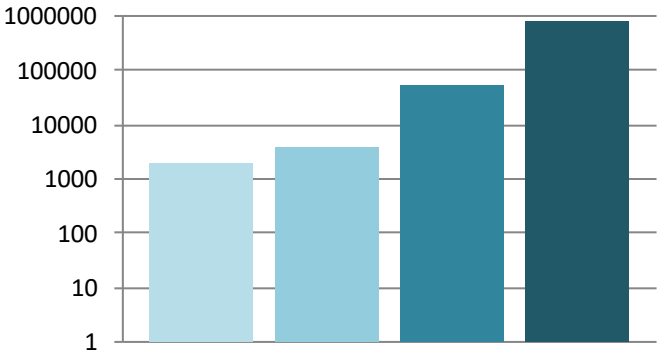


Leveraging Natural and Experimental Gradients to Understand the Drivers of Microbial Community Assembly

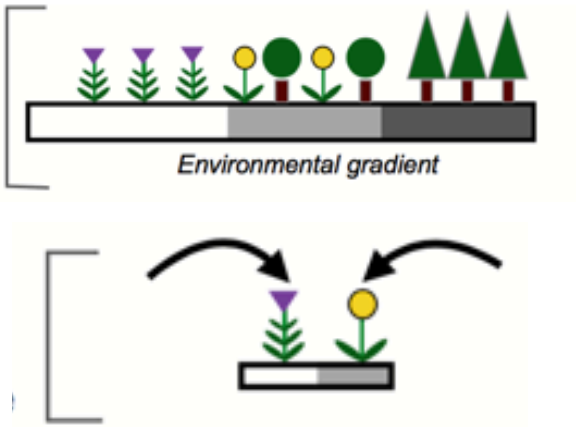
Rebecca Mueller

Measuring assembly: Co-existence in microbial communities

Microbial taxa per gram of soil

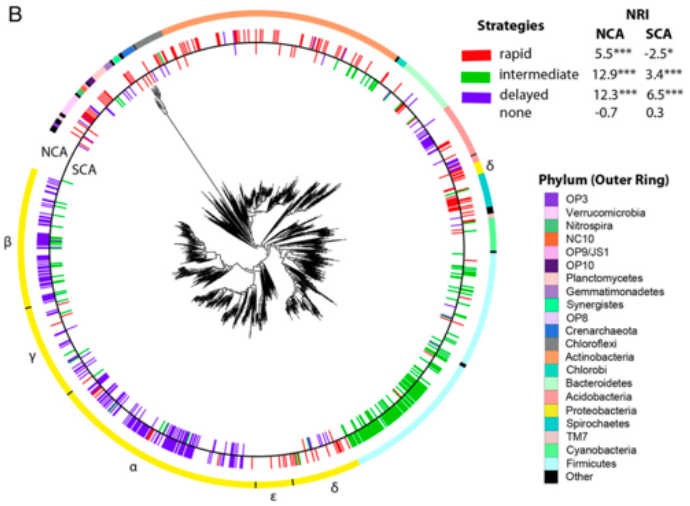


Spatial niche partitioning



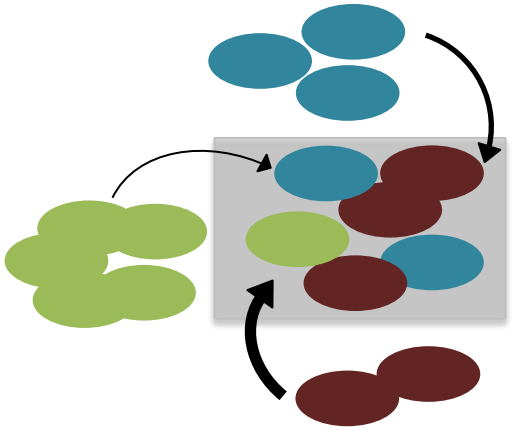
Kraft et al. 2015

Temporal partitioning



Placella et al. 2012

Fluctuating dispersal

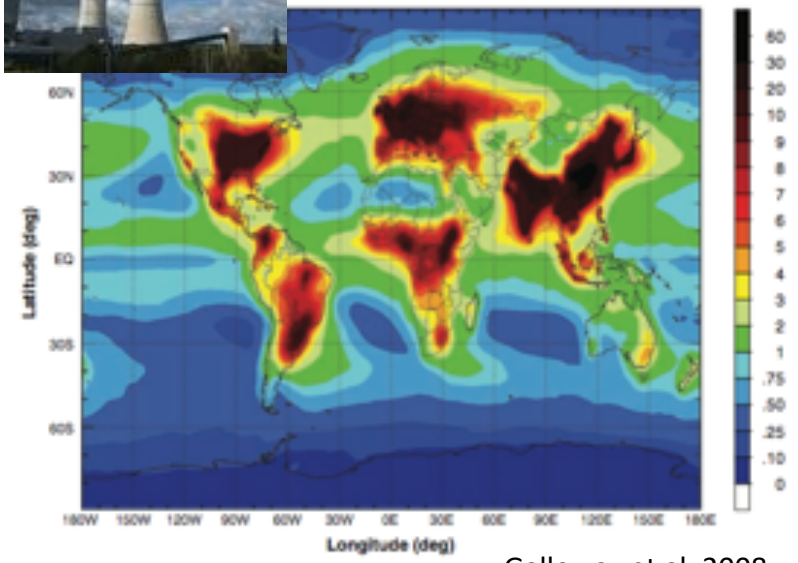


Anthropogenic disturbance and community disassembly

Invasive species

Climate change

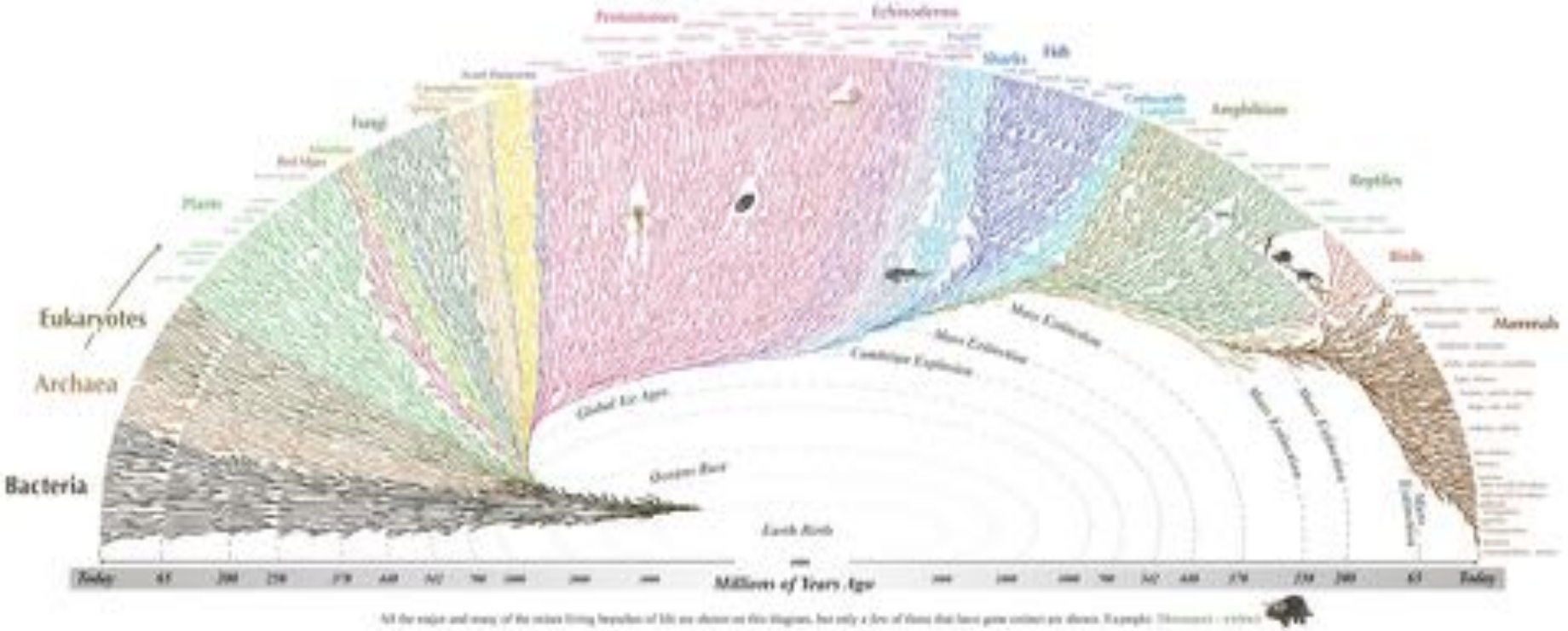
Eutrophication



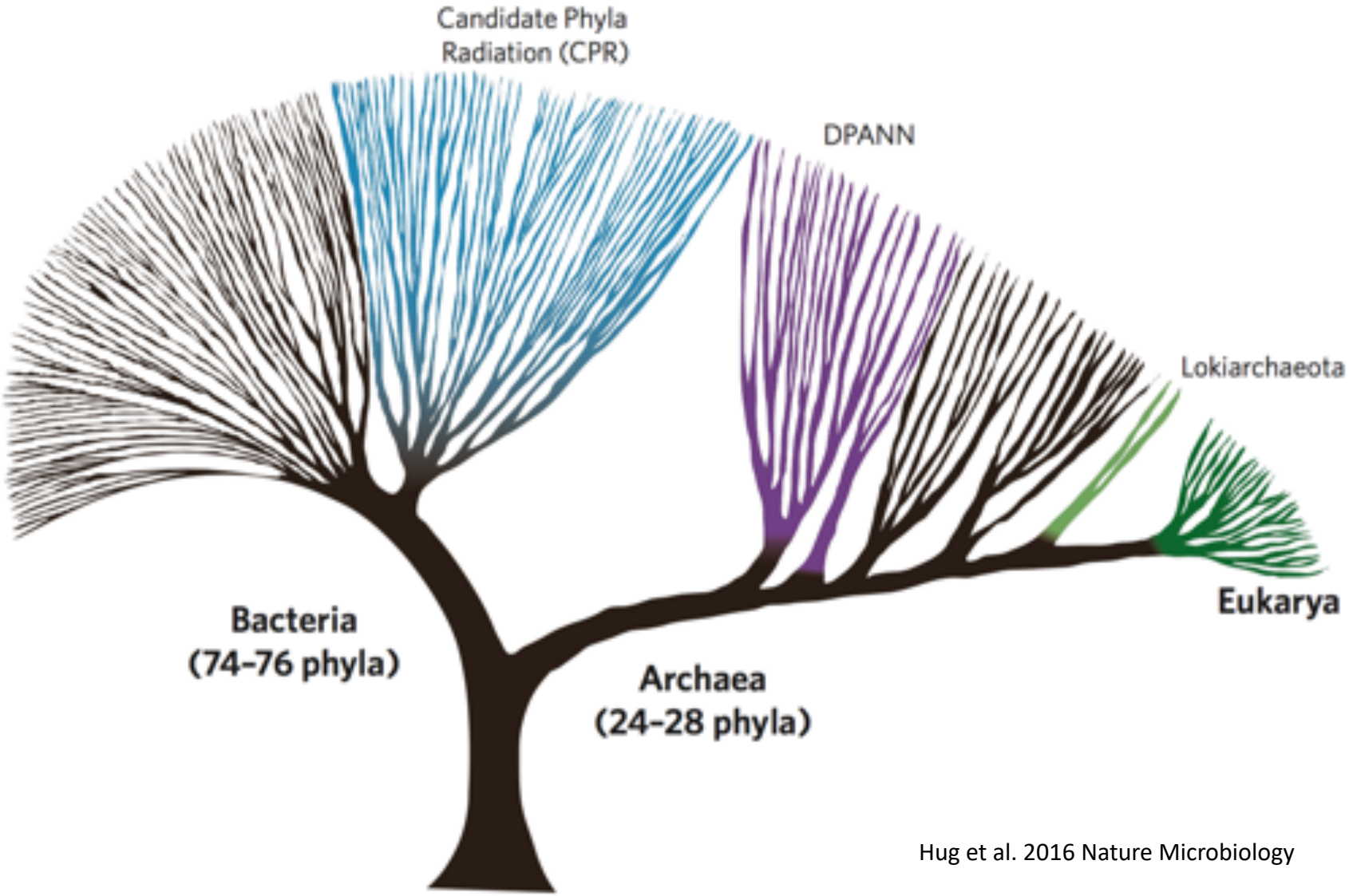
Galloway et al. 2008

Land use change

How does disturbance prune the tree of life?



How does disturbance prune the tree of life?

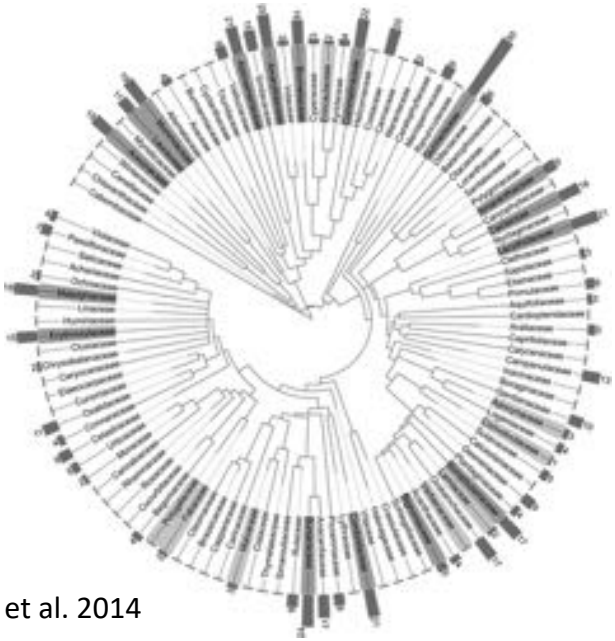


Hug et al. 2016 Nature Microbiology

Response to anthropogenic disturbances: Winners and losers

Winners

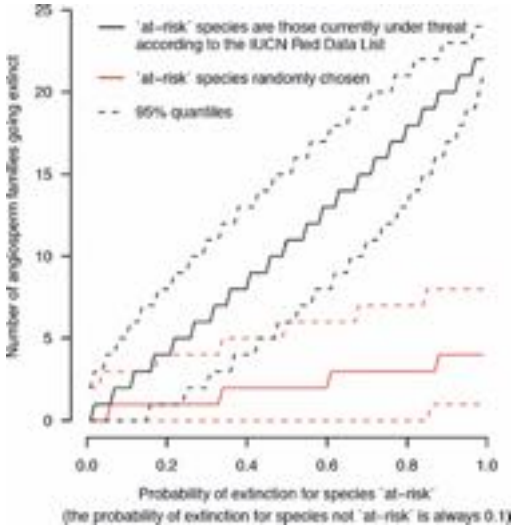
- Some species benefit from perturbations
- Traits linked to survival



Leau et al. 2014

Losers

- Non-random ⟶ loss of evolutionary history
- Models assume random loss
- Traits linked to susceptibility

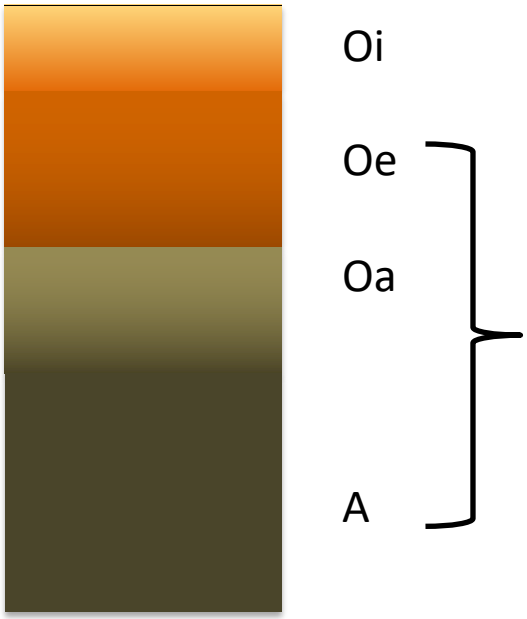


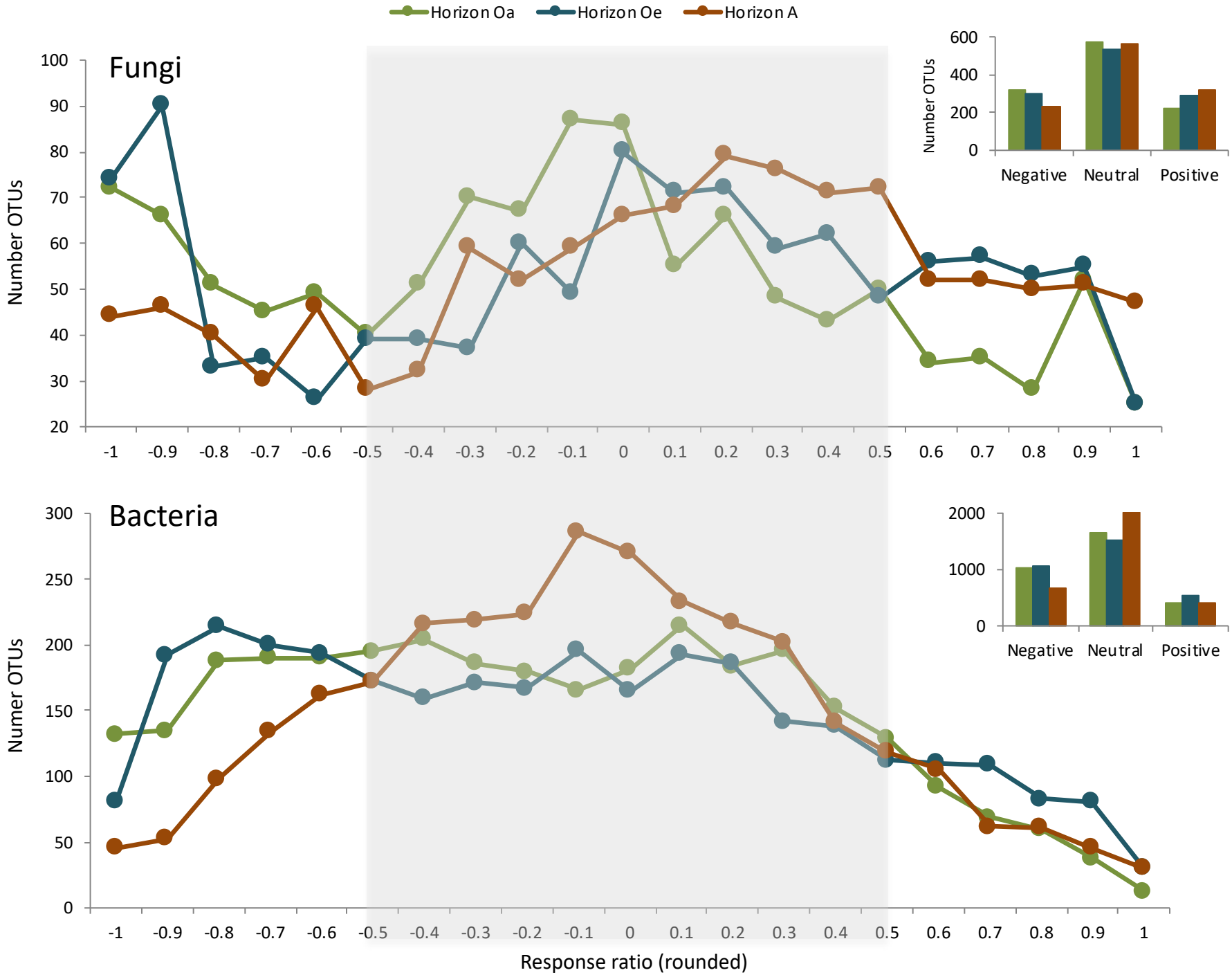
Vamosi and Wilson 2008

Nitrogen addition in a temperate forest

Cheryl Kuske
John Dunbar

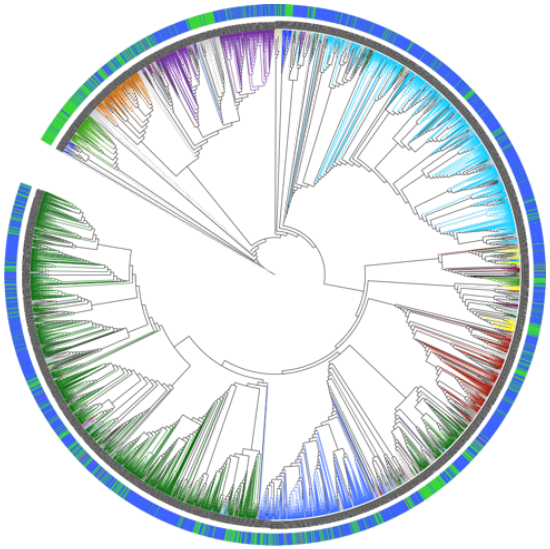
- Duke Experimental Forest
  - Effects of nitrogen addition on microbes across three soil depths

