TOPSOIL REPLACEMENT DEPTH IMPACTS ON FOREST RECLAMATION OUTCOMES

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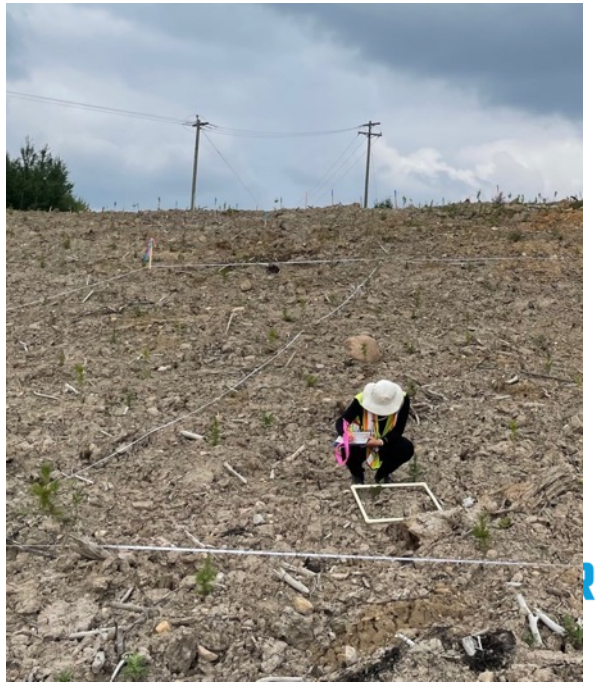

Context

- Current regulatory criteria for in-situ and conventional oil and gas operators require a target of 80% topsoil replacement depth relative undisturbed native soil.
- While the current regulatory target placement depth may still have its advantages in agriculture where crop species are known to respond strongly to growth in topsoil, it may be less directly applicable to in-situ and conventional operators in a forested setting.
- The ability to vary soil-cover design depths also has implications for optimizing the placement of available salvaged topsoil to achieve the best reclamation outcomes across multiple site types where some may be locally deficient of available topsoil.

Study objective

- The objective of this investigation is to evaluate the effect of topsoil capping depth on forest regeneration and soil properties, in a large former industrial disturbance.
- In this study – we compared three topsoil placement depth treatments along with use of pre-emergent herbicide.

Topsoil placement depths:

- **Standard** (high): aimed for 15 cm placement depth – anticipated to approximate 80% of original topsoil depth in surrounding area
- **Shallow** (low): aimed to place 5 cm of topsoil – minimal topsoil placement possible with dozers
- **No topsoil** (none): no topsoil

Pre-emergent herbicide:

- **Control** (no herbicide)
- **Herbicide** (applied in 2 m wide alternating strips, 50% ground coverage)

Timeline of project

- **2020:** seedlings were ordered and grown at a commercial nursery. Planning was underway for the trial – site clean-up activities were completed throughout the year.
- **May 2021:** Earthworks including site recontouring and placement of subsoil and topsoil occurred.
- **June 2021:** site-wide decompaction and herbicide application occurred in early June 2021 prior to planting. Planting was completed by June 17th, 2021.

What was planted?

- The planting prescription was relatively high to account for variable patterns of mortality and to provide a future coarse woody materials source as density-dependent mortality is anticipated to occur.
- A nitrogen-fixing shrub and use of 'hitchhiked' native forbs formed part of the planting prescription.

Species	Stock size (mL)	Density target (stems ha^{-1})	Experiment area
Picea glauca* + *Aster conspicuous	340	600	5520
Picea glauca* + *Apocynum androsaefolium	340	600	5435
Pinus banksiana* + *Chamerion angustifolium	340	600	5405
Populus balsamifera	220	600	6336
Populus tremuloides	220	600	6336
Betula papyrifera	220	600	6336
Alnus viridis	220	1,200	12,552
Total seedlings		4,800	47,920

