Coal mine reclamation and the challenges of establishing forest vegetation in the face significant ruderal competition: a 5-year assessment of the good, the bad and the downright ridiculous

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A LEADING POLYTECHNIC COMMITTED TO STUDENT SUCCESS

Why are we here today?

Because we are interested in turning these disturbances back into something that might resemble a forest one day?

What is holding us back?

Project purpose?

The objective of this study was to quantitatively test the principle of accelerating cover dominance of native plant communities to the exclusion of undesirable pioneer species on reclamation sites from two scales of implementation: **(i)** the first was to test a series of treatments anticipated to have immediate, short-term effects (suppression) on the ingress of non-native species while the second scale **(ii)** (applied concurrently with the first) was to use native species to fully occupy the industrial site thereby preventing invasion and preeminence of non-native species.

Alternative wording but same meaning:

Test operationally feasible approaches to punt out undesirable (largely agronomic) plant species while promoting the establishment of native forest vegetation on a former mine site.

Combination approach to vegetation management and forest development

- Fast-acting treatments: Initial weed suppression approach
- Slow-acting treatments: Native plant occupancy approach
- Weed suppression treatments applied at large scale (¼ ha) with native plant occupancy treatments applied as split-plot within each ¼ ha weed suppression treatment.

Weed-suppression treatments

- No suppression (control)
- Strip application of wood mulch
- Strip application of film mulch
- Pre-emergent herbicide (Torpedo™)
- Rototilling

Wood mulch

- Waste wood from a truss factory.
- Applied with a tractor + manure spreader.
- Tested in strips as previous experience had been mixed with complete application.

Film mulch

- Placed with tractor and mulch laying attachment.
- Biodegradable – film is made from corn starch
- No pins (soil is simultaneously rolled over edges).
- Some issues with mulch lifting – due to light, peaty topsoil in some areas of the site

Pre-emergent herbicide

- Pilot studies conducted at Genesee Mine and in NE Alberta showed promise with this approach.
- This herbicide targets seeds – radicle and cotyledon development.
- Requires rain and a smooth soil surface for maximum effect as the water activates herbicide, creating a thin film that inhibits seed emergence.

Rototilling

- Quack grass (*Agropyron repens*) is a significant competitor on this mine site.
- Anecdotally we had previously observed that rototilling appeared to reduce emergence of other rhizomatous species.
- This treatment also creates a soft surface for planting; it was also a necessary pre-treatment for film mulch application

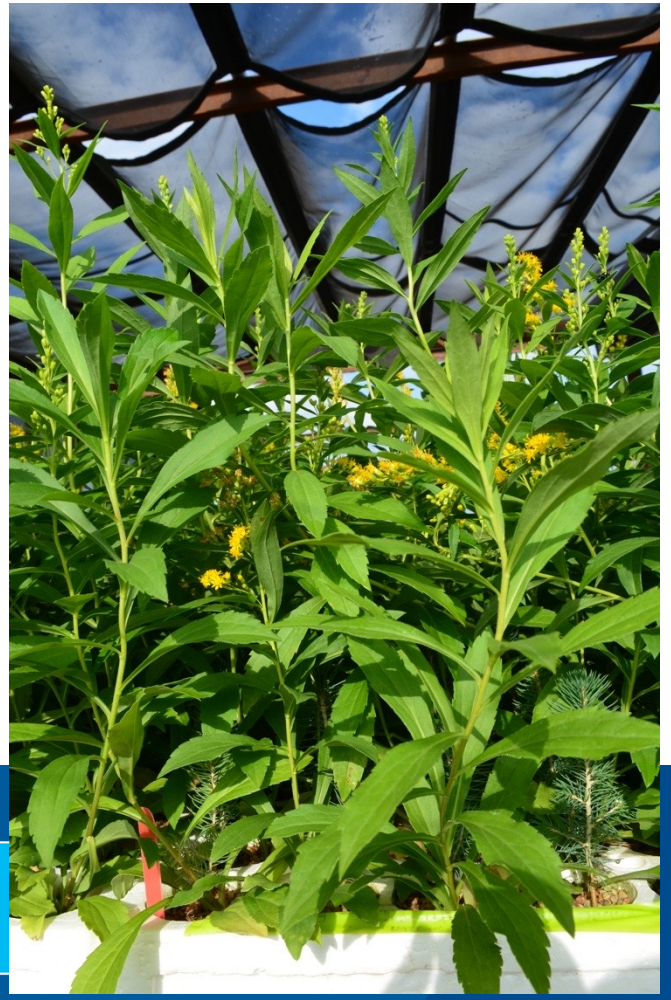
Native plant occupancy treatments

All of the below were planted with the same mixture of tree and shrub species (except for roots treatment)

- No treatment (control).
- Grass seeding (slender wheatgrass 10 kg ha^{-1}) concurrent with seedling planting.
- Hitchhiking of native forbs (goldenrod, fireweed and showy aster) with woody species (white spruce, buffaloberry and green alder).
- Roots-in-a-bag (= Roots treatment) of aspen, sandbar willow and 3 native forbs.

Hitchhiking native forbs with woody species

- Plot-scale field research on this approach has been under evaluation since 2015.
- Some mixtures have shown promise and those were utilized in this trial.
- Easily accomplished with slow growing tree/shrub + native forb.



