FINAL REPORT

Using a Healthy Landscape Approach

To Restore a Modified Landscape in Northeastern Alberta

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David Andison, Bandaloop | Ted Gooding, FORCORP | Bob Christian, FORCORP

Tim Vinge, Alberta Agriculture and Forestry | Tom Moore, Spatial Planning Systems

Margaret Donnelly, Alberta-Pacific Forest Industries | Kim Rymer, Alberta Pacific Forest Industries

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Report Summary

The Canadian boreal forest today is managed based on two principles:

1. A series of independent rules and regulations for each natural resource type (timber vs natural gas, etc.)
2. Defining objectives based on the requirements of individual values (e.g. woodland caribou, recreation, timber, etc.)

An unintended outcome of these policies is that they have helped create landscapes that are far beyond their pre-industrial range in areas where the energy sector is active, such as in northeastern Alberta. There is increasing evidence that these unfamiliar landscapes create lower levels of diversity and productivity, new and unpredictable relationships between species, fewer ecosystem services, and an ecosystem less resilient to climate change.

We propose reversing these two traditional principles as follows:

1. A single set of rules applies to everyone
2. The rules focus largely on defining (collaboratively determined) desirable future landscapes

We hypothesize that both of these principles can be addressed by creating a shared vision of a desired future landscape that uses pre-industrial conditions as a guide. Aligning landscapes conditions more closely with their historical dynamics is thought to have a positive effect on ecological function and productivity, diversity, resilience, and ultimately, sustainability. These outcomes are shared goals of all stakeholders and management agencies today. In this study, we design and test the ability of what we call a Healthy Landscape (HL) planning approach to create a more sustainable future landscape on an industrially modified 330,000 hectare area in northeastern Alberta (see adjacent map).

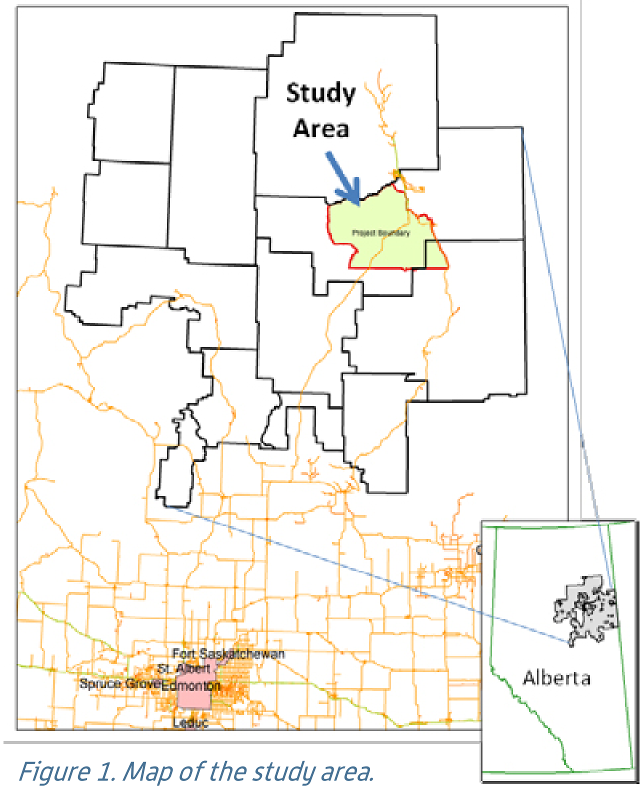


Figure 1. Map of the study area.

The term "HL approach" as used this report is a generic one in that refers to any resource management approach premised foremost on managing natural ecosystems for ecosystem integrity, health, and resilience. The foundation for an HL approach is historical landscape patterns, but also the relationship between climate, disturbance activities, and ecosystem conditions. In other words, an HL approach does not require landscapes to fall within the historic range, but rather the historic range and the associated dynamics becomes a starting point for identifying desired future landscapes. HL theory suggests that ecosystem conditions that are beyond their pre-industrial ranges represent novel conditions that resident species—including humans—will be unable to recognize or predict.

We acknowledge the potential magnitude of change this project represents in terms of both policies and practices. It is also not a simple research topic. As such, we consider this project exploratory in nature—a proof-of-concept, as opposed to a definitive set of recommendations relative to this or any other landscape.

As the name suggests, an HL approach refers more to a concept as opposed to a specific set of rules and practices. There are an infinite number of manifestations of an HL approach. The HL approach that we developed for this study includes two specific, highly novel innovative elements.

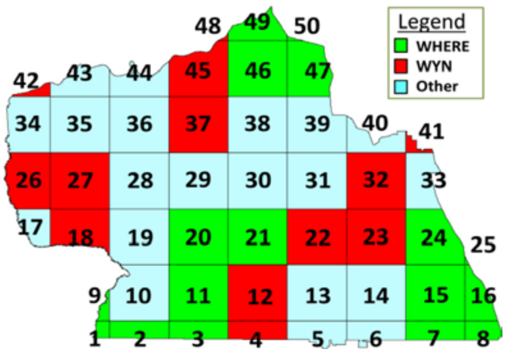
Step 1: Partitioning disturbance activity in time and space

Historical wildfire activity in the boreal clusters over both time and space, at any given time creating areas with both

1. High disturbance activity called WHEREs (i.e. WHERE you are)
2. Little or no disturbance activity called WYNs (i.e. Where You are Not)

The ratio, location, and timing of WHEREs and WYNs is in part how Mother Nature is able to create (for example) large old forest patches, caribou habitat, and diverse, resilient landscapes. In contrast, human-caused disturbance activity tends to spread out uniformly across a landscape, creating neither WHEREs nor WYNs.

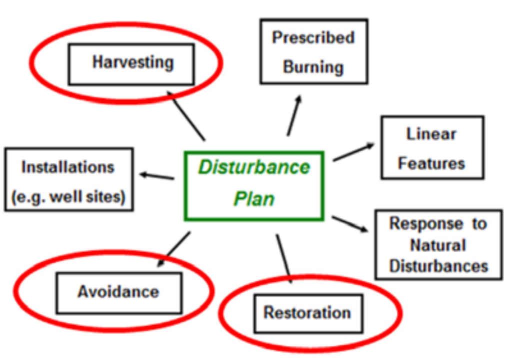
Using this concept as our planning foundation, we identified the historical ratio of WHERE and WYN grid cells from historical fire records in northern Saskatchewan based on a 10,000-hectare cells using 20-year periods. To determine whether a cell was a WHERE or a WYN we created a scoring system. Cells with high levels of existing industrial activity and low levels of old forest were favoured for WHEREs, and those with low levels of industrial activity and high levels of old forest were favoured for WYNs. The distribution of WHEREs and WYNS on the study area is shown on the adjacent map.



Note that we only considered a single 20-year period for this study, but we imagined that the process of identifying WHEREs and WYNs is repeated every 20 years. In other words, a new WHERE-WYN (W-W) map like the one shown here is generated every time period.

Step 2: A disturbance plan

The next step was to assign patterns, levels, and types of industrial activities across the landscape, classified by cell type (from above). We imagined this step being done collaboratively, although for the purposes of this pilot study we imposed our own rules. We call this process a disturbance plan. In this case, we have three types of cells on our landscape; WHEREs (in which industrial activity is concentrated, WYNs (in which industrial activity is not allowed, and Other (in which status quo rules pertain.



1. WHEREs would become focal areas for any new industrial activities such as harvesting, road building, exploration, and industrial installations. In contrast to the approach used today, the spatial design of the desired disturbance pattern at the end of each 20-year period will be defined first, and collaboratively. Moreover, these disturbance designs will be created by forest harvesting, and modelled on historical wildfire patterns. In part, this means leaving a pre-designed network of undisturbed patches and corridors designed to closely approximate those left by a forest fire. How and when the desired disturbance pattern is achieved is up to the stakeholders to reconcile. Although a range of industrial activities will be allowed, harvesting

will play the dominant role in creating natural disturbance patterns given its relative flexibility, and the ability of mechanical activities to ``erase`` the footprint of existing linear features.

2. WYNs are areas where all industrial activity is eliminated – for the 20-year period. The ecological role of WYNs is to be the areas of natural and undisturbed vegetation. That translates into no harvesting, road-building, exploration, or well-site development. In this way, WYNs are *de facto* temporary deferral zones. WYNs also become the focal areas for linear feature restoration activities.
3. Other cells are those in which there are no new specific rules of development. Business as usual can be maintained.

The main hypothesis of our study is that the HL approach described above would create healthier (i.e., more natural) future landscapes than would the continuation of traditional management approaches. To test this, we projected the traditional approach and our HL approach (i.e., the partitioning disturbance activity, plus the disturbance plan) forward in time on the Stony 800 study area using a scenario model called Patchworks.

The results suggested that the HL approach created a significantly healthier landscape than the current, traditional approach. At 20 years into the future, our tested HL approach created twice as much area in large old forest patches, restored twice as much area in linear features, and created 75% less disturbance edge compared to the existing management approach—all with the same financial investment in restoration activities and the same level of harvesting. These are dramatic improvements over the status quo in just 20 years.

The results also suggest that the more classic "NRV" approach adopted by many forest management companies may be challenging to impose on boreal landscapes with either high proportions of non-merchantable vegetation, or a high degree of existing modification by industrial activities.

The proposed management approach addresses several issues that many stakeholders in Alberta agree are high priorities, including sustainability, integrated planning, eliminating cumulative effects, and making ecosystem health a shared priority. However, the predicted improvement in landscape health is only achieved with some considerable changes to policies and practices. First and foremost, the proposed HL approach requires a fully and truly collaborative planning framework, within which responsibility is shared among all stakeholders and managers. Second, the proposed approach assumes that the temporal deferral system suggested by the WYNs will be universally accepted by all industrial partners, or implemented and imposed by the Alberta government. It will take considerable and deliberate political will for both of these changes to occur.

Acknowledgements

This project was a true collaboration. Much of the baseline data and other key study area information were developed previously by Compass Resource Management and GreenLink Forestry Inc. In addition to participating on the project team, Alberta Pacific Forest Industries provided raw spatial data, access to a previously calibrated version of the Patchworks model for the study area, and ongoing technical and operational advice. Many thanks to David Campbell for GIS expertise, and Dave Cheyne for forest management input. This project was funded by the Lands Working Group of the Cumulative Environment Management Association, and administered through the Healthy Landscapes Program of fRI Research.

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1. Introduction

1.1 Background

Industrial development activity has, over the years, affected the structure and nature of Canadian boreal forests. As society continues to require goods from and beneath the forest, industrial activity and its affects upon the forest ecosystem is only likely to escalate. This is especially true in northeastern Alberta where the majority of the land base contains extensive energy resources underlying commercial timber resources. This combination of industrial activity presents special challenges to satisfy the other demands while maintain the ecological integrity of the forest. The situation magnifies the need for a robust and integrated hierarchal planning approach (Andison 2003).

In response, Alberta initiated a comprehensive land use planning framework (GoA 2008). Land use plans are at the very top of the planning hierarchy, and are intended to set the stage for robust growth, vibrant communities and a healthy environment. The provincial land use framework also includes prominent references to the need to “manage for cumulative effects,” and, “healthy ecosystems and environment” (GoA 2008). The first land use plan developed in Alberta was the Lower Athabasca Regional Plan (LARP) in northeastern Alberta, which provided general direction and established legal requirements, but provided no specifics (GoA 2012).

Ideally, the next level of planning should translate this general-level guidance into a series of more specific management activities over both time and space (e.g., detailed forest management plans). In reality, traditional planning models at this level share two key characteristics;

1. Planning occurs via a series of unrelated processes. For example, the requirements for forest management are very different than those for the energy sector, and there is no mechanism for coordination between or among different plans. When activities occur on landscapes with multiple overlapping tenures, this lack of coordination create “cumulative effects” which compromise objectives from individual plans, are difficult to predict, almost always unwelcome.
2. Objectives are framed in terms of the needs of individual values. The list of values we manage for today in northeastern Alberta includes access, recreation, species habitat, timber, clean water, bitumen, and natural gas. A value-based planning system defines a set of rules designed to protect key values, and is used to achieve some universally acceptable balance via a trade-off exercise (often involving computer models). The benefits of value-based planning include familiarity (i.e., the tools, models, data and expertise already exist), the explicit inclusion of key values, and the potential to evaluate trade-offs. However, value-based approaches are being increasingly criticized as being inadequate for addressing overall ecosystem health and productivity, and have in some cases created less sustainable landscapes.

An unintended outcome of the (multiple plan, value-based) traditional planning approach described above is that it has helped create landscapes that are far beyond their pre-industrial range in areas where the energy sector is active, such as in northeastern Alberta. There is increasing evidence that these unfamiliar landscapes create lower levels of diversity and productivity, new and unpredictable relationships between species, fewer ecosystem services, and an ecosystem less resilient to climate change.

An alternative approach to planning at this critical level would ideally reverse these two principles: move from disconnected individual plans to a single integrated planning, and shift from managing values to managing whole ecosystems. We propose the way to do both is to use natural, historical ecosystem conditions and patterns as the backdrop for planning. For example, instead of defining desired levels of old forest based solely on the needs of individual species, historical levels of old forest are used to provide ecosystem health benchmarks. Similarly, disturbances are designed using natural disturbance patterns as templates, rather than defining disturbance attributes based on the requirements of individual values. This shifts the planning focus away from activities to outcomes, which offers greater potential for collaborative planning. The outcome is the desired future landscape, and the various management activities (such as harvesting) become tools with which to achieve it. Such a shift also means that—although values are still a part of the planning process—the primary, shared objective of planning becomes improving or maintaining ecosystem health. Ecosystem conditions (such as amount of edge or the size of disturbance events) become universal indicators of success, whether one is a forest manager, well-site developer, or prescribed burn planner.

The idea of using what we call here a healthy landscape (HL) approach as the foundation for planning was first proposed over 20 years ago (e.g. Franklin 1993) under the auspices of ecosystem-based management, or EBM (Grumbine 1994). The translation of the concept into practice continues to grow and evolve. In the boreal, the HL approach has only been applied to forest management activities so far under the auspices of a series of new NRV (Natural Range of Variation) indicators (e.g., FSC 2004). However, in theory, a broader interpretation of an HL approach is well suited as a foundation for all forest land planning activities. This project explores this prospect via a scenario modelling exercise on a human-modified landscape in northeastern Alberta.

The innovative nature of this project is such that it must be split into two parts:

1. The development of a new HL-based planning process
2. Comparing the attributes of future landscapes generated from the new HL approach against those generated using more traditional planning approaches

This project is funded by the Lands Working Group of the Cumulative Environment Management Association (CEMA), who has been a leader seeking solutions that balance society's desires of industrial development and environmental health in northeastern Alberta. This project builds on previous work supported by CEMA (the Stony Mountain 800 Linear Footprint and Access Management Project) and uses the same land base (CRM 2013).

1.2 Goals and Objectives

Defining, testing, modifying, and ultimately adopting a collaborative and innovative process is a daunting undertaking that requires research, demonstrations, new policies and practices, and countless discussions among and between stakeholders, managers, and regulators. As a first step, this project represents the initial proof-of-concept stage that bridges existing healthy landscape theory and research to a real-life planning process on an actual landscape. This project is not meant to create a specific and recommended action plan for the study area, nor do we advise that the output from this study be applied directly. As we will see ahead, the HL approach proposed here includes a number of steps that would require stakeholder input.

> **The goal of this project is to develop and test a robust planning process based on healthy landscape principles for creating more sustainable landscape conditions in areas modified by industrial activities.**

The first part of this, "to Develop and test a robust planning process based on healthy landscape principles" implies that an innovative planning process is developed and fully described in such a way that anyone could repeat it on any other landscape. The associated objectives largely involve creating a planning toolbox, including:

1. Define a set of universally applicable healthy landscape (HL) planning indicators that represent ecosystem health.

2. Develop and describe an HL-based planning approach, including the steps involved and the full suite of technical details the requirements and assumptions regarding spatial data, healthy landscape based knowledge and decision-support tools.

The second part of the project goal, "…for creating healthier landscape conditions in areas modified by industrial activities," requires the comparison of outcome of the new approach to other, current approaches. The associated objectives are:

1. Use spatial modelling to compare the ecosystem health impacts of alternative planning approaches on a human-modified landscape. The planning approaches tested will include a range of options from the traditional (individual, value-based plans) approach to an idealized HL (single, ecosystem-based plan) approach.
2. Test the practical value of the disturbance plan concept, in which desired future landscape conditions are translated into a series of human activities (such as harvesting, energy sector development and seismic line restoration) that are fully coordinated among all land management agencies.

2. Methods

The methods section of this report are quite detailed as they are meant to allow others to repeat the process on this, or any other landscape in the boreal.

