Boreal tree and shrub development on stockpiled subsoil and topsoil

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Purpose of today's presentation

- This presentation will explore key results from an ongoing case study that was initiated in 2016 to demonstrate the potential for temporary reforestation on industrial soil stockpiles.
- The study site is located within an operating in-situ facility SE of Fort McMurray AB and is approximately 8 hectares in size. This presentation will examine survival and growth of five native tree and two shrub species that were planted on stockpiled topsoil and subsoil six years ago.
- In addition, we will present quantitative evidence of the potential for natural ingress of native trees and shrubs on these contrasting soil types.
- Lastly, we will provide a cost-analysis that reconciles the differences in survival amongst species and soil types against a key forest reclamation goal (i.e. growing desirable trees).

The temporary reforestation case study

- Located within an active in-situ oil sands operation (Surmont 2) SE of Fort McMurray AB.
- 8-hectare soil stockpile associated with the camp and plant facility.
- Construction of the soil stockpile began in 2010 and was completed by 2013 where conventional approaches were initially employed (track packed and seeded to grass).

Short-term goals: quantify planted and natural establishment of a range of woody species under a wide array of environmental conditions. Relate planting density to rates of forest cover development.

Long-term goals: demonstrate that a reforested stockpile will reduce requirements for ongoing weed management, increase plant and animal biodiversity and enhance final reclamation.

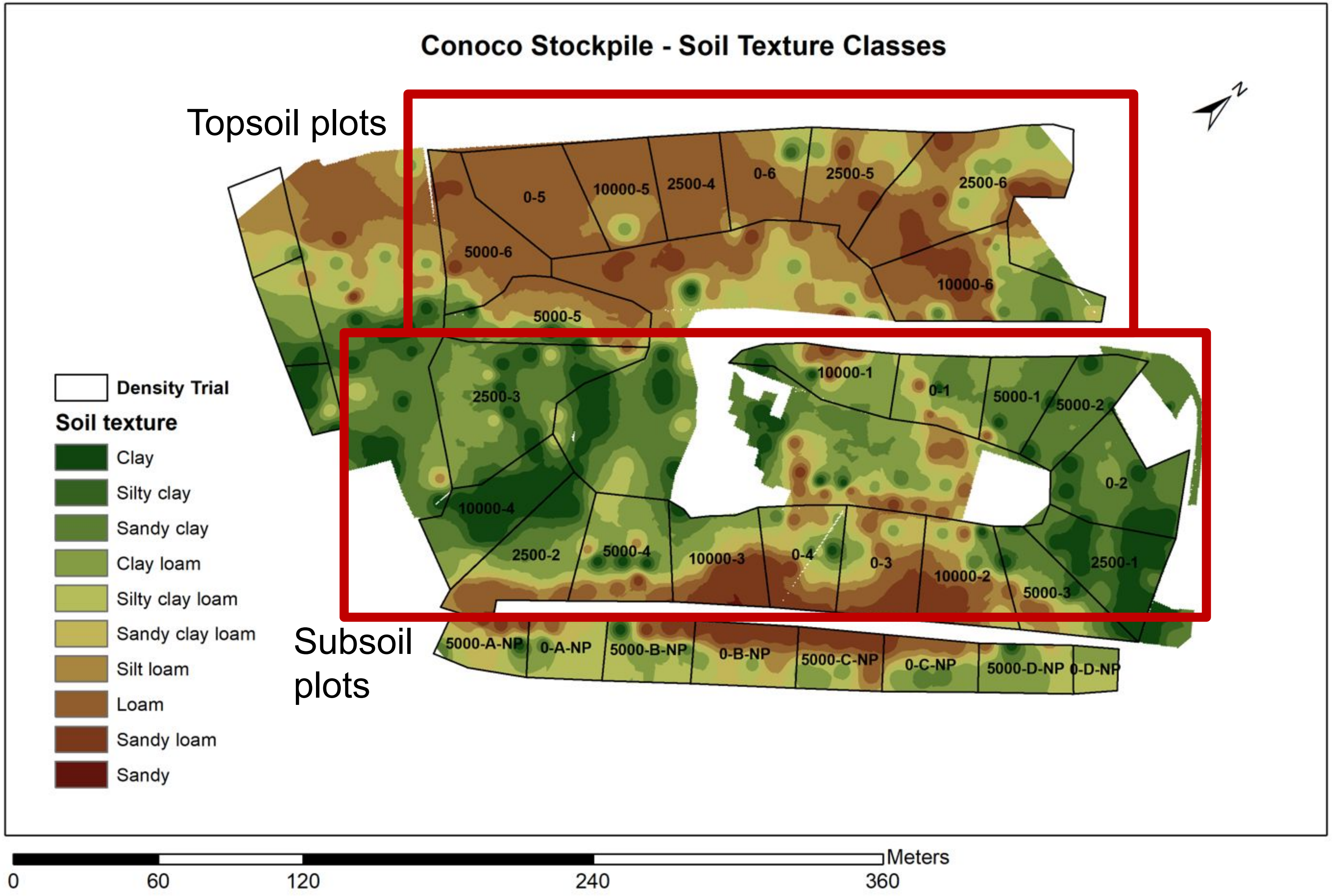
- For more information on the history of this project and core research goals refer to:
- https://www.ser.org/news/499780/Open-Access-Interim-Reforestation-of-Soil-Stockpiles.htm

