

## CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

### 1. PROJECT INFORMATION:

<b>Project Title:</b>	A case study of operational scale legacy restoration efforts in an operating forest management area in NW Alberta: evaluating the restoration of diverse forests and opportunities to improve efforts in future programs
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<b>AI Project Advisor:</b>	Dallas Johnson

### 2. APPLICANT INFORMATION:

<b>Applicant (Organization):</b>	Northern Alberta Institute of Technology
<b>Address:</b>	11762-106 Street NW, Edmonton, AB, T5G 2R1
<b>Applicant Representative Name:</b>	Amanda Schoonmaker 
<b>Title:</b>	Research Chair
<b>Phone Number:</b>	780-618-2606
<b>Email:</b>	aschoonmaker@nait.ca

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### **3. PROJECT PARTNERS**

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## A. EXECUTIVE SUMMARY

The accumulated and persistent loss of forest productivity from legacy oil and gas reclaimed sites is reducing forestry and other land-use potential across Alberta's forested land-base, even while accounting for improved reclamation practices. Today, there remains a substantial legacy of certified-reclaimed industrial disturbances that are presently not growing productive or functional forests, resulting in the need for significant and costly restoration efforts. Success of reforestation efforts on previously reclaimed upland forested sites has been mixed. This project was the first reassessment of a large-scale legacy site restoration program that occurred between 2005-2009. The core **objective** of this project was to provide a quantitative understanding of forest recovery following an operational scale restoration program and to extract patterns in ecological region, ecosite or other attributes that may be used to predict 'success' in future.

**Key results:** There continued to be an observable understory legacy associated with these industrial disturbances in the form of higher relative cover of both grasses and non-native forbs. Grass relative cover depended on natural subregion, with the highest values found in the lowest elevation and driest wellsites (mixedwoods). From the viewpoint of planted tree survival, the restoration program was not entirely successful, though tree growth rates suggest that mechanical site preparation alleviated compaction constraints. Despite low rates of survival, natural ingress of conifers and hardwoods did supplement planted conifer mortality. At high elevations, this may have sufficient offsetting as projected total tree volumes at age 100 were similar amongst reference harvest block sites and re-treated wellsites. However, at lower elevations, projected total tree volumes in wellsites were lower compared with reference harvest blocks.

**Learnings:** Two key challenges were illustrated by examining the operational legacy wellsite restoration program initiated by Weyerhaeuser more than 15 years ago. The first was the continued lag effect associated with higher grass and non-native forb cover. While this understory vegetation is expected to disappear as canopy closure progresses, the higher grass competition has likely been detrimental to tree development and ingress of other trees over time, ultimately limiting canopy closure. This has likely been a significant contributing cause to the poorer tree development outcomes associated with sites in lower elevation regions. The second challenge, which was indirectly related to the first, was the generally high rates of tree seedling mortality of planted species across all natural subregions, though arguably most intensive at low elevations.

Despite an intensive re-treatment strategy of mechanical site preparation – herbicide – planting, these grass and non-native herbaceous vegetation challenges remained, which suggests the biggest 'learn' here has been that we cannot overestimate the competitive potential and long-term legacy impacts these historical practices have had (i.e. seeding agronomic forbs and grasses) and continue to exert on these sites. Moving forward, for forestry companies and other organizations interested in conducting similar programs in the future (resetting grass-dominated industrial sites towards a forested state), this study has illustrated that aggressive strategies are likely necessary, along with additional consideration for incorporating other practices.

**Outcomes and Benefits:** This project identified and reinforced the importance of certain practices (mechanical decompaction) and also highlighted the detrimental impacts of other practices (grass seeding) that can be observed for long periods on these sites. We hope that future practitioners (and regulators) will see these distinctions in practices and focus efforts towards ensuring detrimental practices are not carried into the future.

Despite lower tree survival, many of these re-treated sites were supporting forest vegetation, something that was likely not the case prior to their treatment. Especially at higher elevations, with presumably lower levels of grass competition, there is even more reason to encourage and support proactive re-treatment strategies given the relative success of the operational sequence of events. At lower elevation sites, with higher quantities of grass competition, this project highlights that more intensive and comprehensive strategies may be required to more consistently establish forest vegetation. Forestry companies have an opportunity to integrate re-treatment of legacy sites into harvesting practices, as they often work around and through these sites. To maximize the effectiveness of re-treatment, efforts should be prioritized based on site-specific risk factors and regional management goals.

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## B. INTRODUCTION

**Sector Introduction:** Due to a variety of factors (land removals for protection of wetlands/wildlife habitat, forest fires, insect outbreaks and expansion of other industries), the forestry industry is facing an ever-shrinking harvestable land base. As such, industry must continue to innovate while operating profitably and ensuring they meet regulations and societal needs. The accumulated impacts of historical and ongoing oil and gas (O&G) development, especially within Alberta's boreal forest, is impacting the forest industry. Recent public press releases indicate that there are approximately 14,598 abandoned wells in Alberta, 252,410 other wells of all types, and 241,144 ha of pipeline disturbance (Kemball 2020). The most recently-available ABMI database (2018), when selected only for forested areas in Alberta, shows 3.5 million ha of human footprint (not all active, just visible), including 322,000 ha of conventional seismic lines and 14,000 ha of coal mines. At present, many O&G disturbances remain deletions from the productive forest land base, impacting the growing stock and thus the annual allowable cut for sustainable forestry in Alberta. Collectively, these industrial disturbances provide an opportunity for enhancing biodiversity, establishing important wildlife habitat, increasing tree growth, and for greenhouse gas (GHG) emissions reduction and increased ecosystem carbon sequestration. Innovation and integration of best management practices are required to meet the current challenges in the loss of productive land and the looming challenge of additional losses anticipated from climate change.

**Knowledge Gaps:** Reclamation practices and regulatory requirements and standards associated with O&G disturbances in Alberta have evolved substantially in the last 40 years (Powter et al. 2012). The original reclamation standards developed in Alberta in 1993 (inclusive of the updates in 1994 and 1995, GoA 1995) on O&G wellsites and associated facilities did not require the establishment of forest species; consequently, these sites were often vegetated with a mixture of agronomic grasses and forbs. While the current 2010 reclamation standards (ESRD 2013) have requirements on the presence of woody stems and native vegetation cover, these standards do not necessarily ensure a return of the productive forest, though recent evidence suggests that these standards have resulted in substantial improvements, from the viewpoint that the wellsites certified to newer standards demonstrated attributes more closely aligned with younger fire or harvest origin sites, relative to older standards (Baah-Acheamfour et al., 2022). Nevertheless, there remains a substantial legacy of certified-reclaimed industrial disturbances that are presently not growing forests. Importantly, the fact that many of these legacy sites have shown little to no evidence of forest ingress for many years (Lupardus et al., 2019, van Rensen et al., 2015) suggests they will remain in this state for the foreseeable future unless significantly re-treated. For example, predictions of future regeneration rates on existing seismic lines suggest that approximately one-third of existing linear disturbance footprints in the Boreal landscape will remain un-regenerated 50 years later, resulting in persistent habitat fragmentation (van Rensen et al. 2015).

While forest companies have been engaged in varying levels of reforestation of these legacy sites, success has been mixed. Contributing factors to this have been an underestimation of the competitive effects of agronomic grasses and forbs, compaction issues reducing root egress and healthy establishment, a lack of knowledge on seedling stock characteristics, and species-specific suitability to the conditions of these

types of sites. These restoration programs are conducted with limited follow up regarding the relative success of the practices applied, leaving an important knowledge gap. Between 2005–2009, Weyerhaeuser undertook a large-scale legacy site restoration program that included a decompaction treatment to alleviate soil compaction concerns. As these sites were now more than 15 years old, the Weyerhaeuser program presented a unique opportunity to evaluate forest regeneration success (or lack thereof in certain cases) and to provide future programs with guidance to support effective forest restoration. The present project assessed forest development at Weyerhaeuser legacy wellsites, employing a novel approach that used similarly aged post-harvest sites as reference benchmarks.

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## C. PROJECT DESCRIPTION

**Knowledge Description:** To our knowledge, a comprehensive retrospective of this size and scale has not been undertaken in Alberta. With many forest companies throughout northern Alberta looking at the potential for afforestation of legacy sites, re-evaluation of Weyerhaeuser's Forest restoration program will be of significant utility to these organizations. The resulting data will help provide guidance in terms of effective treatments and conditions associated with success, as well as direction, in terms of future applied research to ensure companies have a reasonable suite of options in tackling challenging sites. This project will provide quantitative data illustrating the similarity and differences amongst contrasting human-disturbed sites (legacy wellsites and benchmark post-harvest sites). Lastly, the insights gained from this study will be broadly transferable to other types of industrial footprints prevalent on the landscape, for example, linear disturbances such as roads and seismic lines, sand and gravel pits, as well as conventional and in-situ oil and gas disturbances.

