

Use of Industrial Residuals and Earthworks in the Reclamation of Abandoned Aggregate Pits in Sudbury, Ontario, Canada.

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Sudbury, Canada today

160,000



Present Sudbury Rehabilitation Strategy:

Aiming for Biodiversity and Carbon Sequestration on landscape affected by Ni-Cu smelting

- Crushed limestone (dolomitic) – 10 t/ha
- Fertilizer (6-20-20) - 200 or 400 kg/ha
- Initial seed mixture (mostly native grasses)
- Over 85 native tree and shrub species used:
(for habitat, structure, food and general diversity)
- Forest Floor mat and other transplants



Sudbury Regreening Program 1978 - 2023

1979



Tree Seedlings Planted 10,144,500

2004



Program Cost \$38,466,000

Temporary Employment 4,868

Awards – 15

1987



Shrubs/Understory Trees 530,000

Area Limed-Fertilized-Seeded 3,500 ha

Forest Floor Transplants 2.2 ha

(ca 1700 plots)

2023



Number of Schoolyards Regreened 50

Volunteer Tree Planters 13,200

Trees Planted by Volunteers 388,600

Trees for Residential Plantings 431,000



Limitations

Dolomitic limestone is expensive and causes land disturbance.
Takes time to build up carbon



Lime Stabilised Municipal Biosolids (LSMB)



Blended Pulp Mill Sludge (PMSs and PMSk)



