Soil microbial diversity and community assembly as related to plant health

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Ecology & Biodiversity: Inst. Environmental Biology

KNPV: Plant and Soil Microbiome – relevance for crop protection: November 2nd, 2017

What I plan to talk about

- Soil-borne microbial diversity is vast

- How plants (alive and dead) steer their associated microbiomes

- Harnessing microbial powers by considering microbial community assembly

Acknowledgements

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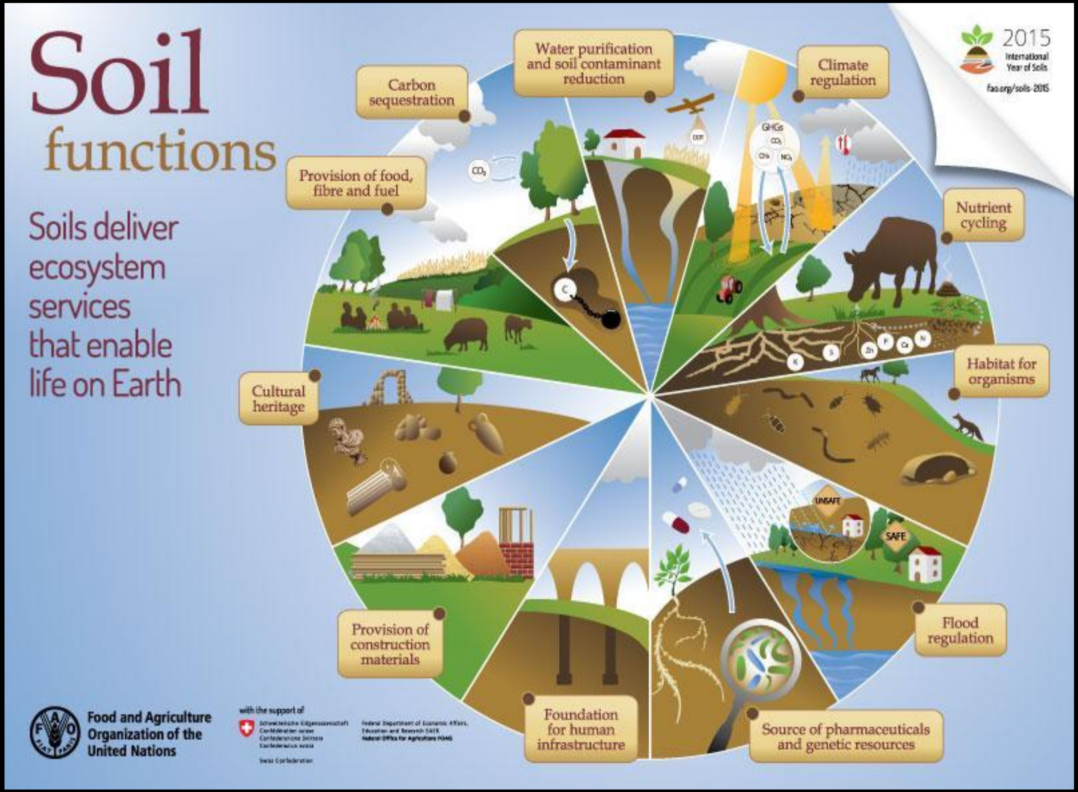
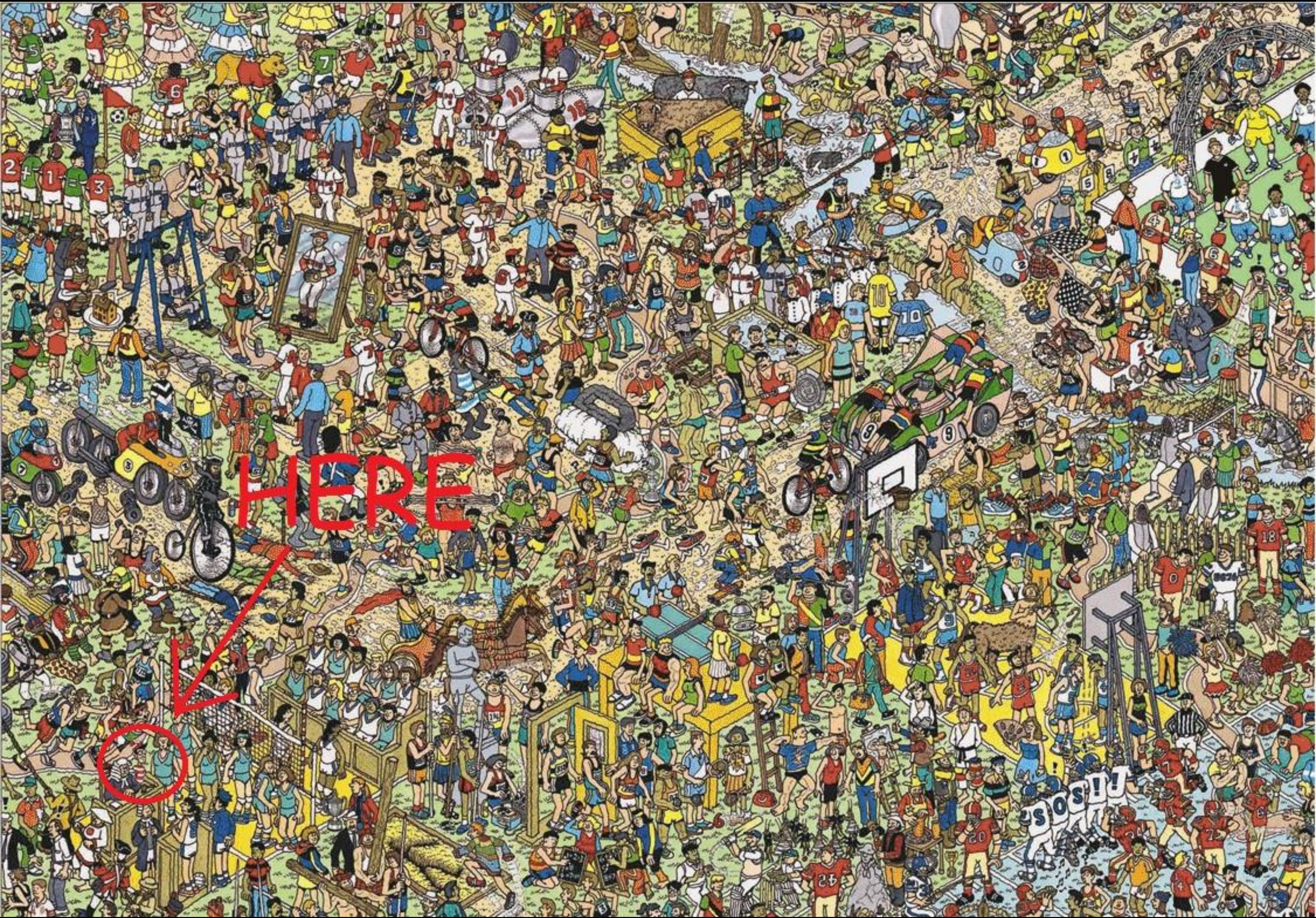
Processes carried out by soil microbes

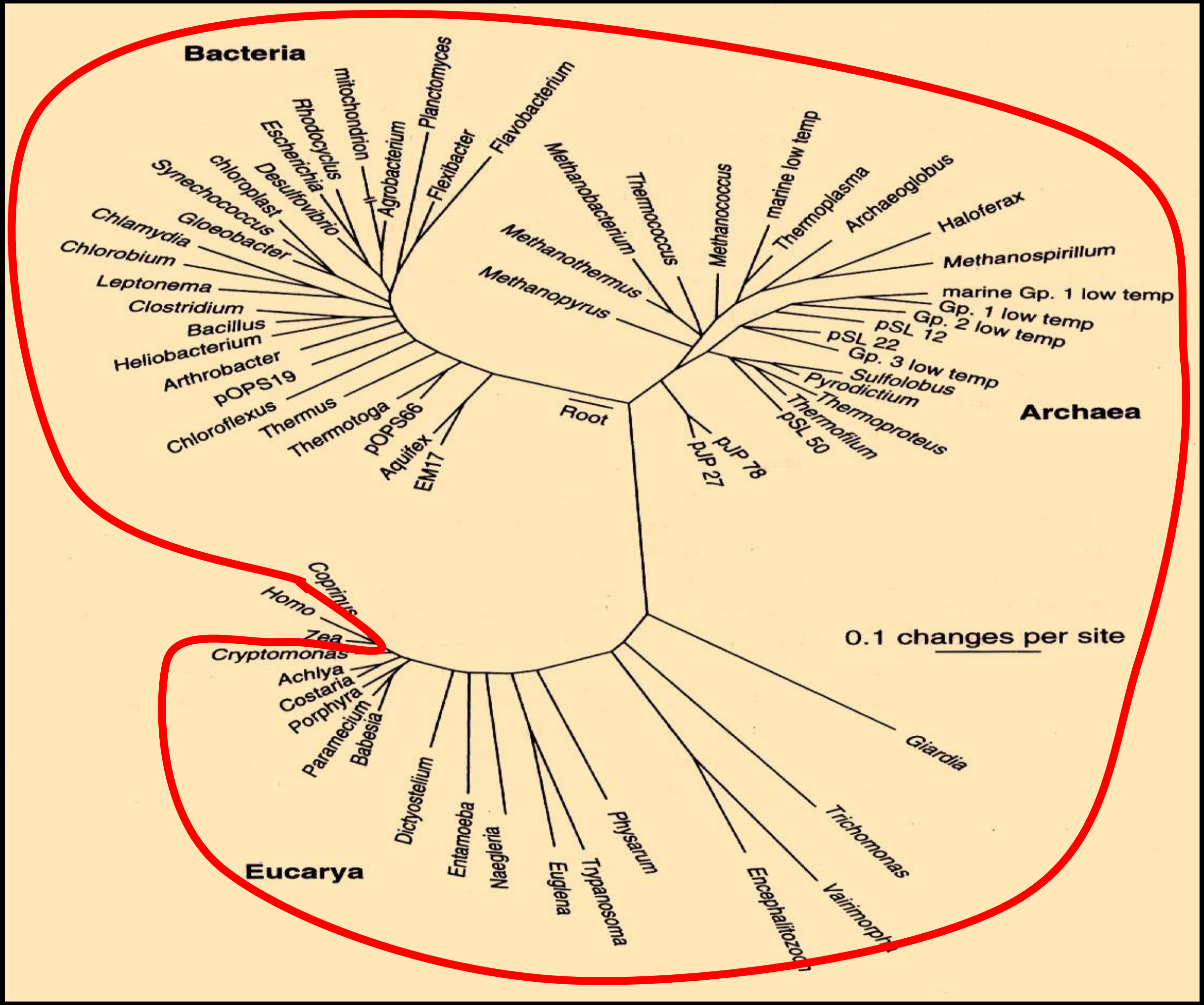
- Driving biogechemical cycles & recycling of nutrients
- Facilitating plant nutrition and growth
- Water purification and degradation of pollutants
- Decomposition
- Agents of disease
- Antagonists of disease
- Maintaining soil structure