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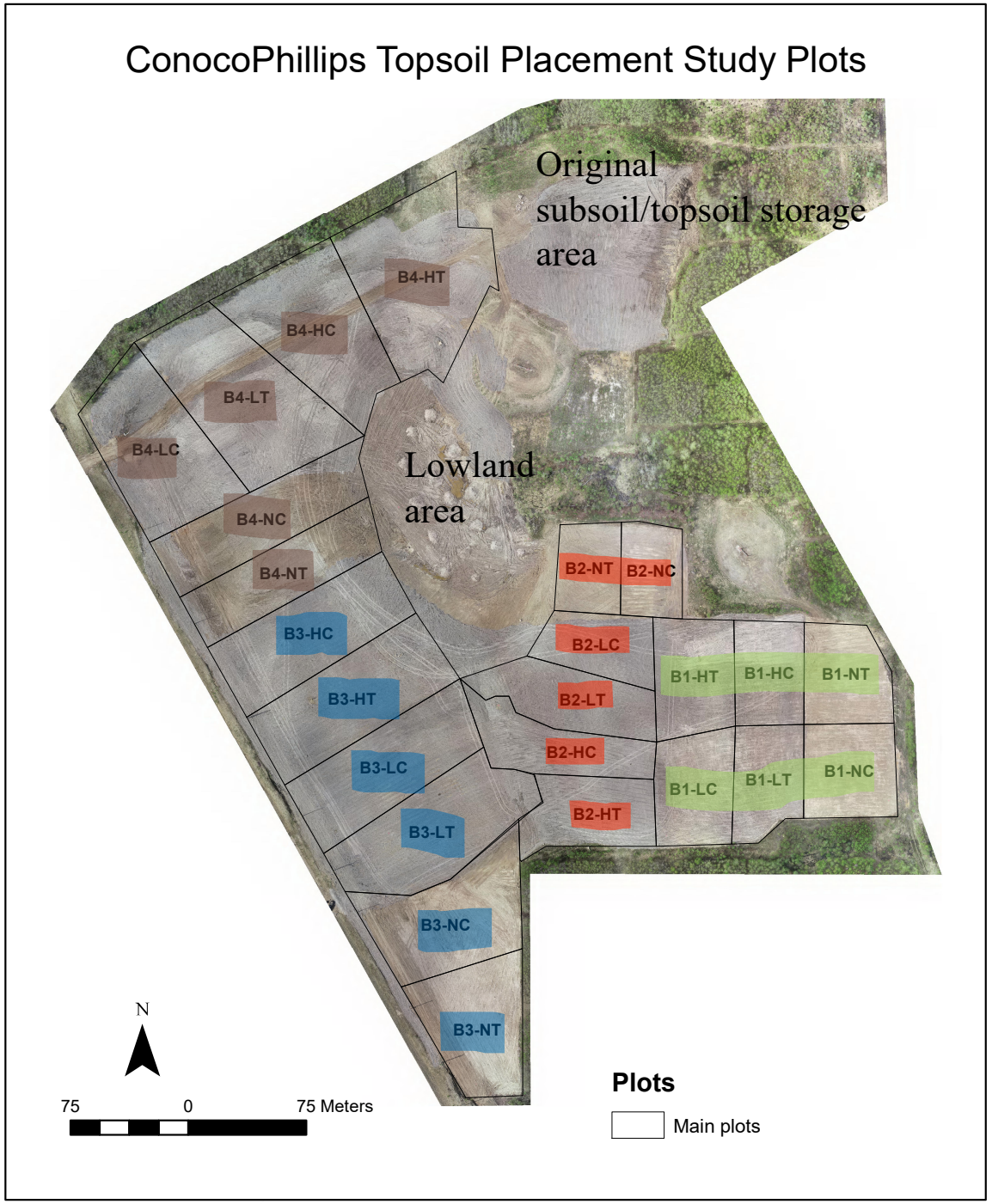
Soil decompaction treatment in action: RipPlow™

- Note that the topsoil is generally still sitting on top of the soil profile after plows have treated the area.

Main study treatment overview

- Randomized block design (n=4).
- Main factor: topsoil placement depth
- Split plot factor nested inside the main plot: herbicide treatment.
- Two 15 x 15 m permanent measurement plots were installed in each treatment combination (48 plots experiment wide) to monitor tree and vegetation cover development.

