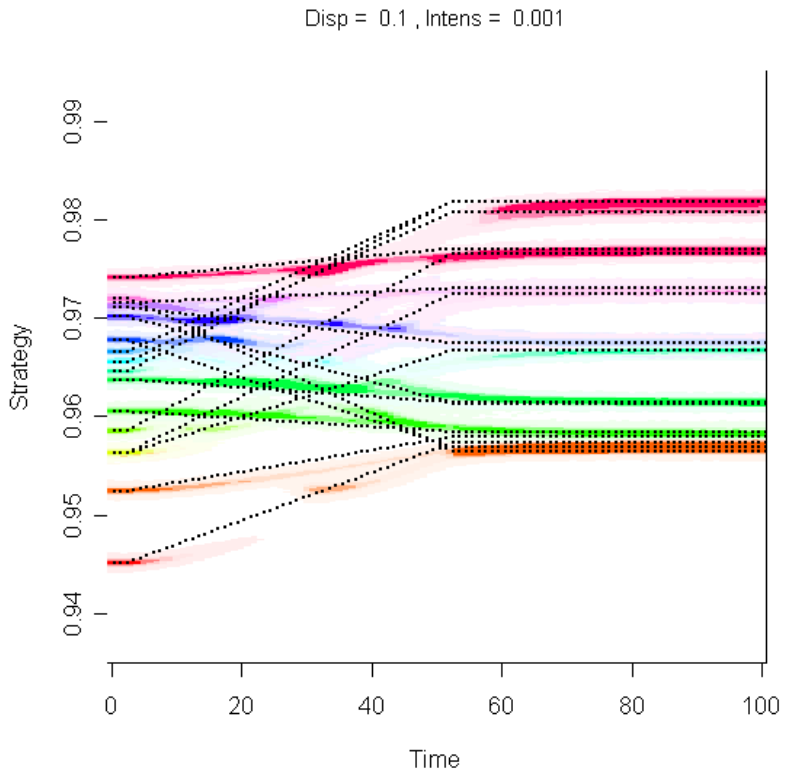
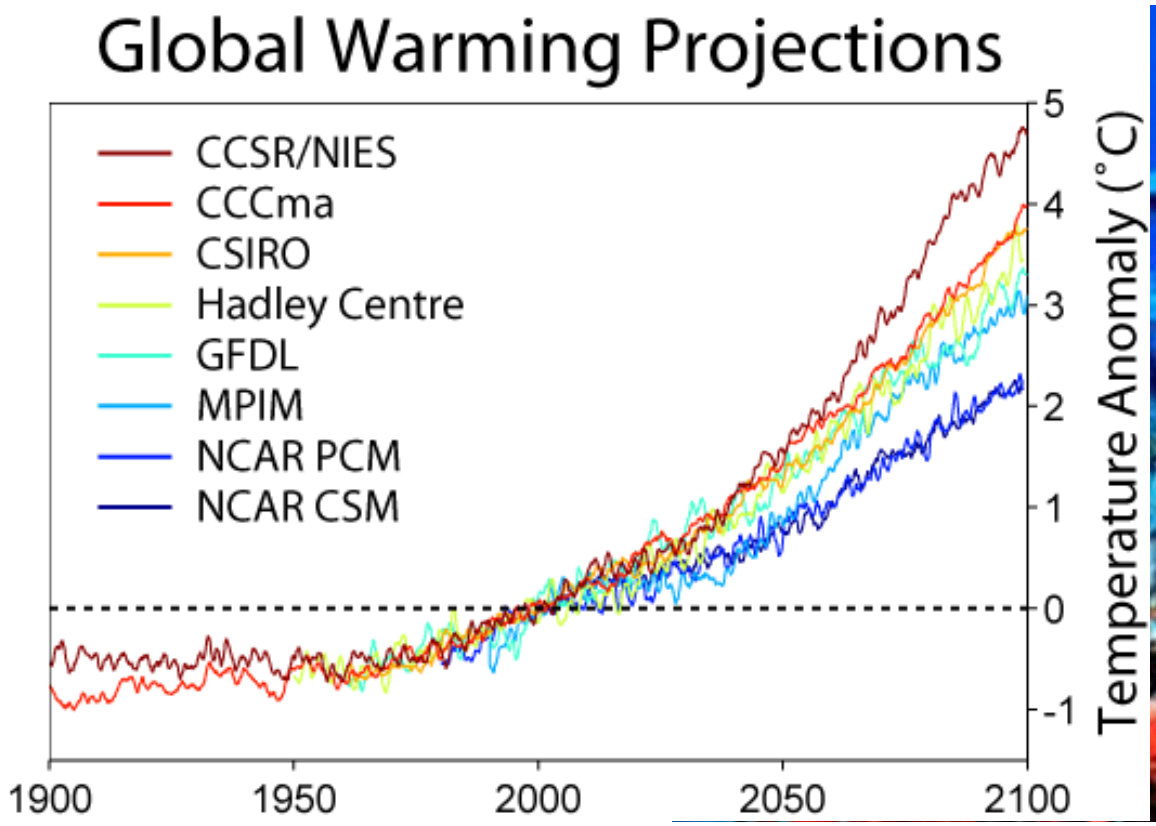
Species interactions and evolution



Tim Barraclough,
t.barraclough@imperial.ac.uk

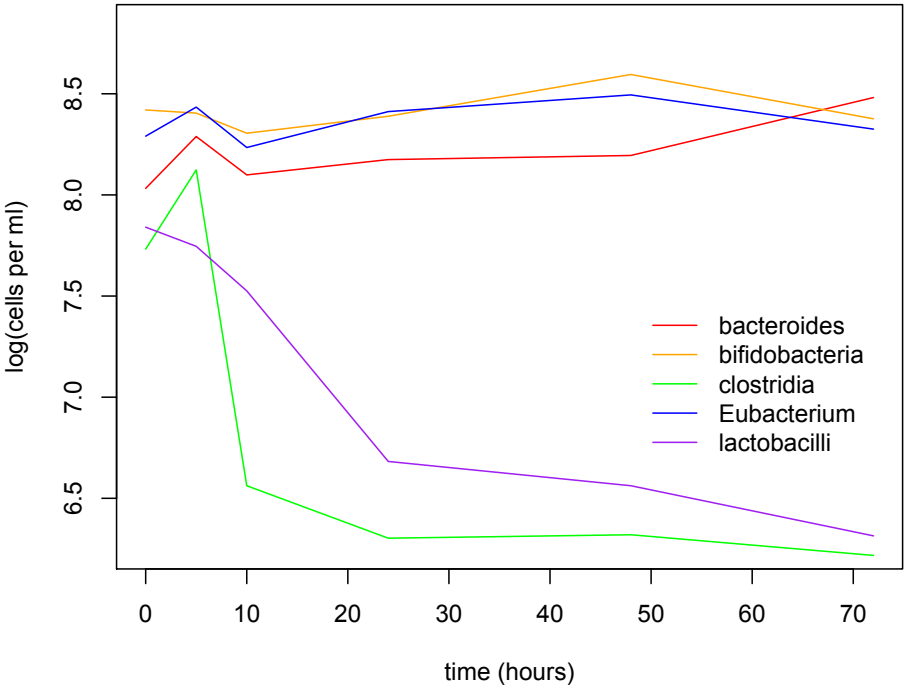
How do diverse communities respond to a new environment?



How do diverse communities respond to a new environment?

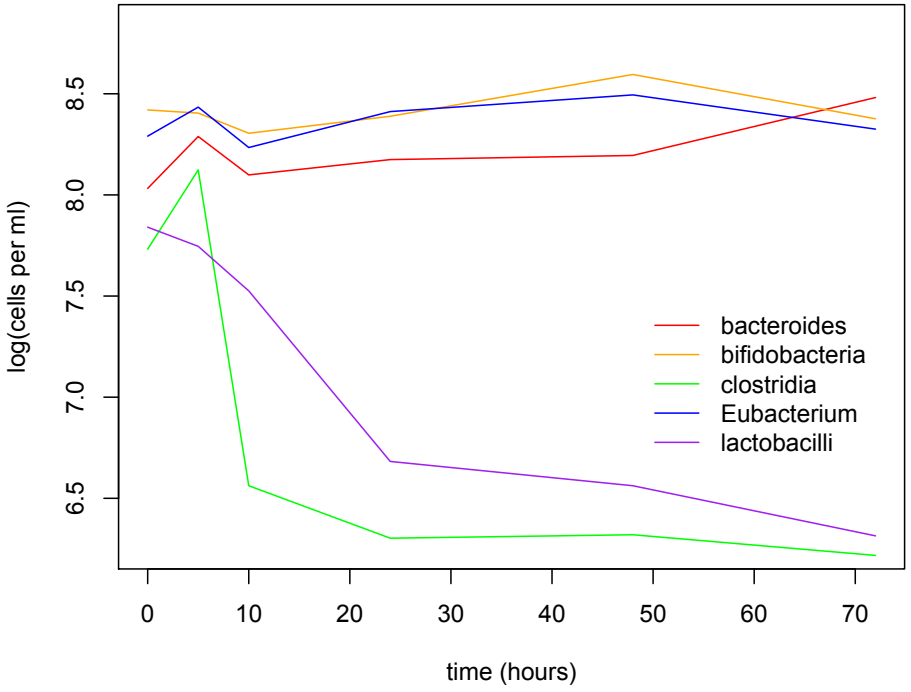
How do diverse communities respond to new conditions?

Ecological changes

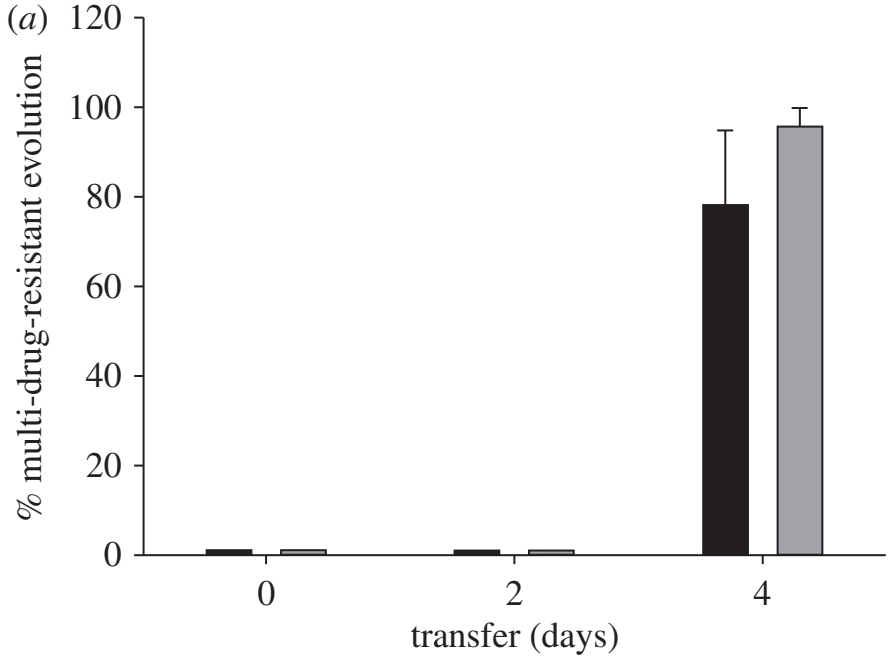


How do diverse communities respond to new conditions?

Ecological changes

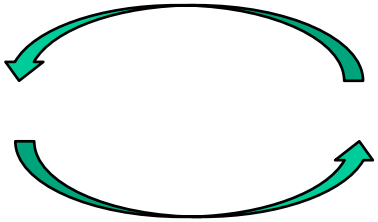


Evolutionary responses



How do diverse communities respond to new conditions?

Ecological changes



Evolutionary responses

How do species interactions affect evolution in communities?

How does evolution affect ecological interactions & functioning?

How do species interactions affect evolution?