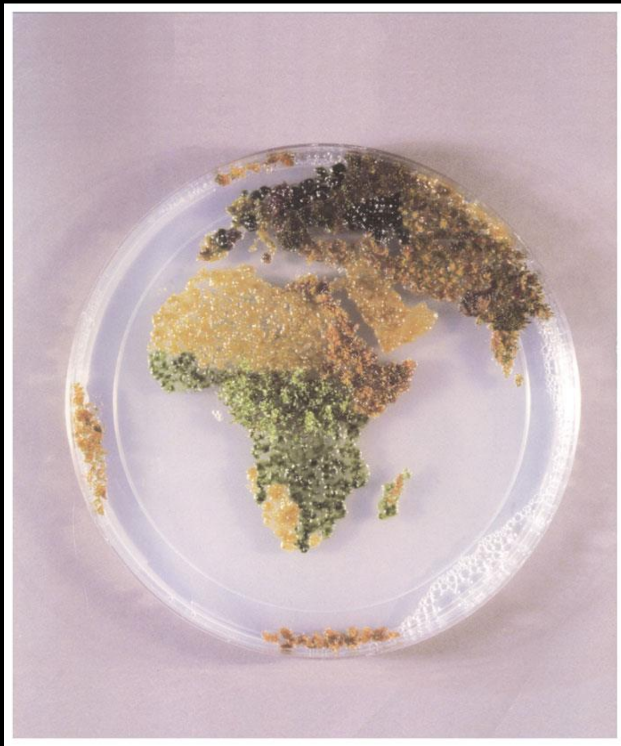
just to name a few




HERE

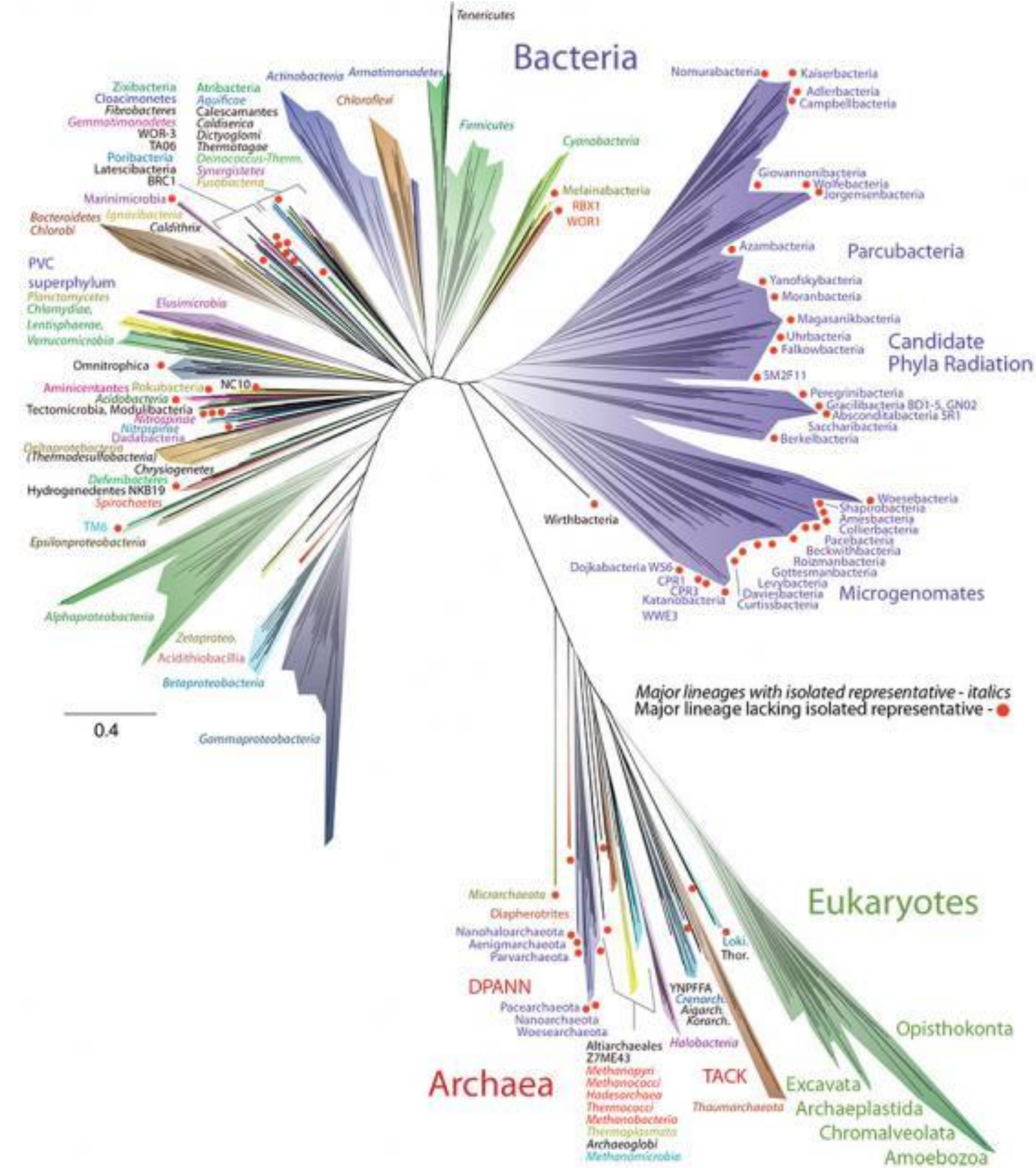
Earth is a microbial planet





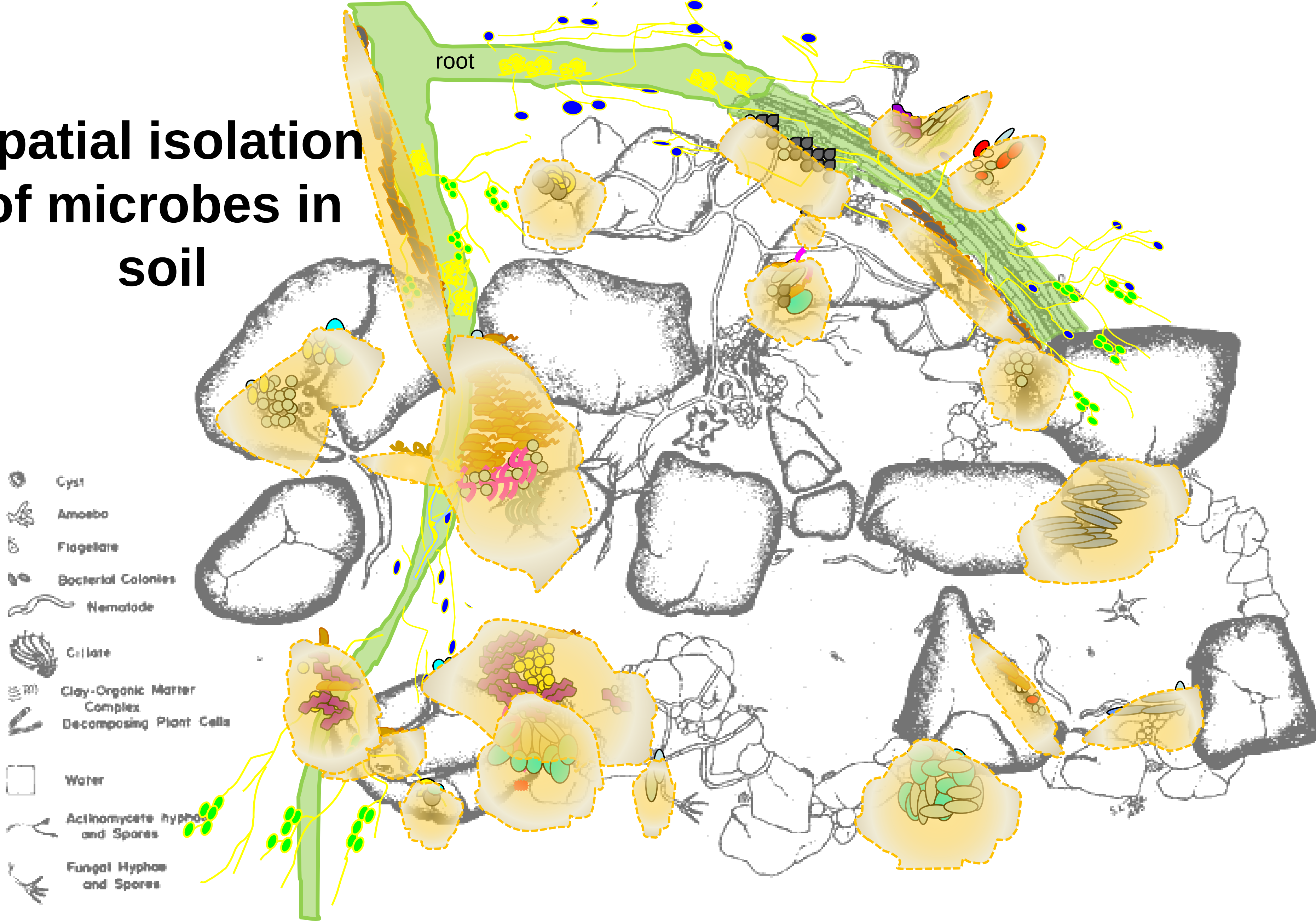
The Earth's biodiversity is 99% microbial

The very newest tree of life

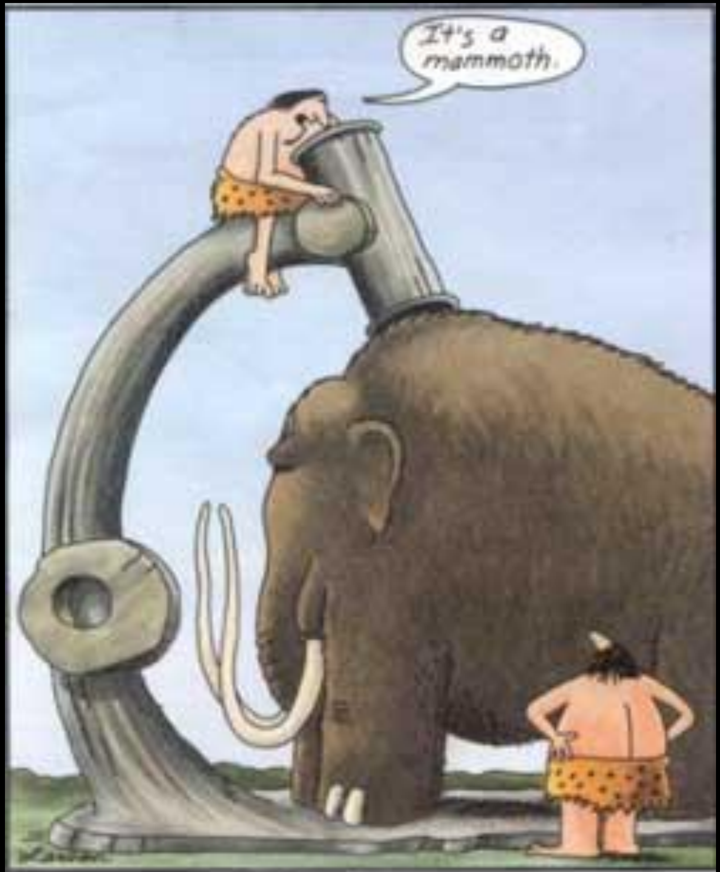


Hug et al *Nature Microbiology* (2016) doi:10.1038/nmicrobiol.2016.48

Spatial isolation of microbes in soil



To date we have generally considered scales of convenience as opposed to those most appropriate to the microbial organisms themselves



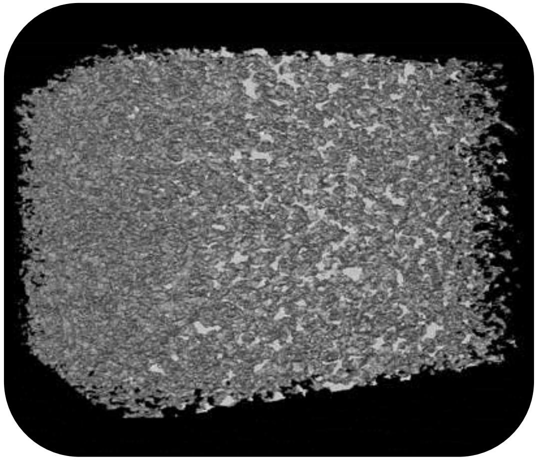
Early microscopes

Two complementary approaches

the dark side…

Micro-scale examination of microbial diversity

into the light…



Experimental manipulation of (artificial) soil parameters

Conclusions from micro-scale soil dissection and manipulation

- Micro-scale community heterogeneity is lost in bulk soil analyses, and this heterogeneity is reduced by soil mixing

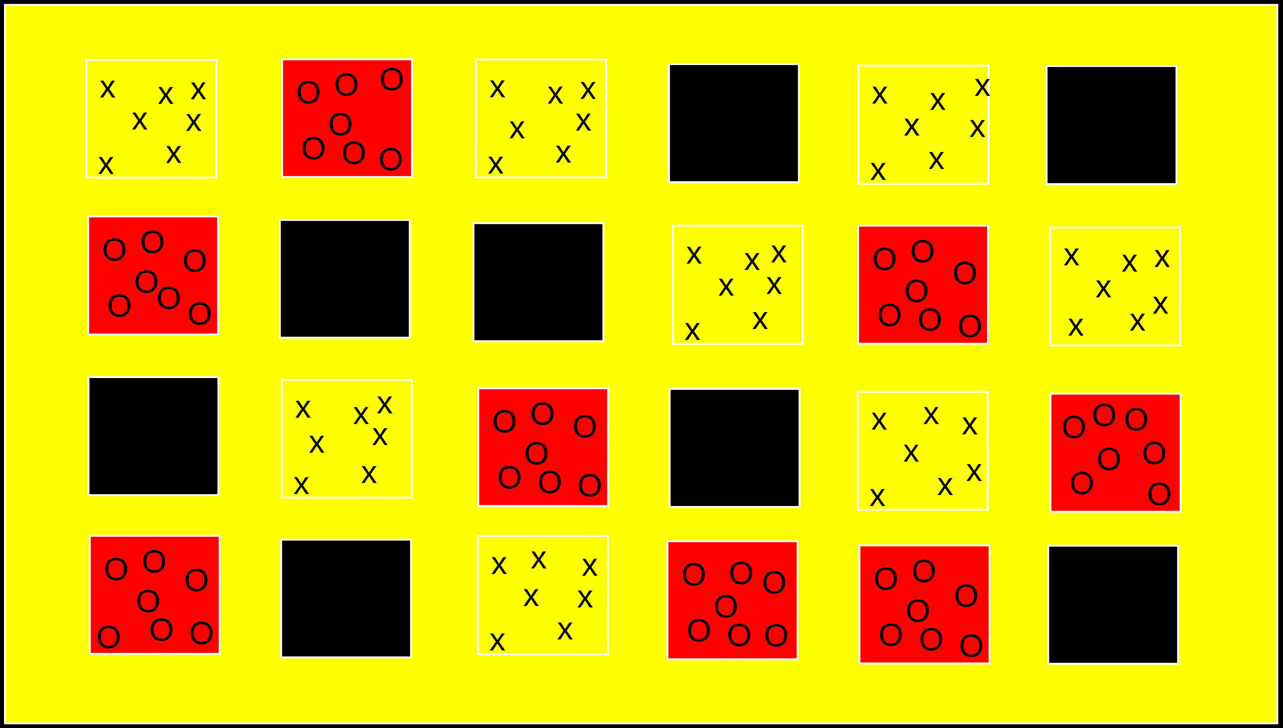
- Low micro-habitat connectivity favors hyphae-producing organisms

- Low connectivity between micro-habitats allows for the maintenance of higher bacterial diversity

How plants (alive and dead) steer their associated microbiomes

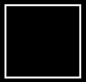
- The plant rhizosphere effect
- Cultivating a beneficial rhizosphere community
- (live) Plant carbon flow into the soil community
- (dead) Plant carbon flow into the soil community

Experiment to examine rhizosphere effect of specific plant species:



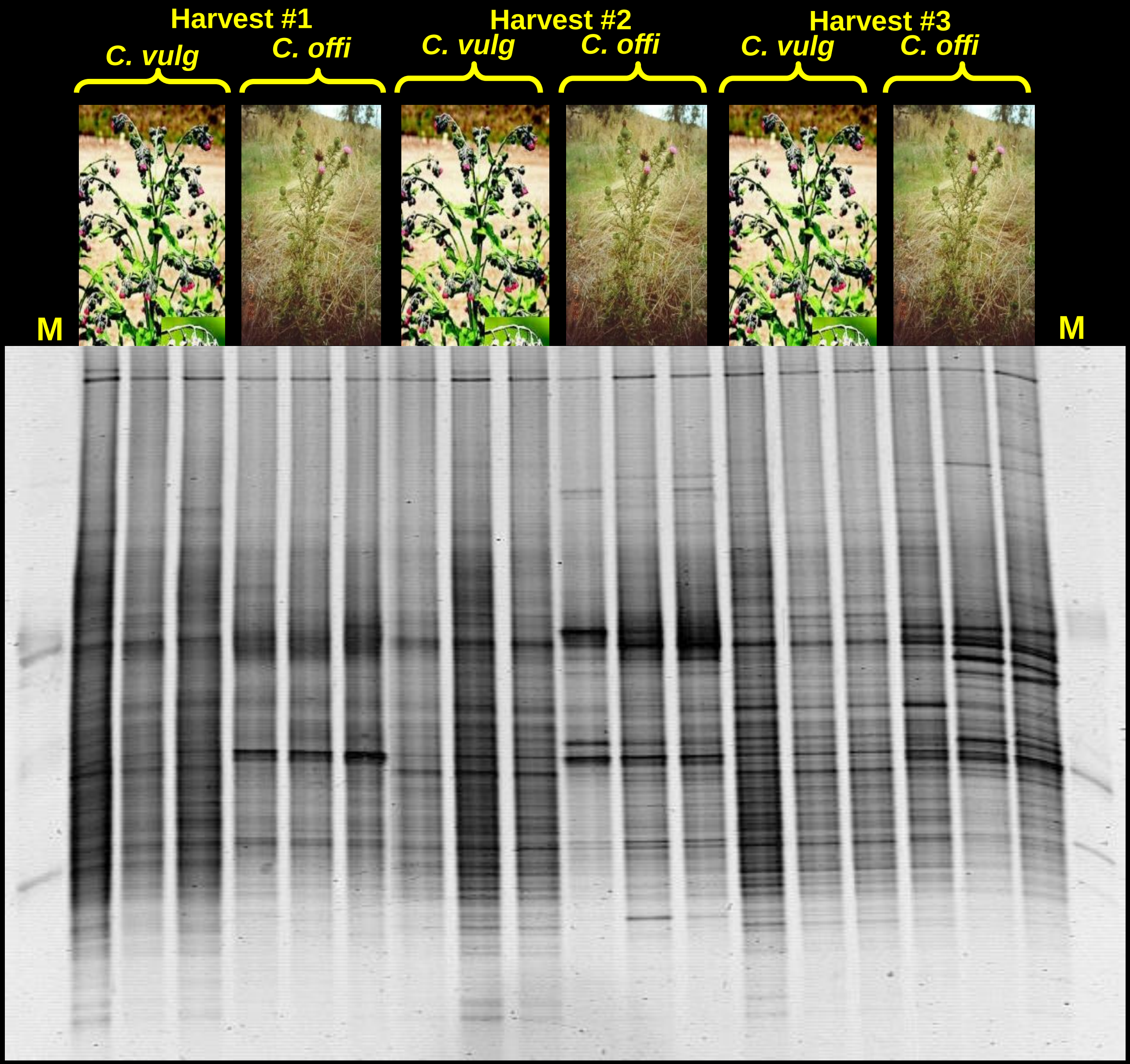
X = *Cynaglossum officinale*

O = *Cirsium vulgare*

 = natural colonisation

Seven plants per plot (with weeds)
Three harvests times

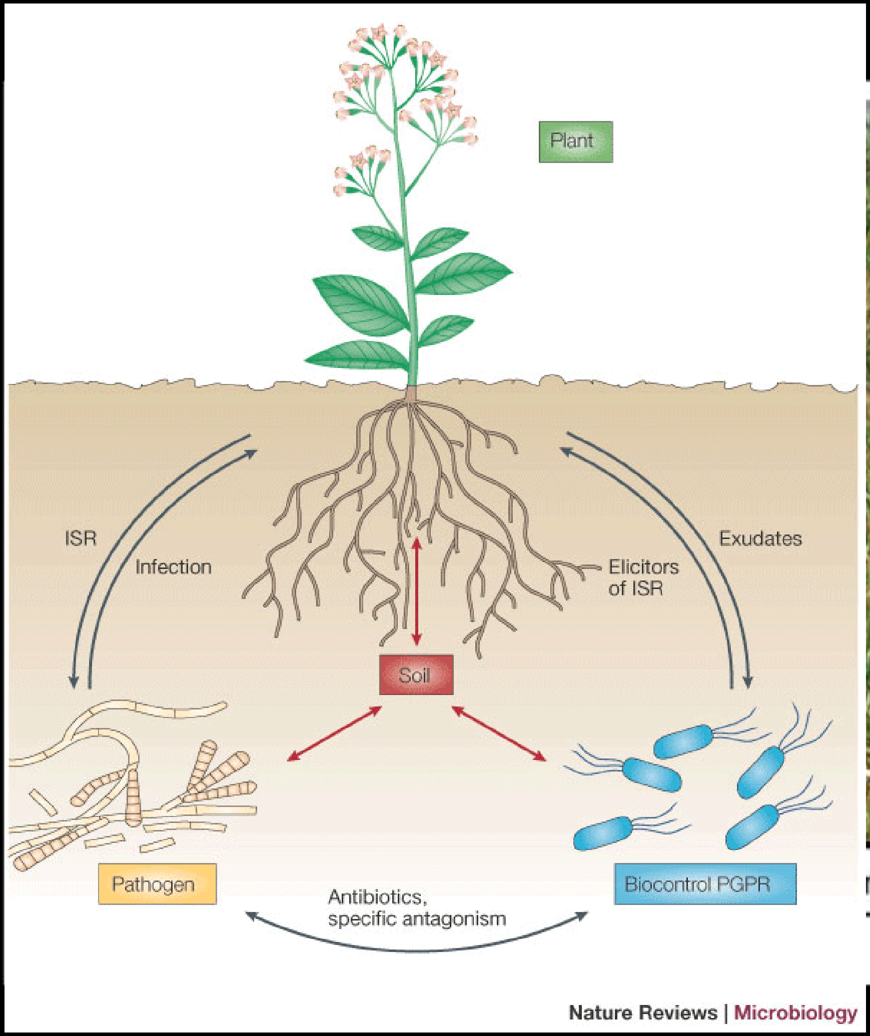
Influence of plant species on rhizosphere communities:



- Plants select for distinct bacterial populations
- Plant-specific patterns maintained over growing season
- All bulk samples look alike
- Sequence ID of dominant bands

Kowalchuk et al 2002

Cultivating a beneficial rhizosphere community

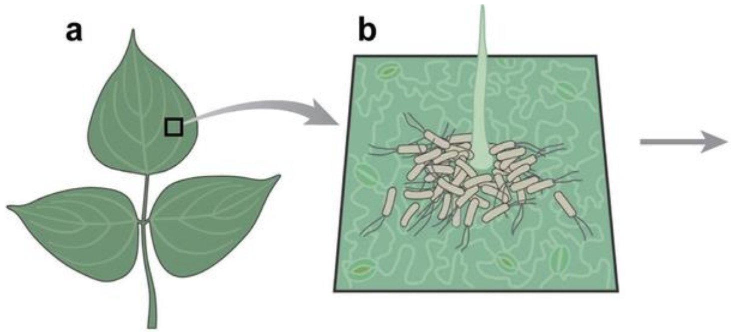


Berensen et al 2013

and soils can be conditioned by growing multiple plant generations

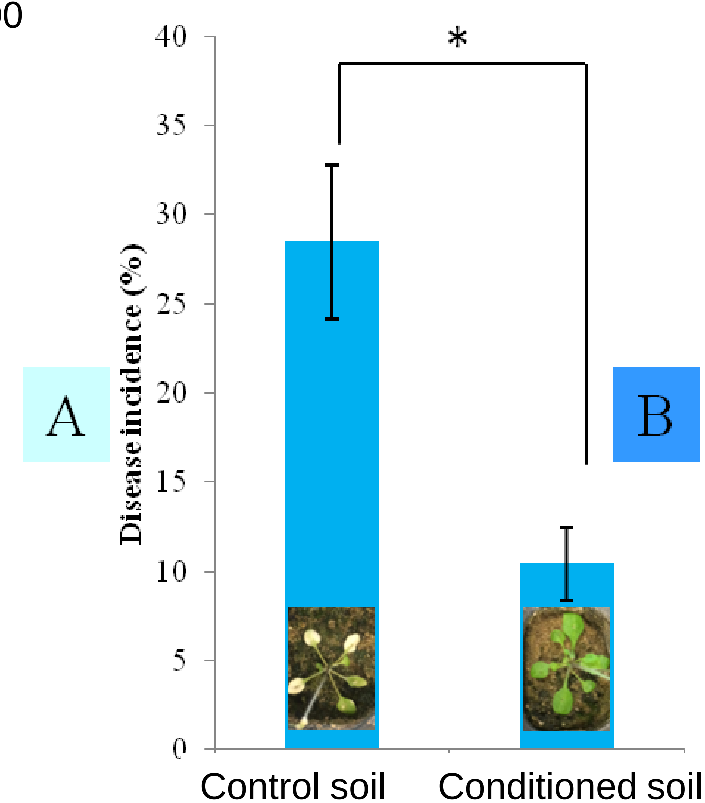
(Raaijmakers et al)

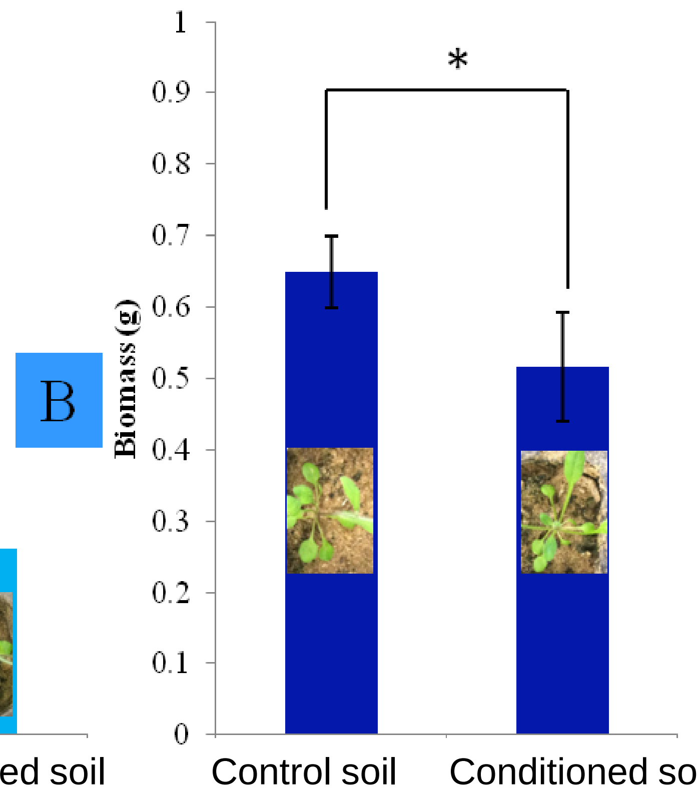
Cultivating beneficial rhizospheres in response to an aboveground pathogen



Pseudomonas syringae DC3000

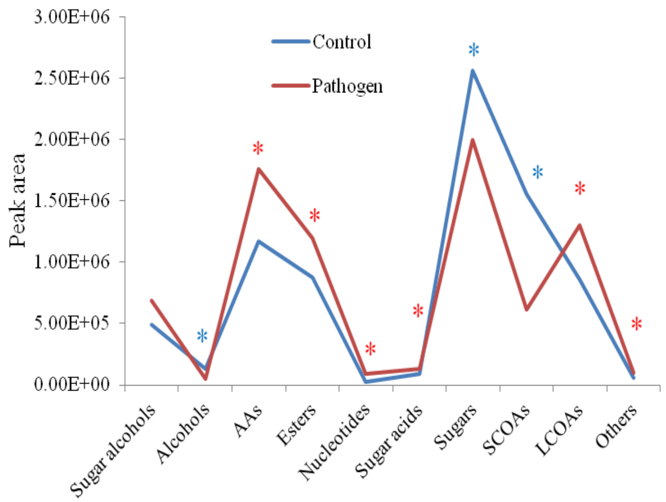
six generations in same soil

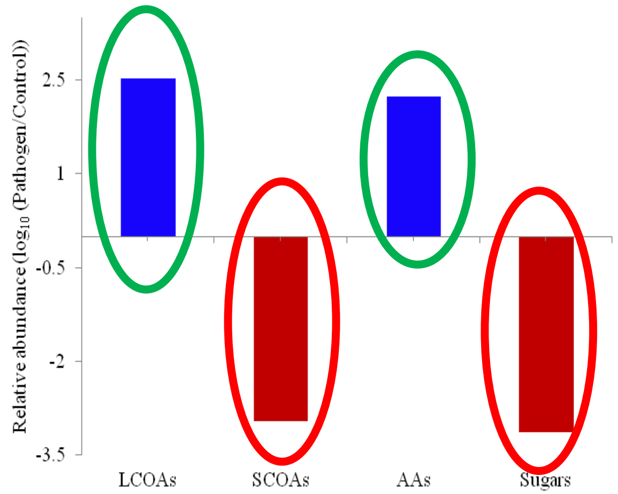




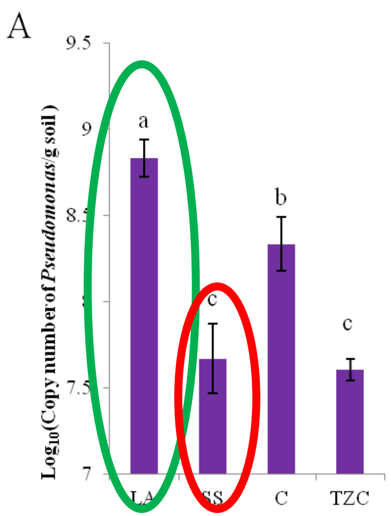
Yuan et al in prep.