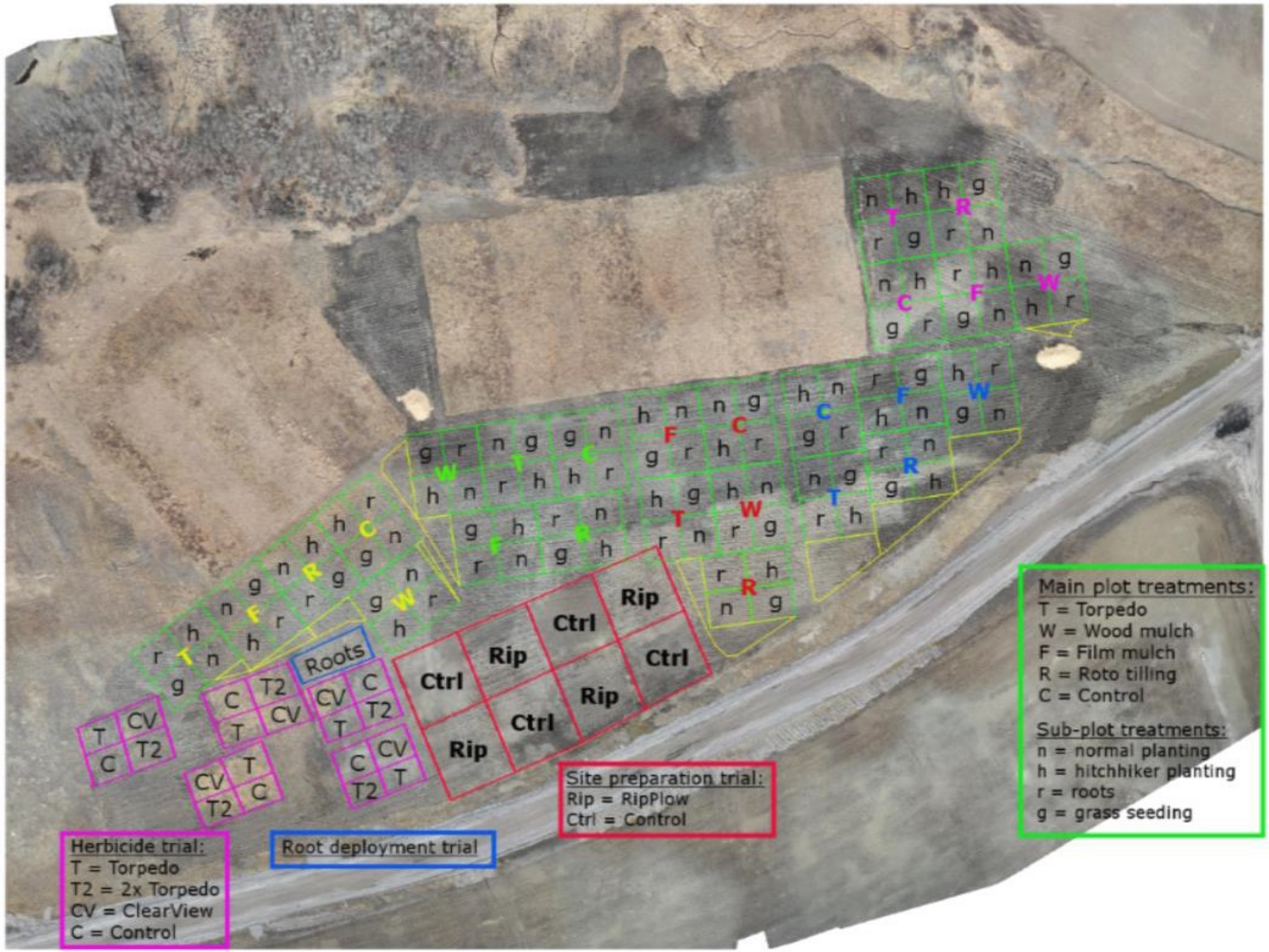
WE ARE

What is ‘roots-in-a-bag’ (roots treatment)?

- The deployment of native plant species to reclamation sites using live greenhouse-grown root material as a propagule source.
- The idea that the propagule material can be handled without live tops and that orientation does not matter during storage and planting.

Roots treatment: Semi-automated planting of native plants

- Modified potato planter
  - Replaced hillers with drag-style closing system
  - Tray for planting material


Main plot treatments:
T = Torpedo
W = Wood mulch
F = Film mulch
R = Roto tilling
C = Control
Sub-plot treatments:
n = normal planting
h = hitchhiker planting
r = roots
g = grass seeding
Site preparation trial:
Rip = RipPlow
Ctrl = Control
Root deployment trial
Roots
Herbicide trial:
T = Torpedo
T2 = 2x Torpedo
CV = ClearView
C = Control

Sequence of site set-up activities

- Topsoil placement summer 2017
- Disced and sprayed 1x in early fall 2017
- RipPlow™ in November 2017
- Disced and sprayed 1x in early May 2018
- All weed suppression treatments were applied by mid-late May 2018
- 30,000+ seedlings were established in the last week of May 2018

Given the above: what I would do differently if I could zoom back in time?

What did we plant?

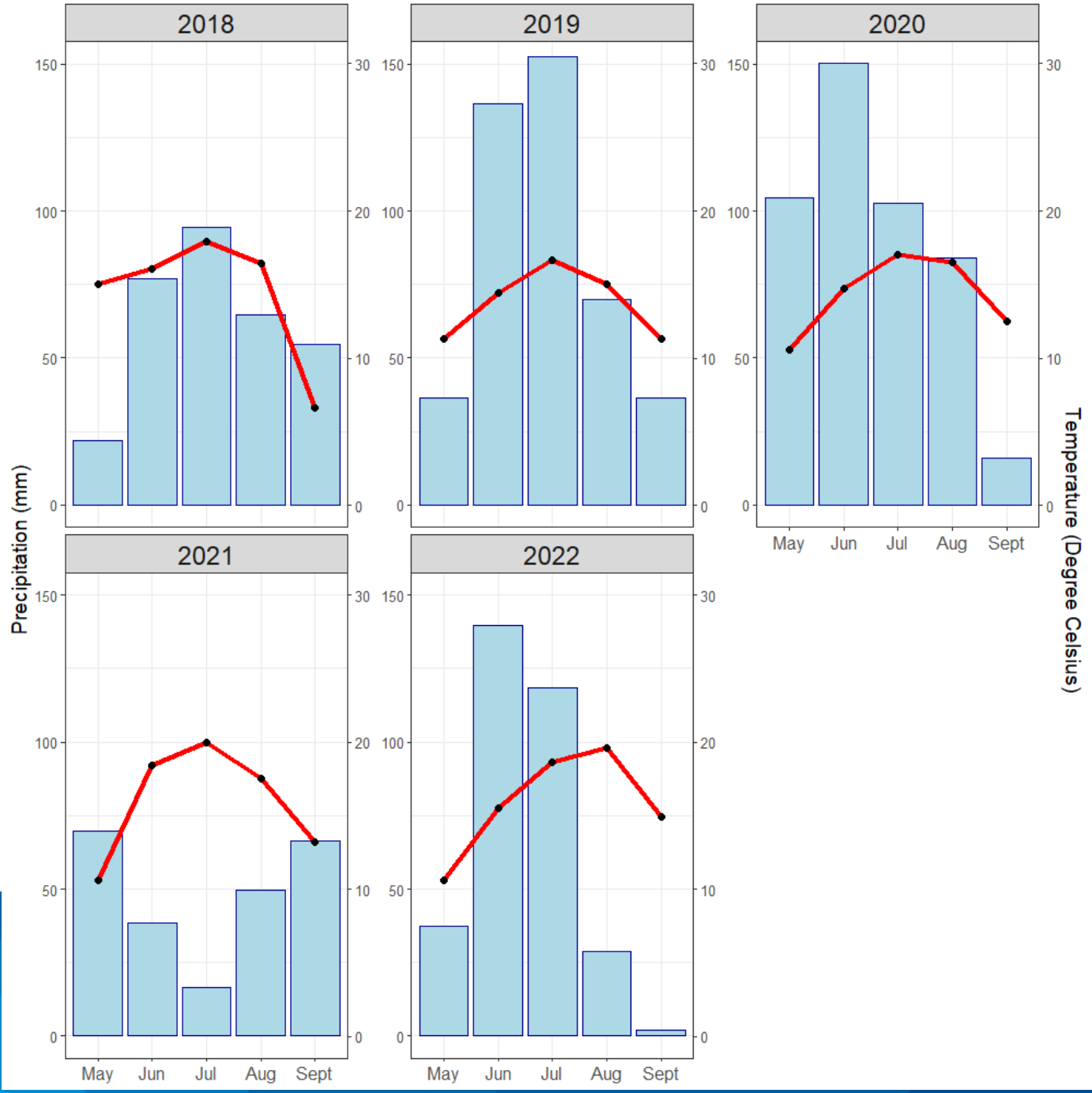
	Control / Grass / Hitchhiking	Roots in a bag
Species	Density (stems ha^{-1})	Density (stems ha^{-1})
Aspen	2,000	4,500
White spruce	700	700
Balsam poplar	1,000	1,000
Bebb's willow	350	350
Green alder	325	325
Buffaloberry	200	200
Sandbar willow	450	625
Forbs	Hitchhiker treatment	
Showy aster	350	625
Fireweed	625	1,000
Goldenrod	625	4,500

A quick note about surface soil quality – it varied across the site

		Replicate block (south to north, 0-15 cm depth)				
	Units	**Yellow**	**Green**	**Red**	**Pink**	**Blue**
pH		7.46	7.04	7.16	6.84	6.85
EC	mS cm^{-1}	0.64	0.49	0.48	0.45	0.79
Total Nitrogen	(%)	0.24	0.32	0.18	0.35	0.51
Total Organic Carbon	(%)	2.81	4.08	2.02	4.81	7.17
NO3-N	(mg kg^{-1})	4.05	7.15	7.60	9.18	16.16
NH4-N	(mg kg^{-1})	12.29	11.41	10.29	15.82	17.00
Available K	(mg kg^{-1})	256.02	198.55	221.15	189.83	196.46
Extractable P	(mg kg^{-1})	14.27	9.17	10.58	11.96	11.03
Extractable S	(mg kg^{-1})	59.65	43.57	44.58	38.53	65.83
SAR		1.33	0.44	0.41	0.55	2.26
CEC	(cmol kg^{-1})	19.05	20.99	19.13	14.96	21.89
Sand	(%)	36.40	26.80	33.70	35.80	36.20
Silt	(%)	29.60	36.80	35.30	34.40	30.80
Clay	(%)	34.00	36.40	31.00	29.80	33.00

Let's start with a bit of good and bad - climate

- Growing season precipitation totals:
- 2018: 313 mm / 14.4°C
- 2019: 431 mm / 13.7°C
- 2020: 457 mm / 14.3°C
- 2021: 241 mm / 15.9°C
- 2022: 326 mm / 15.8°C



The bad continues: the small but mighty insect?