Between 2022 and 2023, 85 sites in the Weyerhaeuser's Forest restoration program were assessed to evaluate the growth and survival of the planted trees, the abundance of other desirable woody vegetation, and the cover of all species found in the herbaceous layer. In 2024, we also assessed a group of post-harvest sites (harvest blocks and the associated in-block roads) specifically selected to have similar age, ecosites and geographic locations compared to the wellsites to be used as benchmarks of forest development. By comparing wellsites with post-harvest sites, we seek to better understand the relative growth trajectories of forest tree species as well as other important forest attributes in these legacy industrial sites in context with disturbances for which we have a better understanding of forest succession and expected growth.

**Project objectives (minor changes from the original submission, simplification of question 3):** The core objective of this project was to provide a quantitative understanding of forest recovery following an operational scale restoration program and extract patterns in ecological regions, ecosites or other attributes that may be used to predict 'successful reforestation' of industrial legacy forest sites in the future. Specifically, this project aimed to answer the following questions:

1. When making comparisons amongst legacy industrial sites against post-harvest sites, is the more appropriate comparison the primary harvest block or a similarly-soil disturbed footprint associated to the harvest block (in block roads)?
2. Are these sites progressing on a similar trajectory to what we might expect from other landscape-scale disturbances?
3. How successful was the restoration program in kickstarting forest development on these legacy sites?

**Project specific performance metrics:** We identified several project success metrics at the onset of this study including:

- Field assessment of 100 sites in the Weyerhaeuser's Forest restoration program.

- Identification and field assessments completed in harvest blocks (reference conditions) where we had aimed to assess approximately 40 blocks.
- Completion of technical reports to Weyerhaeuser.
- Presentation of findings at a conference or workshop (2 anticipated).
- Engagement with Indigenous stakeholders and knowledge exchange on legacy restoration.
- Engagement with Alberta Environment and Parks and Alberta Agriculture and Forestry through discussions of findings.
- Preparation of knowledge translation products (2 anticipated).

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## D. METHODOLOGY

### ***D.1 Study Area***

The study area was located within the Weyerhaeuser's Grande Prairie FMA (6900016) in northwest Alberta, Canada (**Figure 1**). A smaller portion of the FMA (~ 211,000 ha) was located north and northeast of Grande Prairie, with the larger area (~ 906,000 ha) in the south and southwest parts (**Figure 1**). The FMA area was situated primarily within the Lower and Upper Foothills Ecoregions and to a lesser extent the Central Mixedwood, Dry Mixedwood, and Subalpine Ecoregions. These ecoregions are characterized by a boreal climate that is substantially modified by the Rocky Mountains. This results in annual precipitation with short summers and long cold winters (Strong and Leggat 1992). The average May through August temperature is 11.5 °C, average winter temperature is -6.0 °C. The bulk of precipitation occurs between May and September, with July and August being the wettest months. The FMA is characterized by white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) forests at lower elevations and Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) at higher elevations. The Weyerhaeuser FMA has abundant upstream oil and gas development, thus rendering the study area suitable for the evaluation of landscape-scale integration of disturbance. What also makes the area critical for habitat supply and biodiversity conservation is the spatial overlap of caribou (*Rangifer tarandus caribou*). The Alberta woodland caribou population occupies 373,000 ha (112,000 km<sup>2</sup>—33%) of the Weyerhaeuser's FMA area; the caribou occur predominantly in the southwestern portion of the FMA area.

### ***D.2 Upland wellsites previously treated by Weyerhaeuser***

A significant effort was undertaken by Weyerhaeuser to reforest previously reclaimed certified wellsites from 2006 to 2009. The basic approach taken for re-treatment included winter RipPlow™ with D8, spring application of glyphosate to reduce ruderal vegetation followed by summer planting conifers, either white spruce or lodgepole pine. An excel inventory of about 200 sites (wellsites) was received from Weyerhaeuser in both Grande Prairie FMA. The file also contained site-level details related to species type, approximate number of tree seedlings planted, site preparation activity completed (decompaction and herbicide), and legal subdivisions by the Alberta Township System. We converted the legal subdivisions to Latitude and Longitude. The excel file was added as an event theme using ArcMap™, converted to a shapefile and clipped to the FMA area polygon. In some cases, the level of detail in the excel file resulted in some uncertainties in the precise location of the treated wellsite. In this situation, we cross-referenced visually with Google Earth Pro images (Google LLC. 2024). A GIS overlay analysis was performed with the Identity Tool (inside the Overlay Toolset) to flag all previously treated and planted sites within the reclaimed-certified layer from AbaData as another layer of data.

### ***D.3 Wellsite inventory desktop investigation and stratification: AbaData and GIS***

Using the list of wellsites previously treated by Weyerhaeuser we cross-referenced this list with province-wide wellsite inventory data obtained from the AbaData website (AbaData, 2023). The database provides the ability to download publicly available information on each licensed well that is provided to the Alberta Energy Regulator. A summary of information available for global (mass) download and report building in excel included the well unique identifier, well name, licensee, license status, year spud (drilled), year

abandoned (if indicated), final drill date (if indicated), and whether the well was reclaimed (i.e., license status). Query expressions were used in ArcGIS to select a subset of the features and table records (Esri Inc. 2023a). These sites were joined with the existing Alberta Vegetation Inventory (AVI) data (Agriculture and Forestry 2022). This was important for extracting the ecosite, soil, climate, and vegetation class information of each wellsite at the local scale.

We employed a classification scheme focused on scoring the level of visible regeneration of an individual wellsite and applied this to all wellsites. We utilized two imagery sources, SPOT™ imagery in ArcGIS (Esri Inc. 2023b) and Google Earth™ imagery (Google LLC. 2024) and applied the most optimistic classification to assign regeneration level. We defined each wellsite regeneration status as either: *regenerating* (i.e., tree canopy development was evident throughout the site, and was anticipated that forest canopy closure could be achievable within a 40-year time frame), *fractionally regenerating* (i.e., some tree or shrub development was evident but was uneven or sparsely occurring (perhaps isolate to one part of the site or edges), and *no regeneration* (i.e., the site appeared to be dominated by herbaceous understory species). Other information that was documented within the shapefile included: the dates the images were taken (i.e., to better understand where the images were from and to see the accuracy of desktop identification versus field identification), and landform (wetland or upland with additional information clipped from the Alberta Vegetation Inventory layer (Agriculture and Forestry 2020).

**Table 1.** Site grouping of *re-treated reclaimed-certified wellsites* by Weyerhaeuser in the Grande Prairie FMA illustrating the split by natural subregion, ecosite and imagery-based regeneration status.

Primary groupings	Frac Regen	No Regen	Regen
<i>All sites by group</i>			
CM/DMW - d ecosite	40	13	7
LF - e ecosite	85	18	33
SA/UF - d/e ecosite	17	1	6
LF/CM/DMW - f/g/k	7	0	3
		<b>Total:</b>	<b>230</b>
<i>Number of sites measured</i>			
CM/DMW - d ecosite	14	10	5
LF - e ecosite	17	8	12
SA/UF - d/e ecosite	10	0	5
LF/CM/DMW - f/g/k	4	0	0
		<b>Total:</b>	<b>85</b>

We further grouped candidate sites (from **Table 1**) into broad ecosite groupings (ecological area and ecosite) with ground assessments to be conducted on a subset of sites within each of the ecosite groupings by regeneration status. The decision regarding this final grouping was based on the availability of sites within ecological areas and ecosites. As much as practical, we tried to conserve the grouping of similar ecosites and then group across an ecological area. We aimed to sample at least 10 sites per level though in some cases, there were fewer sites available for sampling within a classification grouping and ultimately the available field time and access constraints dictated the final surveyed sampling intensity (**Table 1**).

#### ***D.4 Desktop grouping and compilation: forest post-harvest sites***

We received a shapefile from Weyerhaeuser which included all sites that had been harvested between 2006-2009. The harvested sites spanned multiple natural subregions (Dry Mixedwood, Central Mixedwood, Lower and Upper Foothills, and Subalpine)—the same regions covered we sampled for the wellsite investigation. More than 2,500 entries were mapped and grouped based on ecological region, ecosite, leading tree species and year of harvest. Sites were then screened to include only truck accessible blocks. Using similar ecological region grouping as employed for the wellsites, we randomly selected sites to capture a cross-sectional range of ecological regions and ages (2006-2009) with attention to representing both deciduous and conifer-leading forest types. While we had initially stratified 43 sites for assessment, we were only able to complete surveys in a total of 38 (summarized in **Table 2**). At each post-harvest site, a 1-hectare area was selected within the main harvest block along with a section of in-block road, hereafter referred to as HB and IBR, respectively. The HB received the same type of randomized plot assignment utilized for wellsites where 9 plots were arranged in a 3x3 grid. For the IBR, the 9 plots were arranged linearly with 25 m distance between them. Survey plots were mapped prior to site work. As IBR represented a more analogous level of soil disturbance to that of wellsites, we felt this was an important addition to include along with assessment of HB, which would have received minimal soil disturbance, relatively speaking.

