Community assembly, species invasion, and tests of functional effects of soil microbiomes

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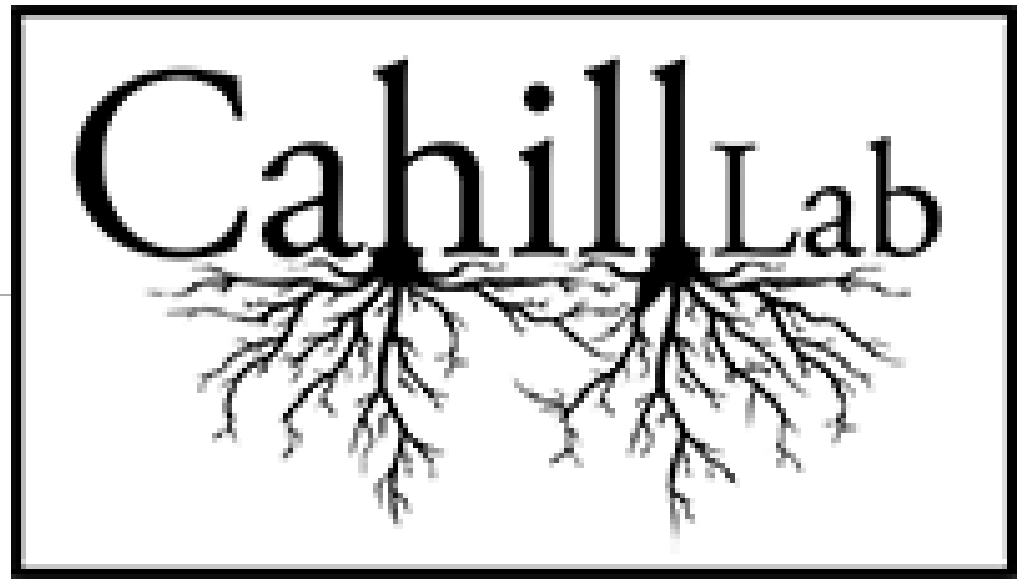
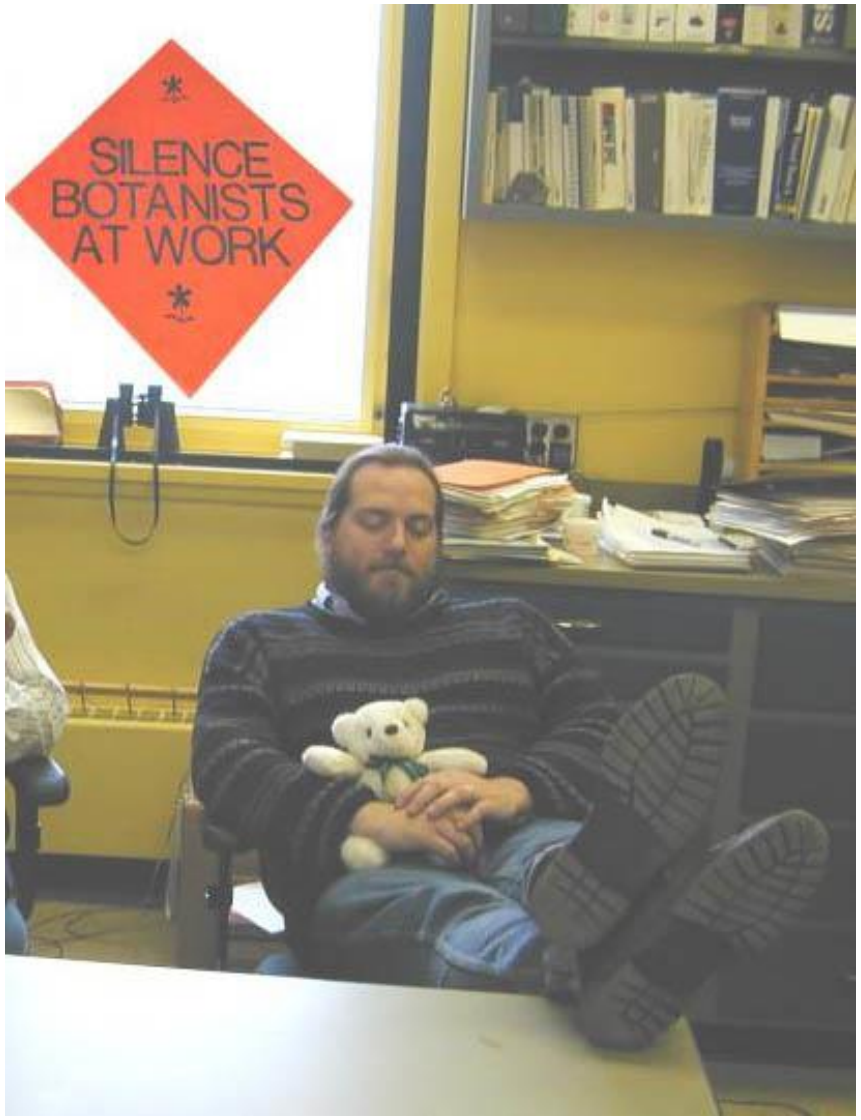




A bit about me

Diverse research interests, focused on the broad area of plant ecology

- Conservation biology (e.g. invasion, climate change, drought)
- Ecology of grazing systems
- Large-scale international collaborations
- Plant social interactions & behavioural ecology
- Mechanisms of community assembly

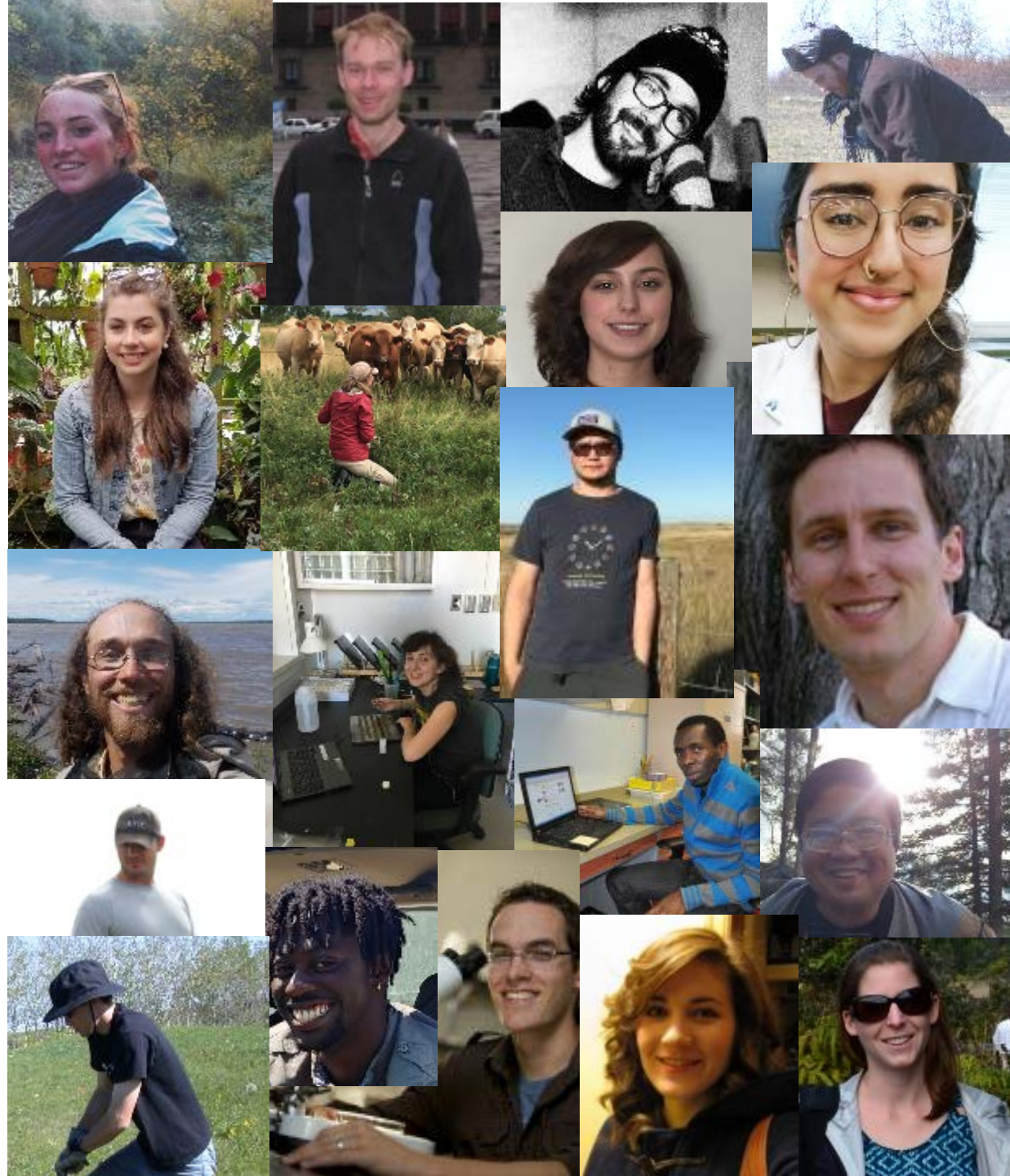
Today, focus on plant-soil-microbes, with an emphasis on functional consequences (for plants)

