DISCLAIMER:

Optimization of cost-effective and functionally effective vegetation management solutions for forest reclamation

Prepared for the Alberta Upstream Petroleum Research Fund (AUPRF)

And

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EXECUTIVE SUMMARY / ABSTRACT

The goal of this study was to evaluate the effect of different vegetation management solutions for forest reclamation. All tested treatments in this study share common overall objectives: (i) to overwhelm a reclamation site with desired herbaceous and woody species and (ii) to concurrently reduce vegetation cover of undesirable species. Five approaches were tested in different combinations:

1. **Planting woody species**: creating a forest cover with a higher density is expected to result in canopy cover decades sooner than low density cover. This approach acts by shading undesirable species, likely 5+ years after planting.
2. **Pre-emergent herbicide**: preventing establishment of agronomic species (clovers in particular) that grow from seed. This type of herbicide inhibits seedling establishment (targets radicle and cotyledon development). It is thought to be conducive to planting nursery stock within 1 day of application and should provide effective control in 18-24 months following application.
3. **Post-emergent herbicide**: aboveground killing of newly emerging vegetation and creation of growing space around target woody seedling to provide a less competitive first year of growth.
4. **Native forbs** (fireweed or goldenrod): aid in creating desirable vegetation cover to reduce dominance by undesirable species, likely to be more effective in the second and subsequent years.
5. **Seeding native grasses**: aid in creating desirable vegetation cover to reduce dominance by undesirable species, likely to be more effective in the second and subsequent years.

All treatments and treatment combinations have been deployed in the field. The key findings after the first growing season were: **(1) herbicide applications do not significantly impair growth and development of the deployed target species** and **(2) herbicide treatments were successful in decreasing undesirable herbaceous species cover**. With only a 3-month growing period from planting to survey (May to August), it was not expected to see the anticipated long-term treatment effects for the other approaches (such as woody and forb planting). These treatment combinations require 2-3 years to fully reach their expected potential. Therefore, it is strongly recommended to continue with annual vegetation surveys for the coming years to draw as much detailed information as possible from this experiment.

1.0 BACKGROUND

Site occupancy with native plant species is a key objective of reclamation and reforestation of industrial sites. However, noxious weeds and other undesirable vegetation (e.g. sweet clover (*Melilotus* sp.), alsike clover (*Trifolium hybridum*), creeping red fescue (*Festuca rubra*), timothy (*Phleum pretense*) and smooth brome (*Bromus inermis*) present challenges to the development of forest plant communities. In northern Alberta, management of aggressive agronomic species is a significant issue to forest development and certification of reclaimed well sites (Bressler, 2008). Regulatory criteria and legislation clearly define the need to control and eradicate noxious weed species (Weed Control Act, 2010; Environment and Sustainable Resource Development, 2013), as well as undesirable species (Environment and Sustainable Resource Development, 2013). Site preparation, cultural control (cover crop establishment) and chemical management represent a range of approaches to control or eradicate undesirable species.

The purpose of cover cropping is to occupy the site with desirable vegetation ahead of the influx of weed species and aggressive agronomic species; effectively, they provide a barrier to invasion of weedy species by occupying physical space (above and below - ground). Cover crops are typically broadcasted as seed either directly on the soil surface or hydro-seeded in a slurry. Most commercially available species are non-native, however, there are few commercially available native grasses that are appropriate for Alberta. Native herbaceous species such as fireweed, goldenrod (*Solidago canadensis*), asters (*Aster* sp.) and sedges (*Carex* sp.) are important components when re-vegetating industrial sites and have potential utility as cover crops in early reclamation. They may provide protection for planted woody species such as white spruce (*Picea glauca*) and low-bush cranberry (*Viburnum edule*) and allow for natural ingress of understory species that require protection. Presently, these native herbaceous species are not commercially available and wild collections must be undertaken by individual companies. Due to small seed size, the quantity of seed required (and effort to collect) is substantial. Planting nursery stock plants of native forbs, however, would negate this issue as very small volumes of seed are required. A nursery stock seedling also has potential to grow and spread at a much faster rate than a field sown plant which may take 2-3 years to attain a competitive size.

