate prey and wolves into caribou range, linear features may lead to an increase in caribou-wolf encounter rates thereby increasing rates of caribou predation. Linear features may also enhance wolf hunting efficiency (kill rate), leading to an increase in wolf numbers (numeric response) within and adjacent to caribou range. 3

Figure 2: Tree felling (top) and fencing (bottom) techniques for functional restoring linear features. Remote cameras are deployed to monitor line use and subsequently assess treatment efficacy. Treatment length and interval are variables to be evaluated during a pilot study. 9

Figure 3: Wolf pack territories in northeast British Columbia identified as potential locations for testing techniques for functionally restoring linear features. The Tsimeh and Snake packs have existing GPS location data sets. The pack in the Dilly Creek area does not have existing data but has logistical advantages due to its proximity to existing infrastructure. 10

Figure 4: Sampling grids of 9 km^2 and 25 km^2 applied to the territory of the Snake wolf pack. Sample blocks of 25 km^2 will likely have a higher expected encounter frequency with wolves travelling within the pack's territory. 12

BACKGROUND

Boreal caribou are provincially *Red-listed* in British Columbia and federally listed as *Threatened* due to population declines throughout much of their distribution. The main proximate threat to boreal caribou populations is hypothesized to be increasing predation (Environment Canada 2012), which has resulted from the following suggested mechanisms. First, human alterations within and adjacent to caribou range increase populations of other ungulate species (e.g. moose [*Alces alces*] and white-tailed deer [*Odocoileus virginianus*]), leading to an increase in populations of ungulate predators that opportunistically prey on caribou (James 1999; Latham *et al.* 2011). Second, linear features such as roads, pipelines, and seismic lines may facilitate predator movement into and within boreal caribou range, thereby increasing caribou-predator encounters (Fig. 1). Linear features may also enhance predator hunting efficiency by increasing predator movement rates (McCutchen 2007; McKenzie *et al.* 2012). Climate change is expected to further exacerbate these issues; for example, by expanding the range of non-caribou ungulates (e.g. white-tailed deer; Dawe *et al.* 2014).

The mechanistic links between linear features and increasing predation of caribou has led to an increased emphasis on developing techniques for mitigating the effects of linear features. Effective mitigation, however, likely depends not only on the technique used, but also where treatments are deployed and over what spatial scale. This latter point is particularly relevant given the large spatial scales of caribou and wolf (*Canis lupus*) home ranges and the potential barriers that may exist for large-scale treatments (e.g., high cost, access to variable habitat types, stakeholder engagement, and regulatory requirements). Nevertheless, recent initiatives in Alberta have begun to address the issue of spatial scale, such as Cenovus Energy's Linear Deactivation Project (LiDea) which spans four townships in NE Alberta (Sutherland *et al.* 2012).

Current mitigation initiatives are ostensibly targeted toward two objectives: ecological restoration and functional restoration. Ecological restoration aims to structurally restore areas to their previous, undisturbed state. Methods for ecologically restoring linear features include soil mounding and tree planting (Golder 2012; Pyper *et al*. 2014; see also Appendix A). Functional restoration, on the other hand, focuses on restoring biological processes to their pre-disturbance state and such restoration may not necessarily result in an area being restored to its previous structural state. Examples of functional restoration methods include tree-felling across lines and fencing (Neufeld 2006; Appendix A). Note that the two objectives need not be mutually exclusive: ecological restoration can result in functional restoration. In the context of boreal caribou and linear features, functional restoration aims to restore historic caribou-predator encounter rates by altering linear features to reduce predator movement rates and/or spatial overlap with caribou. In general, the focus of functional restoration is to immediately affect the targeted biological process (or processes) while impacts from ecological restoration may require a longer time frame.

In NE British Columbia, mitigating the effects of the industrial footprint (e.g. seismic lines) within boreal caribou ranges has become a management priority (Ministry of Environment 2011), including testing potential mitigation techniques over large spatial scales (Wilson 2015). Because of the costs and time-lags associated with large-scale ecological restoration (Pyper *et al.* 2014), recent focus has been on developing effective methods for functional restoration (Bohm *et al*. 2014; Wilson 2015). Currently, the federal recovery strategy does not include language addressing functional restoration as a management lever for stabilizing caribou populations; rather, population recovery and stability are linked to thresholds of undisturbed habitat (Environment Canada 2012). For highly altered caribou ranges, achieving such thresholds through ecological restoration will take decades, a fact acknowledged within the recovery strategy and a time frame that may compromise long-term viability of small, rapidly declining populations (Hervieux *et al.* 2013). This disconnect necessitates the development of complementary tools to ecological restoration, particularly those that can have a more immediate impact by focusing on functional restoration. Moreover, functional restoration methods may eventually be considered as accepted management levers in subsequent range plans and action plans if such methods have scientific evidence supporting their effectiveness in achieving caribou population and distribution objectives (Environment Canada 2012).

In this report, we outline a multi-year framework for developing and testing mitigation techniques for functionally restoring linear features within NE BC caribou ranges. The framework is based on a literature review of existing techniques for limiting wildlife use of targeted areas – with a particular emphasis on linear features (Appendix A) – and outcomes from a project scoping meeting conducted on November 2015 in Edmonton, AB. Representatives at the meeting included university-based researchers, the coordinator of BC’s Research Effectiveness and Monitoring Board, and industry-affiliated biologists, all with expertise in linear feature mitigation.

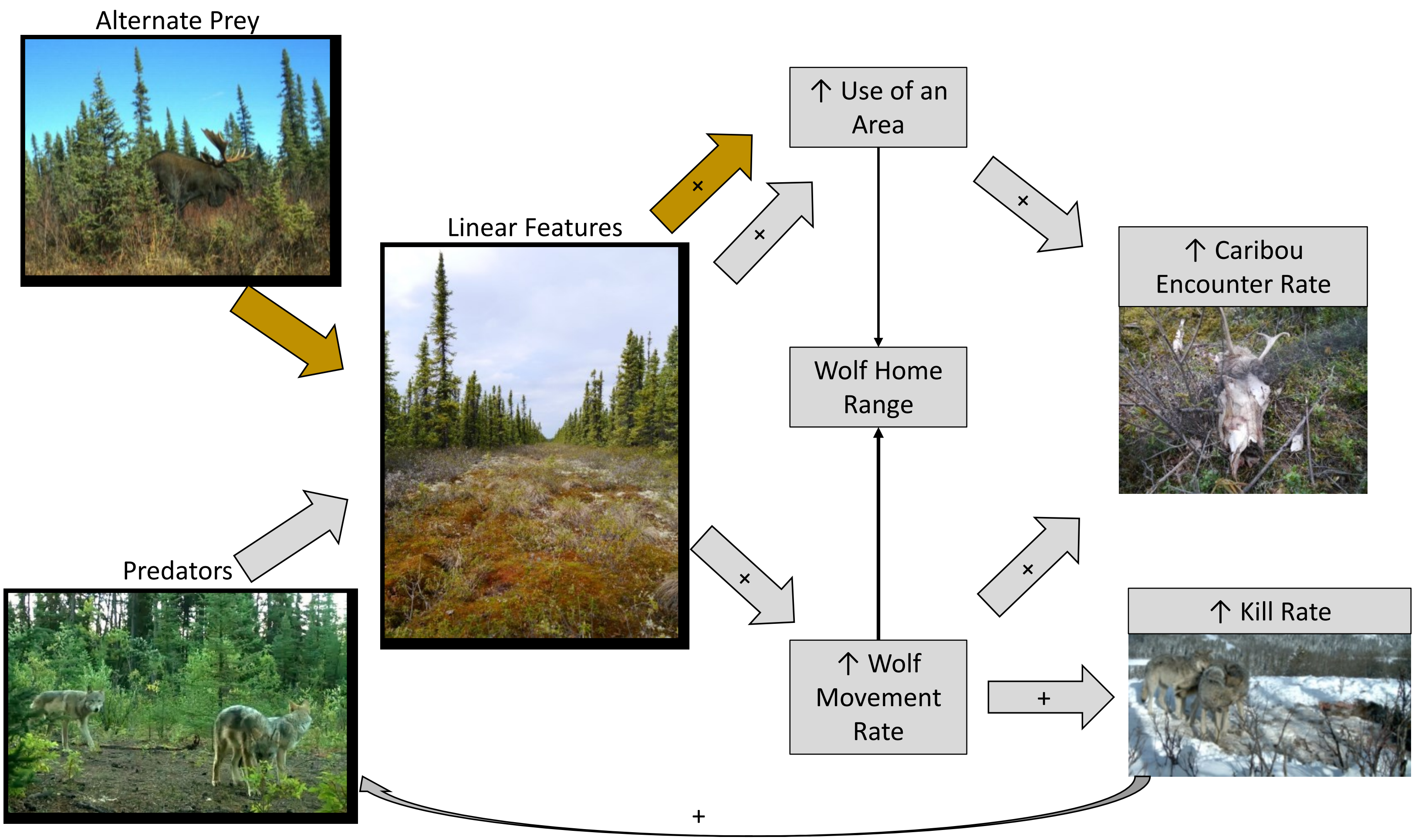

Figure 1: The hypothesized effects of linear features on space use and movements of alternate prey (e.g. moose) and wolves. By increasing wolf movement rates and facilitating movements of alternate prey and wolves into caribou range, linear features may lead to an increase in caribou-wolf encounter rates thereby increasing rates of caribou predation. Linear features may also enhance wolf hunting efficiency (kill rate), leading to an increase in wolf numbers (numeric response) within and adjacent to caribou range.

SCOPE AND OBJECTIVES

Within our framework, the immediate objective is to develop effective techniques for functionally restoring linear features that can be deployed in a cost-effective, logistically-feasible manner and applied over a biologically meaningful area. Here, technique effectiveness refers to how successful a particular technique is in addressing one or both of the hypothesized mechanisms by which linear features affect caribou-predator encounter rates. Specifically, successful techniques should limit predator use of linear features (to decrease predator movement rates) and/or limit predator use of an area (to decrease spatial overlap with caribou). Financial and logistical feasibility dictates that developed techniques should be less expensive and more easily deployed than ecological restoration methods. Financial and logistical feasibility will further factor into whether developed techniques can be applied over a biologically meaningful area. Because predation is the likely proximate cause of caribou population declines and wolves are the primary predator of adult caribou (McLoughlin *et al.* 2003), we follow the suggestion of Wilson (2015) and define a biologically meaningful area as the size of a typical wolf pack's territory.

