Biochar and High-Carbon Wood Ash in Forest Restoration:

an Overview of Field Trial Results from Boreal, Temperate, and Tropical Forests

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Ecological restoration

Definition: The process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value*

Common goals: (and expected biochar addition effects)

- Increased primary productivity ✓
- Reduced bioavailability of toxics ✓
- Enhanced performance of valued species ✓
- ***Biodiversity / Natural community structure ?***

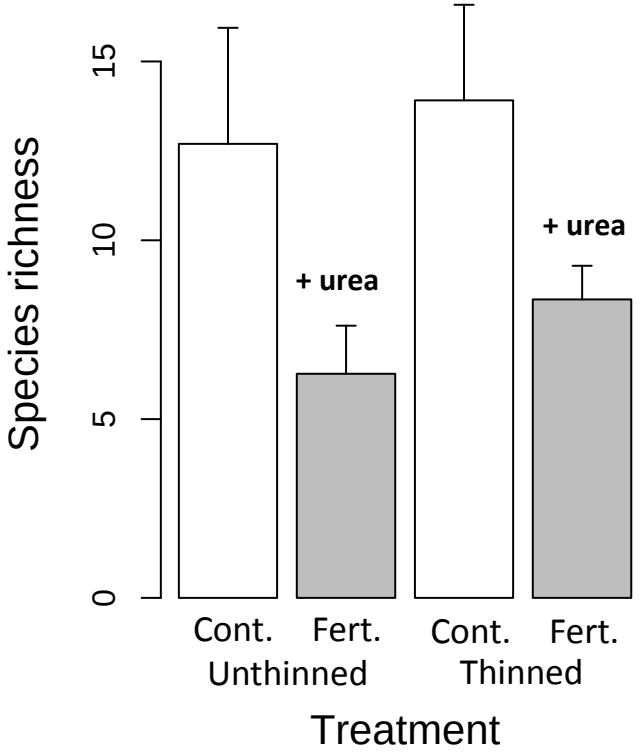
*Martin, DM (2017) *Restoration Ecology*, *25*(5), 668-673.

Biochar and biodiversity?

- Many studies have found large **negative** effects of fertilization on plant diversity (including one published boreal forest study)

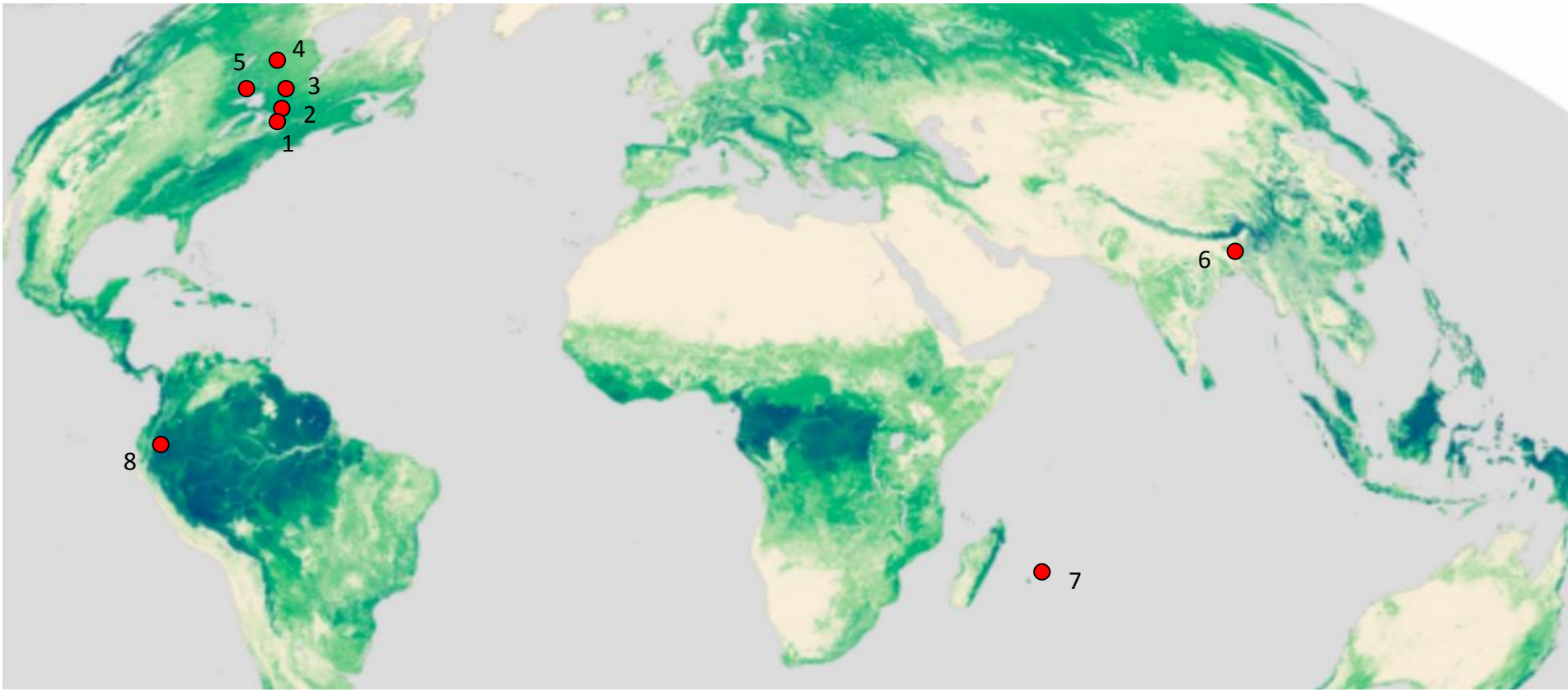
- Mechanisms include
  - enhanced competition
  - toxicity effects

- Is biochar different?
  - High K & P, low N
  - Increased water retention
  - Sorption of toxics, allelochemicals
  - Analog of fire residues in fire-adapted systems



Example: Understory vegetation in managed Douglas-fir after 20 years (Thomas et al. 1999, Ecol. Appl. 9: 864–879)

Thomas lab field trial locations



(1) Downsview Park, Toronto, (2) Haliburton Forest, (3) Porcupine Mine ON, (4) Musselwhite Mine ON, (5) Kakabeka Falls ON, (6) Sylhet, Bangladesh, (7) Black River Gorges NP, Mauritius, (8) CIPCA, Ecuador

Biochar types used in our experiments

Controlled pyrolysis chars:
Haliburton Biochar
Titan Bioenergy
Lallemand Plant Care

Conical kiln and tradiational chars:
Projects in developing countries

High-carbon wood ash:
Wood Ash Industries
Atitokan Power

Most widely available low-cost biochar in Canada
Several sources approved as "biochar" by CFIA

Natural post-fire chars:
Not economically feasible, but informative…

Biochar as replacement product for lime

Forest charring:

- Replaces lime (which is important source of atmospheric CO_2)
- Carbon sequestration benefits
- Addresses nutrient imbalance caused by N deposition
- Potentially enhances fire-adapted species