**Table 2.** Grouping of harvest blocks by ecological region and leading-tree species targeted. Note that 1 site in the UF-SA was noted as leading with Engelman spruce, though it is included with the white spruce grouping.

<b>Ecological region</b>	<b>Aspen</b>	<b>Lodgepole pine</b>	<b>White spruce</b>	<b># sites</b>
DM-CM	2	5	2	9
LF	5	7	7	19
UF-SA	0	6	4	10
<b>TOTAL</b>	<b>7</b>	<b>18</b>	<b>13</b>	<b>38</b>

#### ***D.4 Field investigation***

Site surveys took place from early July through August 2022 and included 17 wellsites. For 2023, surveys took place from early July into early September and included 68 wellsites. In total 85 wellsite previously re-treated by Weyerhaeuser were surveyed. Surveys in post-harvest sites were conducted in July-August 2024, and a total of 38 blocks were visited with sampling occurring in the HB and the IBR.

Site survey measurements were conducted in 3.99 m radius circular plots, except where deciduous tree/shrub density was excessively high, in which case woody species were recorded in a smaller sampling plot of size 1.78 m. A more detailed description of the protocols for locating and measuring vegetation plots is located in **Appendix A**, however, the core elements of field data collection are summarized in the subsections below.

- A visual assessment was conducted at each plot for standing water and any notable ground conditions, as well as any ongoing human disturbance.

- Within each sampling plot (1.78 or 3.99 m), stem count of all woody species, top height of shrub species, the total standing height (diameter at breast height [dbh] if > 1.3 m) and the condition (health) of tree species were recorded. For conifers less than 30cm in height and deciduous trees less than 1.3m in height, stem counts were recorded into a tally sheet along with shrub stem counts. Conifers were always measured within a 3.99m radius plot.
- Vegetation cover (% of ground area by vascular plants, bryophytes and terrestrial lichens) was assessed using a 0.5 x 0.5 m quadrat, where four quadrats were placed on each circular sampling plot (total of 36 quadrat measures/wellsite).

#### ***D.5 Mixedwood growth model***

The Mixedwood Growth Model (MGM) was used to estimate projected growth of the wellsites into the future (MGM Development Team, 2021). We chose this model over the other model available for forest growth and yield predictions (GYPSY) for several reasons: (1) MGM was developed with mixed-species stands in mind, something that likely better reflects the condition of most wellsites which tended to have a mixture of conifers and deciduous tree species, (2) MGM is an individual-tree model rather than a stand model (GYPSY), and we felt the ability to project growth of the individual tree data, which varied sizes within the sites, would be a more accurate reflection of these sites, and (3) MGM allows for batch-processing stand data which considerably improves ease of use and productivity. We combined the tree species observations from the survey points for a given wellsite as a stand. The projection modelled initial growth and at every 10-year interval until 100 years after the reclamation date, as determined by the DSA (detailed site assessment). Since individual trees were not aged, site index was determined based on the natural subregion and ecosite of the wellsite using site indices from MGM research notes (Bjelanovic and Comeau, 2019; Comeau 2020). Site age was based on year the site was abandoned (wellsite) or the year it was cleared (post-harvest sites).

#### ***D.6 Data analysis***

For comparisons of post-harvest site types (HB and IBR) with re-treated reclamation certified sites (WS) we utilized a model selection approach, comparing 9 nested models (3-way interactions, 2-way interactions and no-interactions) to evaluate factors that were important to explain patterns of tree and understory vegetation data. The model with the lowest AIC (Akaike information criterion) value was chosen for subsequent analysis (final models are provided in **Tables 3-8**). For stem counts, basal area, vegetation cover and relative abundance, factors included: natural subregion, site type and site age. For tree size metrics, factors included: natural subregion, site type and tree group (conifer or hardwood). For stem counts of planted trees, which was tested only for WS sites, factors included: natural subregion, species planted (lodgepole pine or white spruce) and planting year. For MGM responses, factors included: natural subregion and site type.

Responses were fit with generalized linear models via the R function `glmmTMB` (package `glmmTMB`, Brooks et al. 2017) utilizing a distribution appropriate to each response. Models with stem counts were fit with a generalized Poisson distribution, basal area with a Tweedie distribution, growth metrics with a

t-distribution, total plant cover with a Gamma distribution, and relative abundance based on ground cover with an ordinal beta distribution. MGM volume was fit with a Tweedie distribution, MGM basal area with a t-distribution and MGM top heights with a Gamma distribution. When significant ( $p \leq 0.05$ ) main effect differences were detected, treatments were separated with a post-hoc (Tukey test) multiple comparison test using the emmeans function (Lenth 2022, Hothorn et al. 2008) with the estimated marginal means presented in tables and figures unless otherwise noted. Model assumptions diagnostics were evaluated using residual plots from the DHARMA package (Hartig 2022).

**Table 3.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, site age, site type (harvest block, in-block road, and wellsite), and their interactions on the vegetation cover of the sites. Functional groups were assessed using relative abundance, while lichen was assessed as a presence or absence.). Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Total Cover (%)</b>	ecoregion	1.403	0.496
	site age	2.259	0.132
	site type	0.209	0.900
<b>Relative Abundance</b>			
<b>Native Forbs</b>	ecoregion	1.35	0.114
	site type	50.34	<b>&lt;0.0001</b>
	ecoregion X site type	14.99	<b>0.005</b>
<b>Non-native Forbs</b>	ecoregion	4.53	0.104
	site type	0.04	0.836
	ecoregion X site type	75.76	<b>&lt;0.0001</b>
<b>Grasses</b>	ecoregion	7.31	<b>0.026</b>
	site type	18.69	<b>&lt;0.0001</b>
	ecoregion X site type	14.86	<b>0.005</b>
<b>Woody</b>	ecoregion	3.76	0.153
	site age	2.49	0.115
	site type	43.42	<b>&lt;0.0001</b>

**Table 4.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, site type (harvest block, in-block road, and wellsite), site age and their interactions on the observed tree count and basal area of the sites. Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)	Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Count</b>				<b>Basal Area</b>			
<b>All Trees</b>	ecoregion	5.20	0.074	<b>All Trees</b>	ecoregion	3.72	0.155
	site type	52.22	<b>&lt;0.0001</b>		site type	67.72	<b>&lt;0.0001</b>
	site age	3.74	0.053		ecoregion X site type	20.24	<b>0.0004</b>
	ecoregion X site type	25.52	<b>&lt;0.0001</b>				
	ecoregion X site age	1.63	0.443				
	site type X site age	1.25	0.535				
<b>Conifers</b>	ecoregion	5.23	0.073	<b>Conifers</b>	ecoregion	6.13	<b>0.047</b>
	site type	33.56	<b>&lt;0.0001</b>		site type	49.48	<b>&lt;0.0001</b>
	site age	2.81	0.094		ecoregion X site type	7.83	0.098
	ecoregion X site type	22.90	<b>0.0001</b>				
	ecoregion X site age	2.36	0.307				
	site type X site age	0.28	0.868				
<b>Deciduous</b>	ecoregion	7.77	<b>0.021</b>	<b>Deciduous</b>	ecoregion	4.71	0.095
	site type	30.21	<b>&lt;0.0001</b>		site type	34.72	<b>&lt;0.0001</b>
	site age	1.94	0.164		ecoregion X site type	28.78	<b>&lt;0.0001</b>
	ecoregion X site type	38.84	<b>&lt;0.0001</b>				

**Table 5.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, tree type, site type (harvest block, in-block road, and wellsite) and their interactions on the observed tree height and diameter at breast height (DBH) of the sites. Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)	Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Height</b>				<b>DBH</b>			
<b>All Trees</b>	ecoregion	24.77	<b>&lt;0.0001</b>	<b>All Trees</b>	ecoregion	6.46	<b>0.040</b>
	tree type	0.24	0.626		tree type	45.55	<b>&lt;0.0001</b>
	site type	12.44	<b>0.002</b>		site type	3.20	0.072
	tree type X site type	14.66	<b>0.001</b>		tree type X site type	12.82	<b>0.002</b>
<b>75% Quantile</b>	ecoregion	22.18	<b>&lt;0.0001</b>	<b>75% Quantile</b>	ecoregion	5.64	0.060
	tree type	0.89	0.346		tree type	48.58	<b>&lt;0.0001</b>
	site type	15.42	<b>0.0004</b>		site type	4.66	0.097
	tree type X site type	13.95	<b>0.001</b>		tree type X site type	12.24	<b>0.002</b>

