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Biochar and ash amendment effects on mine reclamation in the boreal forest

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Biochar and Ash Amendment Effects on Mine Reclamation in the Boreal Forest

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Biochar: Production, Characterization and Applications

Engineering Conferences International

August 20 - 25, 2017

Overview

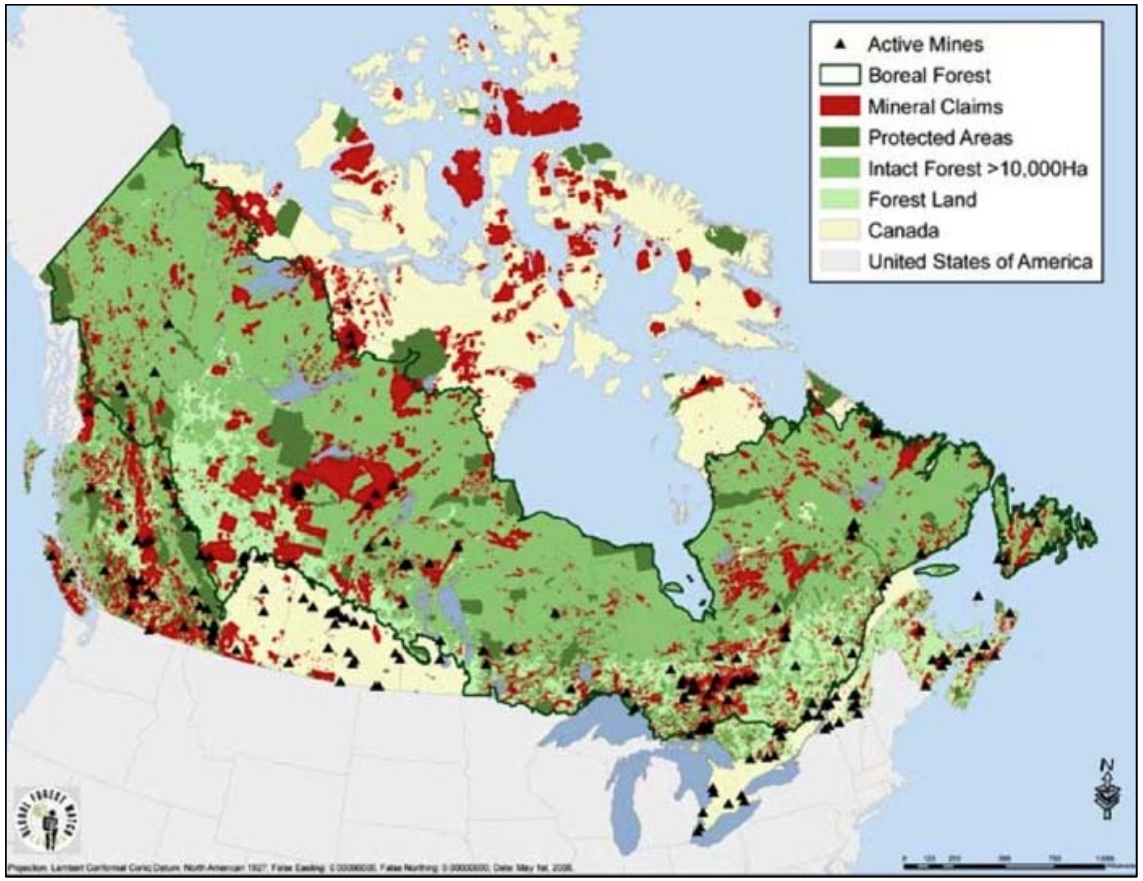
1. The Boreal Forest
2. Mining in Canada
3. Biochar Application in Mining
4. Field Trials at Musselwhite Gold Mine
5. Germination Trials for Invasive Species Management
6. Conclusions
7. Research Next Steps

The Boreal Forest

- Over 270, 000, 000 hectares in Canada
- Jack pine (*Pinus banksiana*), black (*Picea mariana*) and white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*)
- Regulated by natural fire cycles (~50 – 200 years)
- Provides habitat, ecosystem services, carbon storage
- Mineral production = $40.8 billion in 2016
    - Top 5: Gold, copper, potash, iron ore, coal
- ~30% allocated for development & resource extraction
- ~ 15% Not Sufficiently Restocked (NSR)

Natural Resources Canada 2014; Ontario Ministry of Natural Resources and Forestry 2016; Hearndon, Millson and Wilson 1992)