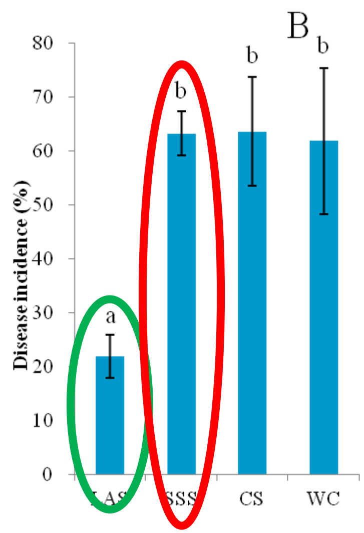
How plants trigger changes in soil communities upon foliar pathogen attack





- Pathogen changes exudation patterns





- Long-chain organic acids and amino acids stimulate beneficial pseudomonads

Yuan et al in review

How living plants drive soil communities

Example: comparison of Ambient vs Elevated CO_2

Rhizosphere microbial community

C.arenaria → non mycorrhizal

F.rubra → mycorrhizal

↓

C3-plants

↓

Incubated for 3-24 months at AMB and ELEV CO_2

↓

Molecular analysis of the micro and meso-fauna and specific communities

Assessing the active community

^{13}C labeled CO_2 in atmosphere for 24 h

↓

Microbial incorporation of label into PLFAs/NLFAs

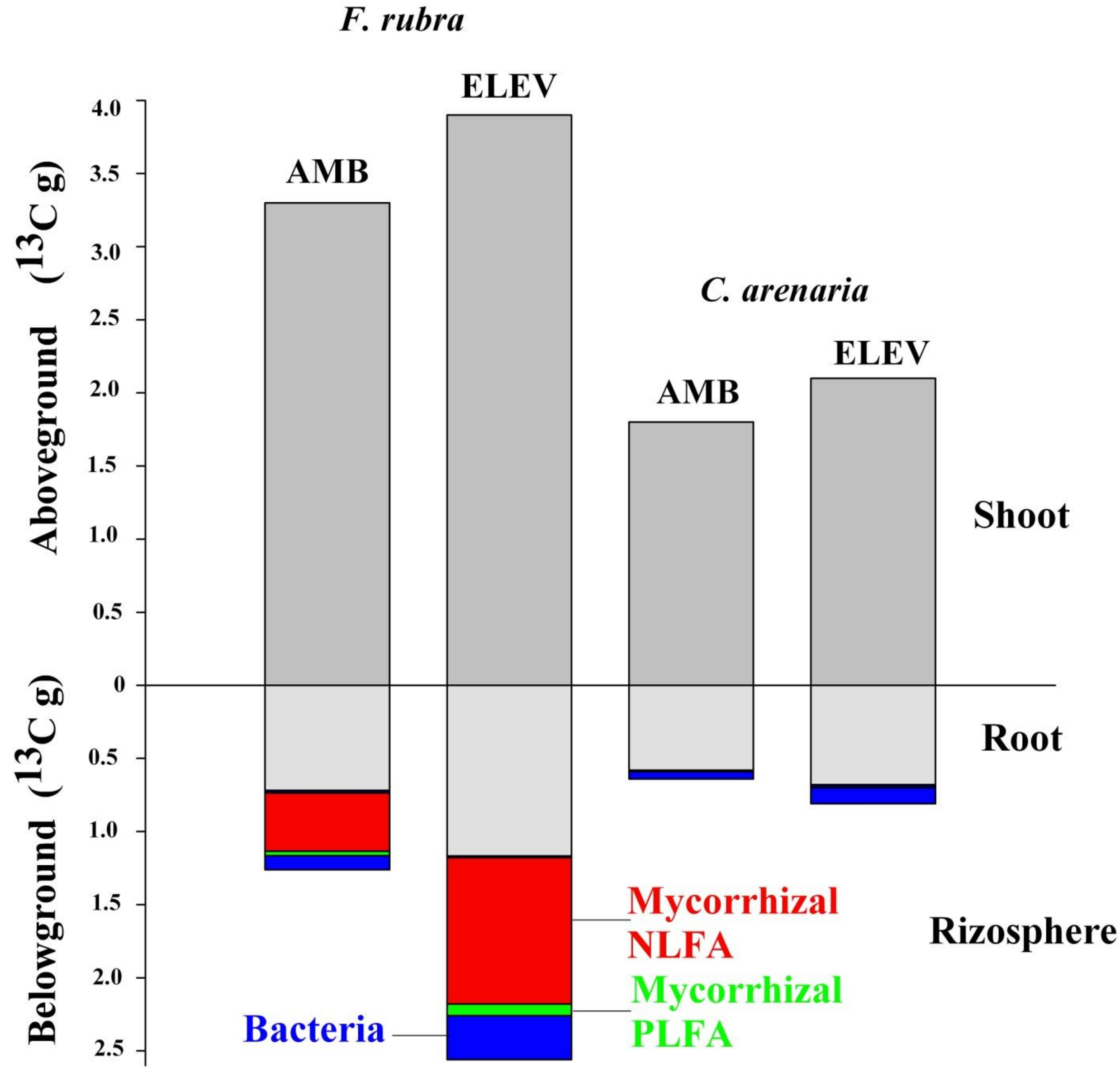
↓

Isolation of "heavy" labeled RNA

↓

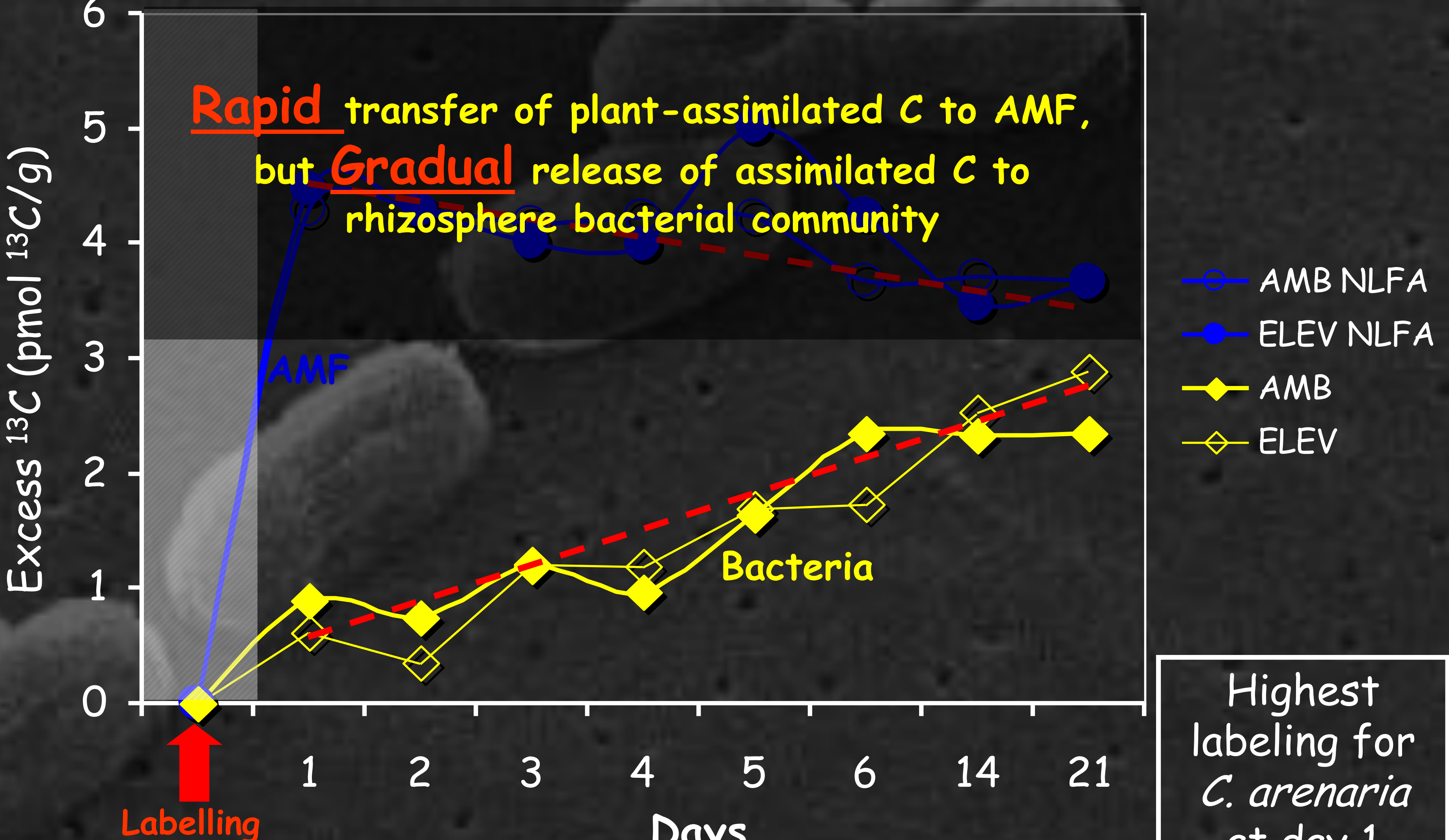
Molecular analysis of "heavy" RNA-fraction

Following the Carbon Flow



^{13}C enrichment of AMF and bacterial* community (PLFAs)

*Mean of 15 bacteria-specific PLFAs



Highest labeling for *C. arenaria* at day 1

Flow of carbon and effects of elevated C-CO_2

BULK

No phenazine production genes detected

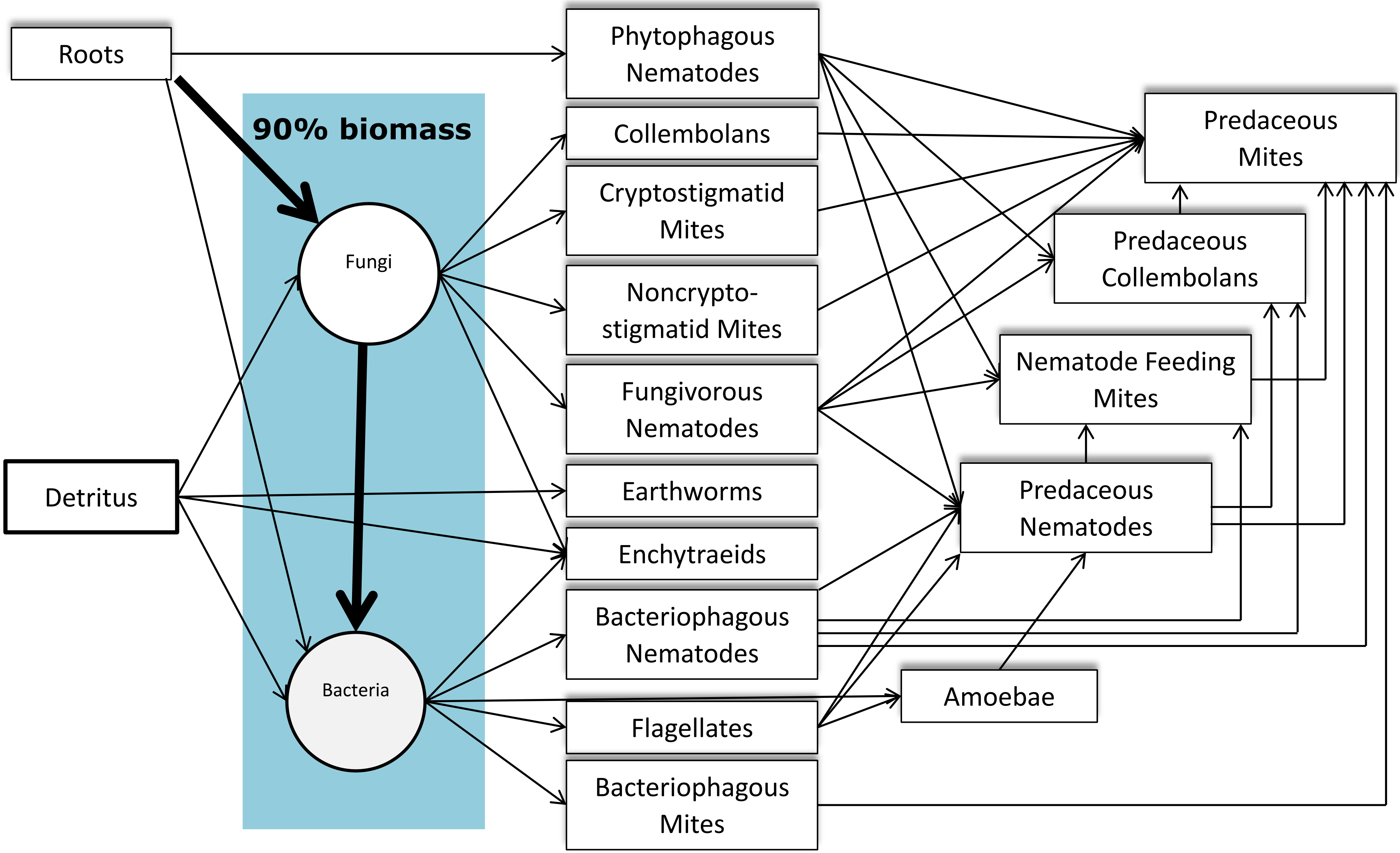
Bacillus

$P=0.20$

Actinomycetes

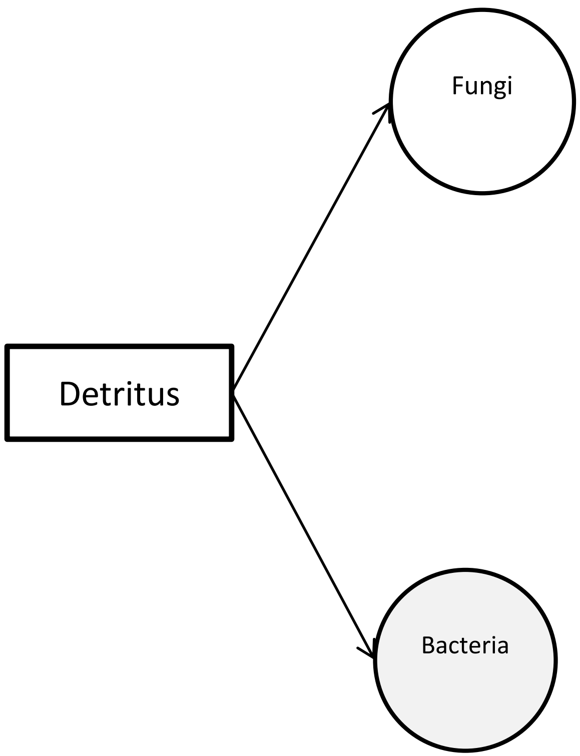
Drigo et al (2008) BFS
Drigo et al (2007 & 2012) GCB
Drigo et al (2009) ISMEJ
Drigo et al (2010) PNAS