A collaborative research program throughout 21 years at UA

- College of Natural and Applied Sciences Collaborators
  - **Science**: Bayne, Boutin, Boyce, Cooke, Currah, Dale, Deyholos, J Hall, Hik, Keddy, Leighton, Merrill, Proctor, St. Clair
  - **ALES**: Bork, Carlyle, Chang, Erbiligen, L Hall, He, Hudson, Juma, Karst
  - **Engineering**: Carey

- Lab Members:
  - PDFs (5), PhDs (15), MSc (11), BSc research (~35), BSc technician (>75)

- Co-authors: Approximately 400, including 20 BSc students
  - Most papers are 3 or fewer authors



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A simple outline

A few words on the emergence of the modern discipline of microbial ecology

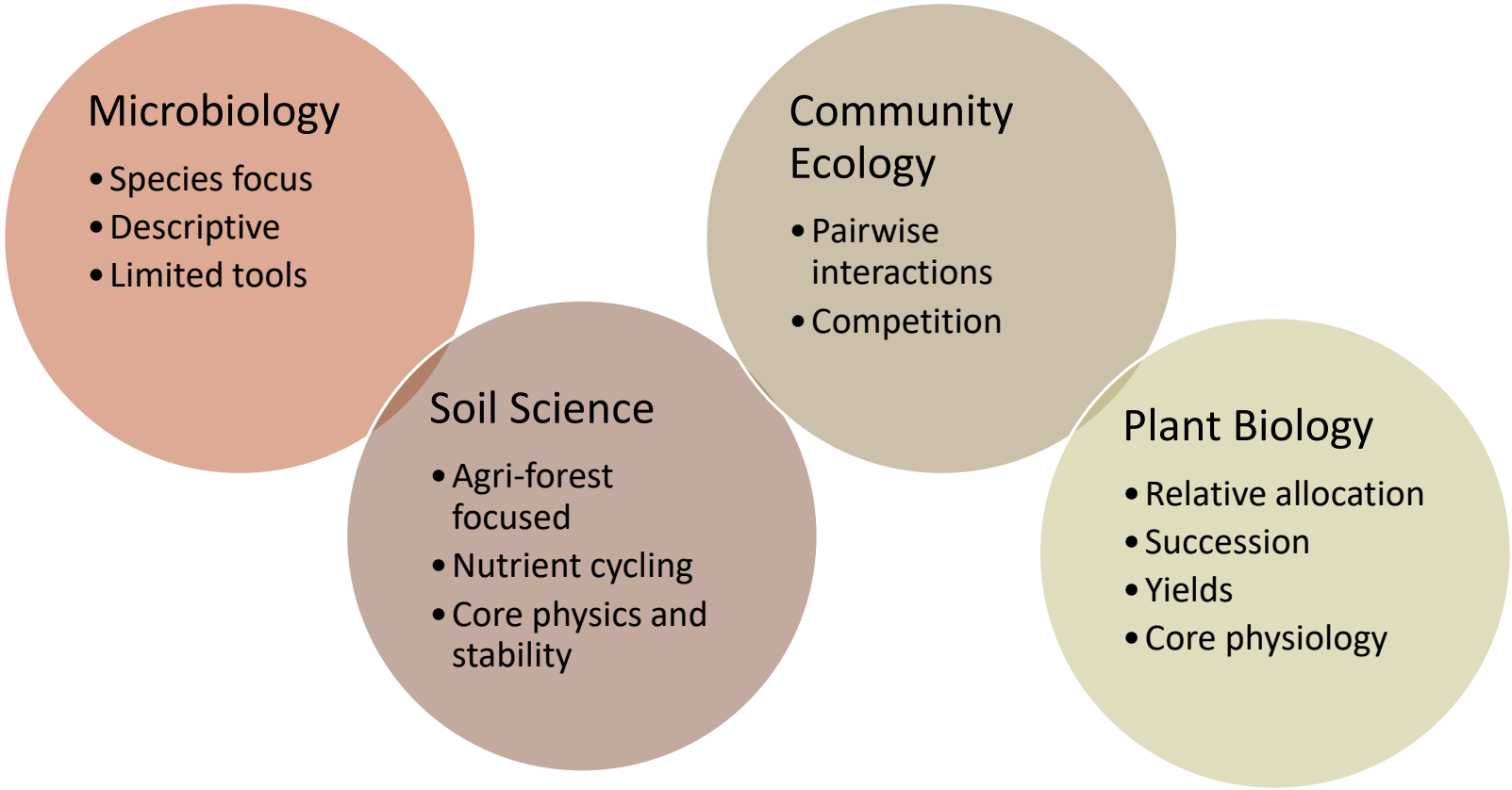
Lodgepole pine and mountain pine beetle

- Impacts on soil microbes
- Microbe impacts on plants
- Application and remediation?

Smooth brome invasion and plant soil feedbacks

- Impacts on plant diversity
- Putting feedbacks into a larger context

As recent as 2000's research disciplines were very separated, with limited overlap of people or ideas



In 2000's began to talk about integration

Links between above and belowground processes

Focus on plants, but recognized diversity of life in the soils

- Wardle's big book on AG/BG processes = 2002

Core biology was at this point still unknown

- Soil biodiversity
- Within plant signalling
- Volatile communication
- Plant behaviour

Key emerging idea: 'Shoot ecology' was not the same as forest/plant/grassland ecology

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Article | Full Access

FERTILIZATION EFFECTS ON INTERACTIONS BETWEEN ABOVE- AND BELOWGROUND COMPETITION IN AN OLD FIELD

James F. Cahill Jr.

First published: 01 March 1999 |
https://doi-org.login.ezproxy.library.ualberta.ca/10.1890/0012-9658(1999)080[0466:FEOIBA]2.0.CO;2 |

Modern era

Core natural history in the genomics era allows us to quantify OTUs and ESV

- Not only culturable taxa

Microbiomes are everywhere!

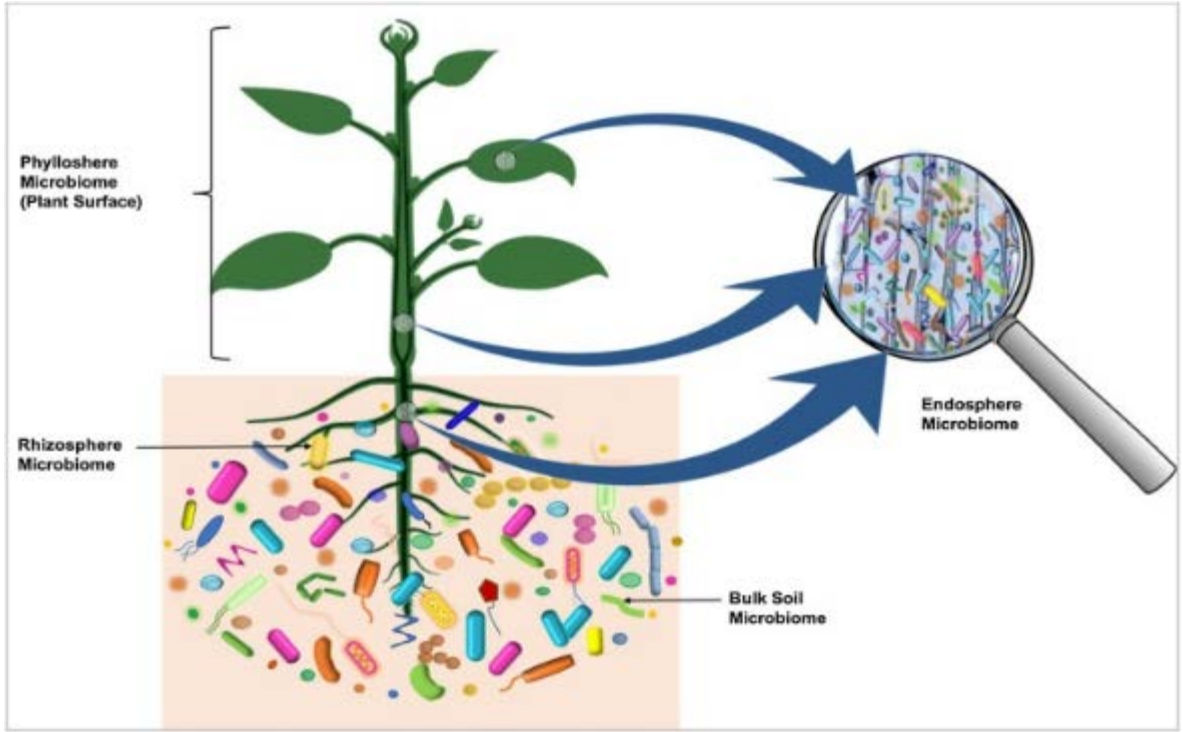
- Leaves, flowers, nectar, soils, etc

Application of modern community ecology

- Assembly mechanisms along gradients
- Multi-trophic interactions
- Plant-soil feedbacks and coexistence

Next frontier: When do microbiomes alter processes WE care about (good & services, diversity) and when do they not?