Achievement of our immediate objective should translate into progress toward the ultimate objective of most, if not all, restoration initiatives conducted within caribou range; that is, restoring the biological conditions conducive to stability of caribou populations. Given our framework's three year timeline, we acknowledge that improvement in caribou demography may not be apparent in the short-term due to lag effects (Serrouya *et al.* 2015). To that end, we focus short-term monitoring on predator behaviour and suggest that behavioural changes that equate to decreasing encounter rates with caribou should eventually result in positive changes in caribou demographic parameters such as adult female survival and calf recruitment (survival to one year of age).

FRAMEWORK METHODOLOGY AND TIMELINES

Developing and testing techniques for functionally restoring linear features over large areas will require a multi-year time line, beginning with a pilot study for technique development then progressing to large-scale testing across a wolf pack's territory. Below, we outline the specific objectives and methods for each year of the framework (also summarized in Table 2 at section end). In all years, we suggest using a before-after-control-impact design (BACI; Schwarz 1998) to rigorously evaluate project outcomes. In this design, predator behaviours are monitored both before and after treatment deployment and treatment results are further compared to control units where no treatments are deployed. The units of comparison (or sample units) will be dependent on year-specific objectives. In addition, treatment and control units should be similar in their environmental attributes (i.e. land cover type, linear feature age and structure, linear feature density) to further isolate treatment effects.

Year 1: Pilot Study

The primary objective in *Year 1* is to develop and test techniques that effectively limit predator use of linear features, an objective that can be accomplished through a pilot study. Conducting such a study will require determining the specific techniques to be tested, identifying linear features for treatment, deploying treatments, then monitoring and evaluating treatment effects.

To determine potential techniques for testing, we conducted a literature review of existing methods for excluding wildlife from targeted areas (Appendix A). This review, combined with input from mitigation experts at the scoping meeting, identified tree felling and fencing as the most promising techniques for functionally restoring linear features. Tree felling involves cutting trees along linear features such that the downed trees lie perpendicular to the line (Fig. 2). Fencing can be more flexibly deployed and we recommend a zigzag design that funnels animals off lines into the surrounding forest (Fig. 2). While this pattern may not keep animals off lines *per se*, it will slow down an animal's linear movement rate (i.e. from point A to point B), which addresses the enhanced movement mechanism that linear feature are thought to afford. Previous fencing trials have used plastic snow fencing (Bohm *et al*. 2015) but the long-term durability of this fence type is questionable. To that end, the scoping committee suggested wire mesh fencing be considered as a more durable option. This type of fencing will likely require stakes for structural support, which will increase expenses compared to snow fencing. There are operational pros and cons associated with each proposed technique (Table 1). For example, drawbacks to tree felling include a potential lack of available trees – particularly in bogs and fens which caribou favour – and a possible increased fire risk (Brown *et al*. 2003), which may require consulting with government forestry officials and obtaining any necessary permits. If fencing is to be used, it is imperative that all treated lines be marked with highly visible signs to alert the public.

Critical to rigorously testing selected techniques will be identifying linear features for inclusion in the pilot study. Because most linear features will individually have a low probability of predator use (Bohm *et al*. 2015; C. DeMars, *unpublished data*), we recommend using previously collected data (i.e. from GPS radio-collared animals or remote cameras) to identify lines highly used by predators. For wolves in particular, specific lines may be repeatedly used by individuals travelling to and from den or rendezvous sites during the spring and summer (Jedrzejewski *et al.* 2001). The availability of such lines and logistical constraints may limit the sample size of such lines; nevertheless, if treated lines are matched to adjacent control lines, a large sample size may not be required to detect treatment effects if, as would be predicted, use on treated lines declines while use on control lines increases or at least remains unchanged.

Analyses of wolf pack territories in northeast BC and input from the scoping committee identified three packs ideal for inclusion in a pilot study (Fig. 3; Appendix B). Two packs – the Snake and the Tsimeh – have existing GPS location data sets, are in close proximity to Fort

Nelson, have all-weather road access adjacent to and/or within their territory and have similar estimated line densities (Snake: 2.2 km/km^2; Tsimeh: 2.5 km/km^2). The third pack, located near the Dilly Creek area, has no current data but its close proximity to existing infrastructure may make it logistically advantageous. The deployment of GPS radio-collars on individuals within this pack will be necessary for its inclusion in a pilot study or in subsequent years of the framework.

After selecting appropriate lines, treatments could potentially be deployed at any time of year. Tree felling in particular may be more efficiently accomplished in the winter when on-ground access is easier. The design of treatment deployments would be a key component to be adaptively investigated during the pilot study (Fig. 2). Specifically, we suggest that the entirety of a line need not be treated; rather, treatments can be deployed at set intervals with the intensity of each treatment and length between treatments being the variables of interest. Because existing evidence suggests that wolf speed is at least double on lines versus off (James 1999; McKenzie *et al.* 2012; Dickie 2015), treating > 50% of a line will likely be necessary to effectively minimize the movement advantage afforded by lines.

To evaluate treatment effects during this pilot study phase, relative line use should be monitored as the response metric. We recommend using two data sources to monitor line use: *i*) data from remote cameras deployed on treated and control lines; and, *ii*) data from GPS radio-collared individuals within a targeted pack. Ideally, cameras should be positioned to capture movement down the line and to record predator behaviour upon approach to treated areas. GPS radio-collars should be programmed for a fix rate (or rate of GPS location acquisition) of every 5 minutes to adequately capture wolf movements on linear features. For BACI designs, data from both sources need to be available prior to treatment deployment. Where possible, monitoring should be extended year round to examine season-specific responses to treatment and to assess treatment durability. Particular focus, however, should be on the snow-free period when both predator line use and caribou predation rates are highest (Courtois *et al.* 2007; Latham *et al.* 2011). Further, because the probability of specific line use on a daily basis is likely to be low, we suggest a minimum monitoring period of at least 3 months.

A number of statistical approaches could be used to infer treatment effects. Paired *t*-tests could be used to evaluate before-after effects on treated lines and treatment-control effects if treated lines are matched to only one control. These effects could also be assessed in an analysis of variance (ANOVA) setting. If treated lines are matched to multiple controls, then a mixed-effects linear regression approach could be used where individual treated lines and their associated controls are specified as random effects. The regression approach may also be advantageous for incorporating site-specific variables such as land cover type or line density to control for their potential confounding effects.

Table 1: Operational pros and cons of proposed techniques for functionally restoring linear features in northeast British Columbia.

Treatment	Operational Pros	Operational Cons	Notes/considerations
Tree Felling	• In upland forest types, (e.g., aspen, white spruce, pine), a sufficient quantity and size of tree is anticipated to be available adjacent to seismic lines. Trees are often dense (e.g., 2-3m apart) and generally have large diameters at breast height (DBH). • Materials required for this treatment are minimal, apart from equipment for tree-falling. • Depending on the seismic line and surround forest conditions, there may be less time required to treat 1 km using this technique as opposed to treating by fence installation. For example, on seismic lines that have some re-growth and are difficult to travel across, it may be difficult and time consuming to install fences compared to falling trees.	• In lowland forest types (e.g., black spruce, tamarack), there will likely be insufficient timber to effectively deactivate seismic lines. Trees are often sparsely distributed, and in some lowland habitats there may only be shrubs. • In lowland forest types, DBH of timber may not be large enough to effectively deactivate seismic lines. • Work crews may be limited by how quickly they can safely treat a seismic line, based on forest density, timber size, and visibility. For example, in a dense forest, trees may often get 'hung-up' on each other and become difficult to fall to the forest floor where they will be effective in deactivating the corridor.	• In some lowland forest types, the density of trees and other vegetation is such that deactivating a seismic line (in an attempt to force animals to travel in the adjacent forest) may not result in a decreased travel speed or use of area, as the surrounding forest may be just as easy to travel on. • All tree-falling must be certified according to Work Safe BC standards and follow all Work Safe BC regulations for Forestry Operations and Similar Activities. This includes regulations for manual tree-falling and bucking. • Build-up of down woody debris can create an increased risk of wildfire in an area. Falling large quantities of trees may not be allowable in some areas and standards must comply with Work Safe BC and the BC Wildfire Management Branch.
Snow Fencing	• If treating a recently cleared or sparsely re-vegetated seismic line, installing sections of fence will be a relatively easy operation. • Snow fences are inexpensive, light, and easy to maneuver single handed or in pairs.	• Seismic lines are often re-vegetated, varying from low ground cover to tall shrubs. Depending on the density of vegetation, fence installation may be difficult. • Though light and easy to handle, snow fences are flimsy and can become	• It is difficult to anticipate how snow fencing throughout a seismic line will hold-up to harsh winter conditions. In previous trails, snow fencing has become brittle and broken.

Treatment	Operational Pros	Operational Cons	Notes/considerations
	• All materials are readily available at hardware stores.	brittle/break in harsh weather conditions. Previous trials have shown snow fences to not be durable long term. However, more robust installation methods could be used in future trials.	• Depending on depth of snow over winter, the fence may become ineffective (e.g., if snow depth become close to or exceeds the height of the fence).
Wire Mesh Fencing	• If treating a recently cleared, or sparsely re-vegetated seismic line, installing sections of wire fence will be a relatively easy operation. • Wire fencing is anticipated to be more robust than snow fencing, and may be less prone to breaking and falling throughout the winter season.	• Seismic lines are often re-vegetated, varying from low ground cover to tall shrubs, making fence installation difficult. Wire fence installation is expected to be more difficult and time consuming than snow fencing. Stable mesh in particular is much heavier and more difficult to maneuver. • Long-term durability is unknown	• There is some concern about visibility and safety of a wire fence. Depending on mesh size, small animals could become entangled in the fence, and exposed sharp edges could injure animals and/or humans. • Depending on depth of snow over winter, the fence may become ineffective (e.g., if snow depth become close to or exceeds the height of the fence).