2.1 Study Area

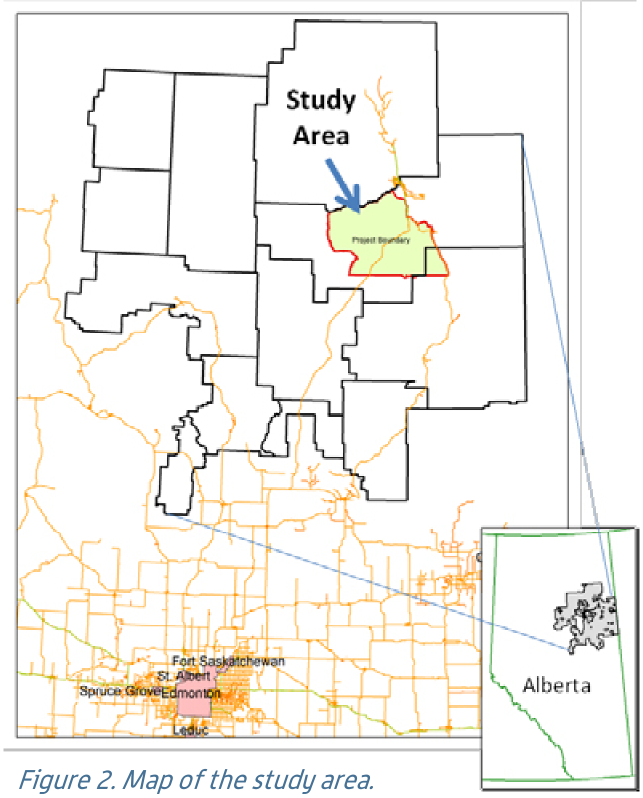

Figure 2. Map of the study area.

The project area is the same as the SM-800 project area (CRM 2013). It is a 325,500-hectare area within the Alberta-Pacific Forest Industries (Al-Pac) Forest Management Agreement (FMA) Area in Alberta, Canada. Highway 63 bisects the study area and Fort McMurray lies just to the northeast (Figure 1).

The study area is mostly contained within the Central Mixedwood Natural Sub-Region (NSR) with just over a third in the lower boreal highlands NSR (AEP 1994). Prominent water features within the study area are the Horse River and Creek and Willow Lake with the Athabasca River forming the northern border of the boundary. There is a total of just over 8,000 hectares of land within the study area comprising mapped water features.

Like much of the boreal forest in northeastern Alberta, the Stony Mountain 800 area has been modified by decades of industrial activity and social infrastructure (e.g. highways). The anthropogenic footprint is obvious from a causal examination of satellite images. However, the total area recently disturbed by human activity is actually relatively low. Records indicate that of the 300,000 hectares of forested area, 11,161 hectares (or 3.7%) was harvested within the last 20 years, and 17,041 hectares (or 5.7%) has been disturbed by other industrial activity such as linear features, well sites, and installations. Less noticeable visually, and more difficult to calculate, is the impact of several decades of wildfire suppression.

2.1.1 NRV for the Study Area

The proposed HL approach described ahead requires knowledge of pre-industrial patterns, often referred to as the Natural Range of Variation, or NRV. Traditional NRV-related requirements in the boreal focus largely on disturbance patterns: frequency, size, shape and severity. One of the more common misinterpretations of an HL approach is that disturbance patterns is the goal (e.g. Klenk et al. 2009). As important as disturbance is, the real focus of an HL approach are the legacies of disturbance rather than the disturbances per se (Long 2009). In an attempt to clarify this distinction, Andison et al. (2009) identified three hierarchical levels of natural range of variation (NRV) (Figure 2):

1. Disturbance patterns—value-neutral or coarse filter patterns that capture only the patterns of "positive space" in GIS terms. For example, disturbance event sizes and shapes.
2. Ecosystem conditions—value-neutral or coarse filter patterns that capture (in this case) the whole landscape. For example, the patch size of old forest.
3. Consequences—value-laden or fine filter patterns that capture our social, economic, and ecological values. For example, species habitat or aesthetics.

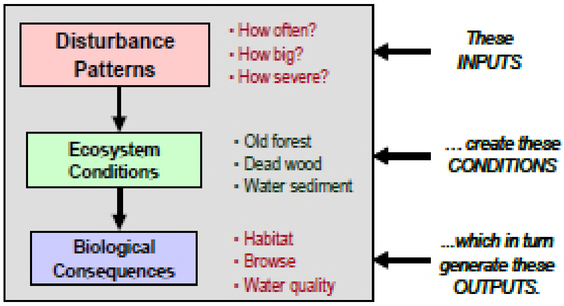

Figure 2. Hierarchy of NRV indicator types (from Andison et al. 2009).

The hierarchy proposed in Figure 2 is valuable in that it can differentiate the condition and needs of landscapes that might already be beyond its NRV because of human activity.

To follow is a brief overview of what we know about the NRV of wildfires in and near the study area, at several different scales.

2.1.1.1 Event

We have a relatively high level of understanding of the disturbance patterns of historical wildfires in this area. Wildfire events in the boreal plains tend to be fairly compact in space and many have multiple discreet disturbed patches caused by spot fires (Andison and McCleary 2014). Most wildfires have one very large disturbed patch accounting for 70–90% of the event area. On average, 20–60% of the area of a wildfire survives. The size, shape, and type of remnant patches varies widely: corridors, isolated patches, partially burned patches, feathered edges, many tiny patches, and only a few large ones. About half of the remnant area in natural wildfires in the boreal plains are partially disturbed (Andison and McCleary 2014).

The complexity of fire patterns at fine scales translates into fine-scale structural and compositional landscape condition diversity, and ultimately a range of critical habitat types.

2.1.1.2 Sub-landscape

The sizes of wildfires in northern Alberta follow the typical trend for the entire boreal with 5% of the fires responsible for 90% of the area burned. Thus, while fires in excess of 100,000 hectares are rare, they dominate the landscape, and are highly influential as regards the resulting landscape conditions. However, cultural disturbance events (as defined above) in excess of ~10,000 hectares are neither socially acceptable, nor practically possible.

An alternative way of capturing this healthy landscape is to measure the proportional area disturbed within large, equally sized cells of different sizes. Andison (2015a) found that the amount of fire in grid cells ranging in size between 10,000–100,000 hectares tends to either be very high or very low over time. In other words, fire activity tends to cluster in space at sub-landscape scales.

A clustered disturbance pattern is particularly relevant to the size of old forest patches (and by association, some habitat types). Clustered disturbances are far more likely to create large older forest patches relative to either evenly or randomly distributed disturbance patterns.

2.1.1.3 Landscape

On average, the historical amount of old forest on the study area varies from 30% for hardwood, 22% for pine, 18% for mixedwood, and 9% for black spruce (Andison 2015b). However, because the study area is relatively small, the historical range of old forest levels varies significantly. Furthermore, as the area of old forest increases, the proportion of old forest in very large patches increases. The same study suggested that the minimum habitat requirements for woodland caribou suggested by Environment Canada (2011) were met only 8% of the time on pre-industrial landscapes.

Another useful landscape scale measure associated with NRV is the relative amount of disturbance event edge. Average NRV for disturbance edge for wildfires in northern Saskatchewan is about 3.6 kilometers for every 1,000 hectares of disturbance. This suggests that natural disturbance events in the western boreal are relatively compact in space.

2.2 Acquire Spatial Data

Since we used spatial modelling for this project, we needed several types of high quality spatial data, including forest vegetation, historical harvesting activity, and existing cultural footprint from harvesting, roads, seismic lines, well sites, and other cultural features. Assembling a complete, current, and accurate spatial dataset representing landscape patterns in the Canadian boreal is challenging, more so for landscapes with multiple active land management agencies. Fortunately, we were able to take advantage of the efforts of a previous study (CRM 2013) regarding the assembly of the necessary spatial datasets as follows.

2.2.1 Vegetation Inventory

The vegetation attributes of the landscape are described primarily through a provincially regulated system known as the Alberta Vegetation Inventory (AVI). AVI requires expert photo interpreters to divide up a given landscape into polygons that share similar vegetation characteristics such as species, age, height, and density. Non-forest vegetation is also captured and classified. The original AVI (circa 2008) used for this project was supplied by Al-Pac for Forest Management Units (FMU) A14 and L11. These data were updated using more recent aerial photos, as available. Recent disturbances such as harvesting and wildfires are identified separately (see below).

2.2.2 Wildfires

Recent disturbance such as that from harvesting and wildfires can be difficult to map with respect to vegetation type for several years, until the forest re-establishes. Fortunately, of the three fires found within the study area by the AVI, none were recent, and the associated polygons have a full suite of vegetation characteristics.

2.2.3 Ecological classification

Like most provinces, Alberta has a multi-scalar ecological classification system. These data are valuable for research, management, and planning at operational, strategic, and land use scales. At the coarsest scale, Alberta is divided up into major ecological zones where climate, soils, topography, and vegetation are similar (NRS 2006). At the site scale is the eco-site phase, the determination of which requires site visits to take a combination of soil and vegetation measurements. As part of the data preparation for previous research in the Stony 800 study area, a complete digital map of eco-sites was created by combining local soil moisture and nutrient information with the Natural Subregion.

2.2.4 Long Duration Industrial Disturbance Features

Vegetation inventory maps like AVI are good at capturing the location, size and attributes of areas that have been harvested. They were not designed to identify, classify, or track the patterns of other industrial activities, and in particular, linear features. Similarly, forest management spatial planning models are highly adept at managing and measuring activities in space using polygon features, but far less so as regards linear features. Over the last decade, this has become one of the most pressing spatial data needs in the western boreal.

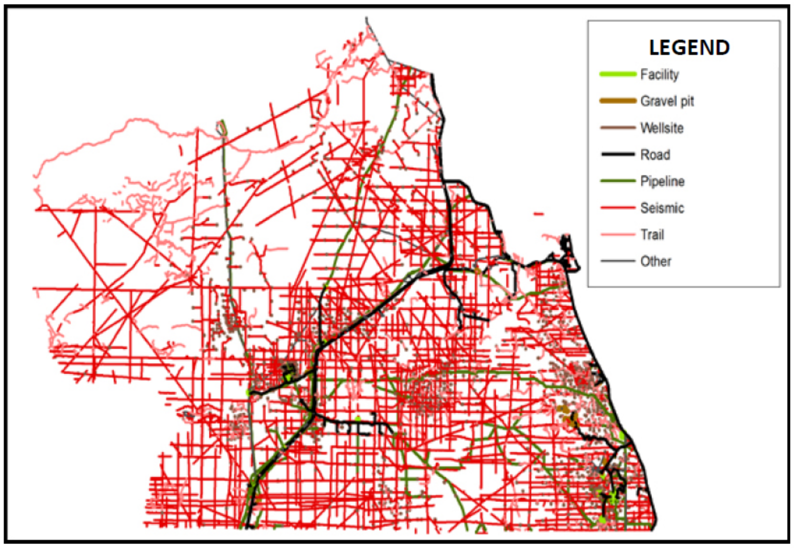

Figure 3. Overview of the linear features mapped for the study area.

Fortunately, in 2012, a detailed industrial feature inventory was completed for the study area. This layer contained information on the type and status of each road, trail, seismic line, pipeline, and power line as well as gravel pits, well sites, and processing facilities. These data were complete, classified by type, and up to date (Figure 3). Although not visually obvious from Figure 3, these data were also highly detailed (see Figure 4). Although these raw data included information on 3-D seismic lines, these were not included in this study.

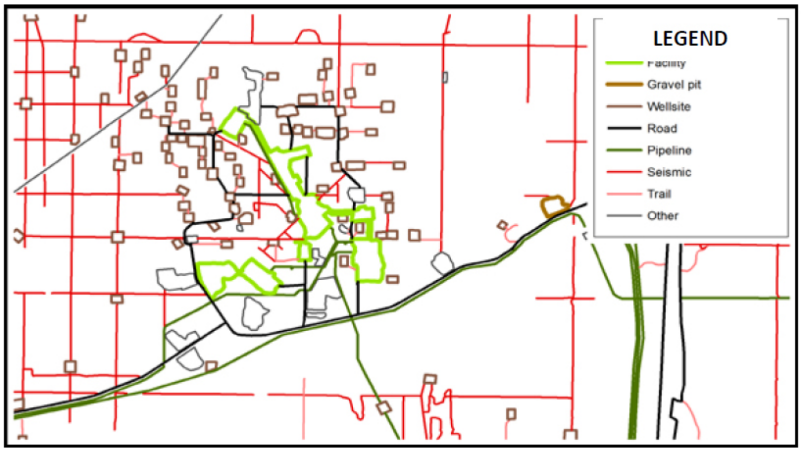

Figure 4. Detailed example of the long duration industrial features mapped on a 5,000-hectare area within the study area.

Of equal value, each linear feature (LF) line segment in the spatial file included information on the disturbance type; its width; and its vegetation condition including moisture, nutrient, vegetation species, vegetation heights, as well as information regarding the species and density of the surrounding vegetation. It also contained information on how the vegetation is distributed along each line, including vegetation height variation.

2.3 Define an HL Approach

At the heart of any true HL approach is the concept of full integration of all planning and management activities using EBM principles. In other words, a (single, fully integrated) plan is developed and carried out by some sort of management cooperative that agrees to use Mother Nature as the primary guide. Towards that, we propose three innovative elements: a disturbance plan, a disturbance activity framework, and ecosystem health indicators.

2.3.1 The Disturbance Plan

Attempts to translate the concept of EBM into practice have thus far created a number of natural disturbance (ND) approaches for forest management (e.g. FSC 2004, OMNR 2001). As the name suggests, the focus of ND approaches has been on identifying appropriate disturbance pattern metrics for forest management modelled on the appropriate historical NRV. This initiative has arguably been highly successful over the past 10–15 years. However, the healthy landscape (HL) approach that we are proposing in this project is broader in several ways. First, it applies to all land management activities and all agencies—not just forest harvesting. Second, the primary objective of an HL approach is to create more natural landscape conditions (i.e., the green box in Figure 2). And third, disturbance is just one of many operational tools available to create more natural landscapes. Other tools include restoration activities and prescribed fire. This is particularly relevant to landscapes that have already been significantly altered by anthropogenic activities.

One of the critical assumptions underlying a healthy landscape approach is that all human activities are coordinated. Creating more natural landscapes without coordination between land management agencies is challenging (Pickell et al. 2014). One possible expression of this concept is to create a disturbance plan (Andison et al. 2009). The idea is to define, and ideally, coordinate all of the activities on a landscape that relate to disturbance over the next 10–30 years. Such a plan might include harvesting, road building, and exploration and development of sub-surface resources, as well as how wildfire and prescribed fire will be managed, and any restoration activities (Figure 5).

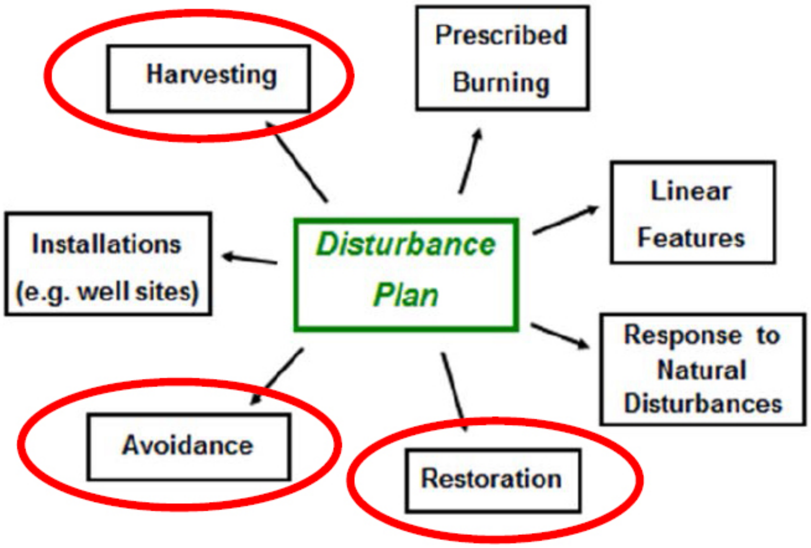

Figure 5. The disturbance plan concept.

When viewed in this way, the disturbance plan becomes a strategy for creating a desired future landscape condition(s), and the various inputs (i.e., the spokes in Figure 5) are the tools with which to achieve those conditions. For simplicity, the disturbance tools we chose to focus on in this study are (linear feature) restoration, harvesting, and avoidance (see highlighted areas in red in Figure 5).

2.3.1.1 Restoration

The term “restoration” refers to deliberate management actions applied to parts of ecosystems that have been degraded in some way(s) by human activities (Hobbs and Norton 2006). Degradation can take many forms, and thus the criteria by which sites are deigned to be restored is vague and inconsistent (Benayas et al. 2009). To further complicate things, the term restoration is also used to describe the re-establishment of habitat requirements of specific species.

In this study, restoration refers to general ecosystem functions and conditions (Young et al. 2001). The key to this relationship is disturbance. Large catastrophic disturbances such as wildfire and insect infestations are a natural component of the boreal forest (Heinselman 1980). These disturbances kill much, but not all, of the vegetation over extensive areas. The boreal forest has evolved so that natural regeneration processes are triggered by disturbances and in turn create healthy new forests (Kimmins

1987). This interaction of natural disturbance, regeneration, and growth creates the natural range of forest conditions that we see, and by association, the historical range of ecological services.

The development of vegetative communities in the boreal after a wildfire is predictable in general terms (although the details are far less so). The duration of a wildfire is relatively short, usually several days to weeks. Activity in the form of germination, growth, and biomass accumulation begin immediately after a fire, creating a massive bloom of growth within just a few weeks. This is called the establishment phase, and it is dominated by the rapid growth of native shrubs, grasses, herbs, and mosses (Figure 6).