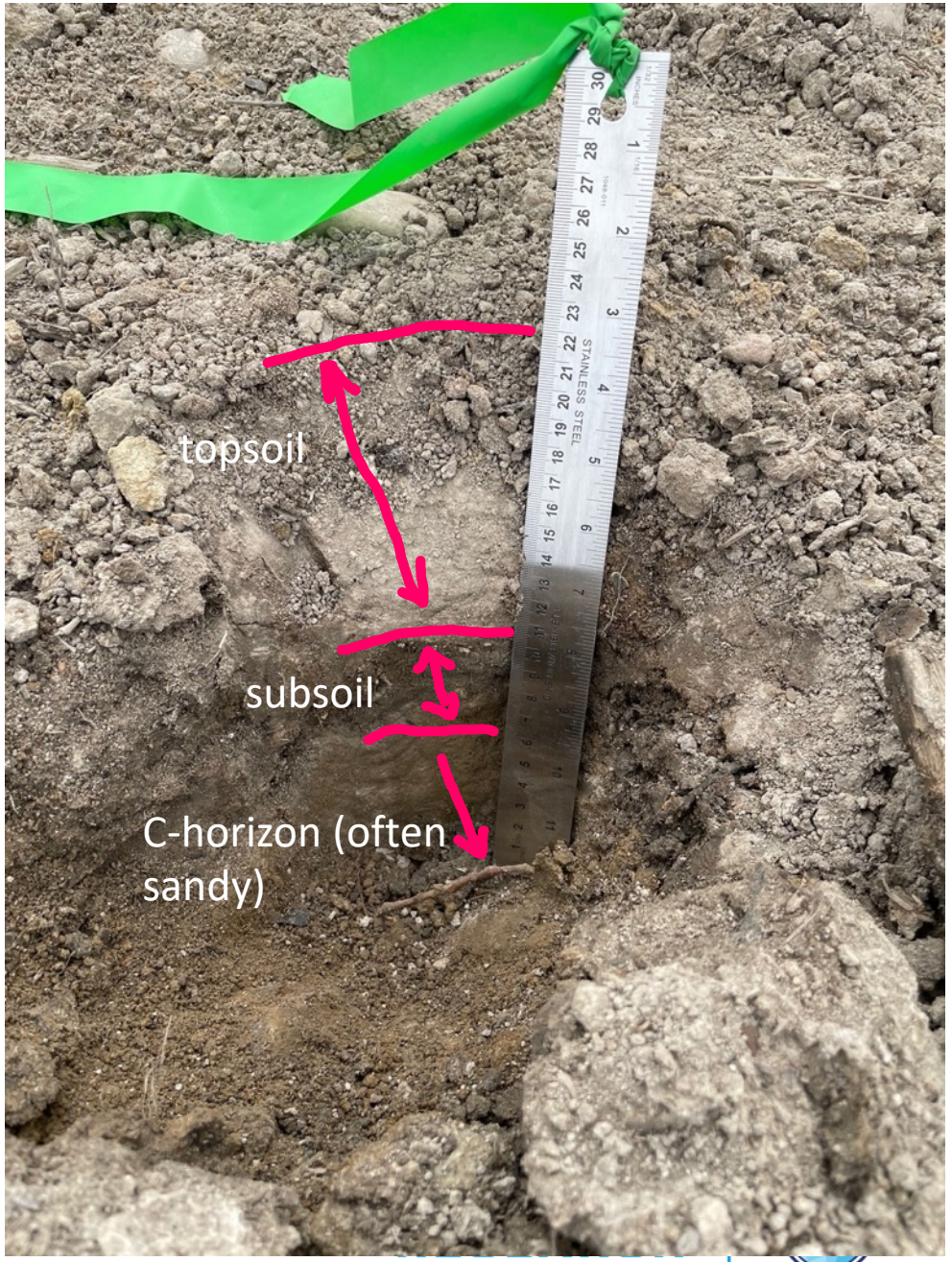
Legend for image on the right
B = block replicate
H/L/N = high / standard (15cm), low / shallow (5cm) or no topsoil
C/T = control or Torpedo™ herbicide application



Topsoil and subsoil depth assessment summary

- 800+ soil pits to confirm topsoil placement depths were completed ahead of decompaction work (late May 2021) and then again in September 2022.
- Values are means (+/- 1 standard deviation mean)

	No topsoil	Shallow topsoil	Standard topsoil
2021			
Topsoil depth (cm)	--	**6.0 (0.1)**	**12.4 (1.4)**
Subsoil depth (cm)	8.6 (1.0)	5.7 (1.4)	5.7 (0.4)
2022			
Topsoil depth (cm)	--	**4.4 (0.7)**	**10.7 (1.0)**
Subsoil depth (cm)	9.9 (1.8)	5.0 (3.4)	4.2 (3.1)



Year 1 (August 2021)

Standard topsoil placement with control (left) and herbicide treatment (right)

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Year 1 (August 2021)

Shallow topsoil placement with control (left) and herbicide treatment (right)

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Year 1 (August 2021)

No topsoil placement with control (left) and herbicide treatment (right)

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Year 3 (August 2023)

Standard topsoil placement control (top row) and herbicide treatment (bottom row)

Year 3 (August 2023)

Shallow topsoil placement with control (top row) and herbicide treatment (bottom row)