1) Species interactions have negligible effect

Evolutionary rates across species depend on:

Generation time

Population size

Mutation rates

Recombination rates

Genetic variance-covariance conducive to selected change

Number of traits under selection

Size and temporal pattern of environmental change

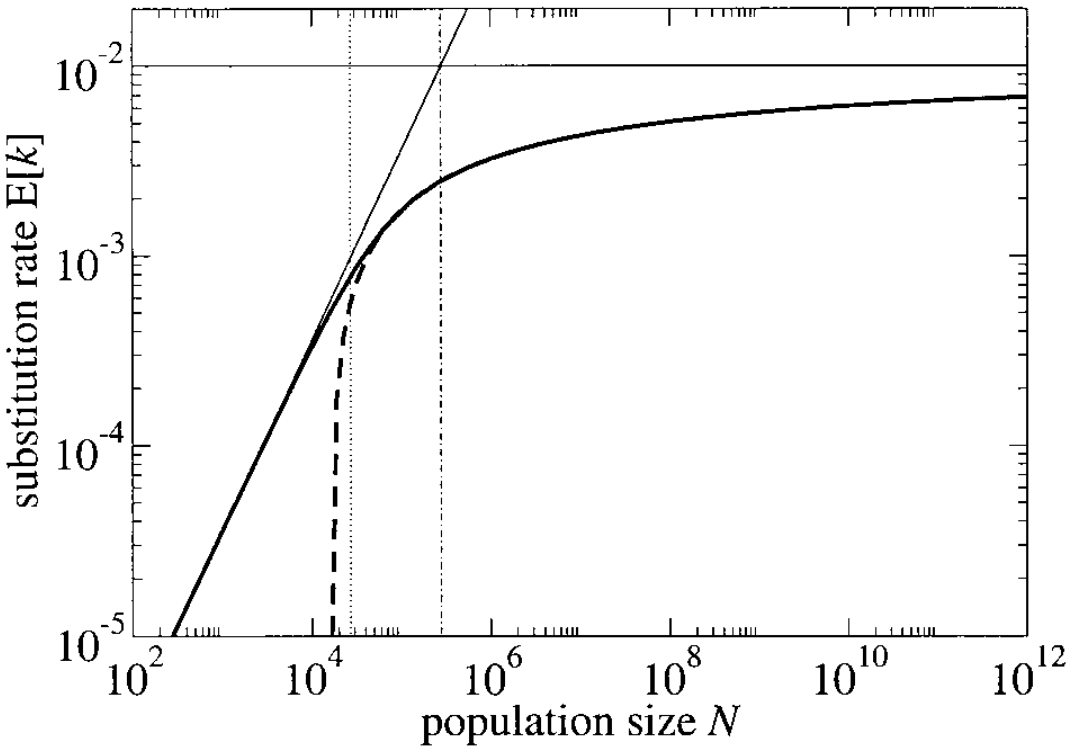
Plasticity and ecological tolerance

Size of selective advantage of new mutations

History of past natural selection

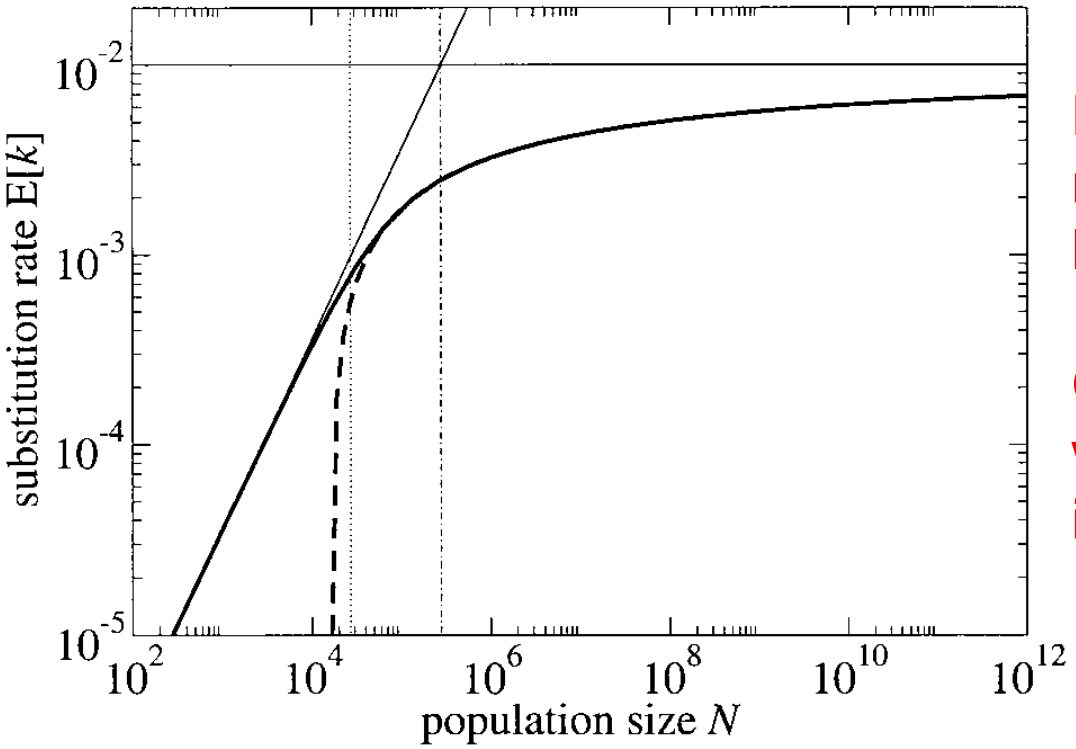
How do species interactions affect evolution?

2) Species interactions affect population size



How does species diversity affect evolution?

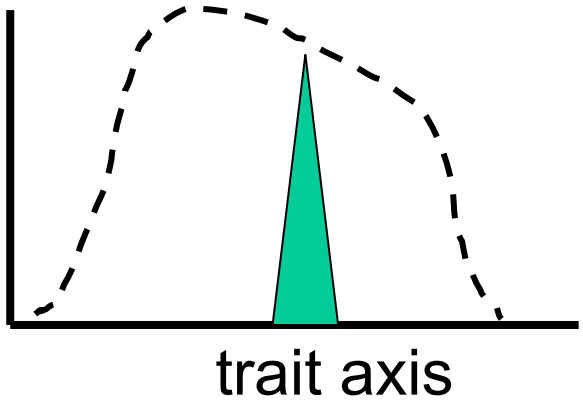
2) Species interactions affect population size

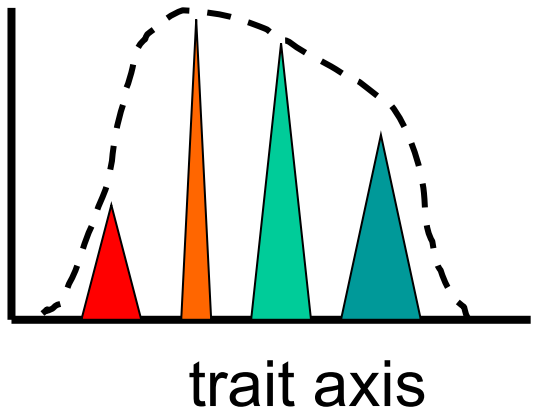


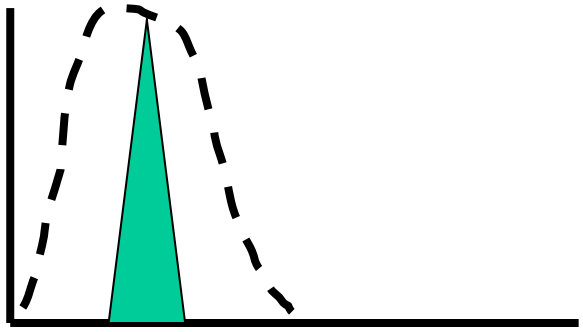
Not clear that species in more diverse communities have lower genetic variation

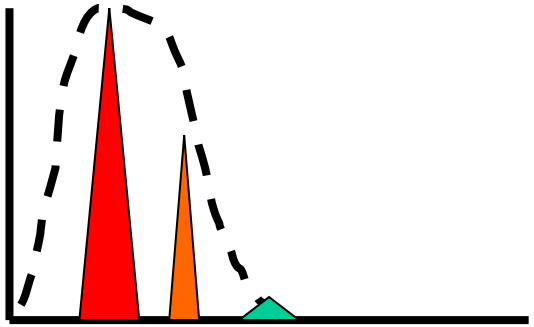
Could predict evolution with single species theory if knew population sizes

3) Ecological sorting inhibits evolution

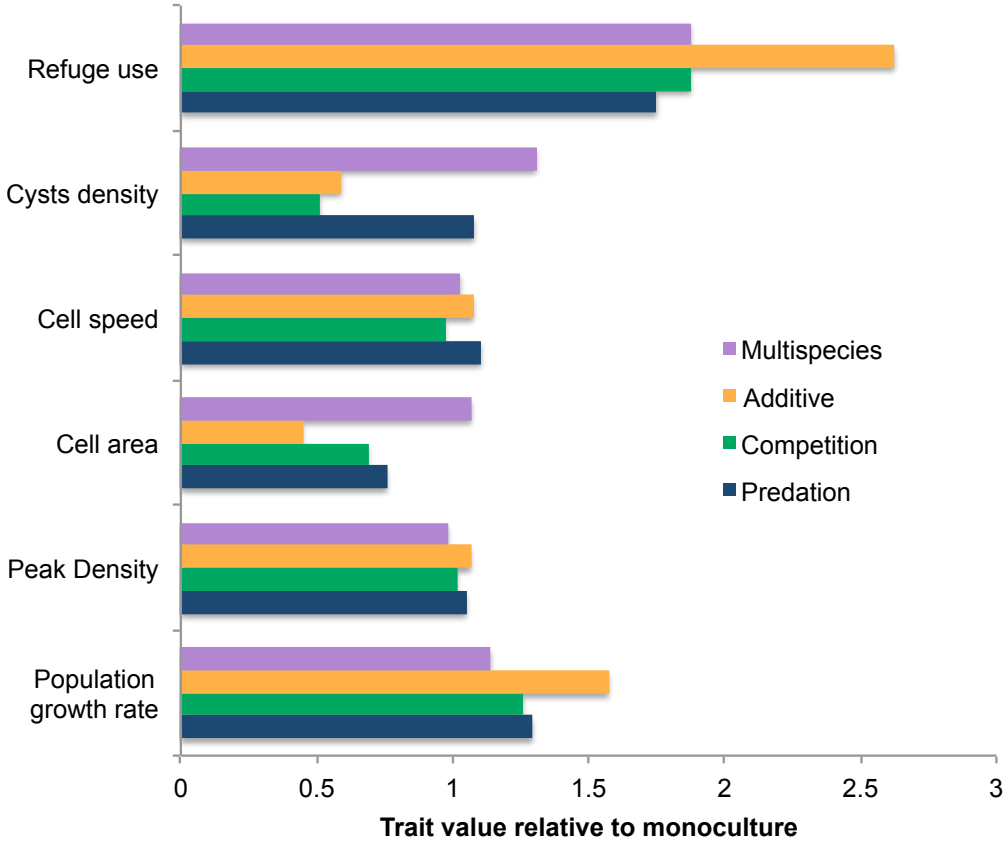








4) Coevolution promotes evolution



terHorst CP. 2010. Evolution in response to direct and indirect ecological effects in pitcher plant inquiline communities. *Am Nat* 176: 675-85

Qu. 1: How do species interactions affect evolution?

1) No effects of species interactions
2) Species interactions change population sizes and evolutionary rates
3) Ecological sorting inhibits evolution
4) Species interactions promote coevolution
5) Interference between adaptation to biotic and abiotic
6) Horizontal transfer promotes evolution

Can we produce general theory and evidence akin to single species?

Barraclough T.G. 2015. How do species interactions affect evolutionary dynamics across whole communities? Ann. Rev. Ecol. Evol. System.

Qu. 2: Does evolution affect functioning?

Enhances:

Species evolve new functions

Selection increases rate or efficiency of resource use

Specialisation increases collective use of resources

Impairs:

Species evolve to destabilize community, e.g. antagonism

No effect:

Functional redundancy or evolution constrained

Barraclough T.G. 2015. How do species interactions affect evolutionary dynamics across whole communities? Ann. Rev. Ecol. Evol. System.

A) Theory

Need model with the following features:

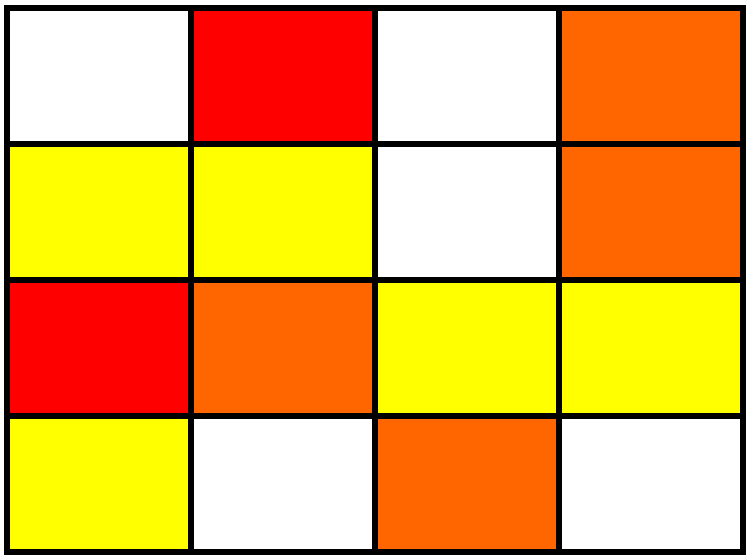
i) Set of co-occurring species (mechanism for coexistence)

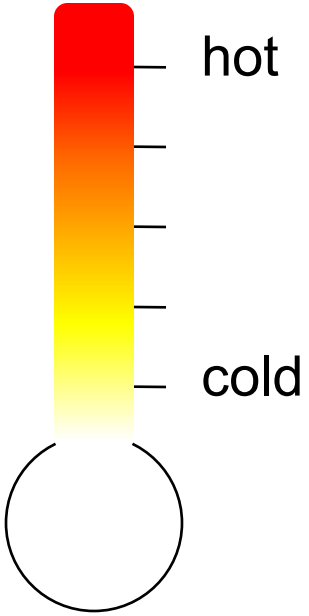
ii) Species traits that determine match to environment

iii) Those traits can evolve (mutation)

iv) Change in environment

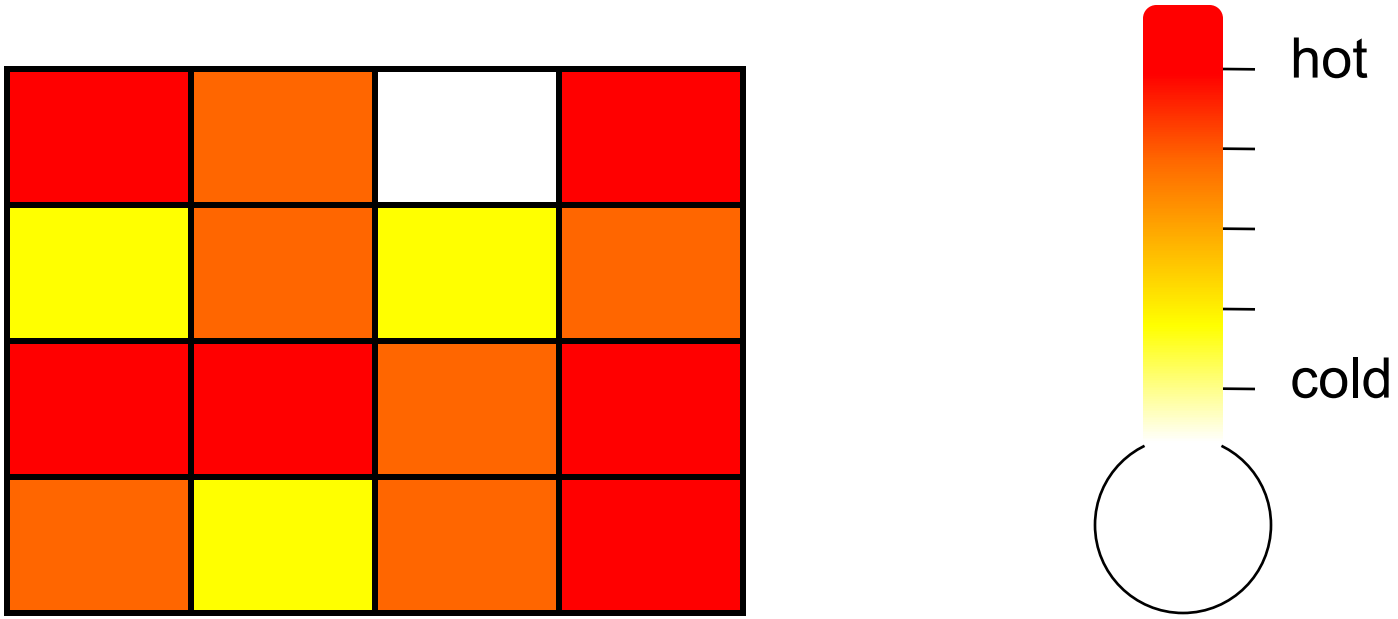
Discrete habitat patches linked by dispersal





De Mazancourt, Johnson, Barraclough 2008. Biodiversity inhibits species' evolutionary responses to environmental change. *Ecology Letters*. 11:380-388.