Mineral Claims and Active Mines in Canada

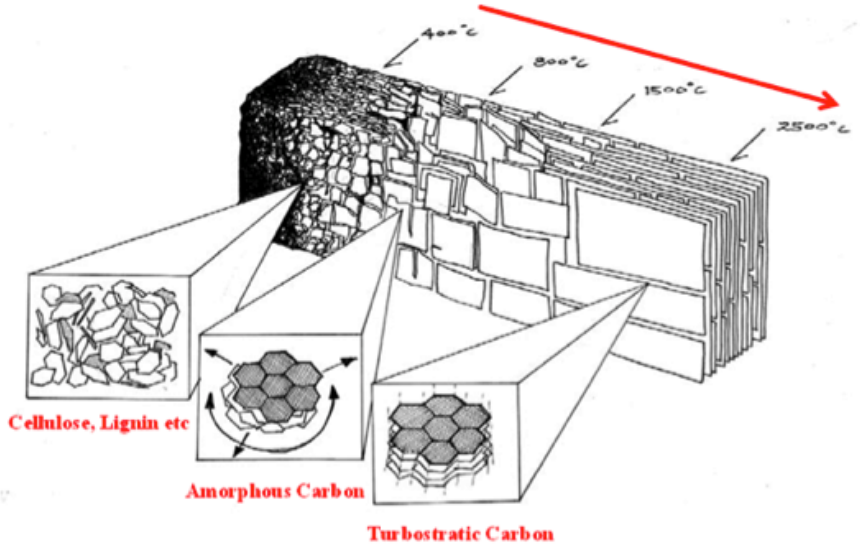


High Ash Biochar to Remediate Mines

- **Tailings**: the main waste products of ore processing for gold extraction consisting of crushed rock
  - Contaminated with heavy metals & other toxic compounds
- **Natural re-vegetation?**
  - Poor nutrient status
  - Limited water
  - Limited organic matter
- **Boreal mine sites potential for invasive species**
  - Disturbed
  - Non-native propagules
  - Climate warming
- **Phytoremediation?**

Wood-Derived Charcoal

- Highly recalcitrant (lasts in soil up to 1000's of years)