Case study information – site preparation and planting

- The entire site was 'roughed-loosed' in October 2015 utilization a combination of furrowing (dozer) and mounding (excavator).
- Coarse woody materials were placed strategically across the study area in areas deemed highest risk for soil erosion.
- The primary experimental treatment being tested on this study site was to look at initial planting density: 0, 2500, 5000 or 10000 stems ha^{-1}.
- A mixture of native tree and shrubs were planted:
  - Trees: aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), balsam poplar (*Populus balsamifera*), jack pine (*Pinus banksiana*), white spruce (*Picea glauca*)
  - Shrubs: green alder (*Alnus viridis*), Bebb's willow (*Salix bebbiana*)
- More than 44,000 seedlings were established in a one-week period in June 2016.

Spatial mapping soil texture:

1. Topsoil was generally loamy in texture while the subsoil included much wider variety of textures from clay – sand and everything in-between.
2. Topsoil aspect ranged from N to W to S with predominantly westerly aspects. Subsoil covered a bigger array of aspect but more predominantly SW to SE.



Methods – survival and natural ingress estimation process

Measurements

- Stem counts were taken within 15 m x 15 m permanent sample plots.
  - 30 plots in subsoil and 18 plots in topsoil.

Planted tree/shrub survival

- The difference between observed stem count and predicted (based on planted stem densities) was utilized as an estimate of survival.
- When values exceeded 1 (this occurred when natural regeneration was observed) the value was reduced to 1 for the purposes of survival estimation.

Natural ingress

- Value exceeding 1 were utilized to estimate natural regeneration.

Statistics

- Probability of survival and presence/absence of natural regeneration were analyzed using a binomial model
- For natural ingress estimates where plants were observed, stem density was calculated using a linear model

Limitations of this approach

- May be under-estimation of natural recovery in situations where planted seedling survival was not high.