Discrete habitat patches linked by dispersal



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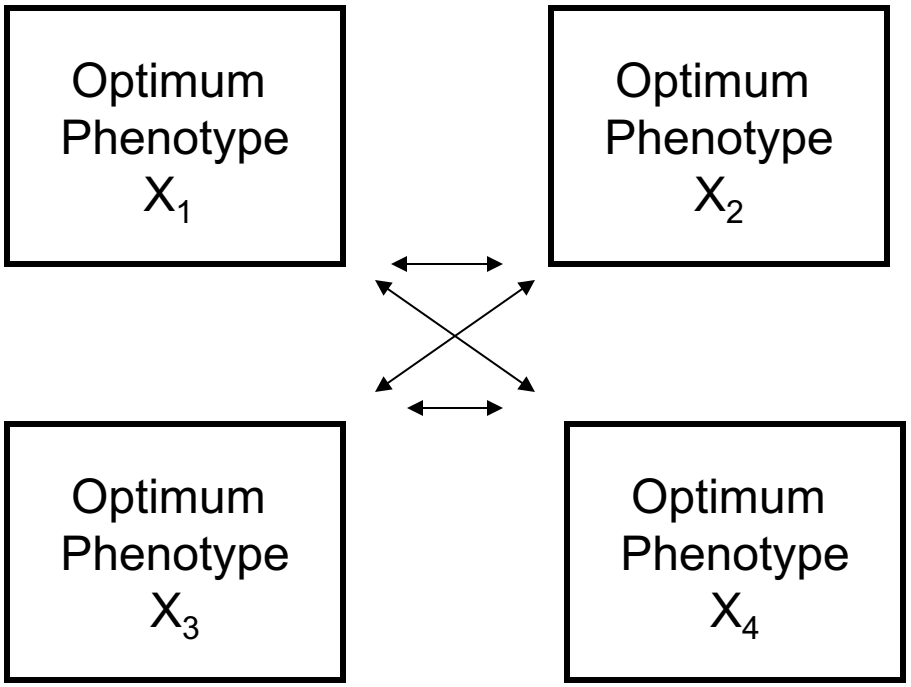
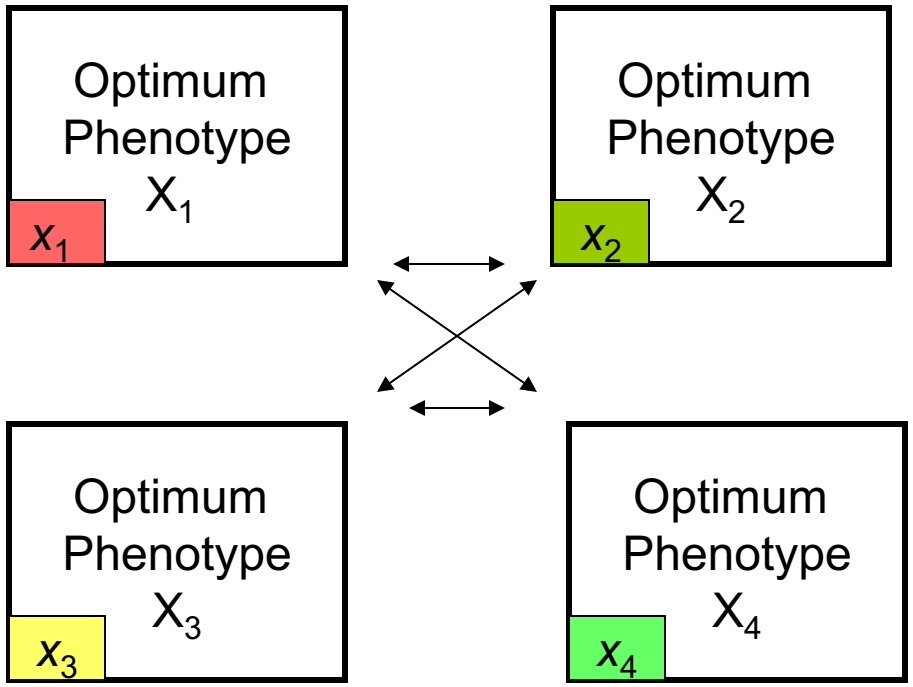
De Mazancourt et al. 2008

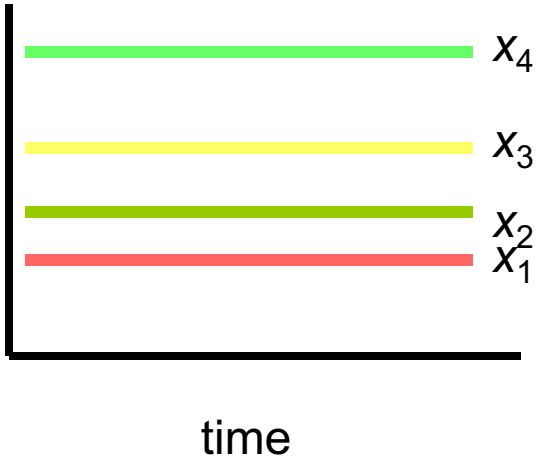
Levene model with discrete habitat patches linked by dispersal



De Mazancourt et al. 2008

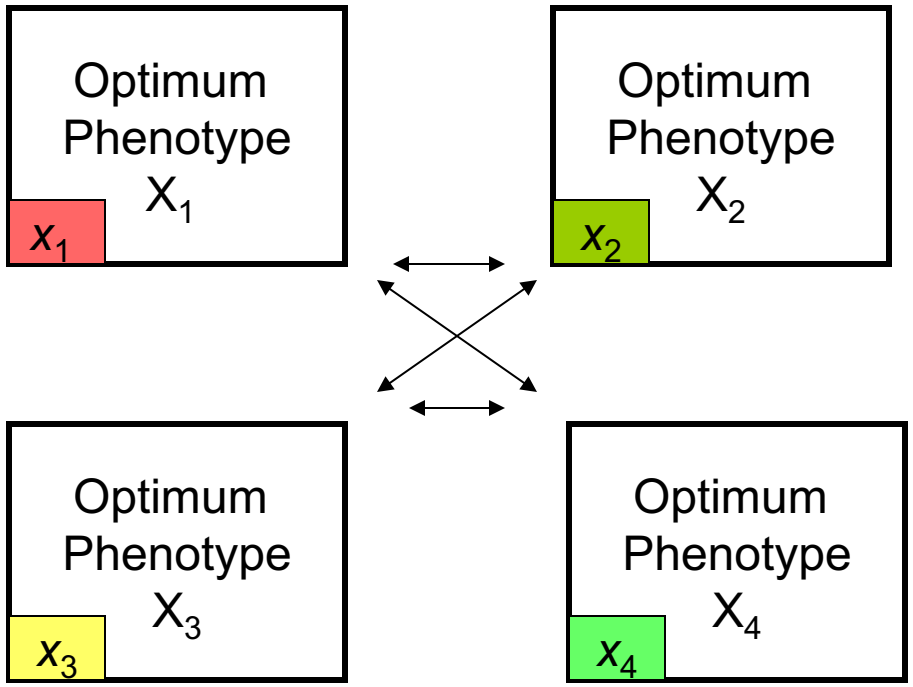
Levene model with discrete habitat patches linked by dispersal
Populate with species adapted to each habitat type
(stabilizing selection)

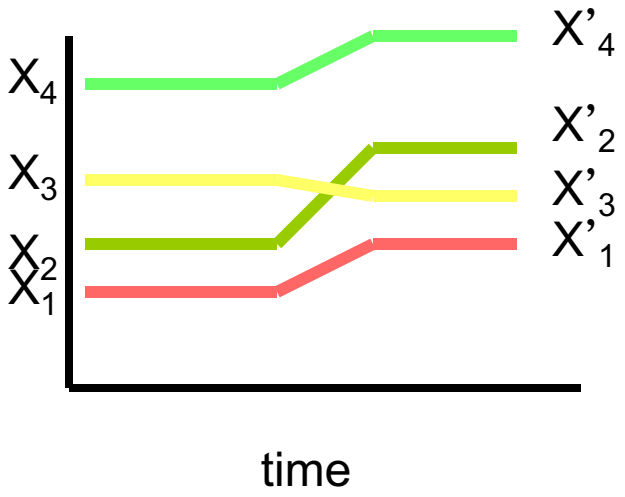




De Mazancourt et al. 2008

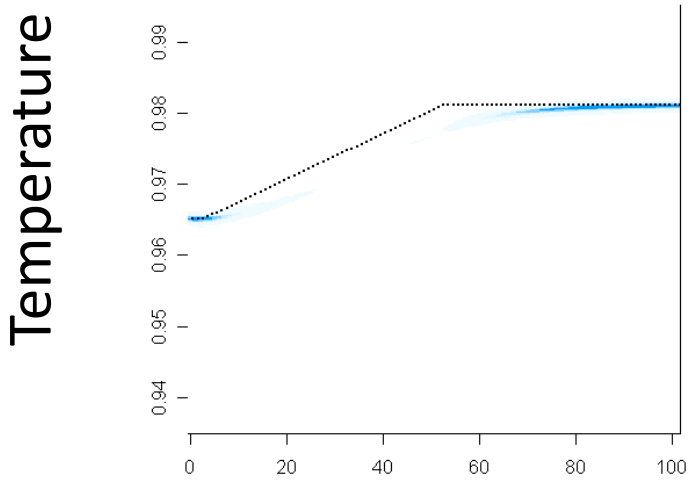
Levene model with discrete habitat patches linked by dispersal
Populate with species adapted to each habitat type
Change in environment; phenotype can evolve





Hypothetical example: plant species inhabiting range of habitats (relief; local water availability) in a region affecting By global increase in temperature, decreased rainfall

A) Single species in homogeneous environment affected by global warming



T_{new}

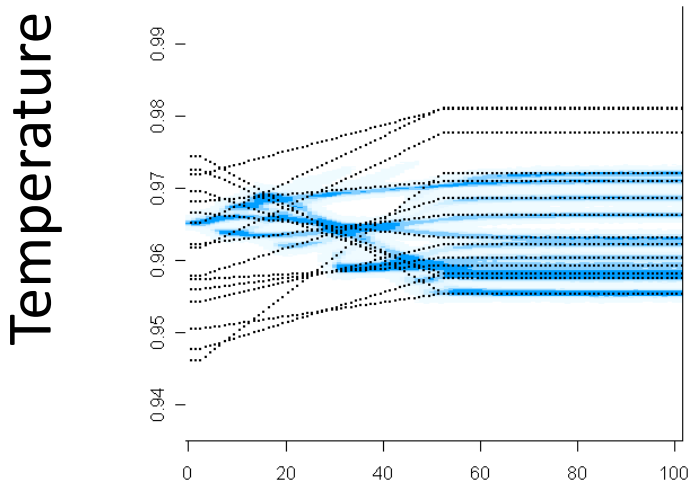
T_{old}

Species adapts - just!