- Showing diversity change is not the same as a functional change



By Khondoker M.G. Dastogeera, Farzana Haque Tumpaa, Afruja Sultanaa, Mst Arjina Aktera and Anindita Chakraborty - [1]doi:10.1016/j.cpb.2020.100161, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=93725739

Trying to identify functional consequences: Examples from my lab

Lodgepole pine, *Pinus contorta*, (Greg Pec & Justine Karst (and Nadir Erbiligen and others))

- Dominant tree in parts of Alberta Boreal Forest
- Important to forestry
- Heavily dependent upon ectomycorrhiza

Pine beetle, *Dendroctonus ponderosae*, outbreak in Western Canada

- Trees go through discrete stages, essentially green to red to dead in < 5 years
- Massive die-offs in Western Canada

We were seeing this as a good tests of functional shifts of microbes

- If dominant hosts die, do microbes change, and then does that matter?

Core design …

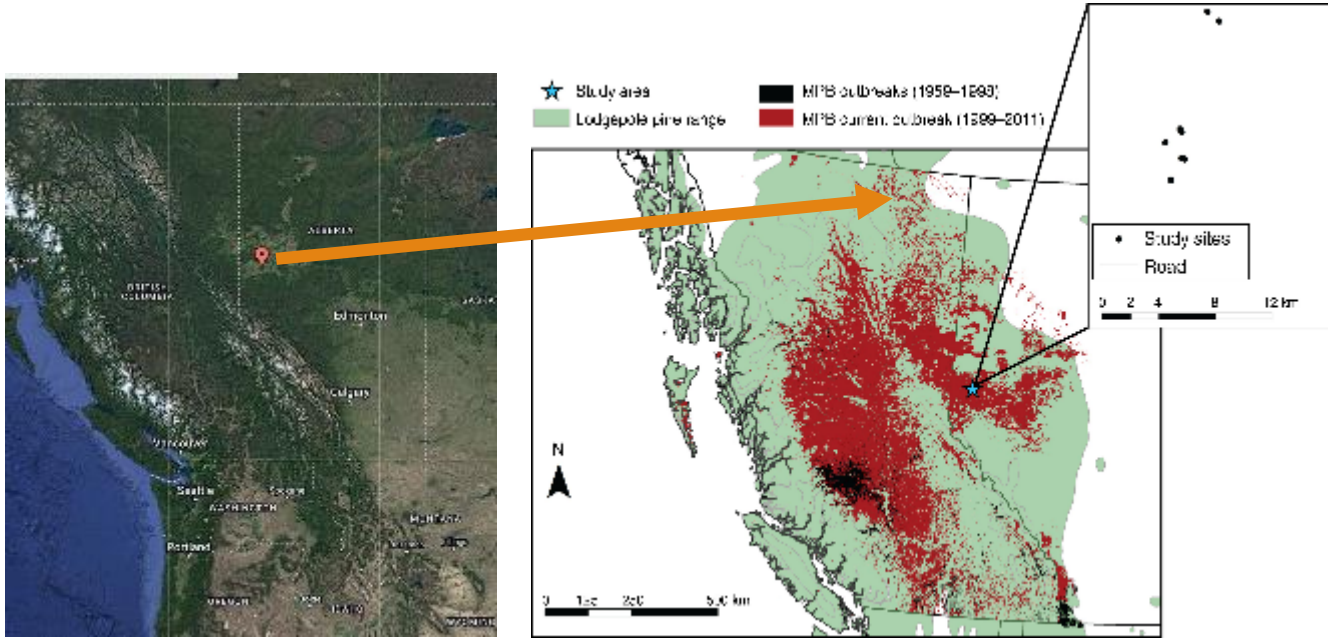
11 Pine stands in Grand Prairie, Alberta, Canada

- On edge of invasion at the time of studies
- Ensured a gradient, not just all dead

Replicate stands for each attack intensity (0-4 yrs), measuring degree of tree mortality per stand

Established plots of varying sizes for different studies

Measure a heck of a lot of ‘what changes along the attack (mortality) gradient’



Fast actions of MPB on soils and understory

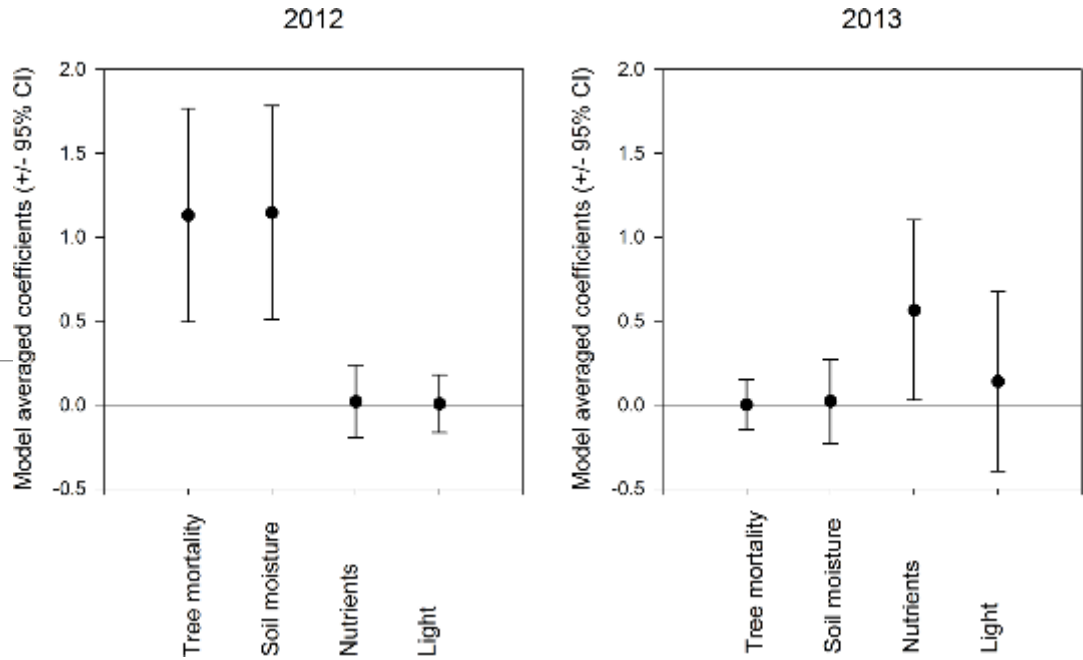
Top: Drivers of understory biomass

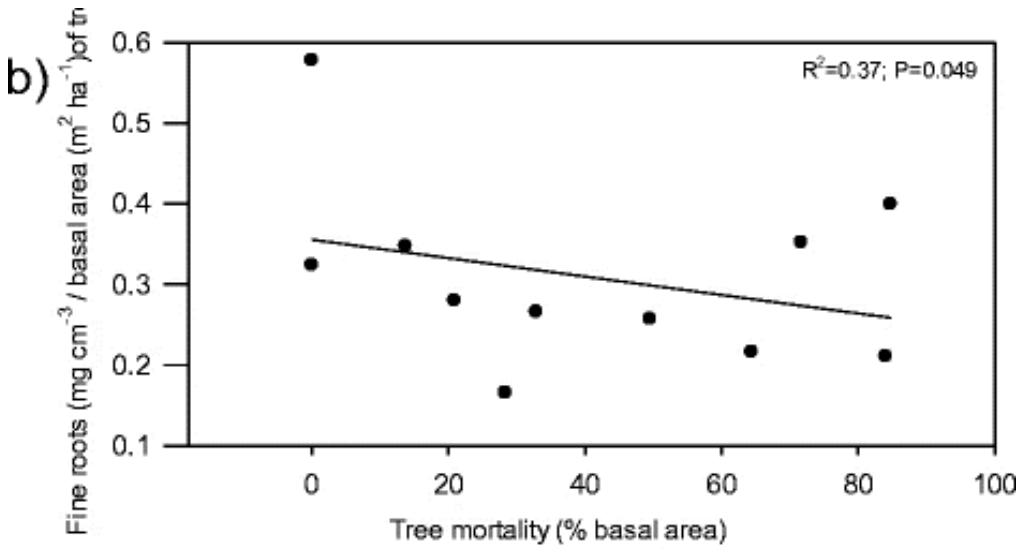
- Tree mortality was critical driver of understory in first year
- Rapidly moved to resources in second year
- In other words, death itself had transient effects (but not due to changes in light environment)

Bottom: Fine roots decline rapidly with tree mortality

- Not shown: Rapid increases in soil resources (N, P, moisture) and pH with tree mortality

Setting the stage for microbial changes!