- Large surface area (sorptive area up to 2500g/m^2)
- Porous
- High ion-exchange capacity
- Properties Dependent on:
  - Feedstock
  - Pyrolysis temperature
  - Length of pyrolysis
  - Rate of pyrolysis



(Zackrisson, Nilsson, and Wardle 1996; Jeffrey et al. 2011; Uchimaya et al. 2010; Zhang et al. 2013; Thomas et al. 2013; Zackrisson 1996; Sacket et al. 2015)

Ash

- Several unique qualities:
  - Amorphous
  - Highly mobile
  - Liming capacity due to high pH
  - No sorptive capacity
  - High in Mg, K, Ca

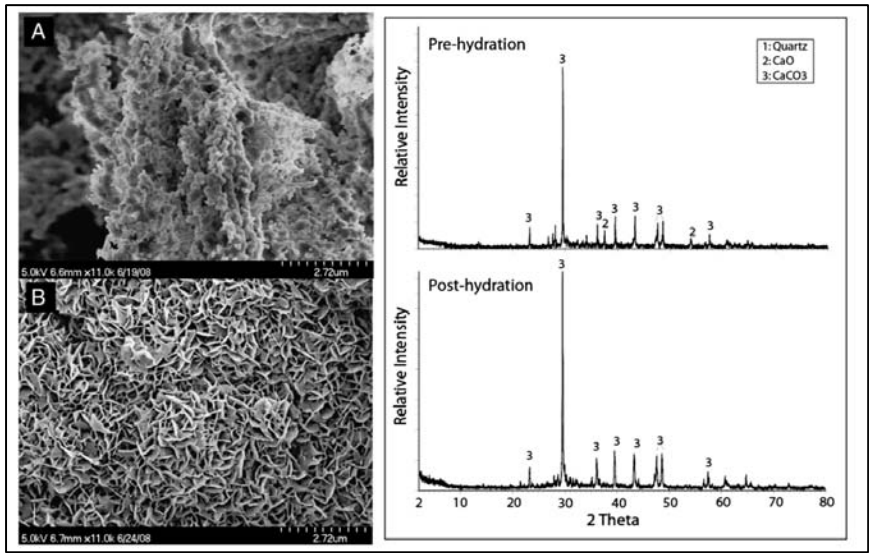
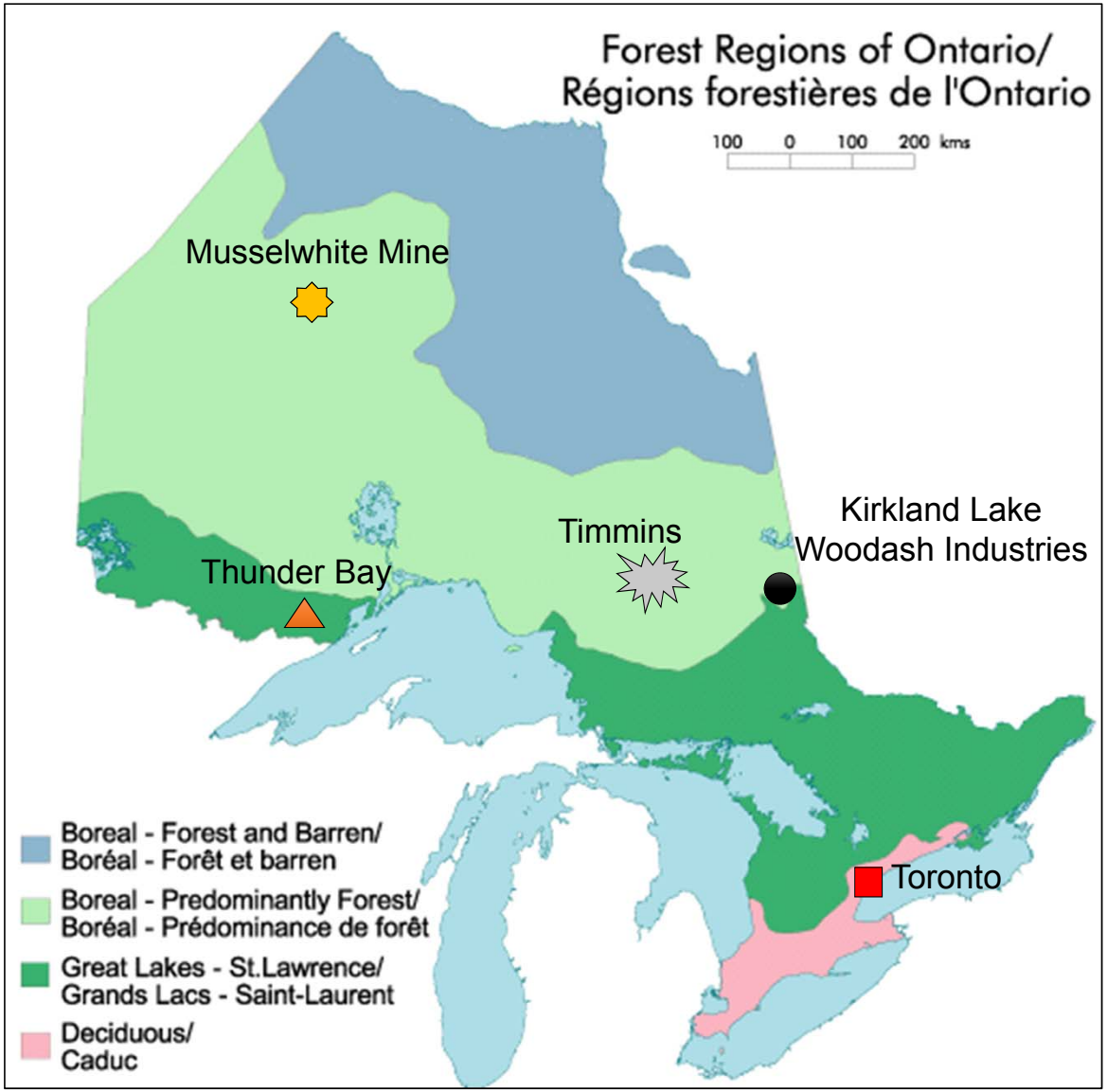