Increasing the density of desirable plant species is likely to increase performance and succession of those plant species, and decrease the generation of undesirable plants dominating reclaimed industrial sites in the early years following reclamation activities (Grime, 2007). Some studies have suggested that simply removing the invasive species is not a viable solution; in contrast, establishment of a competitive plant community will provide occupancy of the area thereby preventing invasion and preeminence of non-native species (Davis *et al.*, 2000; Masters & Sheley, 2001). In addition to utilization of cover crops, as described above, establishment of high densities of native woody species is another approach to managing undesirable species. However, the densities required (likely greater than 10,000 stems per hectare) are generally considered cost-prohibitive, though a reflection of the lifecycle cost when comparing it against multiple years of re-entry to spray or hand-pull noxious weeds may prove otherwise.

There are a wide array of herbicides available in the market, many of which have not been evaluated for use in a forest reclamation context. Conventional herbicide use in reclamation is often with herbicides that have limited residual impact. However, these herbicides often require repeated use to control a noxious weed population. Torpedo™ is a commercially available herbicide that is rated for industrial use and it is utilized to inhibit germination and establishment of all plant species. With appropriate timing, this herbicide may be valuable for forest reclamation as it generally inhibits germination of seeds (rather than plants originating from root stock). If rooted seedlings (woody and herbaceous) are established concurrently, this should allow the target forest plant community to gain a ‘head-start’ by occupying physical space ahead of undesirable plant species originating from seed.

Study objectives and project outcomes

The objective of this study was to examine the ability of combinations of native plant cultural controls (cover crop) and herbicide-based approaches to reduce and eliminate undesirable plant ingress. In this study, we evaluated those approaches that are appropriate for use in the early stages of revegetation development following soil reclamation. Each of these approaches was initiated in the first year following reclamation with plans to monitor the study for three growing seasons. At the completion of the study, we will answer the following questions:

1. Which approaches are most effective at reducing initial establishment of undesirable species?
2. By controlling ingress of undesirable plants, are there also differences in native plant establishment through natural ingress?
3. Is there a tradeoff in growth and productivity of desirable native woody species when utilizing a treatment that is aimed at reducing undesirable plant development?
4. What is the potential return on investment of the vegetation management approaches considering relative benefit/success at managing undesirable species?

As this report comprises results of the first growing season, the questions posed above will be discussed in context of first year trends, though recognizing additional monitoring (2018 and 2019) will be required to fully address the questions.

2.0 METHODOLOGY AND DATA

Experimental design

The study was located on a recently reclaimed borrow pit (site work completed August 2016) and was adjacent to a busy oilfield road and other high-traffic facilities (three multi-well pads). This area posed a significant weed-management problem due to its proximity to these operations, therefore, it was also an ideal location to examine undesirable vegetation management options.

Fourteen vegetation management treatment combinations including two untreated control groups were established in May-June 2017 (Table 1). The purpose for including two untreated control groups was to better capture the natural range in variability expected from the natural ingress of native woody and herbaceous vegetation. For each treatment, five 10×10 m treatment plots were established and grouped into five replicate blocks (Figure 1). The following vegetation management treatments were tested independently or in combination:

- Two woody densities (3,500 and 10,000 stems ha^{-1}; Table 1, 2). The woody species included three tree species (balsam poplar (*Populus balsamifera*), aspen (*Populus tremuloides*) and white spruce (*Picea glauca*)) and two shrub species (green alder (*Alnus viridis*) and bebb’s willow (*Salix bebbiana*).

- Native forbs, fireweed (*Chamerion angustifolium*) or goldenrod (*Solidago canadensis*), planted as nursery stock seedlings (5,000 plants ha^{-1}).
- Utilization of an (i) emergent herbicide (Torpedo™, at 580 and 1160 g ha^{-1} application rates) applied prior to planting or (ii) conventional herbicide which will target spot application around woody species (to create growing space) and spot application of noxious weeds (where needed). The conventional herbicide utilized was Clearview™ and was applied at a rate of 230 g ha^{-1}.
- Seeding native grass, awned wheatgrass (*Agropyron trachycaulum* var. *unilaterale*, 8 kg ha^{-1}).

Grass seeding and pre-emergent herbicide treatments were applied in the second week of May 2017. Woody species planting (dormant nursery stock produced in 2016), forb planting (produced in a nursery and hot-planted), and emergent herbicide application occurred in mid-June 2017.

Measurements

Vegetation assessments were conducted in early August of 2017, capturing the growth and development of planted species as well as ingress of native and non-native species. Four vegetation surveys points, with plot centers located 3.78 m inside from each of the four plot corners, were carried out within each 10 x 10 m treatment plot. At each survey point the following was assessed: (i) within a 1.78 m radius circular plot the count of individual woody species and height of the tallest woody plant (for each species) and (ii) three 0.5 x 0.5 m quadrats were randomly thrown within each circular plot and the percentage cover (by species) of vegetation determined visually.