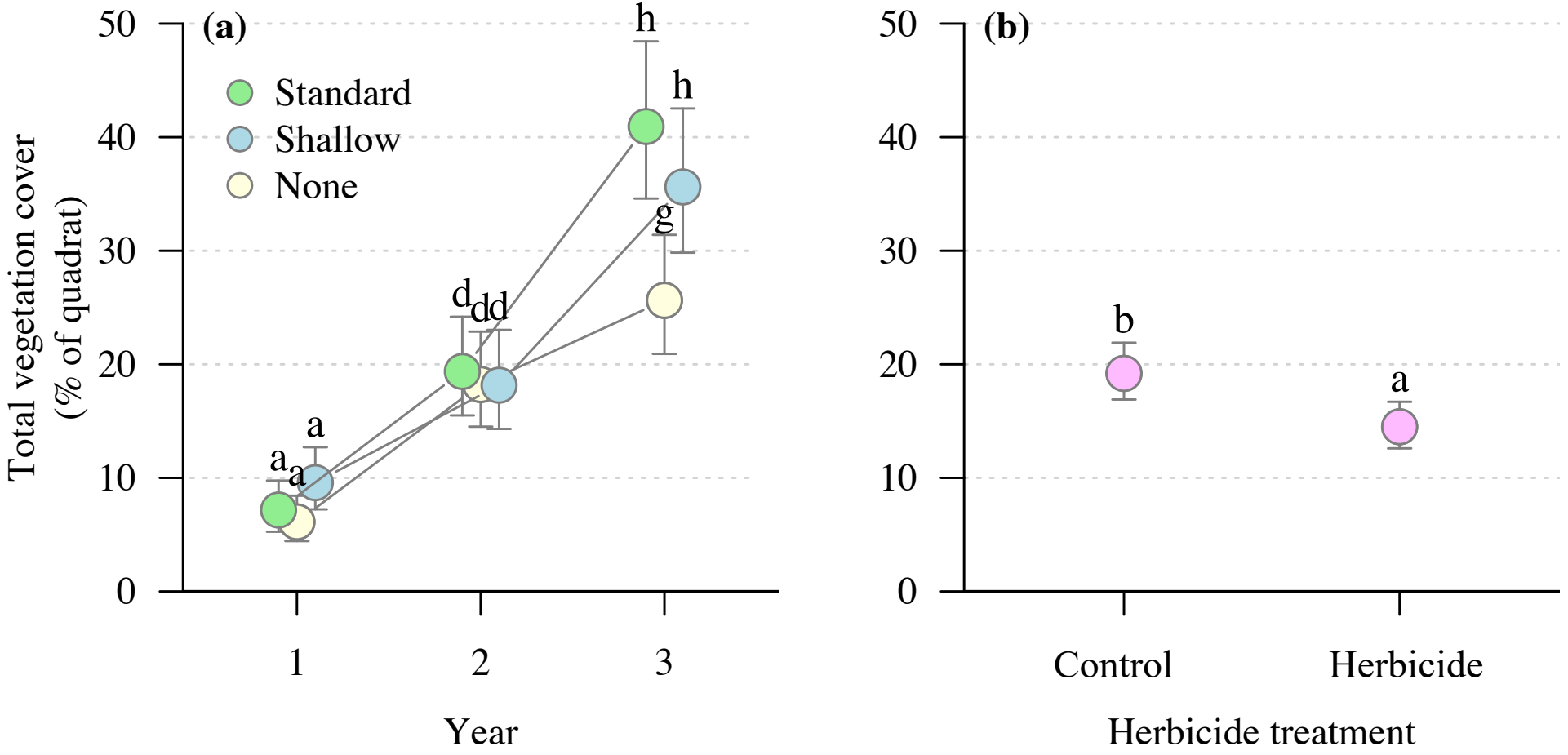
Year 3 (August 2023)

Standard topsoil placement with control (top row) and herbicide treatment (bottom row)