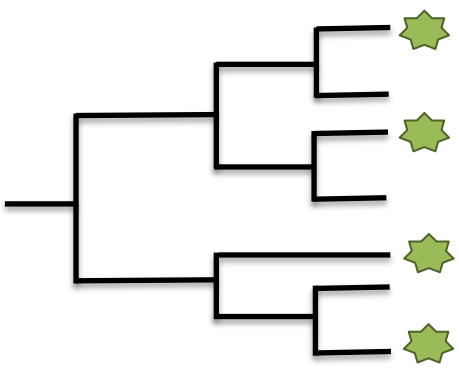


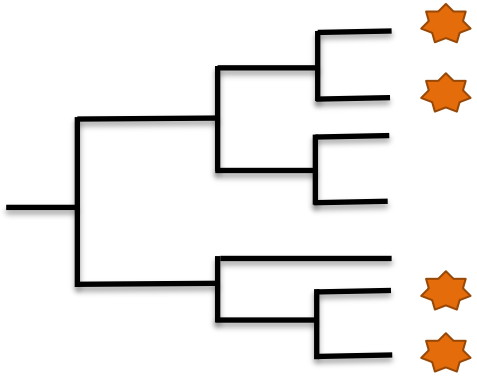

Horizon Oa
Horizon Oe
Horizon A
Fungi
Number OTUs
100
90
80
70
60
50
40
30
20
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
600
400
200
0
Number OTUs
Negative
Neutral
Positive
Bacteria
Numer OTUs
300
250
200
150
100
50
0
2000
1000
0
Negative
Neutral
Positive
Response ratio (rounded)

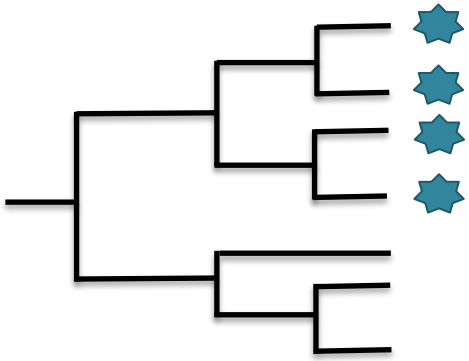
Phylogenetic community measures

- Measures of evolutionary history

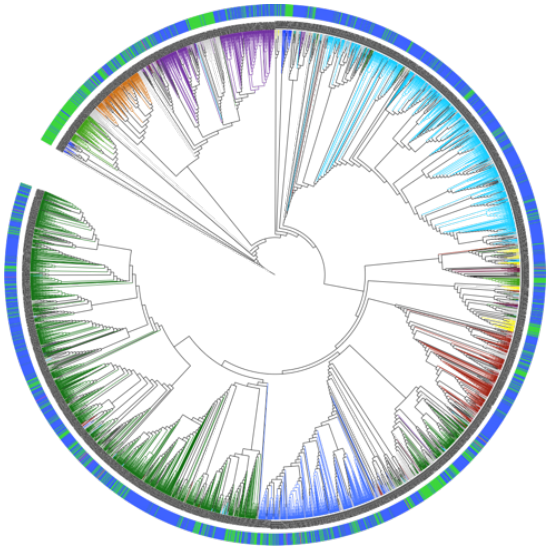




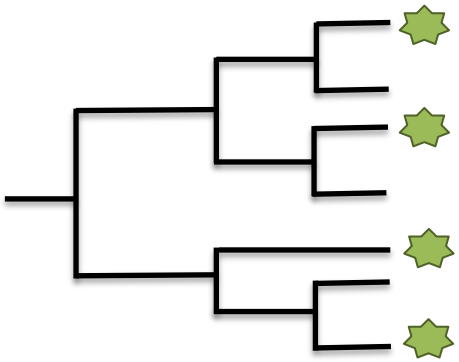




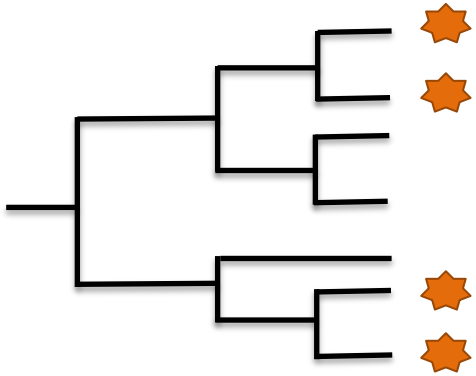
Phylogenetic community measures: Diversity



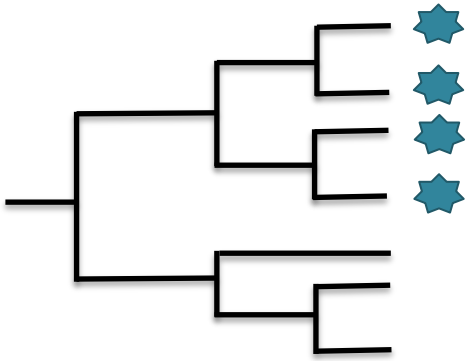
PD = 12



PD = 8

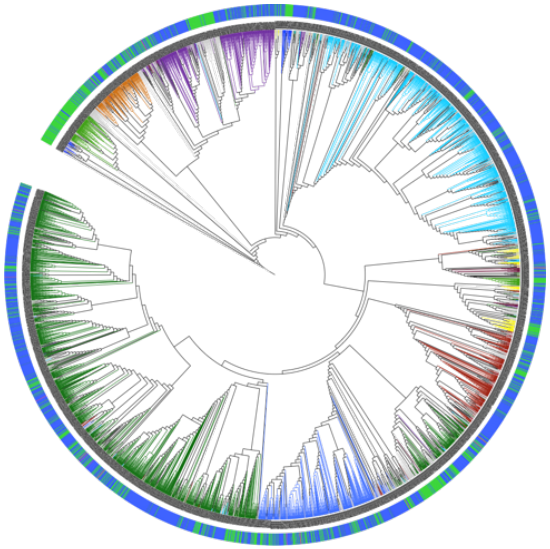


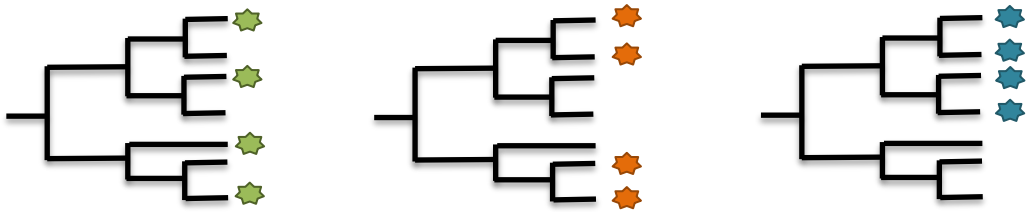
PD = 6



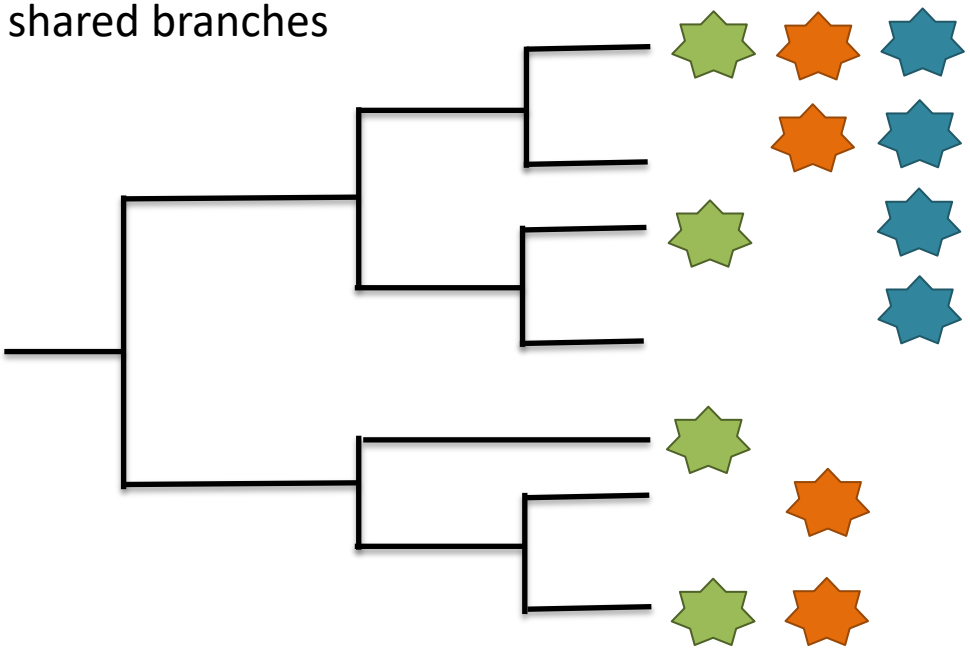
Faith's Phylogenetic Diversity (PD): Sum of branch lengths shared

Phylogenetic community measures: Similarity

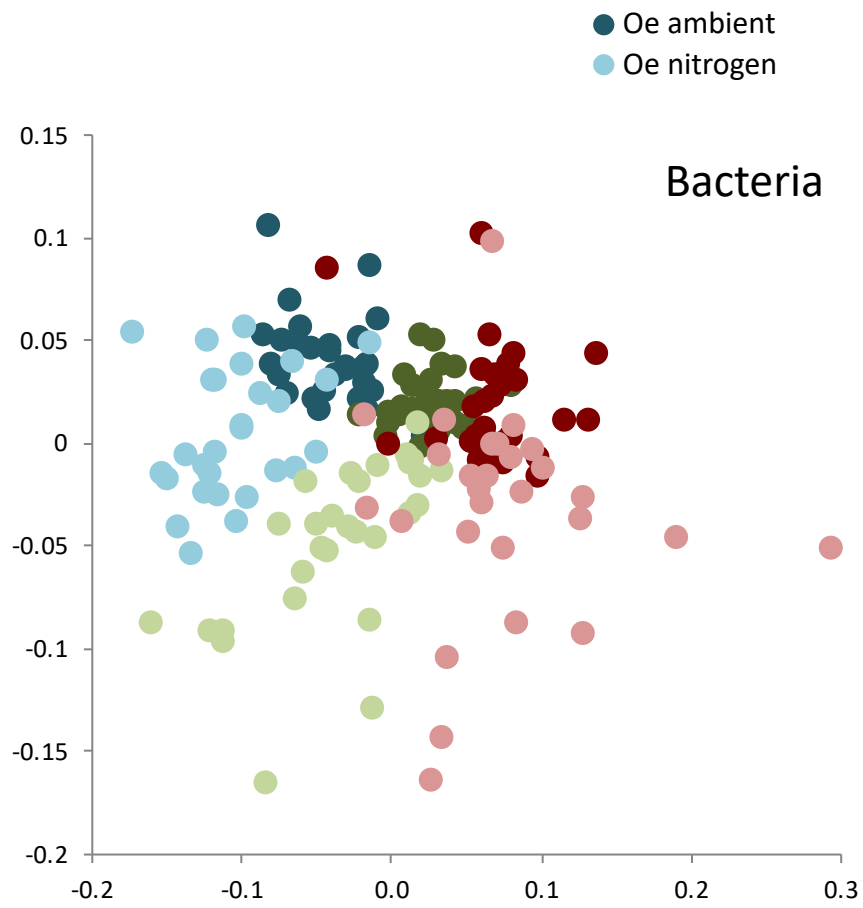




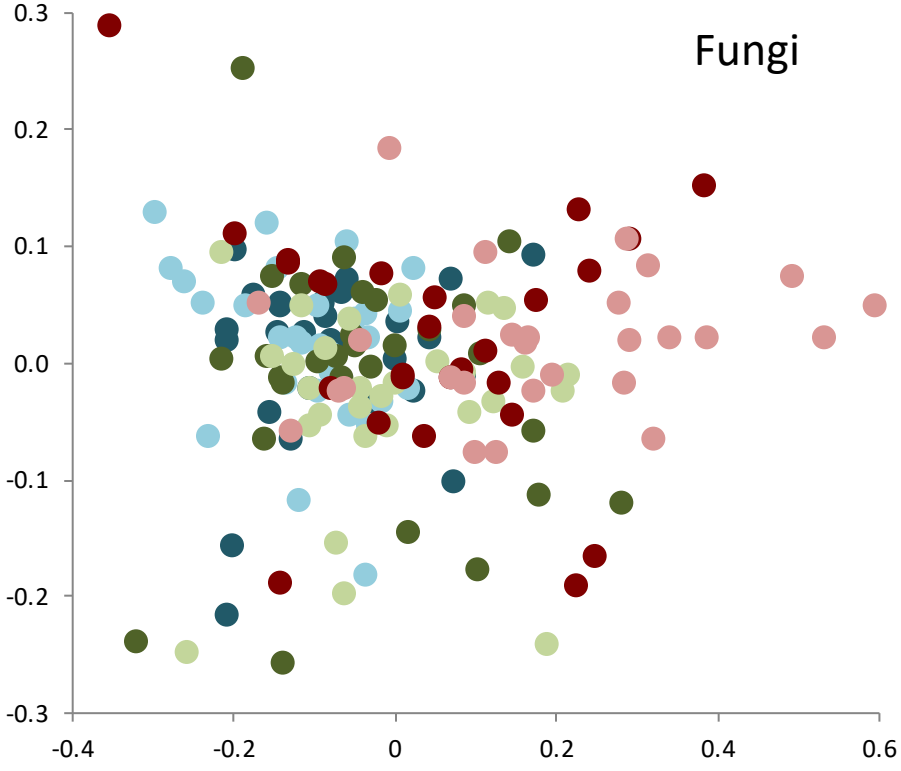
UniFrac: Fraction shared branches over total