Figure 4 in Bodi et al. 2014: Scanning electron microscope photographs and corresponding X-Ray diffraction (XRD) of wildfire ash samples

Study Site

Goldcorp Inc.
Musselwhite Gold Mine
Opapimiskan Lake
Ontario, Canada

GOLDCORP



Study Site

- Boreal Shield Ecozone
  - Podzols and fibrisols & mesisols
- Gold extraction through cyanidation and precipitation with activated carbon
  - Potential for acid mine drainage
- Tailings concentrations of As, Cr, Cu, Pb, Th, and Se exceed human and environmental health safety guidelines
- Substrate tailings with sand cap as per closure plan

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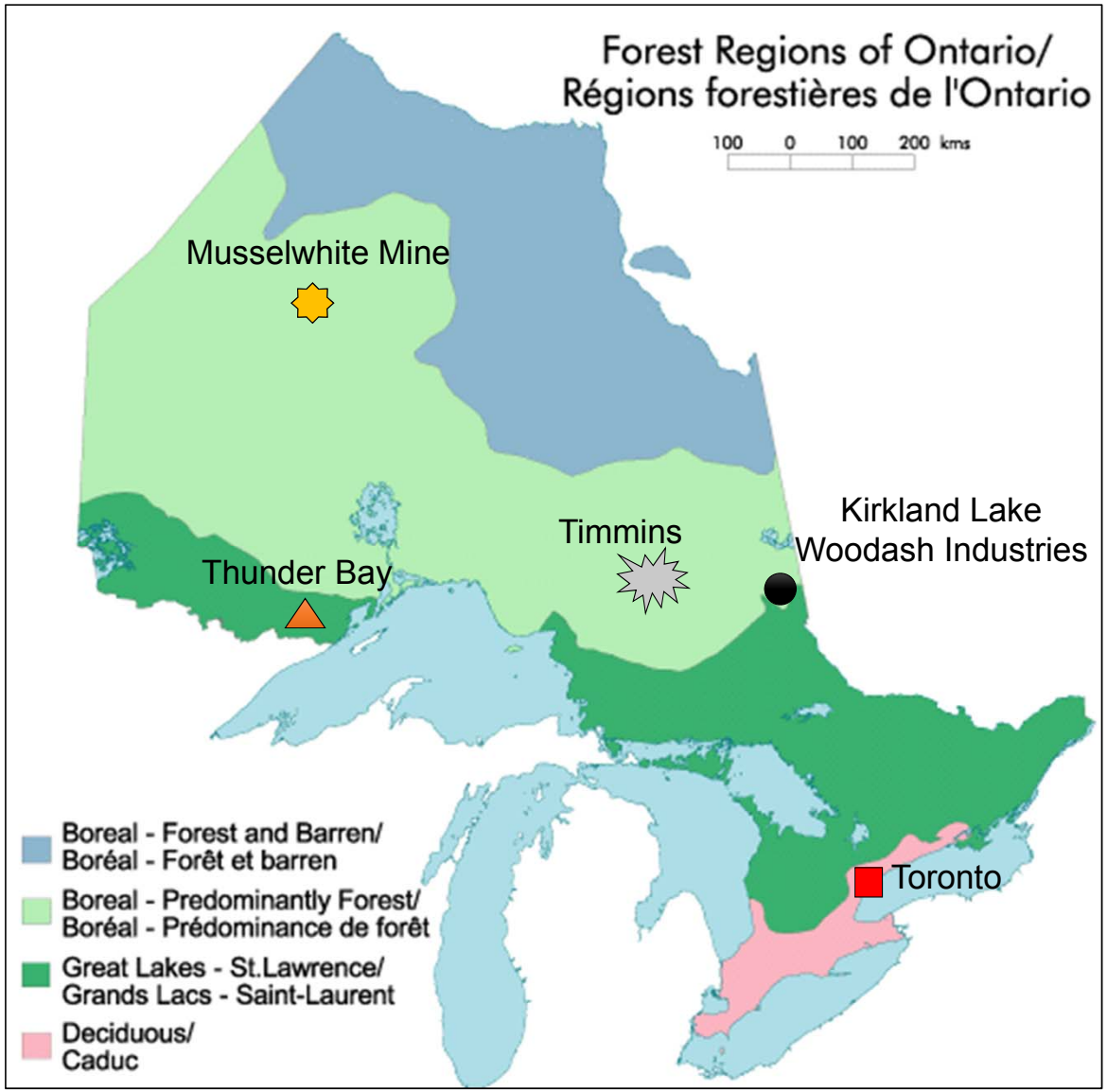


Available Biochars

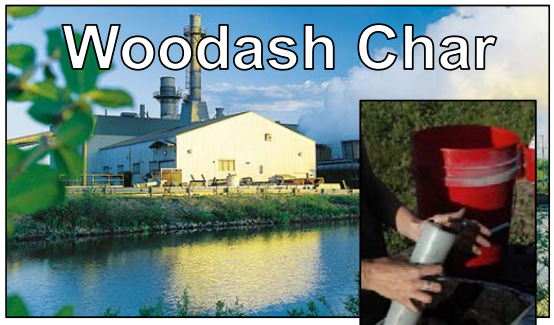
Natural Biochar

- Harvested from 2011 Sioux Lookout Fire adjacent to Musselwhite Mine

Woodash Industries Biochar

- Kirkland Lake, ON
- Wood-fired co-generation powerplant waste

Hypothesis: High Ash Biochars to Remediate Mines



Biochar

- Pores = increased water retention and nutrient holding capacity
- Adsorb heavy metals
- Adsorb allelopathic compounds from invasive species

Higher Ash Content

Species that prefer basic soil

Plant Growth

Native Species

Native Soil Fauna

Experimental Design

- **Treatments**
  - Woodash Industries woodash char (45t/ha)
  - Natural Char harvested from 2011 local fire (45t/ha)
  - Control
- **Growth medium**
  - Engineered till cover of local sand
  - Plots 0.5 m x 0.5 m separated by a 1.5 m distance
  - 9 replications x 3 treatments x 3 species (81 plots)
- **Study Species:**
  - Big Bluestem (*Andropogon gerardii*) – 4.5g seeds (~2565 seeds)
  - Fowl Bluegrass (*Poa palustris*) – 4.5 g seeds (~4500 seeds)
  - Jack Pine (*Pinus banksiana*) – 2 x plot
    - Harvested 3 – 5 year old seedlings from two local areas
    - Seedling height, number of branches, and root collar diameter
- **Site Preparation:**
  - Manual tillage and removal of all above and below ground biomass
  - Soil temperature loggers installed in Fall 2016
  - PRS Probes installed June 2017