October 2013: Stockpile complete

October 2015: rough and loosing of soil

July 2017: 1.5 years post-planting

July 2019: 3.5 years post-planting

10,000 sph

July 2021: 6.5 years post-planting

Topsoil vs Subsoil

YEAR 3: 2018

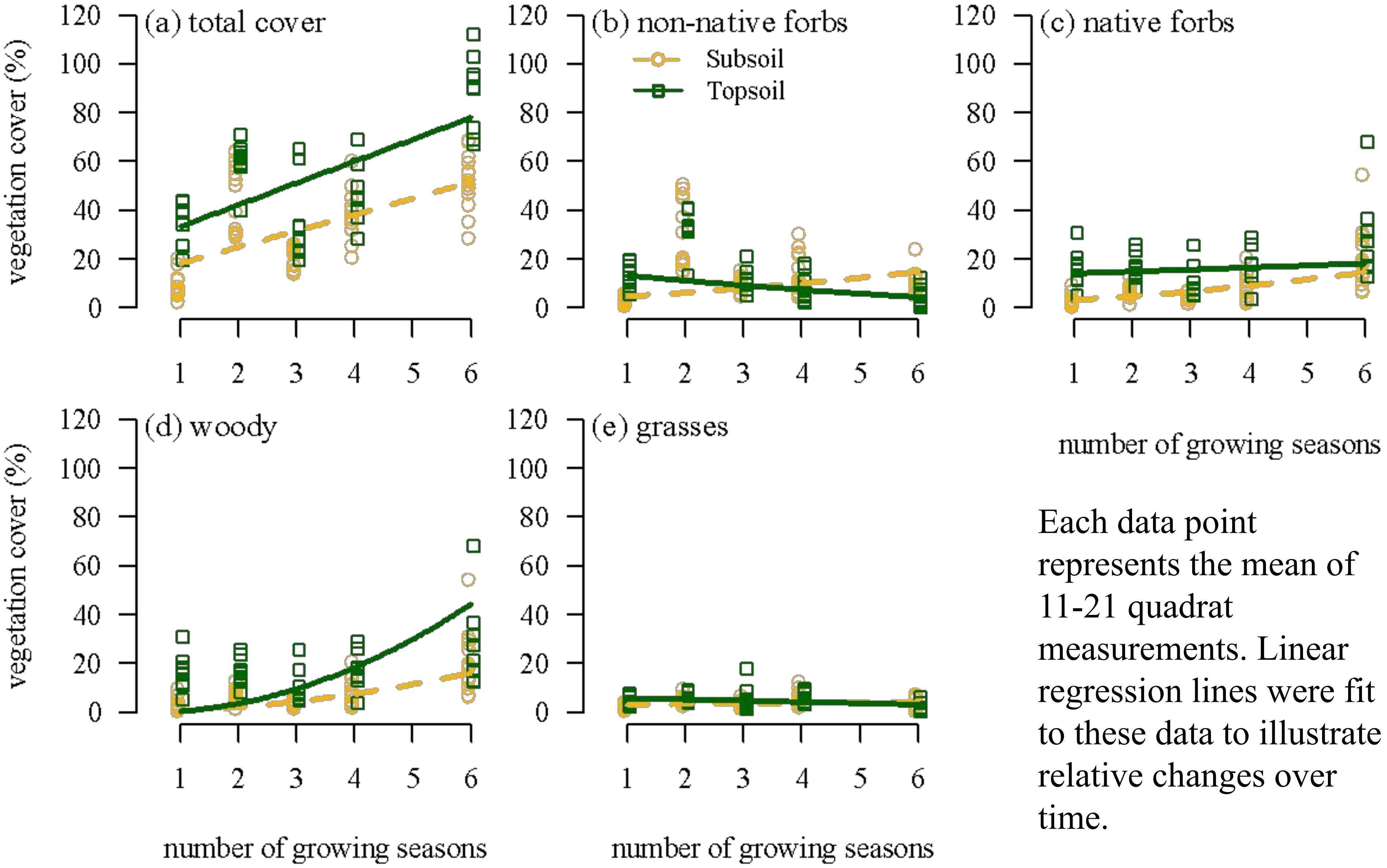
YEAR 6: 2021 at 10,000 stems ha^{-1} planting density