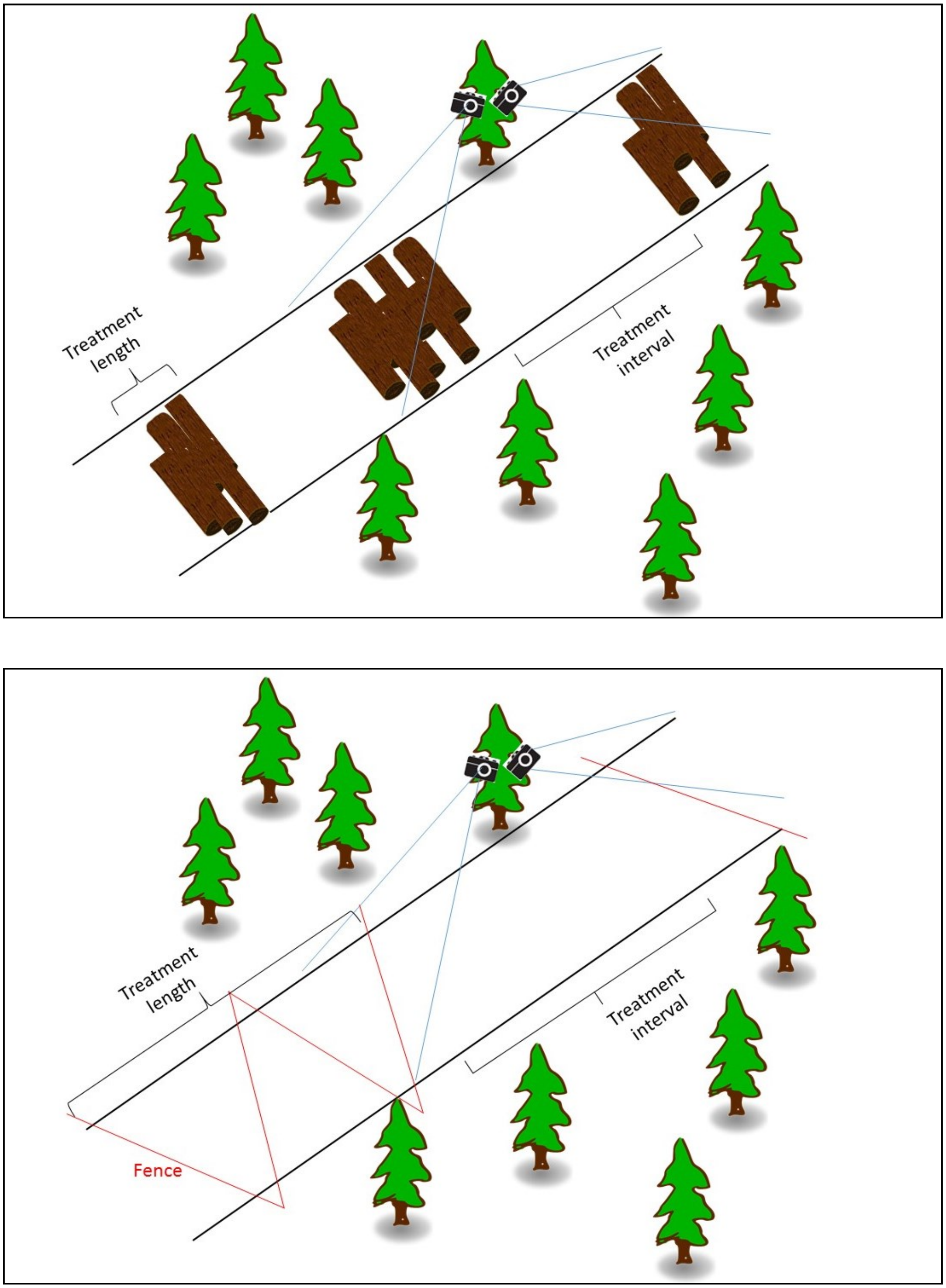

Figure 2: Tree felling (top) and fencing (bottom) techniques for functional restoring linear features. Remote cameras are deployed to monitor line use and subsequently assess treatment efficacy. Treatment length and interval are variables to be evaluated during a pilot study.

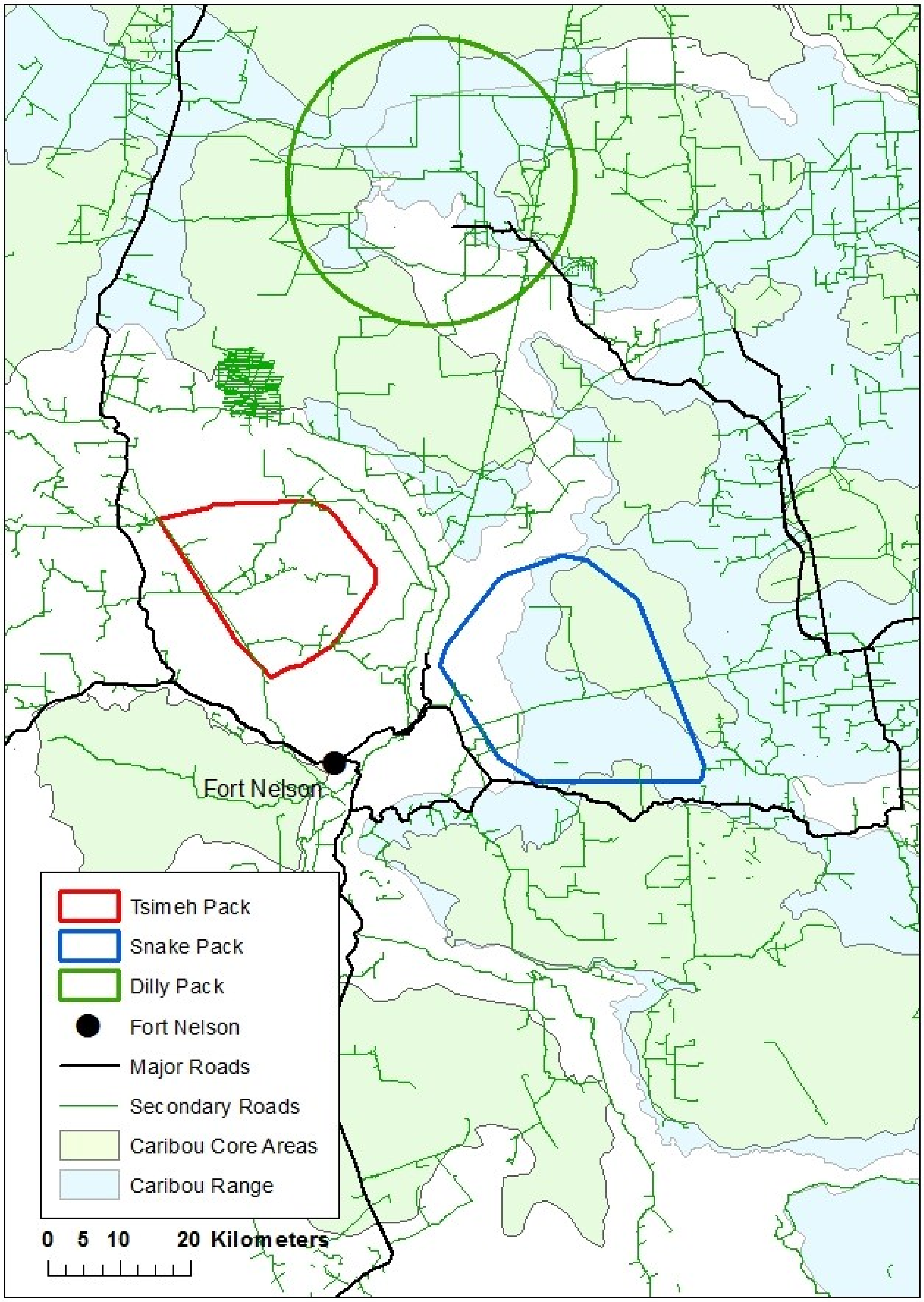

Figure 3: Wolf pack territories in northeast British Columbia identified as potential locations for testing techniques for functionally restoring linear features. The Tsimeh and Snake packs have existing GPS location data sets. The pack in the Dilly Creek area does not have existing data but has logistical advantages due to its proximity to existing infrastructure.

Year 2: Treatment Blocks

In the framework's next phase, developed techniques from the pilot study should be tested for their ability to limit predator use of targeted areas. Here, the sample unit switches from individual lines to blocks. For blocks assigned to be treated, restoration techniques are deployed on all lines within the block, although prioritization algorithms could be used to preclude regenerating lines with structural attributes that no longer provide movement advantages to wolves (Dickie 2015; van Rensen *et al*. 2015). The size of sample blocks should take into account the average size of wolf pack territories, average line density within the territory, daily wolf movement rates and logistical constraints as well as allow for replication within a territory. As an example, we applied these considerations to the Snake wolf pack and suggest a minimum block size of 25 km^2, which should allow for a reasonable expected encounter frequency of wolves with sample blocks (Fig. 4). For strong statistical inference, blocks should be randomly assigned as treatments or controls; however, variation in line density and land cover type among blocks may require a paired design where blocks are first matched based on these attributes then randomly assigned as treatment or control. Logistical and financial constraints may further influence the assignment process. For example, it may be more efficient to treat blocks with low line density.

Treatment effects in this phase can be monitored using two response metrics: relative predator use of blocks and movement rates within blocks. As in *Year 1*, relative use can be monitored by maintaining a sample of GPS collared animals and by using remote cameras on a sample of lines. If treatments are effective, both the number of GPS locations and the number of predator images should be lower in treated blocks. Data from GPS collared animals can also be used to estimate movement rates within treated and control blocks. Because sample blocks will be distributed throughout the pack's home range, a sufficiently long monitoring period (i.e. > 3 months) will be necessary to allow animals time to move into and within sample blocks.

Statistical methods similar to those in *Year 1* can be used to assess the strength of treatment effects. If treatment and control blocks are paired based on environmental attributes, then paired *t*-tests can be used. Alternatively, linear regression models can be used to more explicitly control for possible confounding variables. Determining an appropriate sample size of blocks will require *a priori* power analyses based on the desired effect size. For example, a sample size of ~ 33 treatment-control pairs is required to have sufficient power ($1 - \beta = 0.8$ at $\alpha = 0.05$) in paired *t*-test setting to detect a medium effect size (Cohen's $d = 0.5$), defined as

$$d = \frac{|\mu_1 - \mu_2|}{\sigma}$$

where μ_1 and μ_2 are the means of the treatment and control groups, respectively, and σ is the common error variance. Larger effect sizes will require smaller sample sizes (e.g. $n \approx 14$ for $d = 0.8$). Logistical and financial constraints will also necessarily factor into final sample size determination. A BACI-type design should be helpful in overcoming limitations of suboptimal sample sizes by providing multiple lines of evidence (e.g. pre- and post-treatment comparisons and treatment-control comparisons).