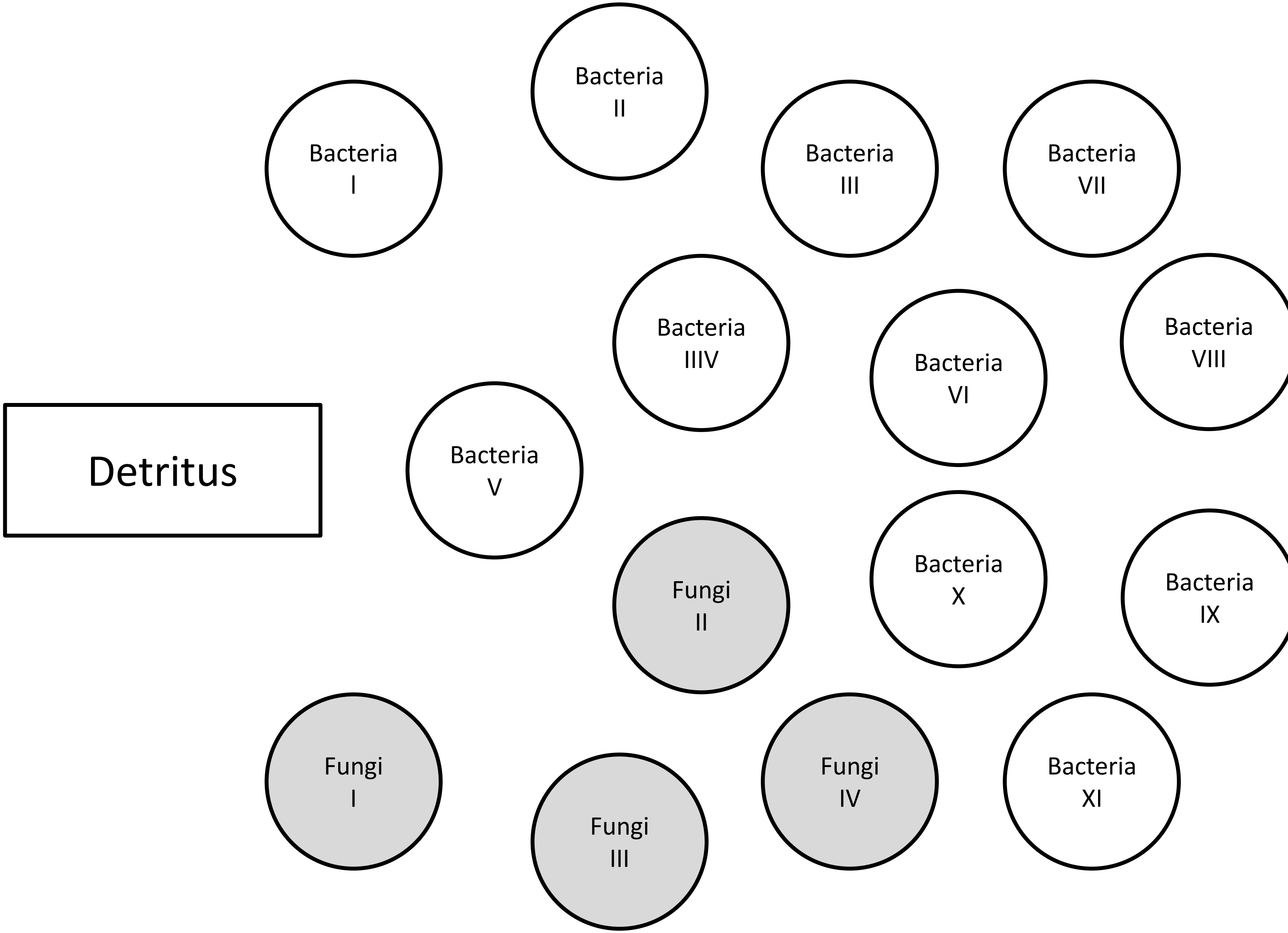
Following dead plant (parts) in soil

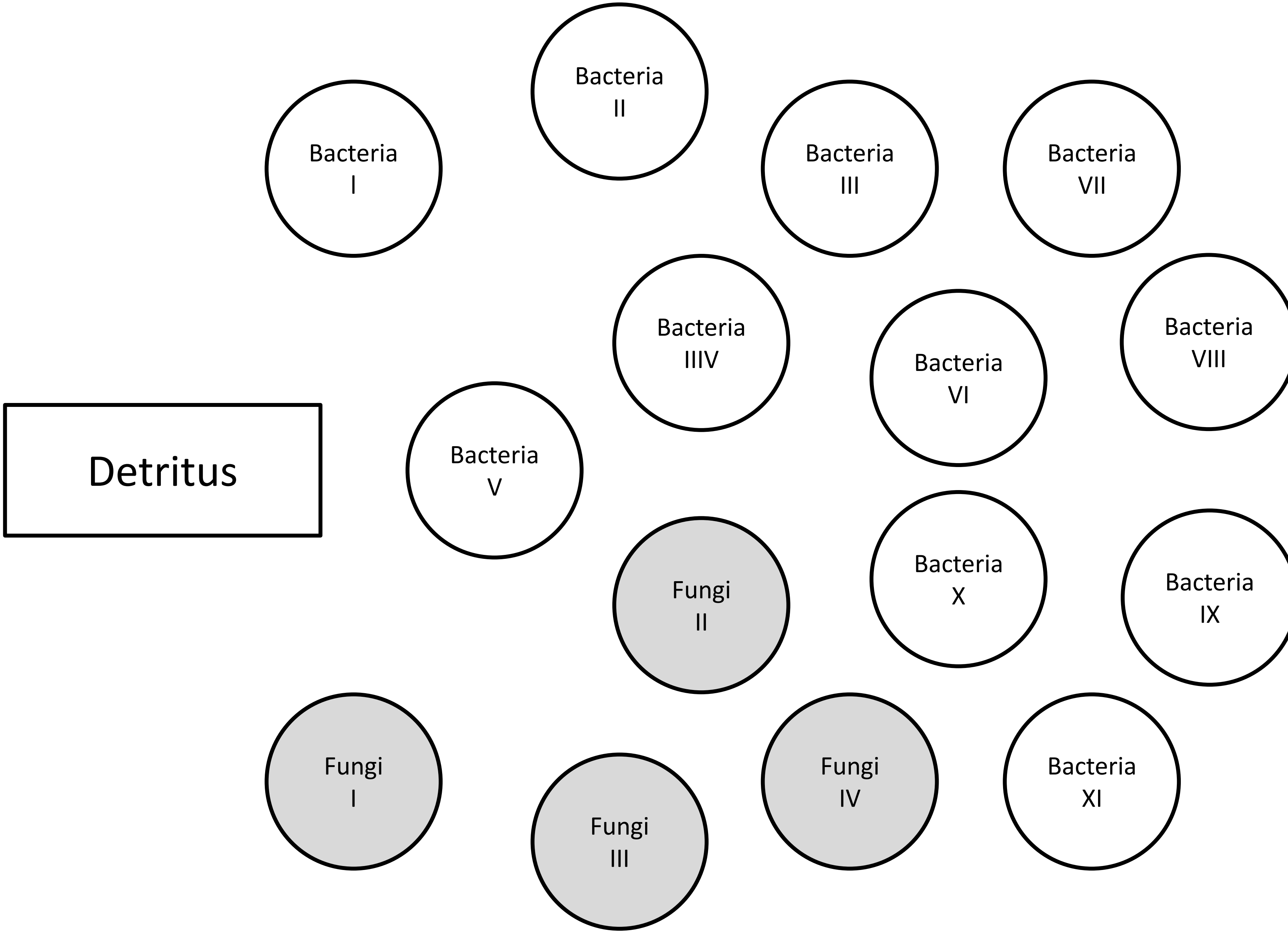


Amber Heijboer

Soil Food Web Model – Microbial diversity




Detritus
Bacteria I
Bacteria II
Bacteria III
Bacteria VII
Bacteria IIIV
Bacteria VI
Bacteria VIII
Bacteria V
Fungi II
Bacteria X
Bacteria IX
Fungi I
Fungi III
Fungi IV
Bacteria XI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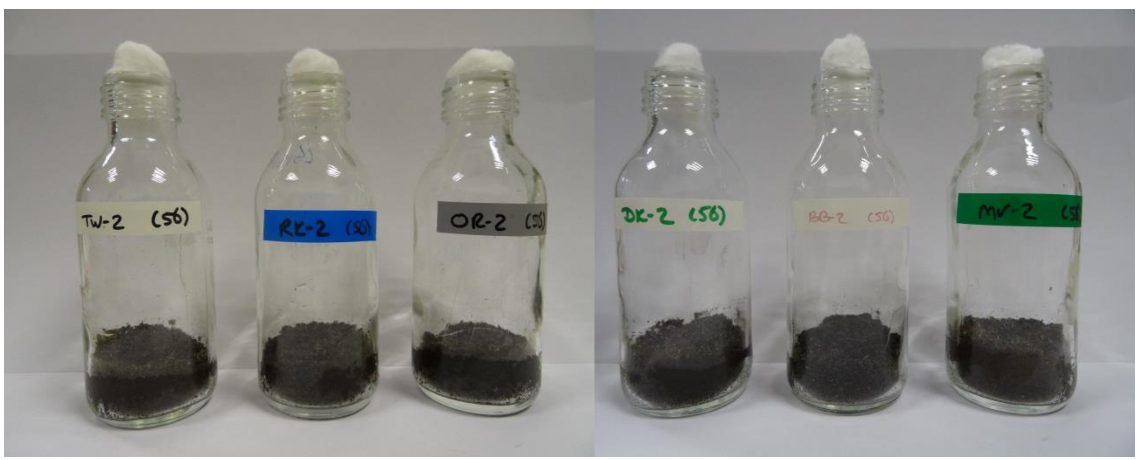
Bacteria I
Bacteria II
Bacteria III
Bacteria VII
Bacteria IIIV
Bacteria VI
Bacteria VIII
Bacteria V
Fungi II
Bacteria X
Bacteria IX
Fungi I
Fungi III
Fungi IV
Bacteria XI

Experimental setup incubation

Addition of labelled plant litter

13C litter



Sampling after 1, 3, 7, 14, 28 & 56 days

Setup

x2 succession stages

x3 fields

x3 replicates

x6 sampling times

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108 bottles

+ 2 * 36 control pots

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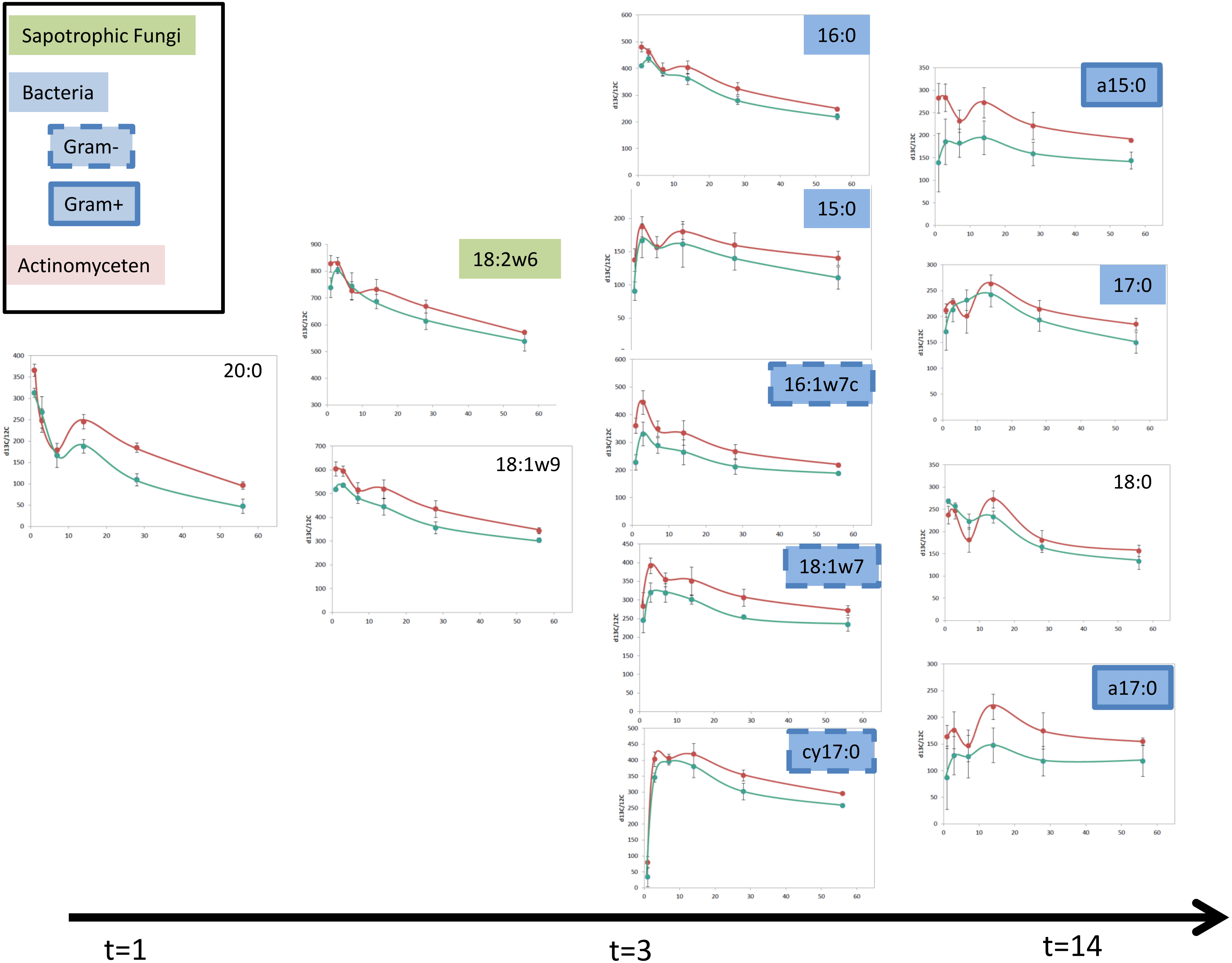
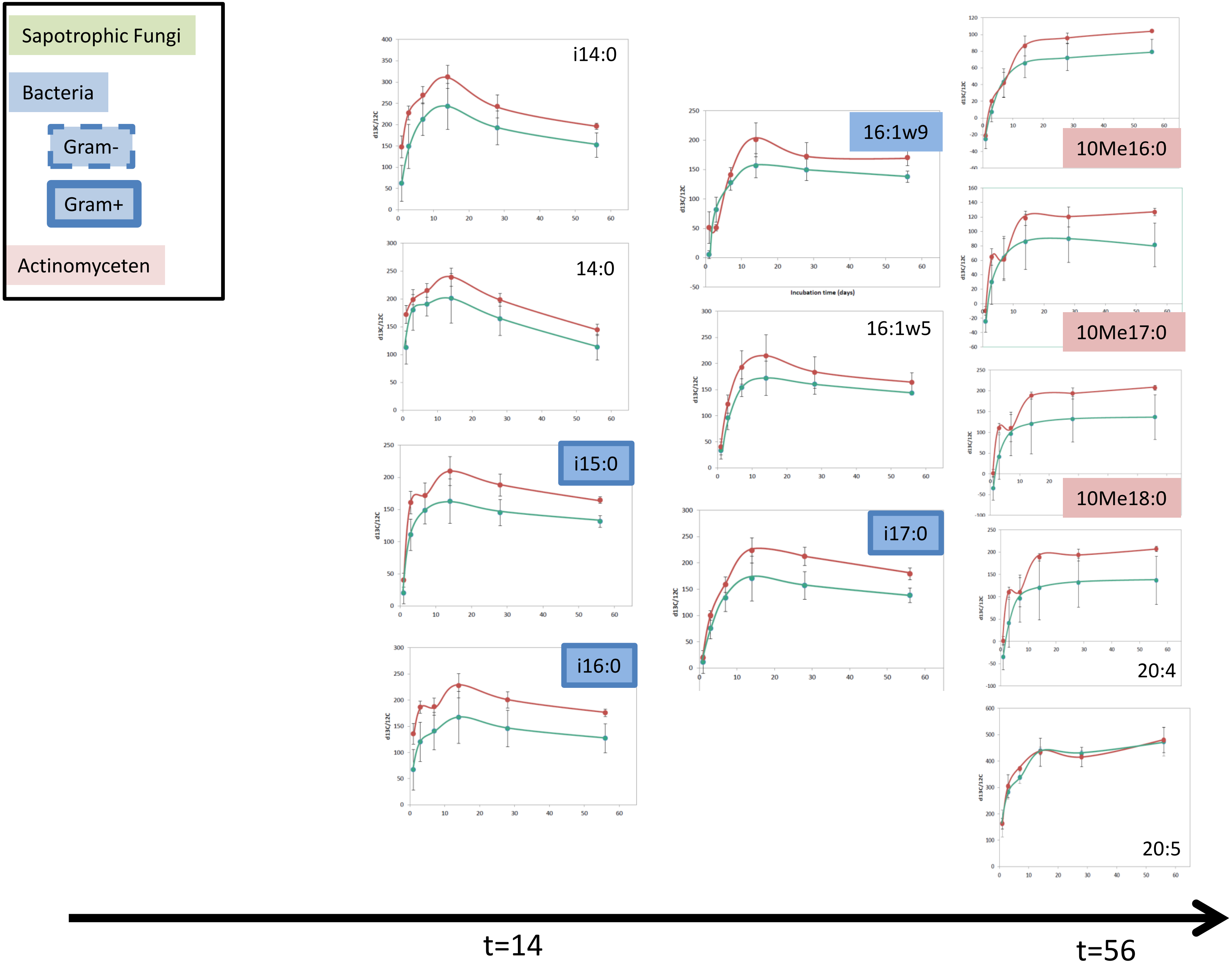
180 bottles