In September 2017, small-diameter (2.5 cm) soil cores were taken at the center of each of the four 0.5 x 0.5 m vegetation survey points noted above and at a single depth (0-15 cm). These cores were taken for a subset of vegetation management treatments (Treatments 1-5, Table 1). Soil cores were placed in plastic bags and stored frozen (-4˚C) until subsequent processing. Roots were manually separated from the soil utilizing soil sieves and water. Roots will be dried in an oven at 70˚C until weight constancy and dry biomass weighed to the nearest 0.0001 grams. Processing of the soil cores is still in-progress and therefore will not be presented in this report.

Statistics

All statistical analyses and graphing were carried out in the R Language for Statistical Computing (R Core Team, 2017). Graphics were compiled utilizing the ggplot2 package (Wickham, 2016). Depending on the outcome variable, i.e. continuous and percentages, linear-mixed effect models or beta regression was performed, using the R packages lme4 (Bates et al., 2015) and betareg (Cribari-Neto & Zeileis, 2010), respectively. When significant results were found ($P < 0.05$), Tukey adjusted multiple mean comparisons were performed to identify whether treatment groups differed from the control treatments. The posthoc analysis and the calculation of least squares means was completed using the lsmeans package (Lenth, 2016).

3.0 RESULTS AND DISCUSSION

First and foremost, all planned treatments and treatment combinations were successfully applied as illustrated in Figures 2-4. The sampled woody densities roughly matched the planned species deployment numbers outlined in Table 2 (Figure 2). All treatments, including the herbicide treatments, did not appear to impact woody densities in 2017, which suggests that all woody species appear to tolerate the initial herbicide treatments. Except for a single balsam poplar seedling, both control treatments (13 and 14, see Table 1) showed no evidence of natural ingress of woody species (Figure 2). The remainder of the discussion will focus on addressing the questions posed at the beginning of this document:

Q1. Which approaches are most effective at reducing initial establishment of undesirable species?

Total vegetation cover was largely driven by non-native forbs (Figure 3). Although not statistically different from treatment #1, there was a clear and consistent decline in non-native forb cover for both pre- and post-emergent herbicide treatments (treatments #2-5, Figure 3) and this was visually apparent at the time of measurements in August (Appendix A8.4-8.5). For these treatments, there was a corresponding increase in non-native grass cover though the absolute cover was still very low at 1-3% (Figure 3). No other vegetation management treatment combination showed a meaningful reduction in non-native vegetation cover during the first growing season (Figure 3).

Q2. By controlling ingress of undesirable plants, are there also differences in native plant establishment through natural ingress?

Native forb cover was low (1-4%) across all vegetation management treatments and untreated control (treatments #13/14, Figure 3). Treatments that included application of herbicides and/or native grasses tended to have lower cover than Treatments #1 and #10 though continued monitoring will determine if this is a consistent trend or simply random noise (Figure 3).

Q3. Is there a tradeoff in growth and productivity of desirable native woody species when utilizing a treatment that is aimed at reducing undesirable plant development?

There was some concern that utilizing a pre- or post-emergent herbicide could compromise early growth of planted woody species. However, there was no statistical difference in terms of density or total height for any of the woody species planted into treatments #2-5 compared with treatment #1 with the exception of increased total height in balsam poplar in treatment #3 (Figure 2, 4). For post-emergent herbicides (treatments #4-5), there were some visual signs of herbicide damage (Appendix A8.4) that may have impact on future growth. There was no visual sign of herbicide damage for seedlings planted into pre-emergent herbicide treatments (Appendix A8.5).

Vegetation management treatments that reduce competition of non-native forbs (and possibly grasses) are expected to be of benefit to these seedlings in subsequent growing seasons and future monitoring will confirm or refute this expectation as well as further validate if some of the early indications of growth improvements become more widespread in other species.

Q4. What is the potential return on investment of the vegetation management approaches considering relative benefit/success at managing undesirable species?