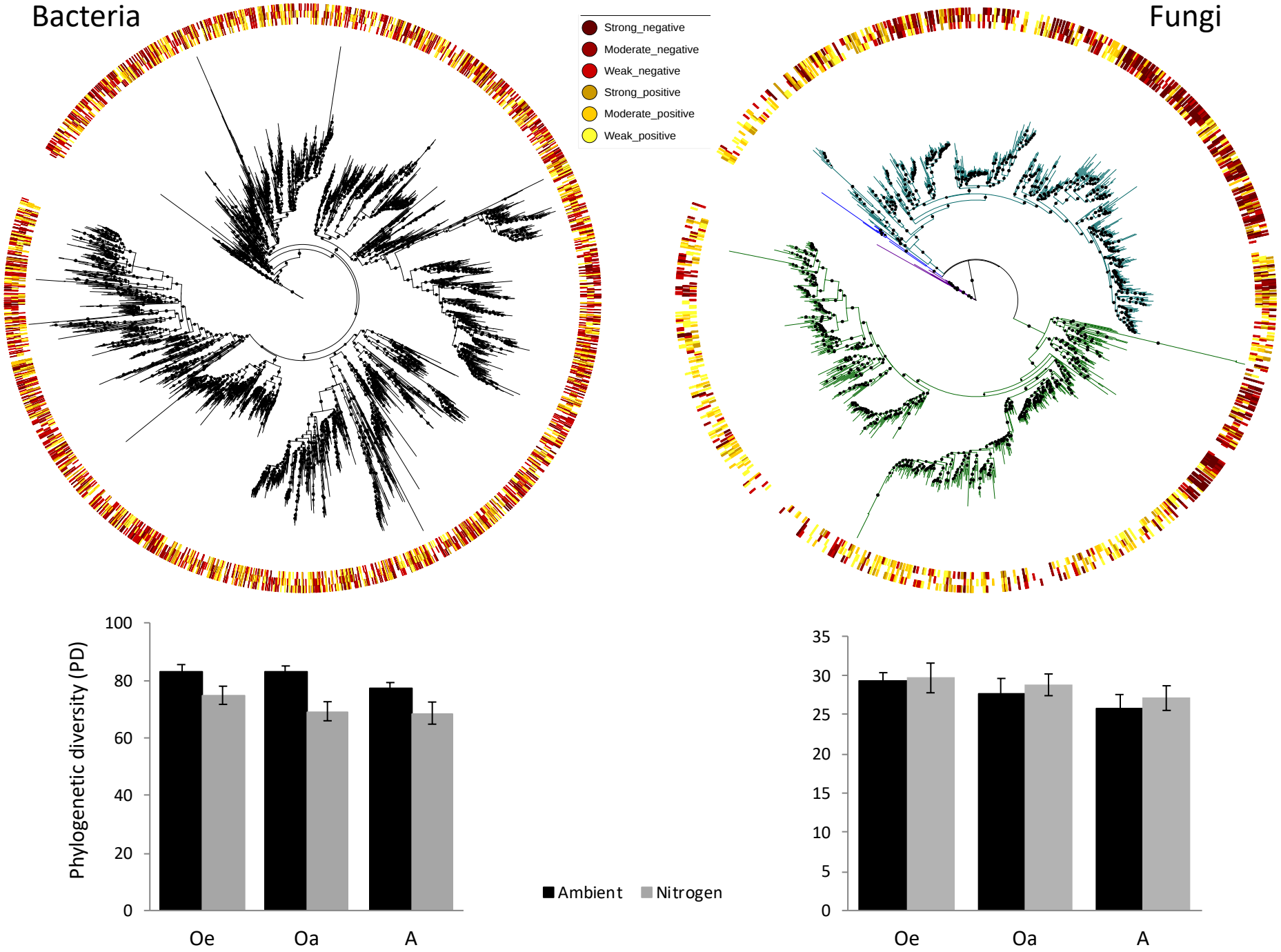
Strong community shifts



Nitrogen: F = 14.3, R2 = 0.06, p = 0.001
Horizon: F = 22.4, R2 = 0.20, p = 0.001

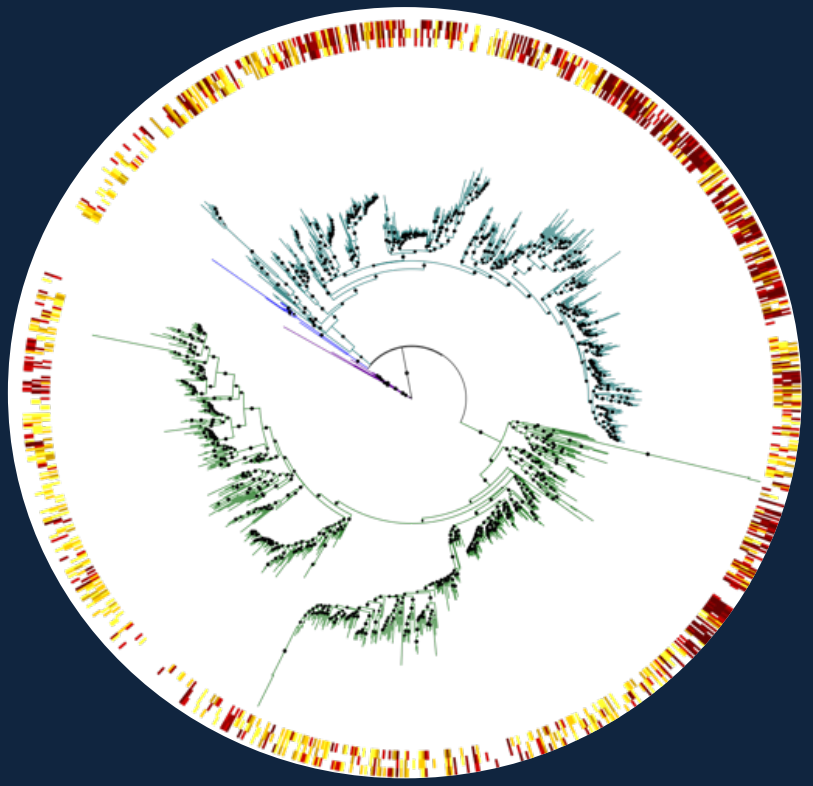


Nitrogen: F = 4.65, R2 = 0.03, p = 0.001
Horizon: F = 5.37, R2 = 0.06, p = 0.001

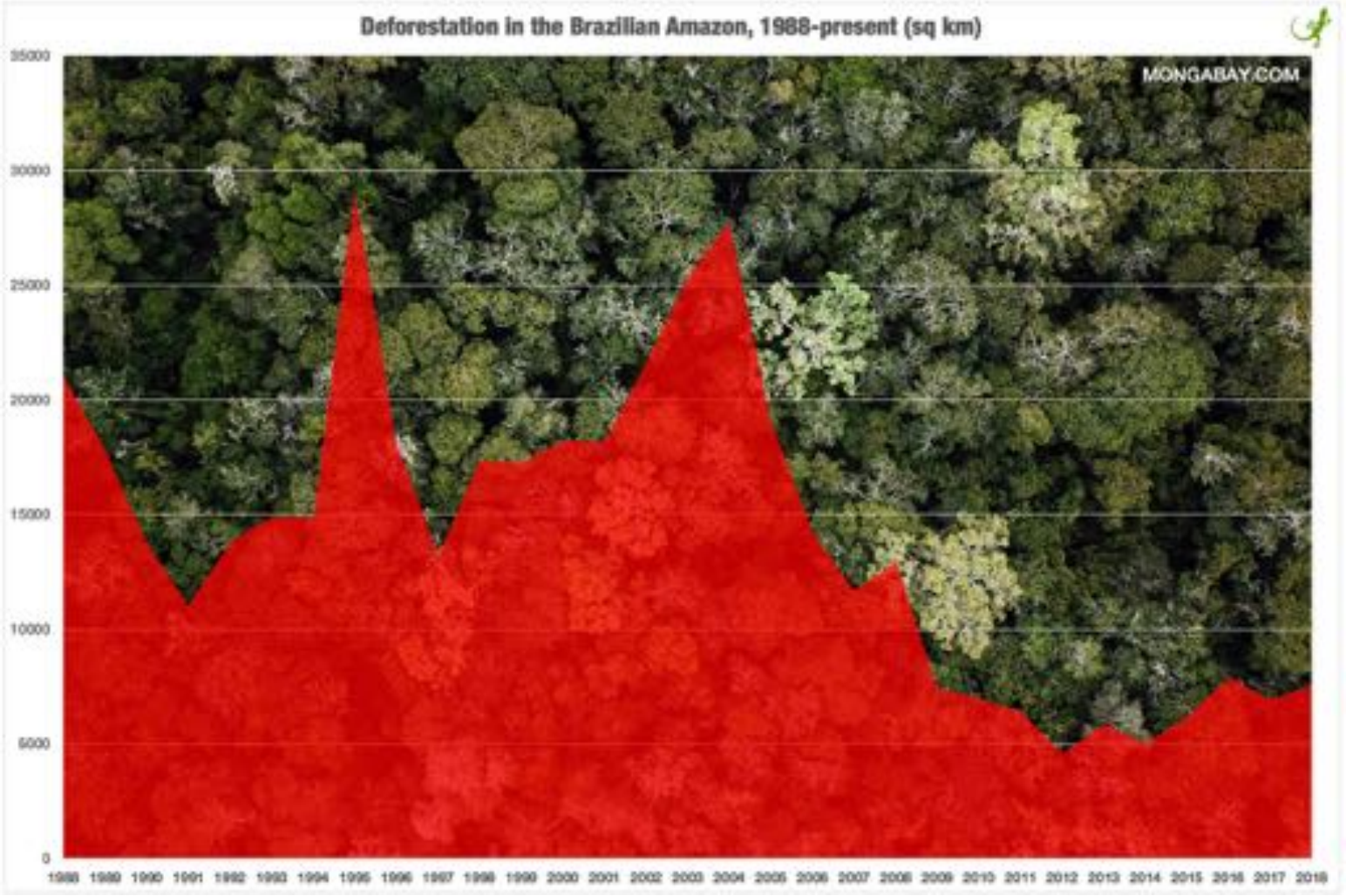

Bacteria
Fungi
Strong_negative
Moderate_negative
Weak_negative
Strong_positive
Moderate_positive
Weak_positive
Phylogenetic diversity (PD)
100
80
60
40
20
0
Oe
Oa
A
Ambient
Nitrogen
35
30
25
20
15
10
5
0
Oe
Oa
A

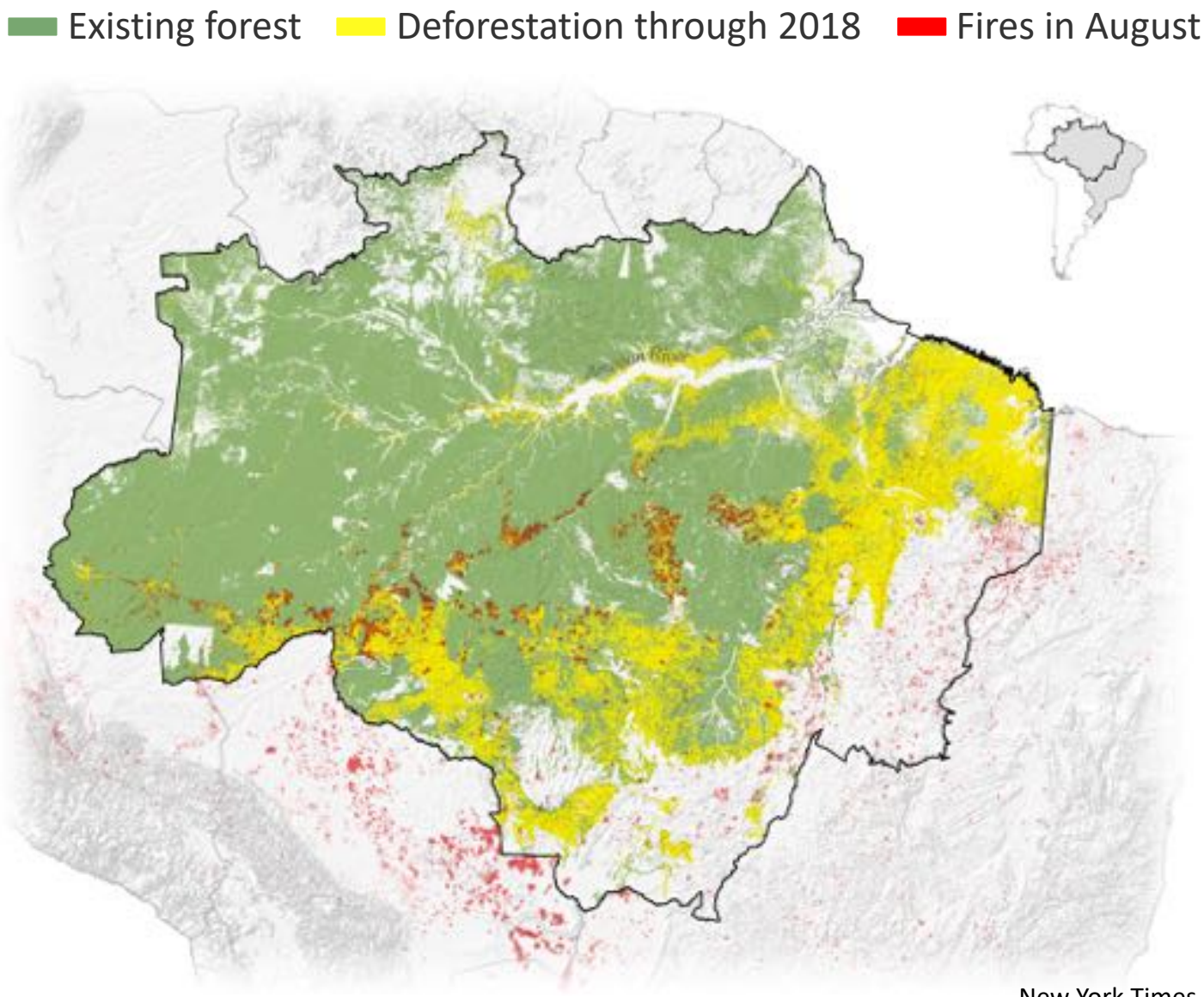
Microbial responses to nitrogen

- Differential responses in Bacteria and Fungi
  - Significant phylogenetic signal for Fungi only
- Random responses led to loss of PD
  - Tipping point for local extinctions
- Maintenance of PD even with strong phylogenetic signal
  - Balanced positive and negative



Deforestation in the Amazon

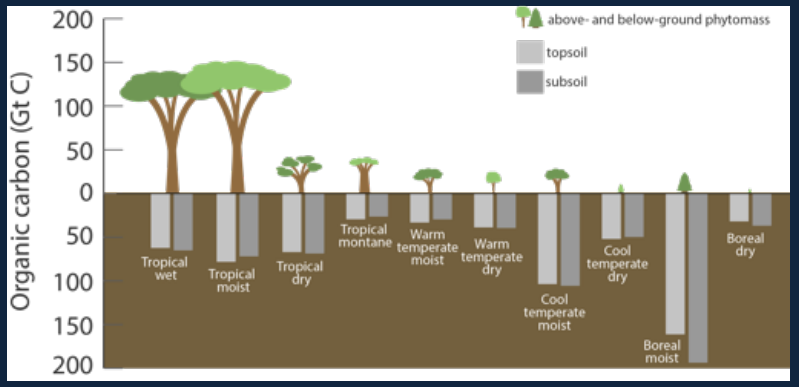




New York Times

Importance of soil communities

1. Biodiversity extends beyond macroscopic organisms
2. Carbon sink/source
3. Potential for restoration of degraded lands

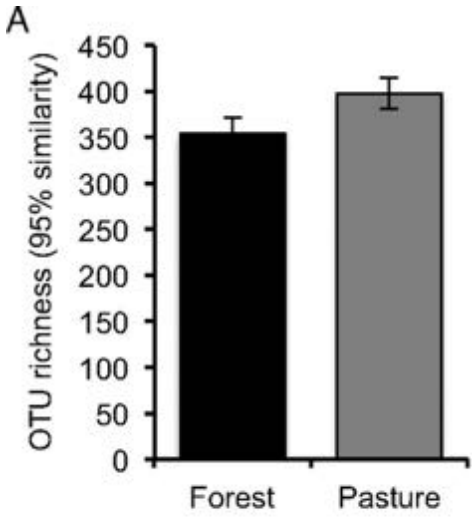


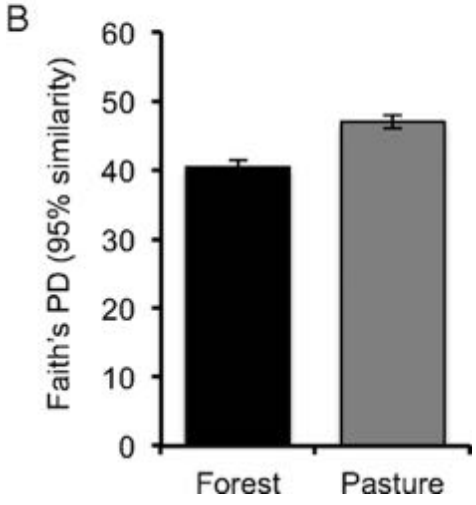
Deforestation in the Amazon Rainforest

Brendan Bohannan, Vivian Pellizari, Jorge Rodrigues, Klaus Nusslein, Fabiana da Silva Paula

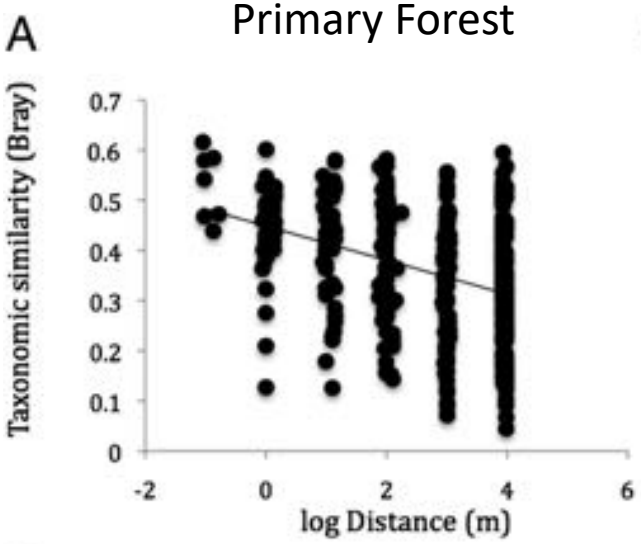
- Amazon Rainforest Microbial Observatory (ARMO)
- Gradients of land use change
  - Primary forest, secondary forest, pastures
- Spatially explicit sampling (0.01 m to 10 km)

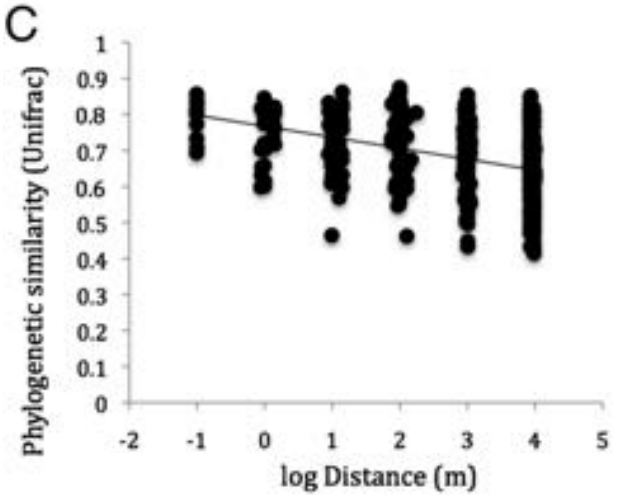
Biotic homogenization with land use change