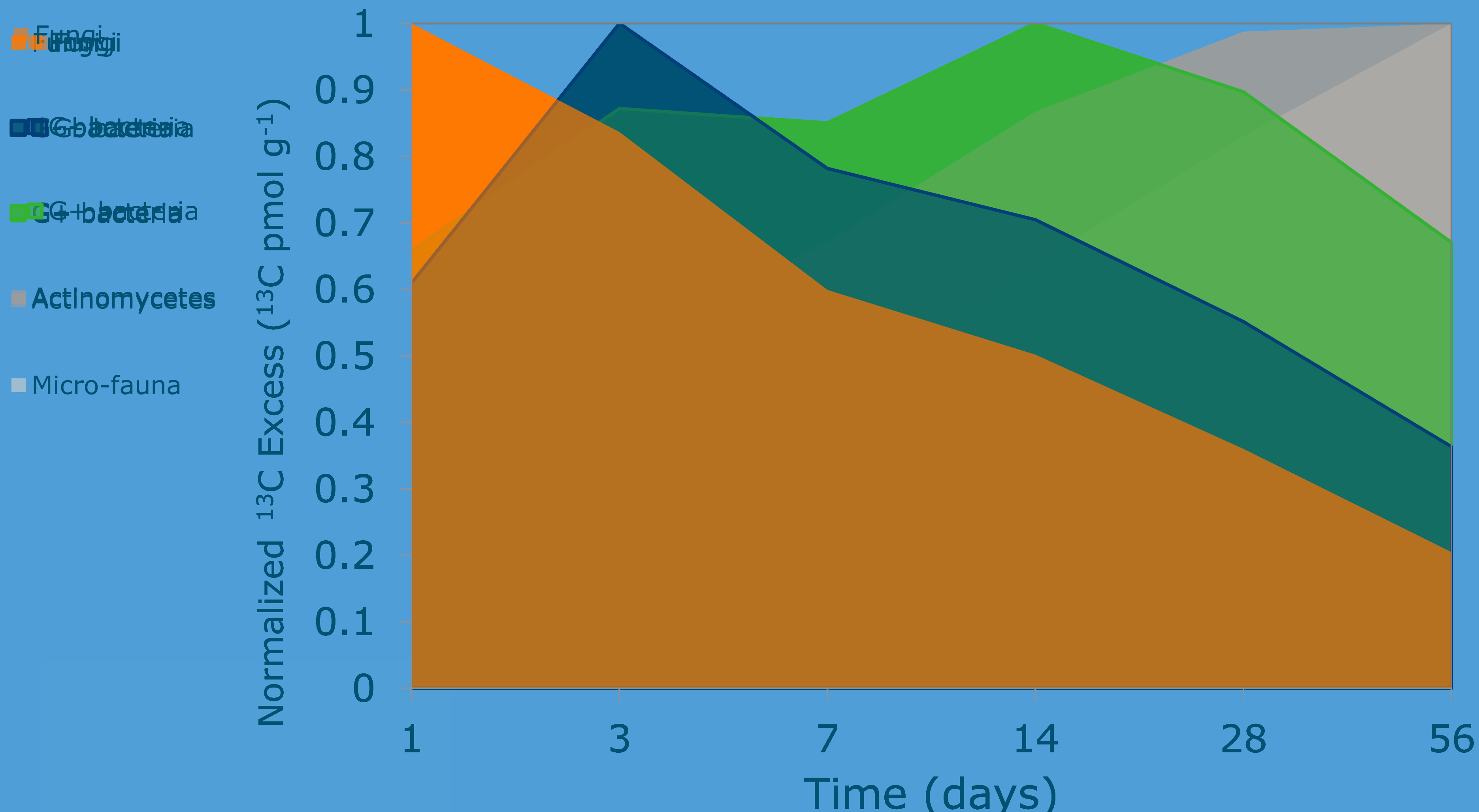


Sapotrophic Fungi
Bacteria
Gram-
Gram+
Actinomyceten
20:0
18:2w6
18:1w9
16:0
15:0
16:1w7c
18:1w7
cy17:0
a15:0
17:0
18:0
a17:0
d13C/12C
t=1
t=3
t=14



Sapotrophic Fungi
Bacteria
Gram-
Gram+
Actinomyceten
i14:0
14:0
i15:0
i16:0
16:1w9
Incubation time (days)
16:1w5
i17:0
10Me16:0
10Me17:0
10Me18:0
20:4
20:5
d13C/12C
t=14
t=56

Timing of ^{13}C incorporation – Functional groups



Bringing microbial assembly into focus

defining some rules of microbial community assembly

We can borrow concepts from macro-ecology, such as:

Bringing microbial assembly into focus

defining some rules of microbial community assembly

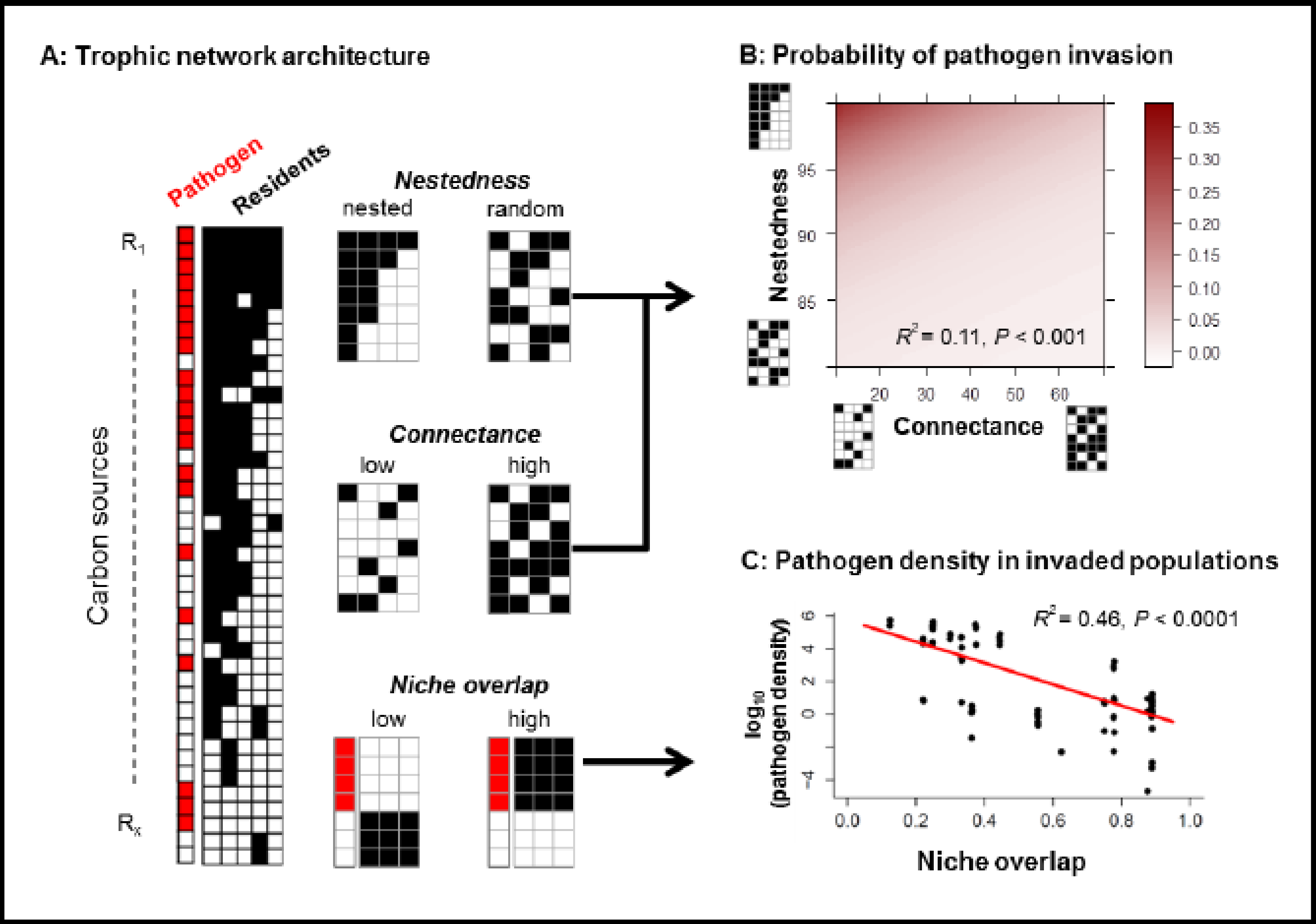
We can borrow concepts from macro-ecology, such as:

- Priority effects, succession and facilitation
- Trophic interactions
- Species-area relationships
- Niche overlap and competition
- Habitat connectivity, stochastic processes and neutrality

Multi-species inoculation improves disease resistance

Wei et al Nature Comms (2015)

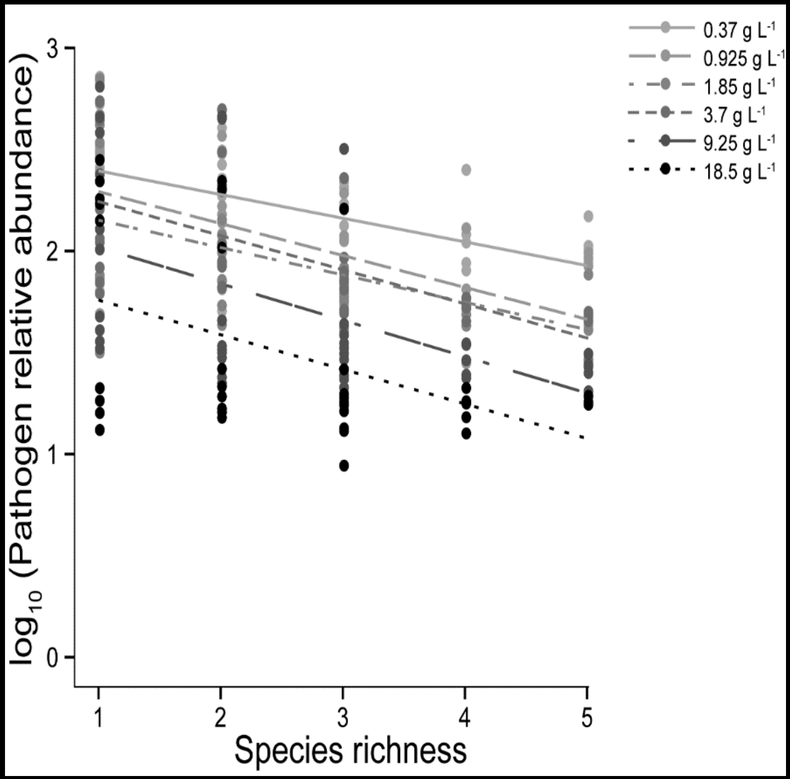
Studying assembly in artificial communities

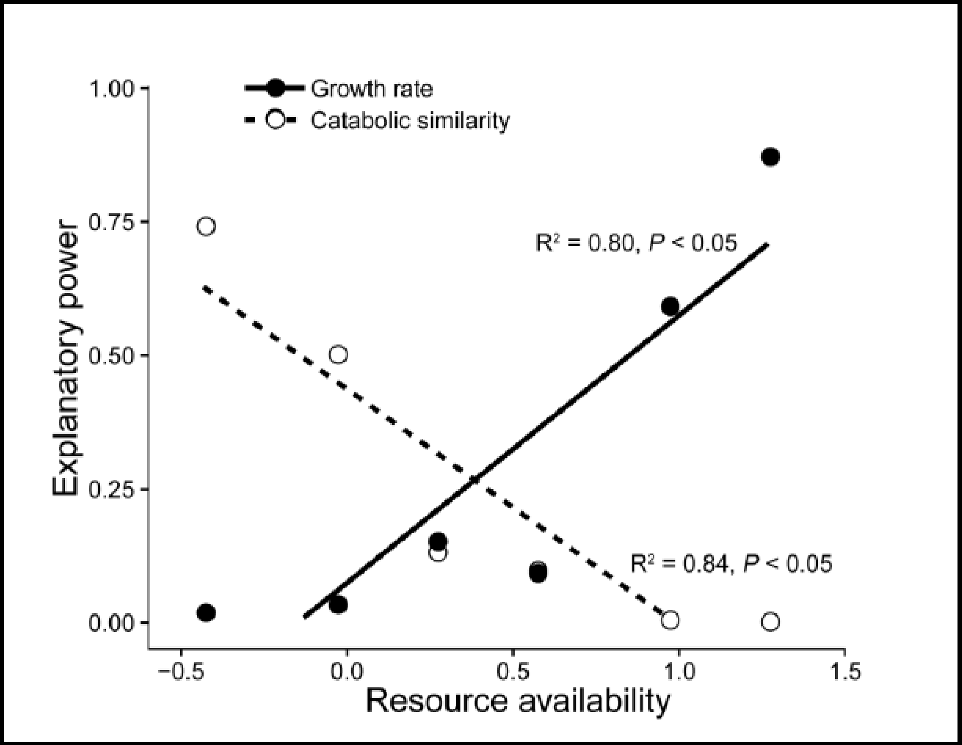


- Communities assembled with defined structure (without direct antagonism)
- Test ability to impede invasion by pathogen
- Population traits predict resistance to invasion

Wei et al Nature Comms (2015)