Pec et al 2015 PlosOne

Cigan et al. 2015 Plant and Soil

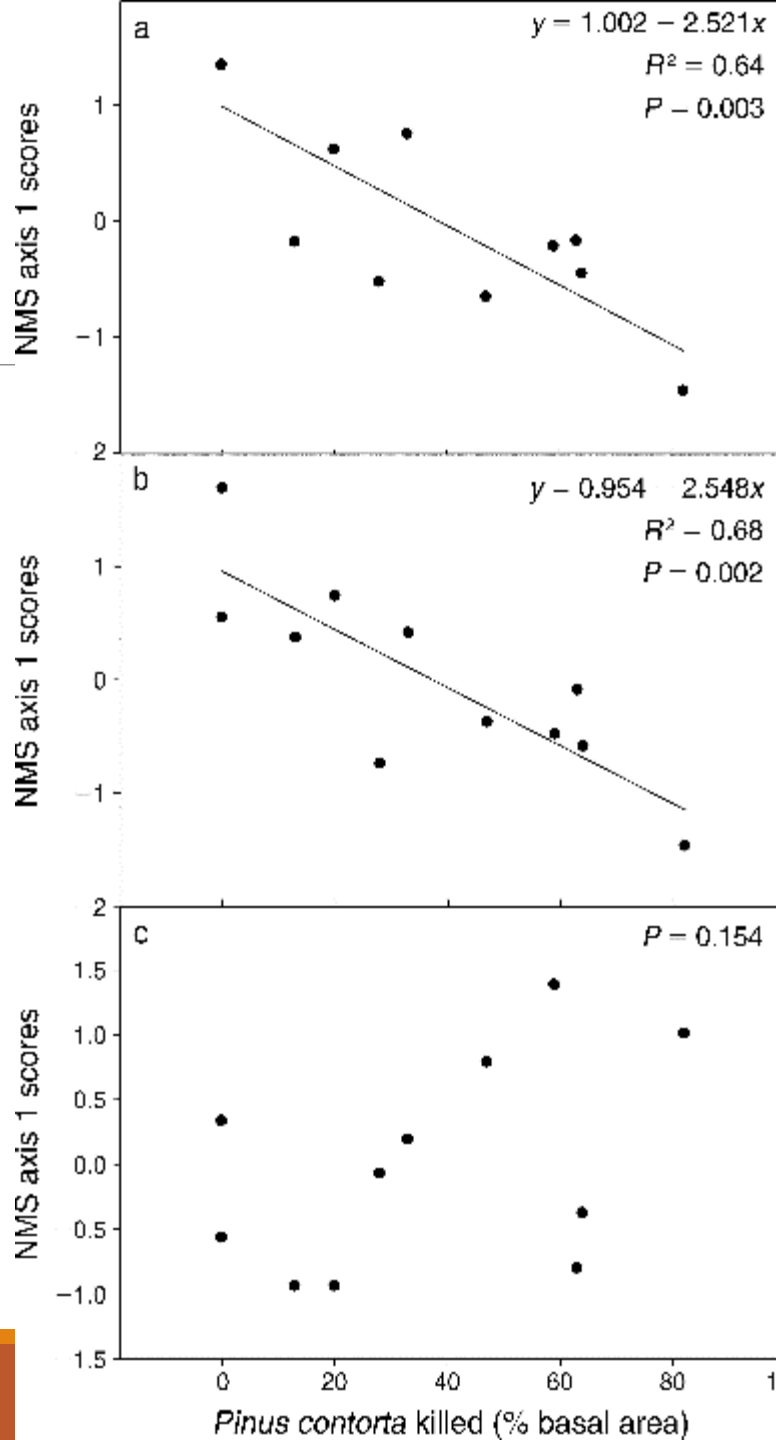
Sporocarp evidence finds a microbial change following tree mortality

Sporocarp survey in our plots, conducted by local mycologist.

- Presented are NMS (ordinations) of sporocarp community composition as a function of attack intensity (% dead)

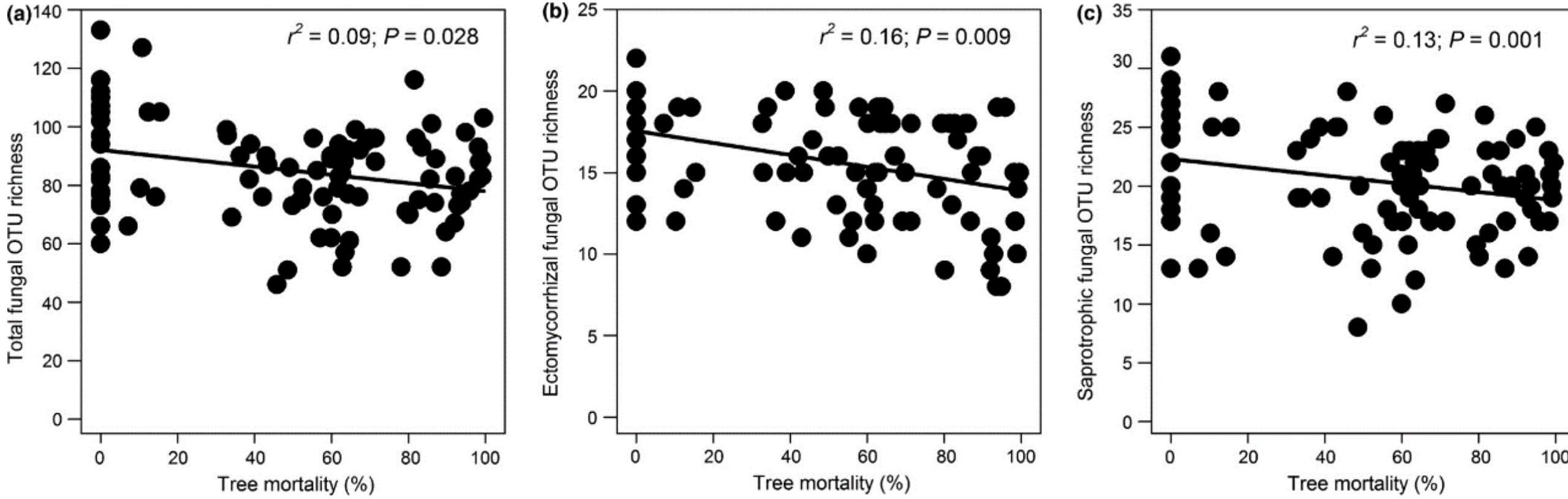
Both total composition (top) and ectomycorrhizal (middle) composition changed with attack

NO change in non-mycorrhizal composition (bottom) along the mortality gradient.



Treu et al. Ecology 2014.

Molecular evidence is supportive. Total OTU diversity, ECM and saprophytes decrease with mortality of pine.



Pec et al. 2016. New Phytologist

So what? Do shifts in soil fungi matter for anything other than soil fungi?

Subsequent pine recruitment?

- If lodgepole pine REQUIRE ectomycorrhizae, perhaps performance/recruitment will be reduced in the resulting soil environment.

Common mycorrhizal networks?

- If disruption of mycorrhizal communities occurs, perhaps this will impact the ability of networks to 'feed' seedlings
- NOTE: Assumes CMN matter!