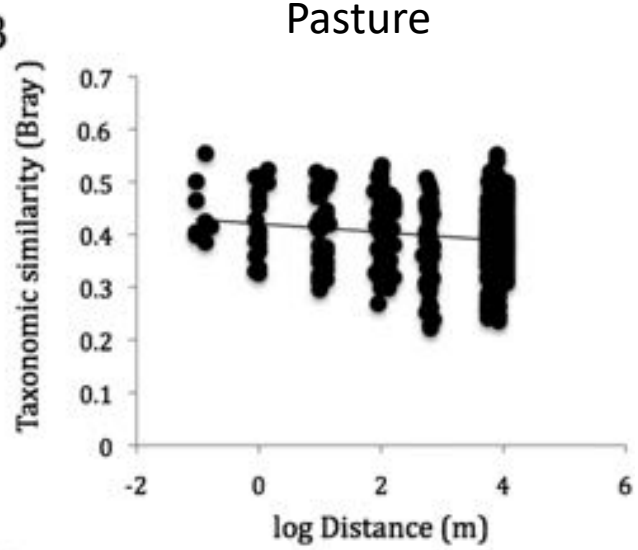


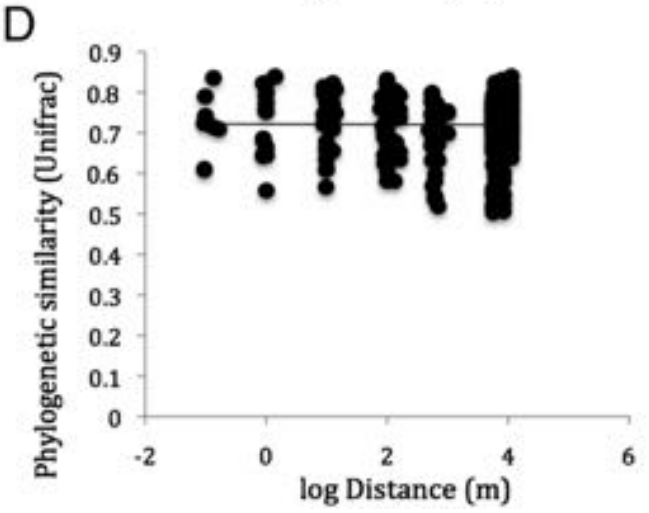
Primary Forest





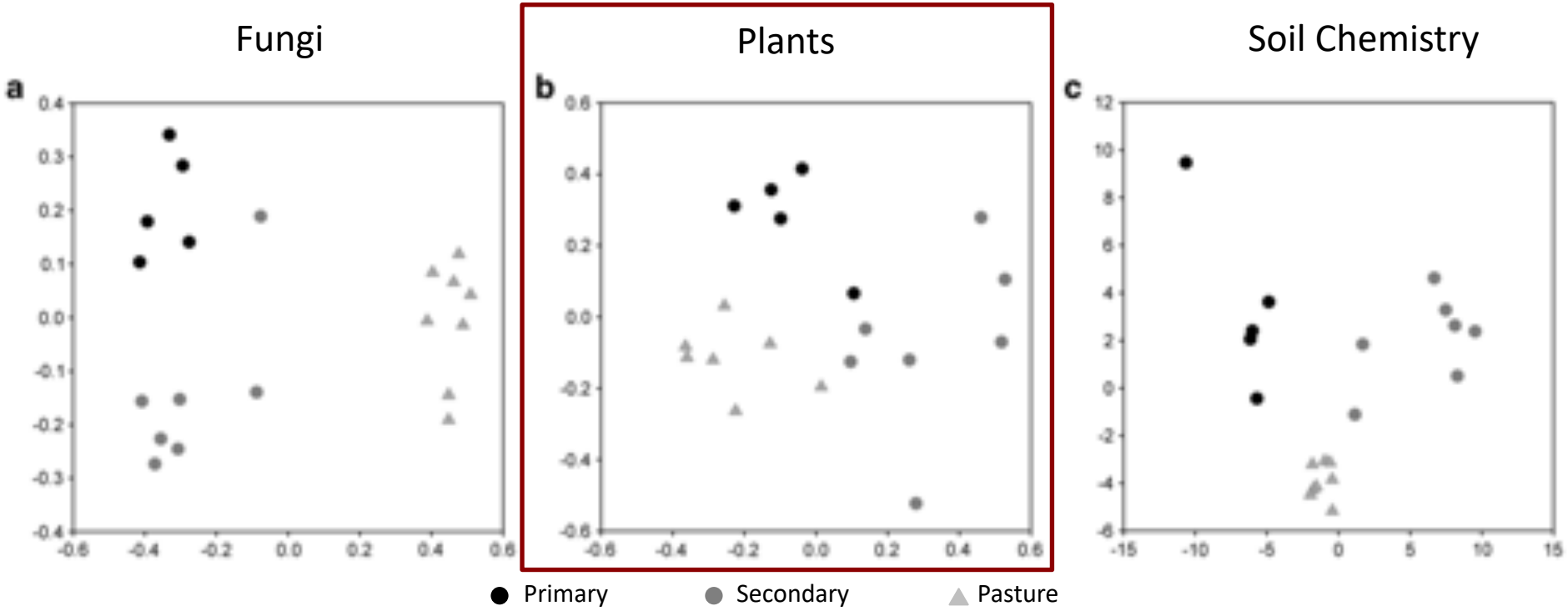
Pasture





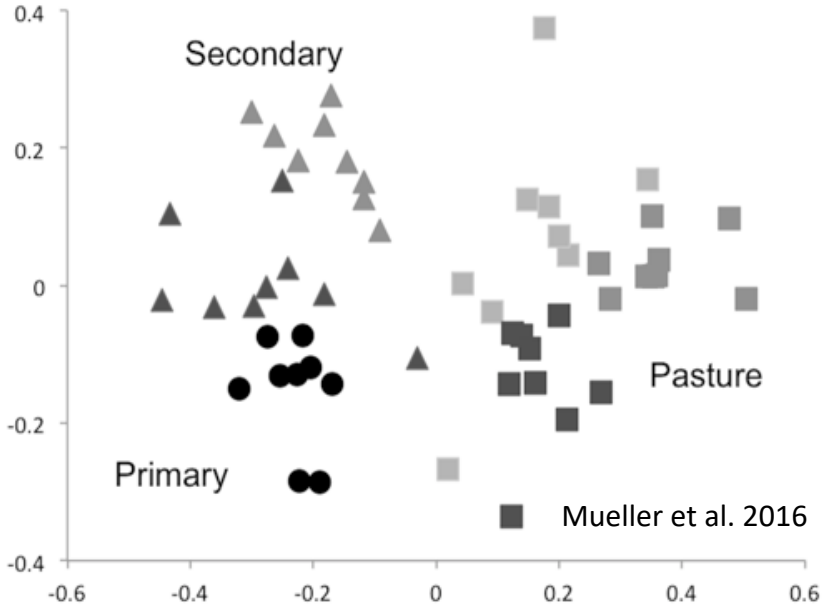
Rodrigues et al. 2013 PNAS

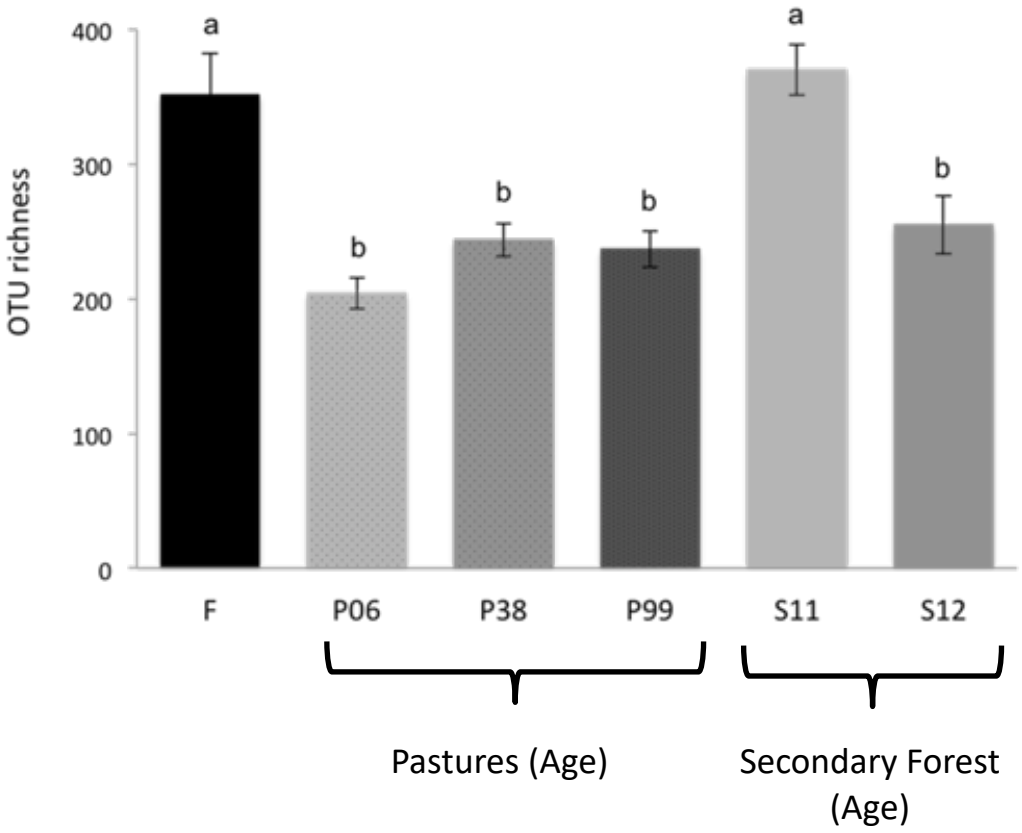
What about the fungi?



Mueller et al. 2014

What about the fungi?





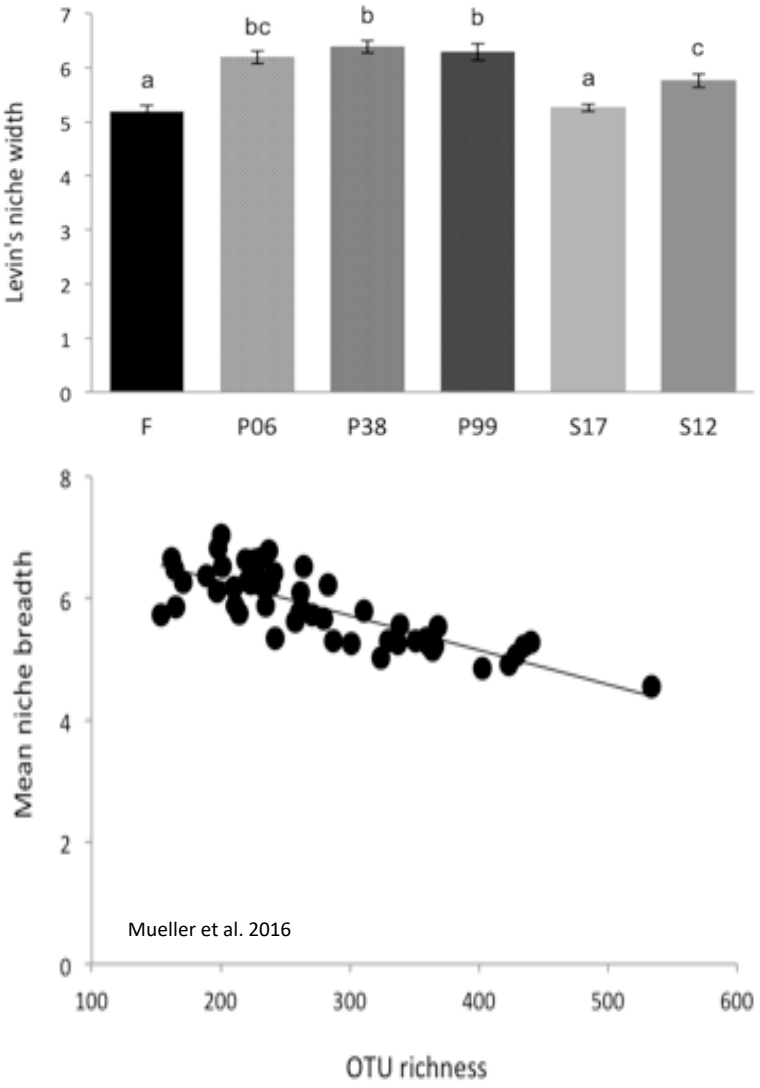
Traits linked to responses

Table 3. Traits influencing whether species are winners or losers in a human-dominated world[a]

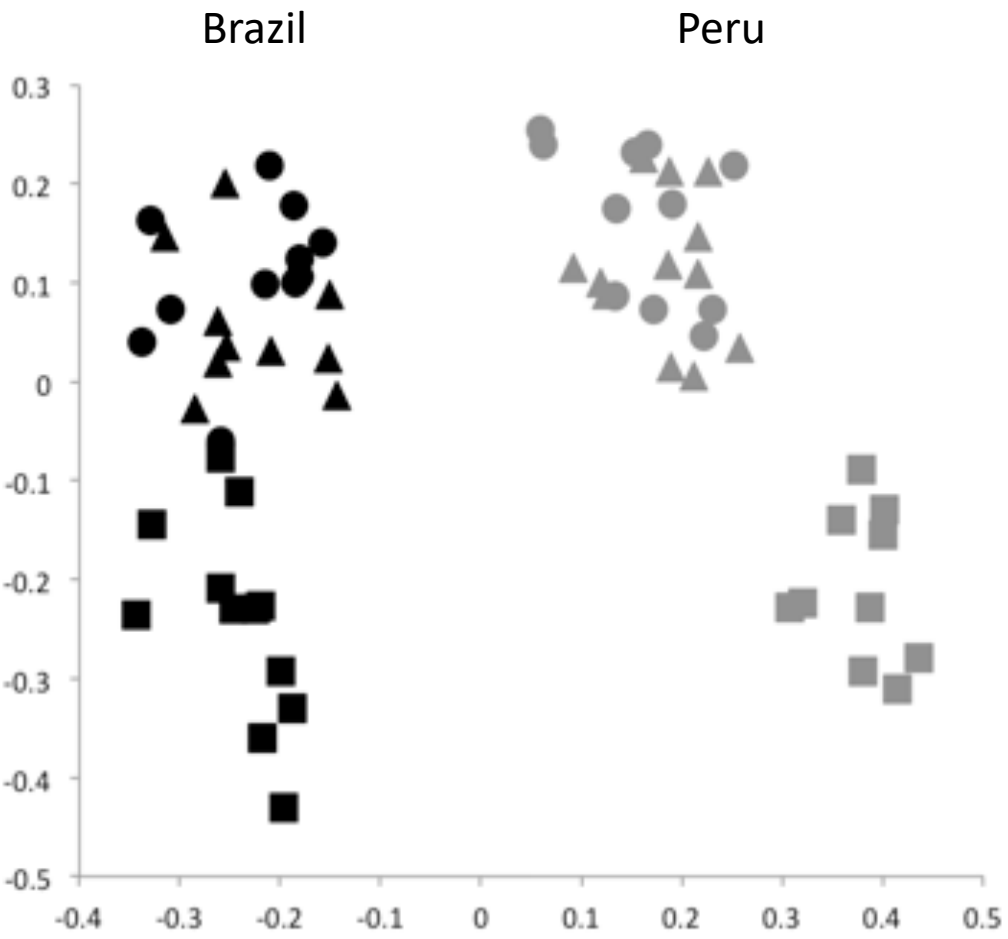
Traits promoting range expansion	Traits promoting extinction
r-selected traits (small size, high fecundity)	*K*-selected traits (large size, low fecundity)
High variability	Low variability
Widespread	Rare
Rapid dispersal	Slow dispersal
Generalist (eurytopy)	Specialist (stenotopy)
Human commensalism	Poorly adapted to human activities

[a]Modified from Refs 1,11,15.

McKinney and Lockwood 1999

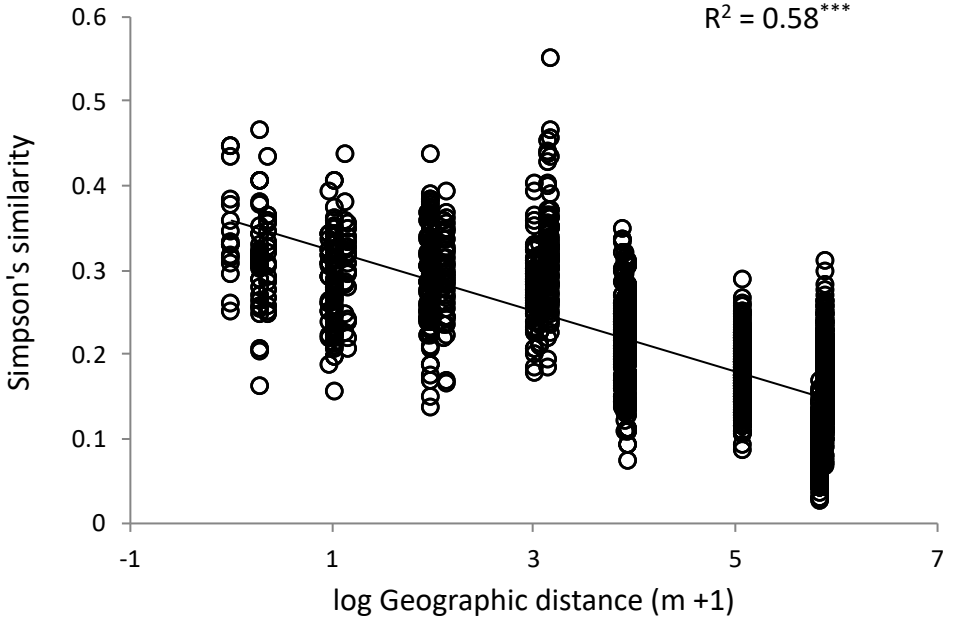


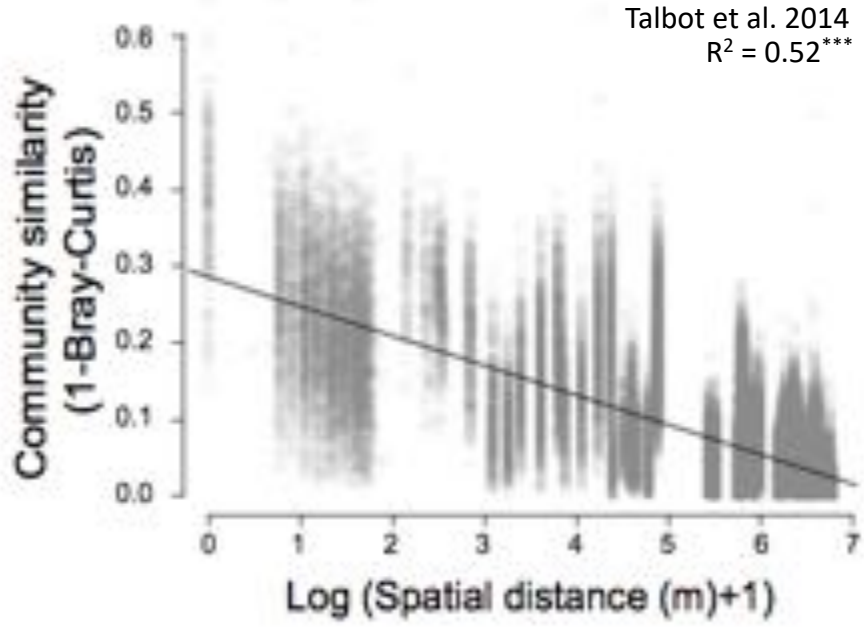
The effect of connectivity



- Brazil and Peru
- Terre Firme forests
- State of Rondonia: deforestation with patches of intact forest
- Tambopata Reserve: large area of protected forests

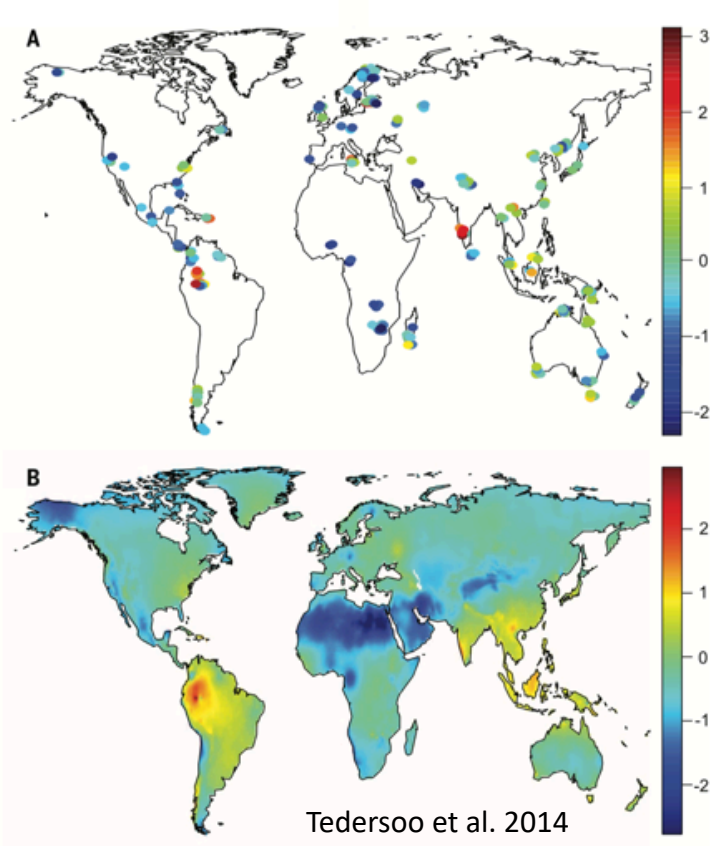
Distance decay of fungal communities





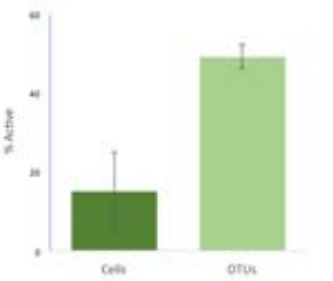
What are we trying to measure?