Blue = species phenotype

Dotted line = optimum phenotype, i.e. temperature of environment

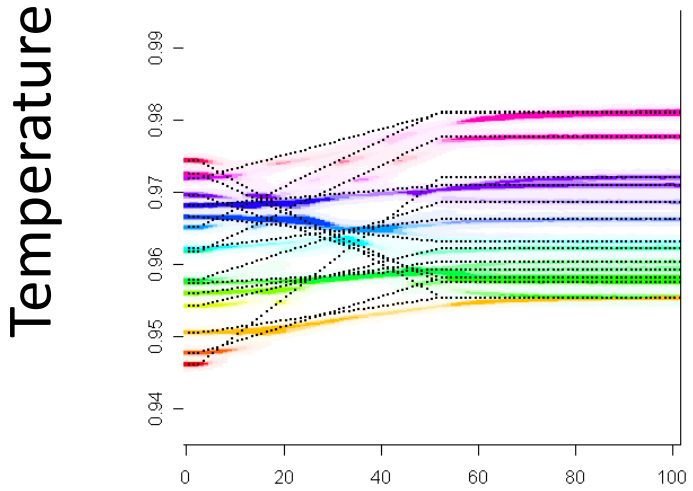
B) Same single species in patchy environment
affected by average global warming



Species diversifies

Patches = microhabitats, e.g. shady and sunny sites for plants

C) Multiple species in patchy environment affected by average global warming

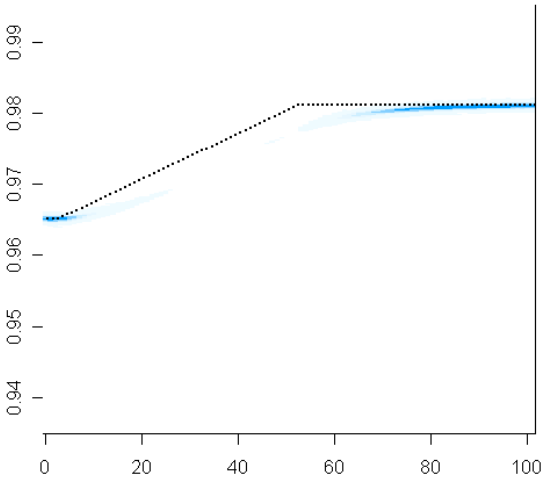


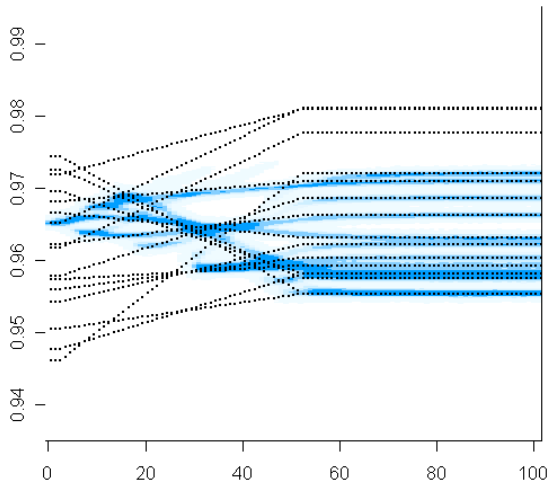
i) Species stay near original patch

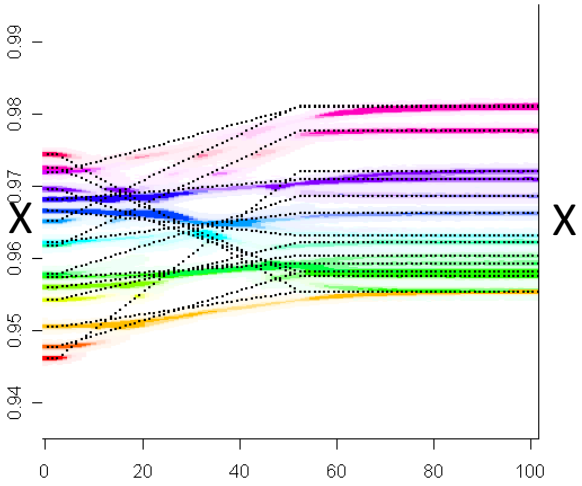
ii) Diversity inhibits evolution

Different colours = different species (16 altogether)

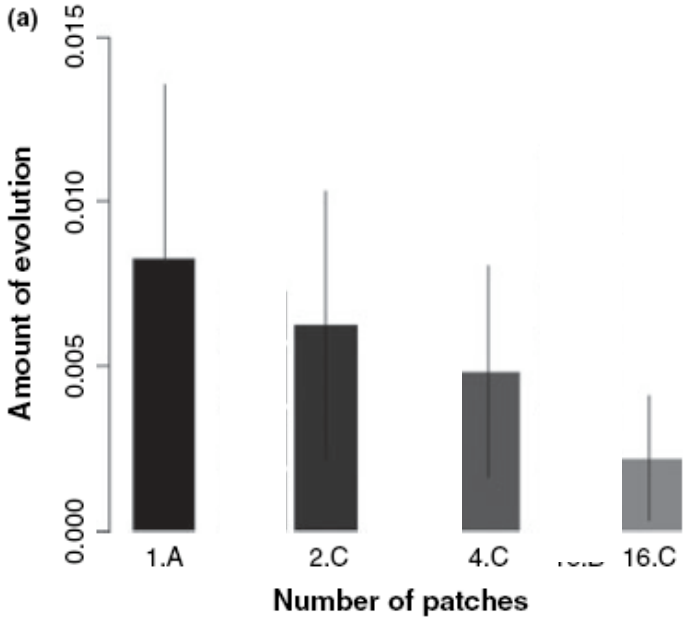
Blue species inhibited to exhibit niche conservatism

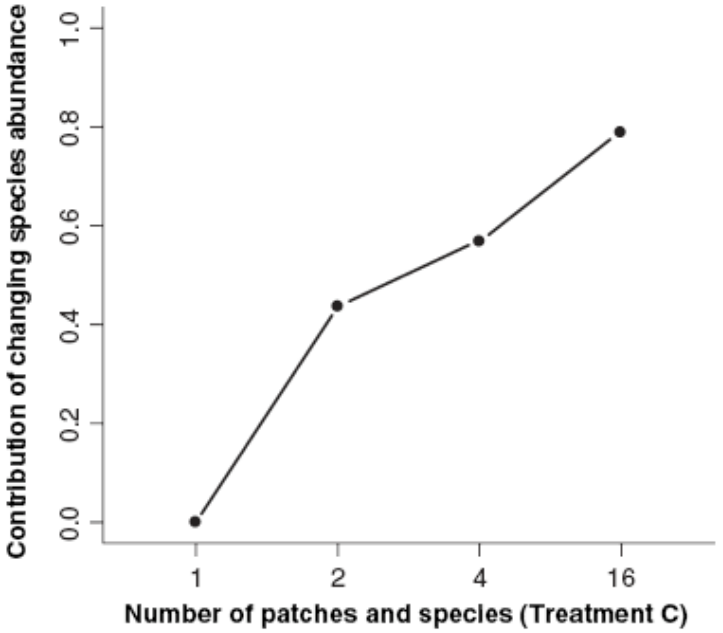






Conclusion:
Species diversity inhibits adaptation and diversification





B) Evidence

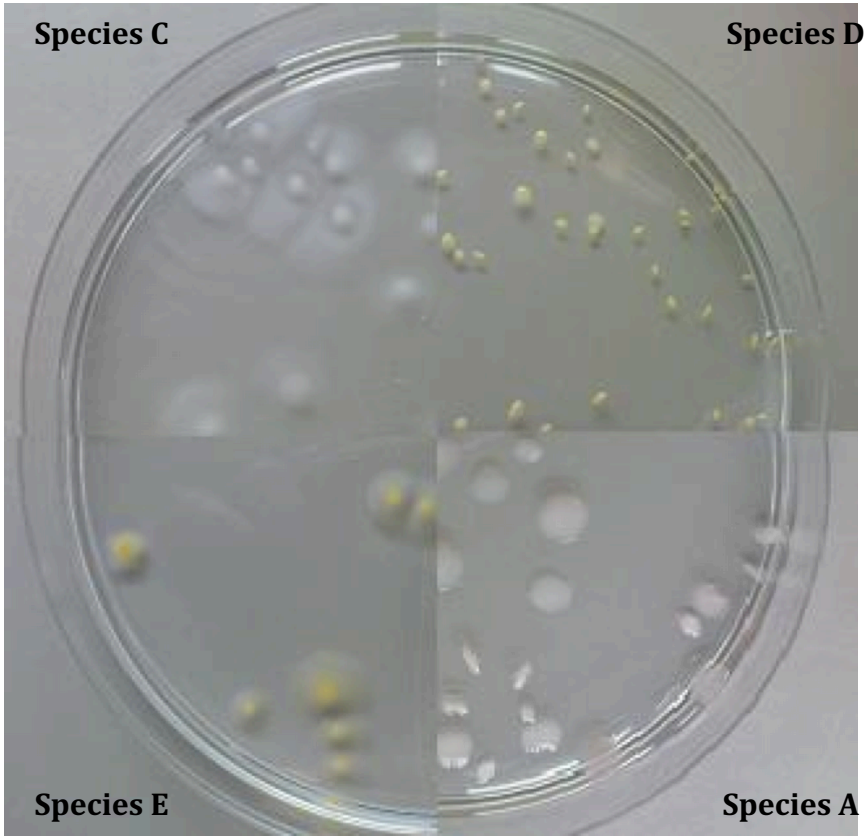
Construct simplified communities, manipulate conditions, track evolution: experiments with tree-hole bacteria

Bacteria from beach tree-holes:

- culture on beech tea in the lab
- rapid generation times
- diverse communities

The Experiment:

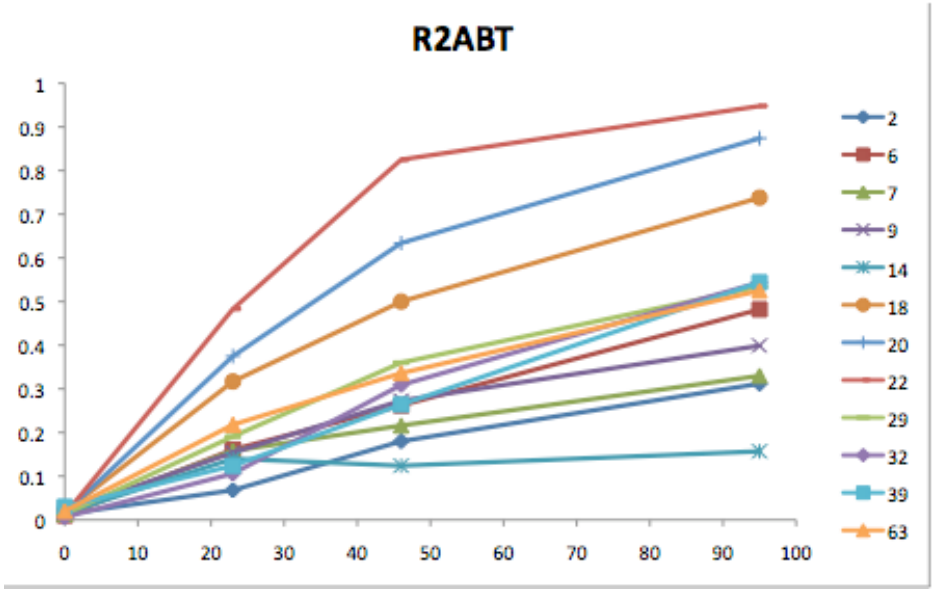
1) Isolate species from tree-hole extracts



The Experiment:

1) Isolate species from tree-hole extracts

2) Choose 5 species that grow in beech tea



The Experiment:

1) Isolate species from tree-hole extracts

2) Choose 5 species that grow in beech tea

3) Store initial strains at -80

The Experiment:

1) Isolate species from tree-hole extracts

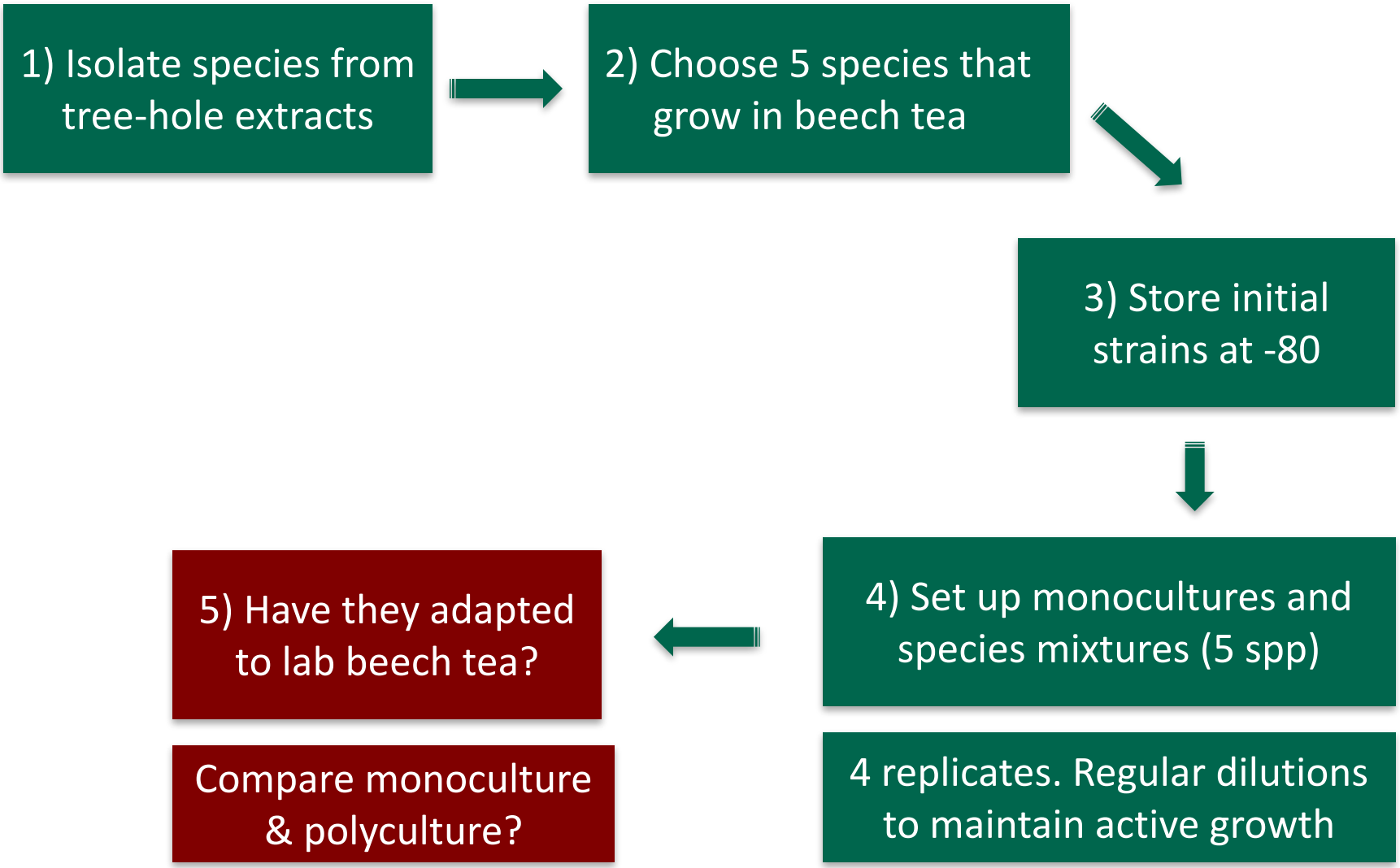
2) Choose 5 species that grow in beech tea