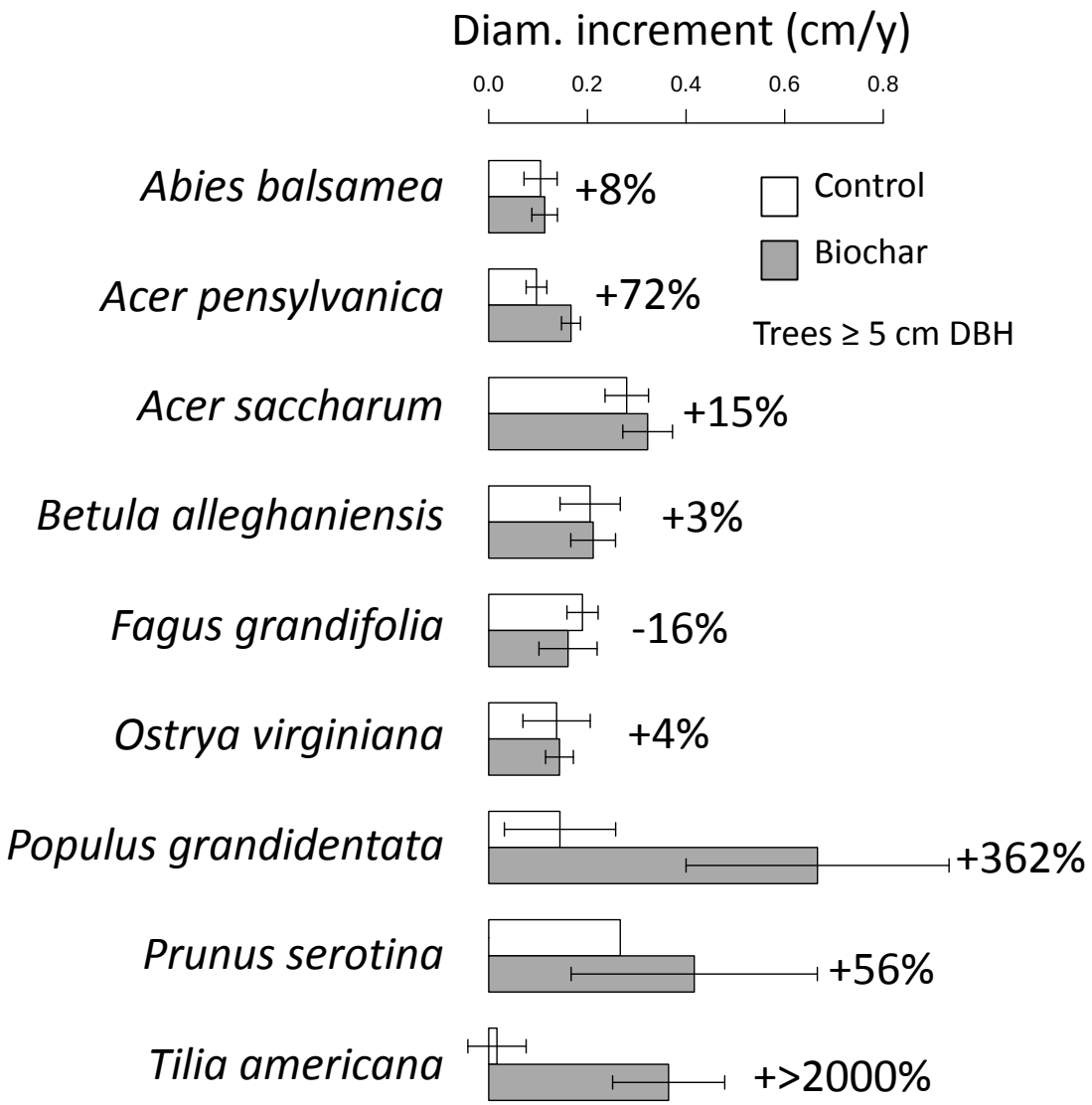
Stand-scale experiment (2012-):
30x30 m plots, crossed biochar x P addition; complete randomized block x 4 replicates – **5 t/ha – sugar maple feedstock at 550°C**

Tree growth responses by species

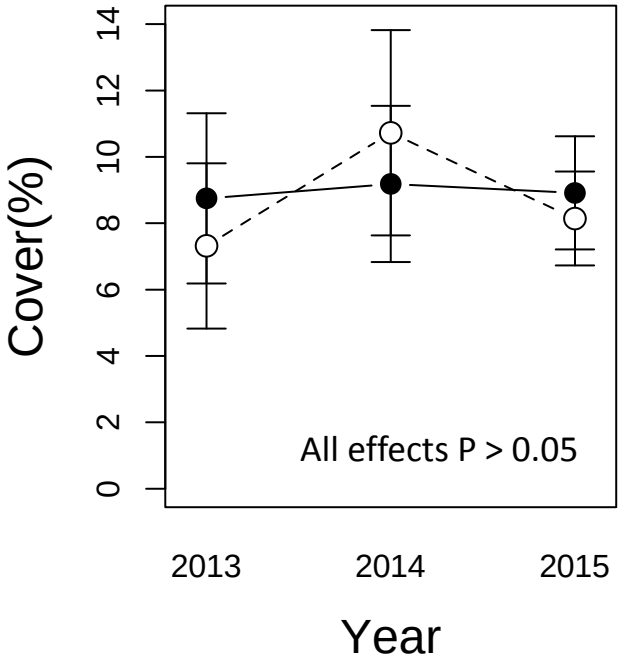
Year 3 (2012-2015) response for species with ≥20 stems

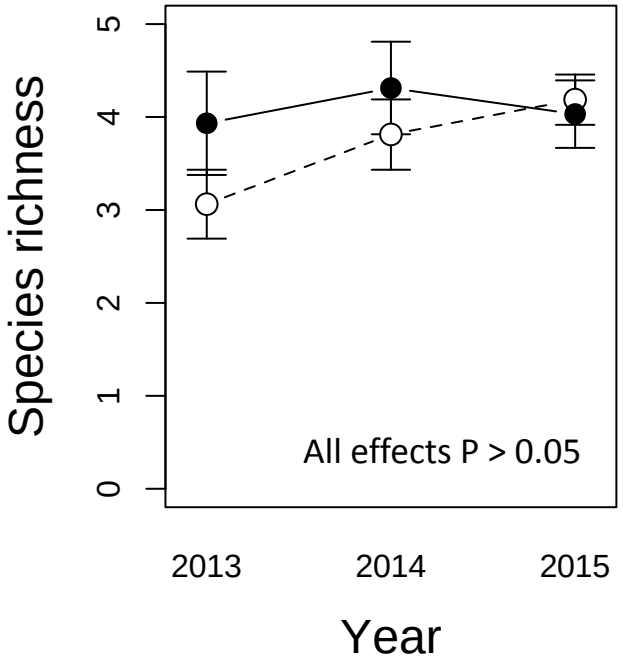
(N = 2309 stems total)

ANOVA results: random plot term ns, species x biochar interaction: *P* = 0.0014



Forest understory response





Control

Maple biochar (5 t/ha)

Total of 64 1x1 m plots

Additional analyses

- No effect on species composition
- Positive effect on *Trillium erectum* flower production

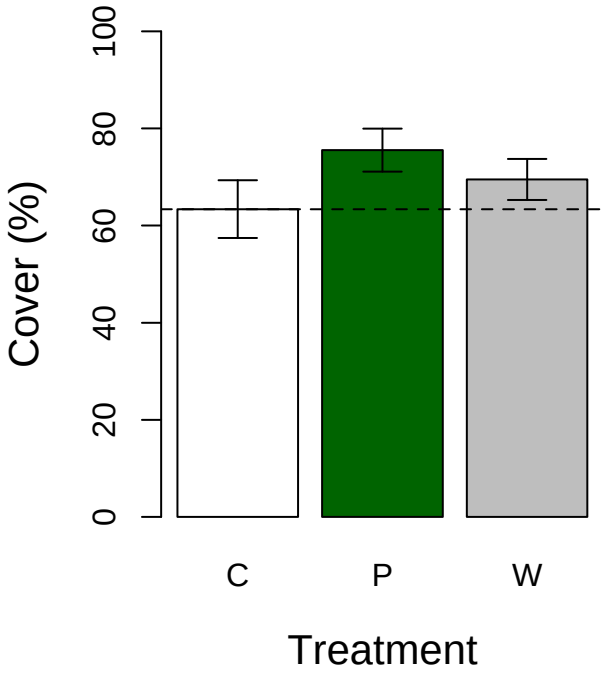
Operational forestry in boreal region

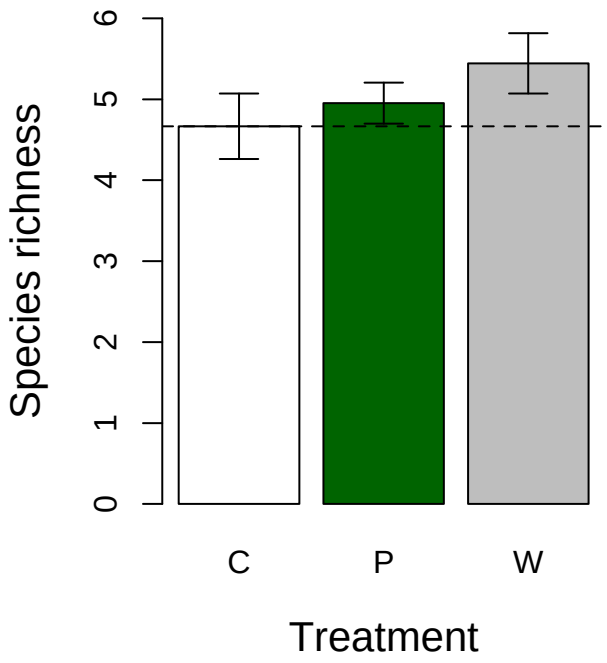
Kakabeka Falls experiment

- Operationally clearcut in 2013; planted with white spruce in 2014 (containerized 1+1 stock at 2.2-m spacing)
- Treated with poplar-feedstock biochar and high-carbon wood ash in 2014
- 5x5-m randomized block design; 7 replicates / treatment
- Measurements made on tree performance, soil chemistry, soil temperature, and ground vegetation (2014-2017)