Experimental Design

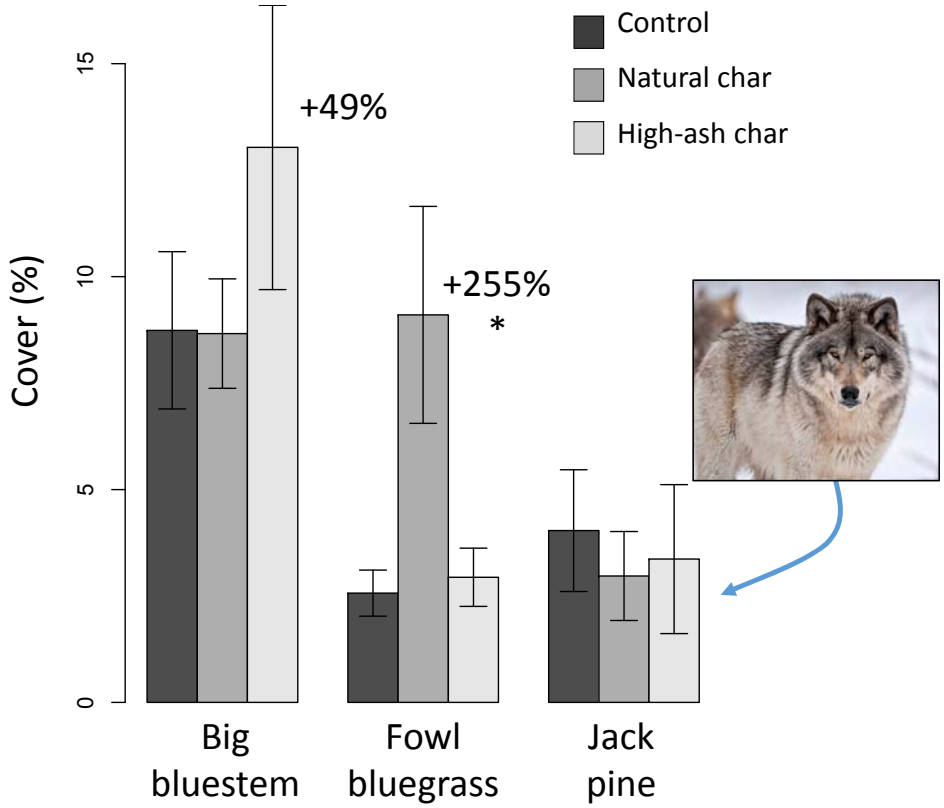
- **Measurements**:
  - Partial harvest of aboveground biomass (Fall 2016, 2017)
  - 'Volunteer' vegetation ID
  - Percent vegetation cover
  - Soil Temperature (Fall 2017)
  - Soil pH
  - Seedling height, root collar diameter, # branches
  - Soil nutrient availability (P, K, Ca, Mg, NO_3, NH_4)
- **Biochar characterization**

PRS ion-exchange probes used to assess availability of major soil nutrients

Soil temperature guage

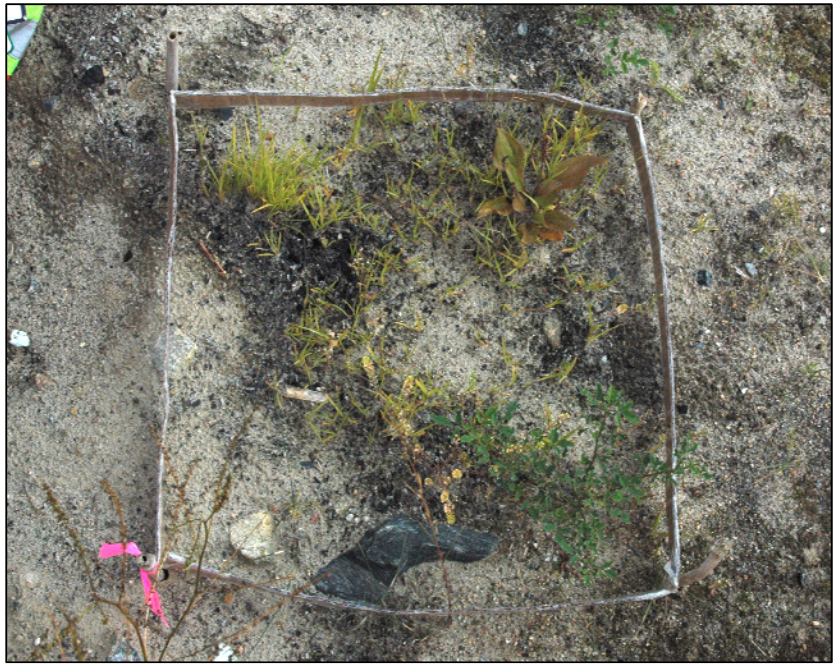
Vegetation Responses % Cover (Year 1)

- **Results:**
  - Biochars enhance growth of both grass species and remaining trees
    - Only 11/54 trees left due to wolves
  - Species-specific responses to biochar amendment
    - *Poa palustris* prefer natural char
    - *Andropogon gerardii* prefer high ash char
  - Biochars enhanced overall productivity
    - Reduced relative abundance of non-native species in seeded plots



Vegetation Responses % Cover (Year 1)