An embedded experiment

Sowed seeds of pine into the same stands used in prior studies

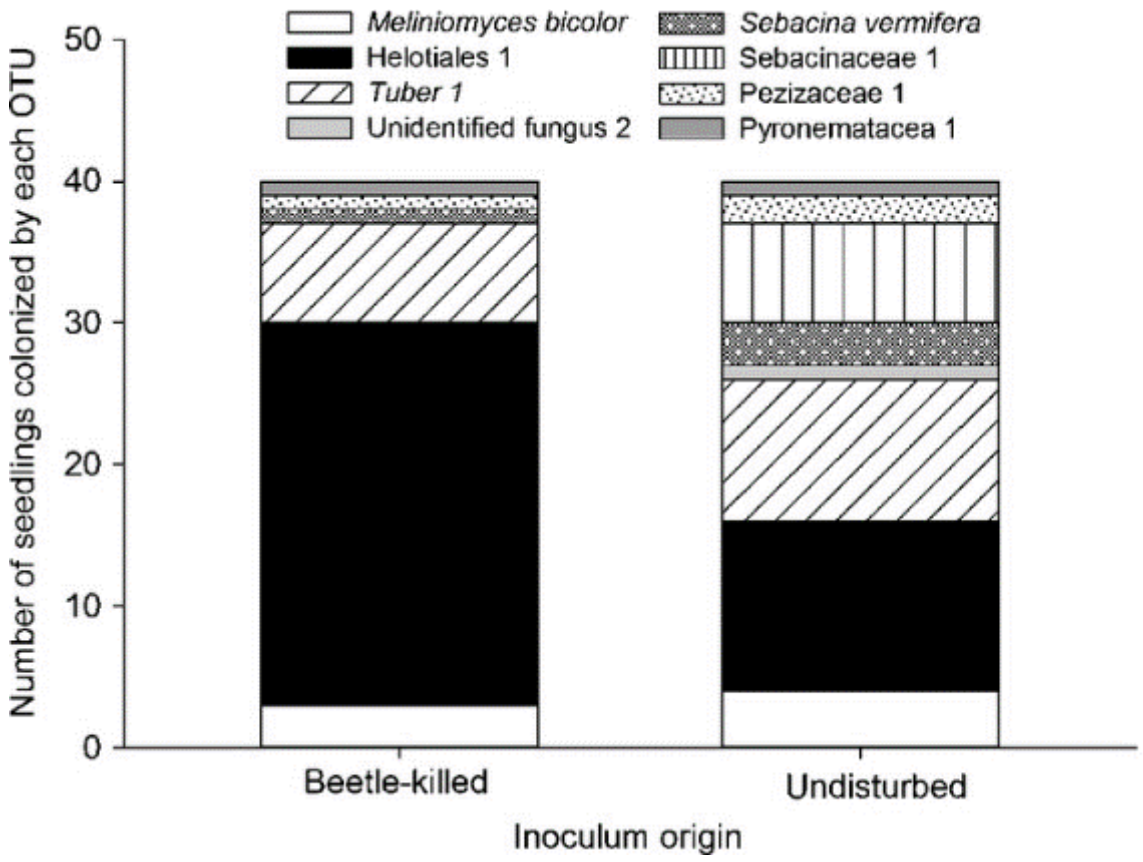
- Measured root colonization by ectomycorrhizae (right)
- Big shifts in root-associated fungal communities

Also performed an inoculum (greenhouse) study with soil sources:

- No inoculum
- Beetle-killed forest inoculum
- Undisturbed forest inoculum

Measured

- Seedling secondary chemistry
- Growth rate and survival



Karst et al. 2015. New Phytologist

Trans-generational effects of inoculum source

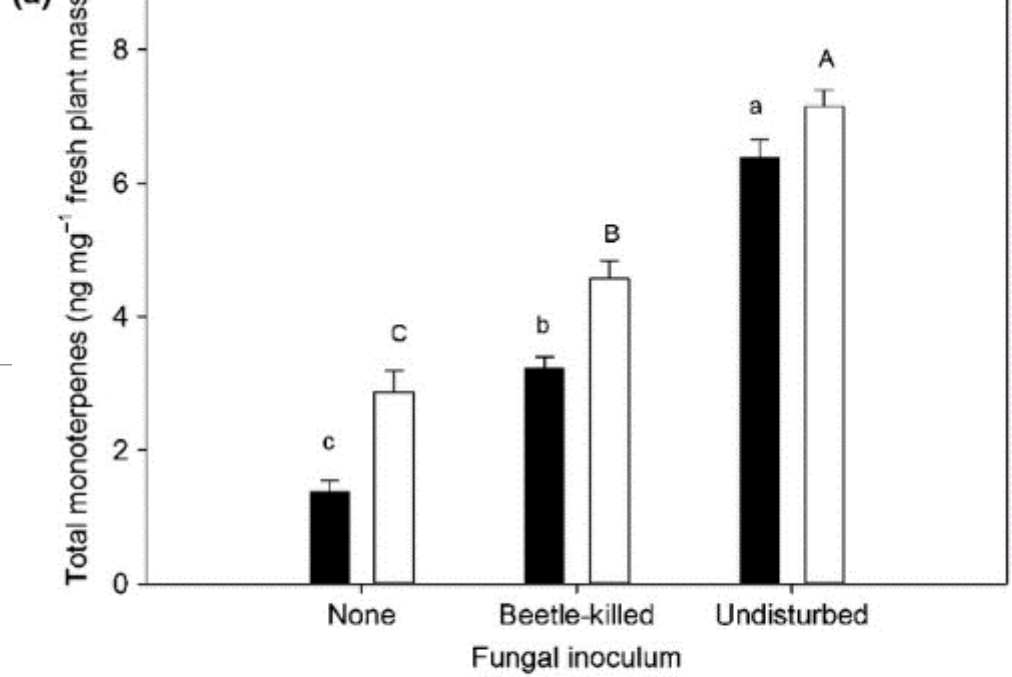
Death of adult trees impacts seedling performance

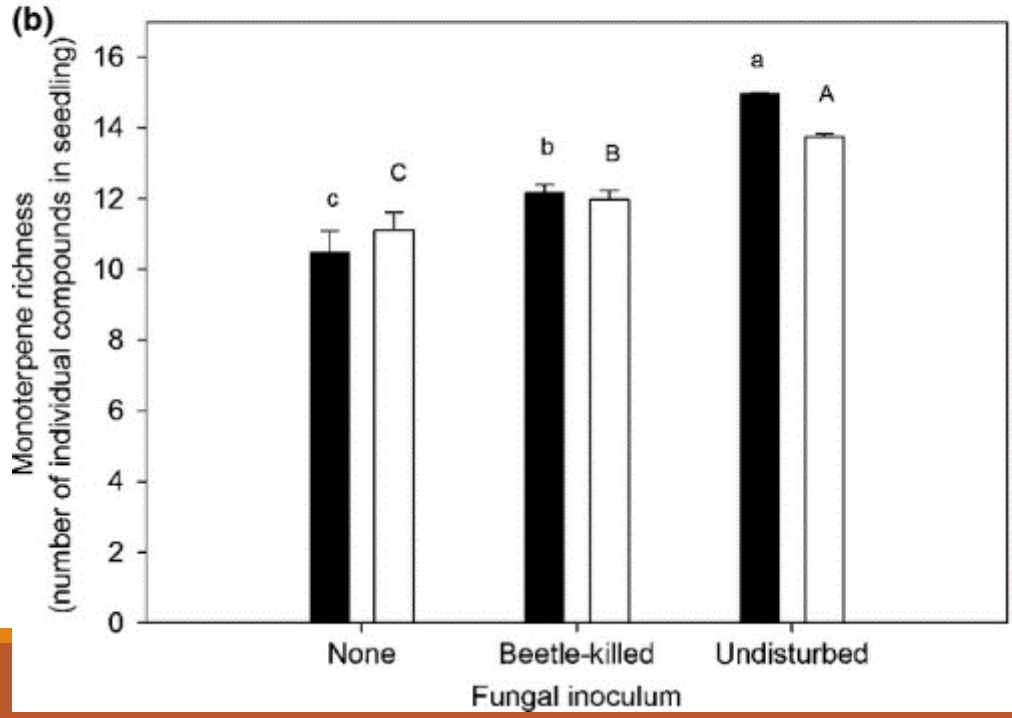
- Top = total monoterpene amounts per mg seedling in the inoculum study
- Bottom = monoterpene diversity

Outcomes

- No innocula (living soil) strongly reduces seedling secondary chemistry (amounts and diversity)
- Beetle-killed innocula strongly reduces seedling secondary chemistry (amounts and diversity)

Shifts in root-associated fungi are associated with shifts in plant defense.