- In the first weeks following seedling planting, we observed widespread stem dieback and webbing associated primarily with aspen but also to a lesser extent on other shrubs planted. This affected >80% of the aspen with stem dieback and resprouting from the base often observed.
- This was likely a death sentence for many plants that would then have to face substantial herbaceous competition.

And the downright ridiculous: unrelenting ruderal competition

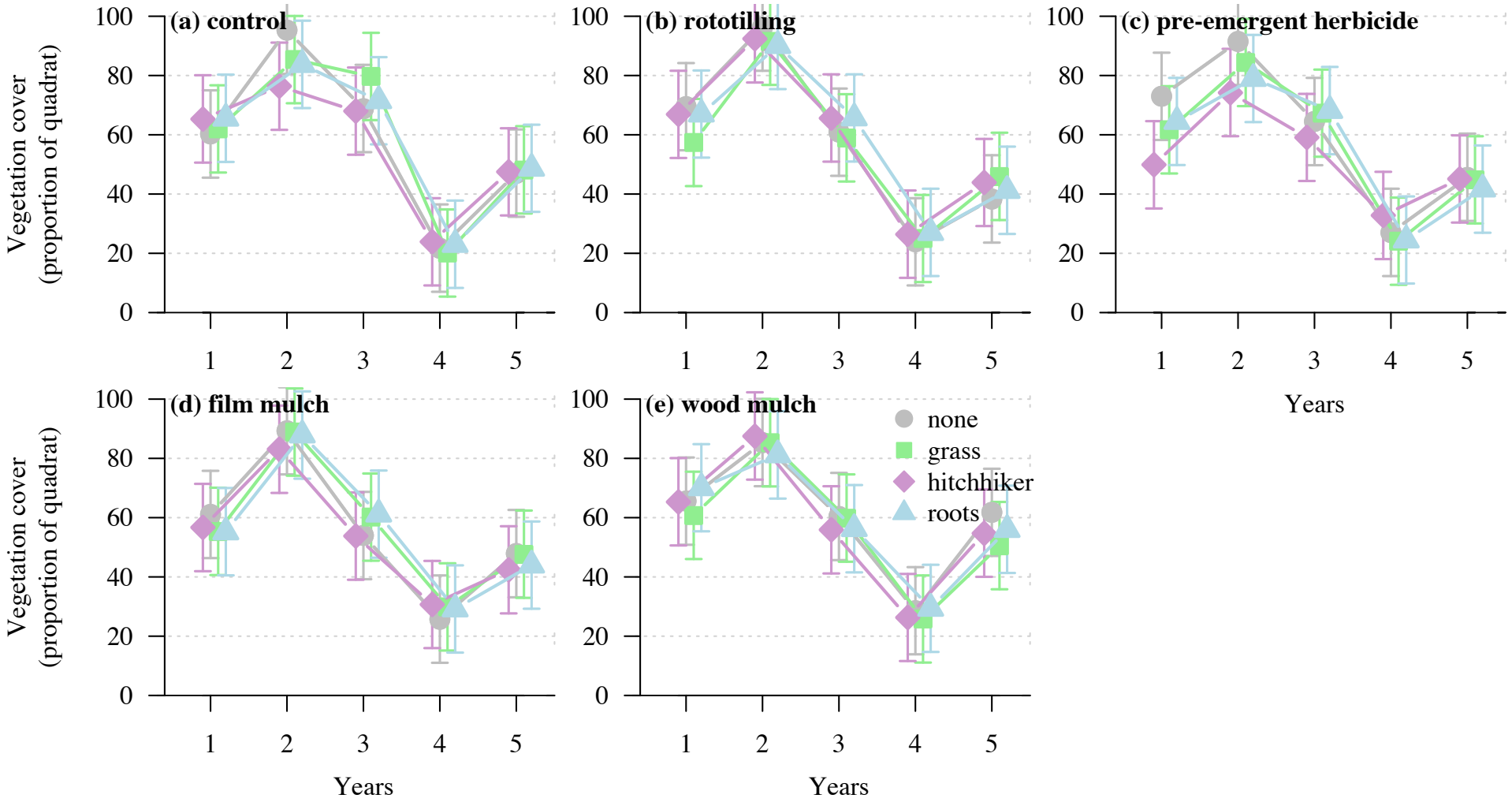
Notes on data handling

- Data was analyzed using R statistical software (R Core Team, 2022).
  - Cover data: beta distribution employed via function glmmTMB (package glmmTMB, Brooks et al. 2017). Total cover used gaussian distribution as there were many values > 100.
  - Stem density was analyzed with stem counts using poisson or negative binomial distribution using the same package above.
- All graphics are shown with estimated marginal means and 95% confidence intervals on the mean.
- No significant difference lettering is shown – too many tests to be sensible.
- The interaction of the main effect [site treatment] X split-plot effect [native plant treatment] are shown throughout except where modelling constraints limited investigation of split-plot effects.

- R Core Team 2022. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org.
- Mollie E. Brooks, Kasper Kristensen, Koen J. vanBenthem, Arni Magnusson, Casper W. Berg, Anders Nielsen,Hans J. Skaug, Martin Maechler and Benjamin M. Bolker (2017). glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal, 9(2), 378-400