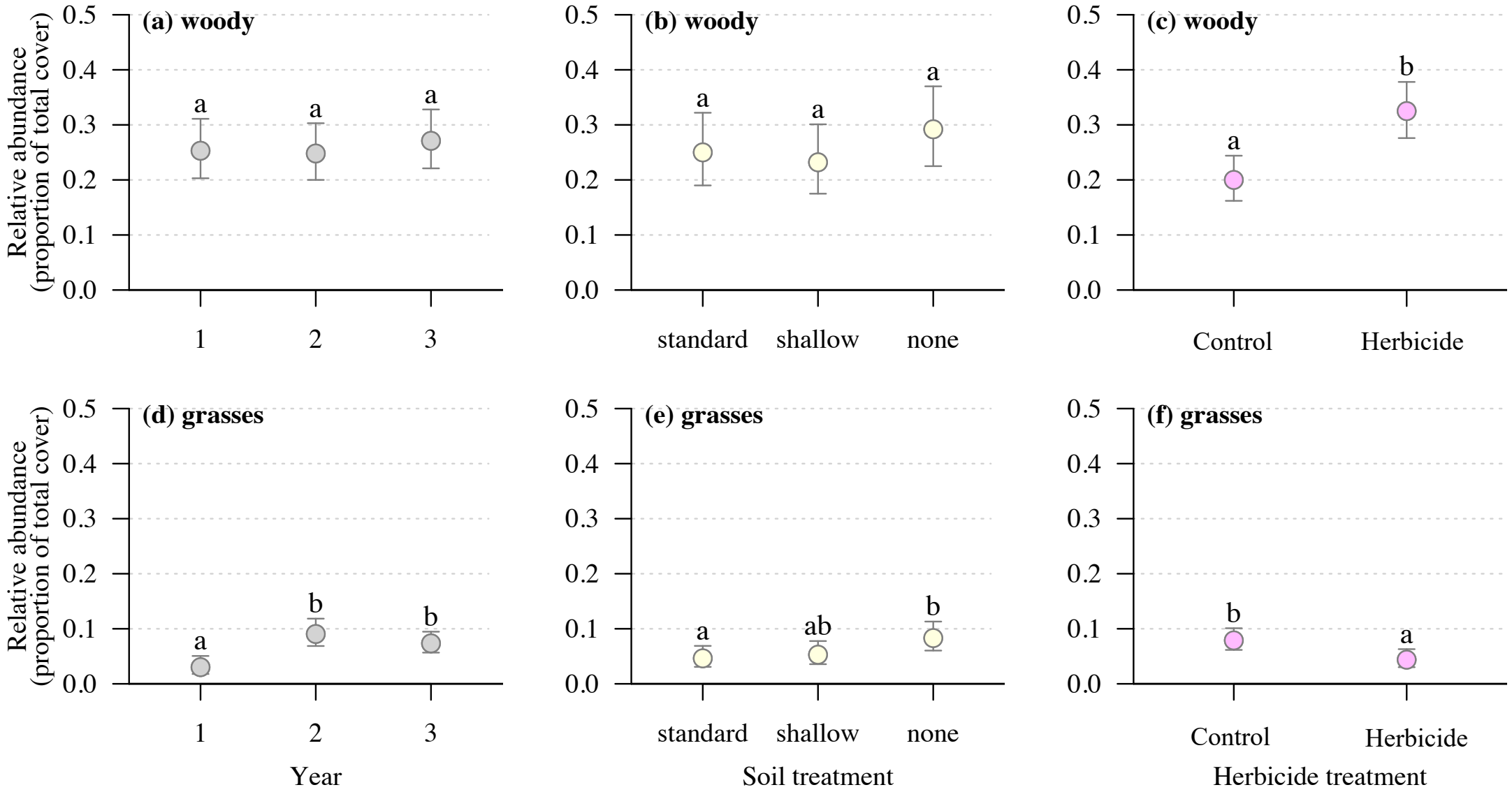
Vegetation cover

- Cover increased steadily over time – low initial cover tied to dry first year coupled with spring reclamation. Use of herbicide reduced cover overall.
- No topsoil diverging with lower cover in year 3.

(Right) Estimated marginal mean total vegetation cover. Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean.



Relative abundance (proportion contributing to total cover)