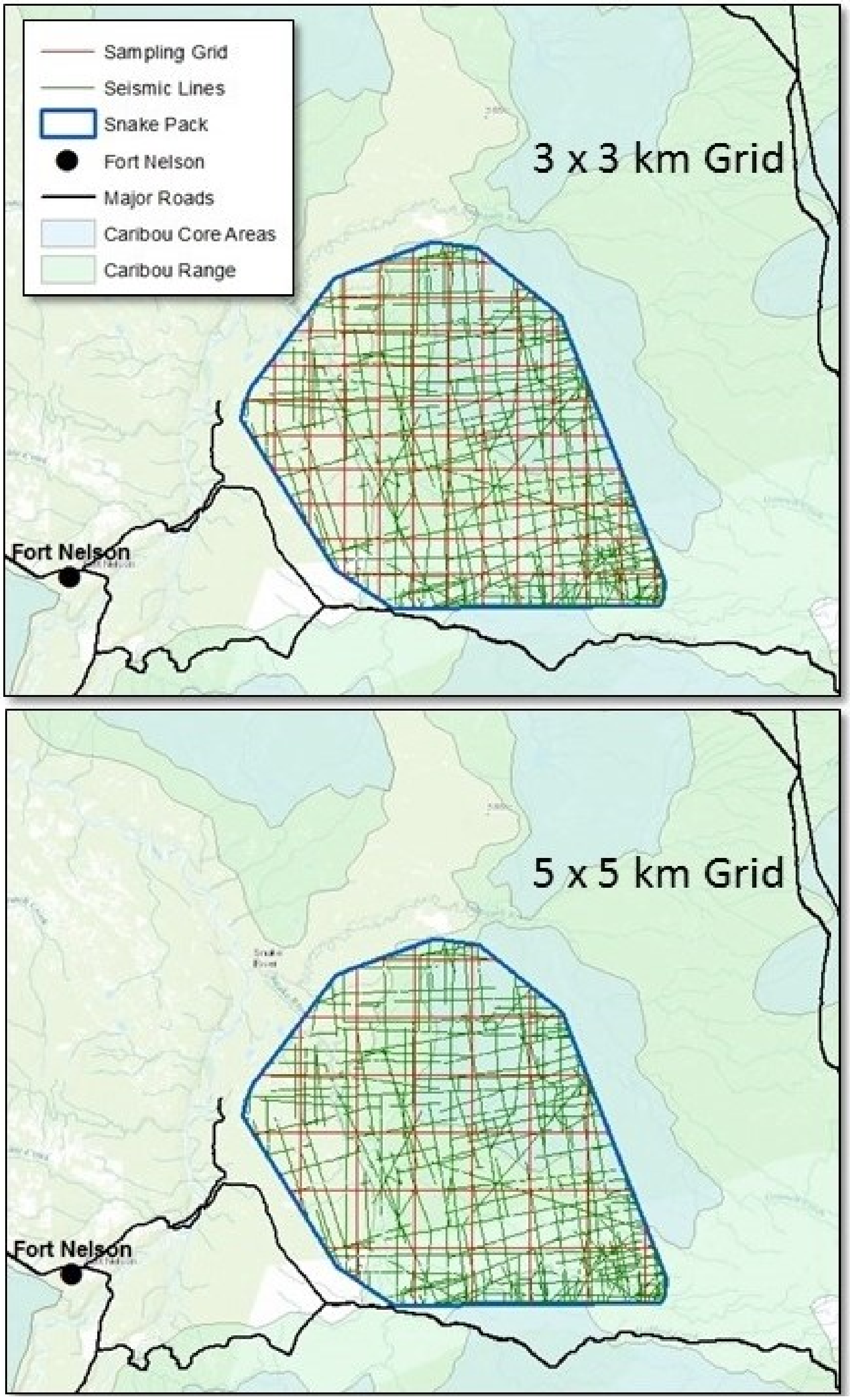

Figure 4: Sampling grids of 9 km^2 and 25 km^2 applied to the territory of the Snake wolf pack. Sample blocks of 25 km^2 will likely have a higher expected encounter frequency with wolves travelling within the pack's territory.

Year 3: Large-Scale Testing

In the final phase of the framework, the sample unit enlarges to a wolf pack's territory to test treatment effects over a biologically meaningful area. Within a BACI setting, data from at least two packs will be required. Ideally, treatment packs should be paired with control packs that have similar environmental attributes within their territories. Treatments can be deployed in a block-type fashion as in *Year 2*; however, because response metrics differ in this phase (see below), at least 50% of a territory should be treated. Based on current simulation work assessing the effect of linear features on predator-prey encounter rates, the spatial configuration of treatment deployment has little effect on prey encounter rates (C. DeMars, *unpublished data*). Thus, treatments do not need to be deployed in one contiguous block, which allows for flexibility to take into account logistical and financial constraints.

Monitoring treatment effects in this phase differs from the previous two. Here, the focus switches from evaluating relative use of targeted areas to metrics that reflect changes in wolf movement behaviour, hunting efficiency and reproduction. These metrics will require maintaining a sample of radio-collared individuals within each treatment and control pack. To best estimate movement rates, radio-collars should be programmed for sampling intervals where the fix rate is every 5 minutes. Decreasing movement rates should equate to a decrease in prey encounter rates and thus kill rates, all else being equal. We recommend, however, that this assumption be explicitly tested by collecting kill rate data. Kill rates can be estimated using approaches that model clusters of GPS locations, corroborated by field investigations of a subset of such clusters (Webb *et al.* 2008). A decrease in kill rate, in turn, should result in a decrease in wolf productivity. Again, this assumption should be verified, which can be done by identifying and monitoring den sites to count pups and by periodic aerial counts of pack size to monitor pup survival to one year of age. We therefore recommend a minimum monitoring period of one year during this phase of testing.

Statistical power in this phase will necessarily be limited by small sample sizes. Nevertheless, monitoring multiple metrics will provide multiple lines of evidence to gauge treatment effects. We also suggest that extending the monitoring period over multiple years will further strengthen treatment inferences.

Table 2: Overview of time line and objectives for developing and testing techniques for functionally restoring linear features.

Time Period	Phase	Objective	Treatment Parameters	Response Metrics
Year 1	Pilot Study	Develop effective technique(s) for limiting predator use of linear features	In a BACI design, deploy and monitor selected treatments on lines highly used by wolves. Vary intensity of deployed treatments. Monitor control lines.	Relative line use, monitored by: • Remote cameras • GPS locations of radio-collared animals
Year 2	Treatment Blocks	Test the effectiveness of developed techniques for excluding predators from an area	In a BACI design, deploy treatments within blocks (i.e. defined areas). In treatment blocks, all lines are treated.	Relative use, monitored by: • Remote cameras • GPS locations of radio-collared animals Movement rate within blocks, monitored by: • Radio-collared animals
Year 3	Large-Scale Testing	Test the effectiveness and feasibility of developed techniques over a biologically meaningful area	In a BACI design, deploy treatments in 1-2 wolf pack territories. Treatments should cover > 50% of territory. Choose control packs with territories having similar line densities and land cover composition.	Movement rates, monitored by: • Radio-collared animals Kill rates • Cluster analyses of wolf GPS locations Reproductive rates • Pup production and survival – monitored by remote cameras at den

ESTIMATED COSTS AND EXAMPLE BUDGET

Explicit in our overall objective is that developed restoration techniques be relatively cost-effective. To that end, we estimated per km costs for the two proposed techniques – tree felling (Table 3) and fencing (Table 4) – and used these estimates to develop example budgets by year. Note that there is considerable uncertainty surrounding cost estimates, primarily related to whether a helicopter is needed for treatment deployment and at what intensity treatments are deployed. Here, we assume that lines are treated in 200-m intervals (200-m treated followed by 200-m untreated) and that a four-person crew can treat 1-km of line per day. Uncertainty also exists specific to each technique. For example, for tree felling we assume that timber is available on site. Obtaining timber off-site will substantially increase per km costs. For fencing, we assume that a zigzag pattern of deployment will require 750-m of fencing per km treated. All cost estimates were derived from available technical reports from projects using similar techniques (Bohm *et al*. 2015) and from discussions with contractors in northeast BC, Alberta-based contractors with experience in linear feature restoration (see Appendix C for a list of sources contacted).

Table 3: Per kilometer costs associated with tree felling to functionally restore linear features in northeast British Columbia. Note that these estimate due not include accommodation and meal expenses and assume that suitable trees are available on site.

Description	Unit	Cost / Unit	No. of Units	Amount
Tree fellers (x 2, with saws)	hourly	$75	8 (x 2)	$1,200
General labour (x 2)	hourly	$60	8 (x 2)	$960
Truck	daily	$250	2	$500
Argo (summer access)	daily	$450	2	$900
Snowmobile (winter access)	daily	$200	2	$400
Fuel	daily	$100	1	$100
Helicopter (includes fuel)	daily	$6,150	1	$6,150
Subtotals				
Cost / km: ground access (summer)				$3,660
Cost / km: ground access (winter)				$3,160
Cost / km: helicopter access *				$8,910

* includes costs for field truck and fuel

Table 4: Per kilometer costs associated with snow or wire mesh fencing to functionally restore linear features in northeast British Columbia. Note that these estimate due not include accommodation and meal expenses.

Description	Unit	Cost / Unit	No. of Units	Amount
Fencing (snow fence or wire mesh) *	15 m	$55	50	$2,750
General labour (4 person crew)	hourly	$60	8 (x 4)	$1,920
Truck	daily	$250	2	$500
Argo	daily	$450	2	$900
Fuel	daily	$100	1	$100
Helicopter (includes fuel)	daily	$6,150	1	$6,150
Subtotals				
Cost / km: ground access				$6,170
Cost / km: helicopter access *				$11,420

* includes costs for field truck and fuel

Year 1 Budget

To estimate a budget for the *Year 1* pilot study, we assumed the following:

i. Three pack territories were selected for developing and testing restoration techniques.
ii. Five lines will be treated within each territory
iii. Each line is 1 km in length
iv. Fencing will be deployed on all lines. Note that this treatment is the more expensive of the two options. If lines were to be treated with tree felling, overall costs would be ~ $45,000 lower (~ $3,000 less per line x 15 lines; see Tables 3-4)
v. Approximately half of the treated sites would require helicopter access
vi. A monitoring period of 6 months

Given this scenario, we estimated a *Year 1* budget of ~ $482,250 (Table 5). A majority of the estimated costs were associated with monitoring treatment effects. The highest cost was associated with the purchase of remote cameras. We estimated using six cameras per line (treatments and controls). Note that these cameras will be used in subsequent years of the framework but a majority of their total project costs are absorbed in *Year 1*. We discuss opportunities for cost efficiencies in the *Summary* section below.