We cannot address this question at this point in time given that many of the vegetation management treatments are not expected to show meaningful 'effectiveness' until at least the second growing season. However, Table 3 does summarize the estimated actual costs (on a per hectare basis) of deploying each of the vegetation management treatments. This table does clearly show that the overwhelming cost of deploying the vegetation management treatments is in the purchase and planting of nursery stock seedlings. The cost of deploying grass seed and the initial herbicide applications were much smaller contributions.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results showed that after one growing season: (1) herbicide applications did not significantly impair growth and development of the deployed target species and (2) herbicide treatments were successful in decreasing undesirable herbaceous species cover. At this point in time, no other firm conclusions can be drawn, or recommendations provided as the other vegetation management treatments (seeding native grasses, planting native forbs and higher density woody planting) are anticipated to become more impactful in subsequent years. To reach more detailed conclusion regarding the tested primary and secondary vegetation management treatments and comparative benefits of each, follow-up monitoring in 2018 is strongly recommended.

5.0 APPLICATIONS

First-year results of this study show evidence that the tested post-emergent herbicide may have a negative impact on future growth as some signs of herbicide damage were noted on individual plants. This was not observed for the pre-emergent herbicide application. From an operational standpoint, it appears that choosing a pre-emergent herbicide in favor of a post-emergent herbicide may be beneficial for reforestation purposes. However, as mentioned in the previous section, follow-up monitoring in the coming years is needed to reach firm conclusions.

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6.0 LIST OF TABLES

Table 1. All vegetation treatment combinations tested in this study. The pre-emergent herbicide utilized was Torpedo™ with rate 1 = 580 g ha^{-1} and rate 2 = 1160 g ha^{-1}. The post-emergent herbicide utilized was Clearview™ at a rate of 230 g ha^{-1}.

Treatment ID	3500 stems ha^{-1} woody	10,000 stems ha^{-1} woody	Pre-emergent Herbicide rate 1	Pre-emergent Herbicide rate 2	Post-emergent herbicide	5,000 stems ha^{-1} goldenrod	5,000 stems ha^{-1} fireweed	8 kg ha^{-1} awned wheatgrass
1	x							
2	x		x			x		
3	x			x		x		
4	x				x			
5	x				x			x
6	x							x
7	x					x		
8	x						x	
9	x					x		x
10		x						
11		x				x		
12		x						x
13	control group - no treatment							
14	control group - no treatment							

Table 2. Deployment density listed by species for the baseline treatments of 3,500 and 10,000 stems ha^{-1} (see also treatments 1-9 and 10-12 in Table 1).

	Base density (stems ha^{-1})		**# plants per plot**	
Species	**3,500**	**10,000**	**3,500**	**10,000**
Green alder	500	1500	5	15
Paper birch	750	2000	8	20
White spruce	1000	3000	10	30
Poplar	750	2000	8	20
Willow	500	1500	5	15
Goldenrod / Fireweed	5000		50	50

Table 3. Estimated costs of deploying vegetation management treatments. Peripheral costs associated with travel to sites, accommodations, overhead expenses etc. are not considered in these calculations. Note that in treatments 2, 3, 7, 8, 9 and 11 native forbs were planted at 5,000 stems ha^{-1}, which increased the planting costs by $10,750 per hectare.

Treatment #	Seedling purchase ($0.90 plant^{-1})	Planting cost ($1.25 plant^{-1})	Seed purchase ($150 per 22 kg bag)	Hand broadcasting (# hours ha^{-1})	Herbicide supplies	Herbicide application (# hours ha^{-1})	Labor cost ($100 ha^{-1})	Total cost ($ ha^{-1})
1	$3,150	$4,375	$0	0.00	$0	0.00	$0	$7,525
2	$7,650	$10,625	$0	0.00	$500	3.00	$300	$19,078
3	$7,650	$10,625	$0	0.00	$500	3.00	$300	$19,078
4	$3,150	$4,375	$0	0.00	$500	6.00	$600	$8,631
5	$3,150	$4,375	$55	3.00	$500	6.00	$900	$8,989
6	$3,150	$4,375	$55	3.00	$0	0.00	$300	$7,883
7	$7,650	$10,625	$0	0.00	$0	0.00	$0	$18,275
8	$7,650	$10,625	$0	0.00	$0	0.00	$0	$18,275
9	$7,650	$10,625	$55	3.00	$0	0.00	$300	$18,633
10	$9,000	$12,500	$0	0.00	$0	0.00	$0	$21,500
11	$13,500	$18,750	$0	0.00	$0	0.00	$0	$32,250
12	$9,000	$12,500	$55	3.00	$0	0.00	$300	$21,858
13	$0	$0	$0	0.00	$0	0.00	$0	$0
14	$0	$0	$0	0.00	$0	0.00	$0	$0

7.0 LIST OF FIGURES

Figure 1. Overview of the experimental layout and design at the Conoco Phillips Borrow Pit 1 (North). The plots in shades of green are those associated with the present study, the other blocks are associated with a separate research trial (refer to the figure legend for additional details).