Jillian Bieser PhD project:
In press, CJFR

Boreal clearcut at 3 years





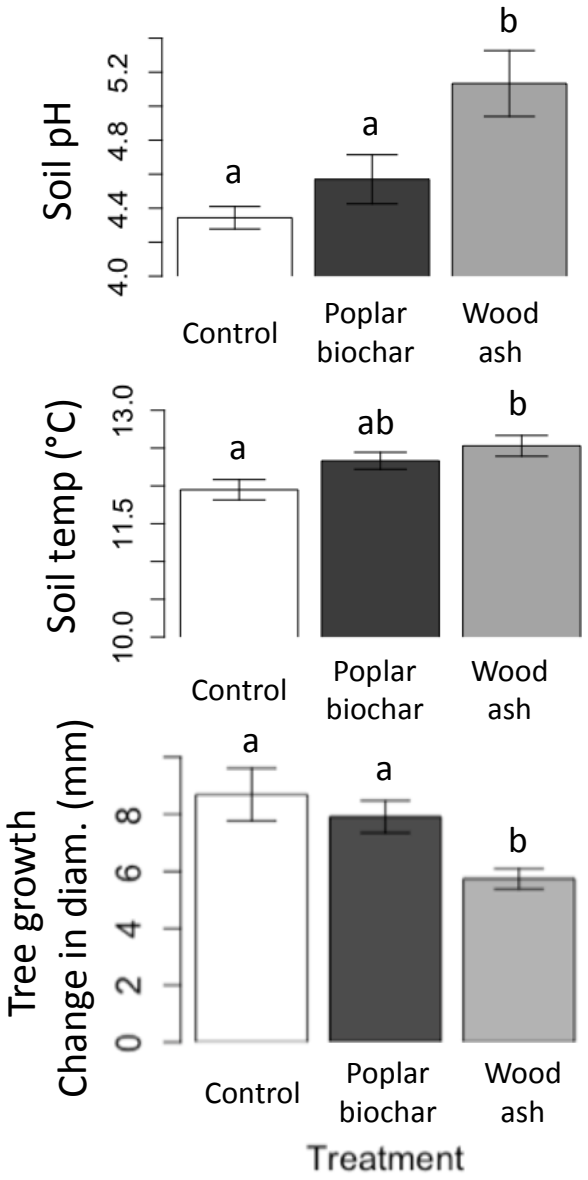
Control
Poplar biochar (5 t/ha)
High-C wood ash (5 t/ha)

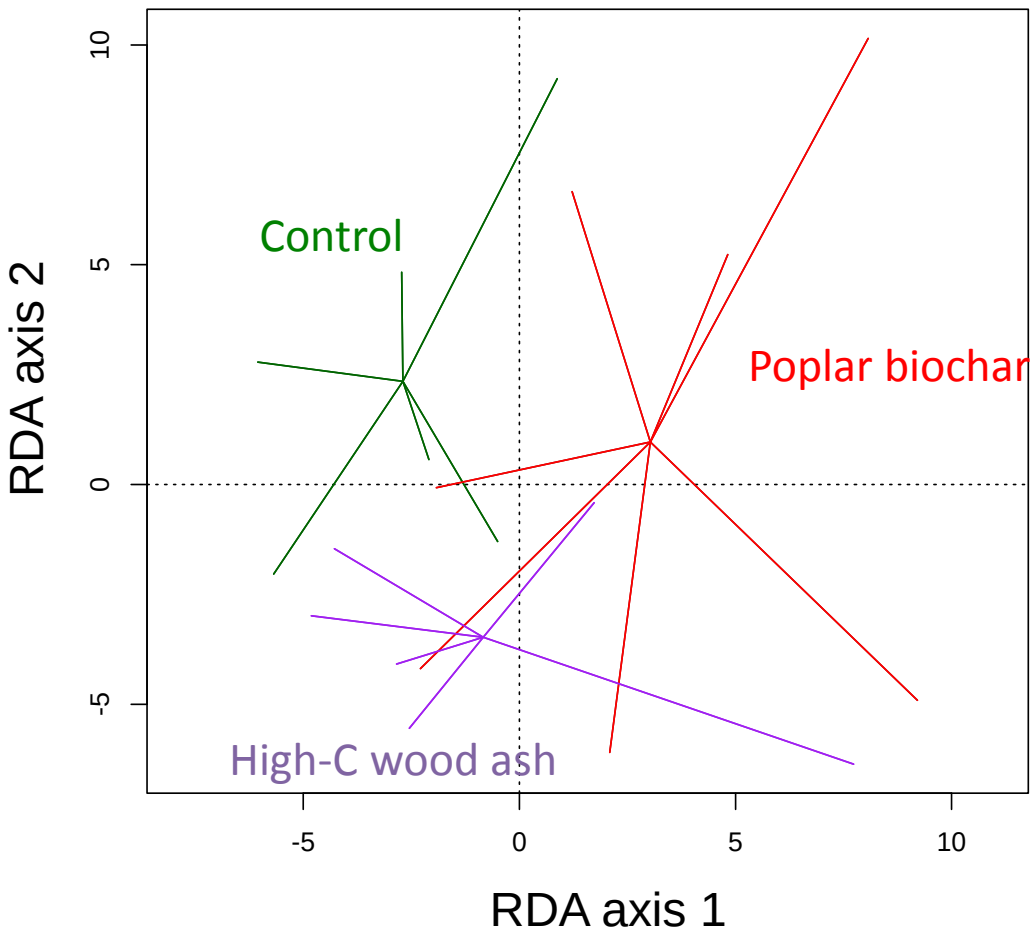
All effects P > 0.05

Additional responses

- Large effect on species composition
- Increase in soil pH
- Increase in soil temperature within first month of addition
- Negative effect of high-C wood ash on planted spruce growth

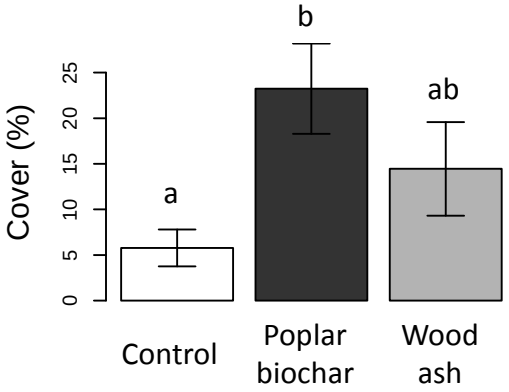
Soil and vegetation composition responses