Topsoil vs Subsoil

Photo credit: Sofia Toledo

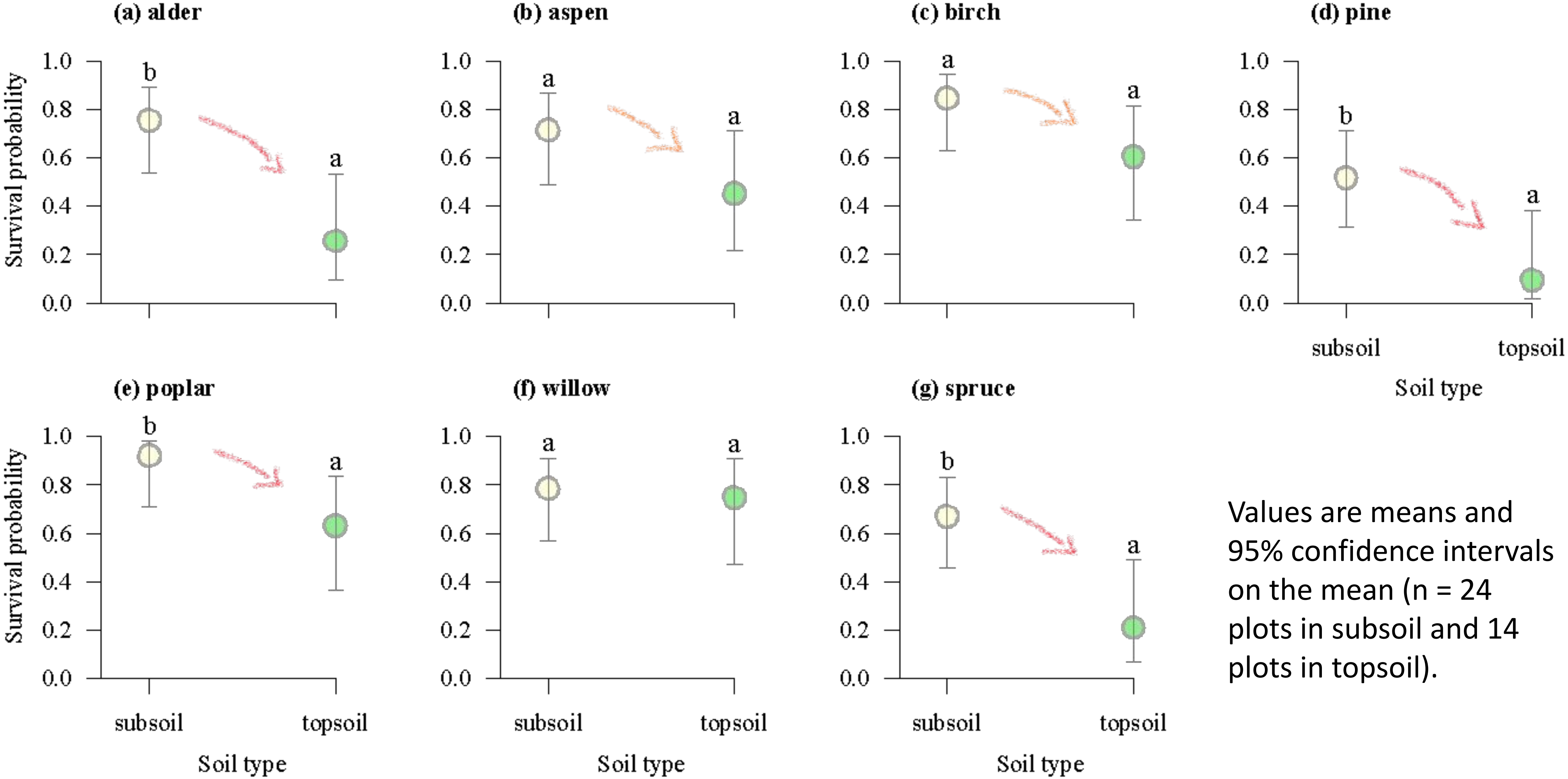
Vegetation cover over time

1. Total cover consistently higher on topsoil but is being driven by different vegetation groups over time.
2. Big spike in non-native forbs in year 2 driven by sweet clover