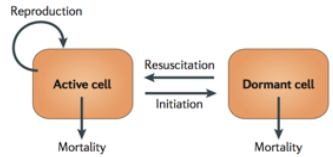
- All biodiversity
  - Global distributions
  - Local extinctions



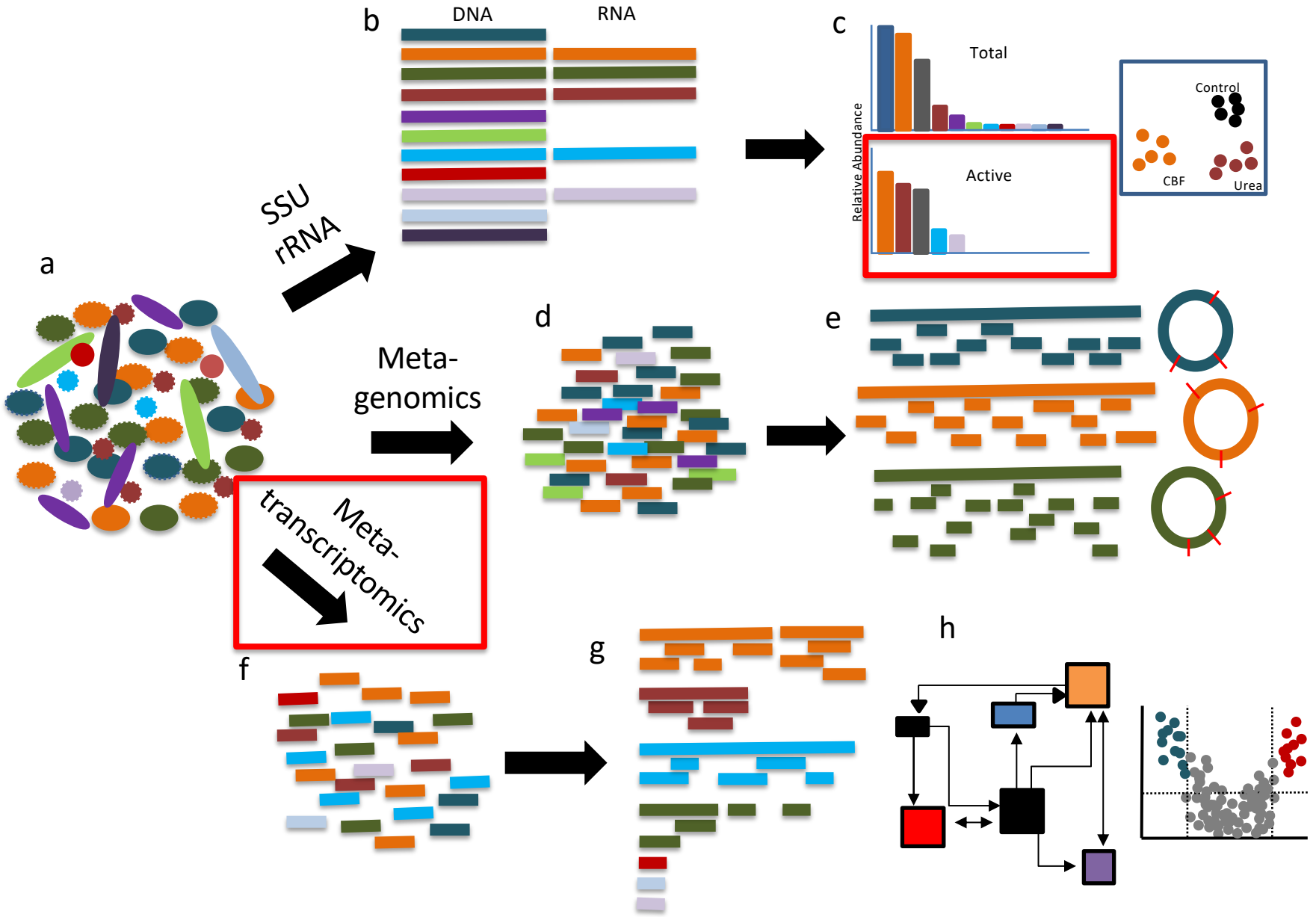
Tedersoo et al. 2014

- Interacting populations
  - Metabolically active populations
  - Ecosystem function

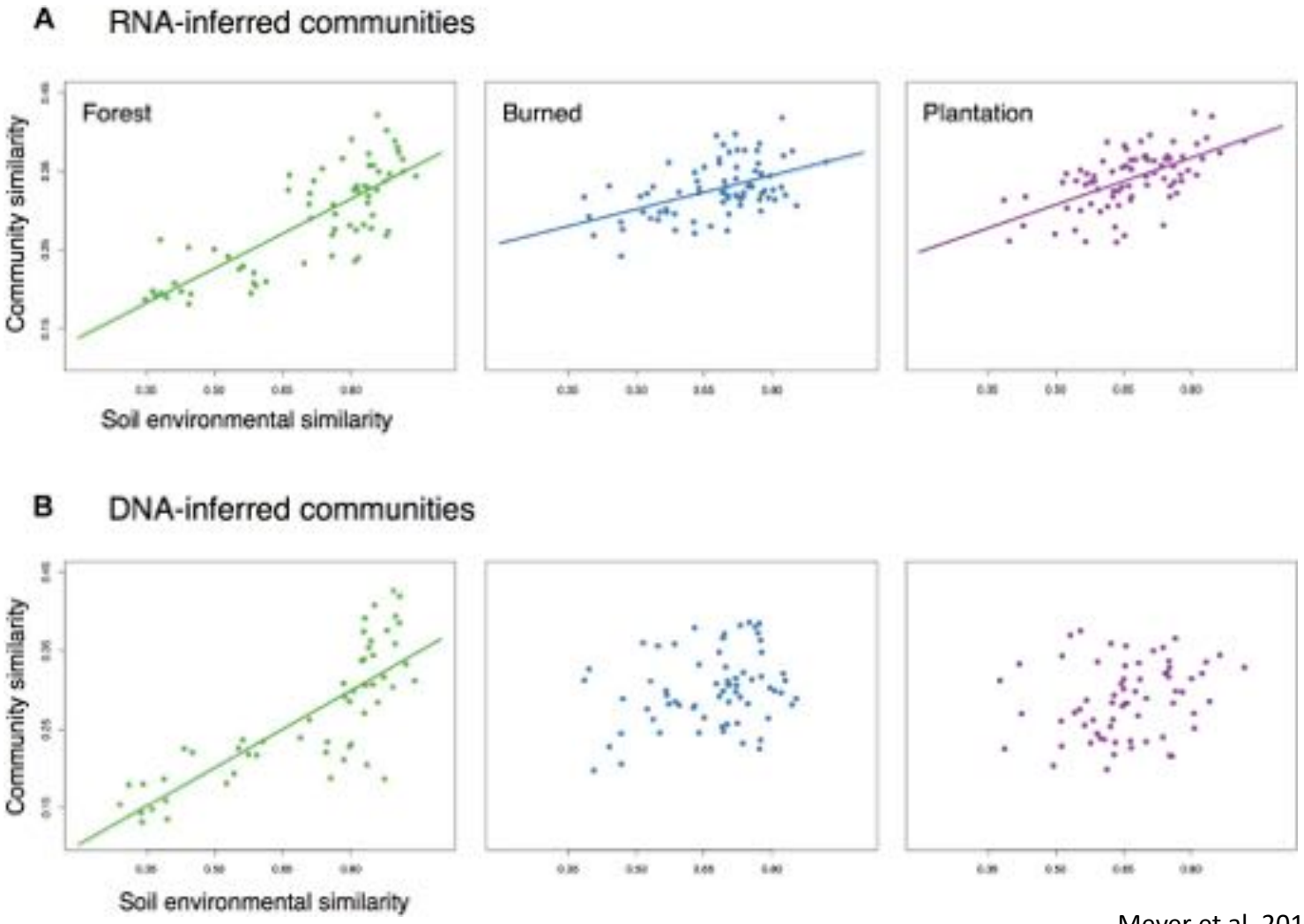




National Geographic


a
b
DNA
RNA
SSU
rRNA
c
Total
Active
Relative Abundance
Control
CBF
Urea
Meta-
genomics
Meta-
transcriptomics
d
e
f
g
h

Response to changing conditions

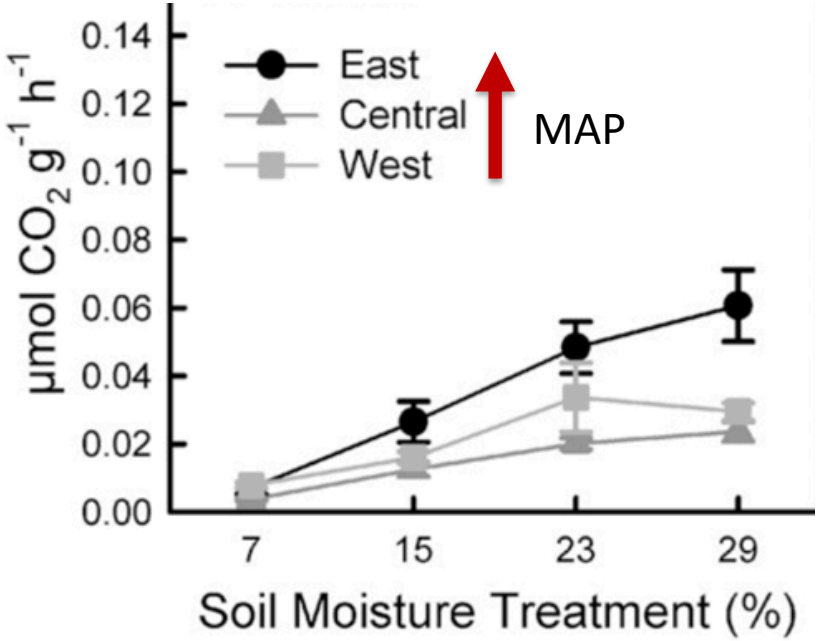


Meyer et al. 2019

Extreme gradients

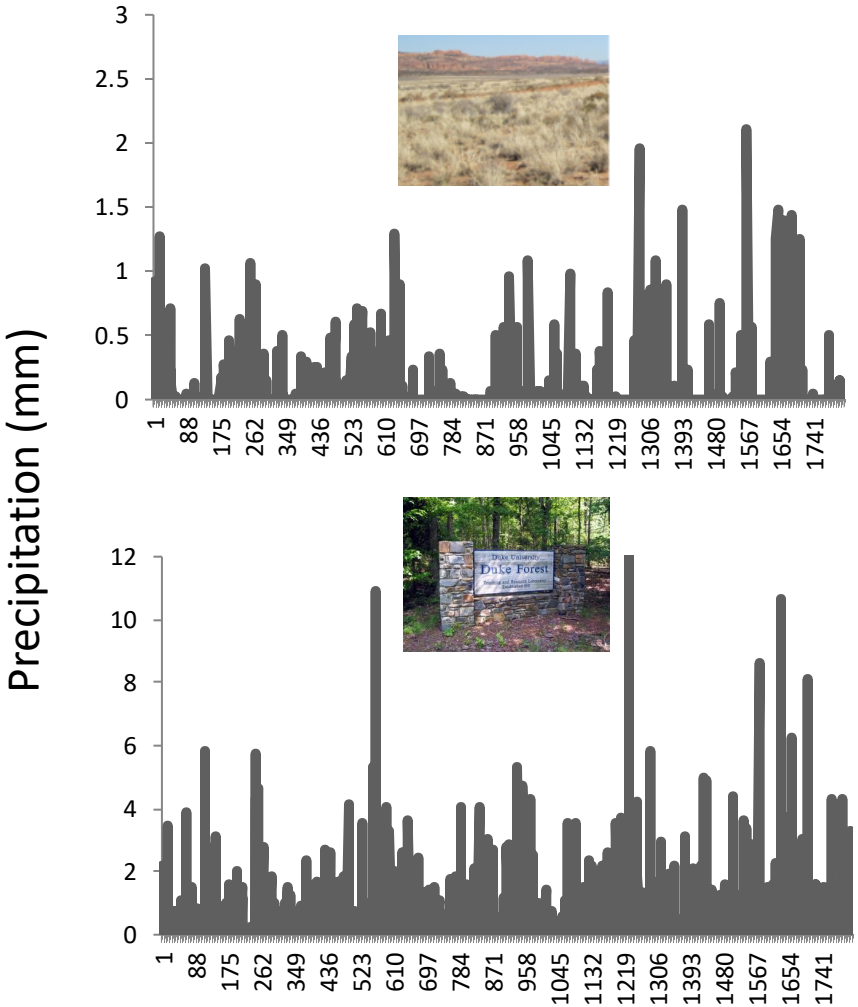
Jayne Belnap
Sasha Reed

- Historical regimes determine future response



Hawkes et al. 2017

- Contrasting sites:



How does historical precipitation regime interact with stress to determine microbial community response to water availability?

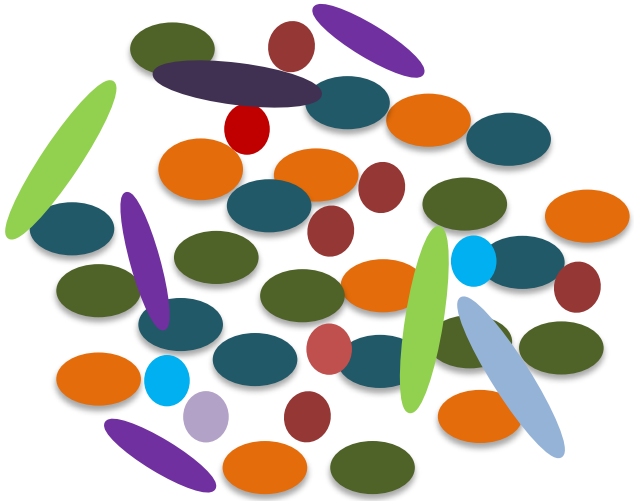
- Desiccation (no water 30 days)
- Four treatments:
  - Initial, water T_2, water T_{12}, desiccation

Temporal shifts

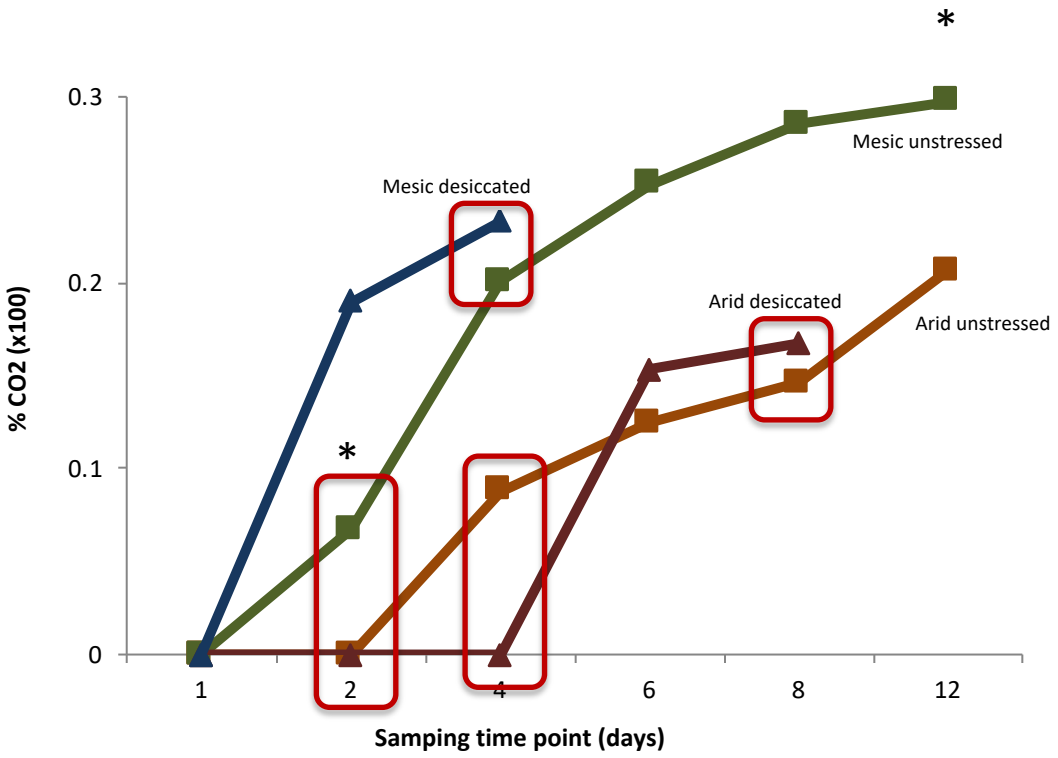
Stress response

Measuring community response to desiccation

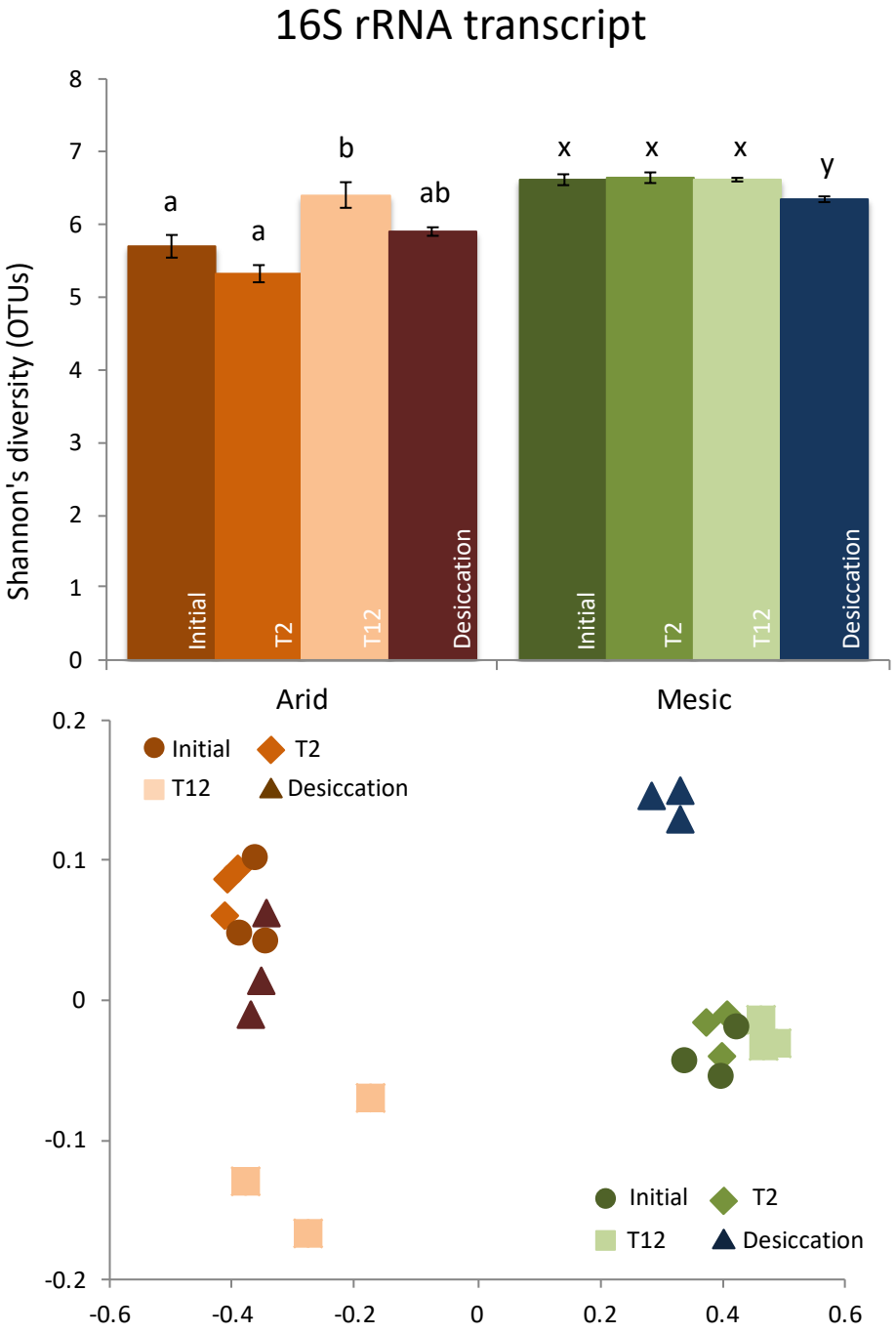
- Gas chromatography for soil respiration
- 16S and metatranscriptome
  - Active community
  - Functional gene regulation