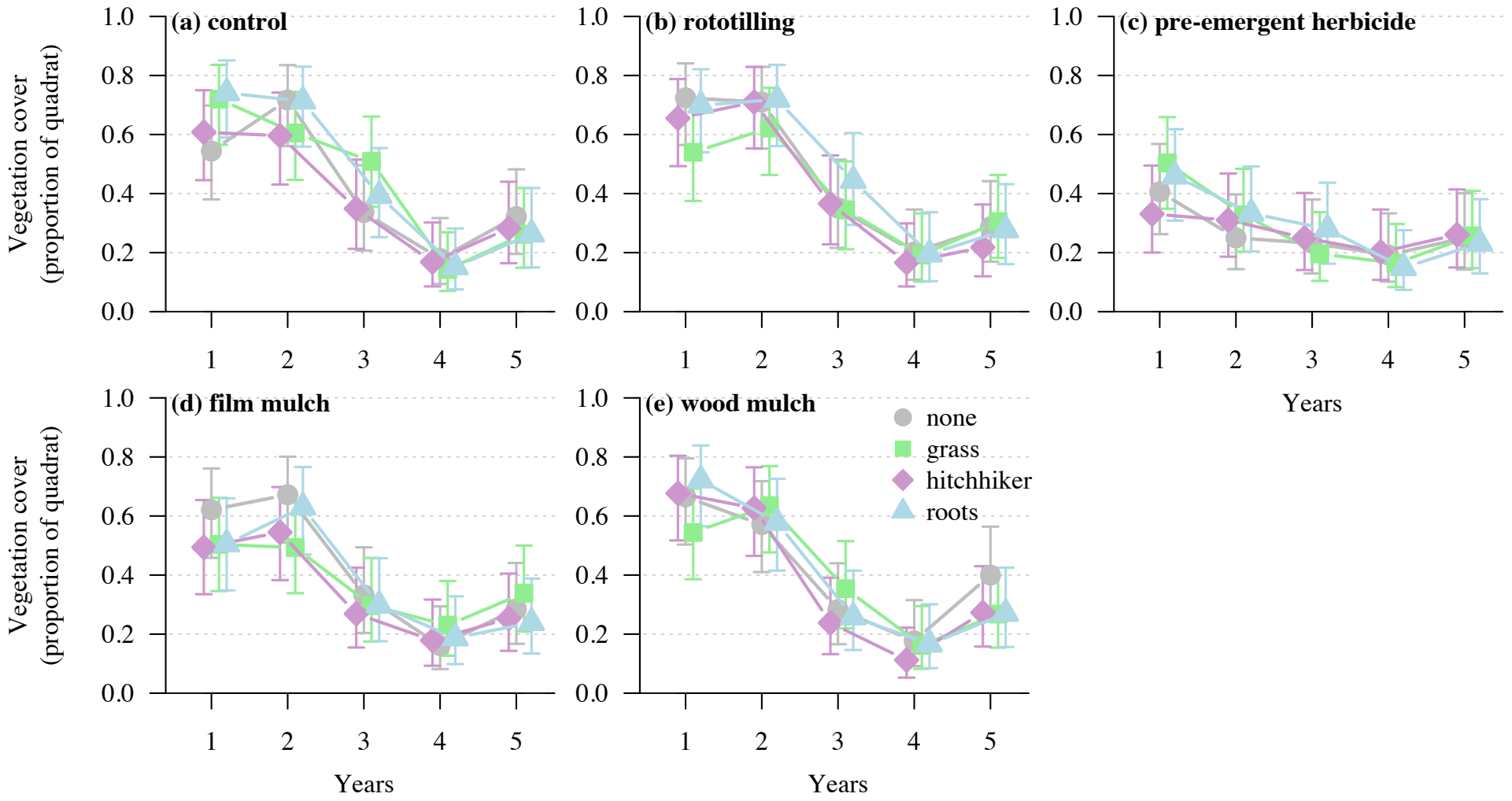
Vegetation cover: total cover

- Showing for illustration, basically no difference amongst site or native plant treatments.
- Hitchhiking treatment tends to track slightly lower overall within site treatments.
- Peak in year 2 associated with sweet clover and lambs-quarter throughout the site.



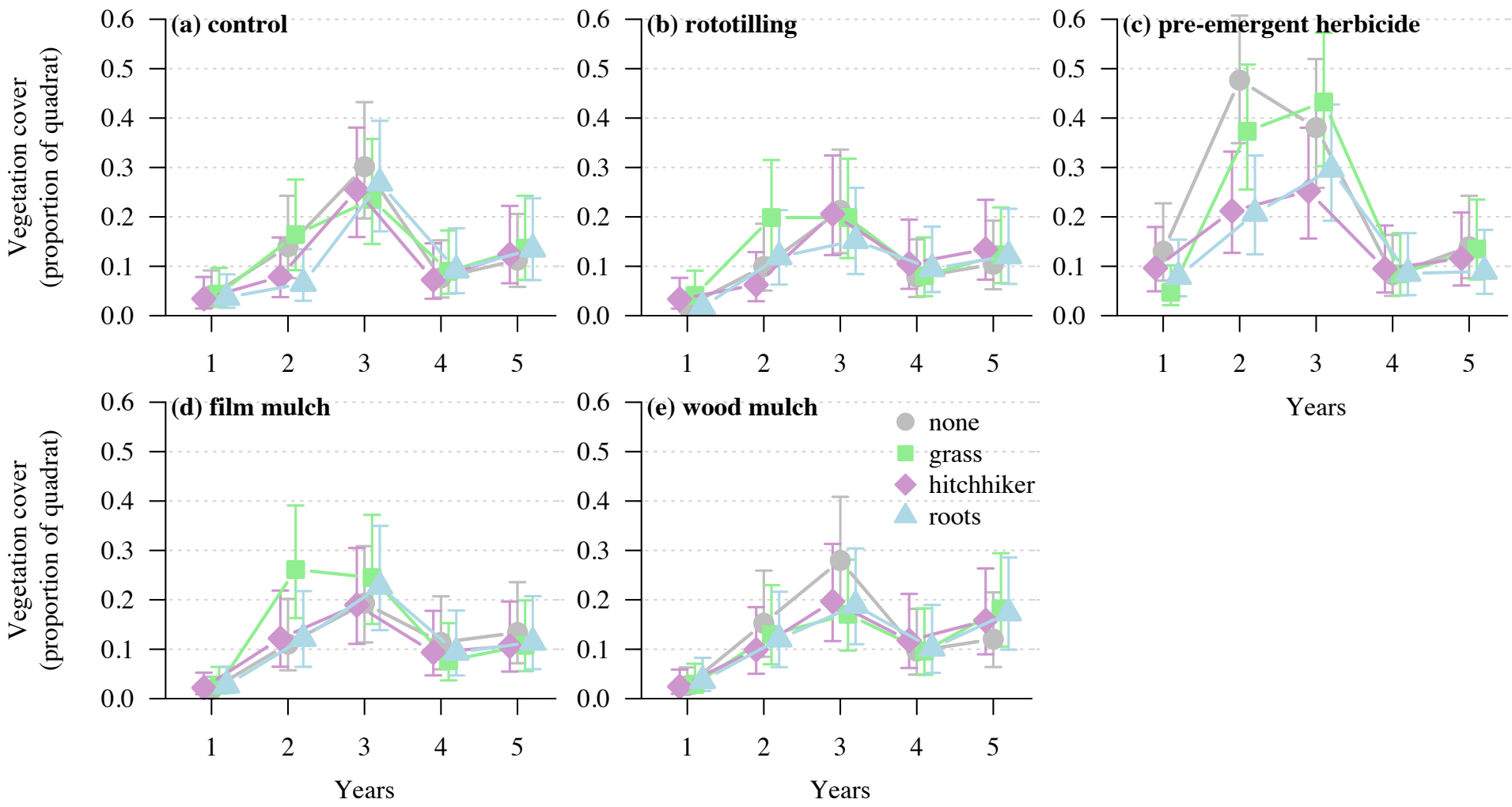
Vegetation cover: non-native forbs (NNF)

- Pre-emergent herbicide treatment had the strongest demonstrated reduction in NNF from the onset of the study.
- While cover of NNF has declined over time experiment-wide, there does appear to be an upward trend in year 5, particularly for control and wood mulch treatments.