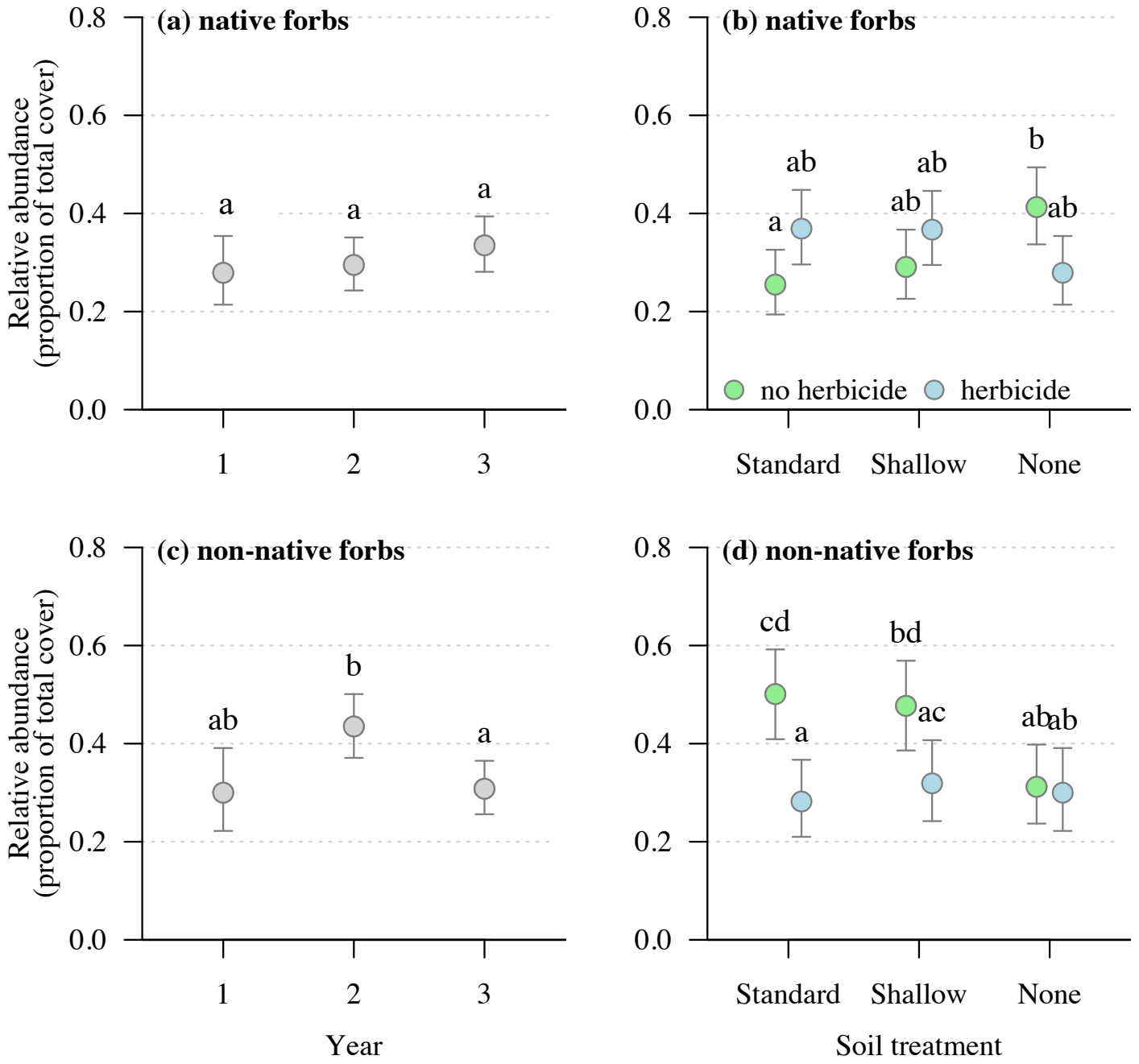


(Above) Estimated marginal mean relative abundance of vegetation. Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean.

Relative abundance (proportion contributing to total cover)

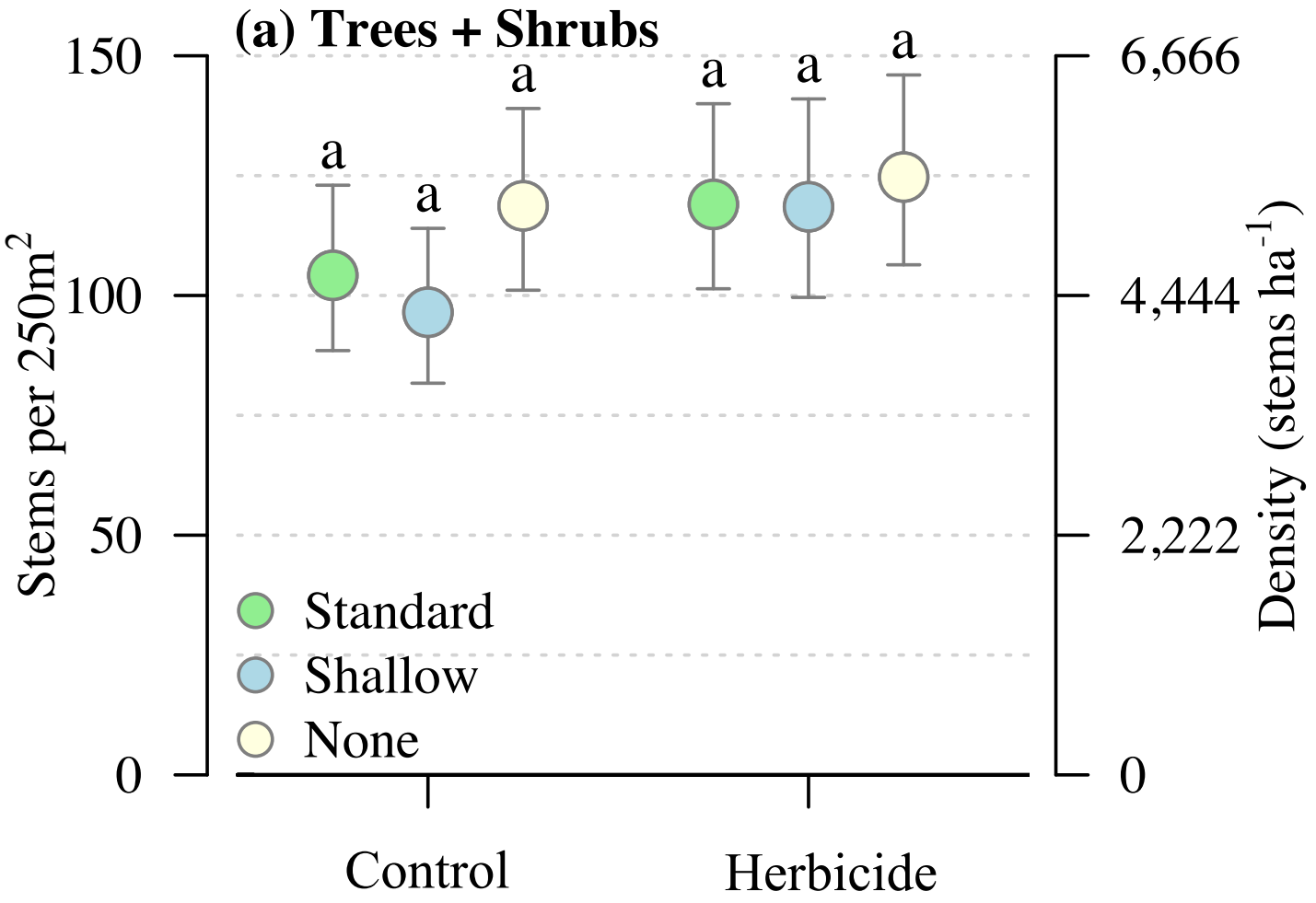
- Native forb RA similar over time; differing effects with topsoil X herbicide.
- Non-native forb RA peaked in year 2 and declining again in year 3.
- RA very high (0.5 or 50% of total cover) with both standard and shallow topsoil without herbicide.