**Table 6.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, species planted, planting date and their interaction on the observed planted conifer stem counts in the wellsites. Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Survival</b>			
<b>Conifer</b>	ecoregion	9.10	<b>0.011</b>
	species planted	0.37	0.540
	plant date	2.55	0.467
	ecoregion X species X planted	1.88	0.391

**Table 7.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, site type (harvest block, in-block road, and wellsite), and their interaction on the Mixedwood Growth Model (MGM) predictions for the merchantable stand tree volume, basal area, and height at year 100. Merchantability criteria used were a minimum DBH of 13.59 cm, with volume calculated up to a top internal diameter of 10 cm, and setting a stump height of 30 cm. Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Merchantable volume</b>			
<b>All Trees</b>	ecoregion	6.59	<b>0.037</b>
	site type	36.15	<b>&lt;0.0001</b>
	ecoregion X site type	13.82	<b>0.008</b>
<b>Conifers</b>	ecoregion	4.59	0.101
	site type	20.24	<b>&lt;0.0001</b>
	ecoregion X site type	14.95	<b>0.005</b>
<b>Deciduous</b>	ecoregion	1.53	0.465
	site type	19.72	<b>&lt;0.0001</b>
	ecoregion X site type	19.37	<b>0.001</b>
<b>Basal Area</b>			
<b>All Trees</b>	ecoregion	7.10	<b>0.029</b>
	site type	70.29	<b>&lt;0.0001</b>
	ecoregion X site type	14.75	<b>0.005</b>
<b>Height</b>			
<b>Conifers</b>	ecoregion	16.36	<b>0.0003</b>
	site type	1.29	0.525
	ecoregion X site type	6.73	0.151
<b>Deciduous</b>	ecoregion	4.97	0.084
	site type	7.48	<b>0.024</b>
	ecoregion X site type	5.09	0.279

**Table 8.** Analysis of deviance (Chi-square and p-value) of the effect of ecoregion, site type (harvest block, in-block road, and wellsite), and their interaction on the Mixedwood Growth Model (MGM) predictions for total stand tree volume at year 100. Significance of  $p < 0.05$  are bolded.

Response	Predictor	Chi-Square	Pr (>Chisq)
<b>Total volume</b>			
<b>All Trees</b>	ecoregion	0.70	0.705
	site type	29.82	<b>&lt;0.0001</b>
	ecoregion X site type	13.61	<b>0.009</b>
<b>Conifers</b>	ecoregion	4.27	0.118
	site type	24.52	<b>&lt;0.0001</b>
	ecoregion X site type	15.89	<b>0.003</b>
<b>Deciduous</b>	ecoregion	1.86	0.395
	site type	22.25	<b>&lt;0.0001</b>
	ecoregion X site type	21.25	<b>0.0003</b>

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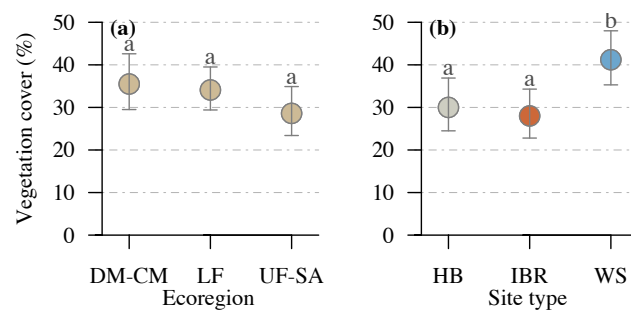
## E. PROJECT RESULTS

We have discussed the results of this project in the context of answering the study questions posed at the onset of the investigation.

**Question 1: When making comparisons amongst legacy industrial sites against harvested sites, is the more appropriate comparison the primary harvest block or a similarly-soil disturbed footprint within the harvest block (in block roads)?**

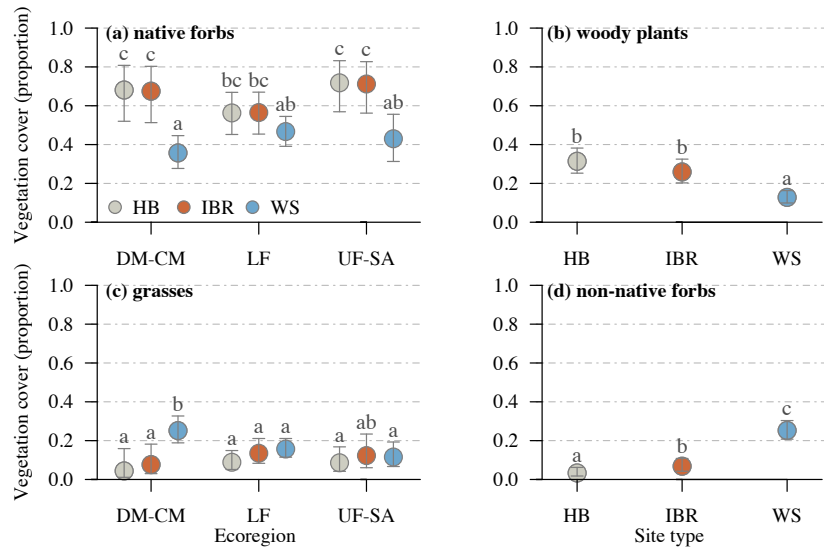
In general, understory vegetation development of HB and IBR was similar in most respects with no differences in total cover observed (**Figure 2**). The main understory distinction between these site types was the slightly higher relative cover of non-native forbs in IBR compared with HB (**Figure 3**).

**Figure 2.** Total understory plant cover (%). Values are grouped by site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and by ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).

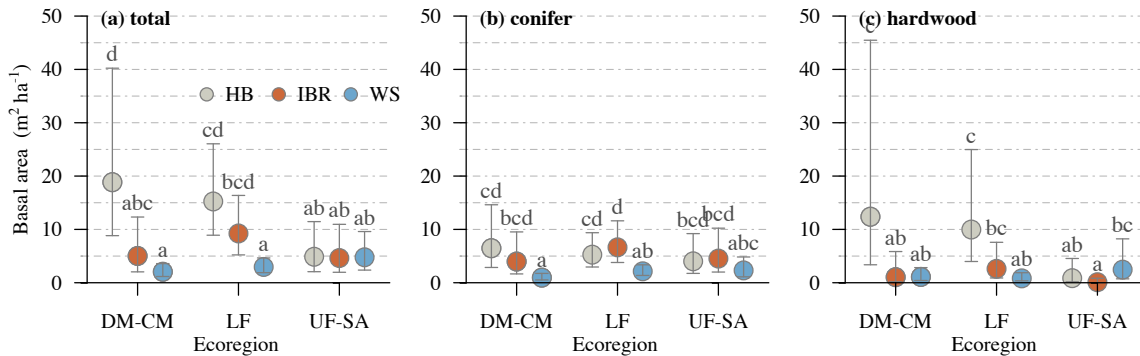


In terms of overstory tree development, HB tended to carry higher basal area of hardwoods, on average, particularly in the lowest elevation natural subregion (DM-CM) though not at high elevation UF-SA (**Figure 4c**). This distinction was presumably a result of surface soil stripping and windrowing during road construction and necessarily resulted in reduced vegetative regrowth of hardwood species. Despite lower basal area, it is notable that stem counts of hardwoods were nearly identical between HB and IBR (**Figure 5**) which further support the notion that hardwood regrowth may have largely occurred through seed-based recovery as growth metrics (height, DBH) were also lower in IBR compared with HB (**Figure 6**). In terms of disturbance intensity, the fact that IBR share a similar degree of surface soil stripping (albeit for a shorter duration) as WS disturbances, we believe this disturbance type reflects a more appropriate reference condition with which to evaluate forest redevelopment on the re-treated WS. Though, as we have illustrated, most understory and conifer tree related parameters were similar between HB and IBR. Nevertheless, in the subsequent sections, we compare and contrast both HB and IBR with WS responses.