Karst et al. 2015. New Phytologist

And, soil inoculum type strongly impacts LP seedling growth

Seedlings inoculated with

- No soil source (open)
- Soil from high MPB induced mortality (gray)
- Soil from stand with no MPB induced mortality (black)

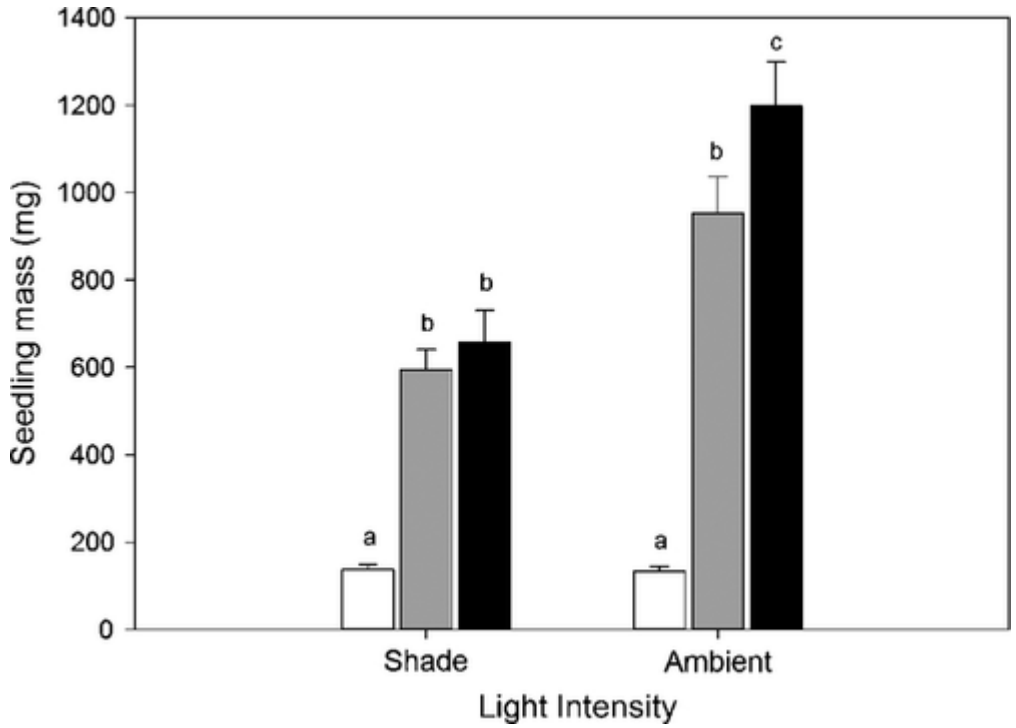
LP is mycorrhizal dependent – and strongly so

Soil from attacked stands is less effective as an inoculum, **particularly under high light conditions**

- Maximum biotic potential reduced

"Yes it matters" – Transgenerational effects

- Reduced defensive chemistry AND reduced growth



Karst et al. 2015. New Phytologist

But … seedlings in a forest do not encounter inoculum alone

A limit of MANY “soil function” studies is they test for microbial effects outside of the whole system context

This ignores the potential mitigating effects of

- Root interactions (e.g. competition)
- Allelochemical interactions
- Complex hydrological dynamics

Thus, inoculum studies might best identify whether microbes have a SIGNIFICANT impact, but not an IMPORTANT effect

- This is become much broadly recognized (e.g. Karst et al Nature EE 2023)

https://earthhavenlearning.ca/blog/the-relationship-between-mycorrhizal-fungi-and-roots/102

Testing for common-mychorrizal-network (CWM) effects

Same plots as the prior studies

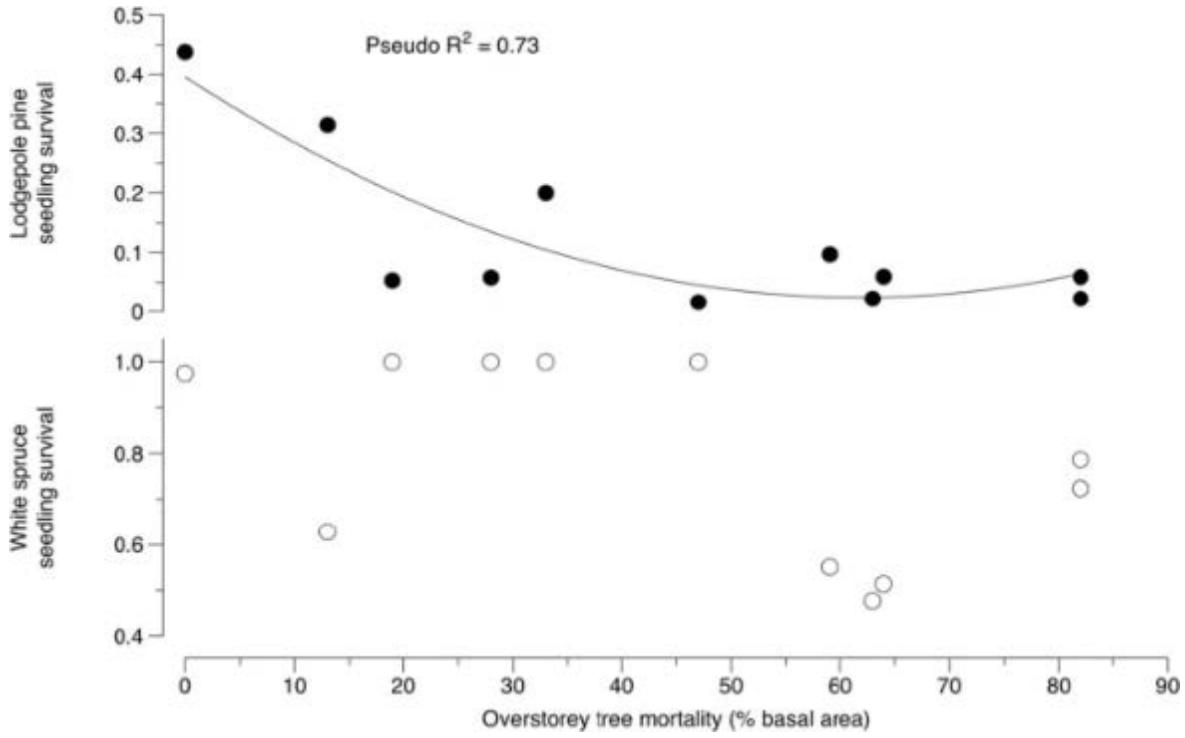
- Lodgepole pine and white spruce, *Picea glauca* seedling growth in the field
- Broadly, LP not WS seedling survival decreases with canopy mortality

Lined 15cm x 35cm deep plots with different sized mesh to modify what could interact with seeds in the plot center

- +EM +Roots (no mesh)
- +EM – Roots (44um mesh)
- -EM – Roots (0.5um mesh)

Measured seedling performance over time

- EM effect = +E-R/-E-R
- Root effect = +E+R/+E-R
- Bulk soil = +E+R/-E-R



Pec et al 2020. Mycorrhiza

Significant, not important

Top: EM benefits for survival decreased with canopy mortality (Pine)

- **Significant effect of connection**
- But note the low effect size, averaging at zero and going only to +/- 0.5

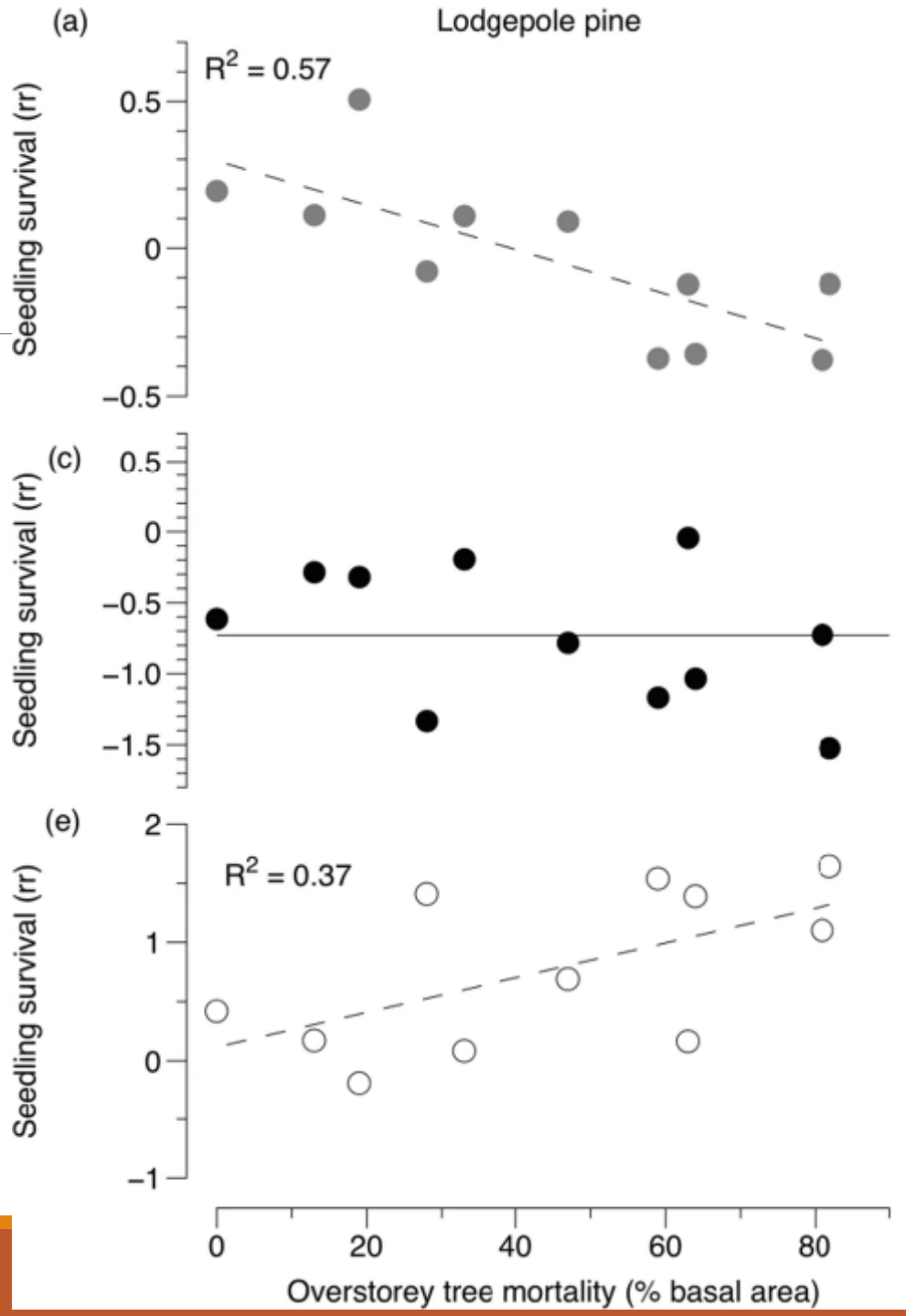
Middle: Effects of root competition constant across mortality gradient