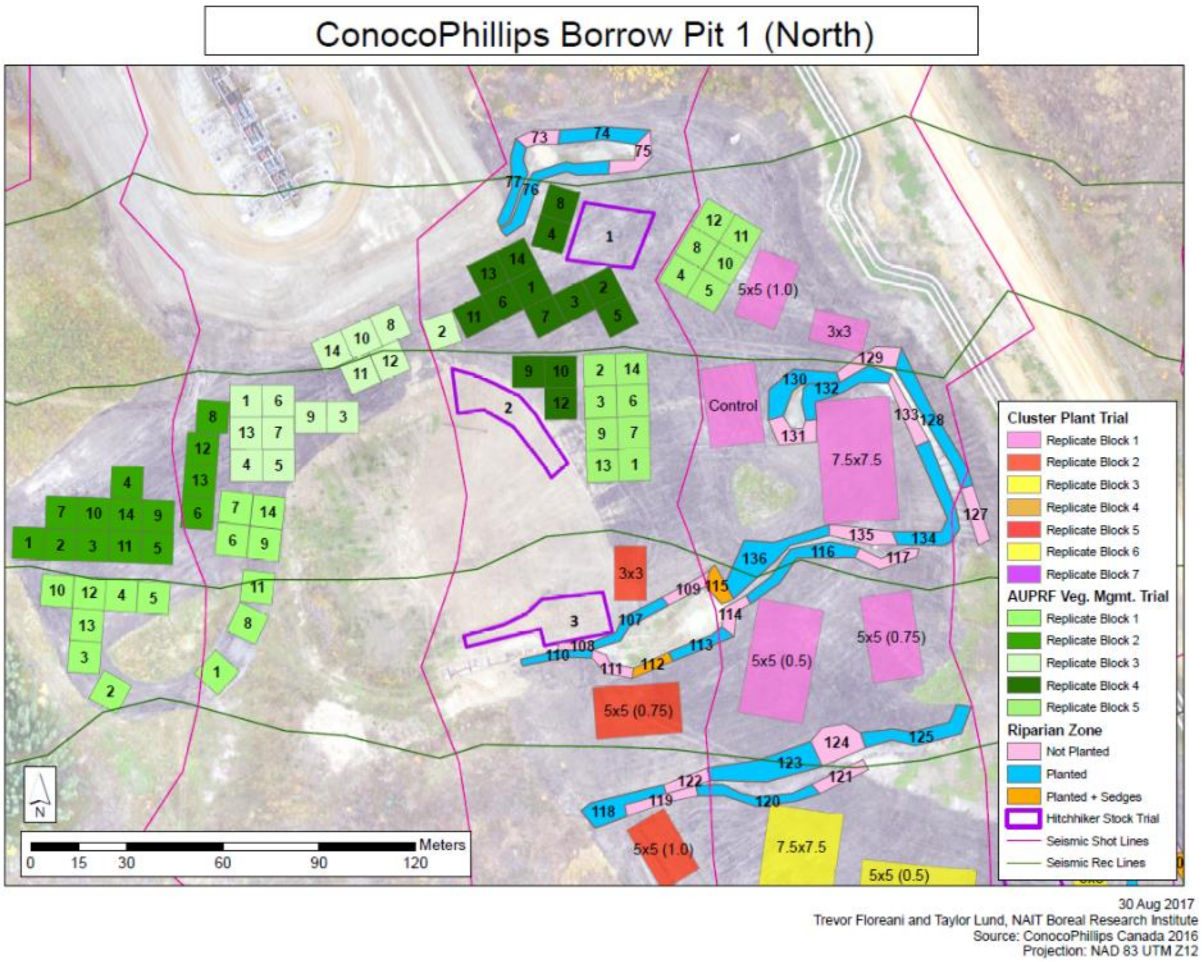


Figure 2. Least squares means of woody density (stems per hectare) for five planted species (green alder, paper birch, white spruce, balsam poplar, willow). Vegetation sub-treatments 1-14 are color-coded into broad categories but refer to Table 1 for full treatment combination detail. Standard errors represent the standard error of the mean (sample size = 5). Different lettering over bars indicates a statistical difference (p-value < 0.05) between treatment means.