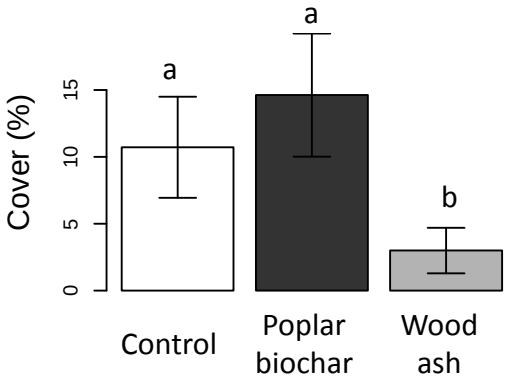


Multiple generalized linear model analysis
Biochar treatment: *P* = 0.006

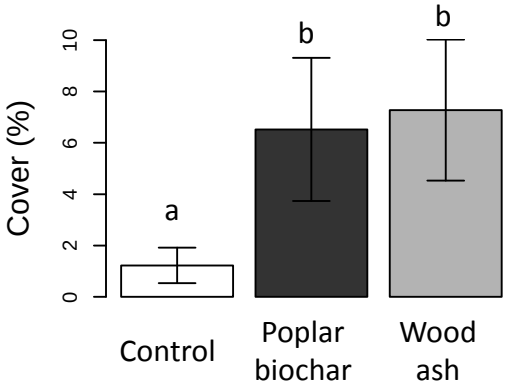
a. *Rubus ideaus*



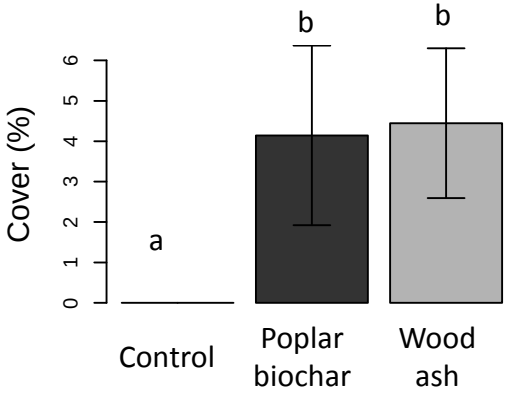
b. *Symphorocarpus albus*



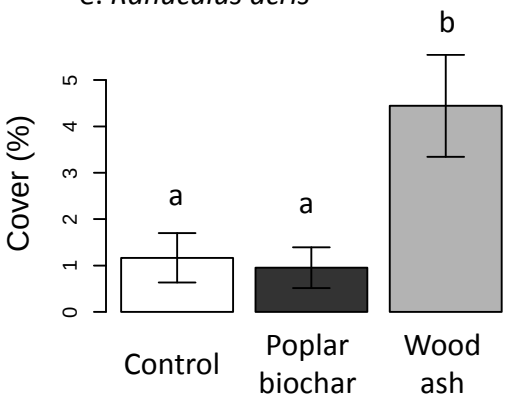
c. *Solidago canadensis*



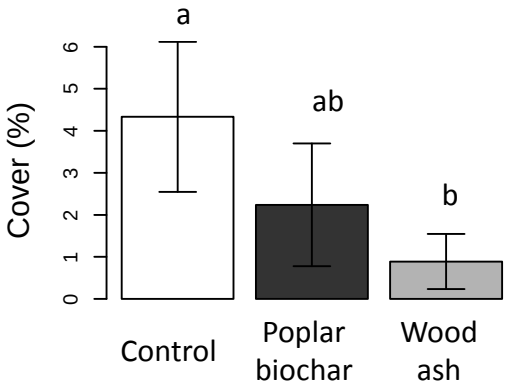
d. *Vicia cracca*



e. *Ranuculus acris*

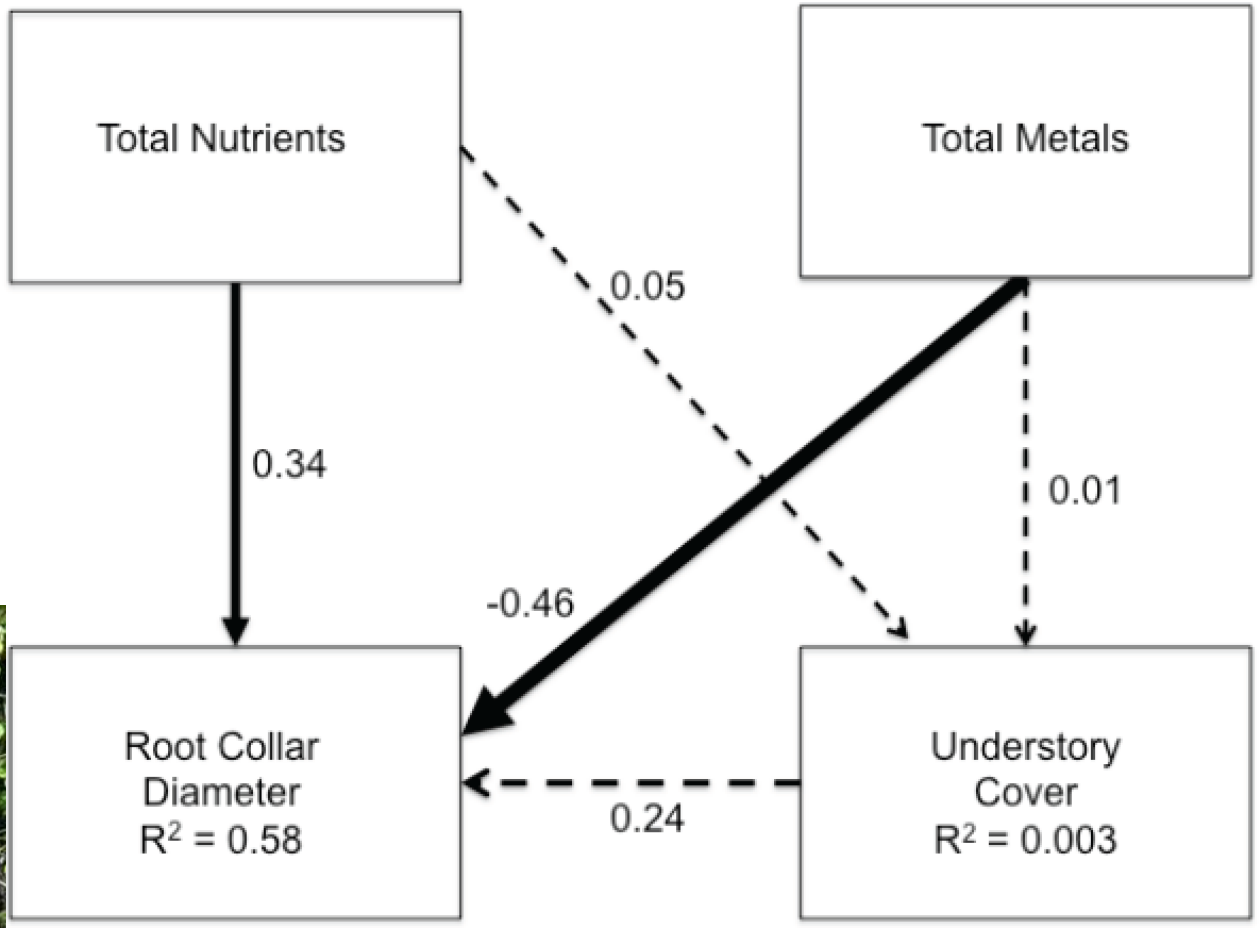


f. *Salix bebbiana*



Structural equation model
(predicting tree growth responses)

First PCA of:
B, Ca, S, K, Mg, Mn, NH_4+, NO_3-, P



First PCA of:
Cu, Pb, Zn, Al, Cd, Fe

- Red: increased with biochar or wood ash treatment
- Solid lines: $P < 0.05$

Mine tailing restoration trials, northern Ontario

Special emphasis on dose-response relationships: How much biochar? Of what type?