- Average and maximum effect sizes MUCH more negative

Bottom: Despite prior results, **seedling survival is strongly enhanced with exposure to roots and EM**

- INCREASED seedling survival with canopy mortality, high effect size
- Strongly suggests other aspects of soil more strongly impact seedling survival

No EM effects on spruce, nor on biomass or nutrition in either species



Pec et al 2020. Mycorrhiza

But maybe that EM effect is ‘big enough’ to be useful?

Disturbances are widespread through Canada’s boreal forest

- MPB, logging, species invasion, fire

Forest recovery critical to both biodiversity and economic development

IF … soil microbiomes are important for regeneration/seed bed conditions can we use inoculum from undisturbed soils to “kickstart” recovery post disturbance

In other words … can we use soil transfers to mitigate disturbance impacts on seedling growth?

Root-associated EcM communities vary among disturbance types

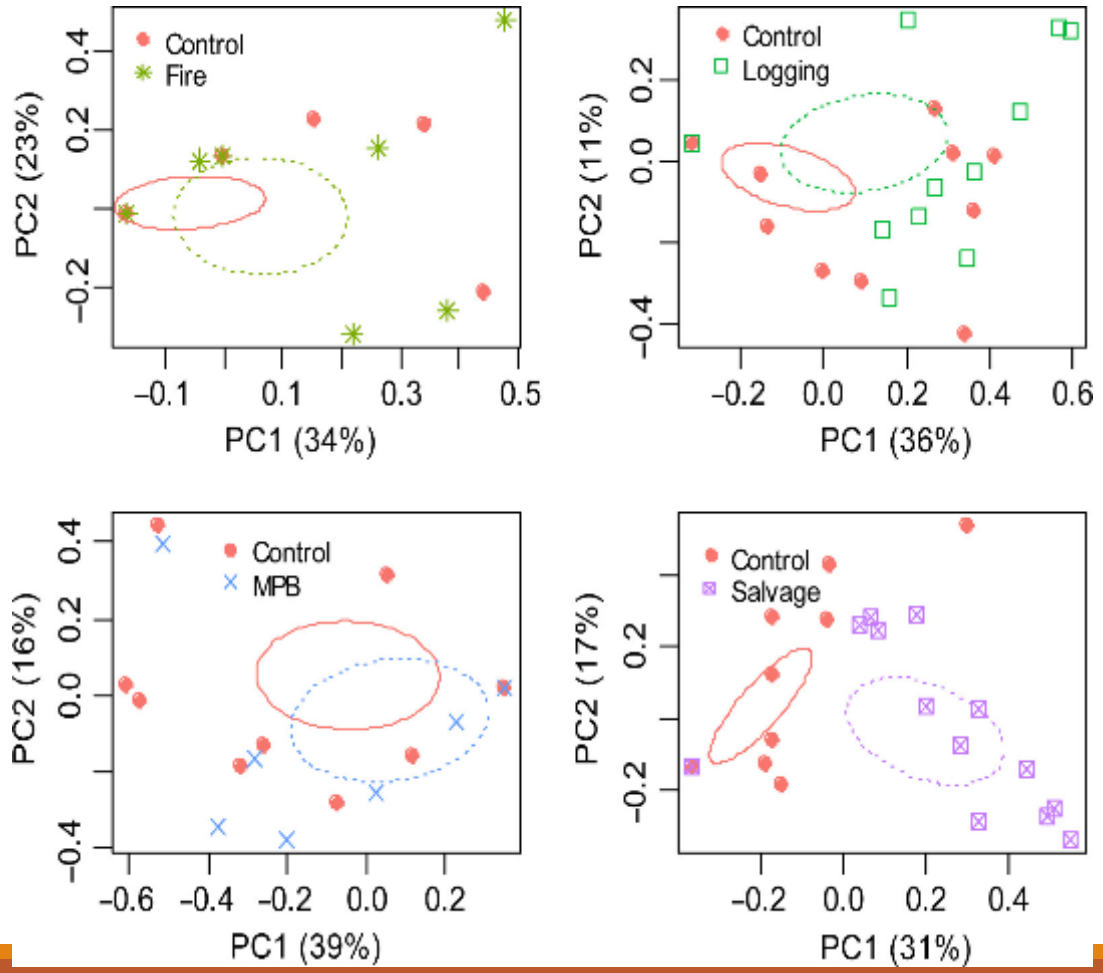
Lodgepole pine seedlings grown in greenhouse, with innocula of soil collected

- Recently disturbed forests x 4 type
- Nearby undisturbed forest stands

Strongest microbial difference associated with logging, both salvage and ‘regular’

Seedlings also typically were larger with control inoculum than disturbed soil inoculum (not shown)

But … does this mean that soil transfers can ‘recover’ seedling performance in the field?



Beck et al. J Applied Ecology 2020

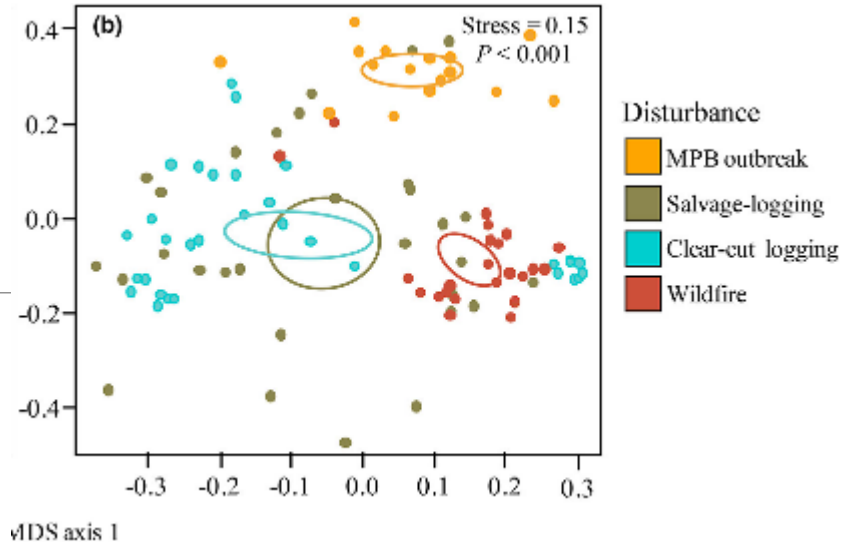
No, at least not in our study

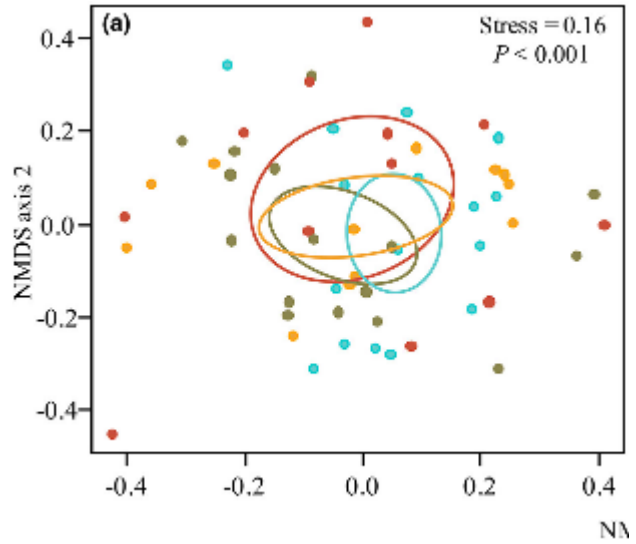
Soil transfers up to 3L NEVER had any effect on*in situ* pine seedling growth or survival.