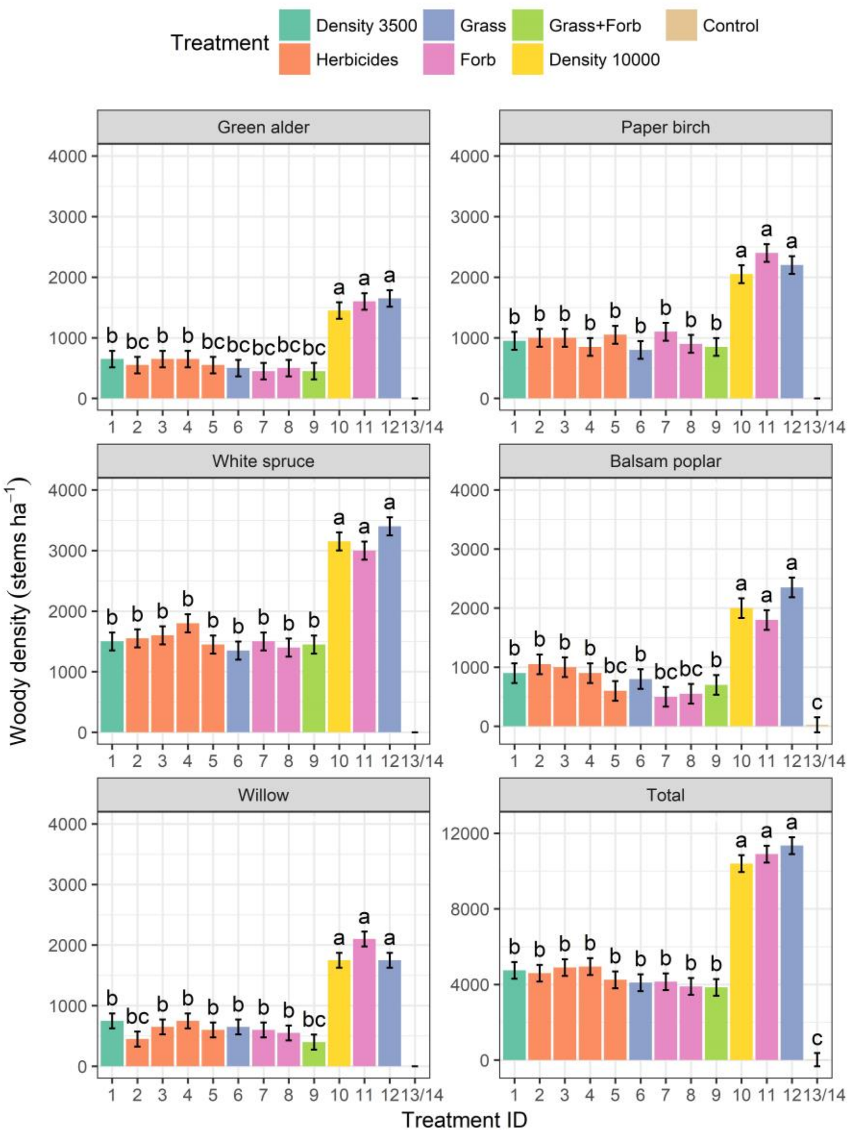


Figure 3. Least squares means of vegetation cover (% of ground area) for species groups including: native forbs, non-native forbs, native grasses, non-native grasses, woody species and total (all species combined). Vegetation sub-treatments 1-14 are color-coded into broad categories but refer to Table 1 for full treatment combination detail. Standard errors represent the standard error of the mean (sample size = 5). Different lettering over bars indicates a statistical difference (p-value < 0.05) between treatment means.