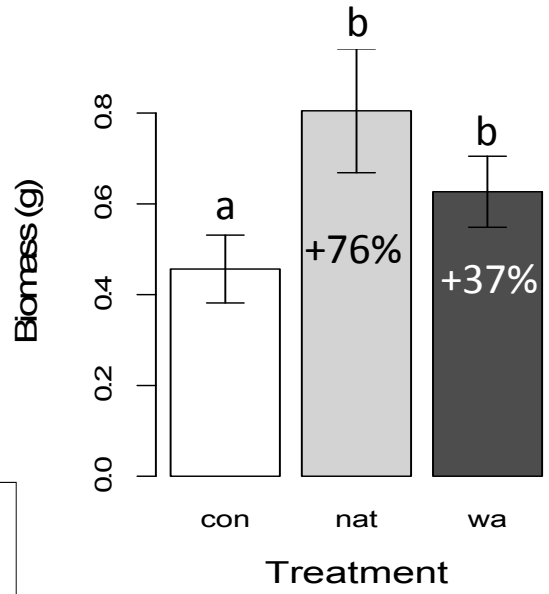
***Andropogon gerardii* x Control**



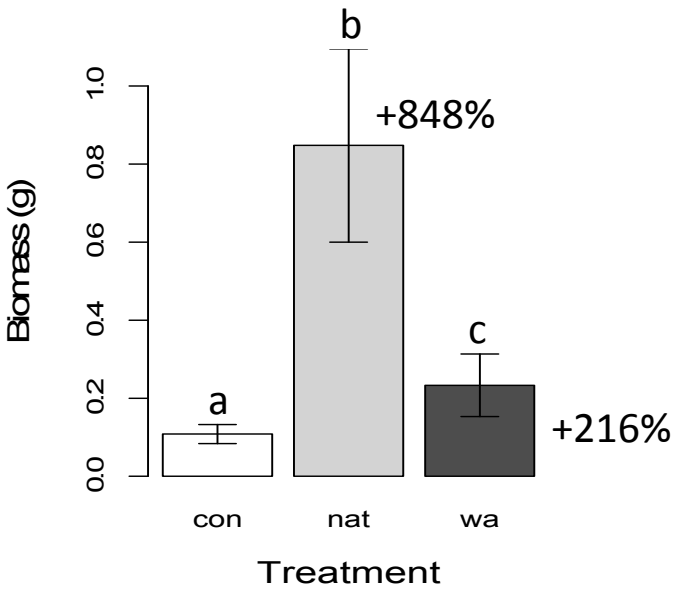
***Andropogon gerardii* x Natural Char**

Vegetation Responses Biomass (Year 1)

Andropogon gerardii
(big bluestem)



Poa palustris
(fowl bluegrass)



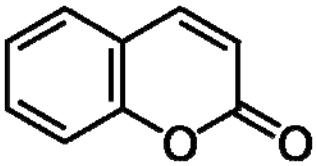
Control
Natural char
High-ash char

ANOVA: Biochar: $P < 0.001$
Species: $P = 0.031$
S x B: $P > 0.05$

Biochar for Invasive Species Management in Mine Reclamation

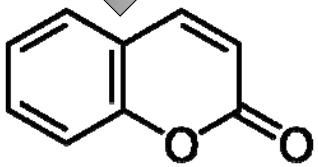
- Biochar can sorb allelopathic compounds
  - Sujeeun, L. and Thomas, S.C. (2017) Potential of biochar to mitigate allelopathic effects in two tropical island invasive plants. Tropical Conservation Science, in press
  - Thomas, S.C., Al-Zayat, M., and Murtada, J. (2017) Biochar mitigation of allelopathic effects of invasive plants: evidence from seed germination trials. American Journal of Botany, in review.
- *Melilotus albus* and *Melilotus officinalis* dominant volunteer colonizer at Musselwhite Mine
  - Legume
  - Allelopathic – Coumarin phytotoxic
  - Invasive
  - Use as biological herbicide
  - **Few studies examining biochar mitigation of alleopathic compounds**
  - **No existing studies on biochar mitigation of phytotoxic effects of coumarin**

***Poa palustris* x Control**



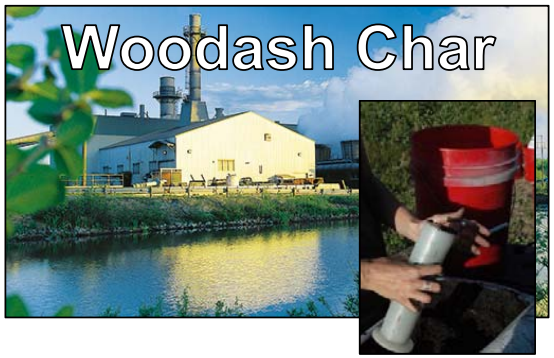
Coumarin ($C_9H_6O_2$)

Hypothesis



Interfere with ATPase
Decrease cell wall elasticity
Decrease root growth

Seed
Germination



Wood Vinegar

Break down seed coat

Biochar
Adsorb
Coumarin

Seed
Germination

Higher Amount of
Wood Vinegar

Break down seed coat faster

Experimental Design

Leaf Extracts:

- *Melilotus alba* collected from Leslie Street Spit, Toronto ON Fall 2016
- Shredded into 2 cm by 2 cm
- Soaked in deionized water at 25° C
- Filtered Whatman #4 paper

Biochar:

- Woodash (WA Industries)
- Natural Char (Musselwhite Fire)
- 1:1 (v:v) mixture deionized water
- Shaker 24 hr
- Filtered Whatman #4 paper

Radish (*Raphanus sativus*)

Lettuce (*Lactuca sativa*)

Big Bluestem (*Andropogon gerardii*)

Fowl Bluegrass (*Poa palustris*)

Experimental Design

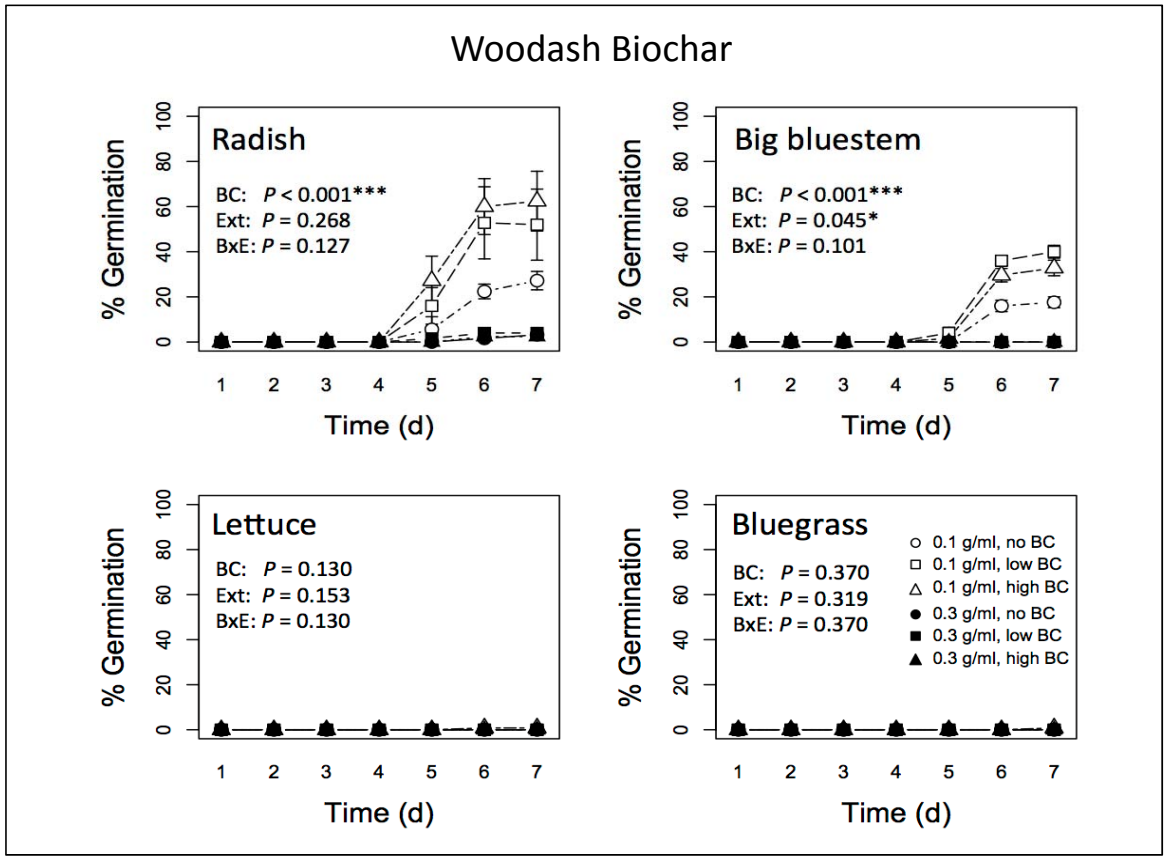
Treatments:

- Leaf extract
  - 0.1 g/ml and 0.3g/ml
- Two biochar types & concentrations
  - 0.002 g/ml and 0.02g/ml
- Three Controls
  - Deionized water
  - Woodash leachate (0.02 g/ml)
  - Natural Char leachate (0.02 g/ml)
- 25 seeds x 5 replicates per species
- Incandescent lights for 7 days