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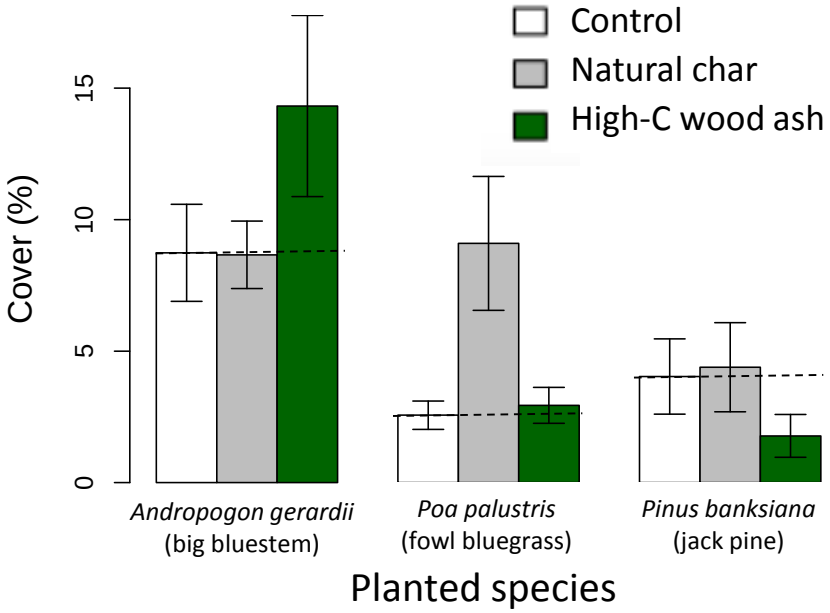
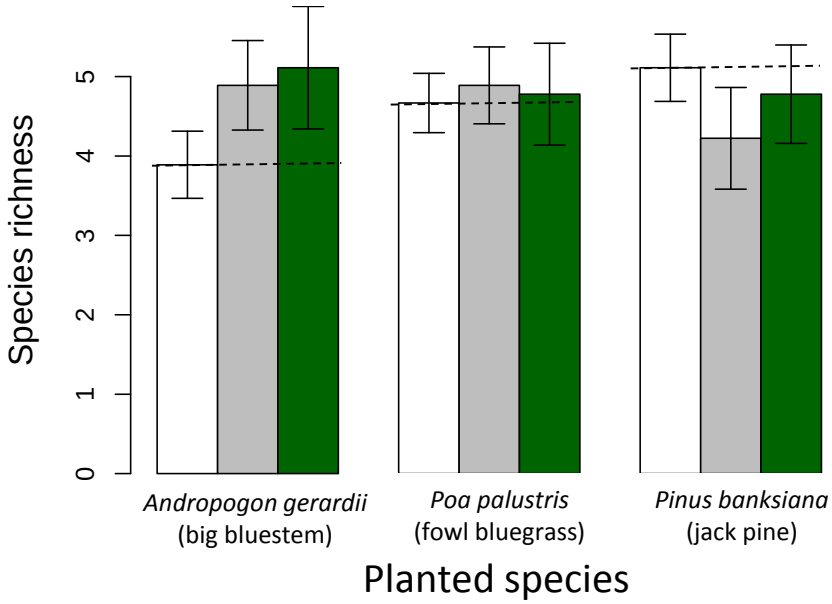
Plant cover and diversity responses





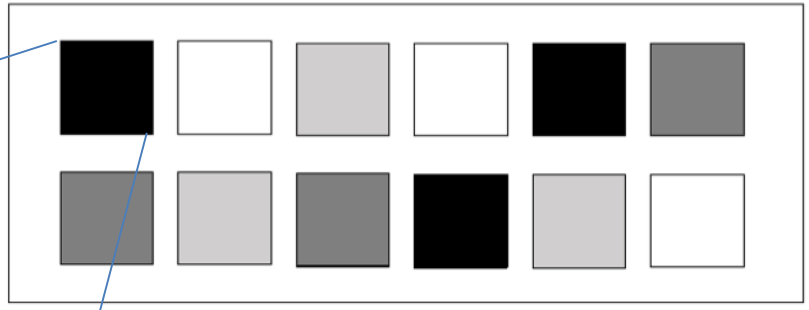
ANOVA: Biochar: $P > 0.05$
(cover) Species: $P < 0.001$ S x

All terms ns for species richness

(Jillian Bieser PhD work)

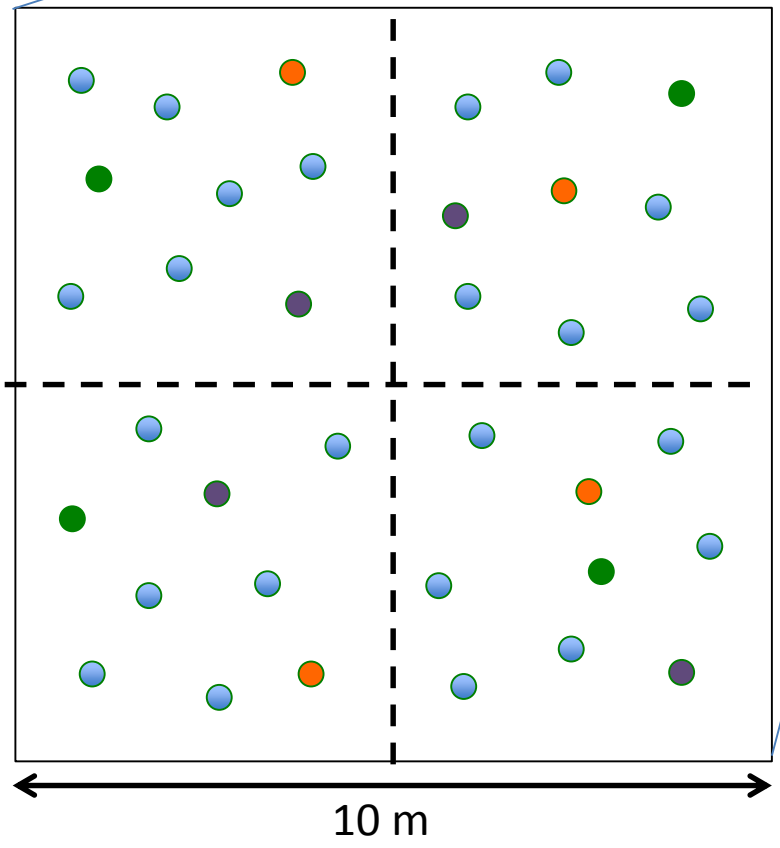
Large-scale high-C wood ash dose-response trial

Experimental / planting design
Large-scale high-C wood ash trial



High-C wood ash dosages

- 0 t/ha (control)
- 6.4 t/ha
- 12.8 t/ha
- 19.1 t/ha

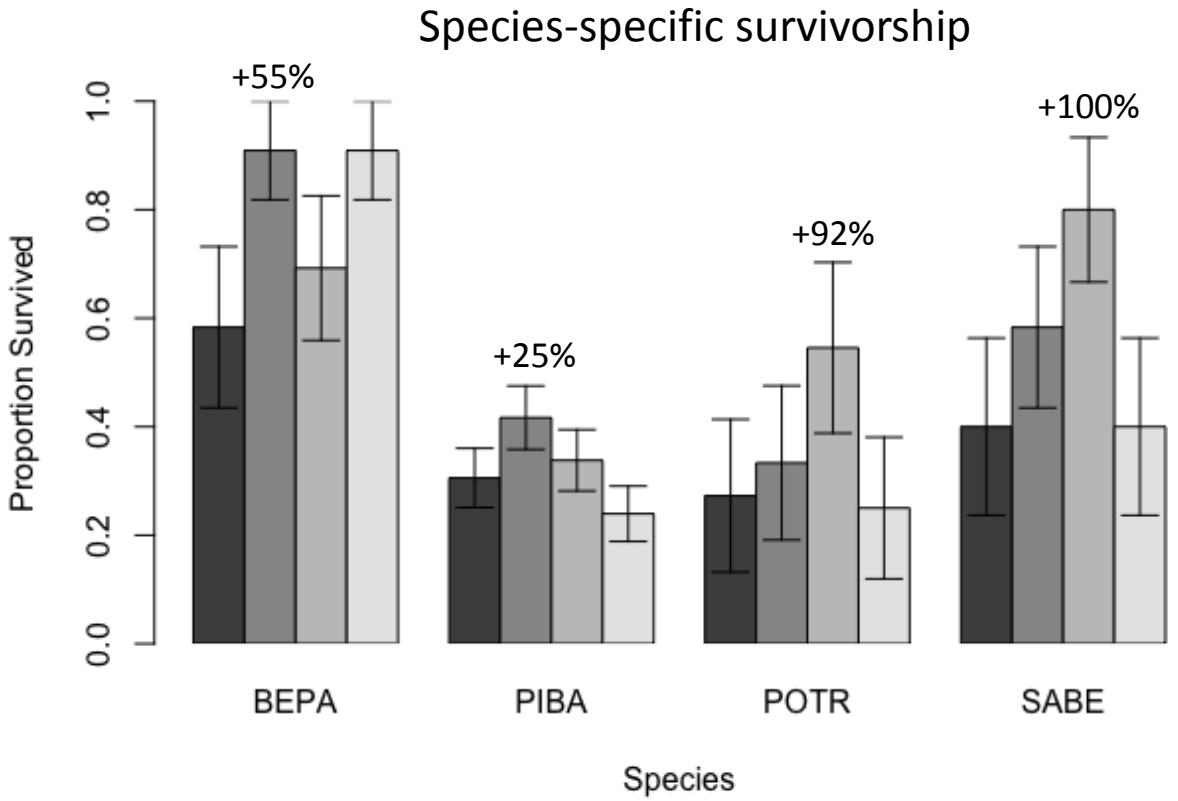


- Jack pine (67%)
- Trembling aspen (11%)
- Paper birch (11%)
- Bebb's willow (11%)