Table 5: An example budget for *Year 1* in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia

Cost Description	Item	Cost / Unit	Units	Amount
Equipment	GPS radio -collars	$3,000	12	$36,000
	Collar data fees	$350	12	$4,200
	Collar deployment	$3,500	12	$42,000
	Remote cameras	$600	180	$108,000
	SD cards and batteries	$50	180	$9,000
	Fencing (per km)	$2,750	15	$41,250
Flight costs	Mortality checks	$12,000	1	$12,000
	Recon flight for site selection	$12,000	1	$12,000
	Site access	$6,150	8	$49,200
Travel / Accommodations	Trucks (2 per day for deployment - contractor)	$250	40	$10,000
	Trucks (1 per week - U of A monitoring)	$555	12	$6,660
	Mileage (per km)	$0.31	10000	$3,100
	Housing (per day)	$100	160	$16,000
	Meals (per day)	$45	160	$7,200
Labour	Deployment labour (per km)	$1,920	15	$28,800
	Research technician (per month)	$2,500	6	$15,000
	Project manager (per year)	$20,000	1	$20,000
	First Nations monitor (per day)	$600	30	$18,000
Subtotal				$438,410
Contingency	10% of total			$43,841
Total				$482,251

Year 2 Budget

In the framework's second year, the focus switches from treating individual lines to areas (or blocks). For this year's budget, we made the following assumptions:

i. Two wolf packs would be monitored: one treatment and one control. We use the Snake pack as the example treatment pack.

ii. A sample block size of 25 km^2. Within the Snake pack territory, this equates to an availability of ~ 26 sample blocks.

iii. Five sample blocks will be treated, equating to ~ 20% of the packs territory.

iv. All lines will be treated by fencing.

v. Average line density is 2.2 km/km^2. Multiplying by five blocks, this equates to 275 km of lines

vi. Seventy-five percent of lines within a block require treatment (i.e. 25% have regenerated sufficiently to impede wolf movements). This equates to treating ~ 206 km of lines in total.

Under these assumptions, we estimated a *Year 2* budget of $1,570,393 (Table 6). Unlike Year 1, the vast majority of costs are now related to treatment deployment.

Table 6: An example budget for *Year 2* in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia

Cost Description	Item	Cost / Unit	Units	Amount
Equipment	GPS radio -collars	$3,000	8	$24,000
	Collar data fees	$350	8	$2,800
	Collar deployment	$3,500	8	$28,000
	Remote cameras	$600	20	$12,000
	SD cards and batteries	$50	180	$9,000
	Fencing (per km)	$2,750	206	$566,500
Flight costs	Mortality checks	$12,000	1	$12,000
	Recon flight for site selection	$20,000	1	$20,000
	Site access	$6,150	20	$123,000
Travel / Accommodations	Trucks (2 per day for deployment - contractor)	$250	160	$40,000
	Trucks (1 per week - U of A monitoring)	$555	12	$6,660
	Mileage (per km)	$0.31	15000	$4,650
	Housing (per day)	$100	900	$90,000
	Meals (per day)	$45	900	$40,500
Labour	Deployment labour (per km)	$1,920	206	$395,520
	Research tech (per month)	$2,500	6	$15,000
	Project Manager (per year)	$20,000	1	$20,000
	First Nations monitor (per day)	$600	30	$18,000
Subtotal				$1,427,630
Contingency	10% of total			$142,763
Total				$1,570,393

Year 3 Budget

The focus in the final year is treating >50% of a pack's territory. Here, we maintain the assumptions listed in *Year 2* with treatments now deployed in a higher number of sample blocks. In this year, an additional 10 blocks are treated, bringing the total to 15, and equating to 412 km of line. Monitoring is now focused on wolf movement rates, kill rates and productivity. As such, camera expenses are replaced with flight costs associated with kill rate and productivity monitoring.

Expanding treatments to a biologically meaningful scale significantly increases costs (Table 7). We estimated a *Year 3* budget of $2,924,262. Again, the vast majority of this cost is attributed to treatment deployment. As with the previous two years, we assumed that all lines were treated by fencing. Tree felling, particularly if done in the winter, could potentially halve treatment costs ($2.5 million vs. $1.3 million).

We re-emphasize that the yearly budgets presented are for illustrative purposes only. The adaptive nature of the framework and variability in logistics will likely result in actual costs differing considerably from those listed here.

Table 7: An example budget for Year 2 in a 3-year framework for developing techniques to functionally restore linear features in northeast British Columbia

Cost Description	Item	Cost / Unit	Units	Amount
Equipment	GPS radio -collars	$3,000	4	$12,000
	Collar data fees	$350	8	$2,800
	Collar deployment	$3,500	4	$14,000
	Fencing (per km)	$2,750	412	$1,133,000
Flight costs	Mortality checks	$12,000	1	$12,000
	Kill site investigations	$30,000	1	$30,000
	Pack survey flights	$12,000	3	$36,000
	Recon flight for site selection	$20,000	1	$20,000
	Site access	$6,150	30	$184,500
Travel / Accommodations	Trucks (2 per day for deployment - contractor)	$250	320	$80,000
	Trucks (1 per week - U of A monitoring)	$555	16	$8,880
	Mileage (per km)	$0.31	20000	$6,200
	Housing (per day)	$100	1800	$180,000
	Meals (per day)	$45	1800	$81,000
Labour	Deployment labour (per km)	$1,920	412	$791,040
	Research tech (per month)	$2,500	8	$20,000
	Project Manager (per year)	$20,000	1	$20,000
	First Nations monitor (per day)	$600	45	$27,000
Subtotal				$2,658,420
Contingency	10% of total			$265,842
Total				$2,924,262

SUMMARY

Developing effective techniques for restoring habitat is a key conservation objective for stabilizing and recovering caribou populations (Environment Canada 2012). Developing and implementing such techniques, however, is not a trivial task because of the large spatial scale of caribou ranges, the extent of disturbance within them, and the need for management actions to produce short-term, tangible results for rapidly declining populations. For these reasons, we focused on how to develop techniques for functionally restoring a ubiquitous form of disturbance in western caribou ranges – linear features. We described a multi-year framework that adaptively tests techniques at progressively larger spatial scales. We emphasize that functional restoration techniques should be viewed as potential short-term management levers that form part of a comprehensive strategy aimed at more permanent, long-term ecological restoration.

Cost effectiveness and logistical feasibility were key components of our overall objective. In term of cost, the techniques suggested here are well under costs associated with current ecological restoration initiatives (mounding and tree planting) on a per km basis (i.e. ≤ $6200 vs. > $10,000; Pyper *et al.* 2014). Nevertheless, developing functional restoration techniques and deploying them over a biologically meaningful area will require a significant financial investment. Moreover, there is considerable uncertainty associated with estimating the actual costs required. For these reasons, we recommend that a project of this magnitude be governed by an oversight committee that is directly involved in project planning, direction, permitting and budgeting, similar to the model of Alberta's Regional Industry Caribou Collaboration. This committee should have representation from all relevant stakeholders, including government, First Nations, and industry.

To give an indication of the financial investment required, we provided estimated costs and example budgets for our three-year framework. These estimates did not include the availability of potential cost efficiencies. For example, the costs of radio-collar deployment on wolves could be reduced by partnering with existing REMB wolf monitoring programs in northeast BC. Accommodation costs could be reduced if housing is available at industry camps.

Cost efficiency will also likely factor into the type of treatment selected after the first year for large-scale deployment. Our estimates suggest that tree felling may be significantly less expensive than deploying fences though, as noted previously, this discrepancy assumes an adequate supply of on-site timber. Knowledge gained from the first year's pilot study will determine whether this assumption significantly biases tree felling costs low. Beyond upfront costs, other factors are likely to influence the choice of treatment. Deploying piles of coarse woody debris may raise concerns of increased fire risk while fencing on a large scale may meet social resistance. Note that we also did not include maintenance or eventual clean-up costs for fencing, both of which may add significantly to per km costs.

Another factor will be speed of deployment. Because a primary aim of functional restoration is to produce rapid changes in current biological processes, the rate of treatment deployment should also be relatively fast in order to quickly treat a biologically meaningful area. We estimated that a four-person could deploy treatments at a rate of 1 km/day. Ultimately, better estimates of deployment rate will be learned after the project's first year. Nevertheless, our estimates suggest that it will take significant manpower to deploy treatments over a large scale (i.e. > 50% of a pack territory) within a time frame suggested by our framework.

In summary, our report outlines a framework for developing and testing techniques for functionally restoring linear features within caribou range. The uncertainty inherent to all phases of the framework indicates that implementation will ultimately be an adaptive process. To best meet the challenges of this adaptive process – and considering the scale and scope of the project, a critical first step to project implementation should be the formation of an oversight committee consisting of representatives of all relevant stakeholders and persons with expertise in linear feature restoration.

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APPENDIX A: LITERATURE REVIEW

To inform the development of our multi-year framework for testing functional restoration of linear features, we conducted an extensive literature review using online databases (University of Alberta libraries). The following search terms were used in various combinations: mitigation, linear features, mitigating use, wildlife, predators, wolves, seismic lines, roads, road block, line blocking, road ecology, deterrent, exclusion fence, screens, carnivore-livestock conflicts, deter, exclude, linear corridors, tree felling, scent deterrent, biofence, flagging, woody debris, slash, and tree planting. We also accessed technical reports, predominantly from mitigation treatments completed in Alberta, and unpublished work through the University of Alberta. For each mitigation technique, we briefly summarized its methodology, subjectively assessed its efficacy and estimated costs. Some cost estimates for techniques were obtained from discussions with independent contractors involved in mitigation projects. Where possible, we attempted to scale costs to dollars per kilometer.