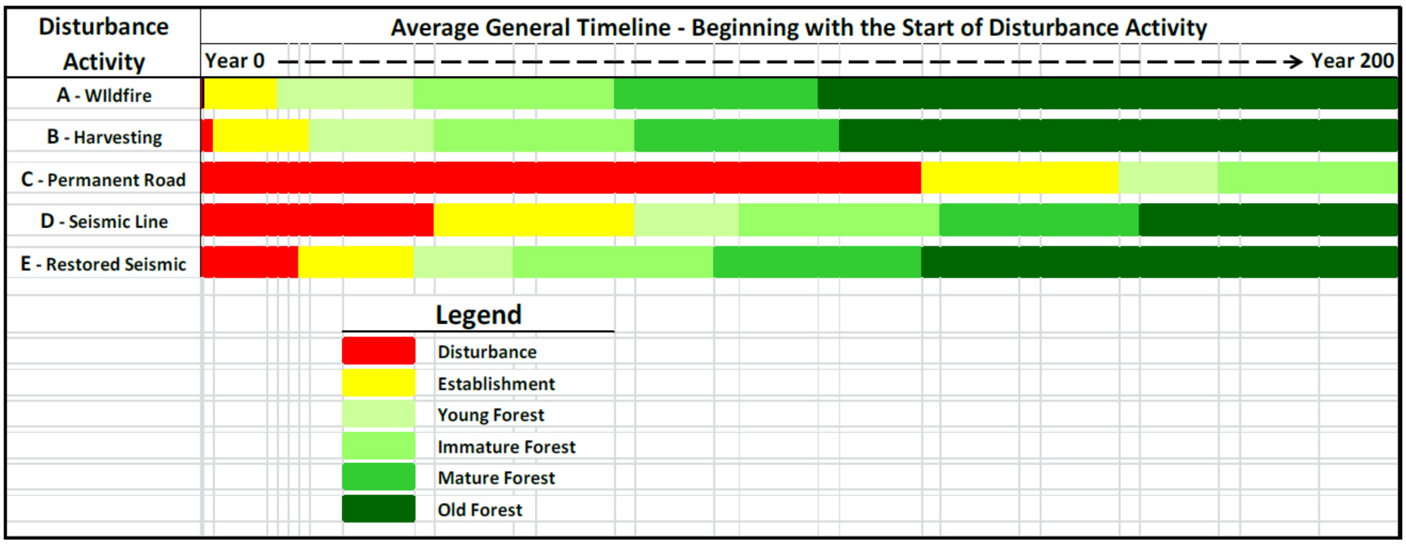

Figure 6. Generalized succession model in the western boreal following disturbances of different types.

To measure progress of the establishment phase of vegetative growth in this study, we used the curves developed by Vinge (CRM 2013). Although many tree seedlings germinate and establish within the first few years after fire, it is often not until 5–15 years later (although this number can vary widely) that the forest re-emerges as the primary vegetation community (Figure 6).

The next phase of vegetation growth involves the rapid vertical and horizontal growth of trees—referred here as the Young forest seral stage which lasts for another 10-20 years. This is followed by the Immature, Mature, and the Old seral-stages of forest development (sensu Oliver 1981) each one lasting anywhere from 20–60 years in western boreal Canada.

A generalized model of post-fire forest development is shown in the Bar A in Figure 6. Note that this is a very simple, generic model of boreal forest succession (e.g. Rowe and Scotter 1973). The exact location and number of the thresholds between different vegetation phases along the axes vary widely depending on location and site.

Not surprisingly, the generalized model of post-disturbance vegetation dynamics differs for various cultural disturbance activities. The vegetation succession pattern for a site disturbed by forest harvesting (Bar B in Figure 6) varies only in subtle ways. First, the duration of disturbance is extended to months to years, since it includes road building, harvesting, site preparation, planting, and rehabilitation. The other difference is that the establishment phase can take longer, depending on the site and the timing and type of harvesting and the nature of any subsequent treatments. A typical generalized boreal harvesting vegetation succession graph looks something like Figure 6, Bar B.

At the other extreme, permanent roads are for all intents and purposes permanent disturbances, or at the very least, another 100 years (Figure 6, Bar C). While the road is active, native vegetation never re-establishes, water and soil processes are disrupted, and no biomass is accumulated.

The successional dynamics of seismic lines and well sites in the boreal fall somewhere between harvested areas and permanent roads. Disturbances last one to five decades and the establishment phases of these sites can be prolonged as well, particularly if native species are not present, the soil has been compacted, or the top layers of the soil have been removed. The other confounding factor for the re-establishment of seismic lines in particular is that they become access corridors for trucks or recreational vehicles. As a result, although some of these areas may have vegetation, they are not necessarily on a (natural) successional trajectory leading to a natural forest (Figure 6, Bar D). Seismic lines that become de facto roads are assumed to have an indefinite duration.

The objective of restoration activities, as defined in this study, is to shorten and/or correct the direction of the establishment phase of this generalized cycle such that the Young forest phase is initiated. The ideal result is to create an establishment phase of development similar in type and duration to that created by a wildfire. So an investment in restoration would shift the vegetative trajectory from Bar D to Bar E in Figure 6. Typical restoration activities include mechanically de-compacting soils, importing nutrient rich overburden, re-introducing native species, and blocking vehicular access using large wood.

For the purposes of this study, two types of restoration are possible:

1. Directed activities to selected seismic linear features that are not within a harvesting event
2. Indirect management actions for any non-permanent linear features that fall within a harvesting event. For the purposes of this study, it is assumed that the mechanical activities associated with harvesting are sufficient to accomplish this without additional time, effort, or cost.

We assume that “restoring” either of these areas will shift the vegetation dynamics trajectory from Bar D in Figure 6 to Bar E without any supplementary treatment or additional costs. However, note that we assumed that restoration activities reset a site back to the end of disturbance (i.e., the threshold between the red and yellow bars in Figure 6). No time credit is given to sites that may have any sort of existing vegetation (whether native or not). In other words, we are assuming that each site must first experience the full (but natural) establishment phase before it can enter the Young forest seral stage.

To evaluate restoration timing and pathways, we adopted the curves developed by Vinge (CRM 2013) for vegetation recovery on seismic lines, differentiated by different site types. Figure 7 shows the best scenario curves for recovery without restoration intervention, and Figure 8 are the curves that apply to those features that have had active restoration. Note the shift in the start point of the two sets of curves, which in part reflect the shift between bars D and E above in Figure 6. For the purposes of this study, we set a fixed level of $1,000,000 for restoration for the first 20 years. We further assumed that the cost / hectare of restoration would average about $9,000 (depending on the line width).

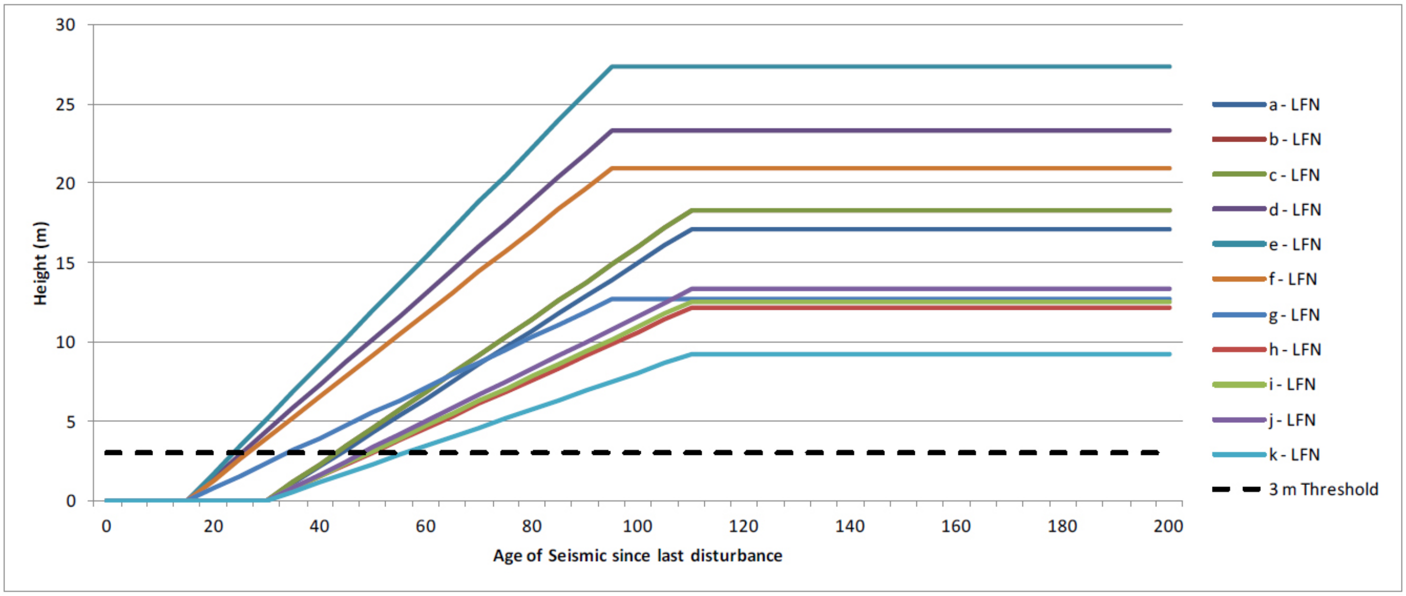

Figure 7. Post-disturbance height growth curves for seismic lines assuming NO restoration effort, for different ecological site types for the study area.

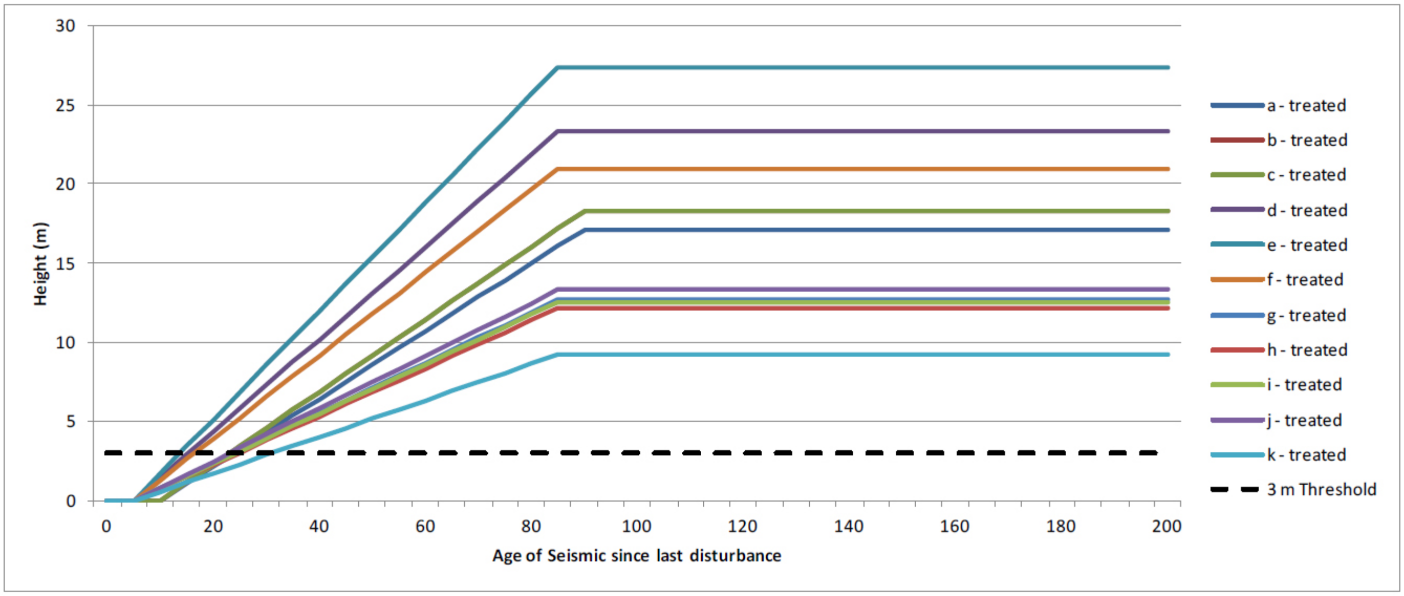

Figure 8. Post-disturbance height growth curves for seismic lines assuming FULL and ACTIVE restoration effort, for different ecological site types for the study area.

2.3.1.2 Harvesting

We propose using forest harvesting as the primary area-based disturbance tool with which to shift the study area landscape to a more "natural" condition. This is based on the assumptions that:

1. Fire control activities in this area will continue to be relatively successful over the long term.
2. Given point #1, the elimination of harvesting as a disturbance vector will push the landscape beyond NRV soon in terms of the amount of Old forest (Andison 2015b).
3. Harvesting is the only area-based anthropogenic disturbance tool available that is economically viable and socially acceptable.
4. Al-Pac is among those forest management companies who have already invested in, translated, and successfully integrated NRV research into practice at this particular scale (see Figure 9).

In other words, we propose using harvesting to not only help restore linear features, but to "reset" the vegetation dynamics clock (from Figure 6) from an unhealthy landscape to one that is more familiar to its inhabitants.

Figure 9. Google images of the boreal showing traditional "checkerboard" harvesting patterns (left) and NRV-based harvesting patterns (right). The area disturbed in both scenes is the same.

The current sustainable yield requirement by the Alberta government means that only the volume of forest growth (i.e., the interest) is available for harvest. For simplicity, we assumed for this study that the study area is a self-contained sustained yield unit. We otherwise accepted or assumed all of the conventions, rules, regulations, and limitations that apply to any other operational area on the Al-Pac FMA.

2.3.1.3 Avoidance

The third and final tool in our disturbance plan toolbox for this study is avoidance, or the deliberate decision to not disturb a given area for a given period of time. To be clear, avoidance is not the same thing as protected areas or reserves. Protected areas and reserves restrict or exclude industrial activities over the long-term, or even permanently. In contrast, the goal of the avoidance tool is to control where and when disturbance occurs across large areas—not if or how much.

The concept of avoidance is about balancing between the relationship between positive and negative space. As defined here, disturbances are positive space, and everything else is negative space. It is useful to think of these two in terms of magnetism; the more the two oppose each other, the more clustered each becomes. Where the two types of landscape elements offer no resistance, the two are well mixed spatially. Where they offer opposition, they are more clustered. To demonstrate, the three panels shown in Figure 10 have identical areas in disturbance (in green). As one moves from right to left in Figure 10, although the total area of positive space (i.e., disturbed green areas) is constant, the contiguous areas of negative space (i.e. undisturbed white areas) increases dramatically.

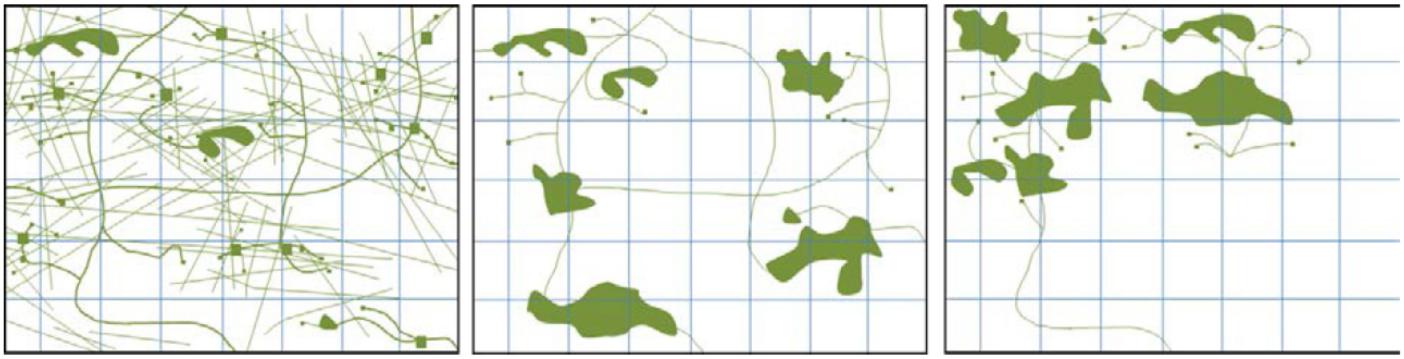

Figure 10. Three different arrangements of positive (green) and negative (white) space across a landscape. The total area disturbed (green) is the same in all three boxes.

The three panels in Figure 10 have different implications for biodiversity. Not only does the massive amount of edge implied by the panel on the left potentially restrict the movements of species such as caribou and songbirds, but also severely limits the ability to ever create large patches of contiguous forest. Given this, it is surprising that avoidance is not a management tool associated with forest land management today. Until now, the focus of regulations, indicators, and modelling has been on positive space. This is also true for all of the NRV-based harvesting guidelines.

As the Google image of northern Alberta on the left of Figure 11 suggests, it is becoming increasingly difficult to find substantial areas with no disturbance in parts of the boreal. This trend is only likely to become more prevalent in the absence of controls over the distribution and timing of cumulative disturbance activities across landscapes.

The mechanics of avoidance (which is the only aspect of avoidance that this study is concerned with) is not difficult: areas to avoid could be identified on maps based on objective criteria, and linked to specific rules (see ahead).