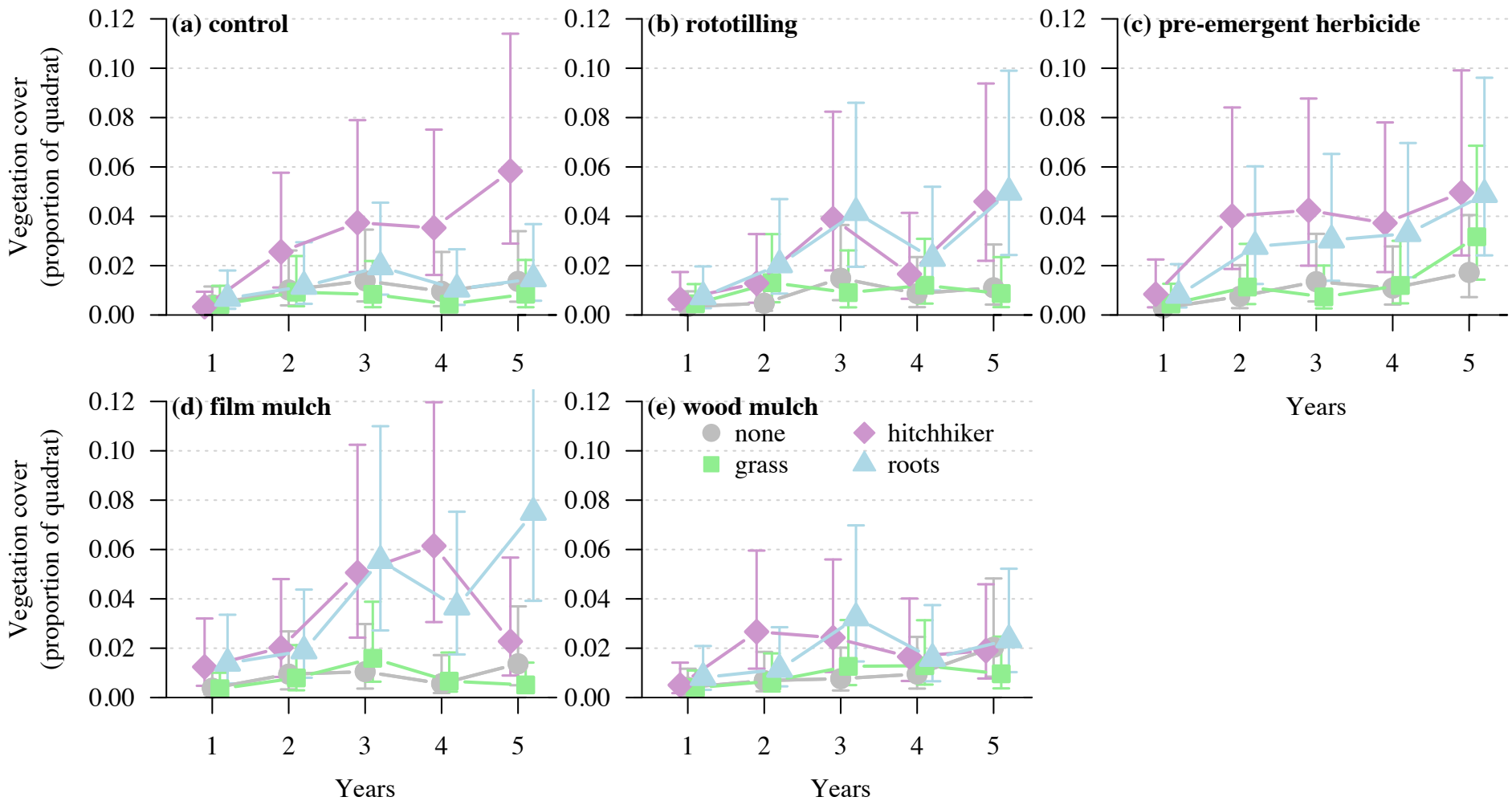
Vegetation cover: grasses

- Grass cover peaked in year 3 with two successively moist growing seasons with a big drop in year 4-5 (droughts).
- Pre-emergent herbicide supported the highest coverage of grasses during the peak growing period in year 2-3, though the effect of this was strongly related to the native forb treatment.



Vegetation cover: native forbs (NF)

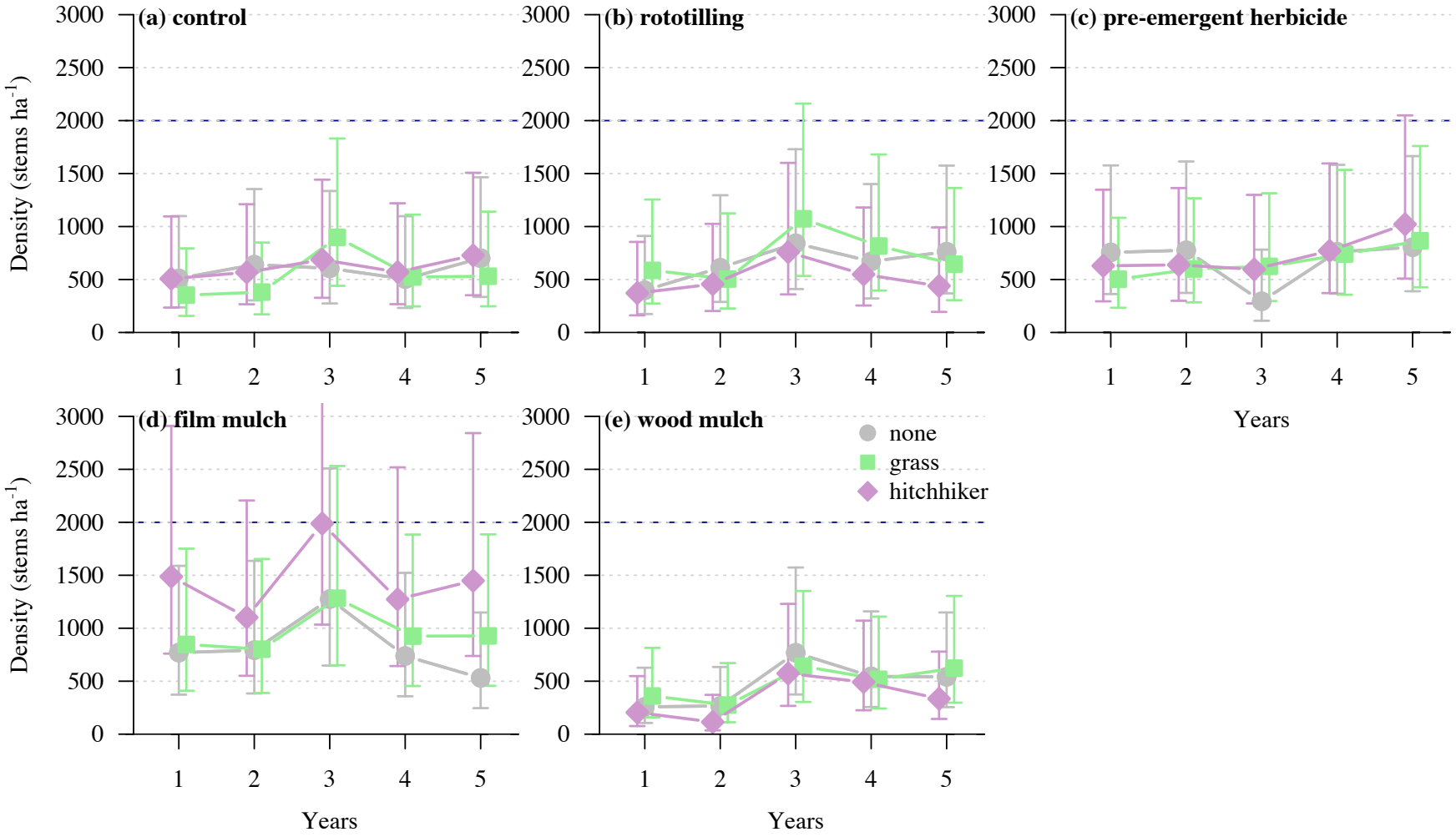
- Native forb treatments (HH, R) show measurable increases in NF cover over time, with a sustained effect up to year 5.
- Hitchhiking treatment tends to be higher compared with the Roots treatment though this varies by site treatment.
- Important to note the cost to deploy is substantially lower with hitchhiking vs roots treatment.