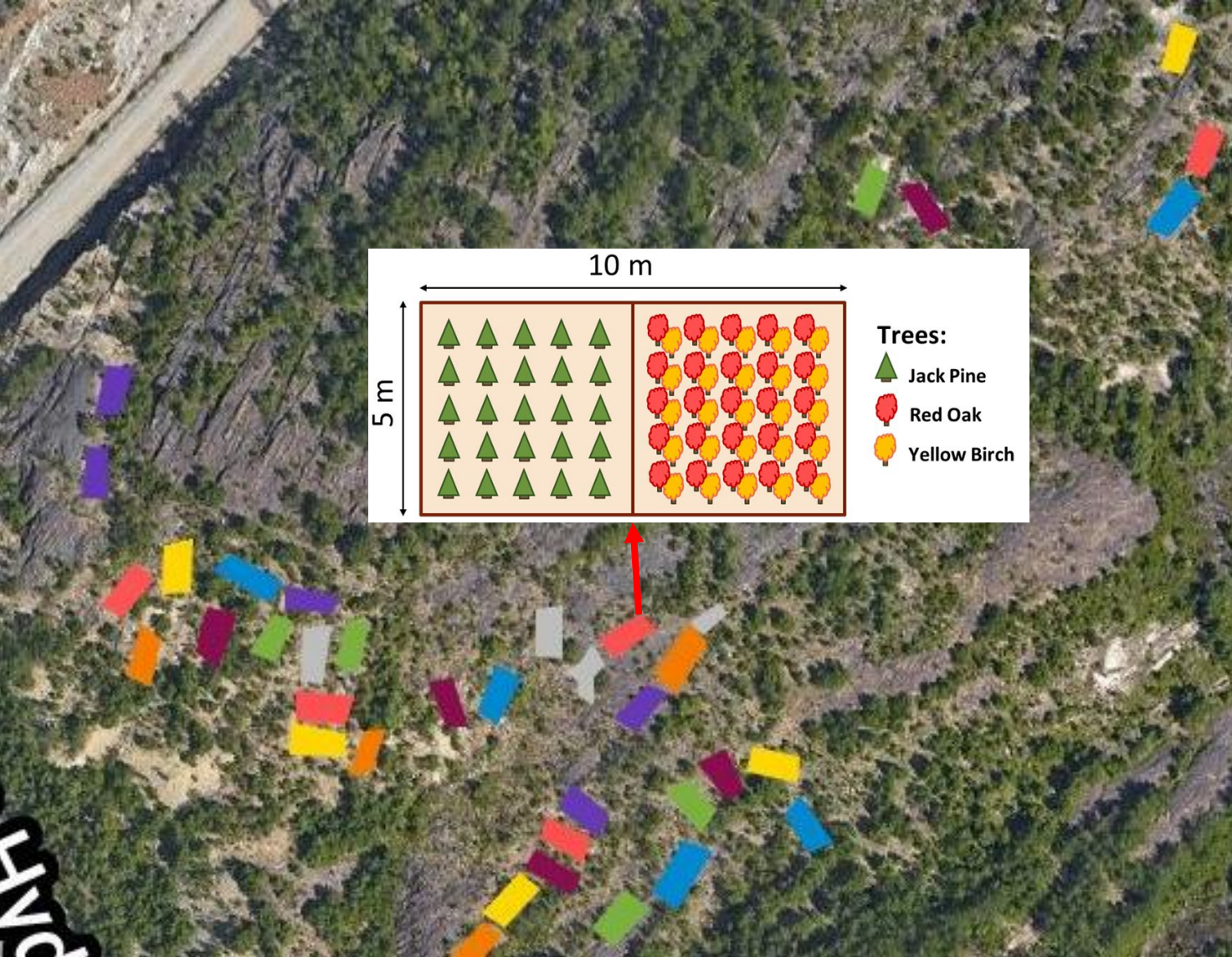
Biomass Boiler Fly Ash

Need for alternative
source of organic
matter

- Industrial solids may fill gap in regreening program
 - Elevated in organics with proper C:N ratios
 - Moderate plant essential nutrients – excellent liming capacity
 - Readily available in large volumes – otherwise landfilled



We applied industrial solids to 2 sites representing the region's most disturbed areas (red circles)
 These are highly acidic (~ 4), with elevated plant available metals
 Both have erosion prone, infertile soils with negligible organic matter
 Vegetation is dominated by acid tolerant pioneer mosses and lichens, with the occasional white paper birch and frequent planted pines



Treatment and Application Rate

Control

Limestone (10 t/ha) + NPK fertiliser (400 kg/ha)

Pulp Mill Sludge-Kraft (73.6 t/ha)

Pulp Mill Sludge-Sulfite (5 t/ha)

Pulp Mill Sludge-Sulfite (5 t/ha) + Ash (20 t/ha)

Ash (20 t/ha) + NO₃ fertiliser (74 kg/ha)

Lime Stabilized BiosolidsB 1 (20 dry t/ha)

Lime Stabilized Biosolids 2 (40 dry t/ha)

8 treatments in all, 2 sites, 5 replicates, 75 seedlings per = 6000 seedlings planted
Over 15 tonnes of material applied by hand over a 4-week period
Seedling (height, survival chlorophyll content), vegetation response, changes in soil chemistry, structure, and microbial/fungal communities were monitored for 4 growing seasons (2019-2022)



Recruitment

- Rapid reactivation of pioneer mosses *Pohlia nutans* and *Polytrichum juniperinum*
- Followed by native grasses (e.g., *Danthonia spicata*), herbs, (e.g., *Chamaenerion angustifolium*)
- Most recently pioneering trees (e.g., *Populus tremuloides*)
- More rapid colonization than just adding limestone



2019

Chlorotic growth, lichen dominated,
mosses present but seemingly dormant

2023

~100% vegetated, multi layered
healthy new growth

Pulp Mill Sludge and Boiler Fly Ash

Sulphite Sludge + Ash



>90% bare soil – lichens gone, made things worse

Kraft Sludge



Exotics issue, some native recruitment, pioneer mosses reappearing

Discussion

- Mosses performing their function, creating mild, humid zone encouraging recruitment and growth, preventing erosion
- Given their similar properties, why the significant differences in vegetation between LSMB and PMS/BBFA?
 - Rapid N turnover?
 - Higher albedo?