Why?

- Root-associated EcM community (TOP) did vary among disturbances, but bulk soil EcM community (BOTTOM) did not
- Likely that the EcM species pool is always in the soil, but some assembly mechanism prevents certain infections
  - NOT likely dispersal limitation and thus adding soil likely won't make a difference

And this is even assuming the function would be strong enough to matter!





Rodriguez-Ramos et al 2022. J Applied Ecology

Diverse fields are become more integrated, but we have a long way to go!

Context dependency

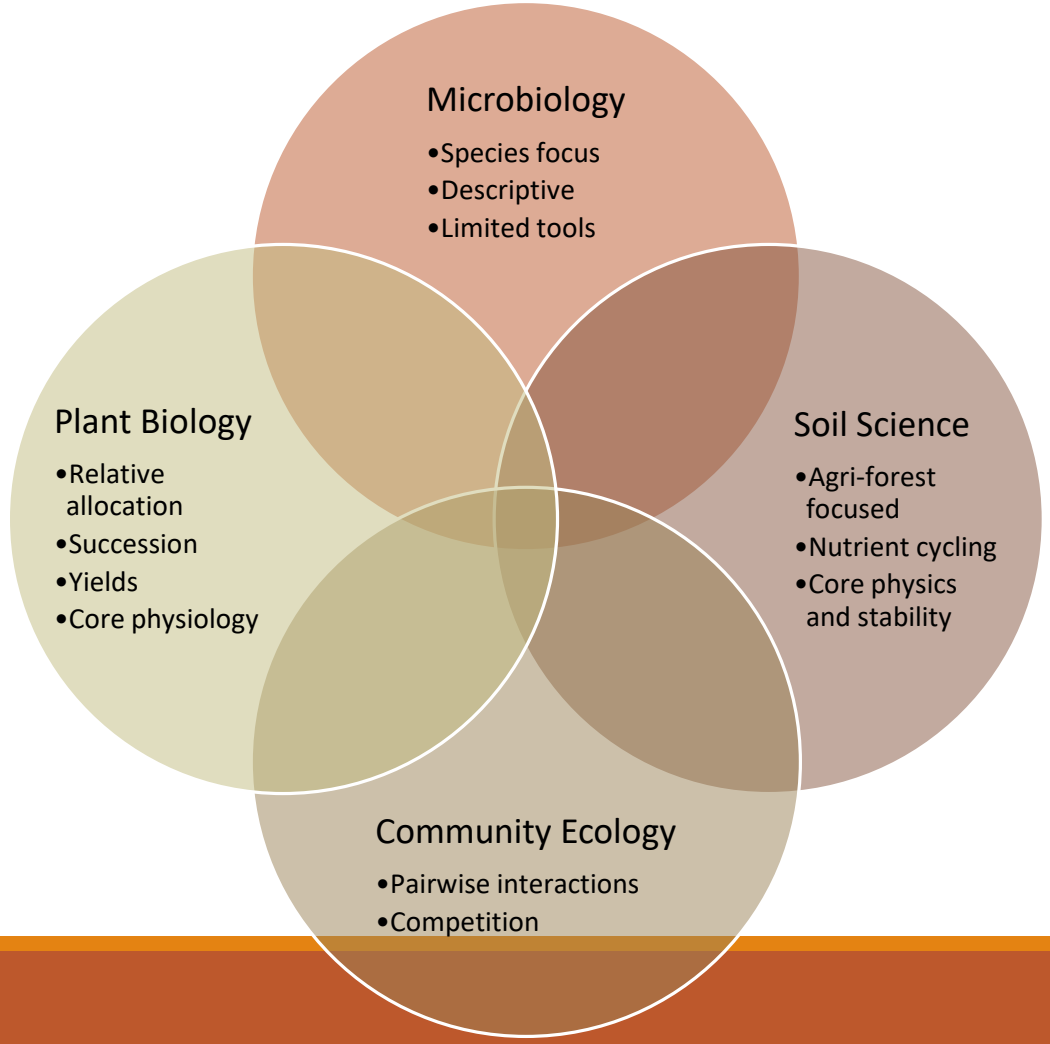
Differentiating between significance and importance

Understanding very diverse and complex research methodologies

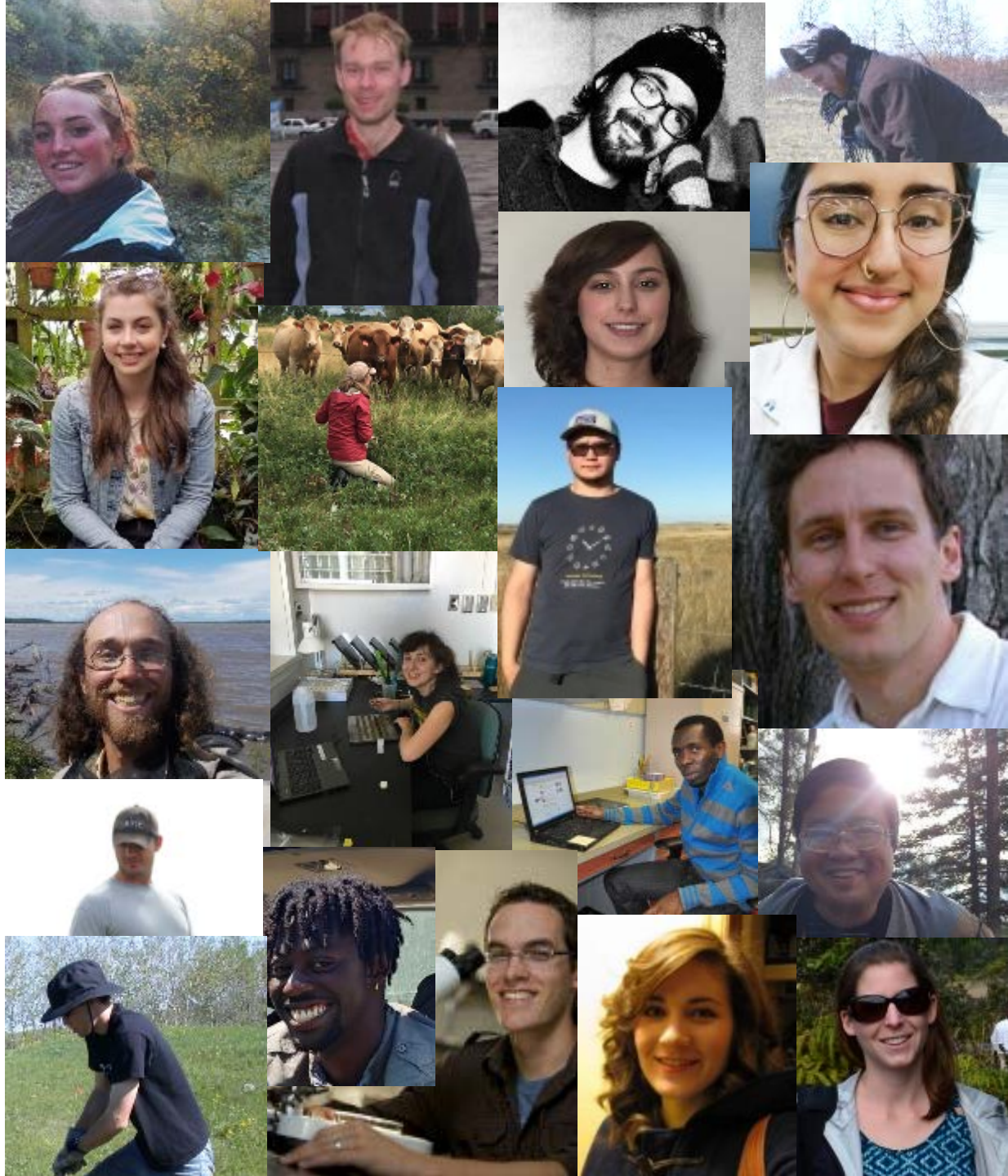
Need integrated training and knowledge that is trans-disciplinary

Teams are critical, but individuals still need unique ideas!

Globally important problems in agriculture, forestry and conservation



Thank you for listening, and thank you for the opportunity to speak today.



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