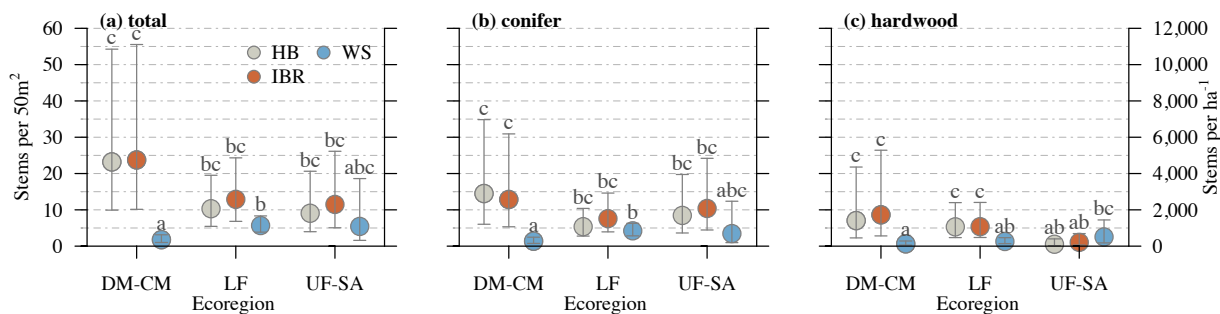
**Figure 3.** Relative cover (proportion of total cover) of understory vegetation. Values are grouped by site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and by ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



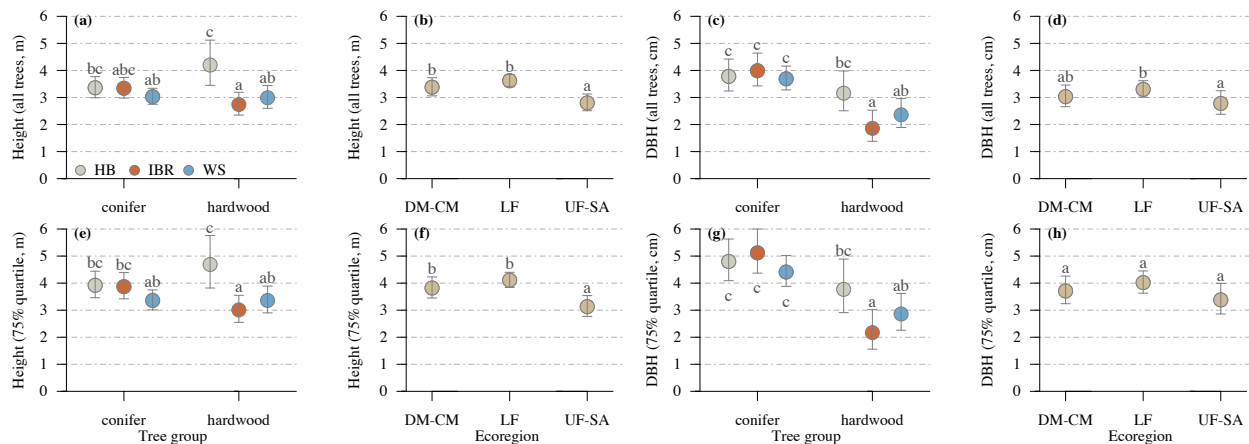
**Figure 4.** Stand basal area grouped by (a) total of all trees, (b) conifer or (c) hardwood. Each panel reflects the interaction of site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



**Figure 5.** Stem counts grouped by (a) total of all trees, (b) conifer or (c) hardwood. Each panel reflects the interaction of site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



**Figure 6.** Average height and diameter of measured trees reflecting (a-d) all measured trees or (e-h) tree measures at the 75% quartile. Values were grouped by lifeform (conifer or hardwood), by site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and by ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



**Question 2: Are these sites progressing on a similar trajectory to what we might expect from other landscape-scale disturbances?**

The re-treatment of previously certified wellsites was intended to restore treed vegetation on sites that would have been presumably (as we were not present at the time of the original re-treatment work) graminoid or forb dominated. However, even 15+ years after treatment, there remains key differences between these re-treated sites (WS) and similarly aged post-harvest sites both HB and IBR. Total understory cover was ~10% higher on average (Figure 2) in WS sites compared with HB and IBR. However, the proportion of this cover represented by desirable native forbs and woody plants was lowest in WS (Figure 3a-b). Interestingly, site type interacted with ecological region to affect grass relative abundance

(**Table 3**), with grass relative abundance being similar for higher elevation areas across site types but substantially higher in WS at the lower-elevation, dry and central mixedwood natural subregions (**Figure 3c**). Non-native forb relative abundance was highest in WS where more than 20% of total cover was represented by this group, while this vegetation group was nearly absent in HB and presented at low relative abundance (<10%) in IBR (**Figure 3d**). While WS had been sprayed in the spring following mechanical site preparation, it appeared that any effect in reducing the cover of undesirable vegetation was short-lived given the high relative abundance of both non-native grass and forbs in these sites more than a decade later.

At the stand level, basal area showed a significant interaction between natural subregion and site type (**Table 4**), with basal area being higher in HB than in WS (and intermediate in IBR) in the dry and central mixedwood and the lower foothills, while there were no differences in the UF-SA, where basal area was generally low (**Figure 4a**). This was primarily due to high basal area of hardwood species as conifer basal area was relatively low overall (**Figures 4b, c**). Total tree stem counts were also highest in lower elevation natural subregions (dry and central mixedwood), with both HB and IBR showing substantially higher stem counts relative to WS sites (**Figure 5a**). However, both the lower foothills and upper foothills – subalpine regions showed similar total stem counts across all site types, though WS were often lower on average (**Figure 5a**). This somewhat complex picture of stand development illustrates the challenges associated with forest reclamation in lower elevation sites, conditions that were invariably exacerbated by higher grass competition (**Figure 3c**) relative to higher elevation natural subregions.

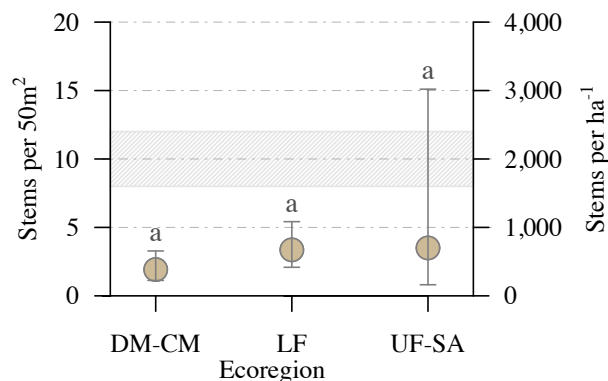
Conifer tree height growth was similar amongst site types though hardwood heights were substantially greater in HB compared with IBR and WS sites (**Figure 6a**); the same pattern was true when examining the tallest trees in each plot (**Figure 6e**). Trees in general were taller in lower elevation natural subregions compared with the higher elevation upper foothills – subalpine (**Figure 6b**). Patterns of diameter (DBH) were somewhat different to that observed for heights, where there was less distinction amongst natural subregions (**Figure 6d**) and no difference when examining the largest trees (**Figure 6h**). There was no difference in basal area amongst conifers (**Figure 6c, g**) though hardwoods in HB had higher average basal areas compared with IBR while WS sites were intermediate in DBH (**Figure 6c, g**). Overall, these patterns support the idea that the mechanical site treatments imposed on the WS were effective in alleviating potential growth-limiting soil compaction as both conifers and hardwoods were growing comparably to IBR and even HB (for conifers). Hardwoods in HB likely maintained a growth advantage since most trees in these sites would have originated from root suckers while IBR and WS sites would have reflected more seed-based regeneration.

Given the findings above, it appeared that the re-treated WS were showing some attributes associated with other landscape-scale disturbances (post-harvest sites) including similar tree growth responses though stem counts of conifer and hardwood trees were depressed in the lowest elevation natural subregions (dry mixedwood and central mixedwood). A finding we suggest was driven by higher levels of competition from understory grasses.

**Question 3: How successful was the restoration program in kickstarting forest development on these legacy sites?**

While mechanical site treatments appeared to benefit tree growth, survival estimates of planted trees were less optimistic though there was a degree of uncertainty regarding this estimate due to lack of precise knowledge regarding planting densities. However, when we examined stem counts of tree species that were known to be planted on these sites, we found that this was best explained by natural subregion, though individual means were statistically similar (**Figure 7, Table 6**). There was no difference in stem counts amongst the two species planted on these sites, lodgepole pine and white spruce (**Table 6**). On average 2-4 stems per 50 m<sup>2</sup> plot were found and we estimate the effective planting density was 10 stems per plot (give or take). This equates to a survival rate of 20-40%, on average with the higher end-estimate occurring at higher elevation. It is notable that the upper foothills – subalpine natural subregion showed substantial variation in the mean estimate (wide confidence intervals) which we attribute to significant quantities of natural regeneration as well as potentially much higher survival rates in some instances.