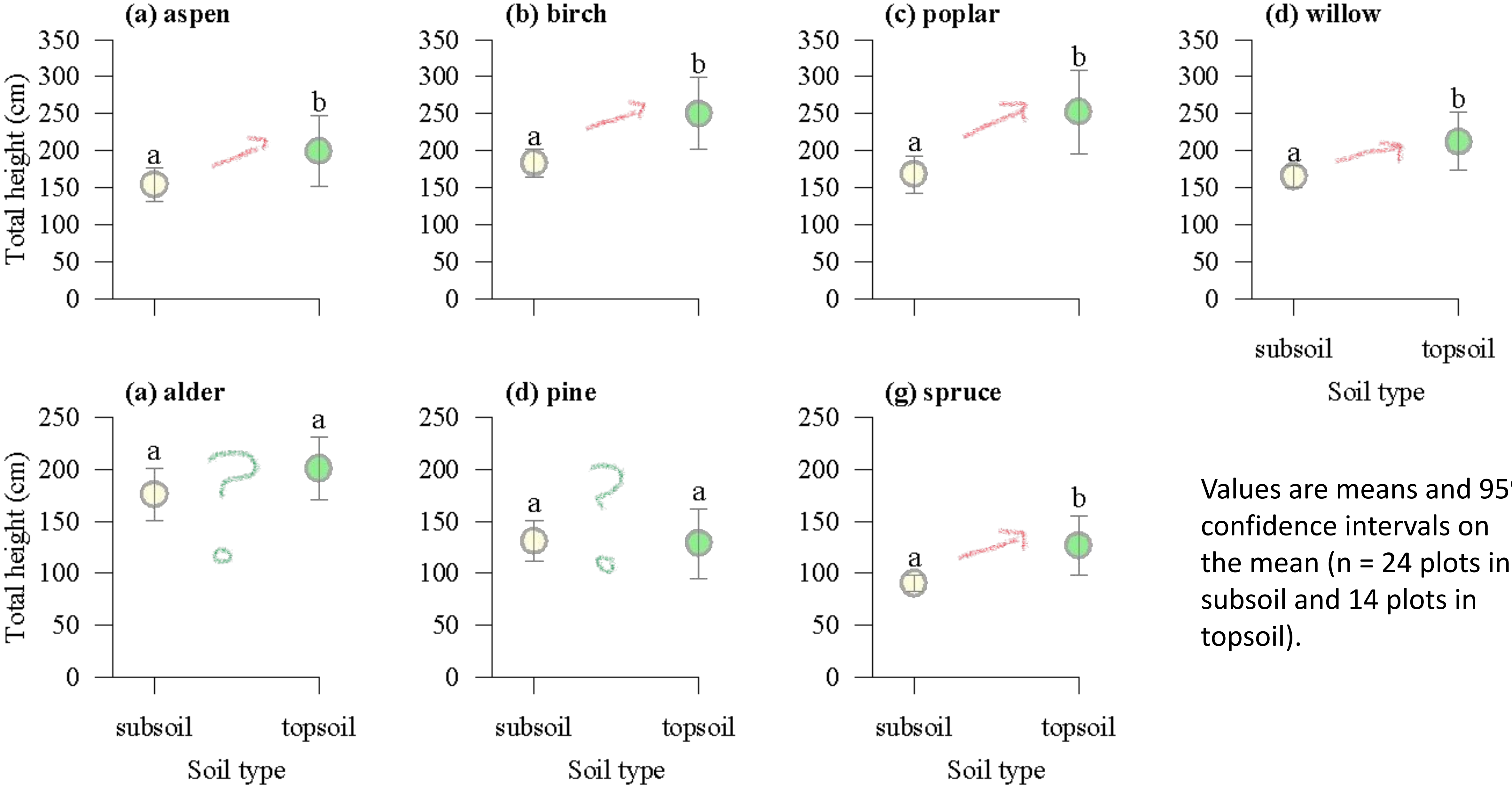


Each data point represents the mean of 11-21 quadrat measurements. Linear regression lines were fit to these data to illustrate relative changes over time.

Planted species: probability of survival over 6 years



Values are means and 95% confidence intervals on the mean (n = 24 plots in subsoil and 14 plots in topsoil).