Soil respiration

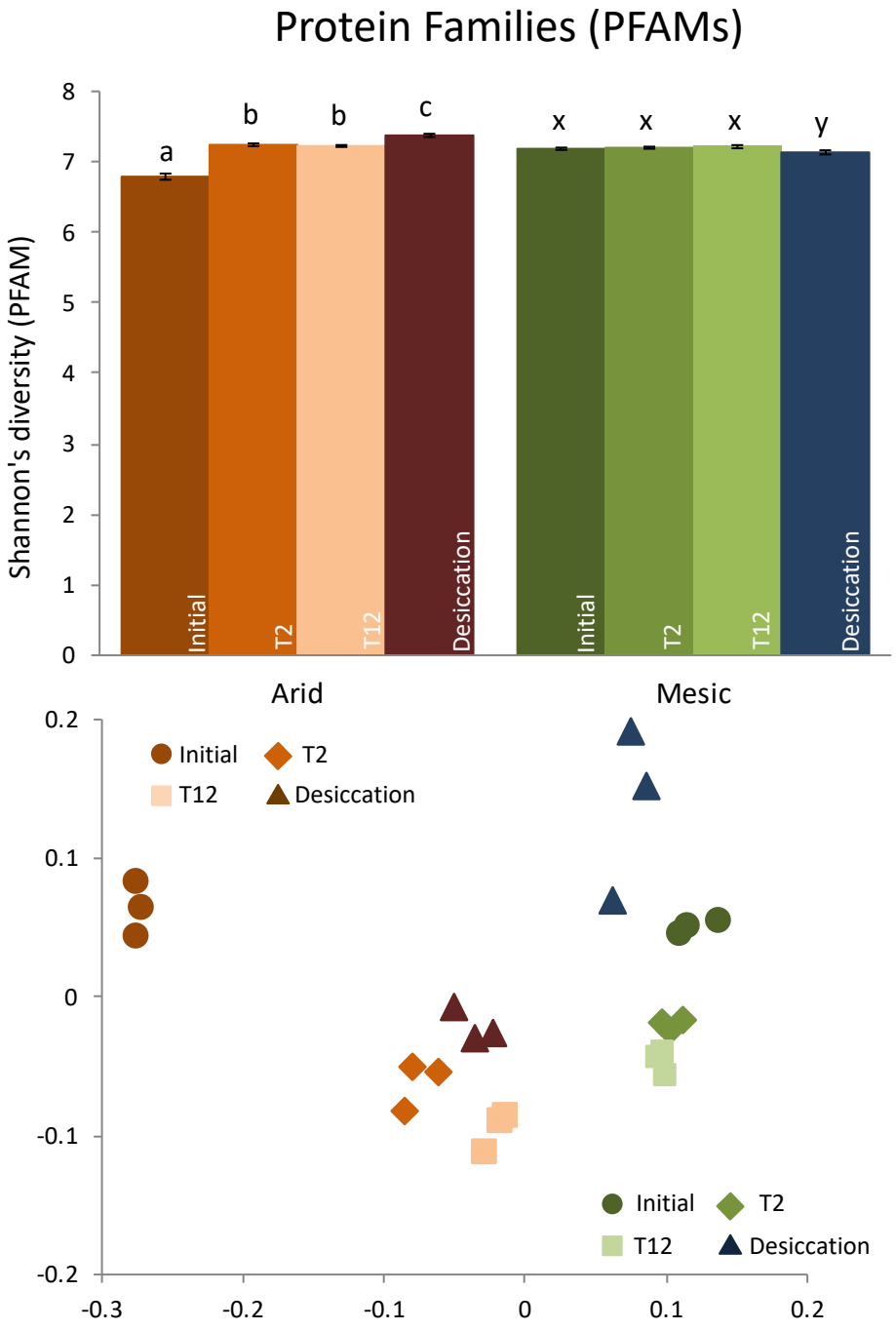


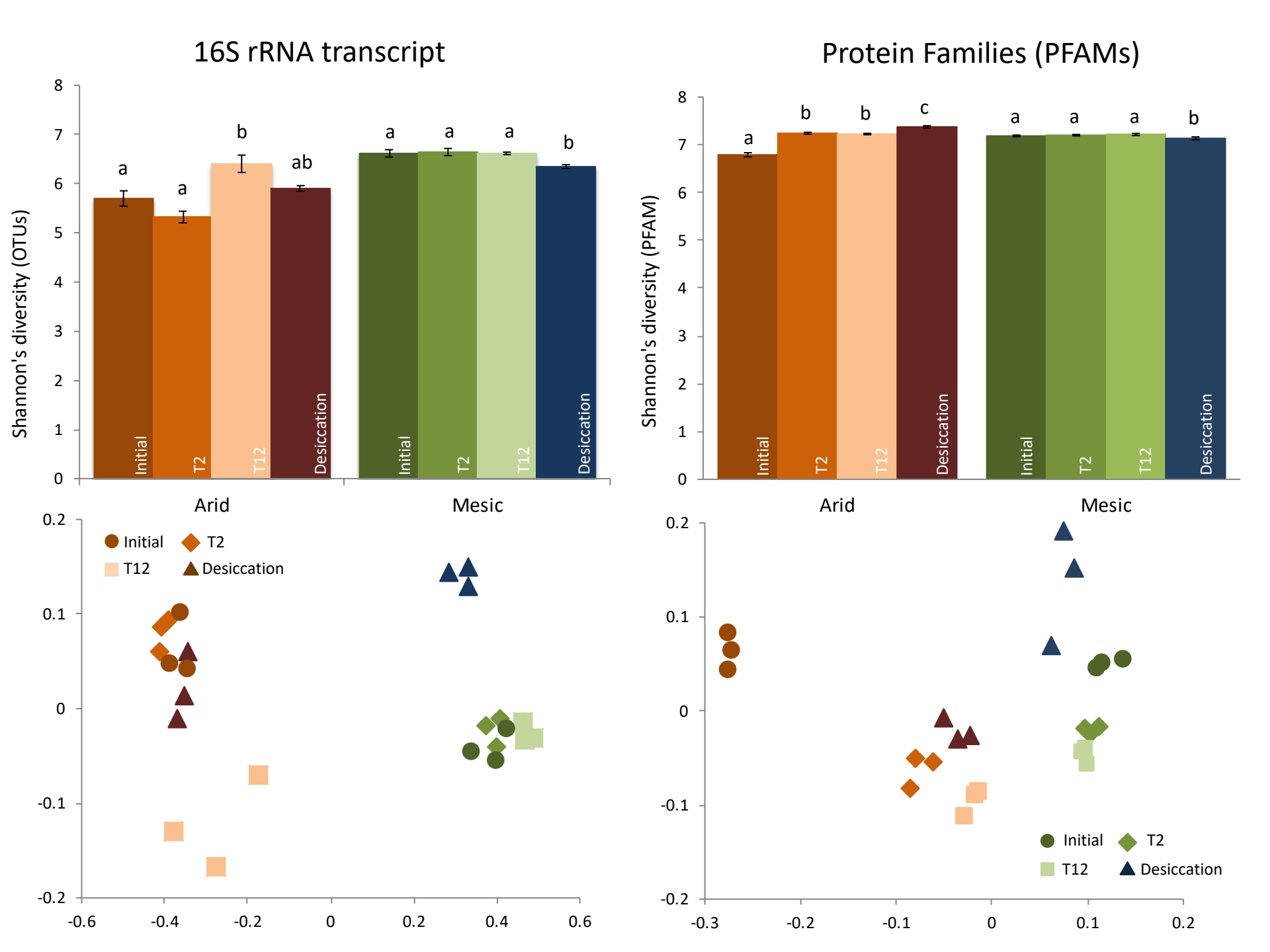
- Higher CO_2 in mesic
- Delayed CO_2 in arid desiccated soils
- Similar CO_2 between treatments within sites at harvest



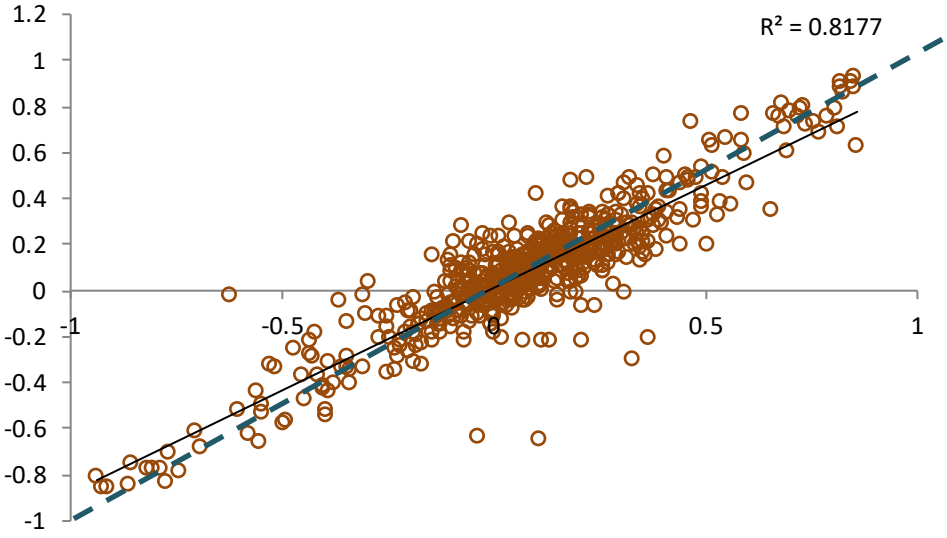
- Higher initial diversity in mesic soils
- Significant differences in community similarity
- Arid responses
  - Increase in diversity over time
  - No effect of desiccation
- Mesic responses
  - No effect of time
  - Strong diversity decline with desiccation
  - Large community shifts with desiccation

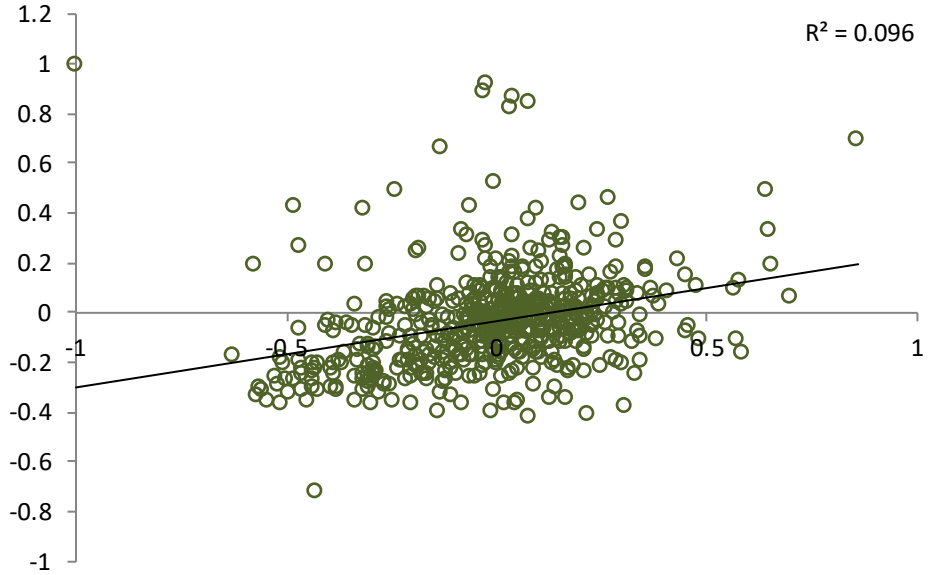
- Higher initial diversity in mesic soils
- Significant differences in community similarity
- Opposing direction of community shifts with desiccation
- Arid responses
  - Increase in diversity with water
  - Stronger effect of desiccation
- Mesic responses
  - No effect of time
  - Decreased diversity with desiccation




16S rRNA transcript
Protein Families (PFAMs)
Shannon's diversity (OTUs)
Shannon's diversity (PFAM)
Initial
T2
T12
Desiccation
Arid
Mesic
a
a
b
ab
a
a
a
b
a
b
b
c
a
a
a
b

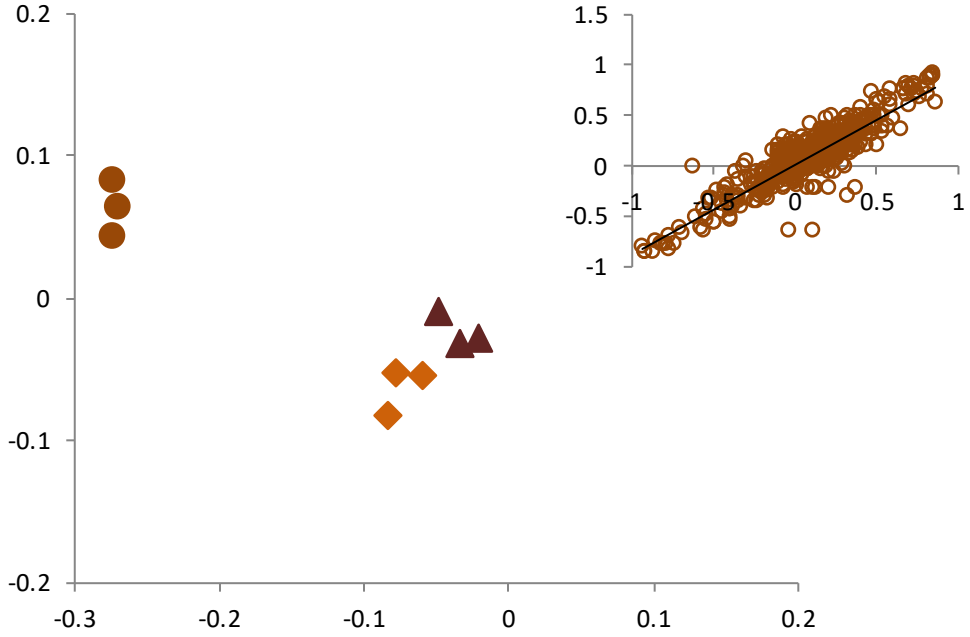
Response ratios of PFAMs

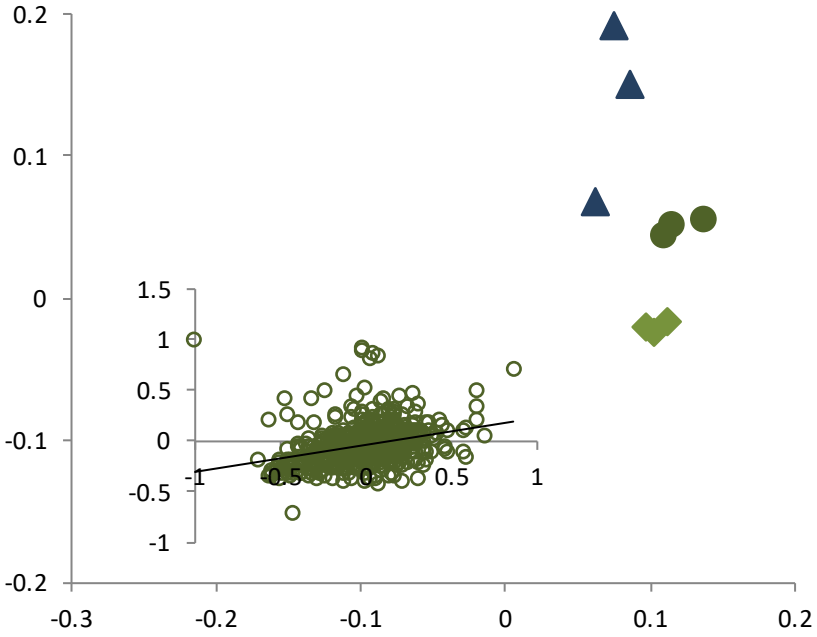


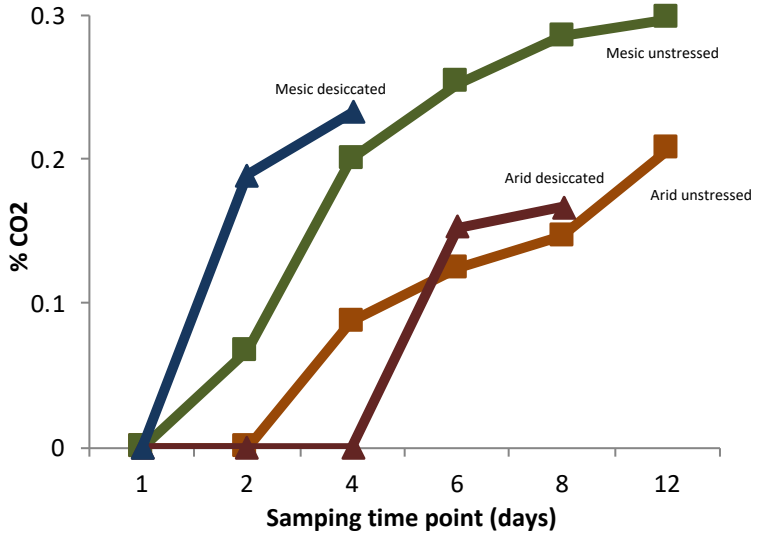


- Cohesive response in arid, not mesic

Significant functional shifts, resilient function

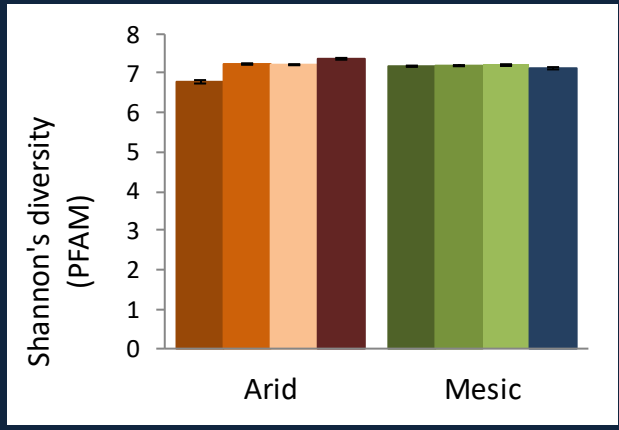






Functional genes and ecosystem function

- Soils from different precipitation regimes have differential responses to desiccation
  - Initial community/functional differences
- Ecosystem function maintained even with strong community/functional shifts
  - Alternative stable states/Compensatory responses
  - Nutrient pulse from necromass
- Role of pulse disturbance for diversity in arid ecosystems