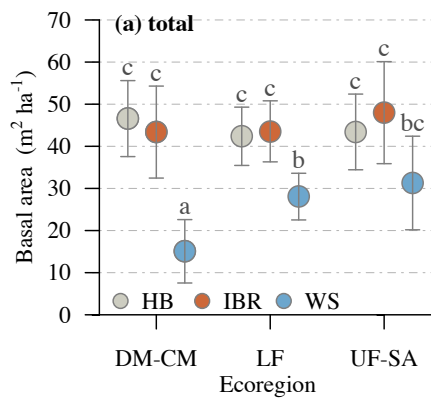
**Figure 7.** Stem counts of conifers planted on wellsites and grouped by ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). The grey hatched area reflects the original planted conifer density of the sites. There was no difference between lodgepole pine and white spruce, therefore values below reflect averaging over both species. Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



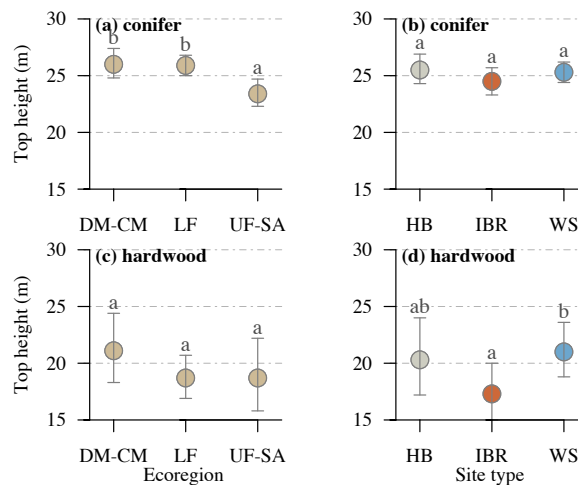
Projecting stand growth at stand age 100 years we found that basal area, which reflects both stem density as well as diameter growth, remained lower in both the dry mixedwood and lower foothills natural subregions. While it was lower on average in the upper-foothills – subalpine, WS were statistically distinct from HB or IBR (**Figure 8, Table 7**). Basal area was particularly depressed in WS in the dry and central mixedwood at 15 m<sup>2</sup> ha<sup>-1</sup> compared with 45+ m<sup>2</sup> ha<sup>-1</sup> for HB and IBR; even WS at higher elevations were ~30 m<sup>2</sup> ha<sup>-1</sup> (**Figure 8**). Top heights at year 100 were similar amongst conifers in different site types (**Figure 9b**) though lower in the upper foothills – subalpine compared with lower elevation natural subregions (**Figure 9a**). For hardwoods, top heights were similar amongst natural subregions (**Figure 9c**) and similar between HB and WS sites with IBR being significantly shorter (**Figure 9d**). Examining projected total stand volumes, we found the patterns in basal area matching those in volume estimates (**Figure 10a**) with a

significant interaction between site type and natural subregion (**Table 8**). For merchantable total volume, WS were only statistically lower than IBR and HB in the dry and central mixedwood natural subregion (**Figure 10d, Table 7**).

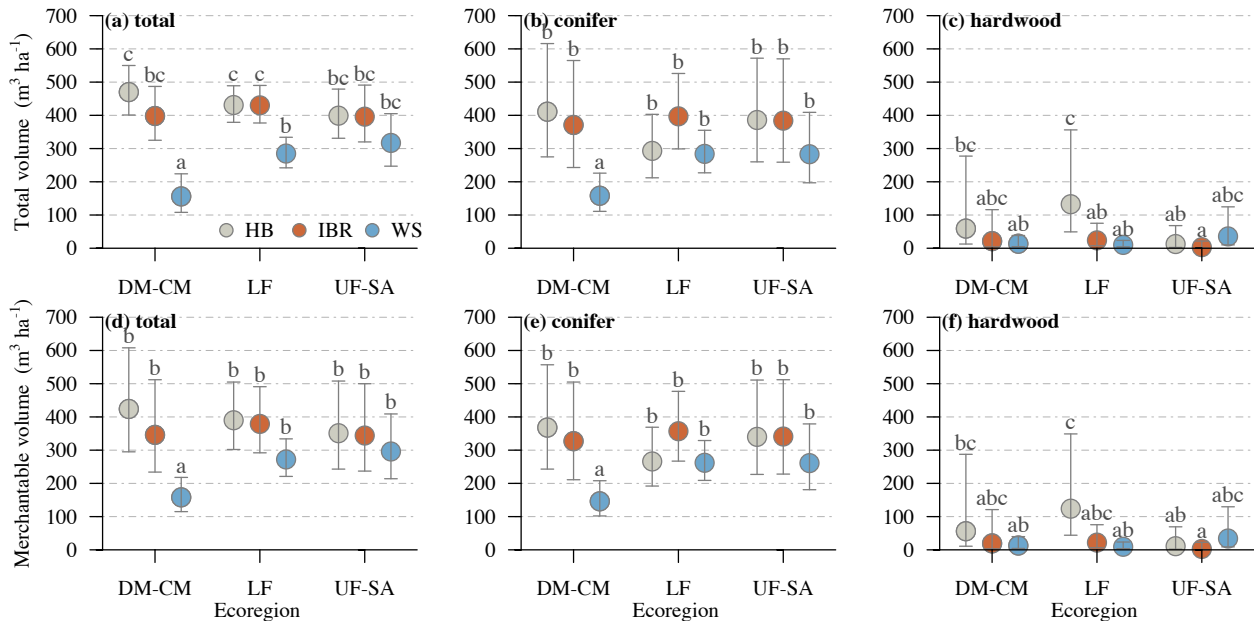
**Figure 8.** MGM predicted stand basal area at 100 years of age by site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



**Figure 9.** MGM predicted top heights at 100 years of age by lifeform (conifer or hardwood), site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and 38 IBR / HB).



**Figure 10.** MGM projected total stand volumes at 100 years of age by lifeform (total, conifer or hardwood), site type including HB (harvest block), IBR (in-block roads of harvest blocks), and WS (re-treated wellsites) and ecoregions: DM-CM (Dry Mixedwood-Central Mixedwood), LF (Lower Foothills), and UF-SA (Upper Foothills-Subalpine). Differing letters between treatment means indicate a significant difference ( $p < 0.05$ ). Error bars represent 95% confidence intervals on the mean ( $n = 85$  WS and  $38$  IBR / HB).



From the viewpoint of planted tree survival, the restoration program was not terribly successful though the rates of growth support the fact that mechanical site preparation was effective in alleviating compaction constraints on tree growth. This was clear in the current measurements as well as projected growth. Despite low rates of survival, natural ingress of conifers and hardwoods (as these were always unplanted), did supplement planted conifer mortality. At high elevations (upper foothills – subalpine), this was sufficient offsetting as projected total tree volumes at age 100 were similar amongst HB-IBR-WS. However, at lower elevations (dry-mixed wood and central mixed wood and to a lesser extent the lower foothills), projected total tree volumes in WS were not expected to recover to similar estimates as the HB and IBR site types. There continued to be an observable understory legacy associated with these industrial disturbances in the form of higher relative cover of both grasses and non-native forbs. While non-native forb cover was similar amongst all natural subregions, grass relative cover strongly interacted with natural subregion with the highest values associated with the lowest elevation sites in WS though this pattern was not observed for HB and IBR. In summary, we consider the program's success to be mixed overall, with outcomes generally improving at higher elevations.

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## F. KEY LEARNINGS

Two key challenges were illustrated by examining the operational legacy wellsite restoration program initiated by Weyerhaeuser more than 15 years ago. The first was the continued lag effect associated with higher grass and non-native forb cover. While this understory vegetation is expected to disappear as canopy closure progresses, the higher grass competition has likely been detrimental to tree development and ingress of other trees over time, ultimately limiting canopy closure. This has likely been a significant contributing cause to the poorer tree development outcomes associated with sites in the dry and central mixedwood natural subregions. The second challenge, which is indirectly related to the first, was the generally high rates of tree seedling mortality of planted species across all natural subregions, though arguably most intense at low elevations.

The original legacy wellsite restoration program implemented a 3-part strategy of deep ripping in winter, followed by spring application of glyphosate and finally planting ~2,500 stems ha<sup>-1</sup> of conifers, either lodgepole pine or white spruce. Despite this rather aggressive strategy, the challenges described above remained, which suggests the biggest 'learn' here has been that we cannot overestimate the competitive potential and long-term legacy impacts these historical practices have had (i.e. seeding agronomic forbs and grasses) and continue to exert on these sites. While current regulatory guidelines strongly discourage use of any grass seeding whatsoever, we know anecdotally that this practice is still being employed, albeit largely with native grass species. Given how difficult it appears to be to reset these sites, additional policy to more strongly inhibit grass utilization in forested regions of the province may be warranted.