RESULTS

Mitigation methods for linear features primarily fell within three major categories: fencing, mechanical treatments and restoration.

Fencing

Fencing was the most common mitigation technique used to deter wildlife and was implemented over the widest range of scenarios (e.g., Clevenger *et al.* 2001; Huijser *et al.* 2009; LeBlond *et al.* 2007; VerCauteren *et al.* 2006). Types of fencing included snow, wire, and numerous forms of electric. Across studies, cost and efficacy varied considerably, depending on fence type and the surrounding habitat. Fencing can physically deter human and wildlife access and may further inhibit use by decreasing the line of sight down a linear feature (Golder 2015a). We note that most studies using fencing involved excluding predators from a closed area (e.g., grazing lease) and did not test inhibiting predator use of linear features *per se*.

Snow Fencing

Snow fencing is typically made of perforated plastic and attached to metal or wooden poles at regular intervals for structural support. Additional support can be installed using heavy steel 'T' posts and a high tensile wire attached and tightened lengthwise through the fence (Scott Renaud, *pers. comm.*). Because materials are relatively low cost and special equipment is not required for construction, snow fencing is an inexpensive option for providing a visual and potentially physical barrier for predators. Cost estimates for a 48" high snow fence can be as low as $10/m.

Two studies used snow fencing as a line blocking mechanism on seismic lines. The first was a pilot study in the Little Smoky caribou range (McCutchen 2003). Fences were placed perpendicular to the line and were sufficiently wide to deter wildlife into the surrounding forest. Of the 13 lines with a snow fence, wolves only visited four; however, wolves were deterred at three out of the four sites. During the winter months, fences were covered with snow which heavily limited their ability to prevent predator access.

The second study, which was developed in conjunction with the original literature review, deployed snow fencing across seismic lines at line intersections (DeMars *et al*. 2015). Fifteen treatment sites were contrasted with 15 control sites and all sites used scent lure to increase the potential for predator visits. Predator use at each site was monitored over four months using remote trail cameras. Results suggested that snow fencing was ineffective at limiting predator use of treatment sites.

In both studies, inferences may have been affected by small sample sizes and each suggested that snow fencing should be tested at a larger scale (McCutchen 2003). Moreover, it is undetermined if snow fencing can affect overall movement rates of predators on lines (DeMars *et al*. 2015).

Wire Fencing

This type of fencing includes wire-mesh, slanted wire-mesh, and barbed wire (VerCauteren *et al.* 2006). Several studies have demonstrated that mesh and woven-wire fencing can deter wildlife access to roads, effectively reducing wildlife-vehicle collisions (WVCs; Oškinis *et al.* 2013; Clevenger *et al.* 2001; VerCauteren *et al.* 2006). For large ungulates, wire fencing along roads has been shown to work as an absolute barrier (Huijser *et al.* 2009). In Kootenay National Park, Ford *et a*l. (2011) compared the number of WVCs per species by length of fence along a major highway. For wolves, a 25 km long fence reduced the total WVCs by 80% compared to only 40% along a 10 km long fence.

Beyond roads, wire fencing has been used as a wildlife deterrent in agricultural areas (Table 1). For white-tailed deer, woven-wire mesh fence that was >3m in height proved to be an effective barrier (VerCauteren *et al.* 2006). In Spain, wire fencing has been used to protect livestock. Fences are built 180 - 200 cm high with barbed wire on top and an additional 50 cm into the ground to prevent digging by wolves (Reinhardt *et al.* 2012). These fences have been shown to be 100% effective for wolves, but may not be practical on a large scale because of cost. Barbed and woven wire fences also have the potential to entangle and kill wildlife (Harrington & Conover 2006).

Although there are drawbacks to wire fencing, such as higher costs (e.g. $30 -$90/m) and the potential for animals to travel underneath where terrain is uneven, fences of this type are generally long-lasting (e.g. 30 years) with minimal maintenance requirements. Under-fence travel can be minimized by installing a single barbed wire along the fence bottom (VerCauteren *et al.* 2006).

Table A1: Comparison of a variety of fences for managing damage caused by deer and their characteristics including: costs (including labor), efficacy, longevity, and maintenance [from VerCauteren *et al.* (2006)].

Fence type	Cost/m ($)	Height (m)	Efficacy (%)	Longevity (yrs)	Maintenance
Woven wire	10.00–15.00	2.40	90–99	30–40	Low
Welded wire	10.00–15.00	2.40	90–99	20–30	Low
Chain link	>20.00	2.40	90–99	30–40	Low
Poly. mesh	15.00–20.00	2.40	90–99	10–20	Medium
Poly. rope 9	5.00–10.00	1.82	70–80	15–25	High
Mod. WW 3 HT[a]	5.00–10.00	2.40	80–90	20–30	Medium
Poly. snow[b]	5.00–10.00	2.12	80–90	15–25	Medium
Offset HT	2.00–5.00	1.05	60–70	20–30	High
Slanted 7 HT[c]	2.00–5.00	1.50	70–80	20–30	High
Penn St. 5 HT	2.00–5.00	1.12	70–80	20–30	High
Poly. tape 2[d]	<2.00	0.90	60–70	5–15	High
Baited electric	<2.00	1.12	80–90	10–20	High

[a] Modified woven-wire fence with 3 strands of high-tensile wire above.
[b] Polypropylene snow fence.
[c] Slanted 7-strand high-tensile wire.
[d] Two-strand poly-tape.

Electric

In general, electric fencing consists of high tensile electrified wire where contact with the wire creates an aversive response by the animal (Shivik *et al. 2003*). Electric fencing has proven to be effective in preventing wolves and bears from accessing livestock in agricultural settings (VerCauteren *et al.* 2006; Reinhardt 2012; Dalmasso 2012). For excluding large mammals (e.g. ungulates, bears and wolves), VerCauteren *et al.* (2006) recommend five chords placed at 30 cm increments with an ideal overall height of 1.5 m. To specifically exclude wolves, fencing should be kept at 4000 – 5000 volts, as lower voltages may lead to habituation (Reinhardt 2012). Electric fencing can also be used as a secondary repellent mechanism in combination with other exclusion methods. For example, electrified fladry (see below) was found to be 2-10 times more effective than regular fladry when tested on captive wolves (Lance *et al.* 2010).

Electric fencing may be a good alternative to wire fencing because it is generally less expensive (Reinhardt 2012; LeBlond *et al.* 2007), although it requires a similar amount of time for installation and has greater maintenance needs. Frequent inspections and voltage testing, seasonal tensioning of electric wires, and ongoing suppression of vegetation during the growing season is needed for electric fences to remain operational year round (VerCauteren *et al.* 2006). Occasional power outages have also been known to occur with electric fences, but this could be mediated by the use of circuit breakers (LeBlond *et al.* 2007). Costs for a large, contiguous section of electric fence has been as low as $22/m installed, an estimated 50% less than a metal wire fence (LeBlond *et al.* 2007).

Besides high tensile wire, other options exist for electric fencing. These include seasonal electric fences, which consist of an electrified steel wire hung between light duty steel or fiberglass posts, and polytape and polyrope, which incorporate electrified wires into synthetic ropes or ribbons (VerCauteren *et al.* 2006). These options are less expensive than high-tensile electric fences but may not be as robust, and have shown varying levels of effectiveness against predators (VerCauteren *et al.* 2006). Electrified fladry was used in a study to protect a food source from captive wolves and was verified by field trails (Lance *et al.* 2010). The study found electrified fladry to be 2-10 times more effective than regular fladry when tested on captive wolves, but results were inconclusive during field studies as there was no depredation on cattle in both the treatment and control pastures.

Light-weight cable systems supported by fibreglass have also been suggested, as these can be set up quickly by hand and reused on different sites as required. These units have been used by beekeepers to keep bears from disturbing hives, and only require a solar system to be energized (Scott Renaud, *pers. comm.*).

Fladry

Fladry is a technique used to deter wildlife by suspending plastic flags from a rope across an area, and is used as a primary repellant to produce a startle or flight response from the predator (Lance *et al.* 2010). Flags are typically suspended 50 cm above the ground at 50 cm intervals

(Golder 2012). The efficacy of fladry may be inhibited by poorly designed flags (Young *et al.* 2015) that can twist and get caught on the suspension wiring, although recent designs may overcome this issue (Young *et al.* 2015). The efficacy of fladry may also be affected by animal habituation. For example, Musiani *et al.* (2003) found that fladry was only effective for the first 60 days with wolves and was ineffective for bears. Fladry has been suggested as a technique to minimize wolf travel along linear features (Boutin 2003); however, the effectiveness of fladry on larger areas is unknown (Musiani *et al.* 2003).

Biofence

Biofence or human-deployed scent-markers have been used as a non-lethal strategy for mitigating predation, primarily on livestock. To deter wolf movements and reduce predation on livestock, Ausband *et al.* (2013) deployed a biofence of wolf scat and urine (from animals not in the study area) to simulate natural wolf use of scent markers. The biofence was placed around the perimeter of livestock pastures and no fences were trespassed in the first year of deployment. In the second year, however the technique was no longer effective in preventing wolf access to pastures, even after redeploying scent marks (Ausband *et al.* 2013). Biofence may be limited by the necessity to maintain consistent scent markers throughout a study period, and therefore may not be a useful long term mitigation technique.

MECHANICAL TREATMENTS

Mechanical treatments such as tree felling and slash rollback can be an effective and fast-acting way to deter human and predator use of linear features. This type of mitigation, however, may be limited by high costs associated with moving machinery to remote areas and the resources needed to complete treatments across large spatial scales. Mechanical treatments are often used in combination with some type of restoration treatment, as some techniques (e.g., slash rollback, mounding) can promote natural regeneration of linear features and/or function as site preparation methods prior to re-planting. Because mechanical and restoration treatments are often used together, it can be difficult to measure the efficiency of individual mitigation techniques.

Tree Felling

Tree felling involves cutting trees along the edges of a linear feature – or within the surrounding forest – and laying them in such a way that blocks or hinders access. In the Little Smoky caribou range of Alberta, a pilot study used tree felling on 21 sites to deter predators from using seismic lines (McCutchen 2003). Only three of the sites were visited by wolves and at two of the three sites, wolf use was prevented. A subsequent study conducted at a larger scale measured blocks of land rather than a single line (Neufeld 2006). In 'treated' blocks, felled trees were placed across all lines and wolf use of treated blocks was compared to control blocks. Wolves were observed using treated blocks less frequently than controls although the difference was not statistically significant. The small sample size may have contributed to the lack of significance (Neufeld 2006). A recent study in NE BC also suggested that wolves avoided using linear features with higher densities of coarse woody debris (DeMars *et al.* 2012).