Interactions between species traits and nutrient availability





Diversity / function relationship

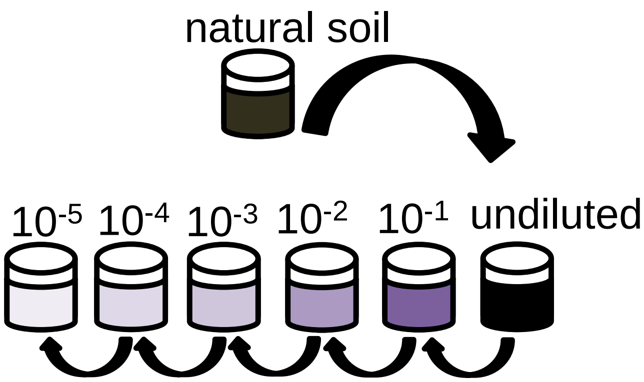
Relative disease suppression modulated by nutrient status

High nutrient availability = Growth rate

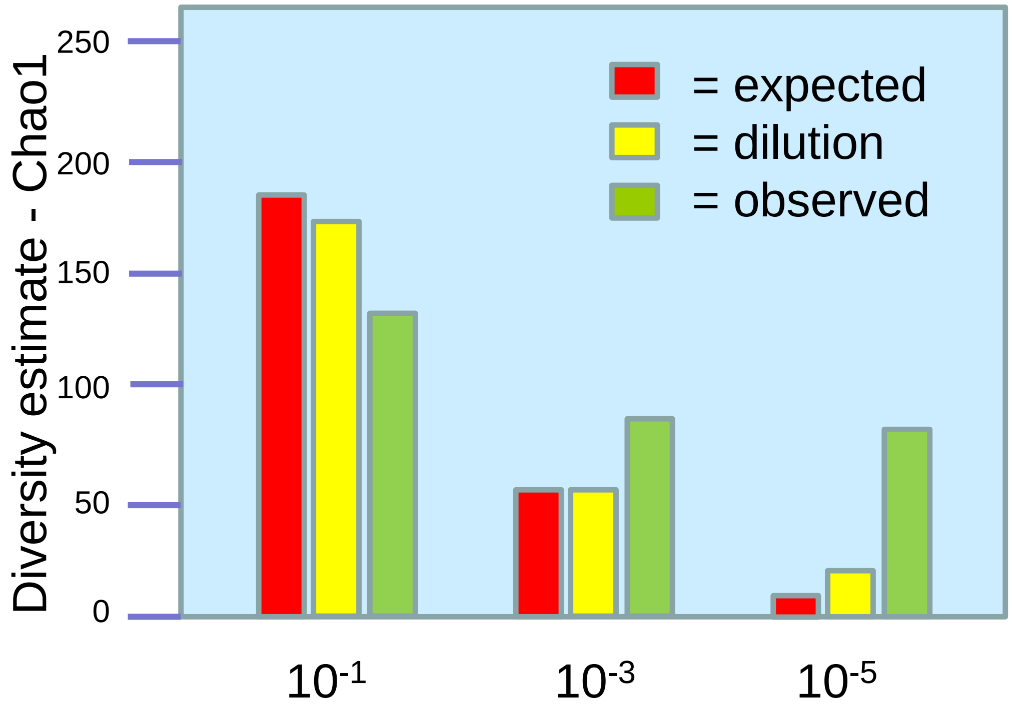
Low nutrient availability = Niche overlap

Yang et al Environ Microbiol. 2017

Community assembly after dilution and re-inoculation

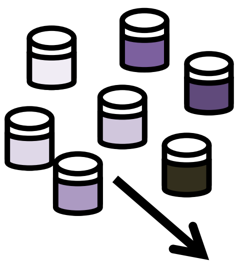


Serial dilution as a means of reducing bacterial diversity to examine diversity/function relationship



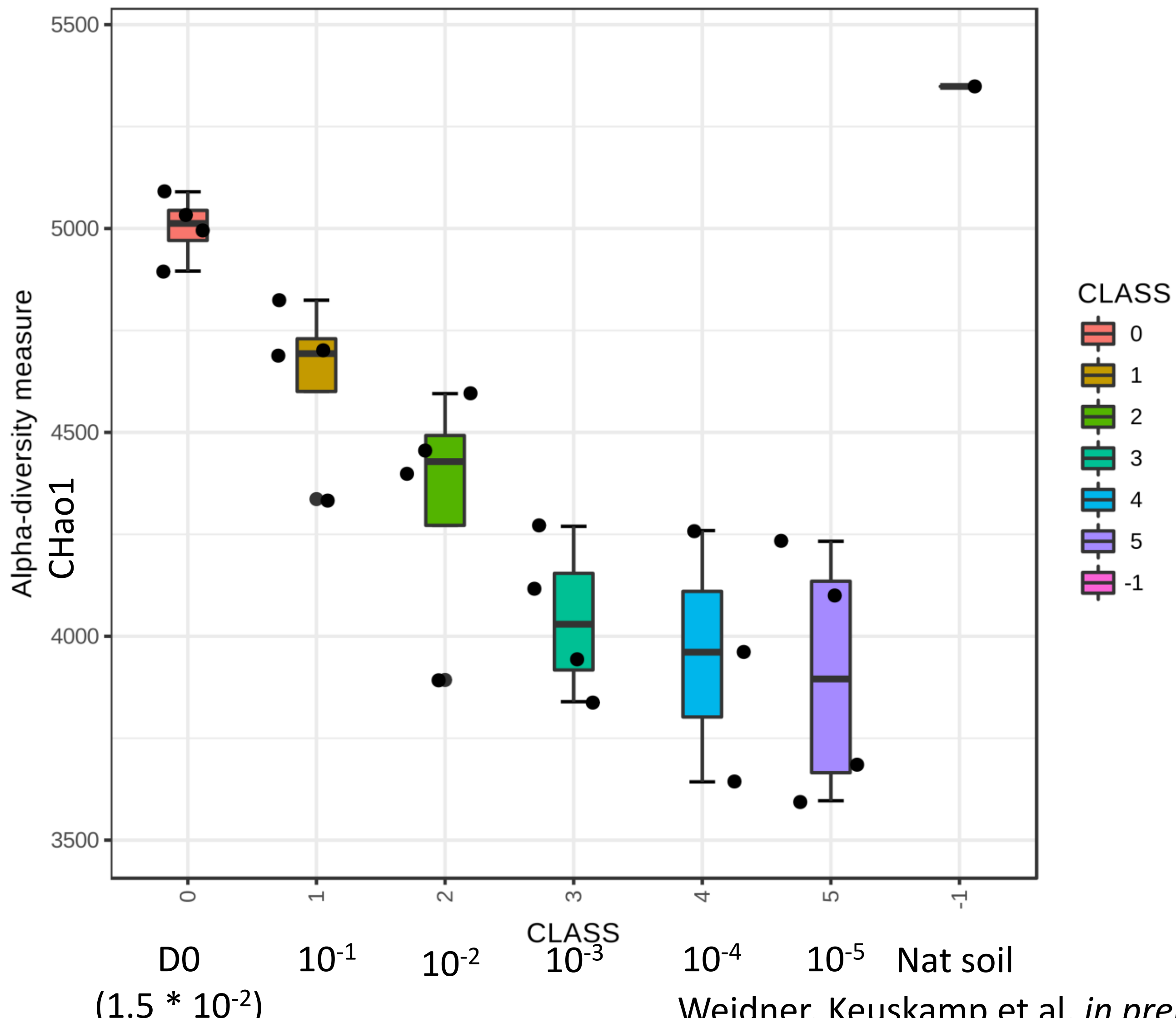
Kuramae et al AEM 2015

Effect of serial dilution on species richness



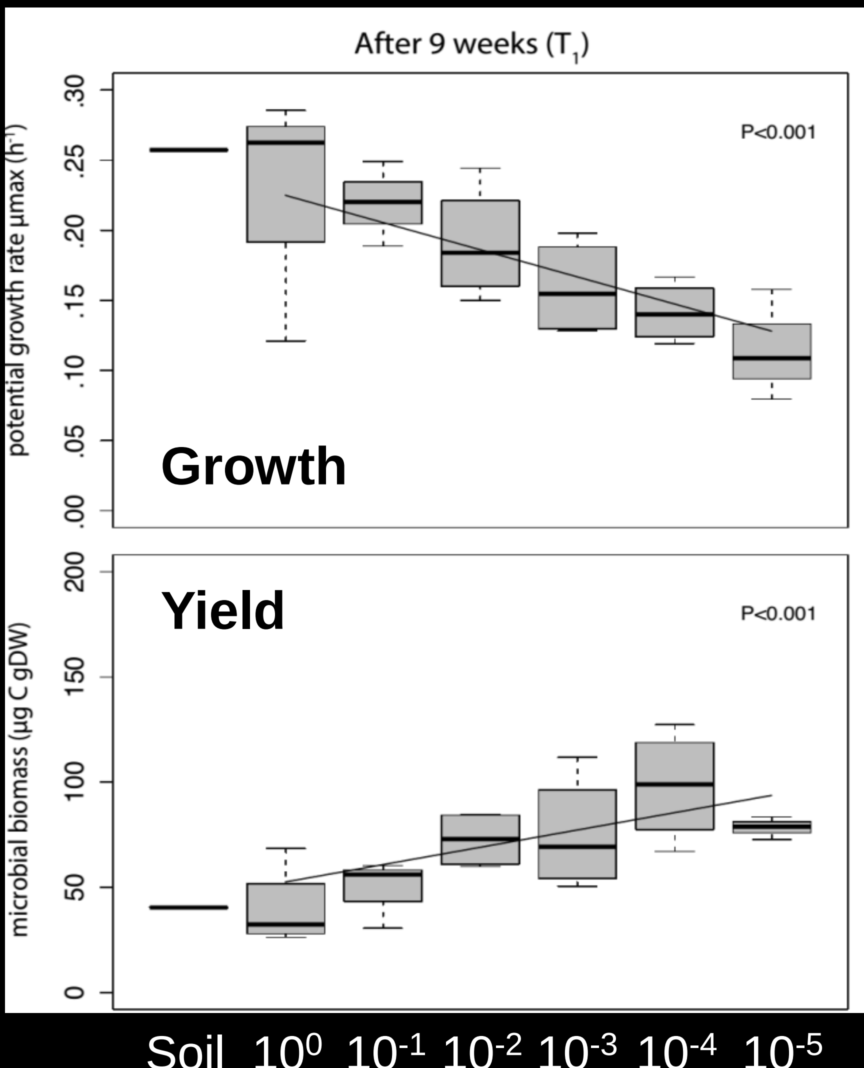
- Lower reduction in diversity than expected

- Greater variation in higher dilutions



Weidner, Keuskamp et al, *in prep*

Selection of microbial growth strategies upon re-inoculation



Higher dilution selects for:

SLOW GROWTH

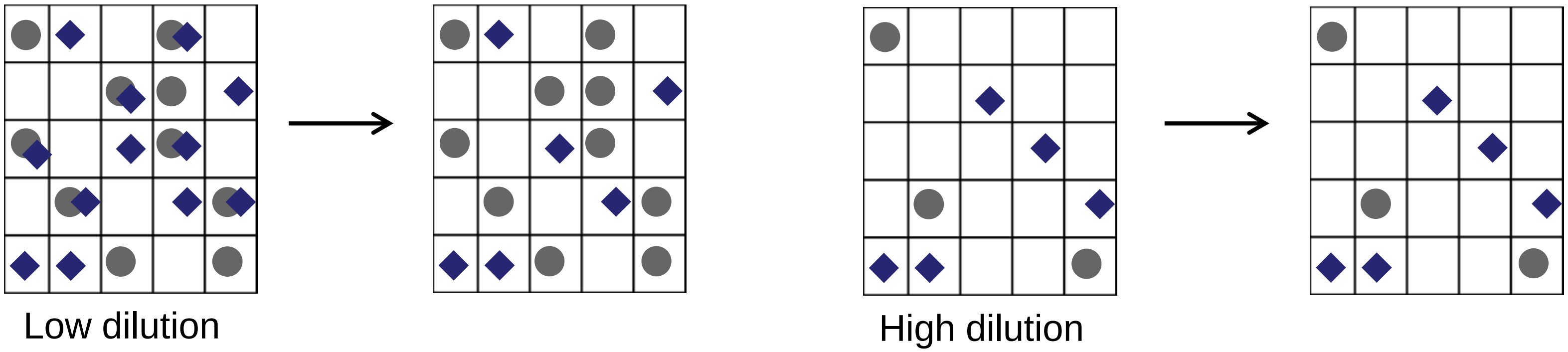
and

HIGH YIELD

Weidner, Keuskamp *et al.* In prep

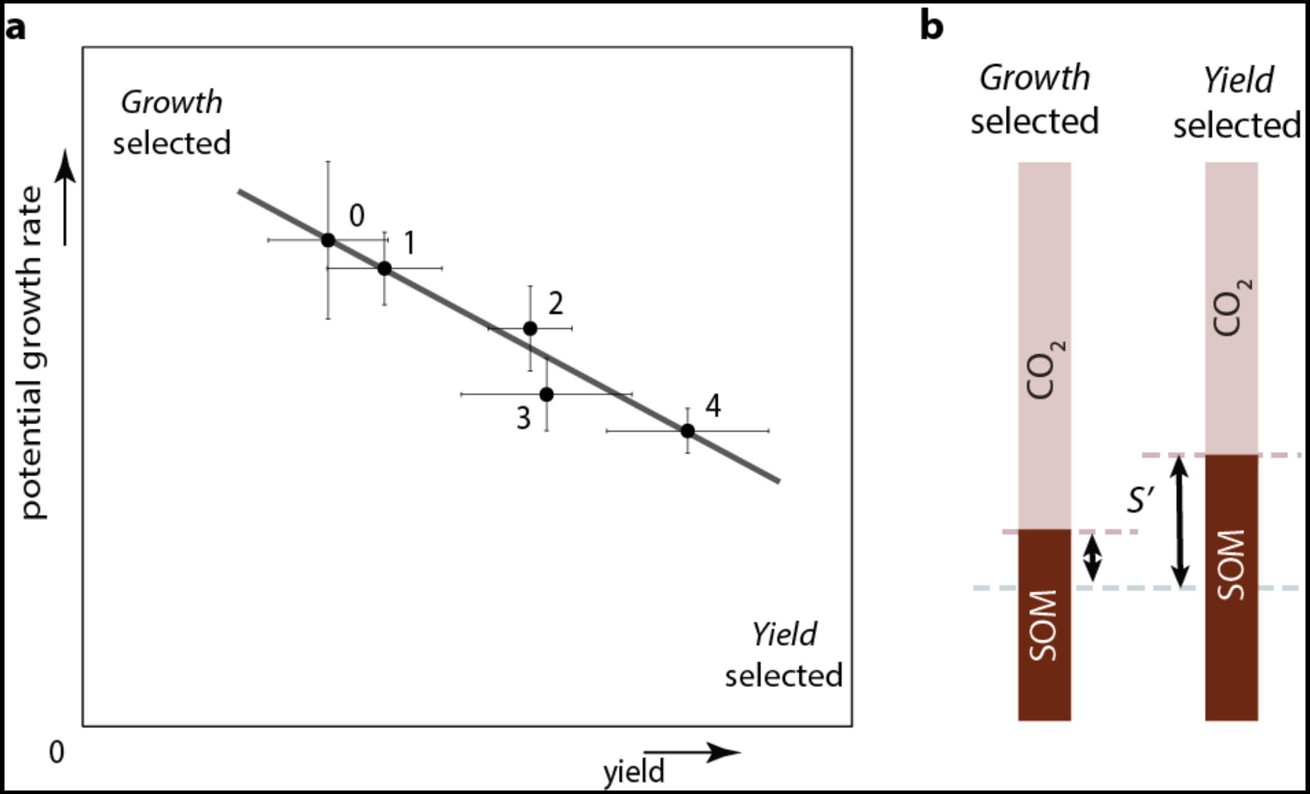
Spatial distribution and modeling yield versus growth communities