Dana Skorupa,
Brent Peyton

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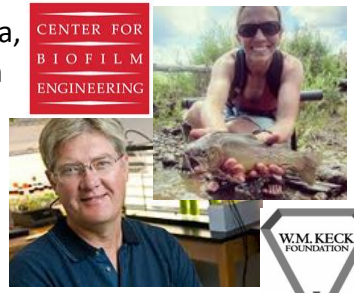

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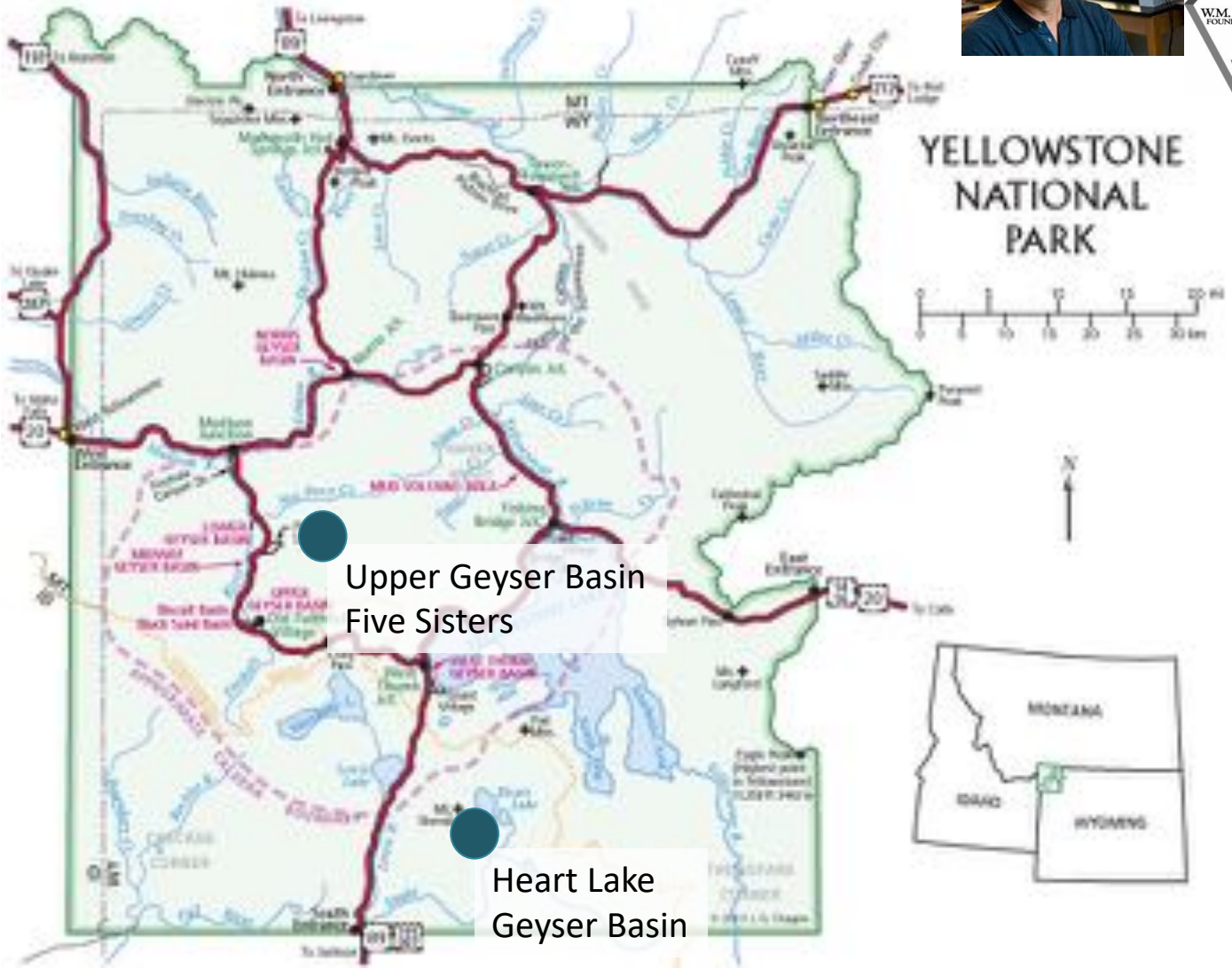
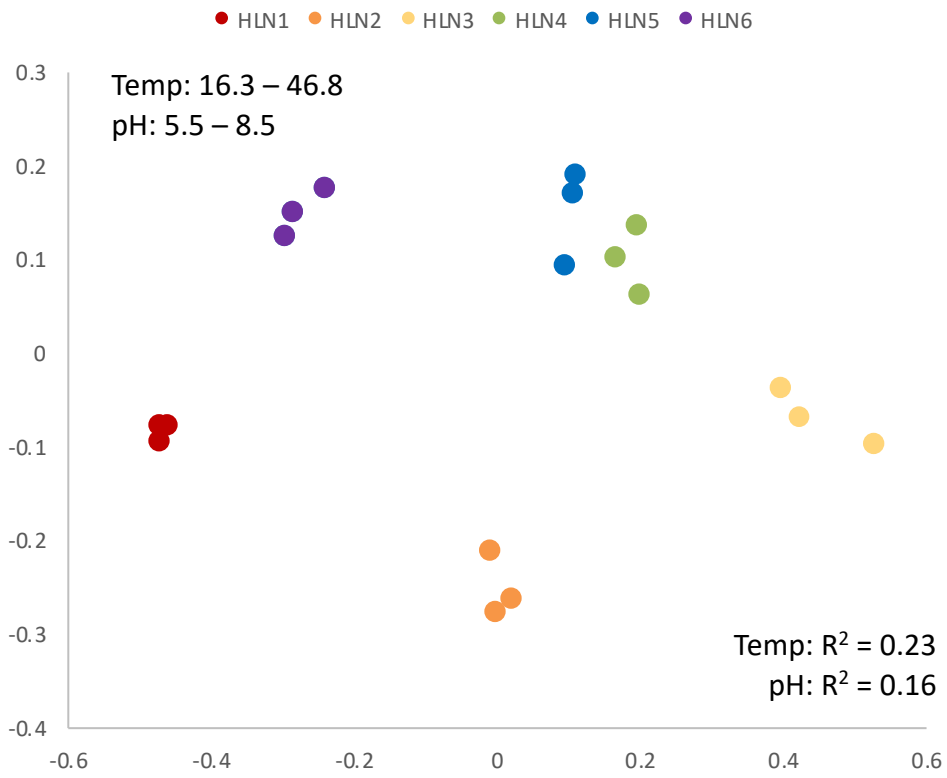
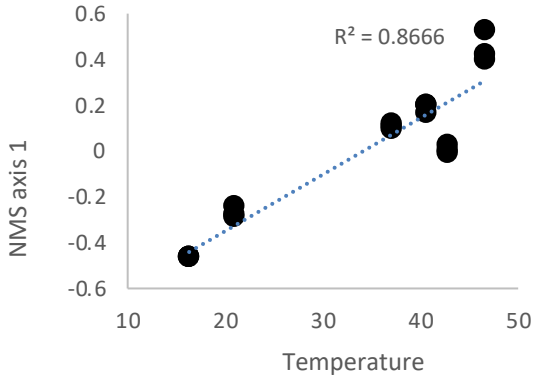
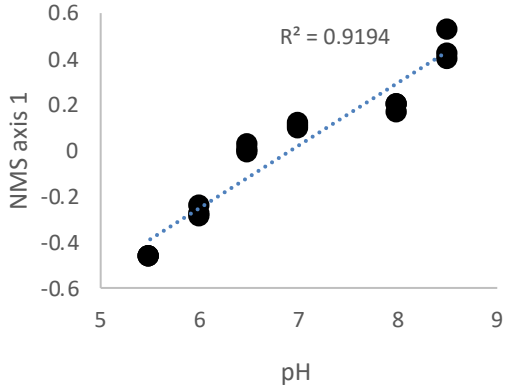


Venturing into the (relative) cold: Microbes in outflow channels

- Leveraging strong environmental gradients across small geographic ranges





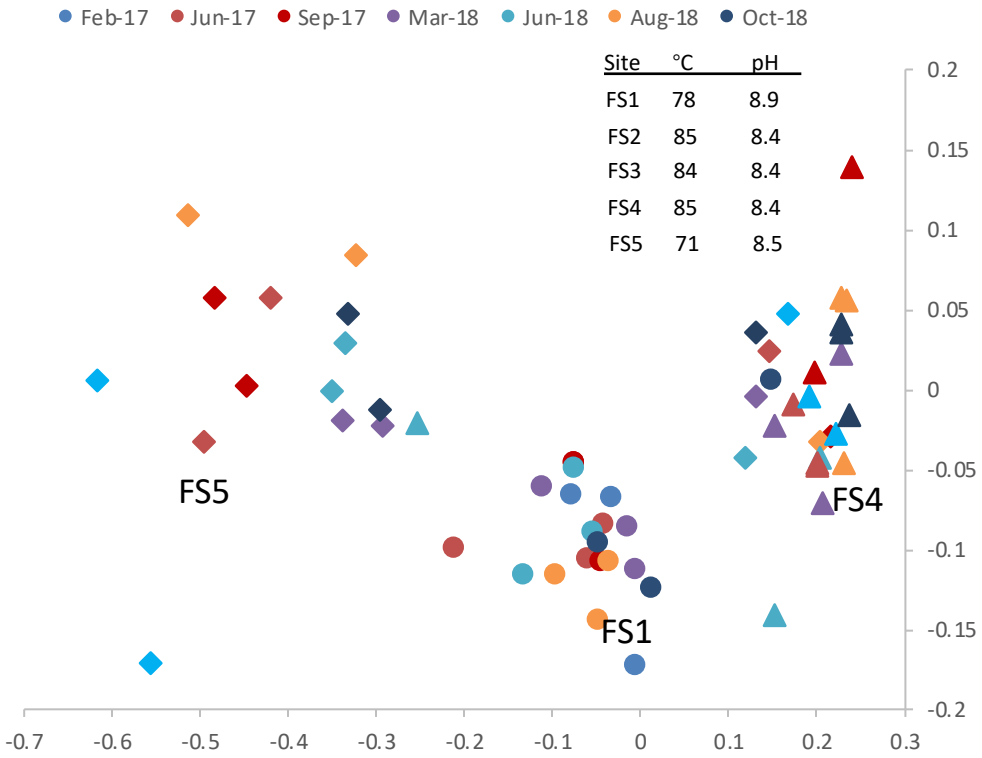


No evidence for geographic distance decay (dispersal limitation)

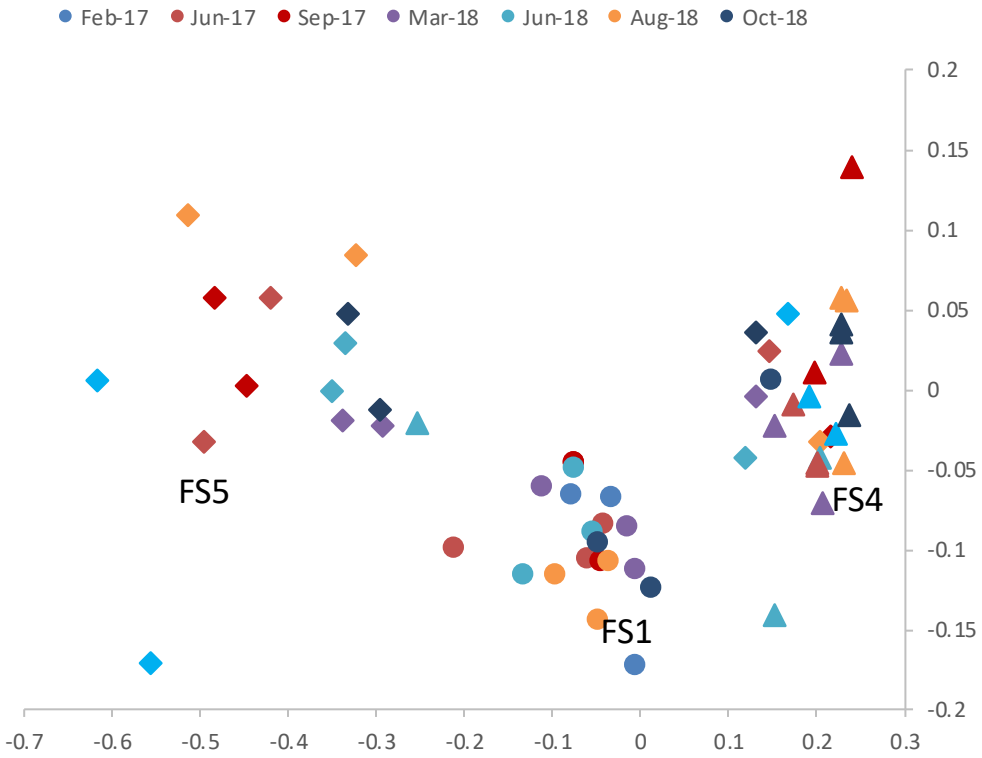

August 2018


October 2018

Seasonal sampling of thermoalkaline hot springs

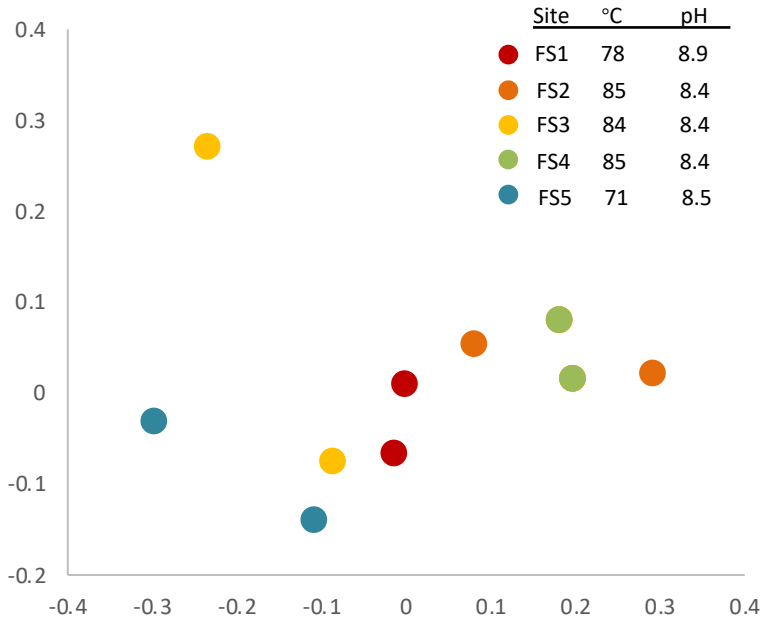


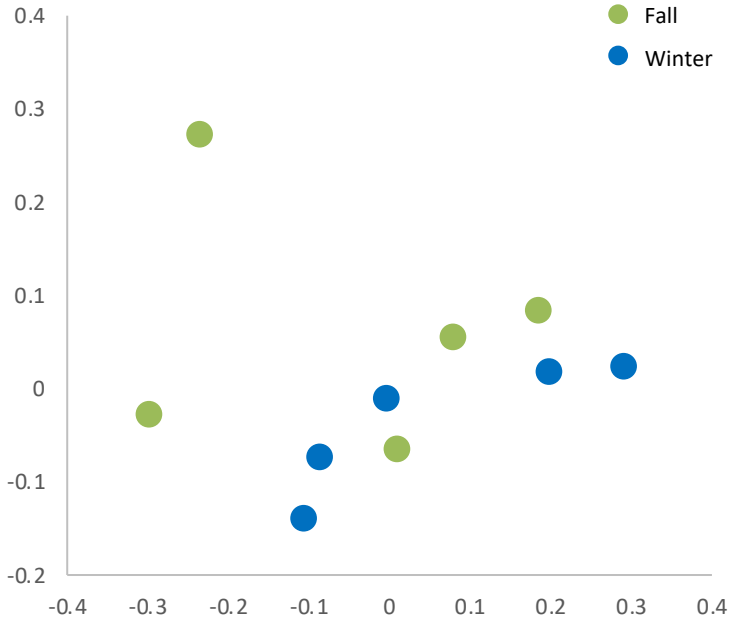
Seasonal sampling of thermoalkaline hot springs



- Significant differences among springs
- Stronger seasonal shifts in FS5, the coolest spring
  - Photosynthetic portions
- No evidence for distance decay

Shifts in potential function: Space and time

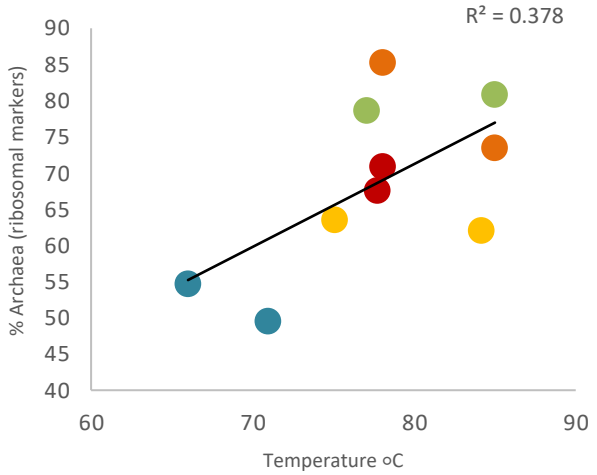




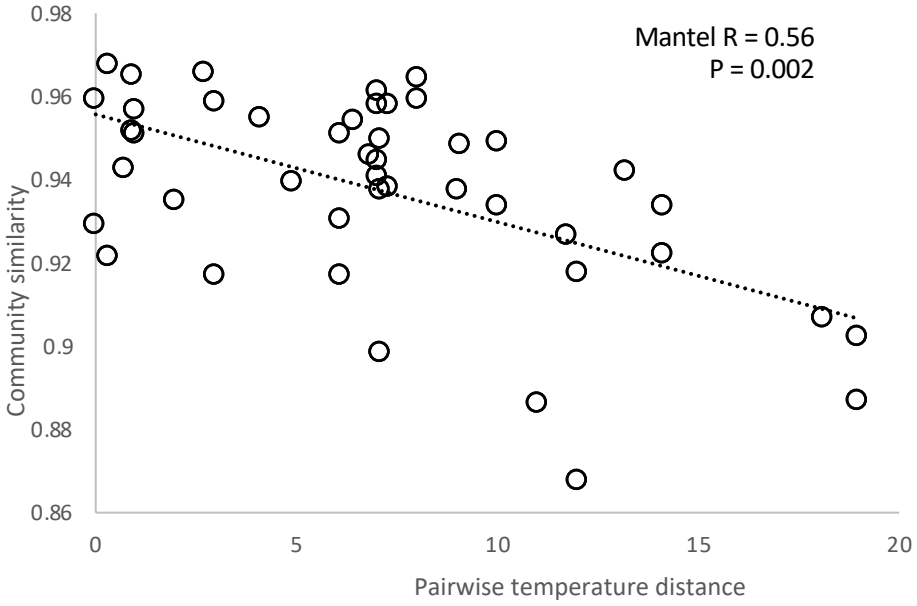
60 Metatranscriptomes as part of the Community Sequencing Program