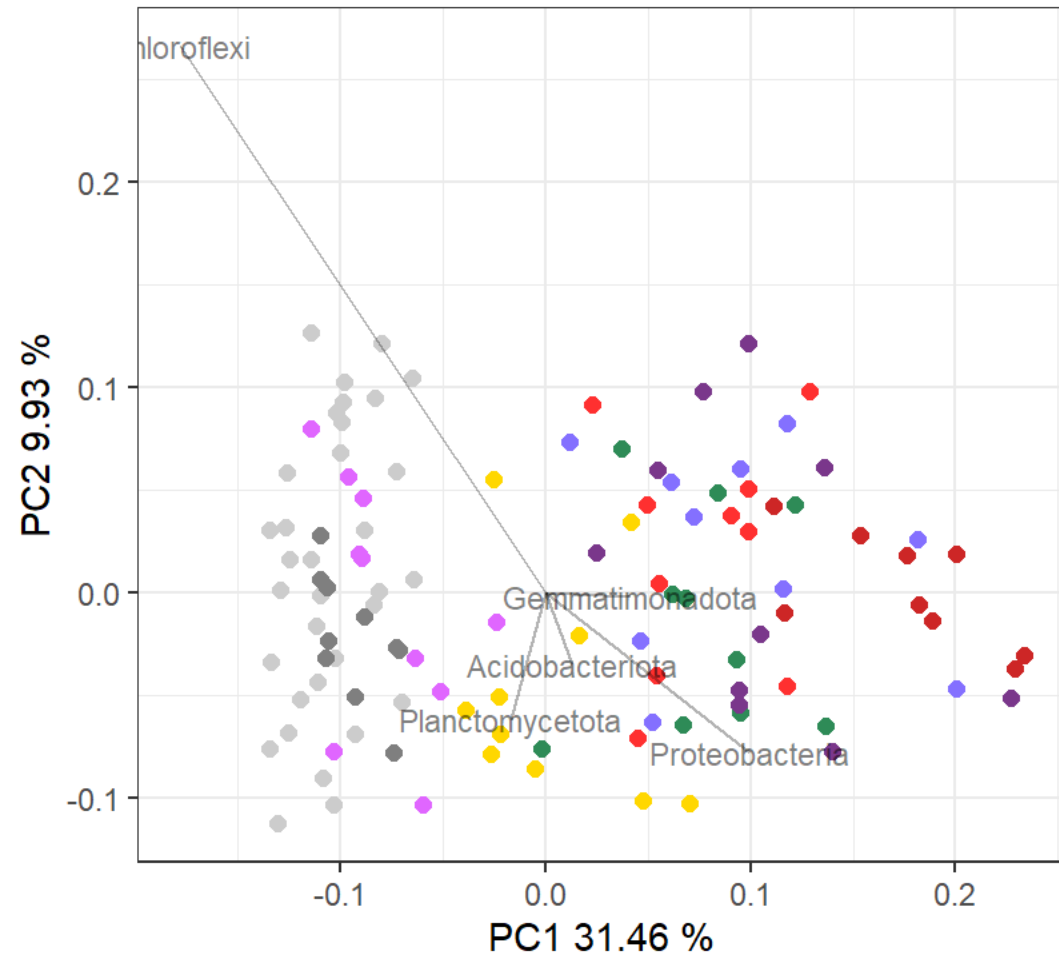


LSMB 1yr post application

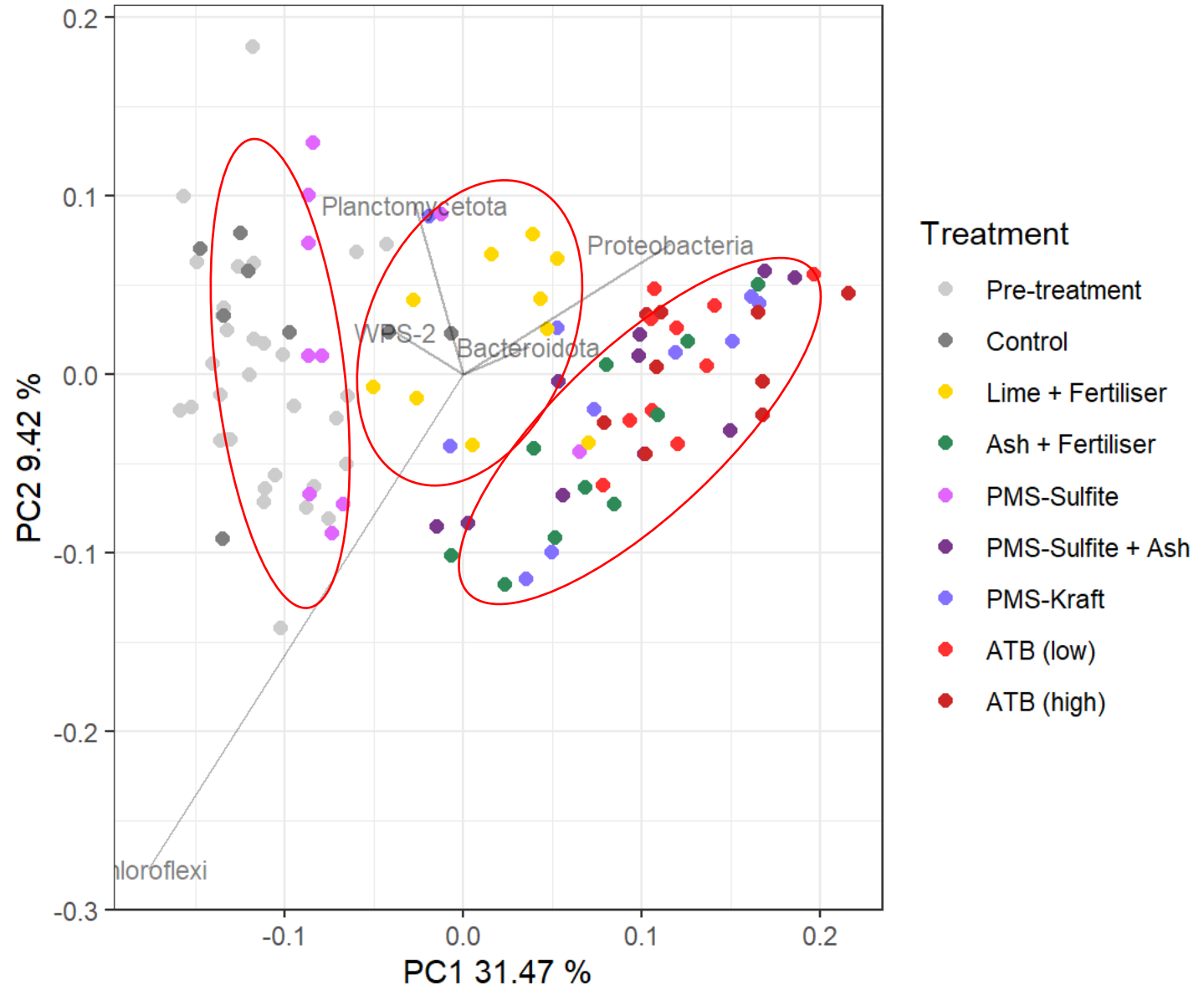


PULP + ASH immediately following application

Falconbridge



Coniston



Microbial communities cluster along pH not treatment. LSMB uniquely associated with a significant increase in enzymes associated with nitrification.

Discussion

- In the context of municipal regreening, Lime Stabilised Municipal Biosolids is an economical and logistically feasible choice which significantly increases plant volunteer recruitment and vegetated ground cover compared to other trials.
- Recommend feasibility study of large-scale aerial application with Regreening Program



LSMB 1yr post application



PULP + ASH immediately following application

Ongoing

An interesting potential application are sand and gravel pits, which are notoriously difficult to restore even with topsoil. These sites have irregular topography, and practitioners often struggle to introduce appropriate species.