- Irregular pattern, min. 1m. spacing
- 36 trees / plot x 12 plots = 432 trees

288 Jack pine, 48 other species

Sapling survivorship at 1 year



Linear mixed effects model:

$p_{species} < 10^{-8}$

$P_{\text{species x dose}} = 0.05$

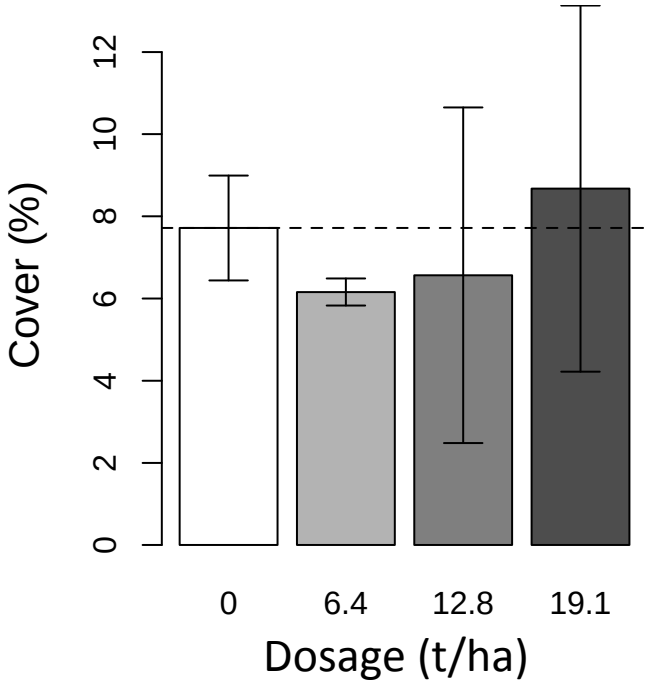
Dosage(t/ha)

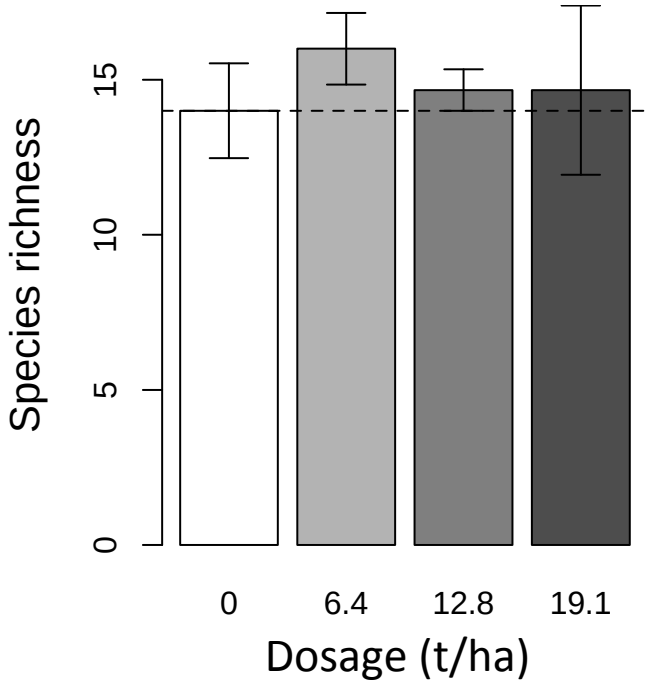
- 0
- 6.375
- 12.75
- 19.125

BEPA: *Betula papyrifera*
PIBA: *Pinus banksiana*
POTR: *Populus tremuloides*
SABE: *Salix bebbiana*

Musselwhite large plot vegetation responses

(year 1)