3) Store initial strains at -80

4) Set up monocultures and species mixtures (5 spp)

4 replicates. Regular dilutions to maintain active growth

The Experiment:

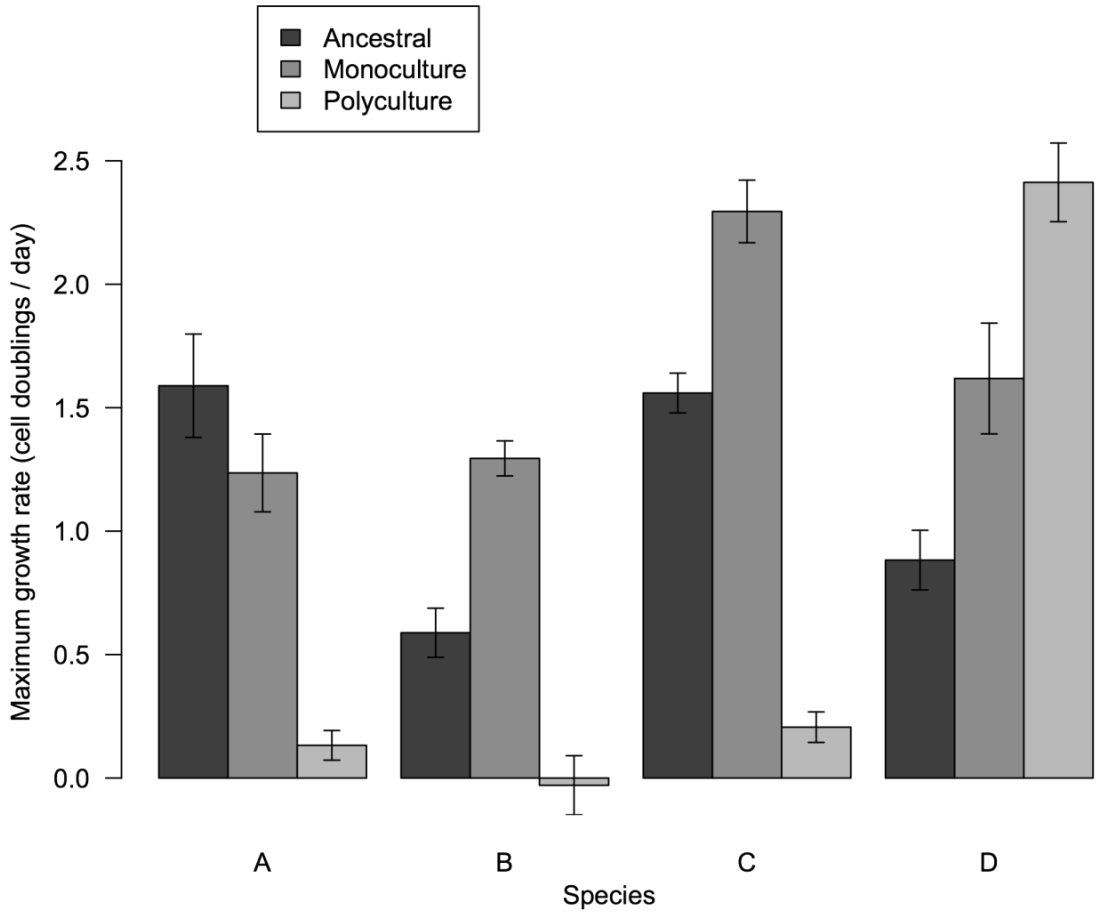


Measuring evolution and its consequences:

- Growth rates on beech tea (abiotic conditions)
- Growth rates on used beech tea (interactions)
- NMR spectra of used and unused tea (resources)
- Productivity of coevolved communities

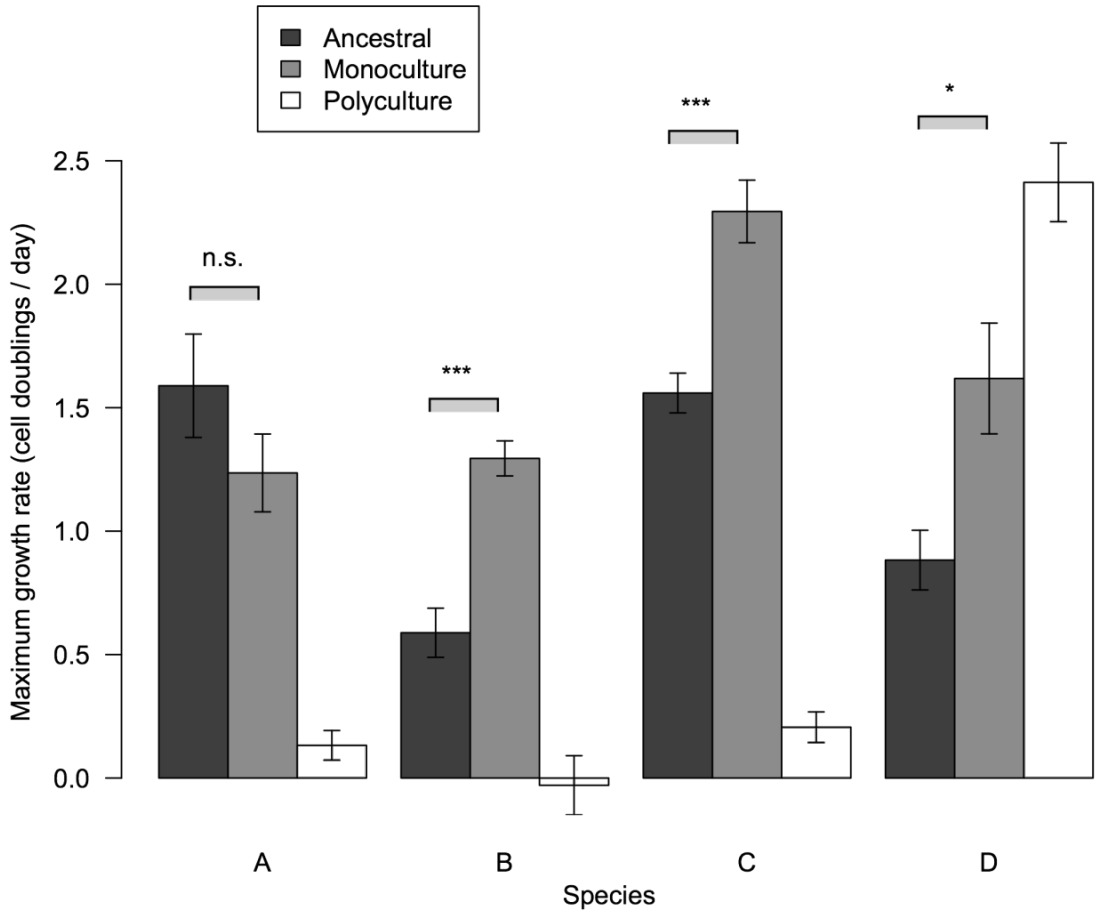
Diane Lawrence et al. 2012. Species interactions alter evolutionary responses to environmental change. PLoS Biology 10: e1001330

Adaptation to new environment



Growth rate of species from different treatments grown alone in beech tea

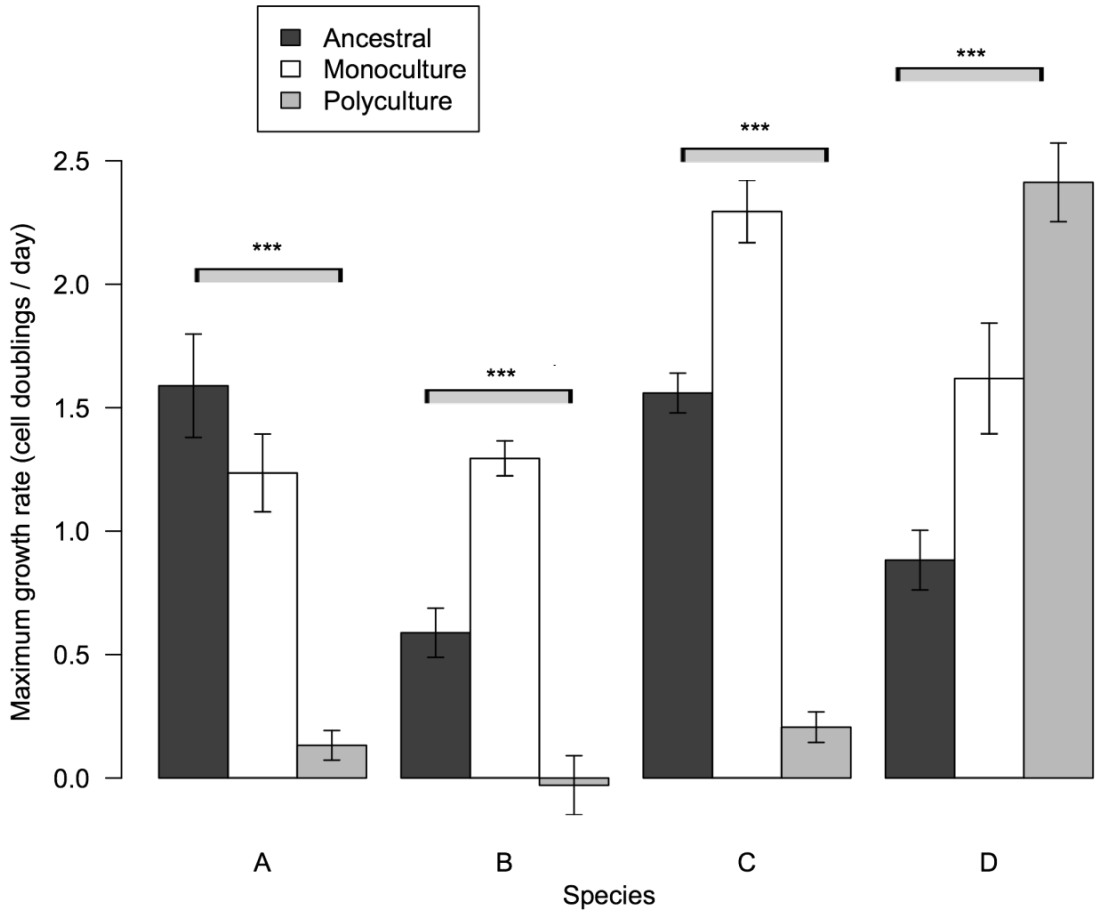
Adaptation to new environment



On average:

INCREASE in growth rate in MONOCULTURE

Adaptation to new environment



On average:

DECREASE in growth rate in POLYCULTURE

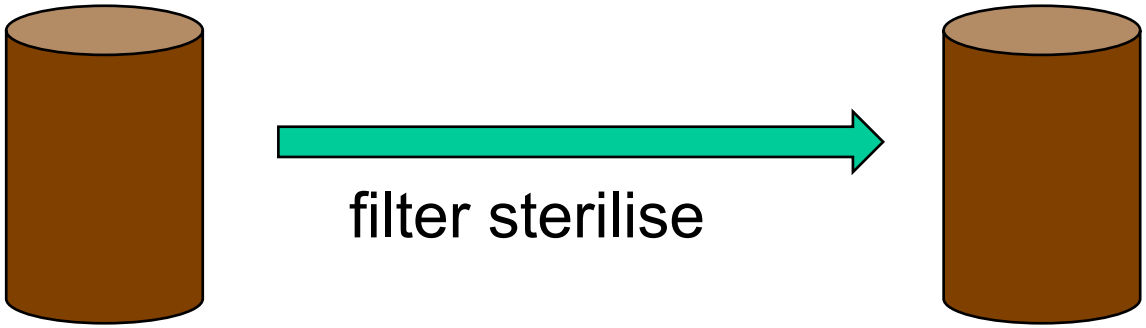
Conclusions

Trade-off between adapting to just physical environment and adapting to co-occurring species

How do species adapt to co-occurring species?