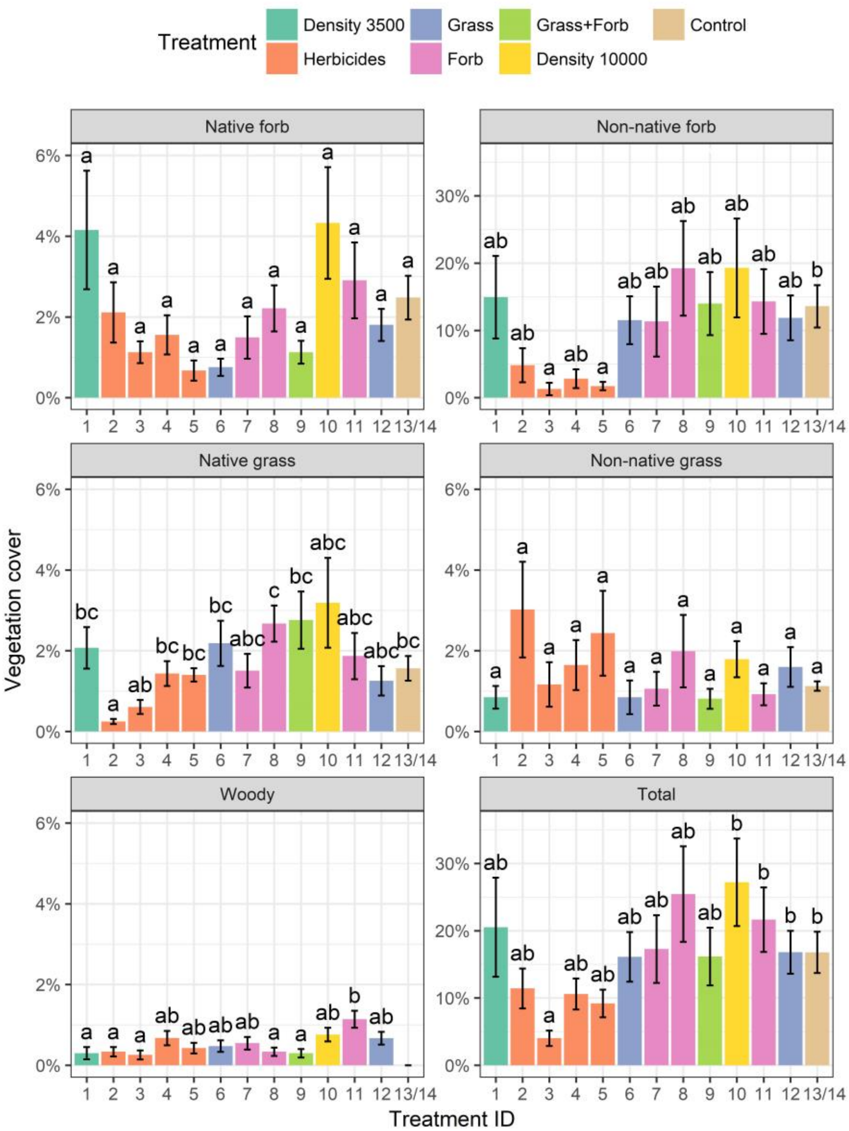
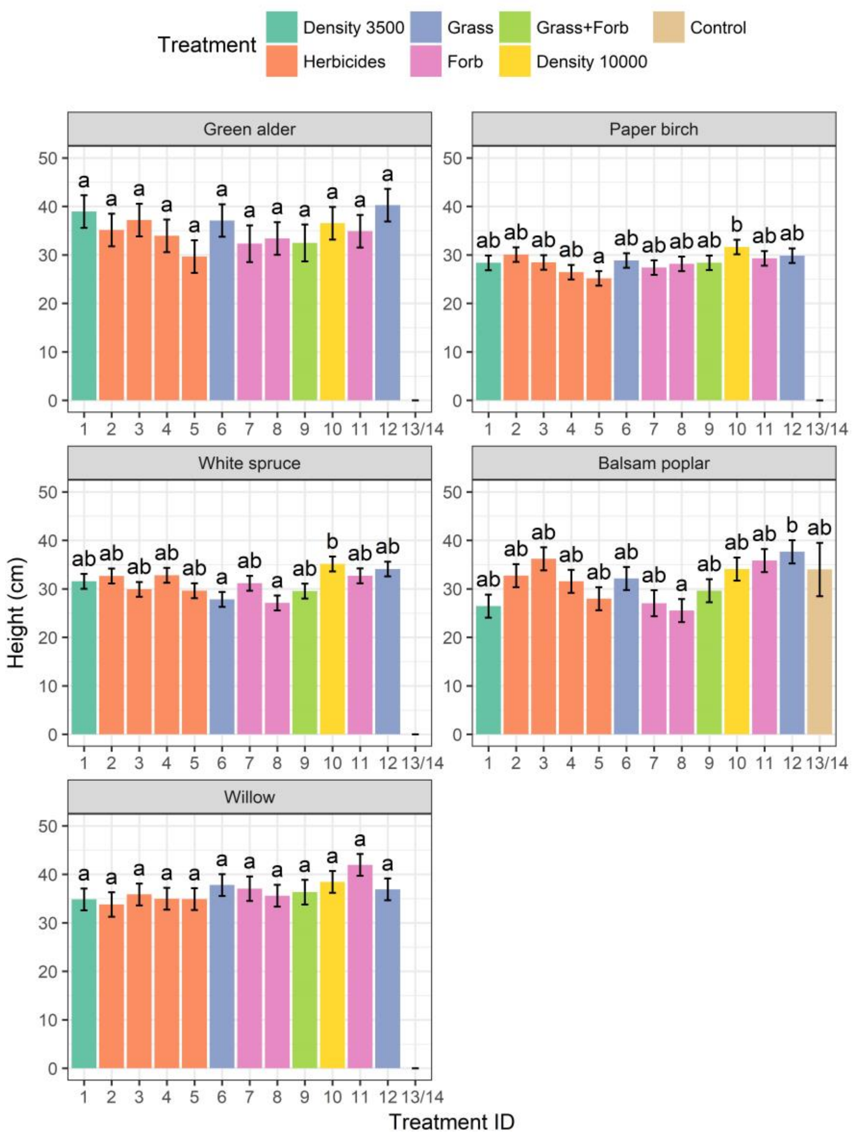