Stem density: aspen

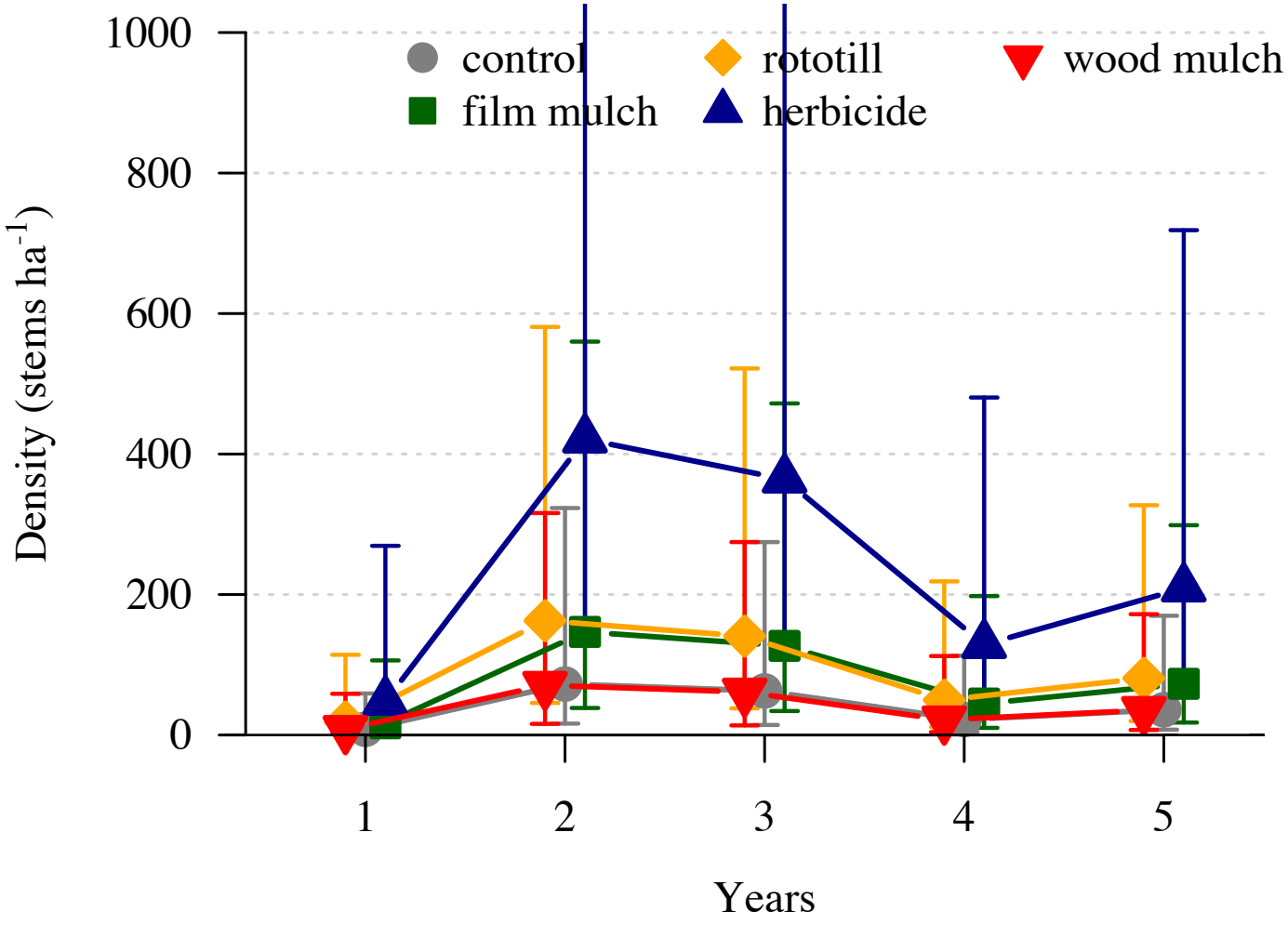
- Highest survival at 1,500 stems ha^{-1} after 5 years was in film mulch + HH followed pre-emergent herbicide + HH/grass and film mulch + grass.

- Control, Rototilling and Wood mulch treatments were similar to each other at 500-700 stems ha^{-1}.
- Nevertheless, mortality was very high and this is likely attributed to initial insect damage coupled with climatic factors in years 4-5.



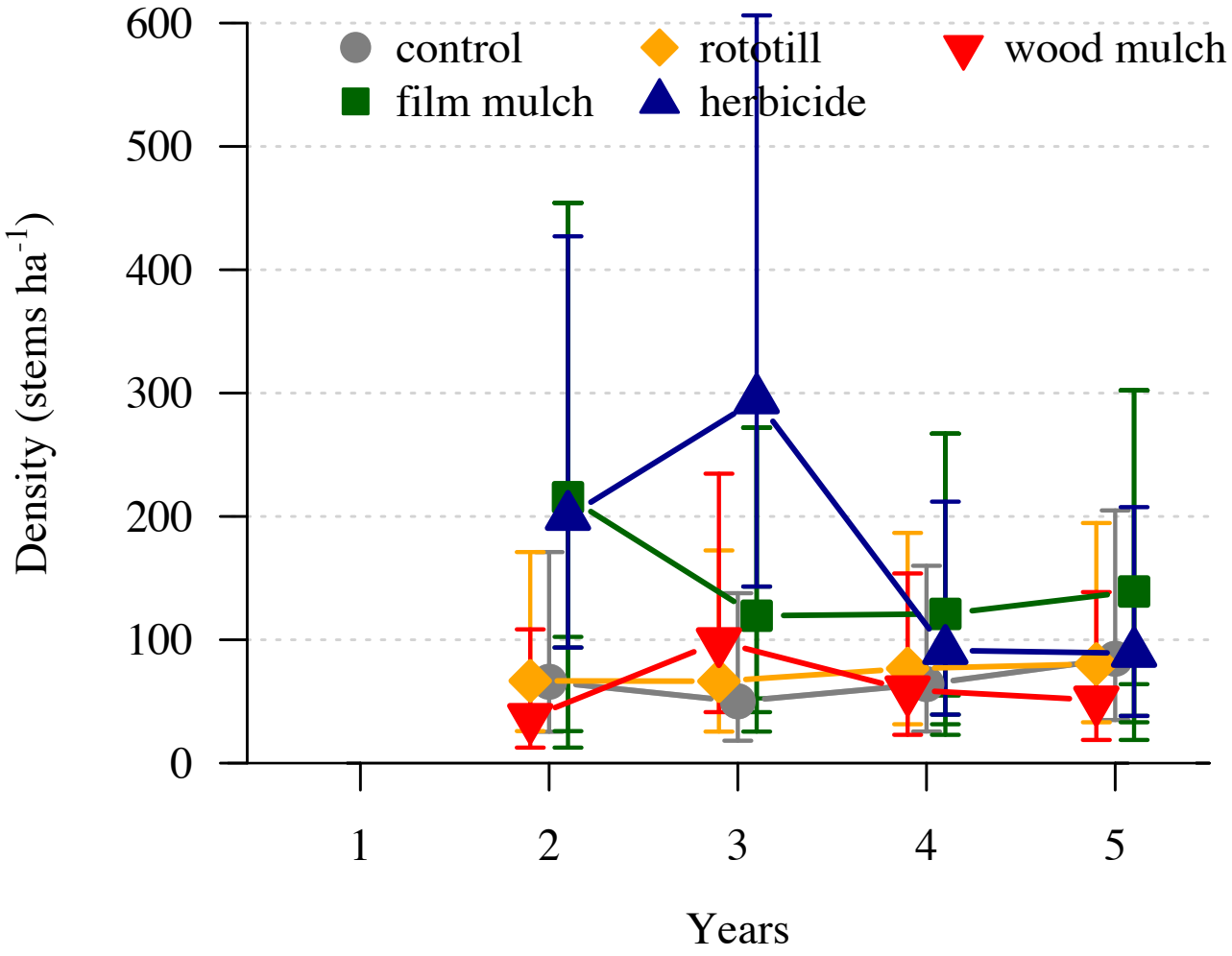
Stem density: aspen roots in a bag

- In general, a big fail considering the quantity of little root plugs installed (4,500 per ha).
- Interesting trend with pre-emergent herbicide treatment ~ does suggest early competition is important for the relative success of this treatment