Evolution of species interactions

Grow bacteria on tea previously used by another bacterium

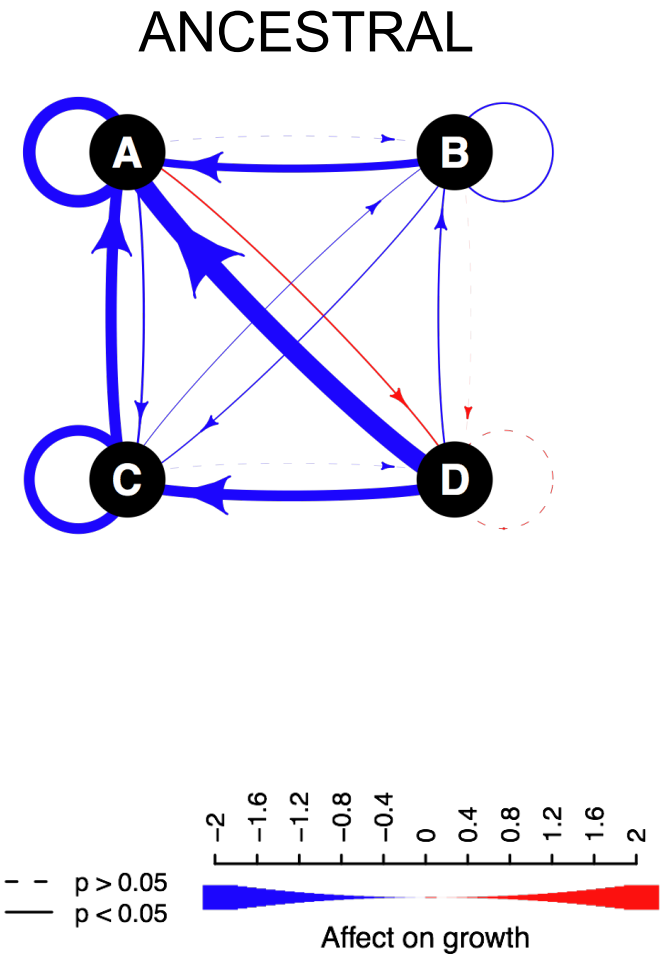


Grow bacterium A

Grow bacterium B

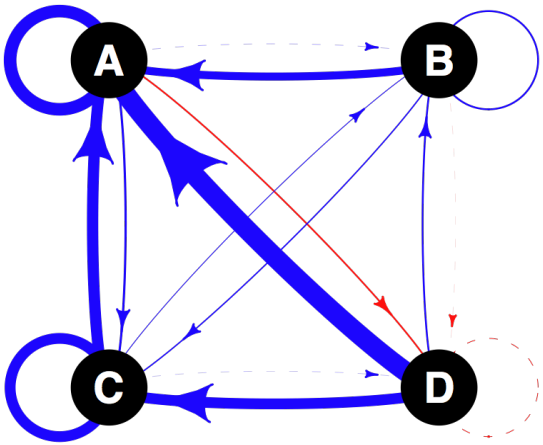
Negative interaction: grows worse than on raw tea
Positive interaction: grows better…

Evolution of species interactions

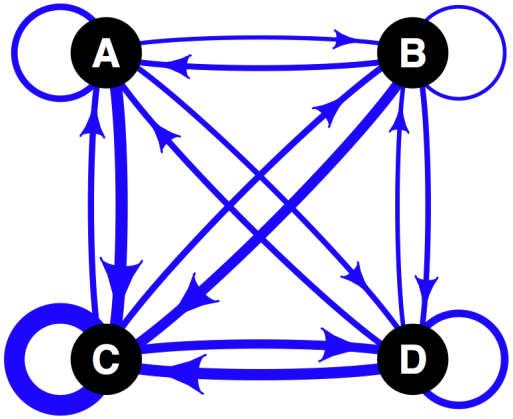


Evolution of species interactions

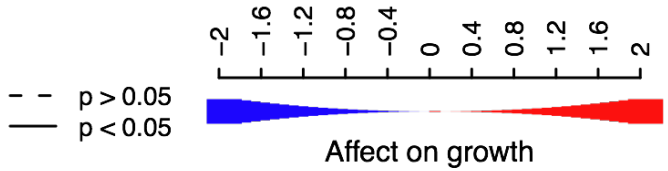
ANCESTRAL



MONOCULTURE

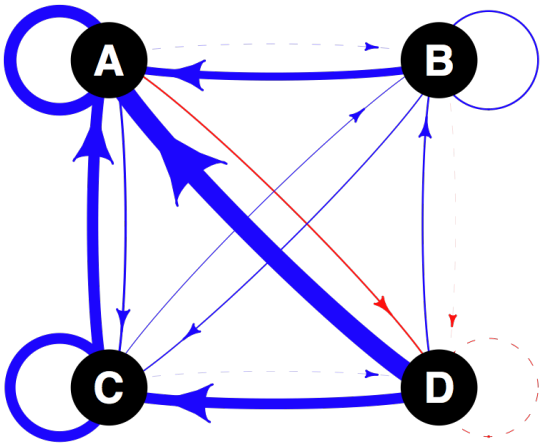


Evolve to use similar resources

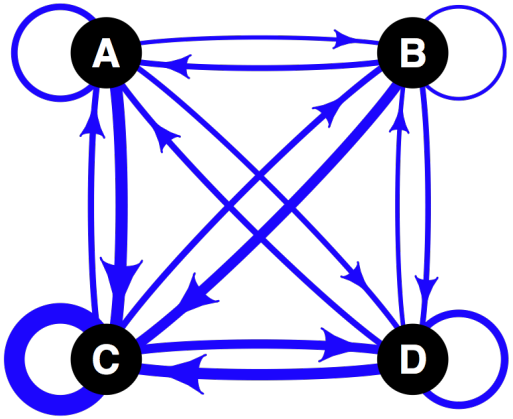


Evolution of species interactions

ANCESTRAL

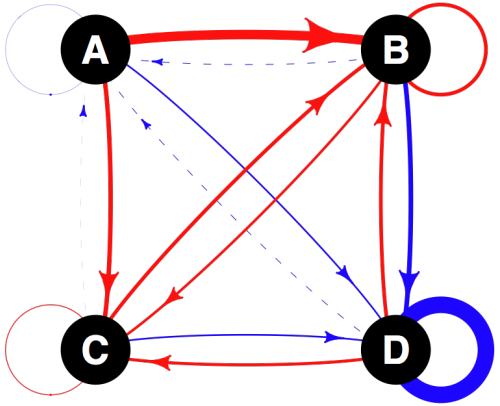


MONOCULTURE

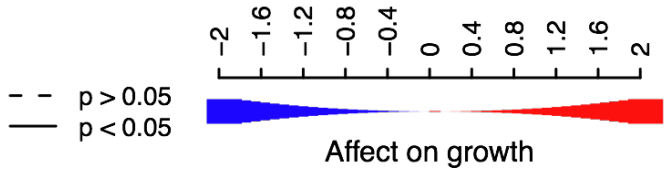


Evolve to use similar resources

POLYCULTURE



Evolve positive interactions: Cross-feeding?



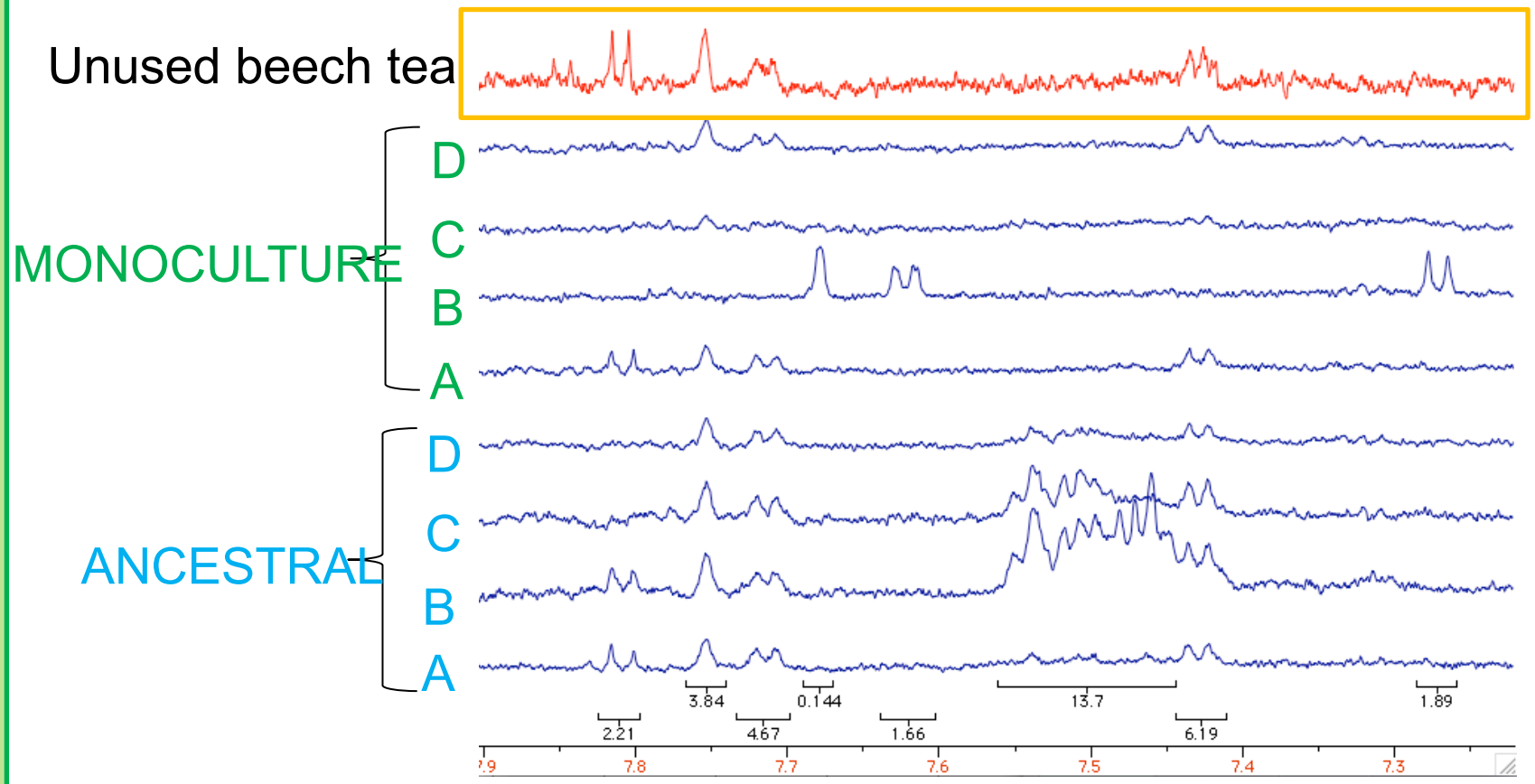
Conclusions

Trade-off between adapting to just physical environment and adapting to co-occurring species

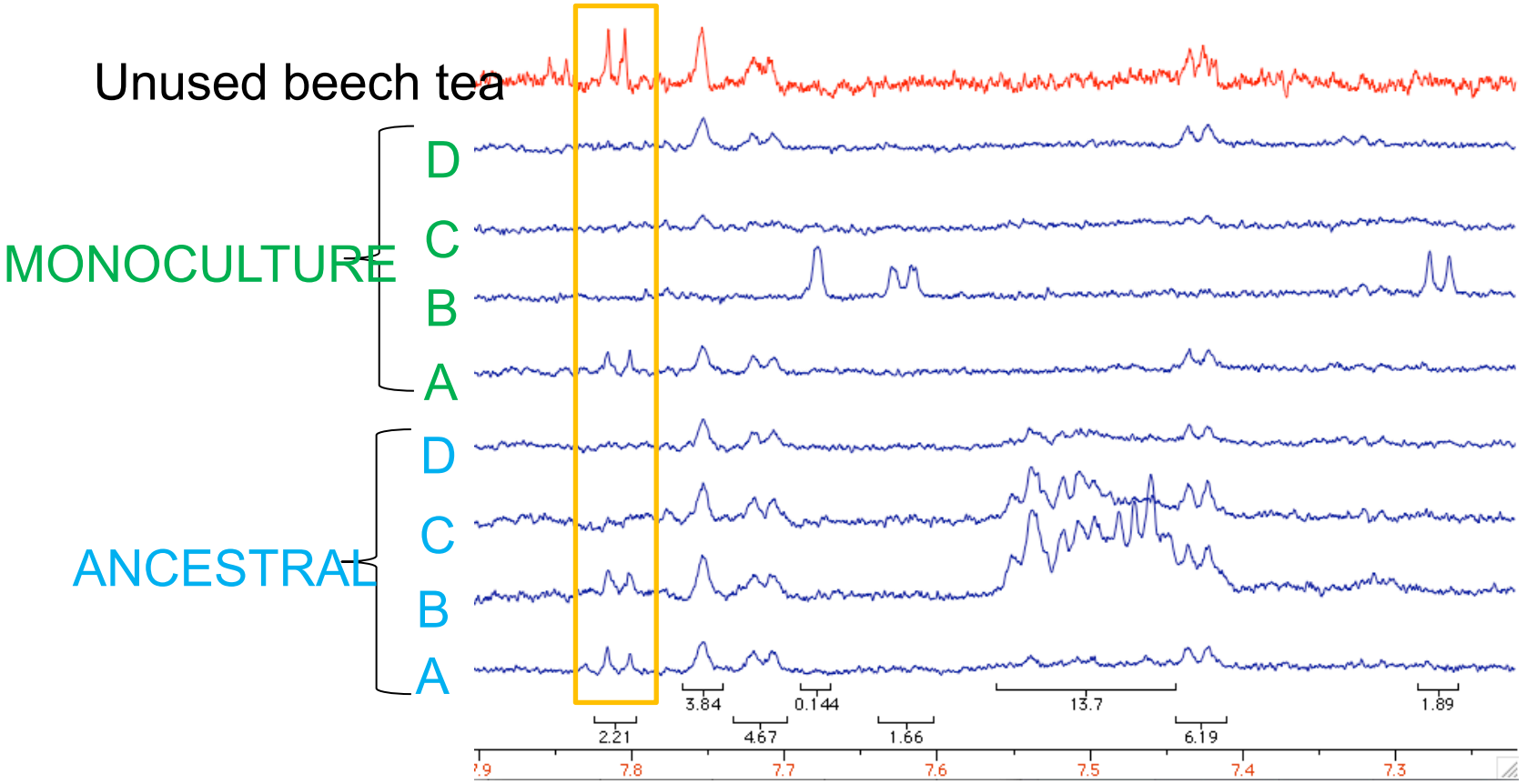
Species in communities evolve more positive interactions

Metabolism or signaling molecules?