Before, 1997



After, 2017

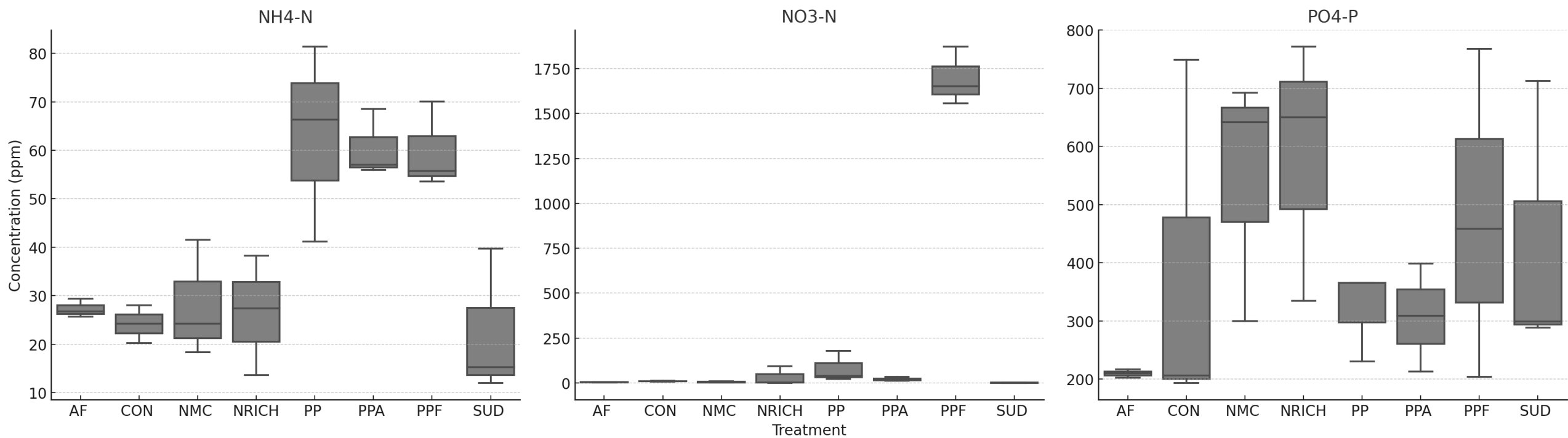
Greenhouse Trial

– Preliminary to field test



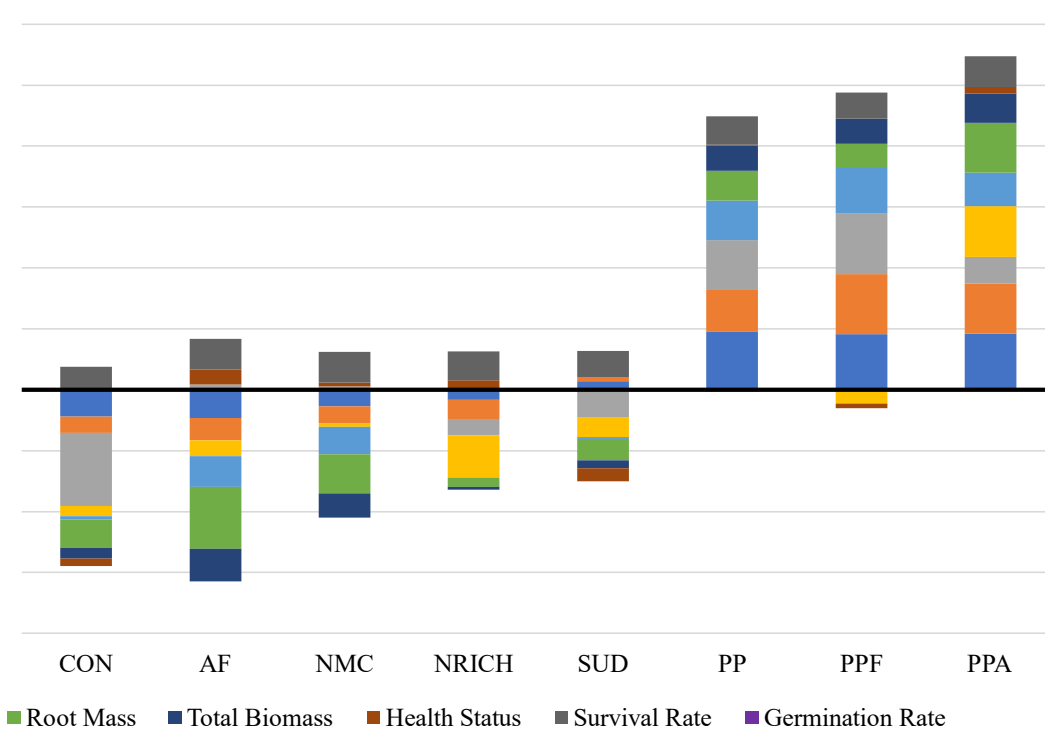
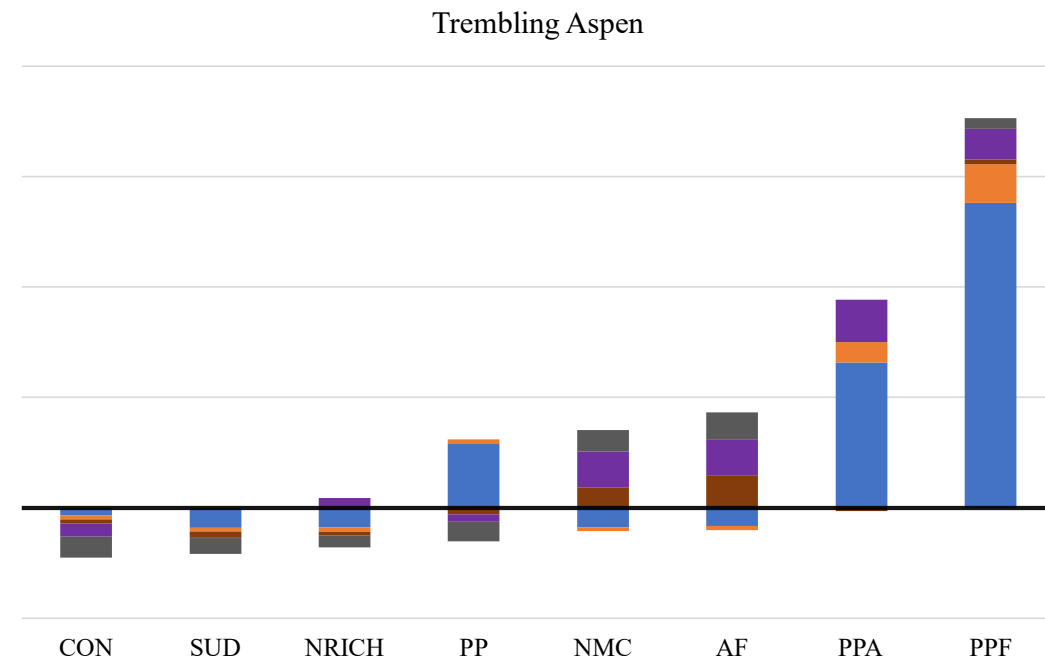
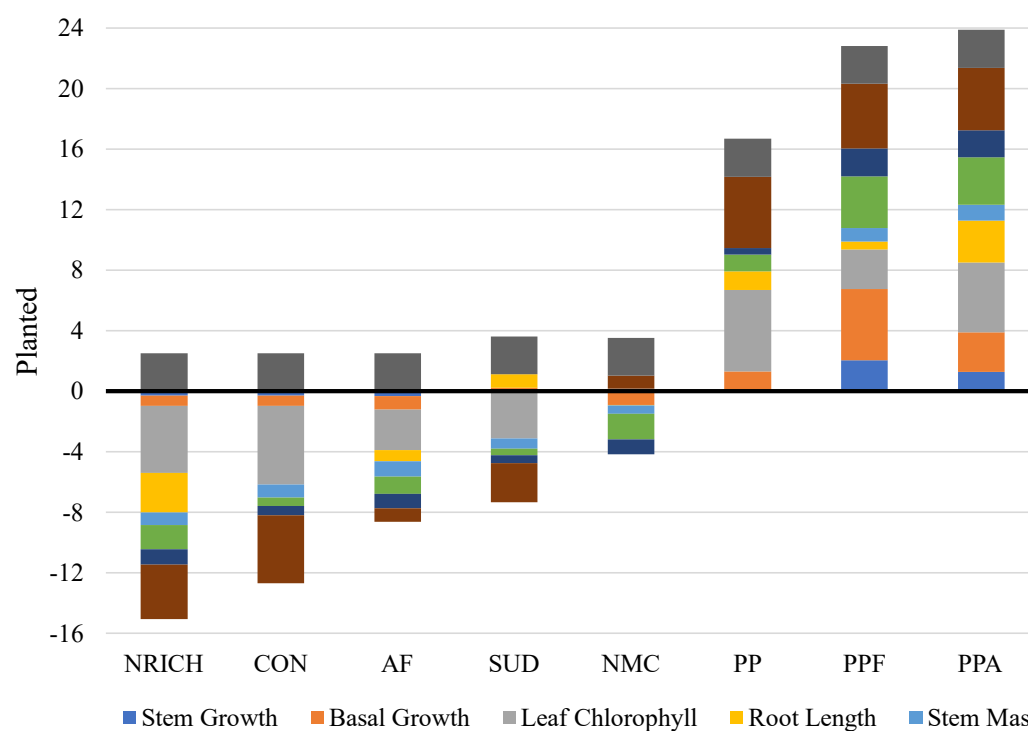
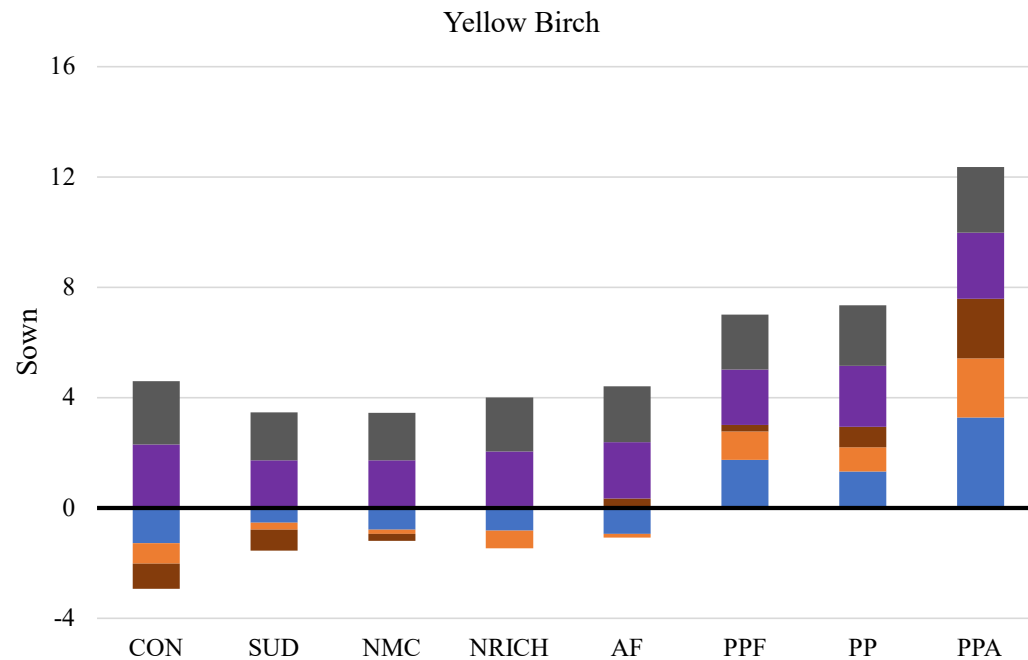
- We incorporated the same industrial solids to gravel soil but at elevated rates (e.g., sulphite pulp mill sludge @ 290t/ha) and at 10cm depth using 2 tree species
1. Monitored soils and tree seedling outcome in simulated heavy precipitation (15 weeks) followed by drought (5 weeks)
 - Pulp Mill Sludge (sulphite) significantly improved every measured aspect of the trial
 2. Determined leachate risk
 - Metals and P below Federal guidelines
 - NO₃⁻ spike immediately following application, other nutrients below CCME