Treatment recommendations include falling two trees perpendicular to the linear feature at intervals of every 15m to 20 m in both upland and lowland habitats (Golder 2015a). Additional trees should be felled near intersections and access points to further deter use by wildlife and humans.

Although tree felling is relatively inexpensive, a lack of sufficiently large trees close to linear features may be a limiting factor, particularly in lowland habitats, and felling machinery may be expensive to transport to sites where manual felling is not sufficient. Additionally, transporting trees from another area could have negative impacts on the surrounding forest. A further consideration is that large amounts of coarse woody debris placed on lines may cause an increase in the local fire hazard (Brown *et al*. 2003).

Slash Rollback

Slash rollback, or spreading of woody debris, aims at controlling human access during snow free periods and can also deter use by wildlife. The treatment uses debris left over from a timber harvest to cover a targeted disturbance, and can be moved and placed along linear features. Slash rollback may be an effective tool to block predator access when placed every couple hundred feet (CRRP 2005). Indeed, restoration efforts of the Christina River floodplains within woodland caribou range found an overall decline in the abundance of wolves at sites treated with slash rollback (Golder 2013). Another study (Keim *et al.* 2014) observed an 89% decrease in wolf use on treated lines over a two year period, while human use decreased by 100% and deer by 52%. Substantial amounts of woody debris, however, may be needed to sufficiently block access (Golder 2015a).

Slash rollback may also aid regrowth along a linear feature by protecting seedlings from extreme weather and damage caused by wildlife and human travel, and by providing nutrients and microsites for plants to establish (TransCanada 2014). However, a number of limitations exist, including: a lack of slash supplies and sustainable supply over time at the study area; snow pack exceeding the slash pile height may re-open access for predators during the winter; a lack of large tree availability; cost of transport of equipment and materials; and possible increased risk of fire on study features (Golder 2007). Moreover, employing slash rollback may be difficult on a large scale and the costs may outweigh the benefits.

Mounding and Ripping

Mounding is conducted with an excavator, which generally operates over frozen ground to modify the land and promote generation of both natural and planted vegetation. The size and density of mounds vary depending on site characteristics and objectives of the project, but holes are typically 0.75 m deep with the substrate placed beside to create the mound (Golder 2015b). Ripping is a similar technique to mounding, but is more often implemented on upland sites to promote creation of microsites and address soil compaction from the initial disturbance (Archuleta & Baxter 2014). In British Columbia, growth rates and survival of planted seedlings were substantially greater on mounds versus untreated areas (Macadam & Bedford 1998).

Excavator mounding may be an effective strategy to limit predator use of linear features although empirical evidence is lacking. Ongoing projects in Alberta (e.g. LiDea) are specifically testing whether mounding limits predator use though upcoming results from such projects will be necessarily short-term effects. A target density of 1,400 to 2,000 mounds per hectare has been shown to effectively restrict human access to lines (TransCanada 2014). Unlike other methods, however, mounding is projected to have both short and long-term effects, with the latter due to the promotion of vegetation re-growth on lines. A major drawback to mounding is its cost, which can be as high as $12,000 per km when combined with other mechanical treatments (Table 2). With many caribou ranges containing thousands of kilometers of linear features, mounding may be prohibitively expensive, particularly at scales sufficiently large to have an impact on caribou population dynamics.

RESTORATION

Tree Shrub and Seed Planting

Restoring linear features by planting trees or seedlings is a slow process and may be an inefficient way to block wildlife in the short term. Slow reforestation rates have been reported for seismic lines as a result of root damage, soil compaction, introduction of competitive species, low nutrient availability due to poor drainage, and repeated disturbances (Golder 2007); consequently, direct management action may be preferable to natural reforestation. Tree planting has been the most reliable and cost effective technique for restoration (CRRP 2005; Golder 2012). Transplanting adjacent trees has not been recommended due to limited supply and degradation of neighboring forests (Golder 2005). Seed planting is effective for regrowth; however, due to the amount of time it takes for seedlings to mature it should only be used as a long term mitigation technique (Golder 2007; Golder 2012) and seedlings should be adequately monitored as survival rates are unpredictable (Golder 2014). Moreover, if access is not adequately controlled while seedlings become established, human use of the linear feature may cause damage to and inhibit seedling growth (Golder 2012).

Soil condition must also be considered where trees are planted as micro-site conditions heavily influence tree survival (Golder 2005). Mechanical site preparation, such as mounding and slash rollback, can improve conditions for tree and shrub planting and accelerate growth (Macadam & Bedford 1998, TransCanada 2014). Tree planting may not be an effective technique for mitigating predator use in the short term; however, it will assist in the overall restoration process and can decrease wildlife use on linear features in the long term.

SUMMARY OF RESULTS

In Table 2, we summarize estimated costs for selected projects that used one or more of the mitigation techniques reviewed above. Note that this table does not include all studies reviewed; rather, only those that included cost estimates. Specific estimates for restoration of linear features generally includes mechanical site preparation (mounding, slash roll back, ripping, etc.) and subsequent tree planting. Costs do not include any type of post-treatment monitoring. There are a variety of considerations that may increase the cost of a treatment type, including but not limited to: hydrogeophysical features on or near the linear feature and surrounding habitat; nature of original disturbance and damage to soil, roots etc.; remoteness of treatment area; and current use of linear feature.

Table A2: Real and estimated costs for selected techniques aimed at preventing or limiting predator use of targeted areas.

Project/Study	Treatments Used	Area Treated	Cost	Comments	References
Pilot project in NW-Central Alberta	Restoration of seismic lines (e.g., mounding, tree and shrub planting)	n/a	$4,000/km	Estimate based on un-named pilot project in NW Alberta.	Schneider *et al.* 2010
Cenovus, LiDea (Linear Deactivation)	Restoration of seismic lines using ripping, mounding and tree planting	4 TWP's	$6,500 - $12,000/km	$12,000/km Includes freezing-in of winter roads and all access requirements. Costs diminish to $6,500/km after access is complete. Preliminary results show fewer large mammals on treated lines and accelerated transition of the disturbed habitat back to forest.	Michael Cody, pers. comm.
Cenovus, LiDea	Tree planting only	4 TWP's	$2.50/tree	An estimate of $2.50 per tree for silviculture treatment, including helicopter access.	Michael Cody, pers. comm.
CNRL, Kirby restoration project	Restoration of seismic lines, included ripping, mounding, and slash rollback of features	57 km	$6717/km	An additional $2572/km is estimated for planning and regulatory procedures prior to implementation.	Jon Gareau, pers. comm.
Presentation: Modeling regeneration patterns on seismic lines for restoration planning, Cassidy Van Rensen	Restoration of seismic lines	n/a	$3066 - $4466/ km	Suggested this is a conservative estimate for restoration.	van Rensen *et al.* 2014. Presentation delivered at Enabling Solutions for Landscape Level Restoration Workshop,

Project/Study	Treatments Used	Area Treated	Cost	Comments	References
					hosted by Golder.
Proposed project with Regional Industry Caribou Collaboration	Tree-felling, mounding, tree planting	77-84 km	$9,800 - $11,000/km	Costs include freezing-in winter road access, potential creek crossings, and all equipment costs. Time estimate of being able to treat 3.2 km/day. Trees are $0.75 each, not including planting.	Cost estimates are based on projected treatment plans. Hann *et al.* 2015.
Electric Fencing as a Measure to Reduce Moose–Vehicle Collisions	Electric-high tensile wire fences	1 km and 1.8 km fence	$210,000 and $407,000, respectively	Estimated cost of metal wire fence of 1.8km in length: $520,000 - $900,000. The study observed an 80% decrease in moose tracks along highways following fence installation, and only 30% of moose tracks observed were made by a moose that crossed an operational fence	Leblond *et al.* 2007
Predator exclosure fence trial	Electric high tensile wire	5m^2	$5,500	Includes solar panel and battery for operation, not including installation. Fence consists of heavy-duty metal fabricated panels with high tensile wire. Prevented predator breaches, though number of recorded attempts is low.	Costs based on electric fence built for a predator exclosure fencing trial (Serrouya, unpublished study, 2015).
Biological, technical, and social aspects of applying electrified fladry for livestock protection from wolves (*Canis lupus*).	Electrified fladry	14 km	$2,032/km	Used electrified fladry to test effectiveness of preventing wolves from accessing cattle. The first km is slightly more expensive ($2,303) which includes electronics. Two to ten times more effective at protecting food in captivity, but results were inconclusive in field trials	Lance *et al.* 2010.

Project/Study	Treatments Used	Area Treated	Cost	Comments	References
Restoring Functional Caribou Habitat: Testing Linear feature Mitigation Techniques in Northeast BC	Snow fencing	5.2 km	$2.25/m	Study applied 15 m wide sections of fence across seismic lines. Construction consisted of snow fencing zip-tied to trees in adjacent forest and held in place by wooden stakes. Cost does not include travel to remote location (required helicopter access). Snow fences were not shown to reduce predator use of seismic lines.	DeMars *et al.* 2014
Fences and Deer-Damage Management: A Review of Designs and Efficacy	Wire-mesh fencing Barbed-wire fencing High-tensile electric fence	n/a n/a n/a	$20/m $4/m $5/m	Literature review of fencing practices used to deter deer. Cost estimates are for materials only and are estimates based on study reviews. >3m tall wire fencing was recommended as the most effective fence type.	VerCauteren *et al.* 2006
Cenovus, LiDea	Wood panel fence	4 TWP's	$55/m	Costs are based on 10' lengths of fence used perpendicular across seismic lines.	Golder 2015a
Score Fencing, Revelstoke British Columbia	Snow fencing Woven-mesh wildlife fencing Ungulate fence w/ buried mesh High tensile electric fencing	n/a n/a n/a n/a	$10/m $90/m $130/m $25/m	Contractor estimates for fencing types. Costs do not include transport of materials to site and installation. High tensile electric fencing is recommended to be the most effective technique.	Scott Renaud, pers. comm.