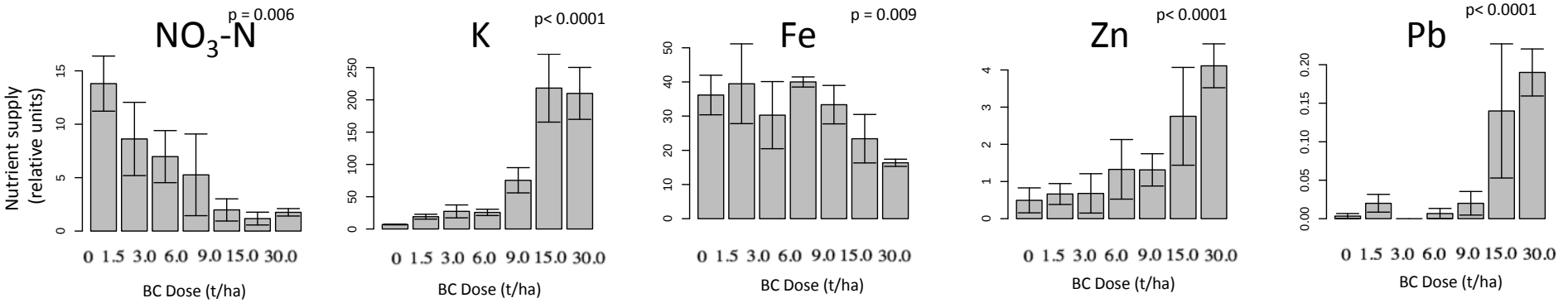


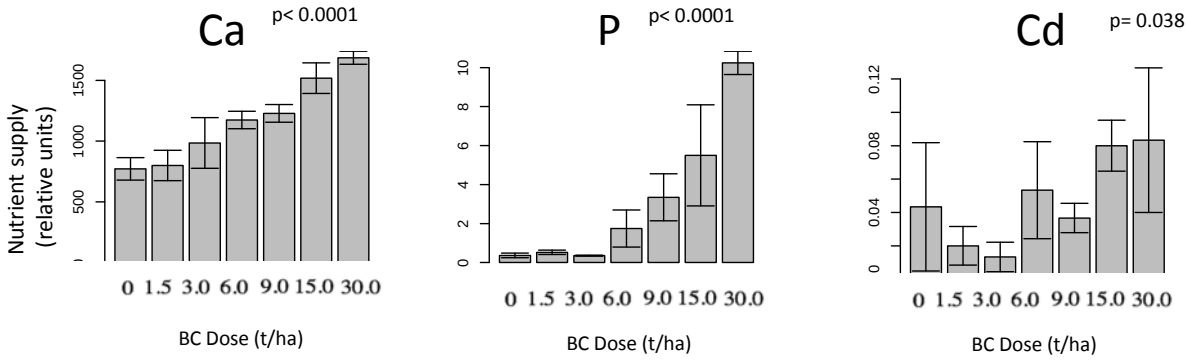


ANOVA results:
Cover: ns
Species richness: ns

Delnite study:
Dose-dependence of high-C wood ash on soil chemistry

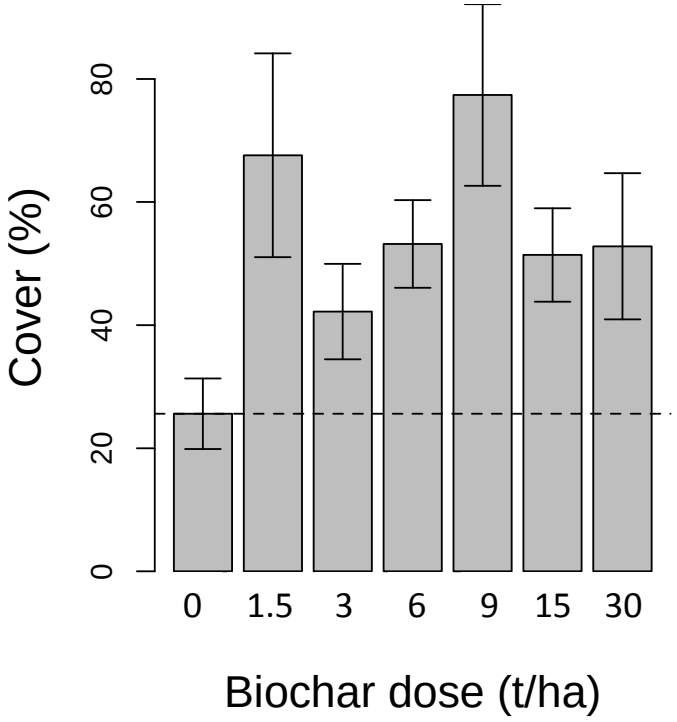
Delnite site (Porcupine, ON)

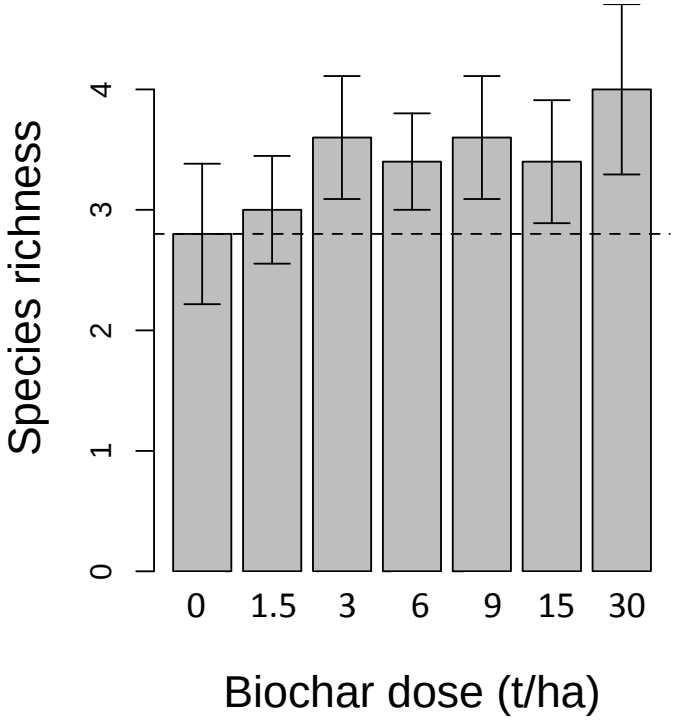




(Jasmine Williams PhD work)

Delnite study vegetation responses





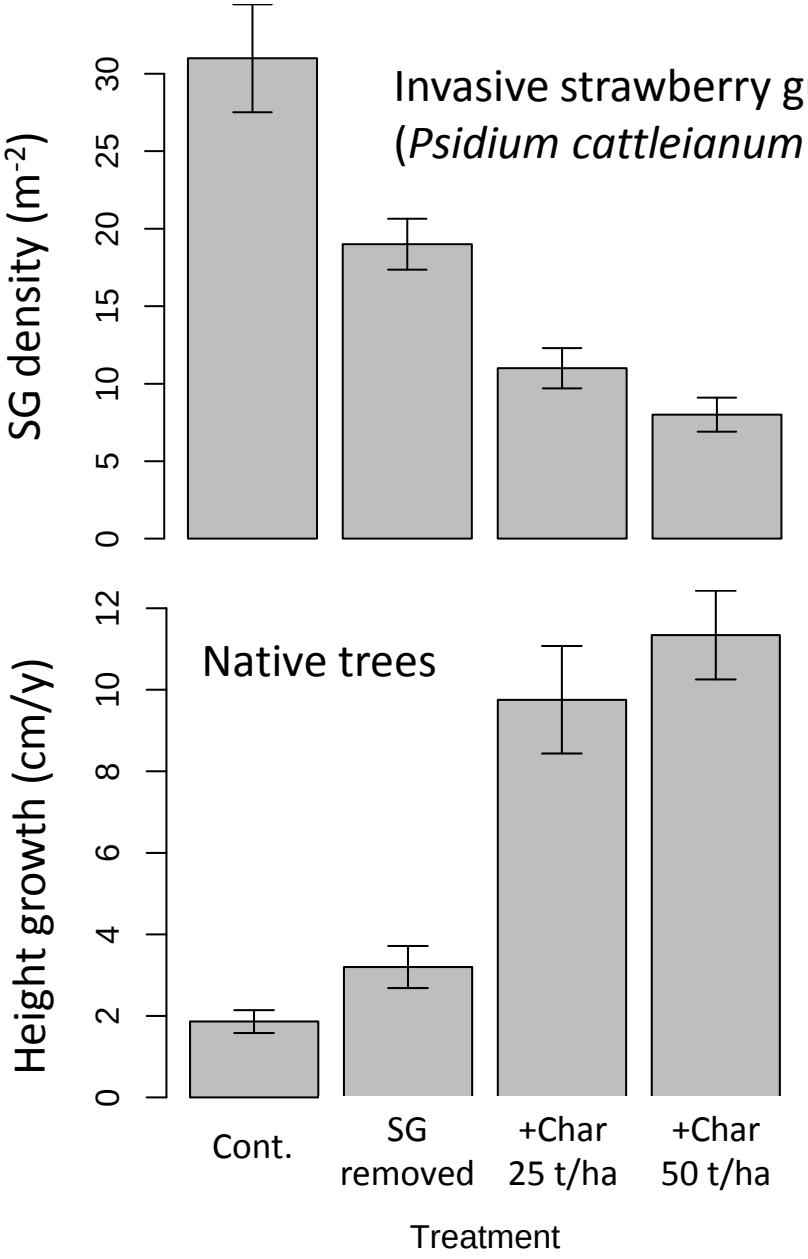
ANOVA results:
Cover: p = 0.013
Species richness: p = 0.210

Site has remained large sparsely vegetated for 30+ years

(Jasmine Williams PhD work)

Mauritius field experiment: combatting strawberry guava

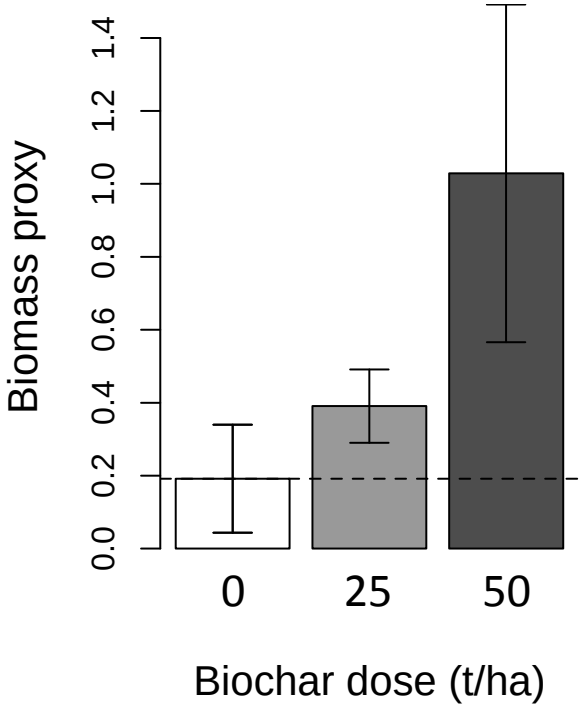
(year 1 results)