Concentration of NH₄-N, NO₃-N, and PO₄-P in Post Phase 1 Leachate Across Treatments at Time = 3



Parameter	CON	AF	NMC	NRICH	PP	PPA	PPF	SUD
pH	6.6	8	7.8	7.8	6.8	7.7	6.6	7.4
Organic Matter (%)	0.4	1.4	3.6	1.3	11.1	10.9	11.2	1
Nitrate (ppm)	0.3	33.6	15.4	5.2	353	311.5	71	7.7
Phosphorus (ppm)	7	14	27	22	66	69	91	23
Potassium (ppm)	34	395	177	208	86	788	99	126
Magnesium (ppm)	41	177	170	107	118	308	156	81
Calcium (ppm)	251	3990	3360	6010	3030	4790	3780	1230
CEC (meq/100g)	2.9	23.6	19.9	32.7	17.6	29.7	21.7	8.3

Seedling Response



■ Stem Growth ■ Basal Growth ■ Leaf Chlorophyll ■ Root Length ■ Stem Mass ■ Root Mass ■ Total Biomass ■ Health Status ■ Survival Rate ■ Germination Rate

Ongoing – Gravel Pit Restoration Trial

- Synthesis of 3 techniques:
 1. Industrial solids as a fertile base (with and without)
 2. Rough and Loose to maximize variance in microtopography, creating safe sites and reducing erosion (with and without)
 3. Functional Trait Selection via PLANTR to maximize soil health (high labile litter production) and resistance to invasion. Includes 3 tree species, 3 shrubs and a wildflower mixture.





Harmony

Rough and Loose

Increasing similarity to natural microtopography

- Increased similarity to post-fire disturbance?
- Transitioned to secondary succession?

- Wide application potential
- Industrial solids may be critical in restoring waste-rock zones

Stable, young, forest stand?

Industrial Solids

Fertile topsoil proxy

Maximizing critical functions through PLANTR (Canadian Forestry Service)



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GLENCORE