(Right) Estimated marginal mean relative abundance Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean.



Stem counts / Density

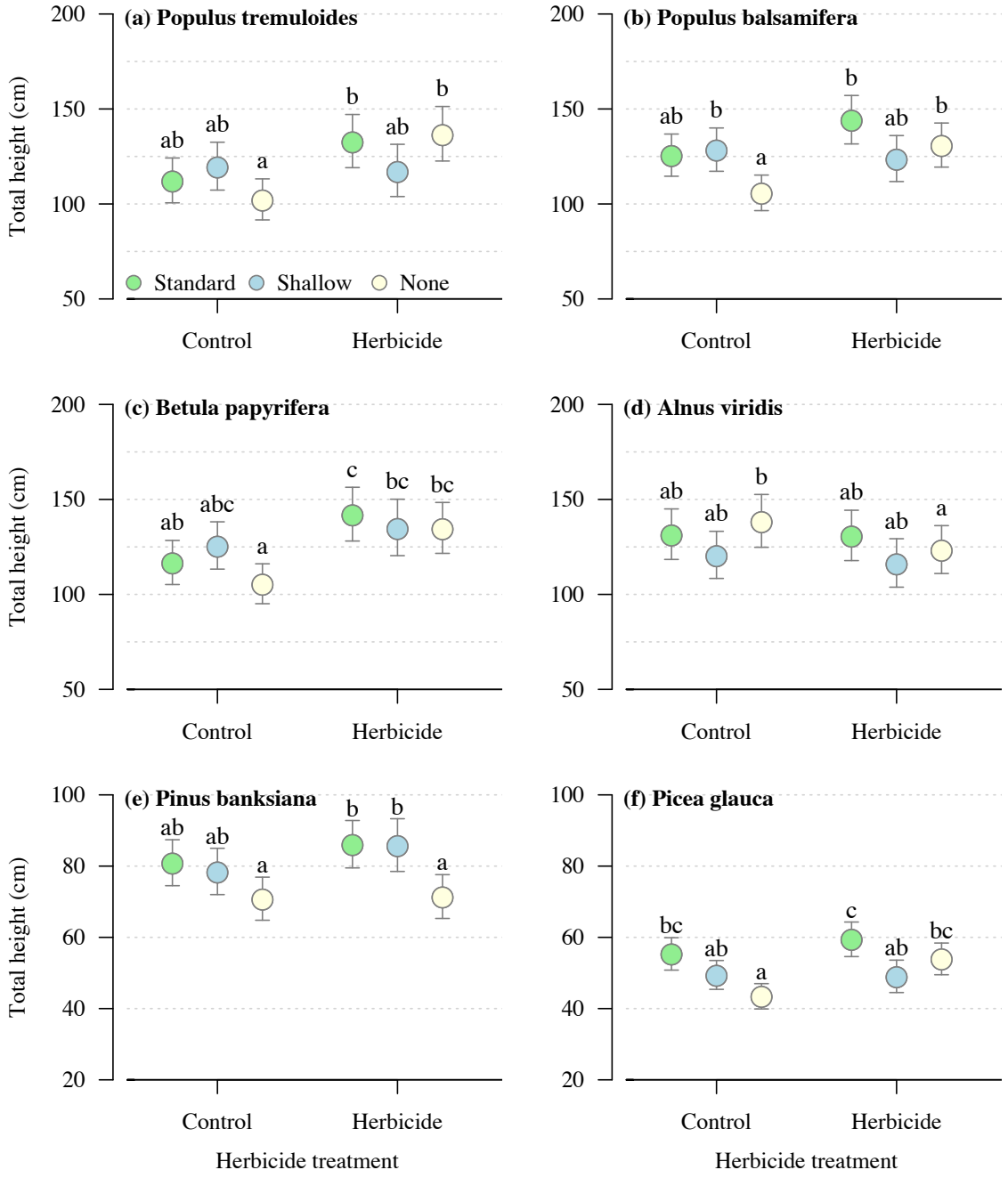
- The total woody stem counts after 3 years run similar patterns across individual species.
- Similar stem counts across topsoil depth treatments within the herbicide treatment.
- Slight reduction associated with standard and shallow topsoil treatments in control treatment. Likely competition driven.