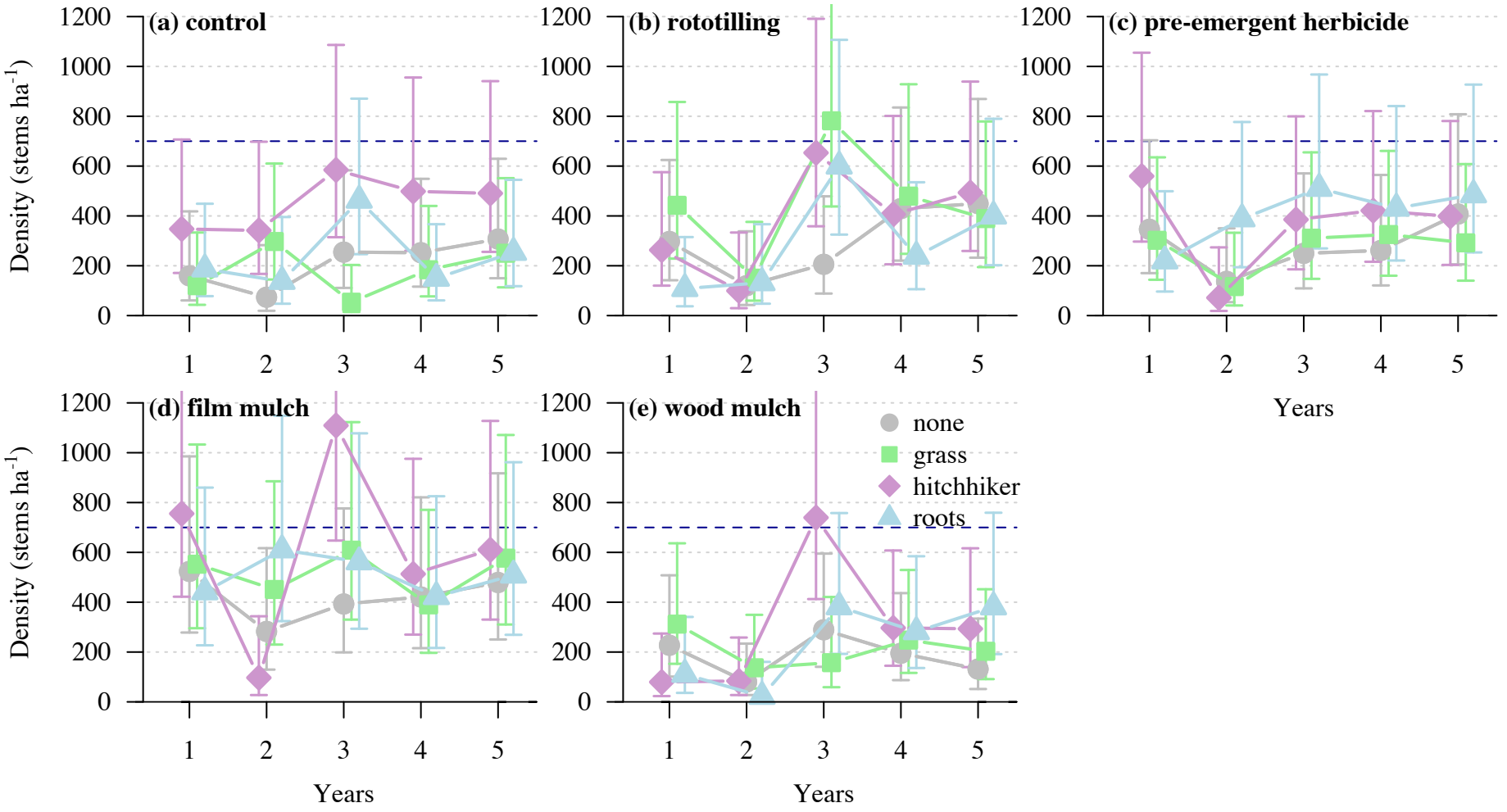
Stem density: balsam poplar

- This species should have had better survival, but it was planted a growing season behind everything else. Often into a substantially competitive growing environment.
- Initially it appeared that film mulch and pre-emergent herbicide were beneficial, but this trend has dissipated over time; likely due to climatic factors between year 3-4.
- Initial planting density was 1,000 stems ha^{-1}. Basically 90% mortality experiment wide. This really illustrates the importance of timely planting, it cannot be overly emphasized how critical this is for survival.



Stem density: white spruce

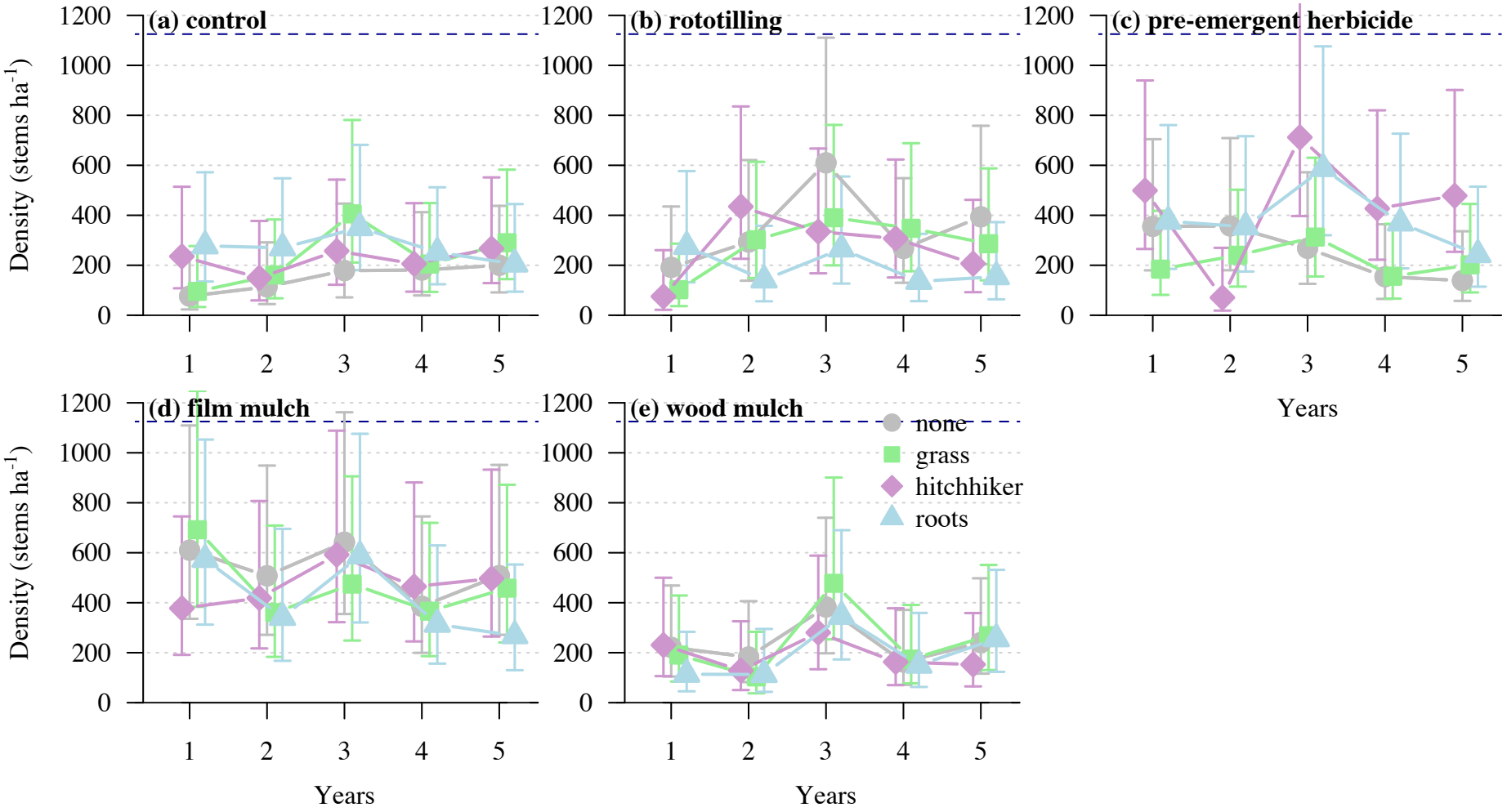
- Spike in year 3 associated with improved visibility experiment wide – downward trend thereafter (in some cases) with progressive drought conditions.
- After 5 years, film mulch had consistently good survival with all other treatments varying substantially by the native forb treatment.
- Hitchhiking and Roots treatments often associated with higher density (survival).