Growth (●) versus yield (◆) strategists



- As dilution increases, competition is decreased
- Maintains higher species diversity than expected
- May ultimately lead to high yield efficiency community

Dilution breeds yield strategies, which impacts C retention



- Tradeoff between growth and yield
- Impact on C retention
- Potential to steer and exploit microbial life history traits

Weidner, Keuskamp *et al.* In prep

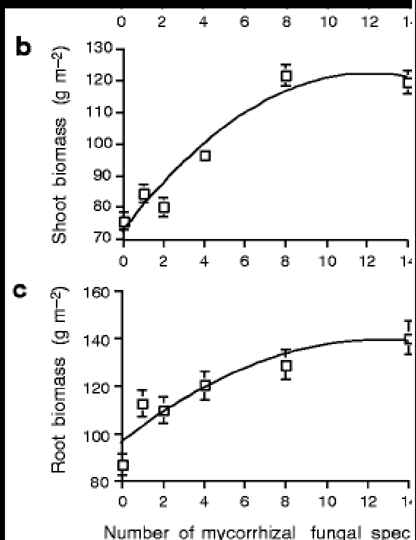
Ecology from a microbial perspective is required

to …

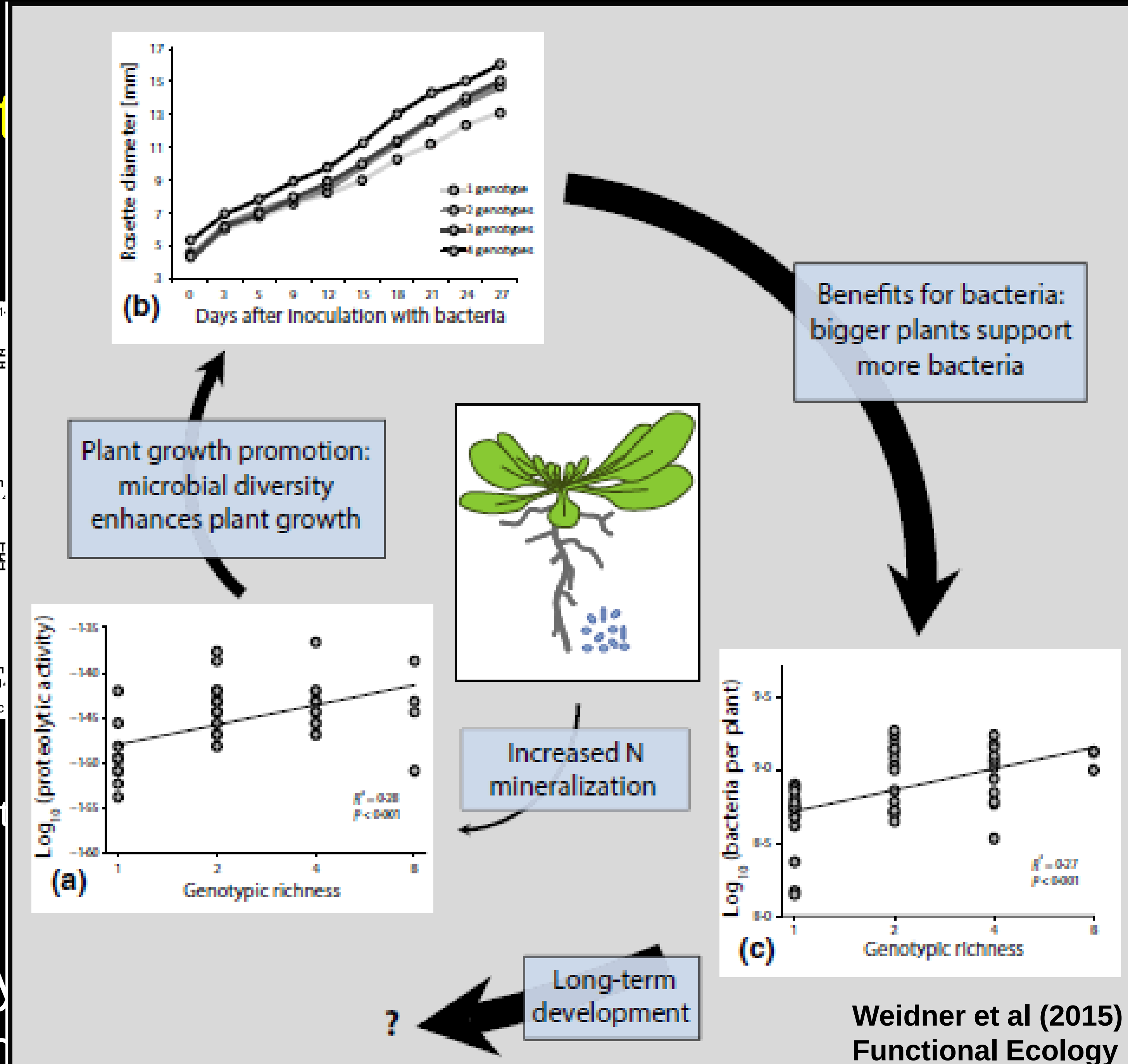
understand and utilize soil-borne microbial

diversity in sustainable plant protection *thanks to the listeners*

The import



Plant biomass:
van der Heijden et
al (1998) Nature



Diversity
func

The importance of soil-borne microbial diversity

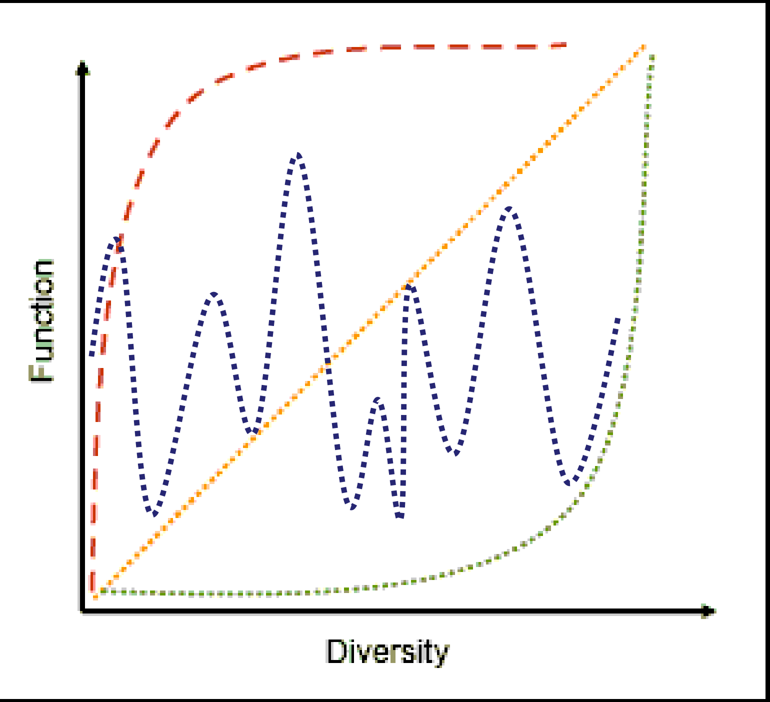
Microbes drive key ecosystem functions, but is their diversity really important?

Redundancy

Linear – additive

Synergistic

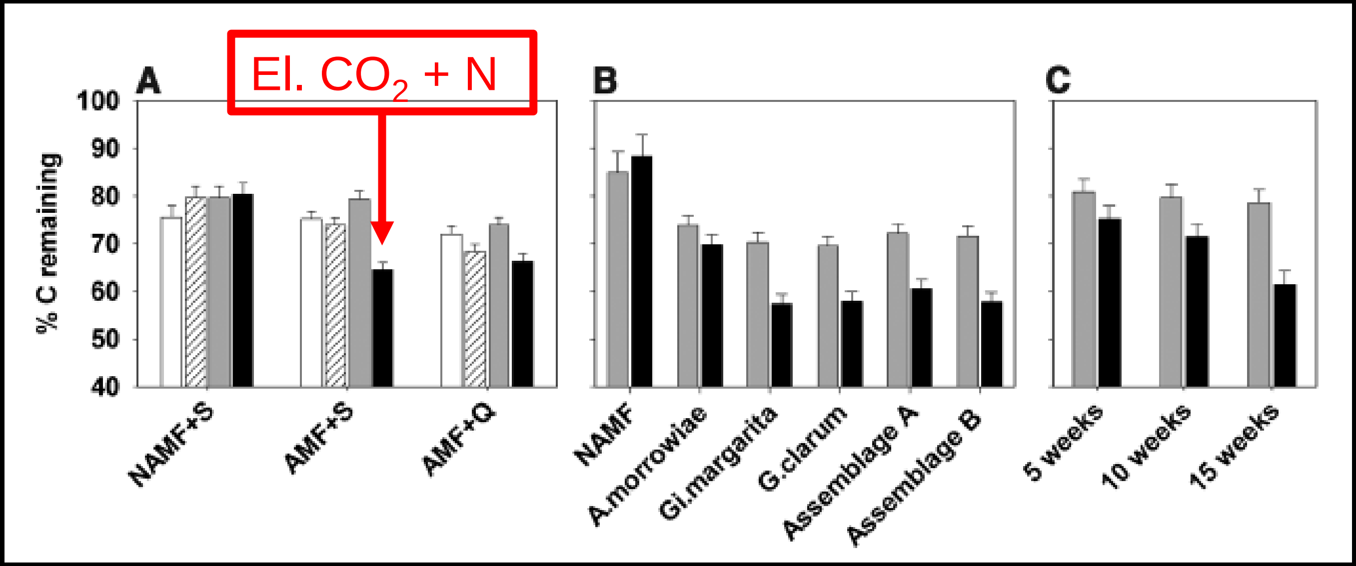
Idiosyncratic



It depends on the function…

However, …. does the extra carbon stay in the soil?

Arbuscular Mycorrhizal Fungi Increase Organic Carbon Decomposition Under Elevated CO_2 L. Cheng *et al*., *Science* 337, 1084-1087 (2012)

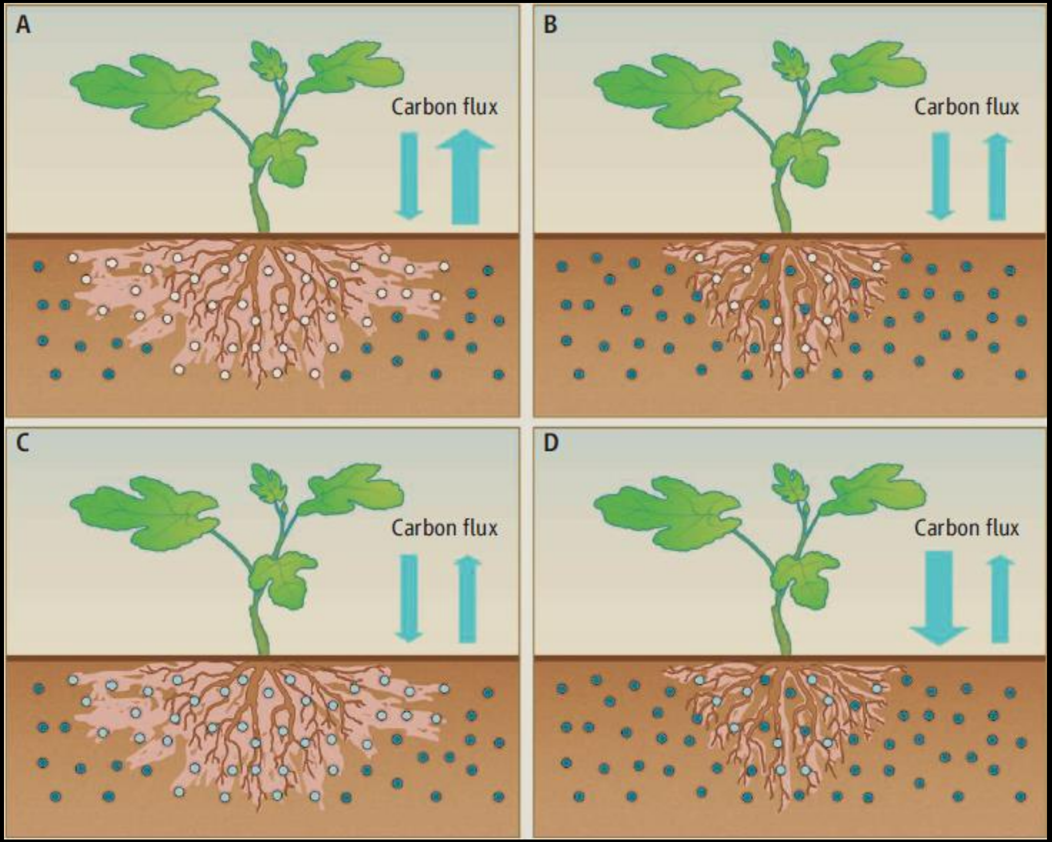


In the presence of AMF, N addition leads to net C loss under elevated CO_2 conditions

However, …. does the extra carbon stay in the soil?

Is the microbial community prepared to access available C sources?

- **Home-field advantage**
- **Nutrient status**
- **Importance of microbial growth strategy**



Bad News for Soil Carbon Sequestration?

George A. Kowalchuk, *Science 31 August 2012: 1049-1050*

Can we steer microbial growth strategies for improved carbon retention?