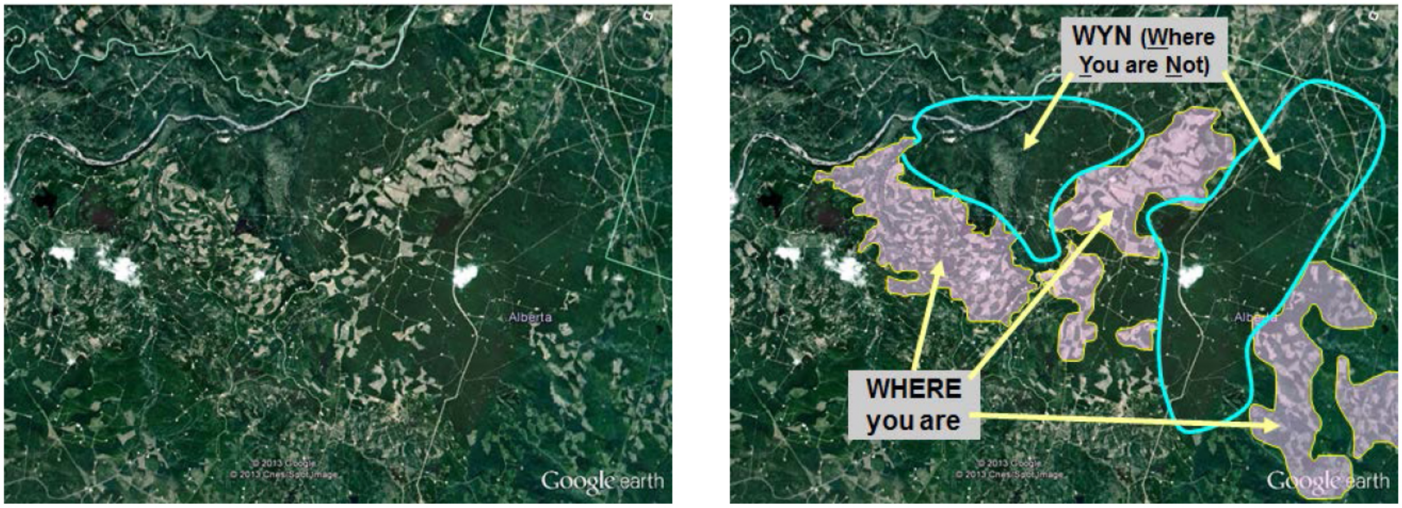

Figure 11. Google images of northern Alberta showing an area of low to moderate industrial footprint. One way of preventing the entire landscape from becoming universally impacted by industrial activities simultaneously is to create (temporary) avoidance pockets called WYNs (Where You are Not). The areas where industrial activities can cluster— over a given period of time— are called WHEREs (WHERE you are).

2.3.2 A Disturbance Activity Framework

As discussed above, classic disturbance-based NRV approaches in forest management focus largely on positive space, as in: where, when, and in what way different parts of the landscape are disturbed (e.g., FSC, 2001, OMNR 2008). What we needed for this study was a framework that deals with not just how much disturbance there is, but where, when, and how the various disturbance activities are distributed across a landscape. In other words, how can we integrate the three disturbance plan tools (identified in the previous Section) over time and space?

In the end, we chose to overlay the various disturbance tools on a grid-based framework because it was simple, objective, applicable at any spatial scale, and it had associated NRV knowledge (Andison 2015b). To understand the power of a simple grid, consider the three disturbance patterns shown in Figure 10 from the previous section. Note how the number of grid cells (in blue) with no disturbance activity increases from zero (on the left) to 15% (middle panel) to almost 40% (on the right) (Figure 10). While the differences are visually obvious, there exist no indicators today to capture this. This is an example of how grid-based summaries can provide new information on landscape patterns not otherwise available.

Andison (2015a) proposed that over several years, natural wildfire patterns in the boreal cluster at multiple scales creating a landscape with pockets of extremely high fire activity in some areas, and no fire in others. To better understand how this might occur over time and space, cumulative fire activity was summarized in northern Saskatchewan (where there is no fire control) at 10,000-, 20,000-, 50,000-, and 100,000-hectare cells, and over a period of 10 years and 20 years. The results strongly supported the idea of clustering of historical wildfire disturbance levels at all eight of the time-space scales tested (Andison 2015a). The clustering results represent a natural pattern that has until now not been captured by any boreal NRV guidelines in Canada, and at spatial scales not typically considered.

These results are also the basis for the HL approach that we propose for this study. The grid-based NRV results in Andison (2015a) were presented as a series of frequency distributions, but also simplified into the proportion of grid cells for each of the eight scenarios in one of two extremes: either no disturbance or very high levels of disturbance (defined as >60% of the forest area burned) (Table 1). For example, in Table 1, for a 50,000-hectare cell size, 10 year measurement period, and a medium fire cycle, 40% of the cells had no fire activity, and another 5% had at least 60% of the forest burn.

Table 1. Historical percentage of cells in northern Saskatchewan with no disturbance (left) and with >60% disturbance (right), by cell size, measurement period, and average fire cycle from Andison (2015a).

Cell Size (ha)	Fire Cycle (yrs)	Measurement Period: 10 Years	Measurement Period: 20 Years
10,000	Long	77	64
	Medium	64	37
	Short	47	18
20,000	Long	71	56
	Medium	55	28
	Short	37	10
50,000	Long	57	43
	Medium	40	13
	Short	22	3
100,000	Long	44	32
	Medium	28	9
	Short	14	1

Cell Size (ha)	Fire Cycle (yrs)	Measurement Period: 10 Years	Measurement Period: 20 Years
10,000	Long	4	11
	Medium	8	19
	Short	16	31
20,000	Long	3	9
	Medium	7	18
	Short	14	29
50,000	Long	2	7
	Medium	5	14
	Short	12	25
100,000	Long	1	6
	Medium	3	10
	Short	9	21

This simplified version of grid-based NRV knowledge has direct practical value. The cells in which high levels of wildfire occur correspond to those in which all forms of industrial activities would be encouraged to cluster for a given period. These areas of concentrated industrial activity are called WHEREs, for WHERE you are. The cells in which no historical disturbance activity occurs correspond to those in which no industrial activity occurs for that same period. These are known as WYNs, for Where You are Not (Andison 2015a). WYNs thus become primary sources of biodiversity. Cells that are neither WHEREs nor WYNs can develop under an independent set of rules, which may be business as usual, or some variation thereof. The determination of WHERE and WYN cells is based on a scoring system (see below). After the first WHERE-WYN (W-W) period has expired, the process of identifying WHERE and WYN cells is repeated. The idea is that over time, all landscape cells cycle through being WHEREs and WYNs.

2.3.2.1 Applying a W-W Grid to the Study Area

The practical value of the results is that it offers a simple method of clustering cultural activity in an ecologically defendable manner. For the purposes of this study, we are interested is a spatial scale that has both ecological meaning and practical value. NRV for W-W proportions was calculated by Andison (2015a) for northern Saskatchewan at four different grid sizes; 10,000 hectares, 20,000 hectares, 50,000 hectares and 100,000 hectares. For this study, we chose to use a 10,000-hectare grid for several reasons. First, this scale is familiar to forest management since it roughly corresponds to the existing scale of forest harvesting compartments. Second, although it is the smallest grid size, 10,000 hectares is still a meaningful size in terms of habitat. And third, as the smallest grid size, it potentially minimizes the potential impacts of limiting surficial access to subsurface resources. Applying a 10,000-hectare grid to the study area created 50 cells ranging in size (because of the irregular shape of the study area).

In terms of timing, the periodicity of the W-W determination represents the lifespan of both WHERE and WYN activities. At the end of each period, the idea is to re-calculate W-W designations for the entire landscape based on a similar (or perhaps a different) scoring system. For this study, we chose 20-year lifespan because it was a reasonable about of time to remove the available merchantable wood from the WHERE cells, and it is superior ecologically as regards the WYNs being free of industrial activity.

2.3.2.2 Creating a W-W Score for the Study Area

Recall that we are interested two types of grid cells: those in which disturbance will be concentrated (WHEREs), and those in which there will be no disturbance coupled with LF restoration (WYNs). We favoured areas of high existing anthropogenic footprint (including both harvesting and linear features) and low levels of Old forest for WHEREs. The idea is to create natural disturbance patterns using harvesting as a tool in areas of the highest existing industrial footprint. The WYNs had the opposite characteristics: low levels of cultural footprint and high levels of Old forest—which together represent high biodiversity value. More specifically:

CELL SCORE = 100 - (normalized %Old) + normalized %Regen + normalized %LF

Where: %Old = the percent of Old seral forest, relative to the total forest area / cell
%Regen = the percent of recently harvested forest, relative to the total forest area / cell
%LF = the percent of the naturally vegetated area of the study area accounted for by linear features.
"Normalized" is a statistical transformation that translates any list of numbers into a range between 0–100 (see Table 2). This ensures that the three parts of the scoring system are weighted equally.
"Old" is any pine and hardwood leading forest >80 years of age, mixedwood leading >100 years, and black spruce leading >120 years.
"Regen" is anything harvested in the last 10 years.

The results of the scoring system applied to the 50 grid cells in the study area are shown in Figures 12 and 13 and Table 2 (note that cell 50 has no forest). To determine the proportion of cells in the WHERE and WYN categories, we used the NRV estimates for the 10,000-hectare, 20-year option in Table 2. There are three options, each one associated with a different fire cycle. The historical long-run fire cycle for the Al-Pac FMA area has elsewhere been estimated to be between 55–65 years (Andison 2015b), which falls between the SHORT and MEDIUM fire cycle options (see the blue boxes in Table 2). Accordingly, we took the average of the SHORT and MEDIUM results, which suggests 25% of 10,000 hectare cells should be WHEREs, and approximately 27% as WYNs. Thus, our NRV targets for the study area would be about 13 WHEREs, and 14 WYNS, depending on their size. In the end, we chose 16 WHEREs (rank 1–16) representing 26% of the forest area, and 13 WYNS (rank 37–49) representing 27% of the forest area (Table 2 and Figures 12 and 13).

Figure 12. Map of WHEREs and WYNs in the study area for period one and linear features.

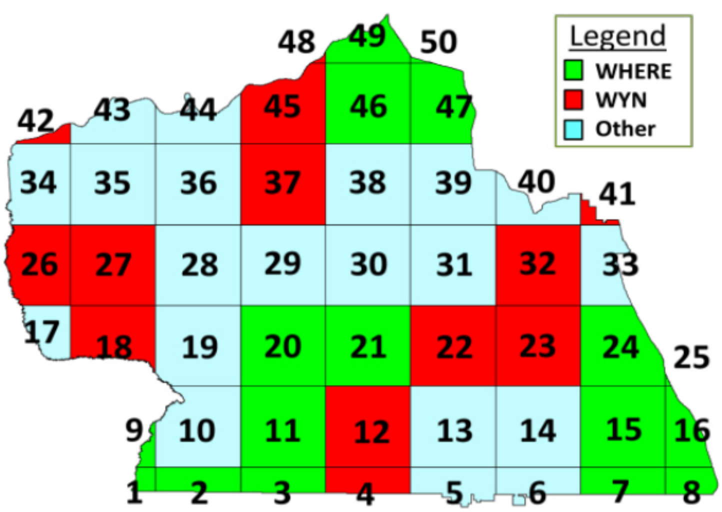

Figure 13. Map of WHEREs and WYNs in the study area for period one.

Table 2. Summary of WHERE and WYN scoring for period 1 of the study area.

Cell #	Area (ha)					Percent Area			Normalized % Area			Score	Rank	Period 1 Designation
	Total	Forest			Linear	Old	Regen	Linear	Old	Regen	Linear			
		Total	Old	Regen										
1	716	752	18	68	14	2.4	9.1	1.9	2.6	24.3	7.1	128.9	14	WHERE
2	3,069	3,024	74	340	76	2.5	11.2	2.5	2.6	30.2	9.4	136.9	12	WHERE
3	3,179	2,915	41	78	454	1.4	2.7	15.6	1.5	7.2	58.0	163.7	5	WHERE
4	3,264	3,123	696	0	60	22.3	0.0	1.9	23.8	0.0	7.2	83.4	44	WYN
5	3,901	3,750	199	0	70	5.3	0.0	1.9	5.7	0.0	6.9	101.3	29	
6	3,576	3,333	62	0	67	1.9	0.0	2.0	2.0	0.0	7.5	105.5	27	
7	3,384	3,112	179	290	204	5.8	9.3	6.5	6.1	25.0	24.3	143.2	11	WHERE
8	1,985	1,873	106	380	324	5.7	20.3	17.3	6.1	54.4	64.5	212.8	3	WHERE
9	691	639	10	122	14	1.6	19.1	2.2	1.7	51.2	8.3	157.9	6	WHERE
10	9,192	9,251	250	521	174	2.7	5.6	1.9	2.9	15.1	7.0	119.3	18	
11	10,000	9,562	179	106	1,163	1.9	1.1	12.2	2.0	3.0	45.3	146.3	10	WHERE
12	10,000	9,775	3,605	88	452	36.9	0.9	4.6	39.4	2.4	17.2	80.3	45	WYN
13	10,000	9,537	1,254	0	627	13.2	0.0	6.6	14.0	0.0	24.5	110.4	23	
14	10,000	8,850	1,150	0	174	13.0	0.0	2.0	13.9	0.0	7.3	93.4	35	
15	10,000	9,453	2,807	1,143	1,231	29.7	12.1	13.0	31.7	32.5	48.5	149.2	9	WHERE
16	3,529	3,040	189	692	773	6.2	22.8	25.4	6.6	61.1	94.7	249.1	2	WHERE
17	3,071	3,053	882	348	50	28.9	11.4	1.6	30.8	30.6	6.1	105.9	26	
18	6,665	6,733	1,154	71	83	17.1	1.1	1.2	18.3	2.8	4.6	89.1	39	WYN
19	9,872	9,576	1,164	197	194	12.2	2.1	2.0	13.0	5.5	7.5	100.1	32	
20	10,000	9,450	469	292	1,265	5.0	3.1	13.4	5.3	8.3	49.8	152.8	8	WHERE
21	10,000	9,582	2,081	511	889	21.7	5.3	9.3	23.2	14.3	34.6	125.7	15	WHERE
22	10,000	9,791	3,785	0	758	38.7	0.0	7.7	41.3	0.0	28.8	87.5	40	WYN
23	10,000	9,674	2,120	33	315	21.9	0.3	3.3	23.4	0.9	12.1	89.6	38	WYN
24	8,528	8,045	3,289	1,059	1,377	40.9	13.2	17.1	43.7	35.4	63.7	155.4	7	WHERE
25	52	39	0	15	8	0.0	37.2	19.3	0.0	100.0	71.7	271.7	1	WHERE
26	7,088	7,074	1,704	233	31	24.1	3.3	0.4	25.7	8.9	1.6	84.8	41	WYN
27	10,000	9,885	3,095	340	208	31.3	3.4	2.1	33.4	9.2	7.8	83.6	43	WYN
28	10,000	9,939	1,673	188	364	16.8	1.9	3.7	18.0	5.1	13.6	100.8	30	
29	10,000	9,893	1,719	250	129	17.4	2.5	1.3	18.6	6.8	4.8	93.1	36	
30	10,000	9,717	2,680	147	499	27.6	1.5	5.1	29.5	4.1	19.1	93.7	34	
31	10,000	9,449	3,279	134	1,171	34.7	1.4	12.4	37.1	3.8	46.1	112.9	21	
32	10,000	6,822	3,369	49	332	49.4	0.7	4.9	52.7	1.9	18.1	67.3	46	WYN
33	5,021	3,503	882	49	328	25.2	1.4	9.3	26.9	3.8	34.8	111.7	22	
34	7,114	7,188	809	132	37	11.3	1.8	0.5	12.0	4.9	1.9	94.8	33	
35	10,000	10,000	2,214	1,038	93	22.1	10.4	0.9	23.6	27.9	3.4	107.7	24	
36	10,000	9,810	3,180	995	201	32.4	10.1	2.0	34.6	27.2	7.6	100.2	31	
37	10,000	10,000	941	8	40	9.4	0.1	0.4	10.0	0.2	1.5	91.7	37	WYN
38	10,000	9,670	1,801	546	300	18.6	5.7	3.1	19.9	15.2	11.6	106.8	25	
39	9,141	8,979	995	0	627	11.1	0.0	7.0	11.8	0.0	26.0	114.1	20	
40	3,671	2,247	303	0	111	13.5	0.0	4.9	14.4	0.0	18.3	103.9	28	
41	655	534	336	0	7	63.0	0.0	1.4	67.2	0.0	5.1	37.8	48	WYN
42	788	701	260	0	3	37.0	0.0	0.4	39.5	0.0	1.4	61.8	47	WYN
43	4,312	3,972	684	0	404	17.2	0.0	10.2	18.4	0.0	37.9	119.5	17	
44	4,358	4,002	966	0	441	24.1	0.0	11.0	25.8	0.0	41.0	115.2	19	
45	8,195	7,981	1,300	0	31	16.3	0.0	0.4	17.4	0.0	1.4	84.0	42	WYN
46	10,000	6,777	752	487	251	11.1	7.2	3.7	11.8	19.3	13.8	121.3	16	WHERE
47	6,747	2,280	342	39	294	15.0	1.7	12.9	16.0	4.6	48.0	136.6	13	WHERE
48	92	34	32	0	0	93.6	0.0	0.0	100.0	0.0	0.0	0.0	49	WYN
49	3,575	1,200	385	171	322	32.1	14.2	26.9	34.3	38.2	100.0	203.9	4	WHERE
50	106	0	0	0	0	0.0	0.0	17.4	0.0	0.0	0.0	n/a	n/a	

2.3.3 Ecosystem Health Indicators

It is important to be clear on the values that we expect from the landscapes we manage. Values are deemed important to be either present on the landscape (e.g. recreation opportunities, spiritual fulfilment or marten populations), or produced from the landscape (e.g. timber products or drinking water). As values are personal, it is often difficult to achieve consensus on the desired values and their respective relative importance. This subjectivity creates challenges for natural resource planning processes. As a pilot study designed to demonstrate a more objective and science-based process, the only value included in this study was general-level biodiversity, often described as landscape health and ecosystem integrity. Recall that the premise of EBM is that a healthy ecosystem is more likely to create a sustainable flow of all goods and services (Christiansen et al. 1996).