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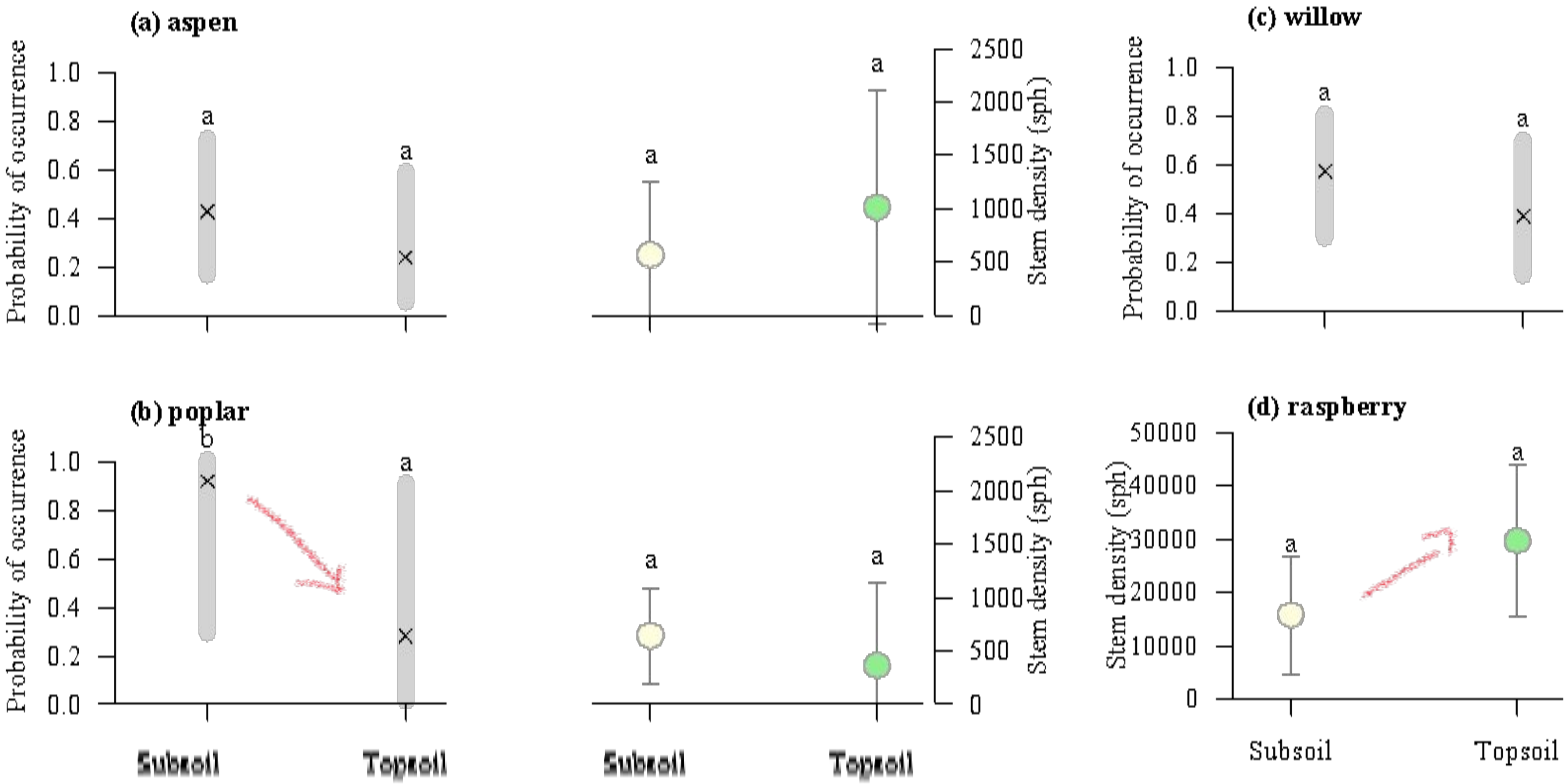
Relative survival and growth

- Amongst the species, survival was generally consistent, for example balsam poplar was #1 or #2 in both cases.
- Seedlings were taller in topsoil though there was a notable switch for top spot between paper birch and balsam poplar. May be a function of balsam poplar suckers lowering the mean height proportionally more in subsoil treatment?