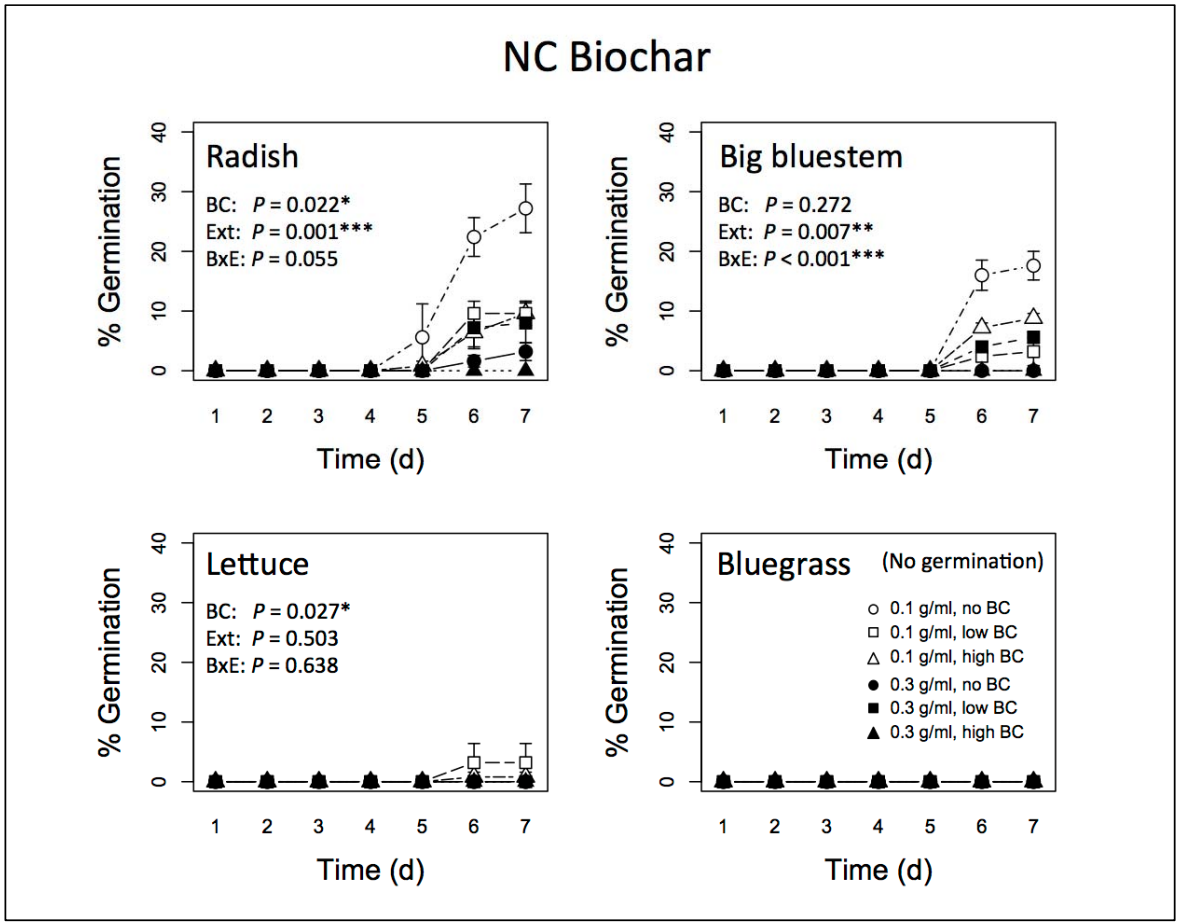
Measurements:

- Daily germination
- Daily cotyledon
- Radicle length day 6

Woodash Biochar Results



Natural Biochar Results



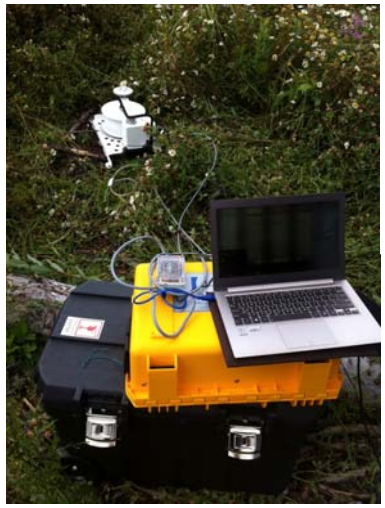
Conclusions

- Both woodash and natural chars perform well
  - High-carbon wood ash is available commercially
    - Consistency a potential challenge
  - Natural (post-fire) chars work well
    - Supply limiting factor
- Char transport minimal in first year when mixed in upper surface of tailings
- Good potential for biochar in mine reclamation
- Alternatives (top-soil, lignin sludge) degrade with time and require repeated applications
- Dosage and characterization key in optimizing results

Next Steps

- Collection of Year 2 Data – October 2017
- Char characterization
- Scaling-up of trials – Ongoing (at this very moment!)
  - 10m x 10m plots
  - Varying dosage with a range of native species planted
  - Install microclimate towers for GHG flux – October 2017
- Cost-benefit analysis
  - Comparison with existing closure plan
  - Combine with mine camp green waste or sewage?

Microclimate tower and GHG Analyzer



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Woodash Industries
Haliburton Forest and Wild Life Reserve

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Ontario Mining Association (OMA)
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Biochar Characterization

- Particle Size Distribution
  - ASTM D2862-10
- Bulk density
- Ash content
  - Loss to ignition at 750°C
- pH and Electrical conductivity (EC)
  - (1:10, w/v)
  - Oakion pHCON 510 series with pH and EC electrode
- Total Ca^{2+}, Mg^{2+}, K^{+}, P
  - Sulphuric acid digest
  - Inductively coupled plasma spectroscopy Spectro Genesis ICP-OES
- Elemental
  - XRF
- BET Surface area
  - NOVAe multi-gas sorption system utilizing CO_2 as a sorptant
- Pore Volume and water holding capacity
  - Gas Pycnometer


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