DISCUSSION

Limiting wildlife use of ubiquitous landscape features over large spatial scales represents many challenges. We reviewed primary and grey literature to assess previously developed techniques for limiting predator use of targeted areas with a specific focus on linear features. We evaluated techniques on their overall efficacy and, where possible, their cost effectiveness. This latter criterion is particularly relevant when deploying techniques over a large spatial scale, such as across a wolf pack's home range, and where over-ground access may be limited. Deploying techniques over large spatial scales will likely be necessary to positively impact boreal caribou populations.

A primary outcome of our review is that, outside of fencing, there have been few published studies to evaluate the effectiveness of techniques specific to linear features. Moreover, criteria or guidelines for what constitutes 'success' are not well developed. With respect to population declines of boreal caribou, linear features are thought to increase predation rates of caribou by increasing caribou-predator spatial overlap and increasing predator hunting efficiency (Latham *et al.* 2011b; McKenzie *et al.* 2012). For addressing the former mechanism, assessing the efficacy of a particular technique is best accomplished by determining whether a predator is excluded from an area (i.e. presence/absence or relative use). Across the studies we reviewed, this response metric was the one most commonly used; yet, from a caribou conservation perspective, it is unclear whether the spatial overlap mechanism has a higher impact on caribou-predator population dynamics than the hunting efficiency mechanism. To date, evaluating whether a mitigation technique limits a predator's hunting efficiency has not been explicitly tested, although current projects in Alberta are working toward this goal (e.g. Regional Industry Caribou Collaboration; Sutherland *et al*. 2015). This type of evaluation requires response metrics that reflect changes in hunting efficiency either directly – such as changes in kill rate – or indirectly via changes in predator movement rates. Ultimately, mitigation techniques that can effectively address one or both mechanisms should result in a positive effect on caribou demography although assessing caribou demographic effects requires long-term monitoring of caribou populations post-treatment.

Our review highlights the difficulty in deploying effective mitigation measures over large spatial scales. Wire mesh fencing is the most effective technique for limiting wildlife use of an area but its cost may make it prohibitive when deployed at scales relevant to wolves and caribou. Moreover, fencing at large scales may have other ecological consequences (i.e. blocking animal migration routes) and may not be socially acceptable, particularly if large swaths of land are made inaccessible. We note, however, that fencing designs aimed at slowing down predators – rather than preventing use of an area *per se* – have not yet been tested. Such designs may require significantly less fencing, which may sufficiently lower treatment costs to make fencing a viable option from a cost standpoint.

The most appropriate mitigation technique(s) to use will vary with project goals. If short-term – or functional restoration – is an objective, then physical deterrents such as tree felling or fencing are likely to be more appropriate and effective because sensory techniques such as fladry and biofence are hampered by the necessity of frequently changing the particular stimuli to prevent predator habituation (Musiani *et al.* 2003). For longer-term objectives, mitigation plans should include techniques aimed at habitat restoration, such as mechanical site preparation (mounding, ripping) and seedling planting. Habitat restoration is now a commonly used mitigation technique in Alberta (Golder 2012) although ongoing monitoring is required to determine long-term efficacy and its high cost will likely inhibit the scale to which it can be applied.

The recent emphasis on mitigating the effects of the industrial footprint has led to multiple projects currently testing mitigation techniques (e.g. LiDea, Regional Industry Caribou Collaboration) and results from these projects will directly inform further testing. In the absence of such results, and on the basis of our literature review, we make the following recommendations for projects seeking to test mitigation techniques for linear features:

1. From the outset, project objectives should explicitly state how mitigation techniques will address the spatial overlap and hunting efficiency mechanisms that negatively link linear features to caribou demography. This exercise will inform the technique to be deployed (i.e. exclusionary techniques versus slowing down techniques).

2. Choose response metric(s) that reflect the project's objectives. In most instances, response metrics will be reflective of changes in predator behavior (i.e. use of an area, kill rate or movement speed). Changes in caribou demography will require longer term monitoring of caribou vital rates (e.g. adult and juvenile survival).

3. Publication of project results should include an accounting of project expenses to allow for assessments of cost effectiveness. Such costs should include estimates of potential expenses associated with the long-term upkeep and monitoring of the treated areas.

We note that these recommendations do not include advice on the spatial scale or extent over which treatments should be deployed. Caribou use space to separate themselves from predators to reduce predation risk (Seip 1992). Ultimately, then, the scale of treatment should reflect the scale required for caribou to sufficiently reduce predation risk. Such a scale has yet to be rigorously quantified (but see Nagy (2011)) although evidence suggests that it needs to be "large" (e.g. hundreds of square kilometers, DeMars 2015). This spatial scale parameter represents a key component in developing effective mitigation strategies for limiting linear feature impacts within and adjacent to boreal caribou range

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APPENDIX B: ANALYSES OF WOLF PACK TERRITORIES

We conducted home range analyses of wolf packs in northeastern BC using existing radio-collar data provided by the Research Effectiveness and Monitoring Board. To quantify wolf territories, we estimated 95% utilization distributions (Worton 1989) using GPS locations from all collared individuals within a pack (Fig. B1). We then estimated the total length of linear features within a pack's territory and linear feature density (km/km^2; Table B1). Linear features consisted of seismic lines, pipeline and roads. GIS data representing pipelines, seismic lines (1996-present) and petroleum development roads were obtained from the BC Oil and Gas Commission. For pre-1996 seismic lines, major roads, and forestry roads, we used BC Terrain Resources Information Management data. To create a parsimonious data set of linear features, all major roads, forestry roads, petroleum development roads, and seismic lines were merged into one file then integrated at a scale of 10-m to eliminate redundancies among the original data sets.

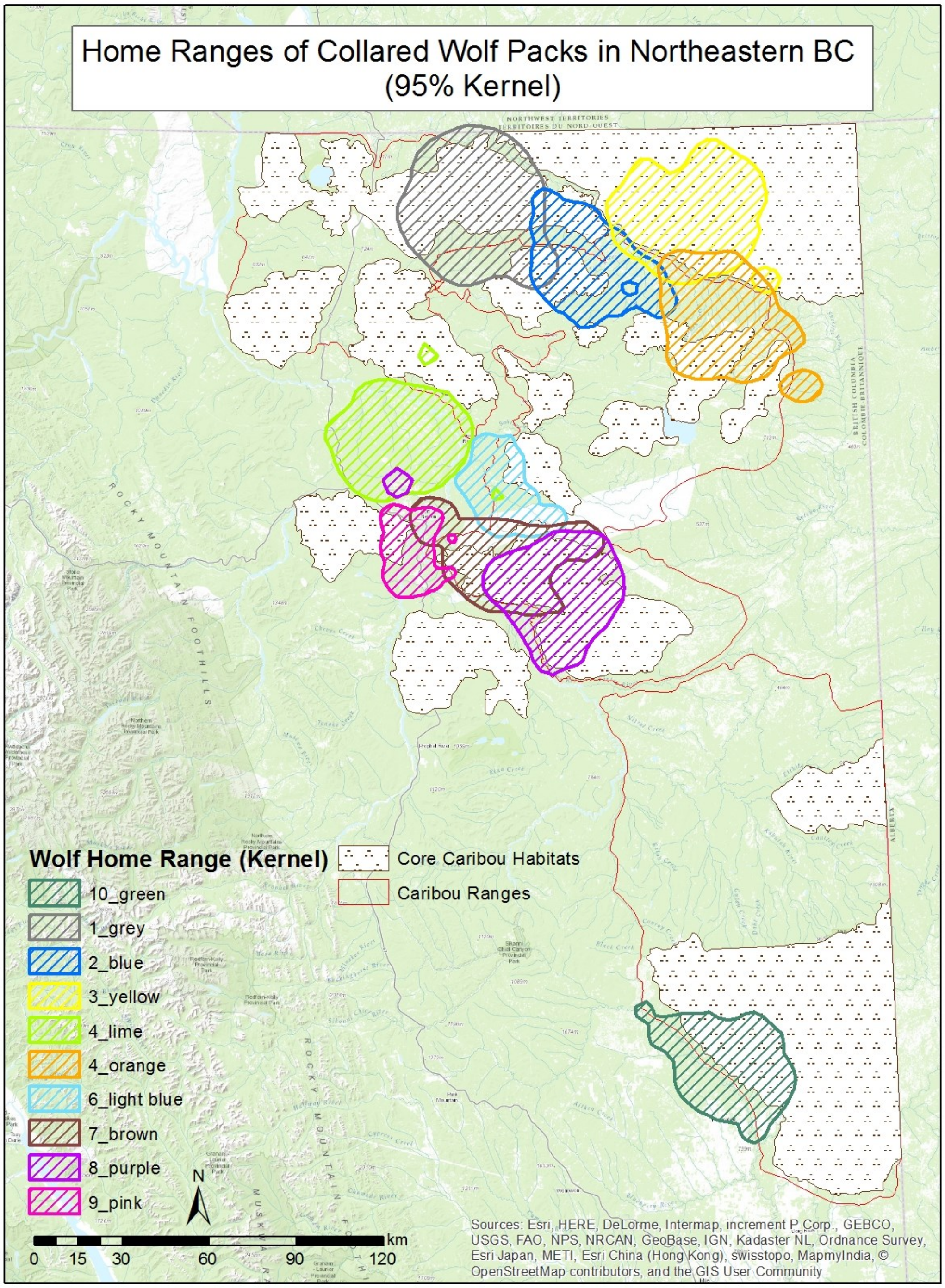

Figure B1: Territories of radio-collared wolf packs in northeastern British Columbia. We used 95% utilization distributions to estimate territories. Wolf packs were assigned generic color names.

Table B1: Linear feature density (km/km^2) and the total length of linear features (km) within ten wolf pack territories in northeastern British Columbia. See Figure B1 for geographic locations of each pack. Note that pack IDs “5_lime” and “6_light blue” refer to the Tsimeh and Snake packs, respectively.

	95% Kernel		
Pack ID	Area (km^2)	Line length (km)	km/km^2
1_grey	2304	10610	4.6
2_blue	1473	6864	4.7
3_yellow	1975	5978	3.0
4_orange	1798	8844	4.9
5_lime	1602	40756	2.5
6_light blue	788	1716	2.2
7_brown	1515	11370	7.5
8_purple	1649	13977	8.5
9_pink	593	2847	4.8
10_green	1513	6502	4.3

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APPENDIX C: COST ESTIMATE CONTACTS

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