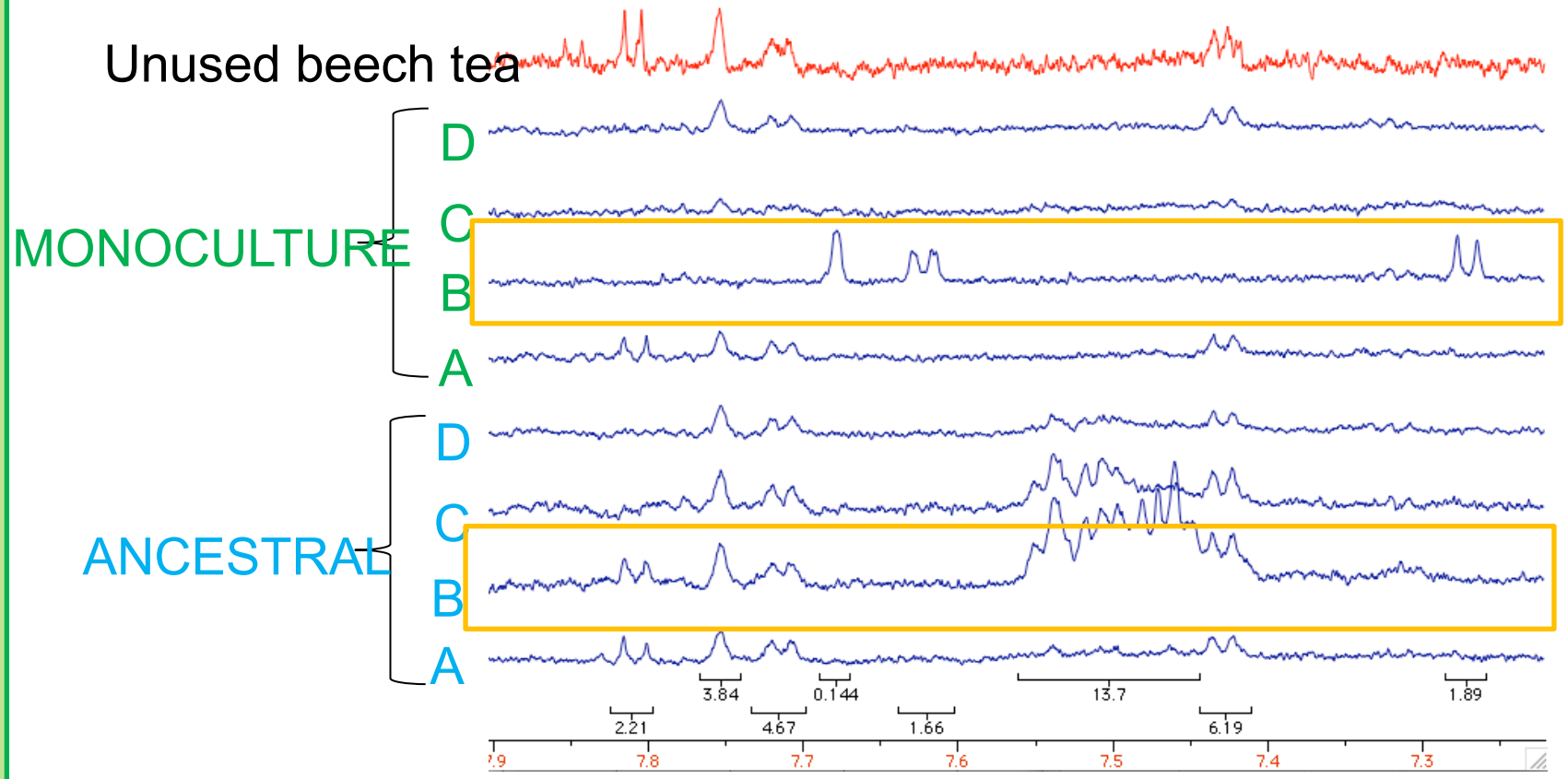
Analysis of Beech Tea



Analysis of Beech Tea



Analysis of Beech Tea

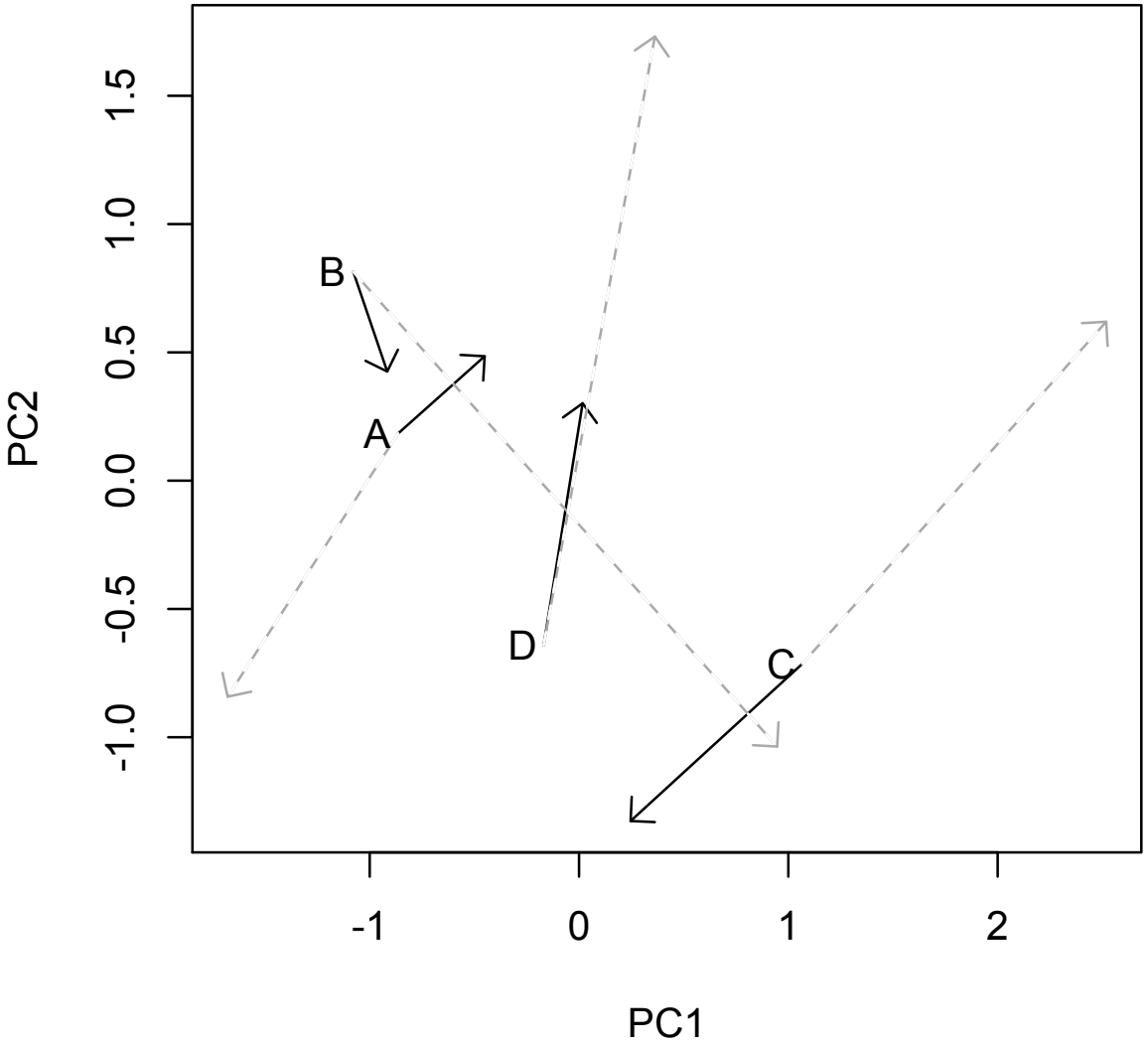


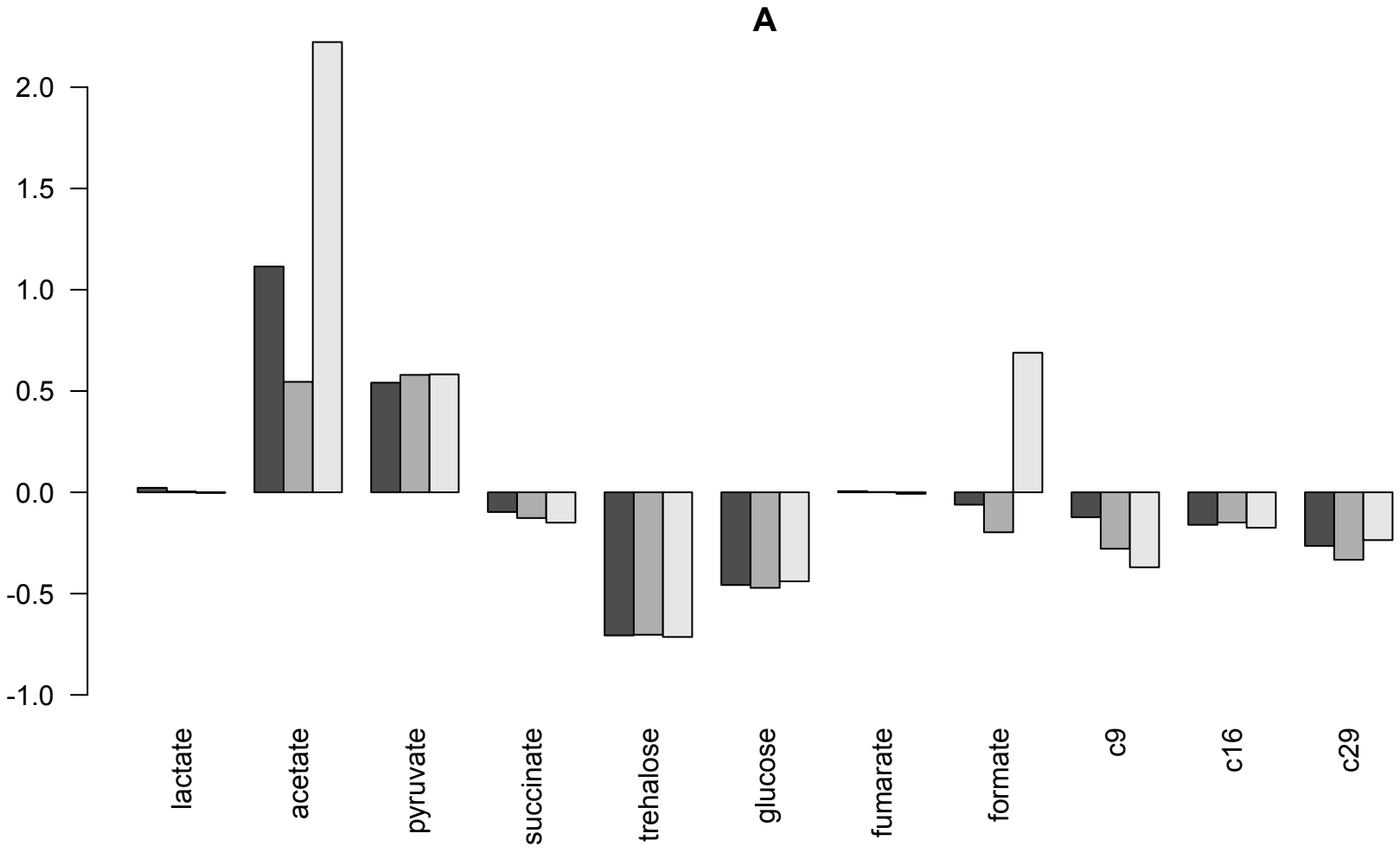
NMR results

Resource use evolves

More in polyculture than monoculture

Greater differences among species

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2.0
1.5
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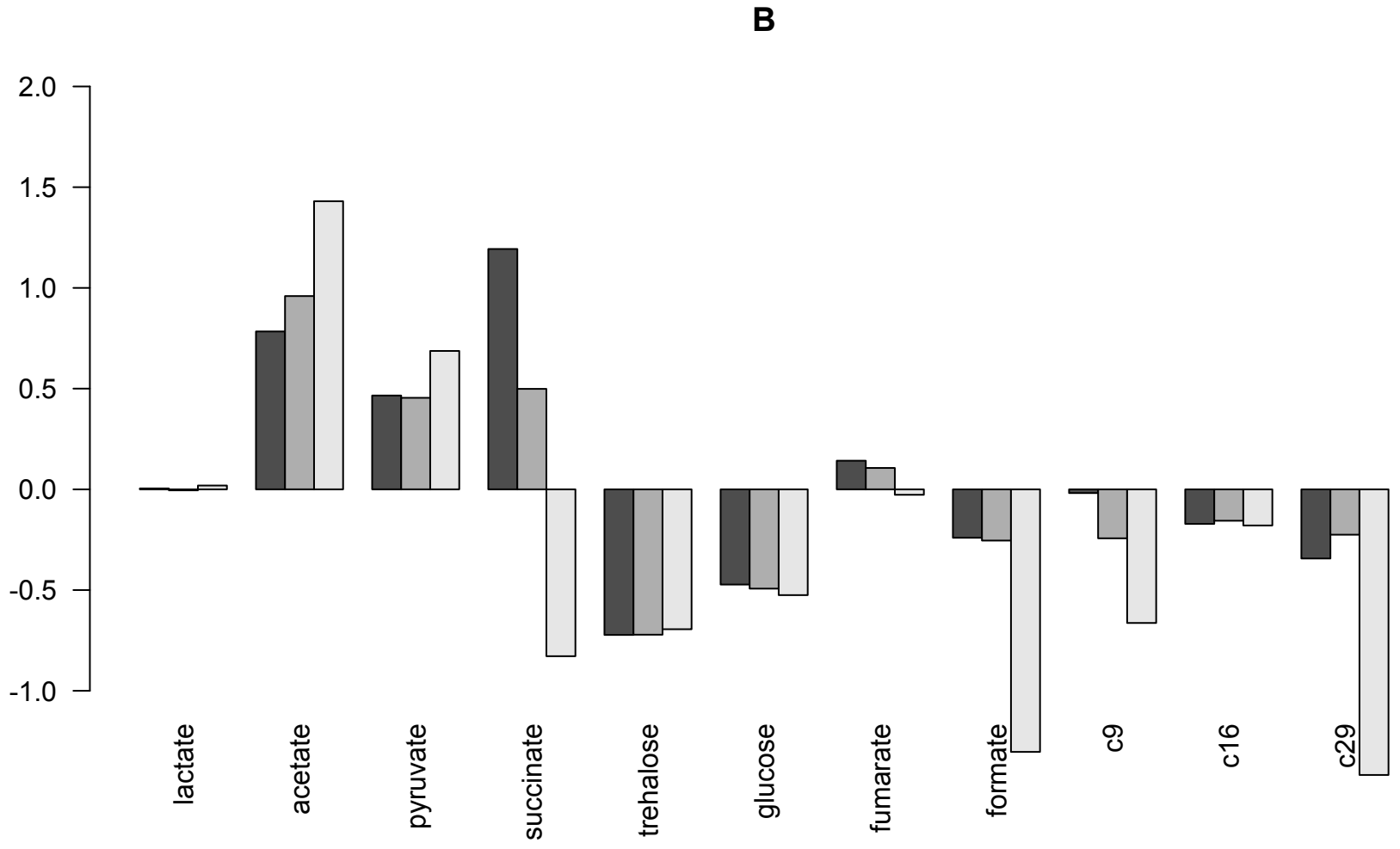
-1.0
lactate
acetate
pyruvate
succinate
trehalose
glucose
fumarate
formate
c9
c16
c29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1.5
1.0
0.5
0.0
-0.5
-1.0
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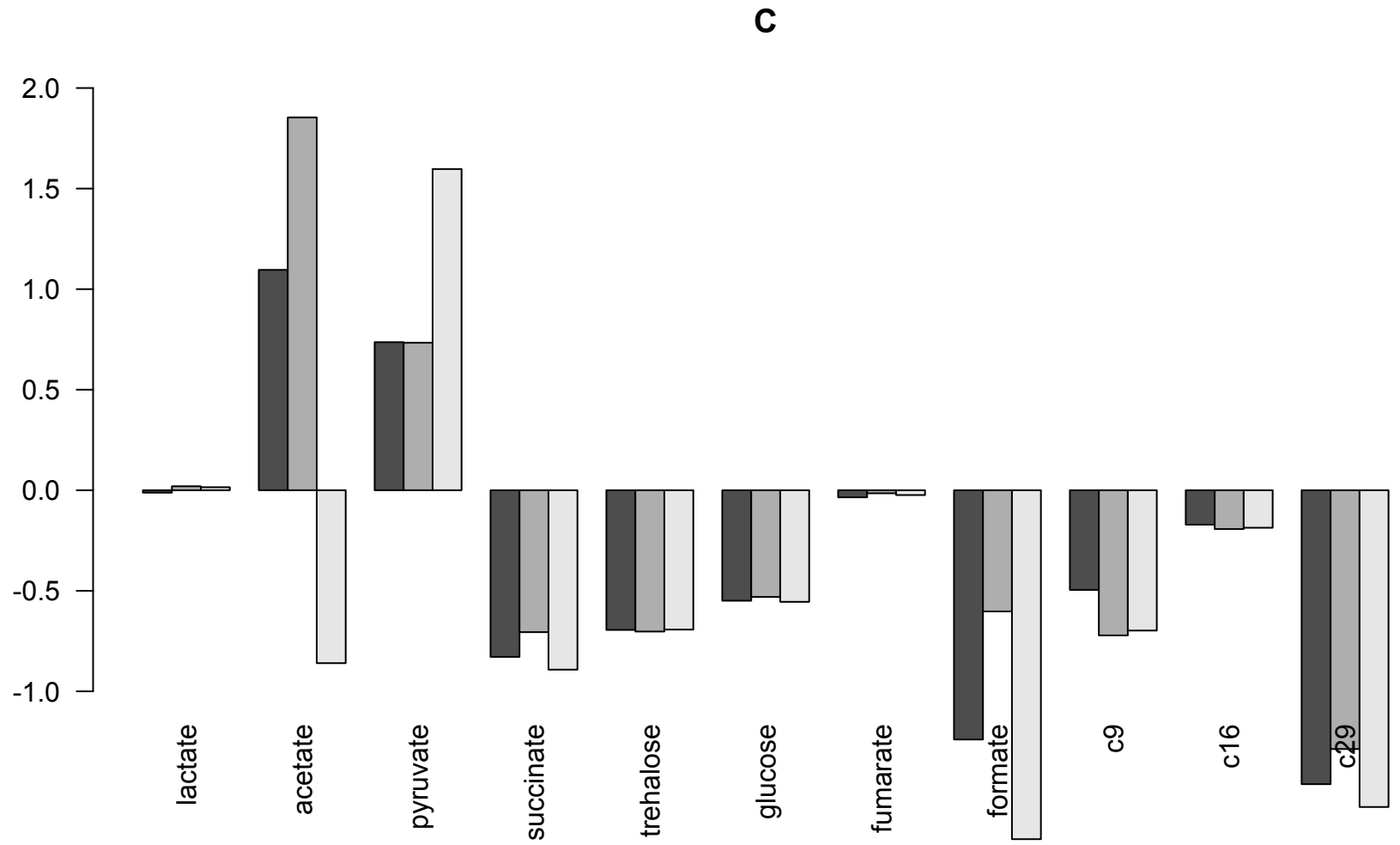
acetate
pyruvate
succinate
trehalose
glucose
fumarate
formate
c9
c16
c29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1.0
0.5
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-0.5
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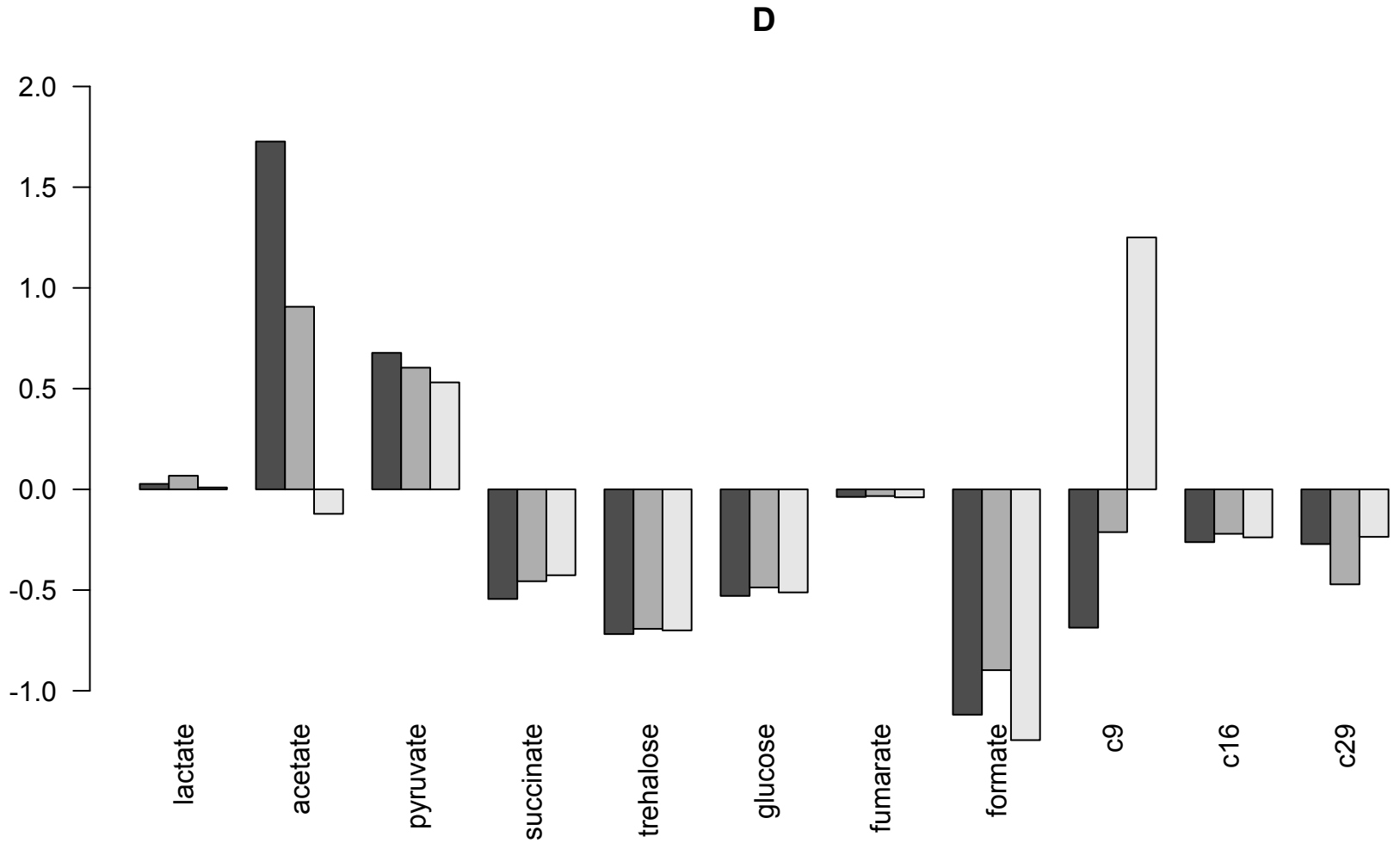
lactate
acetate
pyruvate
succinate
trehalose
glucose
fumarate
formate
c9
c16
c29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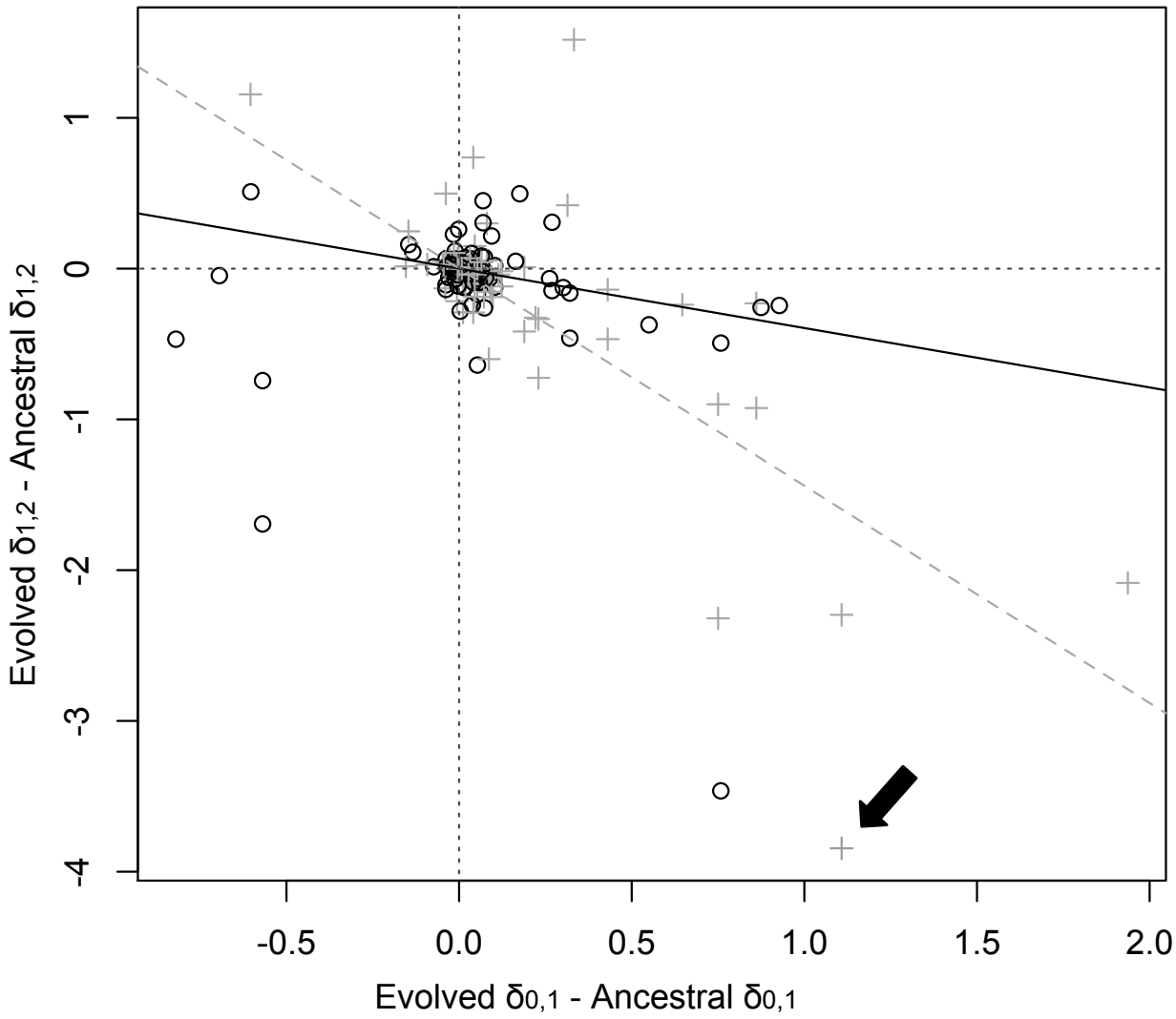
-0.5
-1.0
lactate
acetate
pyruvate
succinate
trehalose
glucose
fumarate
formate
c9
c16
c29

Species in polyculture evolved greater use of waste products being produced in greater amounts by other species



NMR results

1) More evolution in community than monoculture

2) Significant increase in variation in resource use

3) Evolved to use waste products of other species

Conclusions

Trade-off between adapting to just physical environment and adapting to co-occurring species

Species in communities evolve more positive interactions

Caused by evolving resource use

Conclusions

Species interactions increase amount of evolution and change direction => couldn't predict from single species

Resource partitioning and cross-feeding

Resulting changes enhance ecosystem functioning

Diane Lawrence, Francesca Fiegna, Volker Behrends, Jacob Bundy, Albert Phillimore, Thomas Bell, Timothy Barraclough 2012. Species interactions alter evolutionary responses to environmental change. *PLoS Biology* 10(5): e1001330

Overall conclusions

Model: species interactions inhibit evolution of component species due to ecological sorting

Experiment: species interactions promote evolution due to resource partitioning and cross-feeding

Why different results?

What conditions promote each outcome?