Moving forward, for forestry companies and other organizations interested in conducting similar programs in the future (resetting grass-dominated industrial sites towards a forested state), this study has illustrated that aggressive strategies are likely to be needed with additional consideration for incorporation of other practices (which are discussed in Section I). This all comes at a significant cost; therefore, efficiencies that can be found will be highly valuable in maximizing efforts. The single greatest efficiency may be in the incorporation of these types of programs into harvest plan sequences thereby allowing for landscape-scale resets to occur concurrently and also allowing for more cost-effective access to the equipment required to de-compact these sites, something that was shown to be of benefit in the present investigation.

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## G. OUTCOMES AND IMPACTS

**Project outcomes and impacts:** The knowledge gained from this project stresses the importance of mechanical site treatment as a strategy to enhance tree growth on severely disturbed sites. It also highlights the importance of increasing the planting densities of trees and potentially other species at these sites, given the high rates of mortality estimated. The outcomes of this project have also provided correlative evidence that the continued abundance of grasses will be counterproductive to forest growth.

**Clean resources (at application, now Agriculture and Environment) metrics:** We exceeded the sector HQP training metric in terms of the number of students that participated on the project as a total of 18 were participants (compared with 9 planned). Note that these students also worked on other projects as this particular study was focused on measurements during the summer months (July-early September) to best capture vegetation community data.

**Program specific metrics:** We identified several project success metrics at the onset of this study including:

- Field assessment of 100 sites in the Weyerhaeuser's Forest restoration program. *We largely met this target with 85 sites surveyed.*
- Identification and field assessments completed in harvest blocks (reference conditions) where we had aimed to assess approximately 40 blocks. *We achieved surveys on 38 sites – which meets this target reasonably.*
- Completion of technical reports to Weyerhaeuser. *We completed this target with submission of all requested reports to our industry partner (one interim and one final).*
- Presentation of findings at a conference or workshop (2 anticipated). *We exceeded this target through presenting aspects of this work at 2 conferences and a webinar/in-person event (<https://youtu.be/3VvTymDBNew?feature=shared>).*
- Engagement with Indigenous stakeholders and knowledge exchange on legacy restoration. *We did not fully meet this target though we were able to produce a virtual field tour, that we hope will be shared in future engagement events. We also provided two detailed technical updates to a wide audience at Weyerhaeuser to further knowledge exchange within the organization more broadly.*
- Engagement with Alberta Environment and Parks and Alberta Agriculture and Forestry through discussions of findings. *We met this target. Specifically, we utilized findings from this work to inform and support related work that EPA is leading to re-evaluate reclamation criteria. The harvest block data collected in the present investigation was used in demonstrating the potential value of harvest block as reference conditions for the EPA study.*
- Preparation of knowledge translation products (2 anticipated). *We have partially met this target and will fully meet it in the coming months. We have prepared one scientific paper (it is in draft stage) and have a second paper that we are working on that expands aspects of this core work. We are also working*

*on a technical note that more broadly speaks to the challenges/opportunities of legacy wellsite reclamation based on the learnings from this*

**Project outputs:** We have included in the attachments presentations given at (i) the Society for Ecological Restoration Conference (October 2024) in Vancouver and (ii) at the Canadian Land Reclamation Association conference in Edmonton (March 2025). In addition, the link below provides access to a webinar/in-person presentation given at the University of Alberta in their lecture series: <https://youtu.be/3VvTymDBNew?feature=shared>

Note that some of these presentations incorporated multiple research trial works together in the broader topic of legacy wellsite reclamation to increase the breadth of the topic.

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## H. BENEFITS

**Economic benefits:** This study partially supported 9 research staff and 18 term student research assistant positions over the last 2.5 years. Results from this study provided quantitative evidence regarding restoring aspects of forest function to legacy industrial sites in relation to the effectiveness of site preparation and seedling planting. Indirectly, this will benefit Albertan environmental consulting, construction, tree planting, and nursery industries if these treatments are applied more broadly through northern Alberta in the future. Legacy restoration activities are anticipated to require expertise across several economic sectors, including earthworks operators (heavy equipment necessary to treat the site/soils), nurseries to grow seedlings, and commercial planting operations to plant seedlings given the importance that both mechanical site treatment and future planting programs will be in these efforts.

This project contributed to Goal 2 of the Alberta Technology and Innovation Strategy (ATIS) by de-risking the significant economic investment being made by Weyerhaeuser and enabling broader dissemination of research outcomes. Indirectly, project results will benefit forestry companies by increasing their legacy restoration efficiencies as we have identified treatments that were effective (mechanical decompaction) and also identified that herbicide use was ineffective as it did not appear to hinder longer-term development of non-native forbs or grasses. Turning land deletions to productive forests within company FMAs will also incrementally support maintenance of annual allowable cuts (AAC), which is governed indirectly by the quantity of land base in productive forest. Opportunities to bring productive land base back into an FMA can act to counterbalance continual removals (industrial developments) of FMA land.

**Environmental benefits:** In total, over 338,000 ha of the Canadian boreal forest zone is directly disturbed by mines, oil, and gas infrastructure, and wellsites, exclusive of nearly 353,000 km of seismic exploration. While this project was focused on knowledge-building around legacy restoration of previously-certified industrial wellsites, there is also an opportunity for this information to be directly translated to the legacy restoration of other industrial footprints (seismic lines, roads, borrow pits, sumps, coal mines, sand and gravel pits) and to actively reclaiming sites still held by industrial operators. Alberta contains approximately 14,598 abandoned wells, 252,410 other wells of all types, and 241,144 ha of pipeline disturbance. In addition, there are approximately 10,000 inactive wells in BC and 24,000 in Saskatchewan. In the coming decades, there are also several thousand more hectares of land scheduled to be reclaimed to forest on coal mines, and thousands of underperforming legacy sites in the boreal forest (not captured in the number above). This project identified and reinforced the importance of certain practices (mechanical decompaction) and also highlighted the detrimental impacts of other practices (grass seeding) that can be observed for long periods on these sites. We hope that future practitioners will see these distinctions in practices and focus efforts towards ensuring detrimental practices are not carried into the future.

**Social:** The variety of publicly available research extension products that we have developed or are in the process of developing will aid in broadening the potential uptake of this information to a wider audience, not just practitioners but the public more generally. Particularly the 360 virtual field tours provide an

accessible mechanism to illustrate the breadth of outcomes associated with legacy wellsite reclamation. We hope that these products will aid in future social engagement with key stakeholders (Indigenous communities, landowners, and the public) within Weyerhaeuser's FMA through annual public presentations and Indigenous consultation meetings. Feedback from these engagements may potentially influence the terms and conditions under which Weyerhaeuser may consider future legacy restoration efforts and incorporate other forest values into these restoration efforts.

**Building innovation capacity:** This project contributed to Goal 1 of the ATIS by increasing the depth of Alberta's innovation talent pool. In total 18 students participated on this project between summer 2022 and project completion. Most were involved as field research assistants, conducting measurements in the field, developing skills in plant identification, field safety, mapping, and cooperation with team members. Three of those students participated in other aspects of the project, in addition to the field measurements program broadening skill sets in data entry, quality control and data checking, assisting with technical reporting, improving GIS skills through extensive mapping and querying/compiling shapefile layers with two of those students also building the 360-video field tour. Of the 18 students that participated on this project, we know of 6 students that have since secured positions with various environmental consulting firms, government agencies and non-profit organizations. In addition, 2 students have since joined our Centre as salaried staff. Three others are in or entering a graduate school program and 5 are still enrolled in undergraduate programs. In addition, this project also provided financial support (partial) to 9 research staff. Of note, two of those staff have since departed our institution to start a graduate program (doctorate) and to take a permanent role with a provincial government agency. The rest of the staff still work at our Centre, applying the skills and knowledge gained in this work towards other studies.

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## I. RECOMMENDATIONS AND NEXT STEPS

The recommendations and next steps we have described focus on recommendations in applying legacy wellsite reclamation, given what we know from the current project as well as next steps in furthering our understanding of limiting factors to the success of these efforts through additional study.