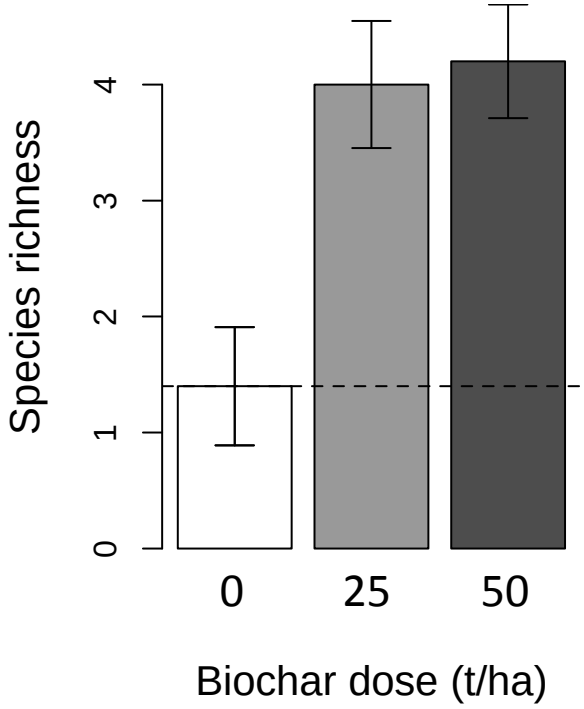


Native tree recruitment in a biochar-amended plot in Black River Gorges National Park, Mauritius

Mauritius vegetation responses

(year 2)





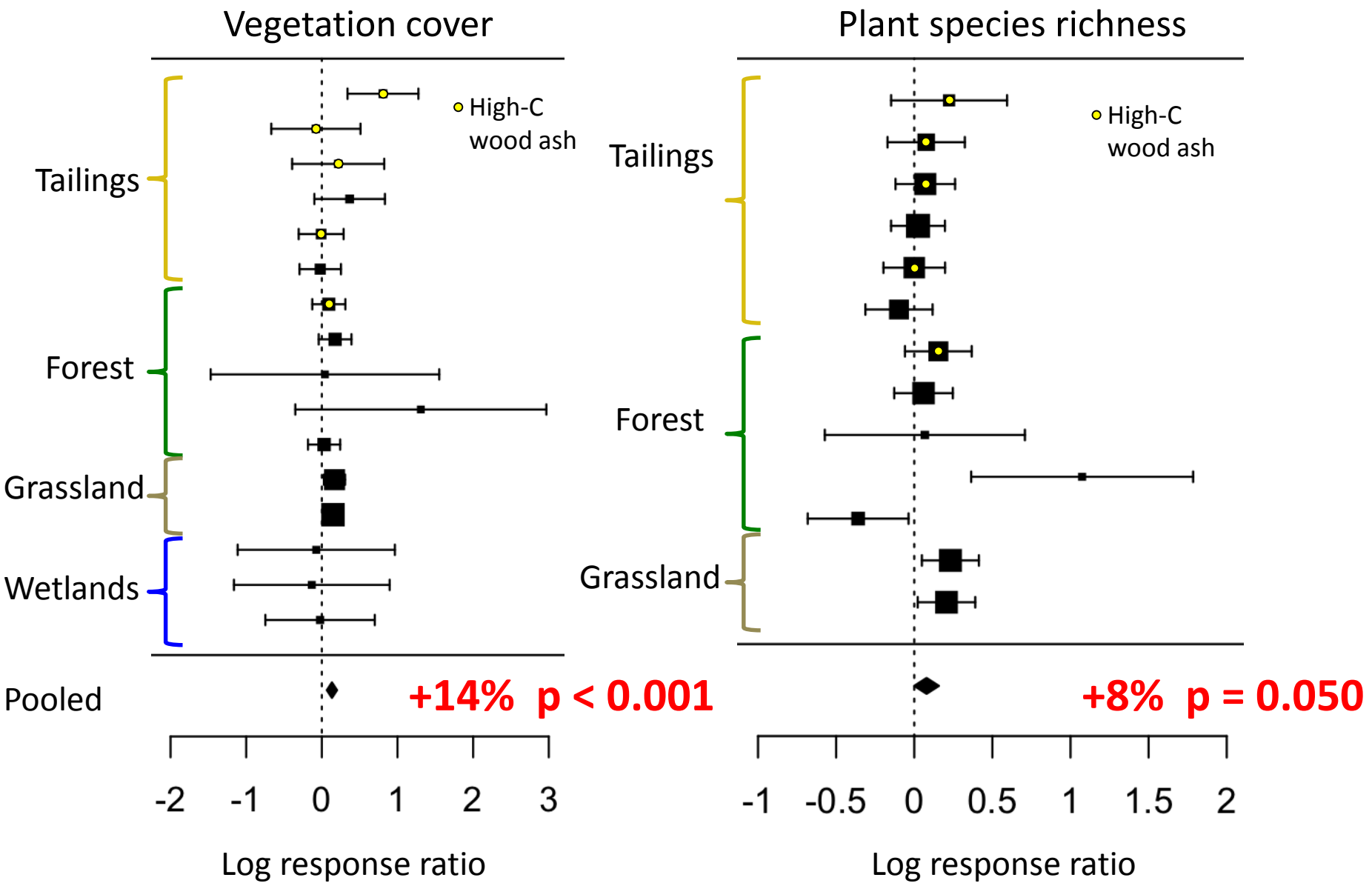
ANOVA results:
Biomass proxy: ns
Species richness: p = 0.004

<1% remaining forest on island; ~2/3 of plants are endemic

(Lutchmee Sujeeun PhD work)

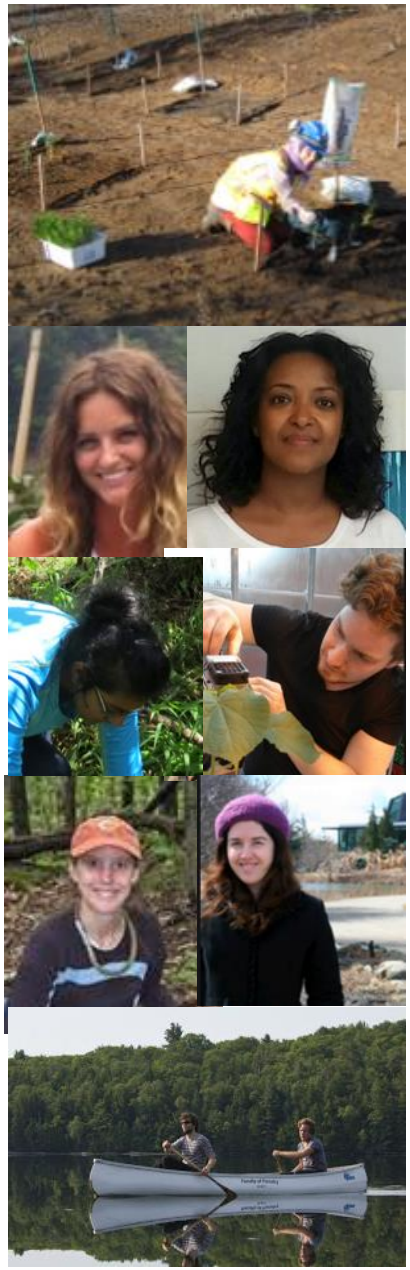
Meta-analysis

(random effects model based on log response ratio)



Some take-home points

- Biochar additions in a restoration context generally enhance both plant cover and local species richness
- High-carbon wood ash is approved as a form of “biochar” under Canadian regulations – but can have negative impacts on tree performance due to high metals concentration
- High-carbon wood ash nevertheless has can have positive effects on revegetation and native species recolonization on mine tailings
- Realizing “win-win” (or “win-win-win”) scenarios for biochar demands finding the right biochar and the right dosage for specific applications



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Recent resurgence in policy interest

Oct. 25, 2018, US National Academy of Sciences report:

Concensus Report: Negative Emissions Technologies and Reliable Sequestration: A Research Agenda

Five *existing* technologies for negative emissions:

1. Protect forested coastal wetlands
2. Plant trees (carbon-centered reforestation)
3. Carbon-centered forest management
4. **Produce and apply biochar**
5. Biomass Energy with Carbon Capture and Storage (BECCS)