JGI JOINT GENOME INSTITUTE
A DOE OFFICE OF SCIENCE USER FACILITY

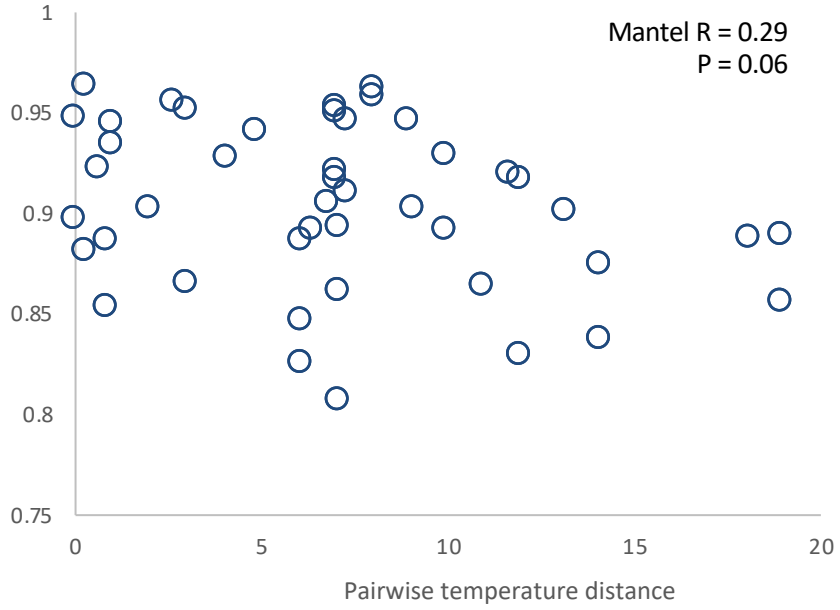
Temperature and community composition

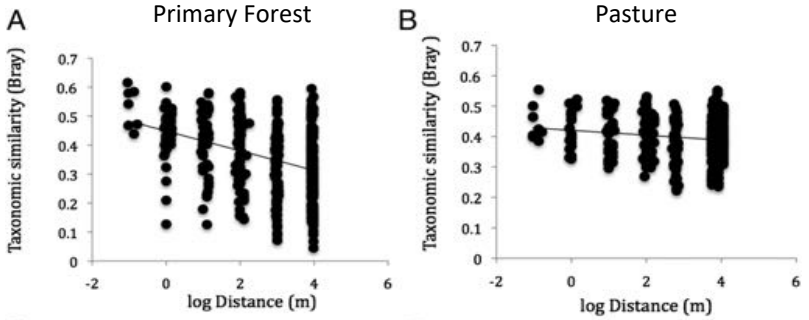


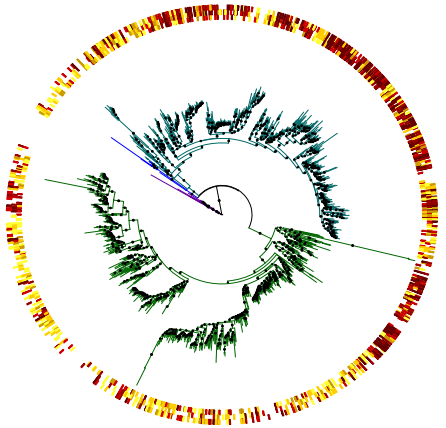
Archaea PFAM similarity

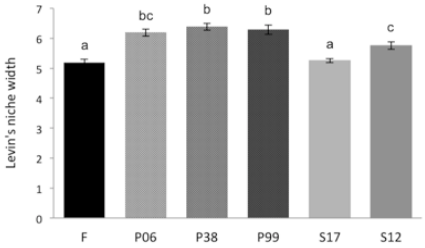


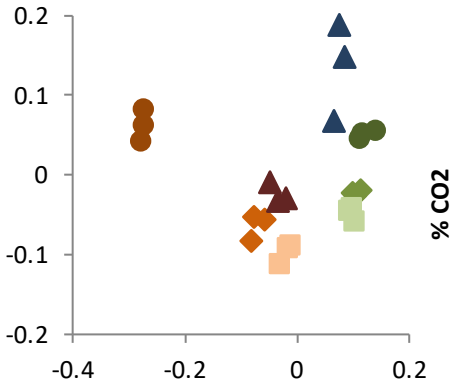
Microbial PFAM similarity

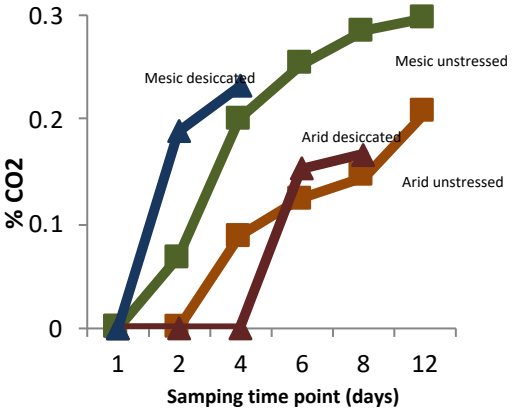








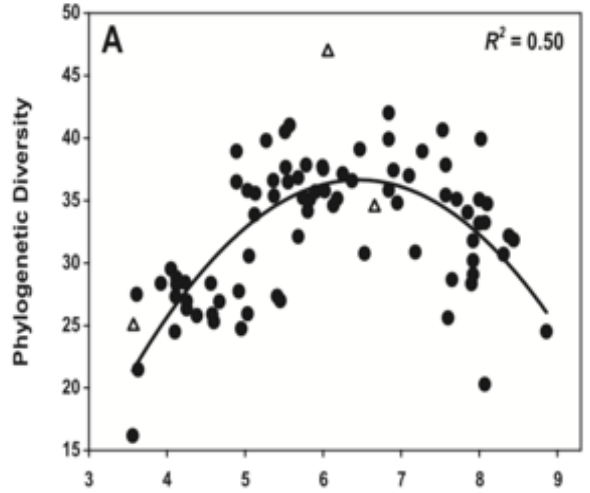


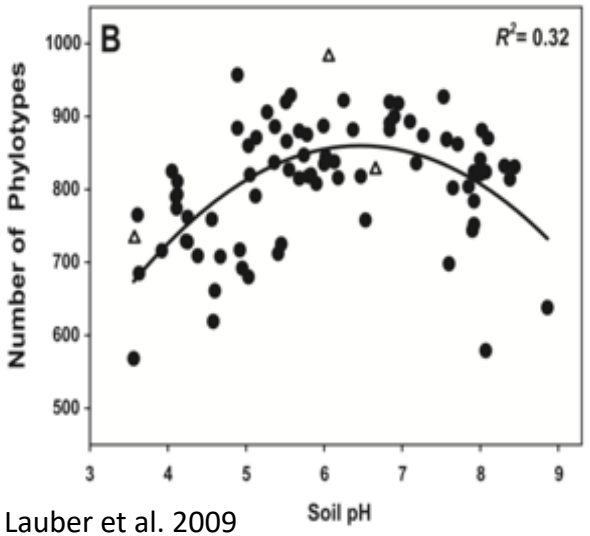


- Microbial communities have strong responses to disturbance
- Non-random patterns (phylogenetic signal), linked to traits
- Community shifts do not necessarily alter ecosystem functions

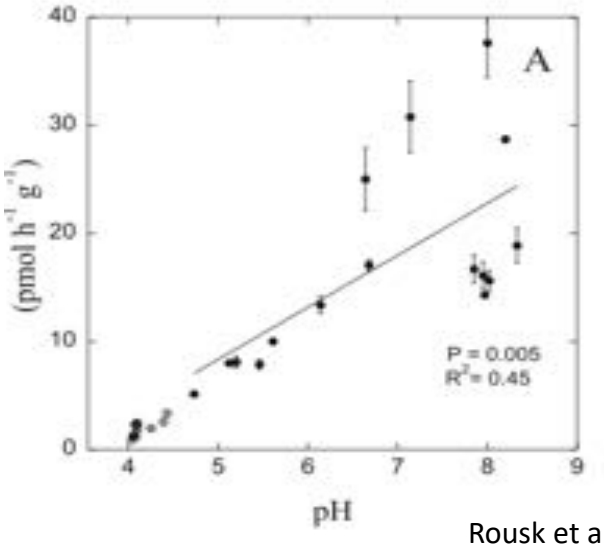
Questions?

Environmental drivers



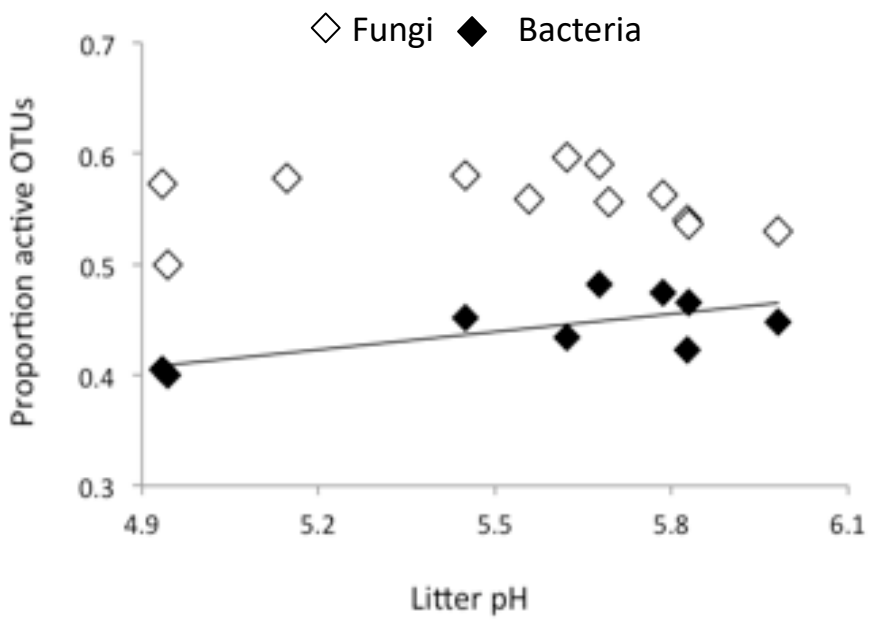


Lauber et al. 2009

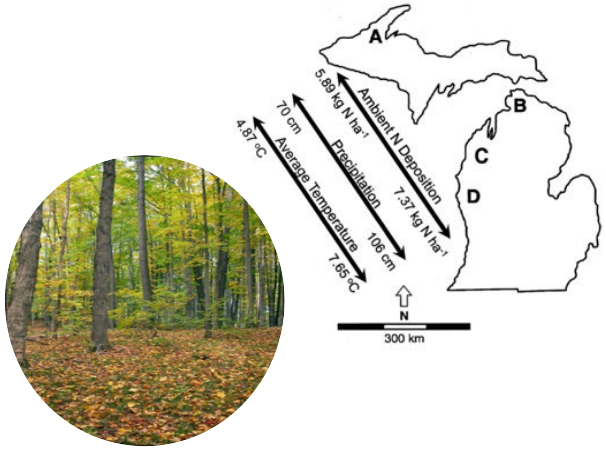


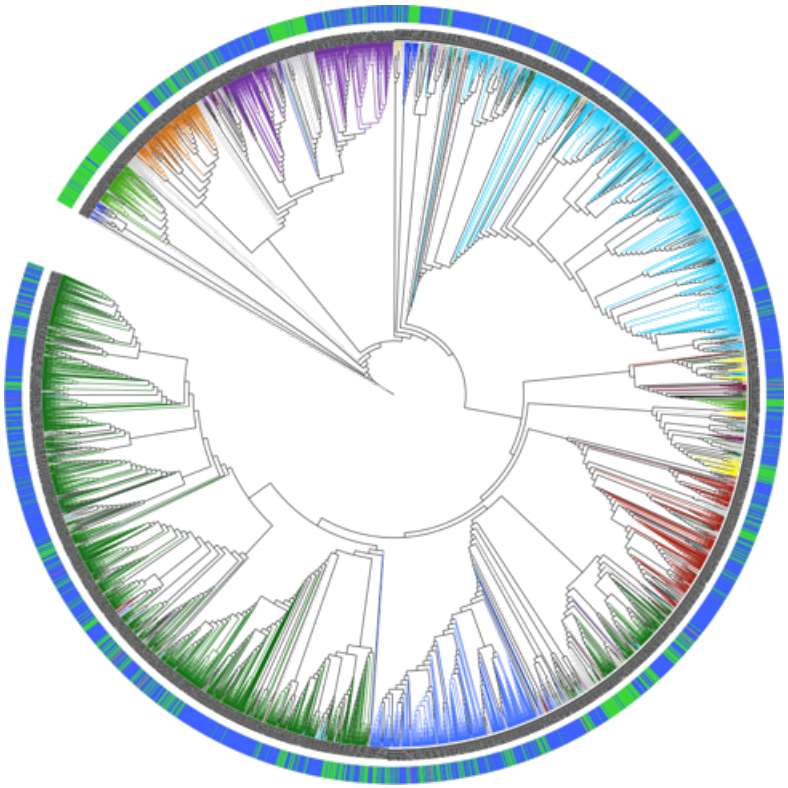
Rousk et al. 2010

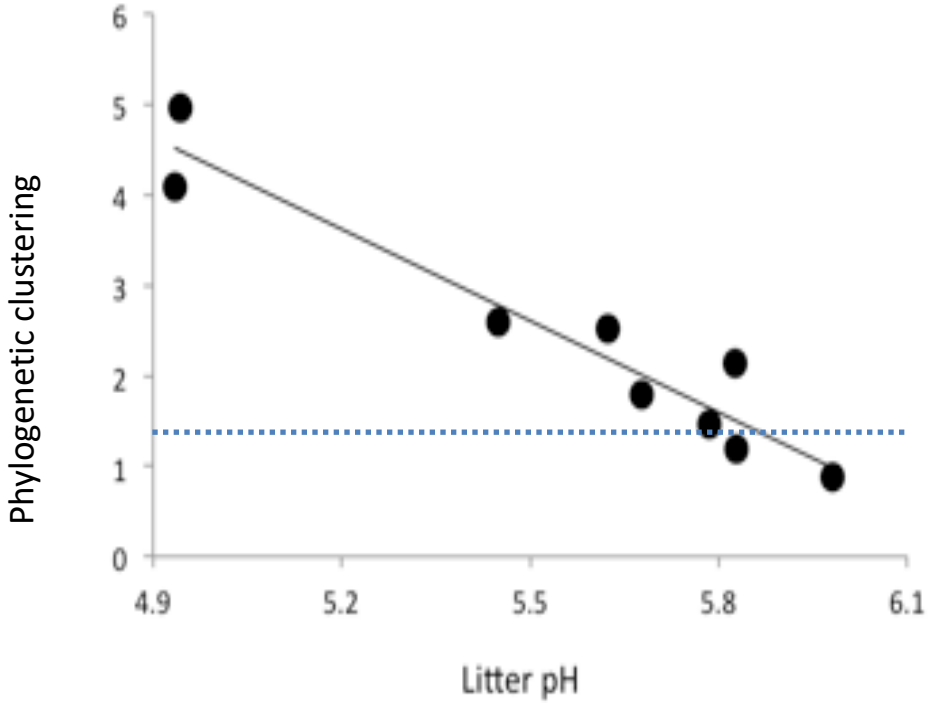
Assembly across a natural environmental gradient



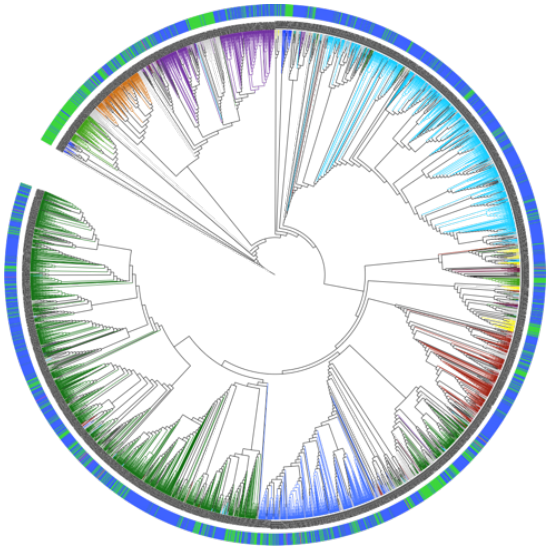
Assembly across a natural environmental gradient



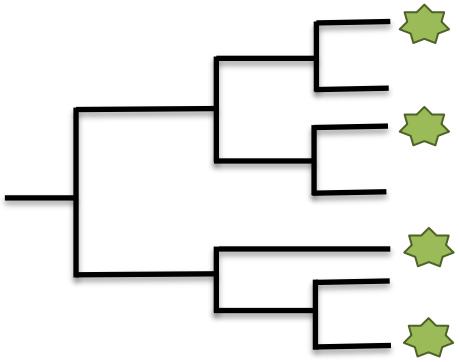




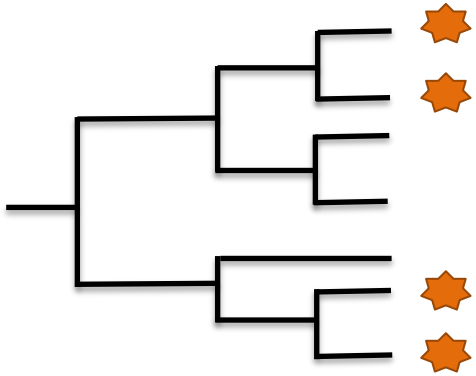
Phylogenetic community measures: Clustering



Random

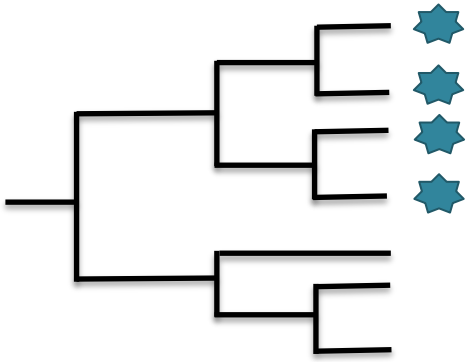


Overdispersed



Less related than expected

Clustered



More related than expected