Once values are identified, how can we tell if they are adequately represented and are sustainably managed? Indicators are a common technique to track and report on the status of values of interest. Ideally, indicators are quantifiable and directly measure the abundance or health of the values of interest (Rempel et al. 2004). Comparing historical, current and predicted future levels of an indicator provides a measure of change over time and the potential response to management interventions. A comparison between the levels of indicators forecasted from scenarios representing different management regimes permits future impacts to be assessed from decisions made today. This provides decision-makers with the information to make informed decisions. It also potentially creates some targets in terms of future landscape condition with which to assess progress and landscape change.

For this study, the indicators were intended to reflect ecosystem health. In general, this is reflected by the top two boxes of Figure 2: disturbance patterns and ecosystem conditions. Note that these NRV-based indicators are by definition SMART-ER (Specific, Measurable, Attainable, Realistic, Trackable, as well as Ecologically Relevant). This means that NRV metrics are already in a usable format for planning and monitoring, and require no interpretation, no secondary modelling, and no continual recalibration via research and veracity testing. For example, Old forest is simply expressed as the total percentage of forest older than a specific age, which has an easily-derived NRV equivalent.

The NRV-based indicators used to date in forest management are largely a reflection of the more common areas of research such disturbance frequency, size, and severity, as well as the amount and size of Old forest. Note that most of these indicators relate to disturbance patterns (see Figure 2 in Section 2.1.1). As per Section 2.1.1 there are three types of NRV indicators: disturbance patterns, landscape conditions, and biological consequences. This hierarchy is particularly relevant for landscapes that are already beyond their NRV because of human activity because the disturbance patterns required to create more natural landscape conditions may not be all that natural.

2.3.3.1 Criteria

Given the objective of this study, the following criteria were used to develop the indicator list:

1. It includes both time and space. Most, pattern indicators focus on spatial pattern. Time is rarely considered, yet disturbance duration (i.e., the red zone in Figure 6) is a critical part of the dynamics of a natural ecosystem.
2. It includes both positive and negative space (see Figure 10). Positive space is the disturbed bits of the landscape (captured by disturbance size and shape), and negative space is everything else, sometimes referred to as the landscape matrix (see Section 2.4.2). Examples of this include contiguous patches of older forest.
3. It captures multiple spatial scales.
4. It is disturbance source neutral. It should not matter if the source of the disturbance is fire, harvesting road building, or mining. In each case, the patterns of each leave behind patterns that can be captured.

5. It is value neutral. We will include both disturbance patterns and landscape conditions, but no "fine-filter" indicators to capture biological consequences. For example, caribou habitat potential will not be evaluated.
6. It must have an associated, measurable NRV. Allowing indicators with culturally specific terms such as length of road / unit area creates another level of (subjective) interpretation. A road (for example) is simply a high duration, high severity disturbance with a complex shape and lots of edge.
7. It relates simply and directly to management activities.

2.3.3.2 Definitions and Assumptions

For this study, the following terms will be used:

Disturbed feature: Any homogeneous feature of previously natural vegetation (i.e., no rock outcrops or open water) that has experienced the sudden death of biomass and has not yet initiated the establishment of native species (i.e., any feature that is still within the red bar in Figure 6). There are two types of disturbed features used in this study are: disturbed patches and disturbed linear.

1. **Disturbed patch**: Natural or cultural polygons of previously natural vegetation that have experienced the sudden death of biomass and has not yet sufficiently established on a native species trajectory.
2. **Disturbed linear**: Culturally imposed linear elements (such as roads or seismic lines) that have experienced the sudden death of biomass and have not yet sufficiently established on a native species trajectory. To qualify as a disturbed linear it must be at least three meters in width.

Disturbance event: A cluster of disturbed patches sufficiently close in space and time (Figure 14). The spatial dimension has both practical value and historical precedent. A maximum distance between patches of 400 meters has been proven an effective distance to gather disturbed patches within individual wildfires into a single event (Andison 2012). In terms of the temporal dimension, we used 10 years to define a harvesting disturbance event. In other words, forest management has up to 10 years to harvest an area for it to be considered within the same event.

Events can contain both disturbed patches and disturbed linears.

Remnant patch: Undisturbed vegetation within a disturbance event (Figure 14). Remnants can take one of two forms:

1. Island remnants (within a disturbed patch)
2. Matrix remnants (between disturbed patches (see Andison 2012 for details)

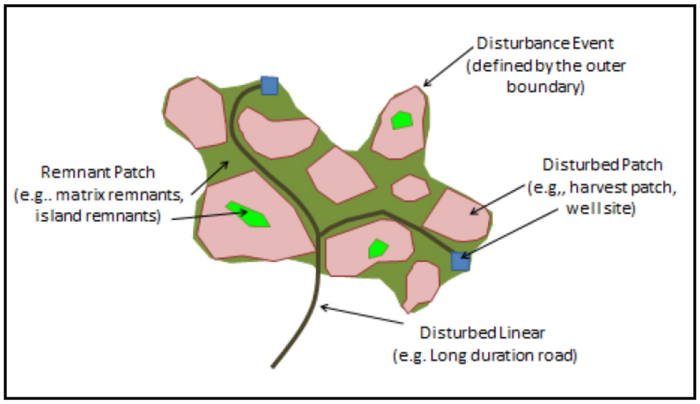

Figure 14. A disturbance event (outer boundary) contains one or more disturbed patches (red and blue) and various forms of remnants (green)

Undisturbed vegetation: All areas of natural vegetation not within either a disturbance event, or disturbed linears. Undisturbed vegetation is classified by forest vs. non-forest, and the forest areas follow the seral-stages defined as above in Figure 14 as follows:

- Young = <20 years for pine (Pj) and black spruce (Sb), and <10 years for mixedwood and hardwood.
- Immature = 21–60 years for Pj, 21–70 years for Sb, and 11–60 years for Mix and Hdwd.
- Mature = 61–80 years for Pj, and Hdwd, 71–120 years for Sb, and 61–100 for Mix.
- Old = >80 years for Pj, and Hdwd, >120 years for Sb, and >100 years for Mix.

Figure 15. A landscape with disturbed (green) and undisturbed (blank) vegetation.

The definitions above are designed first and foremost to partition any landscape into two broad classes: disturbed, and undisturbed. Figure 15 shows the result of applying these rules to a landscape. All areas highlighted in green are disturbed; the outline of disturbance events are the polygons (without the internal details), and the long-duration linear features are the green lines (Figure 15). Everything that is blank (white) is undisturbed vegetation.

Establishment: The phase of native vegetation development between disturbance (in red in Figure 6) and the Young forest seral stage (see Section 2.4.1.1)

Long duration (LD) disturbance feature: Any disturbed feature that was disturbed at least 10 years ago, and has not reached the establishment phase, or was disturbed in the last 10 years but has no chance of starting the establishment phase of vegetation development in the next ten years.

Restoration: As described in Section 2.4.1.1, any management actions required to initiate the establishment process on areas of high severity and long duration culturally imposed disturbance activities (such as roads, seismic lines, or well-sites). Restoration is rarely required in the natural world.

2.3.3.3 Creating HL Indicators

As per the requirements and definitions outline above, we chose 11 indicators to track for this study (Table 3). Note that we made one exception to these criteria; the first indicator in Table 3, Harvest volume (shaded in grey) was included because we believed that it was integral to the larger discussion. If forest harvesting is to become a key tool in the restoration of boreal landscapes, harvesting level is a rough indication (although not a confirmation of) economic feasibility.

Note that of the remaining 10 ecosystem health indicators, several represent the same issue. For example, disturbance clustering is represented by four indicators. Although this may seem redundant, we acknowledged that a criteria or value can be represented by more than one indicator. Moreover, we also recognized that many of the proposed indicators were valuable to introduce as stand-alone management inputs. In other words, a disturbance

Table 3. Summary of indicators used for this study.

Ecosystem Health Indicator	Type of Indicator	Why is this Important to Ecosystem Health?
Harvest volume (m^3)	Planning	Forest management feasibility may be a key
Disturbance frequency (% area)	Planning	Disturbance is a vital ecosytem process
Disturbance distribution (% of forest area disturbed by cell)	Planning	Disturbance clustering
Disturbance event size (ha)	Planning	Disturbance clustering
Disturbance event count (#)	Planning	Disturbance clustering
Single patch event (SPE) count (#)	Planning	Disturbance clustering
Disturbance event residuals (% of event area as live vegetation)	Planning	Critical structural and compositional diversity
Disturbance event edge (km of event edge per 1,000 ha of disturbance)	Planning	Disturbance shape simplicity
Long duration features (LDF) (ha)	Outcome	LDFs compromise several natural ecosytem functions
Old forest level (% of forest in the Old seral stage)	Outcome	Unique ecological values
Old large patch area (Ha in Old patches >5,000)	Outcome	Unique ecolgical values

plan could use the seven disturbance-based indicators highlighted in green in Table 3 as planning indicators.

2.4 Building Scenarios

Now that we have defined a (new) land management approach inspired by HL principles, the second part of this project is to evaluate how it compares to other, more traditional management approaches in the boreal. To do so, we employ scenario modelling to project the associated policies and rules for different options forward in time and space.

2.4.1 Projecting Forward in Time Using Spatial Modelling

Forest management uses scenario modelling as a strategic planning tool with which to help identify where, when, and what to disturb (via harvesting) on different parts of the landscape. These models ultimately create a schedule of disturbance activities over space and time that can mathematically optimize a number of (potentially conflicting) values. One of the advantages of scenario models is that they force us to translate subjective (narrative) values into objective (quantitative) rules. Thus the key to scenario planning is the choice of the input rules. A typical forest management plan today will include rules about haul distance (to minimize costs), the age, size, and species of trees (to maximize return), and restrictions in areas of high ecological sensitivity or critical habitat (to minimize loss of biodiversity). The number and weighting of the various input rules define a unique management scenario. Each scenario creates one or more specific future landscape scenes in the form of maps and indicators. The ability to create optimal future landscapes, based on the choices of which values to include and how to weight them relative to each other is the ideal tool for this study.

For this study, we used the Patchworks (PW) model because it is powerful and flexible, creates highly visual output, is already being used by Al-Pac for planning, and is already calibrated to the study area.

2.4.2 Creating Scenarios

The real power of scenario modelling is the ability to compare how different input assumptions regarding policies and practices can influence both ecosystem outputs (such as wood volume) and the landscape condition 10, 50, or 100 years into the future. Forest management scenarios typically involve different assumptions regarding how much wood can be harvested, where, and when. For the purposes of this project, we expanded the definition of a scenario to include different disturbance plan options, which includes both harvesting and restoration.

We chose to test four different harvesting options:

1. **None**: All harvesting ceases immediately.
2. **Business as usual (BAU)**: Traditional harvesting approaches favoured the oldest areas of highest quality wood, the lowest hauling costs, and upper limits on disturbance patch sizes of 1–500 hectares, and require removing the merchantable wood from an area in two or three phases. This harvesting strategy has created the “checkerboard” harvesting pattern that can be seen across Canada.
3. **Event-based NRV (NRV)**: Many forest management agencies in boreal Canada today are moving away from traditional harvesting strategies towards adopting harvesting guidelines based on the size, shape, and severity of natural wildfire events. Events up to 8,000 hectares are encouraged.
4. **WHERE**: This builds on the natural grid-clustering pattern of boreal wildfires identified by Andison (2015a) where a certain proportion of grid cells (WHEREs— Where you are) are designated for harvesting activity, and become focal areas for other industrial activity.

The volume and ratio of hardwood of wood harvested is held constant for harvesting options two through four. This means that harvesting costs, and the resulting seral-stage distribution will be similar, if not identical, for options two through four.

We also identified four options to test for linear feature restoration:

1. **None**: Let nature take its course and do not interfere.
2. **Random**: Linear features are randomly selected for restoration investment. This scenario is meant to emulate the result of an uncoordinated restoration investment strategy whereby each company would focus on restoring its own linear features.
3. **Strategic**: Investment in linear feature restoration is 100% coordinated across the entire landscape, and designed to maximize the creation of very large (>5,000 hectare) Old forest patches. For this scenario, all energy sector companies have to work together and agree to invest in broader, landscape-scale objectives.
4. **WYN**: The second half of a W-W strategy is to identify a subset of landscape cells in which restoration activities would be concentrated, and coordinated (similar to option #3 above). This restoration option also assumes that WYN cells are also “no-go” zones for any form of industrial development over the duration of the WYN designation (i.e., 20 years).

For options two through four, the investment in restoration activities is a constant. Over the first 20 years, only $1,000,000 of restoration investment was allowed. We assumed that the cost / hectare of LF restoration was about $9,000 (depending on the width).

The two sets of four options each for harvesting and restoration created (four times four =) 16 different combinations, or scenarios for this study (Table 4).

Table 4. Summary of 16 modelling scenarios tested in this study.

Restoration Option	Harvesting Option			
	None	**BAU**	**NRV**	**WHERE**
None	Walk away. No harvesting, no linear feature restoration	Traditional two-pass harvesting & no linear feature restoration.	More natural range of harvest event sizes and remnant levels & no linear feature restoration.	Pre-defined harvesting zones (WHEREs) using NRV details, & no linear feature restoration.
Random	No harvesting & each energy company does their own LF restoration independently	Traditional two-pass harvesting & each energy company does their own LF restoration independently	More natural range of harvest event sizes and remnant levels & each energy company does their own LF restoration independently	Pre-defined harvesting zones (WHEREs) using NRV details & energy companies do their own LF restoration independently
Strategic	No harvesting & all energy sector companies coordinate a landscape-scale restoration strategy.	Traditional two-pass harvesting & all energy sector companies coordinate a landscape-scale restoration strategy.	More natural range of harvest event sizes and remnant levels & all energy sector companies coordinate a landscape-scale restoration strategy.	Pre-defined harvesting zones (WHEREs) using NRV details & all energy sector companies coordinate a landscape-scale restoration strategy.
WYN	No harvesting & all energy sector companies coordinate a landscape-scale LF restoration strategy within pre-defined temporal deferral zones (WYNs).	Traditional two-pass harvesting & all energy sector companies coordinate a landscape-scale LF restoration strategy within pre-defined temporal deferral zones (WYNs)	More natural range of harvest event sizes and remnant levels & all energy sector companies coordinate a landscape-scale LF restoration strategy within pre-defined temporal deferral zones (WYNs)	Pre-defined harvesting zones (WHEREs) using NRV details & all energy sector companies coordinate a landscape-scale LF restoration strategy within pre-defined temporal deferral zones (WYNs)

2.5 Running Scenarios in Patchworks

This section provides a summary of the technical details that were required to set up and run the 16 scenarios in the Patchworks model, as defined in Table 4. The following is just an overview. For a more detailed explanation, please see Appendix A.

1. Data prep: The spatial data layers required for this study include forest inventory, complete and accurate industrial feature inventory, and detailed ecological site-types.
2. Identify the required PW model assumptions: Yield curves, succession rules, re-vegetation rules, height growth curves, and coding the new indicators defined in Section 2.4 were included directly in the model. We also allowed for 5% of the merchantable volume to be left as island remnants.
3. Define the scenario rules. The architecture of PW is such that it is possible to impose a large number of input rules (or "objective functions") based on a range of values. The harvesting scenarios identified in this study required creating a set of rules that dictate where, when, and how much harvesting and linear feature restoration activities will take place. To ensure credibility and consistency, we engaged Al-Pac planners to assist with this step. In order to better compare the results of all future scenarios as regards pattern, the total amount of wood removed from the study area will be standardized using the harvest level suggested from the BAU scenario using the study area as a sustained yield unit.
4. Calibrate and run PW: Create a series of landscape scenes using the 16 different scenarios as defined in step above. This step may require some iteration involving changes to some of the initial input rules. The model was run forward in time 200 years to ensure that the wood supply was indeed sustainable. However, we were only interested in the output from first 20 years.

2.6 Analysis

As a reminder, the main hypothesis of this study is that an ecosystem-inspired HL approach to forest land management is more likely to create healthier, and ultimately more sustainable future landscapes than either the status quo or the other management scenarios described in Table 4. The HL-based approach that we designed for this purpose is the WHERE-WYN (W-W) scenario in Table 4.

We could have simply compared the W-W scenario with a status quo scenario, and one, or perhaps two other possibilities for the 11 indicators, and indeed that was our original plan. However, our initial results were not particularly informative as regards why significant differences in some of the indicators occurred. The W-W scenario that we created differed from the traditional, status quo approach in too many ways. This led us to create the experimental design in Table 4.