Lowest	←		**Survival probability**		→	**Highest**
			subsoil			
pine 0.52	spruce 0.67	aspen 0.71	alder 0.76	willow 0.79	birch 0.84	poplar 0.92
			topsoil			
pine 0.09	spruce 0.21	alder 0.26	aspen 0.45	birch 0.60	poplar 0.63	willow 0.75
shortest	←		**Mean height**		→	**tallest**
			subsoil			
spruce 90	pine 131	aspen 154	willow 165	poplar 168	alder 176	birch 183
			topsoil			
spruce 127	pine 129	aspen 199	alder 201	willow 212	birch 250	poplar 252

Natural ingress



	Effective density (stems ha^{-1})	
	subsoil	topsoil
aspen	239	240
poplar	589	100
raspberry	15736	29711
willow	115	141

Values are means and 95% confidence intervals on the mean (n = 30 plots in subsoil and 18 plots in topsoil).

Nature always finds a way and our ‘control’s will not be controls for much longer

Cost considerations – illustrating the link between survival and cost of implementation

- This example illustrates the number of plants and relative cost to establish for the 7 species in the present study.
- This assumes a target density of 2,000 stems ha-1 per species and the cost per seedling to grow/plant at $2.00 per seedling for deciduous species and $1.50 per plant for conifers.
- Clearly, the cost per ha to establish seedlings on topsoil is relatively higher!

	# plants needed per ha		**cost per ha**	
	subsoil	topsoil	subsoil	topsoil
alder	2649	7813	$5,298.01	$15,625.00
aspen	2801	4435	$5,602.24	$8,869.18
birch	2370	3317	$4,739.34	$6,633.50
pine	3873	21368	$5,809.45	$32,051.28
poplar	2174	3170	$4,347.83	$6,339.14
willow	2548	2677	$5,095.54	$5,354.75
spruce	2985	9569	$4,477.61	$14,354.07

Lessons learned: planting nursery stock seedlings

- Jack pine and green alder (both pioneer species) appear to be particularly adept at surviving on subsoil, moreover, these species did not show an improvement in growth rate when planted into topsoil relative to subsoil. In addition, low survival rates for these two species in topsoil suggest they may not be good candidates in reclaimed areas where richer soil conditions might be expected; whether this is driven by a lack of tolerance for higher levels of competing vegetation or directly by the properties of the soil remain unclear.
- When developing planting prescriptions, consideration for soil quality should be incorporated on the front end. Study 1 illustrated that there are substantial differences in survival associated with topsoil versus subsoil and this is likely indirectly due to the level of competing herbaceous vegetation — though other factors related to physical or chemical differences in soil properties may also contribute. Balsam poplar, paper birch and pussy willow demonstrated the highest levels of survival (> 60%) of the seven species planted.
- Planting diverse mixtures of tree and shrub species on areas to be reclaimed is recommended. This study illustrated that even species expected to be relatively tolerant of competition (white spruce) can be at risk for high rates of mortality when extreme environmental factors occur (such as the winter desiccation observed in Study 1).

Lessons learned: natural recovery

- Natural recovery of woody species was more consistent in subsoil compared with topsoil — presumably this is due to differences in initial competing herbaceous vegetation, though this study did not specifically test this hypothesis.
- This suggests that developing surface soil treatments that create a more heterogenous range of surface conditions (exposed mineral soil coupled with patches of more organic rich topsoil), may better facilitate more consistent and dependable rates of natural recovery.
- For example, balsam poplar was extremely dependable in terms of occurrence in subsoil with a rate of 90%, though where it occurred, the mean density was only 640 stems ha^{-1}. Aspen, on the other hand, showed an average stem density of 1,000 stems ha^{-1} in topsoil but the rate of occurrence was extremely low at 23%.
- Together these results suggest that natural recovery on sites similar in size and terrain to this study area are unlikely to succeed to a functional forest within a reasonable time frame given the spatial variation (uneven/clumpy distribution) in natural regeneration coupled with the relatively low densities observed to date. ***BIG LESSON = it is worthwhile to plant trees***

Acknowledgements

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