(Above) Estimated marginal mean woody stem counts after 3 growing seasons. Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean.

Total height – trees and shrubs (year 3)

- Mixed and interacting responses between topsoil and herbicide treatments: species specific responses.
- Herbicide often conferred benefit within a topsoil treatment (standard topsoil)
- No topsoil treatment often shortest within herbicide treatment.



(Right) Estimated marginal total tree height after 3 growing for planted species. Treatments not sharing the same letters indicate a significant ($p < 0.05$) difference in means. Error bars represent 95% confidence intervals on the treatment mean.

Practical outcomes and recommendations

- While it is premature to draw any firm conclusions from this project, the results so far suggest that the lack of topsoil has not been a severe limitation to the development of the planted tree and shrub species.
  - *It is likely that composition and productivity of the future forest will be different amongst the topsoil treatments; stand-scale compositional diversity may contribute to greater landscape heterogeneity.*
- In several cases, total height is progressing at a similar pace across topsoil depth treatments with stronger differences attributed to the competition-mediated effects of using a pre-emergent herbicide.
- Total understory vegetation is beginning to diverge amongst the no-topsoil compared with shallow and standard topsoil depths. **More monitoring needed!**
- ***Important to recognize that we have employed a high-diversity (trees, shrub and forbs) planting approach within this study – this is expected to affect outcomes longer term***

Thanks for listening! Questions?

Images above are from one of the seedling-scale field trials examining hitchhiked ericaceous species with conifers

Extra slides

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NO TOPSOIL (LEFT) AND STANDARD TOPSOIL (RIGHT)

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SHALLOW AND NO TOPSOIL

STANDARD TOPSOIL

Soil chemical properties (September 2021)

- TOC, N, P and K all decline with less topsoil. pH and EC similar across soil treatments.
- Values are means (+/- 1 standard deviation mean, n=4 replicate blocks with 2 samples per block X soil type).

		TOC (%)		pH		EC ($mS\ cm^{-1}$)		Total N (%)		Ext K ($mg\ kg^{-1}$)		Ext P ($mg\ kg^{-1}$)	
Soil depth (cm)	Topsoil depth	**Mean**	SD	**Mean**	SD	**Mean**	SD	**Mean**	SD	**Mean**	SD	**Mean**	SD
0-15	Standard	**1.39**	0.21	**7.33**	0.39	**0.17**	0.06	**0.07**	0.02	**75.6**	6.86	**12.0**	2.67
	Shallow	**1.08**	0.22	**7.34**	0.15	**0.13**	0.03	**0.05**	0.01	**66.2**	6.25	**9.34**	1.90
	None	**0.37**	0.05	**7.75**	0.28	**0.11**	0.03	**0.02**	0.00	**57.0**	7.01	**6.69**	1.80
15-30	Standard	**0.94**	0.32	**7.64**	0.39	**0.19**	0.06	**0.05**	0.02	**68.4**	6.25	**8.84**	1.69
	Shallow	**0.91**	0.21	**7.63**	0.30	**0.16**	0.03	**0.04**	0.02	**62.8**	5.36	**8.63**	2.08
	None	**0.37**	0.05	**7.75**	0.32	**0.12**	0.03	**0.02**	0.00	**54.7**	2.88	**5.13**	1.40