Using Table 4 as a template, each indicator listed in Section 2.3.3 was calculated for the current (i.e., 2014) landscape condition, and the average at year 20 for each of the 16 scenarios described in Section 2.4.2. Cells with less than 1,000 hectares were eliminated from all analyses, leaving 43 cells.

3. Results

It is important to keep in mind the complex nature of this project. It involved many moving pieces, some of them highly innovative (e.g., the disturbance plan, the W-W grid system, new indicators). We attempted to minimize any noise in the results by eliminating or neutralizing as many of the details as possible to allow an objective evaluation of the major elements we are most interested in. We fully acknowledge that some of those assumptions are overly simplistic, such as the assumption that there will be no future energy sector development, or that the study area is a self-sustaining harvesting unit. However, do not confuse the legitimacy of these assumptions with the validity of the results. By holding as many elements as possible as constants, we increase our confidence that any significant variation in the results presented here can be attributed to the management approaches, and not one or more of the assumptions we made.

3.1 Harvest Volume

One of our hypotheses for this study is that there are no significant barriers to implementing an ecosystem-based HL approach from a forest management perspective. One of the critical tests of this assumption is the amount and type of wood that will be harvested.

Recall that we set the maximum allowable harvest levels as a constant based on the assumption that it will produce a continuous supply of wood. Furthermore, we assumed that 5% of the harvested area for both the NRV and WHERE harvesting options will be left in island remnants. Given these restrictions, comparing harvest levels was more of a reality check; the wood volume for the NRV and WHERE harvesting options should be about 5% lower than that of the BAU option.

As Tables 5 and 6 suggest, this assumption was not entirely true. Al-Pac requires a sustainable and predictable flow of two main groups of harvestable wood volume: deciduous and conifer. As Table 5 suggests, the deciduous harvest levels for the first 20 years were relatively constant across all scenarios (after allowing for the 5% adjustment). However, all of the WHERE harvesting options created a shortfall of 60–70,000 cubic meters of conifer volume relative to the NRV option over the first 20-year period (Table 6).

Table 5. Deciduous volume harvested in the first 20 years (cubic meters).

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	384,445	373,580	364,466
Random	0	382,499	385,490	365,011
Strategic	0	380,609	382,787	364,760
WYN	0	380,842	377,631	365,392

Table 6. Conifer volume harvested in the first 20 years (cubic meters).

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	317,464	303,531	239,262
Random	0	319,066	307,796	237,948
Strategic	0	317,260	306,802	238,841
WYN	0	317,218	305,351	238,411

3.2 Disturbance Frequency

The total amount of forest area currently disturbed in the study area over the last 20 years was about 28,200 hectares, or 9.4%. This is on the low end of the long-run historical average of about 96,000 hectares of forest burned per 20 years, based on a long-run fire cycle of 62 years (Andison 2015a). Under the assumption that the study area will be self-sustaining with respect to wood supply, the annual area harvested was between 900–1,200 hectares or about 20,000 hectares every 20 years. In other words, the disturbance level from harvesting was only 1/3 of the pre-industrial average.

The explanation for this discrepancy requires an understanding of how forest management calculates annual allowable cut, or AAC. Allowable harvest level calculations are based on projections of the amount of forest growth. In theory, if harvesting is limited to the annual forest growth level, a “sustainable” supply of wood exists. The AAC concept is similar to that of “harvesting” only the interest on the principle in financial terms. The AAC concept has been provincial policy across most of boreal Canada for many decades.

The discrepancy between pre-industrial disturbance levels and the AAC noted in this study arise from the details of the AAC calculation. Due to a variety of ecological, economic, and logistic constraints, only a portion of the forested portion of any given landscape are available for harvesting. For example, mechanical activities within ecologically sensitive areas such as riparian zones or steep slopes are not allowed, and harvesting very small diameter trees within lowland areas is not economically feasible. Since AAC is designed to generate a sustainable supply of merchantable wood, these areas are not included in the calculation.

Of the 300,000 hectares forested area in the study area, only 100,000 hectares qualified as being available for harvesting activities. Most of the remaining 200,000 hectares of forested area was lowland, low density black spruce unavailable for forest harvesting. So the AAC used for this study was calculated only on that portion of forest that was available for harvest, which in this case was 100,000 hectares. The "sustainable" level of 900–1,200 hectares of harvesting / year calculated in this study reflects only the projected volume growth from that particular 100,000 hectares. Obviously, the other 200,000 hectares of forest was growing older and accumulating biomass, but it was not included in the calculation.

To be clear, AAC was never intended to represent a biologically sustainable level of disturbance, only a sustainable level of harvest. What we found in this study is that the chosen harvest levels (based on AAC) allowed for a sustainable supply of merchantable wood volume, but the overall disturbance levels at a landscape scale were quite low relative to pre-industrial levels. This deviation potentially creates some ecological risks. For example, it means that significantly less Young forest habitat type will be available relative to that which would have occurred historically. High levels of older forest have also been associated with higher risks of wildfire, disease, and insect outbreaks.

3.3 Disturbance Distribution

Even in one of the most highly active wildfire zones of the Canadian boreal, Mother Nature clearly clusters disturbance activity in space. Since 1950, most of the 1.5% of the landscape burned every year in northern Saskatchewan was concentrated in just 25% of the 10,000 hectare cells over a 20-year period (see Table 1 above). Perhaps more remarkably, 28% of the 10,000 hectare cells in the same landscape were entirely undisturbed over the same 20-year period (Andison 2015a). The remaining 47% of the cells experienced somewhere between 1–60% of their area disturbed by wildfire (Figure 16).

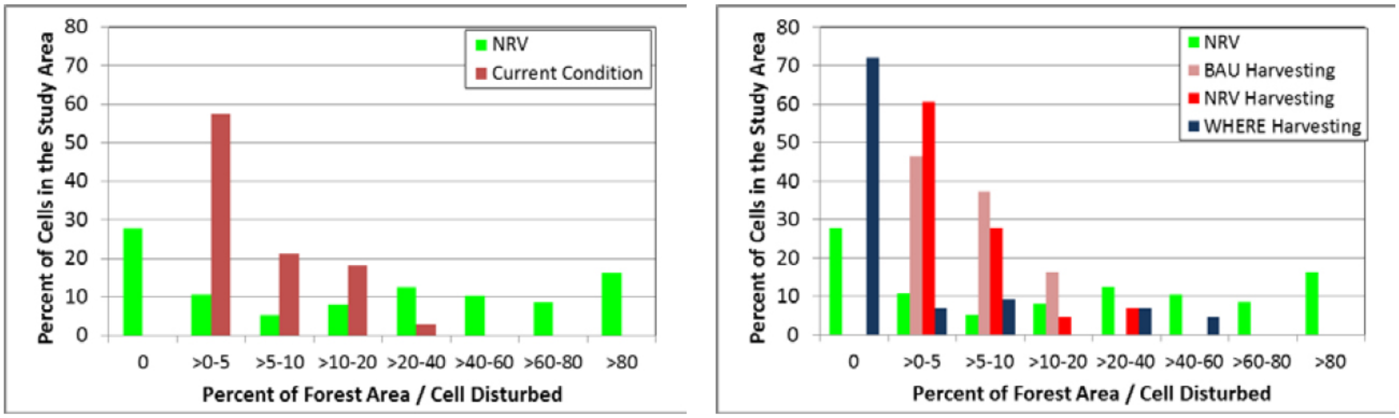

Figure 16. Frequency distributions of the percent of forest area disturbed by 10,000-hectare cells in the study area every 20 years. The left panel shows NRV (green) and current conditions (brown). The right panel compares NRV (green) with the three harvesting scenarios (with no linear feature restoration) tested in this study; BAU(blue), NRV(pink), and WHERE (red).

In contrast, that there are no undisturbed 10,000-hectare cells in the study area today. Nor are there any cells in which more than 25% of the forested area is disturbed (Figure 16). In other words, more recent human-caused disturbance activities are everywhere, all of the time, but at relatively low levels.

Of the four harvesting options tested, BAU created a distribution of cell disturbance frequencies similar to the current condition. On average, 6% of each cell was disturbed. The highest disturbance level was 20%, and no cells were entirely undisturbed, and almost half of the cells had less than 5% disturbed (Figure 16). The NRV harvesting option created a slightly more clustered disturbance pattern. Although no cells were undisturbed, two cells (or 5%) had over 35% of their area disturbed, and over 60% of cells had less than 5% disturbance, and (Figure 16). The WHERE harvesting option created the greatest amount of disturbance clustering of the scenarios tested. This scenario generated a landscape in which 72% of the cells were entirely undisturbed, and three (or 7%) with more than 40% of the forest area disturbed (Figure 16). (Note that of the 72% of cells with no disturbance only 26% are WYNs. The other 46% of the cells were designated as "Other" – which we defined here as those parts of the landscape where business as usual rules of development prevail, or perhaps a second set of development rules apply.)

These results highlight the tactical differences between taking a pure NRV harvesting pattern approach, and applying the W-W grid system. In theory, both should create landscapes with clustered disturbance activity. The reason the NRV harvesting option did not is because there was not enough adjacent merchantable wood in any single locale. This was due to two factors; first, merchantable forest is naturally fragmented. Recall that most of the forested area in the study area was not available for harvesting. Second, many of the larger pieces of merchantable forest were fragmented by previous harvesting activity. Replacing a localized and variable set of spatial requirements for clustering disturbance with a fixed-area generic system (i.e., the WHERE option) created greater disturbance clustering. In essence, the W-W system created operational-sized zones within which harvesting was encouraged, regardless of whether or not that activity ultimately created large events.

Also keep in mind that while the NRV harvesting option encouraged larger event sizes, it did so across the entire landscape. The model was given no restrictions on where to find merchantable wood. In contrast, a significant portion of the landscape (about 72% in this case) was at any one point in time off limits to harvesting under the WHERE harvesting option. The WHERE cells were also meant to be focal areas for other industrial activities.

It is also interesting to note that the WHERE harvesting option could not create the extremely high levels of disturbance found historically (Figure 16). As above, the reason for this is that merchantable forest is scarce and spatially discontinuous on this landscape.

3.4 Disturbance Patterns

Disturbance patterns are important measures in and of themselves in terms of habitat and ecosystem function, but also as regards their impacts on future landscape conditions. We considered two scales of disturbance pattern impacts in this study: disturbance event sizes and numbers, and disturbance event details.

3.4.1 Disturbance Event Sizes and Numbers

After standardizing the area harvested (to allow previous and future harvesting to be compared), historical harvesting scattered the equivalent of 310 disturbance events averaging 114 hectares in size over a 20-year period (Tables 7 and 8). None were larger than 3,000 hectares.

A more "natural" disturbance event size distribution would have a higher proportion of very large events, which would be reflected in not only a

Table 7. Number of disturbance events per 20 years at AAC. Current condition is 310.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	361	394	47
Random	0	341	384	52
Strategic	0	351	377	44
WYN	0	381	230	40

higher average event size, but a much smaller number of events. As discussed above, forest harvesting has traditionally artificially limited the maximum size of disturbance events to 5–10,000 hectares, even under NRV guidelines (e.g., OMNR 2001).

Of the three harvesting scenarios tested, the WHERE harvesting options created significantly larger, and fewer disturbance events than any of the other options. This is not entirely unexpected, although the difference between the results for WHERE and the NRV options was surprising.

Table 8. Average disturbance event size (hectares). Current condition is 114 hectares.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	n/a	96 ha	85 ha	600 ha
Random	n/a	101 ha	97 ha	554 ha
Strategic	n/a	95 ha	87 ha	666 ha
WYN	n/a	95 ha	134 ha	735 ha

NRV harvesting option generally created the largest number of events, and generally smaller ones. Even the BAU harvesting scenario generally created slightly fewer and larger events (Table 7 and 8). This is surprising given that the NRV-based rules that we applied in Patchworks specifically required larger events. There are at least three possible reasons for this unexpected outcome:

1. Although the NRV-based rules are intuitively simple, the details of how they are represented within a complex optimization tool like Patchworks remains a work in progress. This is not the first time that overly-simplistic NRV-based disturbance rules have created less natural landscapes using a scenario modelling platform (e.g. Neilsen et al. 2008). Forest management is still new at the adoption of NRV-based harvesting, and the translation between intent and the technical modelling details may need further refinement. This project had neither the time, nor the resources to test this hypothesis.
2. Disturbance-based NRV rules do not (always) create more natural disturbance patterns or landscapes when they are applied to culturally modified landscapes. Presumably, for economic reasons, the first-pass harvesting pattern in the study area focused on the largest pockets of merchantable forest. This limits the ability of future harvesting options to cluster harvesting into confined areas. Fortunately, it is possible to test this hypothesis by repeating the scenarios and analyses tested in this study using a landscape that eliminates all of the existing harvested areas. Time and resources did not allow us to test this possibility.
3. The harvesting rules are interacting with the restoration rules in the model. In support of this theory, note the difference between the results for the NRV-None scenario to the NRV-WYN scenario in terms of event size in Table 8. The number of events drops from 394 to 230, and the average size of events increases from 85 hectares to 134 hectares.

Another useful measure of the degree of disturbance clustering is the number of disturbance events that include only a single disturbed patch. The vast majority of larger wildfires have multiple disturbed patches. So-called single-patch events (SPEs) tend to be relatively small (Andison and McCleary 2014). Although common natural phenomenon, the challenge with industrially defined SPEs is that each one requires road access. Furthermore, and as argued above, there are currently no policy or practice controls on the spatial distribution of disturbance events (SPEs included). So our assumption in this study is that minimizing SPEs is desirable from a landscape health perspective.

The results suggest that the WHERE harvesting options significantly minimize the proportion of SPEs relative to either the current condition, or other harvesting options (Table 9).

Table 9. Number of single patch events per 20 year AAC. Current condition is 110.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	118	150	13
Random	0	90	148	16
Strategic	0	103	150	12
WYN	0	132	89	11

It is interesting to note that the NRV harvesting options generally create the highest levels of SPEs (Table 9). This is an outcome worthy of further investigation. None of the existing NRV harvesting guidelines provide for rules for how events are defined as regards disturbed patches. Perhaps this is a science-policy gap that needs further attention as regards current NRV guidelines.

In the end, on average, the WHERE harvesting options all created significantly fewer and much larger, disturbance events relative to the other harvesting options tested. Relative to the BAU harvesting option, the average event size increased five- to seven-fold (Table 8) under the W-W option. More importantly, the number of events decreased by 80–90% (Table 7). In fact, the largest events for all of the harvesting W-W options were in excess of 20,000 hectares.

3.4.2 Disturbance Event Edge

Perhaps the ultimate measure of the degree of spatial clustering of disturbance activities is the amount of edge created by the disturbance events since it takes into account the number, size, and shape of events. Fewer, larger, and simply shaped events will create less (spatial) interaction between disturbance events and the rest of the landscape. Recall that disturbance activities are highly clustered within natural boreal landscapes dominated by wildfires, and thus have very low historical levels of disturbance event edge. Average NRV for disturbance edge for wildfires in northern Saskatchewan is about 3.6 kilometers for every 1,000 hectares of disturbance.

The results of event edge results for this study show fairly clear patterns. The BAU harvesting options created the highest levels of event edge (14.9–15.9 kilometers / 1,000 hectares) followed by the NRV harvesting with 8.7–11.3 kilometeres / 1,000 hectares. The WHERE harvesting options produced 4.0–4.4 kilometers of edge / 1,000 hectares of disturbance, which is close to the historical average of 3.6 (Table 10). The BAU options generated almost four times as much event edge as the WHERE options, and about 50% higher than the NRV options. These results confirm that, of the harvesting options tested, WHERE was significantly better at clustering disturbance activities, NRV was intermediate, and BAU was the least effective.

Table 10. Kilometers of disturbance event edge per 1,000 hectares of disturbance. Current condition is 14.2.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	14.9	11.3	4.4
Random	0	15.1	10.7	4.1
Strategic	0	15.8	10.9	4.0
WYN	0	14.6	8.7	4.0

3.4.3 Disturbance Event Residuals

The vast majority of natural disturbances agents in the Canadian boreal leave a significant amount of live vegetation including wildfire. More specifically, natural (i.e., those not modified by control activities) wildfires in the western boreal typically leave behind an average of almost 40% of their event area in some form of live vegetation (Andison 2012). That 40% translates into roughly 30% of the number / volume of trees after accounting for areas of partial mortality.

The details of the size, shape, frequency, and nature of natural wildfire residuals are well documented (Andison and McCleary 2014), and others have begun exploring the relative biological value of each type. For simplicity, we have chosen to compare only the overall residual levels for this study.

All three of the harvesting options created overall remnant levels near or above the average level created historically (Table 11). The reason for this is

Table 11. Average percent of event areas in total remnants. Current condition is 27%.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	n/a	37%	39%	43%
Random	n/a	39%	39%	41%
Strategic	n/a	38%	38%	42%
WYN	n/a	37%	41%	45%

combination of the high proportion of non-merchantable forest in the study area, and any previous harvesting blocks that qualify as Young forest (as per Section 2.3.1.1) would now qualify as residuals. To emphasize this point, consider that the WHERE harvesting options remove most of the merchantable timber within each 10,000-hectare WHERE cell, which—at best—represented only 41–45% of the area of WHERE cells.