Stem density: shrubs

- Shrubs: willows, green alder, buffaloberry and roses (raspberries excluded)
- Native plant treatments had strong influence on shrub survival (density) within weed suppression treatments.

- Highest survival associated with Pre-emergent herbicide + hitchhiking = most film mulch treatments (except roots) at ~500 stems ha^{-1}.
- Most other treatments varied from 200 – 300 stems ha^{-1}.



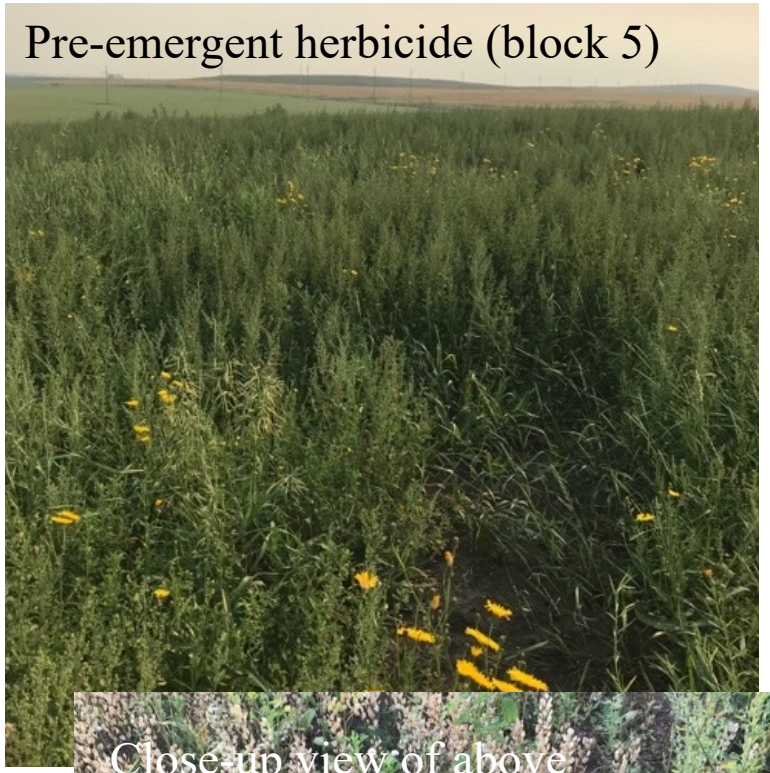
No treatment: year 1

Year 5

Film mulch: year 1

Year 5

Pre-emergent herbicide: year 1



Year 5

Summary

- In the context of establishing native forest vegetation in the aspen parkland, clearly, everything wants to kill our trees. In the short term, non-native forb competition has been an important driver with climatic factors becoming increasingly important in years 3-5.
- Treatments that appeared to reduce the abundance of non-native forbs:
  - Pre-emergent herbicide + native forbs (either hitchhiked or via roots) in the short term with all pre-emergent herbicide treatments associated with the lowest NNF cover after 5 years (~20%).
  - To a lesser extent, Film mulch provided some non-native forb reduction in the first 2 years.
- In general, treatments that supported the highest relative survival of planted trees and shrubs:
  - Film mulch > Pre-emergent herbicide >> Control = Wood mulch = Rototilling
  - Within site treatments, hitchhiking / roots application of native forbs were often associated with improved tree/shrub survival outcomes

If I could go back in time – what would I do differently?

- Completed all soils-related treatments in the fall prior to planting.
  - This would have kept higher soil moisture in spring, desirable for planting
  - This would have made the pre-emergent herbicide treatment more effective
- RipPlow^{TM} treatment as the surface soil disturbance treatment rather than further discing.
  - This would have created more hills and valleys to better capture soil moisture
  - This treatment is effective in improving hydraulic conductivity
  - The above points may have better mitigated for the low snowpack winters and prolonged summer droughts that were prevalent through a large part of the study time frame.
- Planted a higher effective density of trees + tall shrubs.
- Planted more balsam poplar and less aspen.
- Swap out green alder for river alder ~ this species seems to be more suitable for wide ranging soils, green alder really prefers loamy-sandy soils with low EC.
- Swap out buffaloberry for sandbar willow ~ more work needs to be done to understand the use-case for buffaloberry as it is sensitive to conditions. It is thriving in bits and pieces throughout the site but is completely absent in other areas.

Operational recommendations

- For large-scale revegetation programs, plant a diverse mix of trees and shrubs. Consider planting at least 4,000 or even 5,000 stems ha^{-1} to buffer for mortality. If you are lucky and mortality is low, then you will achieve forest canopy closure faster.
  - Development of forest cover is the best long-term strategy to mitigate for ongoing weed invasion.
  - Diversity of trees: hardwoods and conifers. Mix aspen and balsam poplar (or possibly birch) to mitigate for biological and abiotic factors.
  - Focus on tall shrubs: these will be more likely to support forest canopy closure.
- While planting native forbs may be more expensive up-front, there does appear to be mounting evidence that this treatment is associated with better survival outcomes for other planted woody species.
- Film mulch is consistently beneficial in terms of tree survival ~ however, this treatment will not be operationally feasible in all situations. Use of pre-emergent herbicide offers the next best option in terms of mitigating for excess seed-based ruderal weed competition.

Acknowledgements

- NSERC, Capital Power (CP) and Westmoreland (WM) for funding, study site access and experimental set-up.
- Special thanks to CP staff both former and current: George Greenhough (retired), Jen Linder and most recently Megan Hill who have continued to provide site access and support our project; to the WM team (Kelvin Stevenson and Doug Bell) for supporting our field safety onboarding every year!
- Thank-you to the many summer students at NAIT who have supported the setup and monitoring of this study in the last 5 years!

NSERC CRSNG

Capital Power

WESTMORELAND COAL COMPANY

NAIT

More site and treatment images – time permitting

Wood mulch: year 1

Year 5

Rototilling – year 1

Year 5

Hitchhiking: year 1

Year 5

Roots-in-a-bag: year 1

Year 5