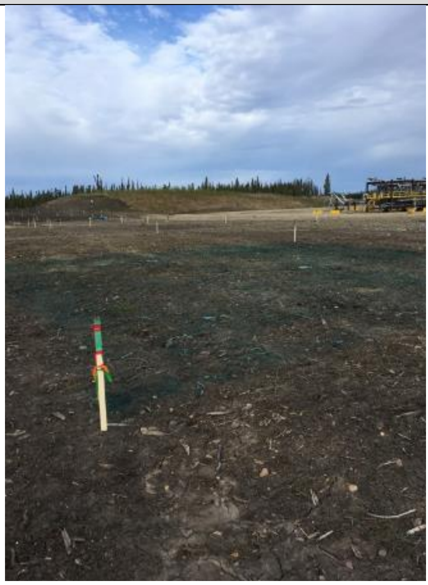
Figure 4. Least squares means of total plant height (cm) for five planted species (green alder, paper birch, white spruce, balsam poplar, willow). Vegetation sub-treatments 1-14 are color-coded into broad categories but refer to Table 1 for full treatment combination detail. Standard errors represent the standard error of the mean (sample size = 5). Different lettering over bars indicates a statistical difference (p-value < 0.05) between treatment means.



8.0 APPENDIX

Photos

A8.1. Field site photos and preliminary observations from May in contrast with August 2017: (a) Site was clear of vegetation, with only minor amounts of grasses and other species just starting to emerge. (b) Shows the same treatment plot with pre-emergent herbicide in September and (c) another view of study area from August where herbicide treated plots are visible in background.

(a)	(b)
	

(c)


A8.2. Field site photos and preliminary observations from mid-June 2017: (a) Recently sprayed with conventional herbicide. (b-c) close-up view of spray that was placed around individual seedlings (gaps of soil around blue areas).

(a)	(b)
	
(c)	
	

A8.3. Field site photos and preliminary observations from early August 2017 (at time of vegetation surveys): Treatment 1 in early August, showing (a) plot-view and close-up of individual species including (b) balsam poplar, (c) white spruce and (d) green alder.

(a)	**(b)**
	
(c)	**(d)**
	

A8.4. Field site photos and preliminary observations from early August 2017 (at time of vegetation surveys): (a-b) Visual effect of Clearview™ herbicide (treatments 4/5), showing good control of competing vegetation. Some visual damage to planted seedlings: (c) balsam poplar with curled leaves and (d) chlorotic white spruce.

(a)	**(b)**
	
(c)	**(d)**
	

A8.5. Field site photos and preliminary observations from early August 2017 (at time of vegetation surveys): Arrows in (a) and (b) pointing into plots (10 x 10 m) treated with pre-emergent herbicide (treatments 2 and 3). Examples of planted woody species (c) balsam poplar and (d) white spruce in Torpedo™ herbicide treatments.

(a)	(b)
	
(c)	**(d)**
	

A8.6. Field site photos and preliminary observations from June, August and September 2017: Planted goldenrod seedlings in (a) August and (b) September 2017. Fireweed seedlings (c) at the time of planting in June and in (d) early August 2017.

(a)	**(b)**
	
(c)	**(d)**
	

A8.7. Field site photos and preliminary observations from early August 2017: Comparison of herbicide treatments: (a) pre-emergent treatment #2, (b) pre-emergent treatment #3, (c) post-emergent treatment #4 and (d) control (treatment #1) within block 1 to visually demonstrate the relative differences between treatments.

(a)	(b)
	
(c)	**(d)**