Although this study does not explore the details of disturbance patterns more closely, there is one key difference between the scenarios tested here that is worth emphasizing: The amount and location of the undisturbed residuals for all of the WHERE options is collaboratively planned, and has a lifetime of at least that of the WHERE cell designation, if not longer. In other words, the proposed disturbance plan includes having residuals within WHERE cells designed for maximum ecological benefit, and then remain in place long enough to function much as they would naturally. There are no such requirements under traditional planning approaches.

3.5 Landscape Condition

We chose three measures of landscape condition representing overall ecosystem health: net change in the area in LDFs (Long Duration disturbance Features), Old forest levels, and Old forest patch sizes.

3.5.1 Long Duration Features

LDFs have both direct and indirect impacts on ecosystem health. Directly, areas in LDFs do not contribute to vital ecosystem functions such as carbon sequestering in above ground biomass, nutrient conversion, soil C storage, and CO_2-O_2 exchange. In other words, overall ecosystem productivity could simply be reduced by the percentage of area in LDFs. In this case, a 2.5% reduction in the provision of these critical ecological services is a significant number.

Indirectly, LDFs can create impediments to sub-surface and surface water flows, a fixed travel corridor network for predators, artificially high levels of forest edge, and artificially small contiguous forest patches. The influence of LDFs on these indirect impacts is not necessarily linear. On landscapes where LDFs are ubiquitous and evenly spaced, their impact will be higher – perhaps even dangerously so. On those landscapes where LDFs are clustered, the indirect ecosystem impacts will be moderated.

We already know that the vast majority of LDFs for the study area are linear feature attributes, which are well spaced across the landscape. So any reduction in the level of LDFs will contribute to the mitigation of both direct and indirect negative ecological impacts. As a reminder, we assumed for this study that LDF can only be reduced by restoration activities either within harvested areas, or stand-alone areas.

First, note that any stand-alone restoration activities reduce the amount of LDF—in this case by about 115 hectares. Again, keep in mind that this figure is entirely based on our input assumption of a restoration budget of $1,000,000 at a cost of ~$9,000 / hectare.

Table 12. Net change in area (hectares) of Long Duration Features in the first 20 years. Starting condition is 8,070 hectares, or 2.5% of the landscape.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	0	-98	-112	-226
Random	-112	-184	-185	-341
Strategic	-116	-172	-238	-339
WYN	-116	-168	-238	-337

Of the harvesting options tested, those associated with WHERE reduced the LDF footprint the most (Table 12). In fact, the WHERE harvesting options restored 100–150 hectares more of LDFs than either BAU or NRV harvesting options in the first 20 years. While at first glance this may not seem significant, keep in mind that this study tested relative levels of investment in restoration. We deliberately kept the restoration costs very low. One can always change the absolute level of restoration investment (for all 16 scenarios), but we assume that in doing so the outcome will be the same pattern of results noted here.

Note that the results in Table 12 also provide a measure of value of forest harvesting as a tool for LF restoration. In this case, harvesting significantly increased the reduction of LDFs over restoration activities alone, and in some cases almost tripled it.

3.5.2 Old Forest Levels

The area of Old forest today accounts for 59,500 hectares, or almost 20% of the forested area, which is well within the long-run historic range (Andison 2015b). Assuming that fire control will eliminate all future fires in the study area, the amount of Old forest eventually increases to unprecedented levels under all of the scenarios tested (Table 13). However, Table 13 also suggests that harvesting activities mitigate the transition to an Old landscape. For example, in 20 years, no harvesting will result in 42% Old forest, compared to 38% when harvesting is allowed. In 40 years, the amount of Old forest will be 67% when no harvesting is allowed, compared to 55% for all harvesting options (Table 13).

The reason for the growing levels of Old forest is that the harvesting levels used in this study fall well below historic disturbance rates. As discussed in Section 3.1, when overall disturbance levels are constantly below the pre-industrial average, it will always generate more older forest.

Table 13. Projected future percentages of Old forest in the study area under the assumption of no harvesting, and (any) harvesting options. Numbers highlighted in red are beyond NRV.

Years Into The Future	Pct. Of Old Forest	
	No Harvest	Harvesting (all options)
0	20%	20%
10	31%	30%
20	42%	38%
30	59%	51%
40	67%	55%
50	74%	58%

3.5.3 Old Large Patch Area

The final indicator employed in this study is the amount of Old forest in large (i.e., larger than 5,000 hectare) patches. This is a particularly sensitive indicator because it projects forward in time and space the cumulative impacts of all (harvesting and restoration) options tested in this study.

Of the harvesting options tested, None always created the greatest amount of large patches of Old forest (Table 14). This is not surprising given that, by definition, it is the only option that does not remove Old forest. Of the three remaining harvesting options that add new disturbance to the study area, the WHERE options created significantly more Old forest in large patches relative to either BAU or NRV (Table 14). In fact, the projected area in large Old forest patches for WHERE harvesting options was in most cases more than double that of the associated BAU harvesting option. The NRV harvesting options created intermediate levels of Old large patches—more than that of BAU, but less than that of WHERE (Table 14).

Table 14. Area (hectares) of Old forest in patches >5,000 hectares at 20 years.

Restoration Option	Harvesting Option			
	None	BAU	NRV	WHERE
None	17,597	12,829	13,582	17,520
Random	23,426	14,085	15,850	17,470
Strategic	44,776	13,708	25,034	29,940
WYN	31,883	14,454	19,666	29,751

Of the restoration options tested, the Strategic option consistently maximized the area of Old forest in large patches (Table 14). This suggests that the greatest ecological benefits of LF restoration can be had by focusing collective resources at landscape scales. On the other hand, the Random restoration option only created marginally higher large patches than did walking away (i.e., the None restoration option).

The WYN restoration option created similar or lower levels of large Old forest relative to the Strategic option. Although the Strategic option created higher levels of Old patch sizes, there is no guarantee that the benefits will be compromised by the installation of new linear features. In contrast, restoration activities for W-W options occurred only in WYN cells, which cannot be disturbed for (at least) the duration of their WYN designation. Recall that for the Random, Strategic, and W-W restoration options the total area restored is identical; the only thing that changes is where restoration occurs.

It is also interesting to see how the two activities (harvesting and LF restoration) interact. For example, the large Old forest patch sizes were fairly constant for all of the BAU harvesting options, regardless of with which restoration option it was coupled (Table 14). This suggests that uncoordinated harvesting activities can negate the benefits of uncoordinated restoration activities, presumably because BAU harvesting requires the most new roads.

The most successful scenario combination overall was the W-W scenario, which produced almost 30,000 hectares of large patch Old forest. This is the scenario that we designed based on HL principles under which harvesting uses WHEREs and restoration uses WYNs. The most likely of the 16 scenarios that would occur today is the BAU-Random scenario, which produced less than half as much area in large older forest patches as the W-W scenario, for the same cost and effort.

3.6 Summary

Table 15 offers an overview of the pre-industrial range (i.e., NRV), current range (CRV), and the most significant gaps between NRV and CRV for the 11 indicators used in this study. Also given in Table 15 is a brief explanation of the relevance of each indicator, and the scenario that best achieved minimizing the gap(s) between NRV and CRV.

Table 15. Summary of the results of this study.

Ecosystem Health Indicator	Type of Indicator	Why is this Important to Ecosystem Health?	Historic Range (Pre-Industrial)	Current Range (Post-Industrial)	Ecosystem Health Gaps	Best Scenario	Worst Scenario
Harvest volume (m^3)	Planning	Forest management feasibility may be a key	None	~30,000 m^3 / year	n/a	BAU & NRV harvesting*	None harvesting
Disturbance frequency (% area)	Planning	Disturbance is a vital ecosytem process	1.5% per year	0.5% per year	Increase *overall* disturbance levels	Any harvesting	None harvesting
Disturbance distribution (% of forest area disturbed by cell)	Planning	Disturbance clustering	25% have zero, 25% have a lot, 50% are intermediate	100% are intermediate	Need cells with zero, & need cells with "a lot"	WHERE harvesting	None harvesting
Disturbance event size (ha)	Planning	Disturbance clustering	Very few, very large events dominate	Mostly intermediate sizes (i.e., 100-2,000 ha)	Create larger cultural disturbance events	WHERE harvesting	None harvesting
Disturbance event count (#)	Planning	Disturbance clustering	Very few, very large events dominate	Large number of very small events	Minimize the # of cultural disturbance events	WHERE harvesting	None harvesting
Single patch event (SPE) count (#)	Planning	Disturbance clustering	Account for about 50% of historical disturbance events	Accounts for 1/3 of all events, but are very small	Minimize / eliminate SPEs	WHERE harvesting	None harvesting
Disturbance event residuals (% of event area as live vegetation)	Planning	Critical structural and compositional diversity	Events average 40%	Events average 40-50% - *but can be compromised*	Ensure the long-term integrity of event residuals	Any harvesting	None harvesting
Disturbance event edge (km of event edge per 1,000 ha of disturbance)	Planning	Disturbance shape simplicity	On average 3.5 km / 1,000 ha of disturbance	Averages 10-20km / 1,000 ha across the study area	Reduce disturbance event edge	WHERE harvesting	None harvesting
Long duration features (LDF) (ha)	Outcome	LDFs compromise several natural ecosytem functions	No historical precedent	Accounts for about 2.5% of the landscape	Reduce LDFs	WHERE harvesting	None harvesting
Old forest level (% of forest in the Old seral stage)	Outcome	Unique ecological values	On average, 10-30% Old forest.	20% (But mature forest levels are well beyond NRV)	Increase *overall* disturbance levels	Any harvesting	None harvesting
Old large patch area (Ha in Old patches >5,000)	Outcome	Unique ecolgical values	On average, about 20,000 ha	Zero	Maximize the area within larger old forest patches	W-Stragetic W-W	BAU harvesting

The choice of which harvesting option was least likely to increase overall ecosystem health depends on one's perspective. The None harvesting option is one possible candidate for the least desirable option because Young forest and all of its vital associated habitat associations are eliminated, while Old forest increases to unprecedented levels. The other possible candidate for the least effective harvesting option would be BAU. Although BAU harvesting slowed the accumulation of Old forest and reduced LDFs, it also created the least natural disturbance patterns and the least natural landscape conditions of the three harvesting options.

NRV harvesting created intermediate levels for most of the ecosystem health indicators used in this study. The NRV results were better than those associated with BAU harvesting options for several key indicators (e.g., more compact shape, more large Old forest patches), but not consistently so. Not only did NRV harvesting not create larger events (as intended), but it also did little to encourage harvesting clustering across the landscape. In fact, it created almost as many kilometers of new roads as the BAU options, and only had slightly more grid cells with very small levels of disturbance activity, and none with zero disturbed area (contrary to historical patterns).

The most successful harvesting option for creating healthier landscapes was easily the WHERE option. WHERE harvesting options were equal to or better than either BAU or NRV harvesting options for all but one or the 11 indicators tested; Harvest Volume (which is easily managed by increasing the proportion of WHERE cells). In some cases the WHERE options were orders of magnitude superior to other harvesting options at creating more natural conditions and patterns. WHERE harvesting created a high degree of disturbance clustering, which not only created more natural disturbance patterns, but also had a positive effect on the landscape condition indicators.

Of the restoration options tested, the answer is less obvious as to which was more successful from a landscape health perspective. Any type of restoration reduced the amount of Long Duration Features (LDFs) and increased the area of large Old forest patches. However, the benefits of the different forms of LF restoration varied. The Strategic option provided the best results overall. Recall that this option pooled all restoration options and prioritized seismic line segments for restoration actions in order to maximize the creation of large contiguous forest patches. The second most successful restoration option was the WYN option, whereby restoration efforts are similarly coordinated based on landscape-scale needs (as above), but focused only in designated parts of the landscape (i.e. the WYN cells). The Random LF restoration option was the least successful option, sometimes only marginally better than doing nothing. However, of the four restoration options tested, only WYN prohibits the installation of any new cultural features within WYN cells for the duration of the designation (which in this case is 20 years). The remaining options have no such restrictions on where or when new industrial activities can occur. Given that it is extremely likely that this landscape will continue to be developed for access to sub-surface resources, the immediate advantages associated with the Strategic option (over the WYN option) are likely be nullified within several years.

Details aside, the results clearly suggest that coupling a disturbance plan with a disturbance activity framework (represented by the W-W scenario at the bottom right of the Tables in Section 3) provides several ecological benefits over business-as-usual, or any of the several other possible future scenarios tested.

4. Discussion

4.1 The Old Forest Dilemma

Eliminating harvesting might seem a logical way of creating more “natural” landscapes, but only if natural processes (i.e., wildfire) are allowed to function unchecked to re-create a more natural balance of Young and Old forest types. Under current provincial policies, there is little chance of allowing wildfires to burn on this particular landscape. If fire control efforts continue to be effective, harvesting is the only tool we have today with which to manage historical seral-stage dynamics over time and space. A landscape under a no-harvest scenario would not only artificially restrict the range of historical ecological services, but would also present an unprecedented risk of natural disturbance agents such as wildfires, insects, and disease, some of which we may already be experiencing. So while it is true that wildfire will still influence this landscape on rare occasions, it will do so in the least desirable, least predictable, and most perilous manner.

Whether the rate of harvest we have chosen for this study is ecologically appropriate is a good question. All three of the harvesting options ultimately lead to extremely high levels of Old forest, although not as soon as a no-harvest option. The evidence suggests that disturbance rates must triple in the study area, to maintain the current age distribution. However, should that translate into an increase in harvest rates?

On one hand, increasing harvesting rates over the short term on landscapes of this size is a viable short to medium-term solution. In areas where values-at-risk are particularly high, intelligent harvesting can not only improve ecological health, but mitigate natural disturbance risk. On the other hand, it would be difficult to argue in favour of significantly increased harvesting rates over the long term, and over large landscapes. Harvesting only focuses on a subset of upland ecological site types and effectively ignores the lowland black spruce dominated areas (for example). So increasing harvesting would create an age–vegetation type imbalance; the upland ecotypes would be hyper-dynamic, creating vast areas of Young forest, and little or no Old seral forest, while the lowland areas would be disturbance-free, creating vast areas of Old, and little or no Young. While this may seem a reasonable solution on the surface given woodland caribou's preference for lowland black spruce, this is an unsustainable landscape scenario. Moreover, harvesting is not the equivalent of wildfire at fine scales since it removes large biomass, is less efficient at converting nutrients, and requires roads for access.

Unfortunately, the status quo may represent an even higher risk. Fire will be re-introduced on this landscape in some way, at some time. We can decide now on what terms that will occur. Combined with the impacts of climate change, as the buildup of older forest (and the associated fuels) continues to increase, the new version of "typical" wildfires may exceed current fire control capacity on a regular basis. This is true of not just on this landscape, but large portions of the western boreal. We have been able to ignore the buildup of older forest so far. Old forest is now on the high end of, but still within, the historical range. That will change dramatically within the next decade or two.

The re-introduction of fire on this and other boreal landscapes is the only other logical solution, either through prescriptions or wildfire management. Although many jurisdictions are beginning to move in this direction, efforts to truly integrate fire as a landscape management tool are still in their infancy. The primary concern is that values-at-risk such as human lives, infrastructure, and timber values are becoming ubiquitous in the southern part of the boreal. However, that would potentially change under a W-W strategy, making the non-industrial (WYN) portion of the landscape available for fire management. In other words, the next version of a disturbance plan as describe in this study could, and should, include a range of disturbance tools, including harvesting, prescribed fire, and managed wildfire.

4.2 Harvesting as a Landscape Health Tool

In this study, harvesting had two major benefits as regards ecosystem health: reducing the area in LDFs by "erasing" their pattern during the harvesting activity, and moderating the increase in Old forest levels. However, based on the dramatic differences between the (other) results from the three harvesting options tested, the specifics of where and when harvesting occurs is relevant. The results also suggest that policies do not always or necessarily create the intended outcomes.

There are two patterns in the results that we would like to underscore:

1. The most unexpected result from this study was the modest benefits of NRV harvesting relative to BAU harvesting. To be fair, NRV harvesting generally created healthier landscape conditions relative to BUA, which suggests that the NRV

guidelines were doing their intended job. However, depending on the indicator, the benefits of NRV harvesting were not universal, and often only marginal. However, in most cases, NRV harvesting was significantly inferior to the WHERE harvesting options as regards most of the indicators.

2. The strong, and almost universal superiority in terms of the ecosystem health indicators tested here of the WHERE strategy for allocating harvesting over time and space supports our original hypothesis. In some cases, the results from WHERE options were orders of magnitude better than those of either the BAU or NRV harvesting options.

Thus, while it is encouraging that for this study the WHERE harvesting strategy was so clearly superior, it was disappointing to find that the NRV harvesting strategy was only marginally better than the BAU option. For example, NRV harvesting did nothing to prevent the spread of disturbance across the entire landscape. The difference between the two was the vastly superior ability of the WHERE option to cluster disturbance activities in space and time. This suggests that the NRV guidelines tested here, and perhaps others, have a critical gap.