Given the demonstrated benefits of re-treatment in improving forest development in Weyerhaeuser's Grande Prairie FMA, regulatory and industry frameworks should encourage proactive re-treatment strategies. Forestry companies have an opportunity to integrate re-treatment of legacy sites into harvesting practices, as they often work around and through these sites. This is especially relevant in regions where forest vegetation recovery has been slow. To maximize the effectiveness of re-treatment, efforts should be prioritized based on site-specific risk factors and regional management goals. Recommendations for industry when applying legacy wellsite reclamation:

- Intensive mechanical site preparation is a necessary first step, ideally completed in later summer through winter to allow for some freeze-thaw action to facilitate better spring planting. In the present investigation a McNabb RipPlow™ was utilized attached to a D8, pulling a single plow due to deep frost. This treatment could continue to be utilized as it was certainly beneficial, although rough and loose mounding using an excavator may offer an alternative strategy that is known to be more effective at burying grass sod. In separate, ongoing trial work, our team has seen a doubling in height growth after 4 years using this type of mounding compared with no-treatment.
- Prompt spring planting (unless using a post-emergent herbicide). Spring offers the best window to get trees established ahead of competing vegetation, which is often intensive due to a variety of non-native forbs that exist in the seedbank of these sites.
- These sites are difficult – mortality rates are high, therefore much higher tree establishment densities are required than most practitioners would normally consider in post-harvest sites. We would recommend upwards of 4,000 stems ha<sup>-1</sup> of trees. Increasing the number of trees that survive will have long-term benefits on stand volume, this is particularly relevant for the low elevation sites which appear most at risk. The opportunity for natural recruitment is highly variable, therefore planting offers the most consistent approach to ensuring sufficient trees are established. This is especially relevant in low elevation sites where grass competition appears to be elevated and associated with poor tree development.
- Multi-species tree planting should be utilized to manage risk of plantation failure associated with any single species. Consider combining a conifer with a hardwood such as balsam poplar, in some cases paper birch may be suitable.
- Consider planting desirable shrub species – again this is about controlling what establishes to push the site to a less graminoid dominated site, early on. Planting shrubs may be more important in the higher-risk, low elevation site types but certainly all sites would benefit from a diversity viewpoint. Shrub species such as green alder (on coarse textured sites), buffaloberry or red-osier dogwood all have demonstrated capacity for growth on these site types. Willow species are also good candidates though actively planting these may need to consider other site objectives.

Additional treatments that could be considered following additional comparative study to better understand their efficacy:

- Utilization of Imazapyr to maintain longer grass control. This treatment should be completed in summer after mechanical site treatment as it will then do the dual function of reducing grass competition as well as the initial wave of non-native forbs that arise after soil disturbance on these types of sites. We have not observed this treatment on many industrial sites though the ones that have had heavy grass crops were effectively controlled for 2-3 years, allowing for the natural regeneration of native shrubs and forbs.
- Planting larger cavity container stock may help conifer establishment and reduce mortality rates though there is presently no comparative data available for wellsites. Ongoing research on post-harvest sites in the Weyerhaeuser FMA may provide better guidance on the relative success and best-use case for a treatment such as this.
- Planting native forbs as a long-term control strategy for grasses – no mechanical or herbicide treatment strategy will keep the grasses controlled forever, therefore displacement with alternative species may offer another tool for long-term management. However, this is also an active area of research and there are currently few examples to draw on.

Future partnership opportunities and discussions are ongoing. In recent conversation with Weyerhaeuser, they had identified a need to repeat this assessment in their Pembina operations to understand the relative success of re-treatment of legacy wellsites in that region of the province. In addition, they are interested in further exploring other experiments to further knowledge and continue the improvement of practices, given the varied responses observed and low establishment rates of planted conifers.

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## J. KNOWLEDGE DISSEMINATION

**Conferences / Technical sessions:** In addition to the 2 conferences and webinar/in-person event described in section G, we also provided a comprehensive technical update presentation to Weyerhaeuser on two occasions (in person in April 2025 at their office and a briefer discussion with the project team in June 2025) to ensure a broad cross-section of their staff had received knowledge about the project and relevant outcomes.

**360 virtual tours:** we have compiled a virtual tour of a small selection of wellsites that were retreated as well as untreated sites that reflected the likely starting condition of the retreated sites (grassy). We are hoping to have this tour publicly available on our website in an embedded provincial map so that interested practitioners and the broader public can view these sites even if they are unable to visit them in person.

**Scientific publication:** we have a draft scientific publication prepared that we are currently editing. We hope to have it submitted to a peer-reviewed journal by end of the summer. In parallel with this publication, we are also drafting a second manuscript that utilizes the data from this project as well as other data collected to look more broadly at predictive modelling of reclamation ‘success’.

**Technical note development:** we are planning to prepare a technical note that broadly encompasses the key learnings from this work in conjunction with narrower-scoped research projects we have been conducting on legacy wellsite reclamation. There are common threads and themes from all of these trials that we believe can be brought together into an informative set of recommendations on how to approach these sites, given our current insights and information.

**Impact on the industry:** we believe that collectively the knowledge dissemination activities will positively influence future operational-scale programs, similar to the one that Weyerhaeuser undertook.

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## K. CONCLUSIONS

**Objective:** the core objective of this project was to provide a quantitative understanding of forest recovery following an operational scale restoration program and to extract patterns in ecological region, ecosite or other attributes that may be used to predict ‘success’ in future.

**Key components:** this project surveyed 85 previously treated certified-reclaimed industrial sites (WS) and 38 similarly-aged post-harvest sites (main harvest block [HB] and in-block roads [IBR]) located in the Weyerhaeuser Grande Prairie FMA. The wellsite retreatment program involved mechanical site preparation, pre-planting herbicide and summer planting either white spruce or lodgepole pine seedlings. Between 2022 and 2024, comprehensive vegetation data was collected and comparatively analyzed to understand if these re-treated sites were developing along a forest trajectory similar to that of other large-scale anthropogenic disturbances (post-harvest sites).

**Key results:** There continued to be an observable understory legacy associated with these industrial disturbances in the form of higher relative cover of both grasses and non-native forbs. While non-native forb cover was similar amongst all natural subregions, grass relative cover depended on the interaction between natural subregion and site type, with the highest values associated with the lowest elevation sites in WS, though this pattern was not observed for HB and IBR. From the viewpoint of planted tree survival, the restoration program was not entirely successful, though tree growth rates suggest that mechanical site preparation alleviated compaction constraints. Despite low rates of survival, natural ingress of conifers and hardwoods did supplement planted conifer mortality. At high elevations, this was sufficient as projected total tree volumes at age 100 were similar amongst HB-IBR-WS. However, at lower elevations, projected total tree volumes in WS were not expected to recover to similar estimates as the HB and IBR site types.

**Learnings:** Two key challenges were illustrated by examining the operational legacy wellsite restoration program initiated by Weyerhaeuser more than 15 years ago. The first was the continued lag effect associated with higher grass and non-native forb cover. While this understory vegetation is expected to disappear as canopy closure progresses, the higher grass competition has likely been detrimental to tree development and ingress of other trees over time, ultimately limiting canopy closure. This has likely been a significant contributing cause to the poorer tree development outcomes associated with sites in lower elevation regions. The second challenge, related to the first, was the generally high rates of tree seedling mortality of planted species across all natural subregions, though arguably most intensive at low elevations.

Despite an intensive re-treatment strategy of mechanical site preparation – herbicide – planting, these grass and non-native herbaceous vegetation challenges remained, which suggests the biggest ‘learn’ here has been that we cannot overestimate the competitive potential and long-term legacy impacts these historical practices have had (i.e. seeding agronomic forbs and grasses) and continue to exert on these sites.

Moving forward, for forestry companies and other organizations interested in conducting similar programs in the future (resetting grass-dominated industrial sites towards a forested state), this study has

illustrated that aggressive strategies are likely to be needed with additional consideration for incorporation of other practices.

**Outcomes and Benefits:** This project identified and reinforced the importance of certain practices (mechanical decompaction) and also highlighted the detrimental impacts of other practices (grass seeding) that can be observed for long periods on these sites. We hope that future practitioners (and regulators) will see these distinctions in practices and focus efforts towards ensuring detrimental practices are not carried into the future.

Despite lower tree survival, many of these re-treated sites were supporting incipient forest vegetation, something that was likely not the case prior to their treatment. Especially at higher elevations, with presumably lower levels of grass competition, there is even more reason to encourage and support proactive re-treatment strategies given the relative success of the operational sequence of events. At lower elevation sites, with higher quantities of grass competition, this project highlights that more intensive and comprehensive strategies may be required to more consistently establish forest vegetation. Forestry companies have an opportunity to integrate re-treatment of legacy sites into harvesting practices, as they often work around and through these sites. To maximize the effectiveness of re-treatment, efforts should be prioritized based on site-specific risk factors and regional management goals.

**Next Steps:** Complete knowledge extension products by submission of the scientific manuscript, post 360 virtual tour online and prepare a technical note; all of which are aimed at supporting uptake of this concept and knowledge share with the broader industry and public. Continue dialogue with the industrial partner regarding opportunities to assess operational programs in other FMAs and test new methods to support higher rates of planted seedling survival, a constraint identified in the present investigation.