In fact, none of the provincial or certification NRV guidelines in Canada include indicators for the distribution of disturbance over space across a landscape. To be fair, the reason for this is that the assumption was that the indicator(s) capturing event size would adequately capture this time-space dynamic. Unfortunately, there are at least three reasons that the assumption that historical disturbance event sizes could be emulated by guidelines is seriously compromised:

1. The upper threshold of disturbance event sizes imposed by most NRV guidelines is 5–10,000 hectares, which is artificially low. Over 80% of the area burned in the western boreal are from fires in excess of 10,000 hectares, and a few beyond 100,000 hectares. This natural wildfire size dynamic creates a highly clustered pattern of disturbance activity (as noted by Andison 2015a). By limiting the size of harvesting disturbance events to only 5–10,000 hectares, the NRV pattern of disturbance clustering over time and space across hundreds of thousands of hectares is compromised.
2. Disturbance via harvesting is limited to that part of the forested landscape that is available for harvest. There is no part of the boreal where this figure is 100%. In the study area, it is only 33%. Finding enough merchantable timber within that 33% is even more challenging. Not surprisingly, we noted in this study that Patchworks had trouble finding enough area of merchantable wood close enough in space to be within the same disturbance event. The model simply could not find enough contiguous wood to harvest to create large events.
3. The cultural disturbance history of the landscape has compromised the ability to create larger disturbance events. Previous first-pass harvesting activities have reduced and fragmented some forested areas that would otherwise have created large disturbance events.

If nothing else, this study demonstrates the deficiencies of simplistic NRV harvesting guidelines. The superiority of the results for WHERE harvesting over NRV harvesting options found here suggests that the current NRV harvesting rules may not always be sufficient to accomplish the desired outcomes (of creating more natural landscape patterns). At this time, there are no NRV-based rules regarding the location of disturbance activities in time and space across a given landscape.

This has implications for both forest management, and broader land use planning applications. Demonstrations and testing of NRV guidelines have been largely restricted to small areas and ideal landscape situations (e.g., where no first-pass harvesting has taken place or there is no other industrial activity). While the study area used for this project may seem overly restrictive, it represents the reality of a large portion of western boreal landscapes. NRV guidelines for those parts of the boreal that have either been culturally modified, and/or have a high proportion of non-merchantable area may need to be adapted. For example, it may be necessary to apply a wider buffer distance to gather disturbed patches into events, or forcing harvesting clustering at sub-landscape scales by other means (such as the W-W system described here) are two options that may be worth further testing.

4.3 Landscape Restoration

As a reminder, the restoration component of this study relates to minimizing the impacts of past (and potential future) cultural modifications to a landscape. This was presented in two parts as it relates to (non-3-D) seismic lines: erasing seismic footprint via harvesting, and erasing seismic line footprint via dedicated restoration activities.

It was encouraging to see that all restoration options reduced the amount of Long Duration Features (LDFs) and increased the area of large Old forest patches. However, the benefits of the different restoration strategies tested here varied widely. The Strategic option provided the best results overall. Recall that this option pooled all restoration options and prioritized seismic line segments for restoration actions in order to maximize the creation of large contiguous forest patches. A close second was the WYN restoration option, whereby restoration efforts are similarly coordinated based on landscape-scale needs (as above), but focused only in designated parts of the landscape (i.e. the WYN cells). The Random LF restoration option was by far the least successful option, sometimes only marginally better than doing nothing. If nothing else, the results validate the value of collaboration. There are very clear benefits to pooling resources and establishing mutually agreeable success criteria

However, of the restoration options tested here, only the WYN prohibits the installation of any new cultural features within designated cells for the duration of the WYN (which in this case is 20 years). The other restoration options have no such restrictions on where or when new industrial activities can occur. Given that it is extremely likely that this landscape will continue to be developed for access to sub-surface resources, the immediate advantages associated with the Strategic option (over the WYN option) are likely to be nullified within several years. Thus, over the longer-term, the WYN restoration option is more likely to create healthier landscapes.

4.4 HL Approach

Details aside, the results clearly suggest that coordinated approach to forest land management involving the coupling of a disturbance plan with a disturbance activity framework (represented by the W-W scenario) provides significant ecological benefits over business-as-usual—for the same investment. There are both ecological and practical implications of an HL approach that are worth discussing further.

4.4.1 Ecological Relevance

By design, the only indicators used in this study were of the coarse-filter type, or, ecosystem-based patterns. Our primary concern was not the relative improvement of habitat value for individual species, and we included no fine filter indicators. Having said that, the extrapolation of the results from this study to the likely impacts on key fine-filter values is not difficult. The list of changes to the ecosystem include reducing long duration features and linear features, reducing edge density, increasing large patches of contiguous older forest, limiting the location of industrial activity, and creating more fine-scale residual forest diversity—all of which are associated with positive ecological benefits. The strategic reduction of linear features and the increase in large patches of older forest are particularly beneficial to woodland caribou.

4.4.2 Policy and Practice Implications

There is little doubt that the results of this study support the original hypothesis that the HL approach we designed maximized landscape health. However, the W-W scenario also introduced some new ideas such as the application of some general-level, (or coarse-filter) indicators. For example, separating harvesting from long-duration industrial activity via the LDF indicator is a critical differentiation ecologically. Similarly, using an indicator to track and understand areas of (temporary) disturbance avoidance proved to be highly effective. Despite their value, neither one is being used in the boreal today. This study also demonstrated the value of spatial scenario planning models, both as a policy exploration tool (as with this study), and for planning.

Beyond the details, the W-W scenario also has some significant policy implications. First, the implementation of the W-W scenario requires an unprecedented level of coordination among all land management activities. The elements included in the disturbance plan for this study included forest harvesting, restoration, and avoidance, but one could easily add wildfire management and prescribed fire management to the list of activities that could be coordinated. As discussed above, the introduction of WYNs as temporal deferral zones for all industrial activity potentially creates a new opportunity for both wildfire and prescribed fire management. As regards wildfire, WYNs could be considered modified response zones. As regards prescribed fire, WYNs could be used to help create more FireSmart landscapes.

Collaborative planning is an entirely new concept, and would likely require a new planning framework. The existing policy and practices frameworks, and their associated systems and tools, were designed in silos to serve a single resource need or value. Defining what this new framework might look like is beyond the mandate of this study, but the disturbance plan concept should be prominent. The objective of the planning exercise shifts from inputs (i.e., focusing on individual resources, and hoping that the cumulative effects will not cause undue harm) to outcomes (i.e., focusing on desired future landscapes first, and then designing and coordinating all of the associated industrial activities in time and space to align with that).

The concept of collaboration also applies to roles and responsibilities. Not only are costs and effort shared, but the outcomes now become a shared responsibility. An unfortunate by-product of silo-based planning is that it is impossible to assign responsibility for the inevitable cumulative effects. Under a W-W scenario, the team of resource managers who operate on the landscape is responsible—including government agencies as appropriate.

The HL approach suggested here would also necessitate implementing a temporary deferral system. The concept of temporary “no-go” zones is not new to forest management. However, forest management companies hold large tenures for extended periods of time. Implementing a deferral system for the energy sector, with a much more restrictive definition of tenure, would be more challenging. First and foremost, the regulator would have to agree to limit the sale of sub-surface rights in designated WYN zones for the desired duration period. Moreover, those rights that have already been granted within WYNs must be re-negotiated. The idea of a temporary deferral system for access to sub-surface resources represents a fairly significant policy shift for any provincial government in Canada—although there is precedent for it internationally.

5. Summary

This study is ultimately about the growing concern over the increasing distance between the health and integrity of pre-industrial “natural” landscapes and that from those that we have been creating through a range of overlapping and uncoordinated management activities. We hypothesized that we could halt or reverse this trend on landscapes that had experienced moderate to significant deviation from healthy historical conditions by coordinating all harvesting and linear feature restoration activities into a disturbance plan based on a 10,000-hectare grid system of WHEREs (where disturbance can occur) and WYNs (where disturbance does not occur, but restoration does). Harvesting in the WHERE grids was intended to erase the existing linear feature footprint, and leave behind a natural level and pattern of residuals, which will be protected. The WYN cells functioned as temporary deferral zones for the duration of their designation. They were also the primary targets for linear feature restoration investment. We called this package of practices and policies a WHERE-WYN (or W-W) strategy.

Given the innovative nature of the W-W strategy, we approached this as a proof-of-concept study, which is to say, we were largely interested in understanding if, or to what degree a W-W strategy might work, and how it might compare to alternative strategies. That meant simplifying as many elements of the W-W strategy as possible, and testing it against alternatives.

We tested the robustness of the W-W strategy using spatial scenario modelling. Scenario modelling is a tool that allows one to project forward in time and space the outcomes of various management policy and practices. In this case we translated 16 different management strategies into modelling scenarios: four harvesting options X four restoration options. Most were either the status quo today, or likely alternative future scenarios, as well as the W-W scenario that we designed. The indicators used for our scenario test were all designed to measure ecosystem health. We included no value-based indicators such as species habitat.

Generally, the results supported our hypothesis. Over the next 20 years, most all of the indicators for the W-W scenario were superior to those from any other management scenario tested. The findings suggest that harvesting can be an effective tool for erasing industrial footprint, and collaborative planning can not only be highly efficient, but can lead to superior ecological benefits. However, more than anything else, the results suggest that having a single, shared, disturbance plan works.

As to the specifics, there are several significant policy and practices implications of the NP approach proposed here, some of which go to the very heart of the tenure system for allocating Crown rights to resources. This was not unexpected given that this represents a fundamentally different approach to how the boreal is managed. On the other hand, perhaps a fundamental shift is exactly what we need. The proposed strategy delivers on some lofty promises. For example, the Alberta Land Use Framework (LUF) specifically promises to take a “new approach to manage public lands and natural resources”. More specifically, the vision of the Alberta LUF is: “The peoples of Alberta work together to respect and care for the land as the foundation for our economic, environmental and social well-being.” Furthermore, one of the three desired outcomes of the framework is, “healthy ecosystems and environment,” supported by a, “land stewardship ethic.” (GoA 2008) Similar claims of ecosystem health and integrated management are included in many strategic plans from industrial partners. Not only does the proposed NP approach potentially deliver on these promises, but in the process, provide a much-needed boost to social license for all natural resource agencies involved. The various policy and practices challenges notwithstanding, at its heart, this has the potential to be a good-news story for the boreal.

5.1 What is next?

Studies with so many moving pieces tend to raise as many questions as they answer, particularly when they are exploratory in nature. There is a long list of possible extensions to this study, starting with many of the assumptions that we either held constant, or ignored. We designed this first step such that testing many of these is a relatively simple matter. The model is already set up, and the protocols for the indicators established. The possible extensions include:

1. Score and play out the WHERE-WYN grid beyond a single 20-year cycle. Recall that the idea is that WHEREs and WYNs cycle across a landscape over time and space. We only tested a single cycle.
2. Include other industrial features. We only restored (non-3-D) seismic lines, but the list could include roads, installations, and well-sites.
3. Variable harvest levels. We held harvest constant and assumed the study area was a sustainable harvest unit. What happens when harvest rates double (for example)?
4. Variable linear feature restoration levels. We held this at a low, constant level of $1,000,000. What if that budget doubles or triples?

5. Change the criteria for picking WHEREs and WYNs. Our scoring system was very simple, and based only on three relatively simple criteria. The possibilities for how to score cells are endless, and could include fine filter values, economic criteria, sub-surface potential, existing leases, and so on.
6. Change the duration of WHEREs and WYNs. What happens when duration increases or decreases? What happens when the duration of WHEREs is different than that of WYNs?
7. Change the size of the grid cells. This system can work on any size of cell. Is there a more convenient or economical scale?
8. Change the criteria for defining “restoration”. We used a very conservative and simple rule based on vegetation community only. This delayed the benefits of restoration by 10–15 years. The results would be sensitive to a different set of rules, perhaps based on species needs (e.g. woodland caribou).
9. Add fine-filter indicators to the analyses.
10. Project future energy sector development. This is perhaps the most logical next step—to repeat the modelling runs with one or more different projections of how the energy sector will expand in the next X years.

There are also several untested assumptions that could be explored independently. For example:

1. Does harvesting activity restore seismic lines (or other LDFs)? Or does it require some additional effort? If so, what are the associated costs in terms of time and money?
2. Can different restoration activities reduce the time to “restore” a site?
3. What are the potential economic and social implications of WYNs?
4. Overlay historical fire risk analyses (and possibly simulation analyses) to evaluate the potential for WYNs becoming modified (fire control) response zones, and anchors for landscape FireSmart designs.

More immediately, perhaps the biggest challenge will be if and how the results of this study are interpreted and integrated. This study was just a simplified proof-of-concept, and represents a first step in the process of change. A big part of “what is next” for us includes sharing the results, and engaging a wide range of mangers, regulators, and stakeholders in meaningful conversations.

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Appendix A: THE PATCHWORKS MODEL

The Patchworks data, setup and assumptions will be based on the existing model developed for Al-Pac's most recent long-term forest management plan, with several innovative additions to incorporate the seismic rehabilitation and the metrics required for this project.

Seismic

The provided shapefile of seismic lines has attributes to describe the current condition of the vegetation and the traffic types that are using the lines. This data is static and does not change over time. The model will use the curves from section 2.3.1 to grow the seismic lines over time. The curve that each seismic line will start on will be determined by the seismic inventory. Management actions within the model can cause the seismic line to change curves or to reset its age back to zero.

Harvesting

We assume in this study that harvesting by forest companies removes localized linear footprint. This method assumes that a seismic line within or immediately adjacent to a block boundary will be revegetated and grow along with the rest of the block. This results in a seismic line that has been blended into the harvest block. The seismic height curve will start over at age zero on the appropriate eco-site height curve without a regen lag.

Seismic Re-Vegetation

Re-vegetation of seismic lines that are not within harvest blocks is achieved by planting shrubs and trees and by restricting vehicle access to certain lines by distributing logs and other debris. The intent is to change seismic from a non-restored curve to a restored one, and then limiting the vehicle usage along the line.

The treatments required to achieve successful re-vegetation are varied and are site specific. For this study, it is not important to determine which treatment will be used to achieve a re-vegetated seismic, but instead the focus is on the outcome of the re-vegetation. If a seismic section requires brush piling and has ample natural vegetation, the result is expected to be the same as other areas that may also require planting or soil decompaction.

Patch Rules

Patchworks works with spatial data in polygons, which represent different combinations of vegetation and site types. The model requires a set of rules about how to gather, make decisions on, and report on the pattern of these polygons. The patch rules applied for this study include: the maximum distance that two (raw spatial data) polygons can be separated and still be considered a "patch" in the model is 400 meters.

Patch targets can be based on almost any attribute in the model. The three important types of patch targets for this project will be based on disturbance patches, seral stages and heights.

1. Disturbance patches. Disturbance patches are based on age since disturbance. In this case, "disturbance" will last 10 years. Thus, at year 11, a polygon is no longer classified as disturbed. Disturbance event sizes for the NRV harvesting option were: 0% of events <10 hectares, 7% 10–40 hectares, 25% between 40–600 hectares, and 68% between 600–5,000 hectares.

2. Seral stages. Seral stages are based on stand age and vegetation type. The four used in this study were Young, Immature, Mature or Old, as defined by Al-Pac. Seral stage definitions are used generate patch targets and are the foundation for many of the spatial metrics (i.e., Old forest area and patch size).
3. Heights. Polygon height is calculated using height curves, and is used to calculate basic metrics and indicators. For this study, we used height curves used by Al-Pac for harvest patches, and those developed by Vinge (CRM 2013) for LF restoration.

Roads

Patchworks has the capability to model road networks and road usage required for harvesting. As this project is concerned with the reduction of linear disturbances, the roads built to access harvest patches would add to the linear disturbances while the footprint of the harvest patches would decrease the seismic lines. The net impact will be evaluated separately in Neptune after the Patchworks model has been saved, as the patch targets in Patchworks cannot factor in the roads constructed.

Costs

The Patchworks model tracks the costs of all management actions. Those tracked for this study include:

- Harvest costs: $/hectare costs of harvesting action
- Silviculture costs: $/hectare, includes seismic that are within or adjacent to harvest blocks
- Road Construction: $/kilometer cost of creating a new road, in this model this is mostly conversion of seismic into roads. We can investigate the possibility of making it more expensive to build roads on seismic that has already been treated
- Road maintenance: $/kilometer cost of using a road in each period
- Haul cost: $/meter^3/kilometer is the cost to deliver the wood to the mill
- Seismic re-vegetation costs
- Soil decompaction, expressed in $/kilometer
- Tree planting: $/kilometer
- Placement of debris - $/kilometer

Appendix B: The NEPTUNE model

NEPTUNE is an online spatially explicit decision-support tool that allows one to evaluate the degree to which the spatial patterns of disturbances are similar to those of natural, local wildfires. Unlike Patchworks, NEPTUNE makes no decisions, and offers no alternative future scenarios. It is merely a GIS shortcut that manipulates spatial files, creates disturbance events, takes some measurements, and compares those measurements to the natural, historic range.

NEPTUNE measurements include the area and shape of disturbance events, the number and size of disturbed patches, and the amount of different types of residual vegetation. The model works on all natural and cultural disturbance features including wildfires, harvest blocks, well sites, and roads, and has already been calibrated to the study area based on published research results (Andison 2012, Andison and McCleary 2014). NEPTUNE offers an objective method of evaluating and comparing the relative value of current and future disturbance patterns from a biodiversity perspective. There are no comparable models to NEPTUNE, but the algorithms are published, and easily repeated by anyone with GIS software. One of the advantages of using NEPTUNE is that the model automates the process of defining a disturbance "event", which removes any subjectivity associated with the definition of residual vegetation.