Mountain grassland dynamics: integrating phenotypic plasticity in a new agent-based model

Ph.D. defence of

Clément Viguier

realised under the supervision of

Björn Reineking

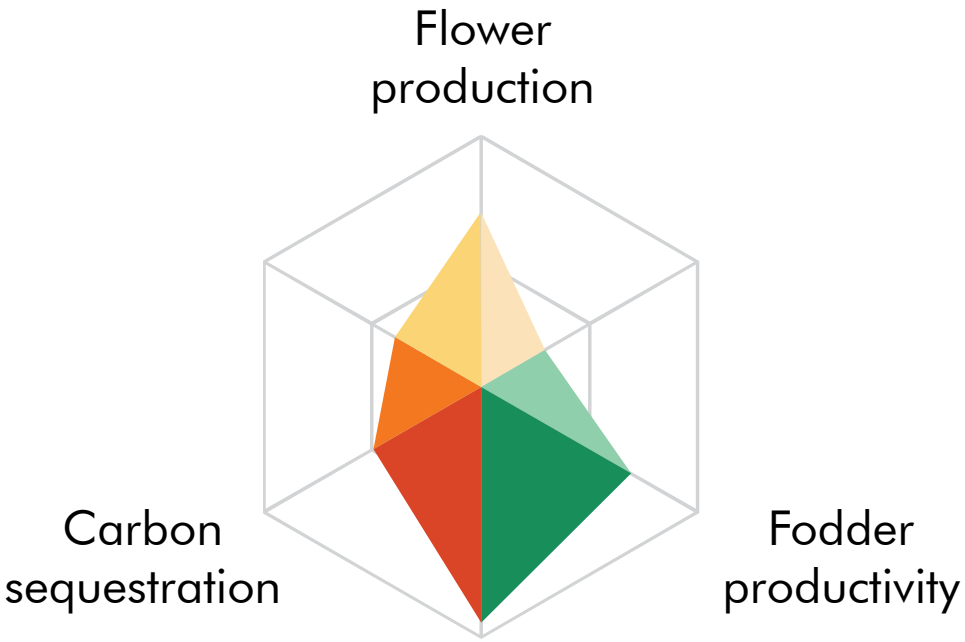
at IRSTEA Grenoble – LESSEM

Uta Berger	Marie-Laure Navas	Annabel Porte	François Munoz
Technische Universitat Dresden	Montpellier SUPAGRO	INRA – Université de Bordeaux	LECA – Université Grenoble Alpes
Rapporteur	Rapporteur	Examinatrice	Examinateur

1 Introduction

From context to questions

Mountain grasslands provide services

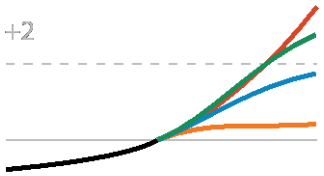


Various and depends on the properties of the community shape by environmental drivers

Assessing grassland ecosystem services

Drivers → Community structure → Summary statistics → Services

Climate



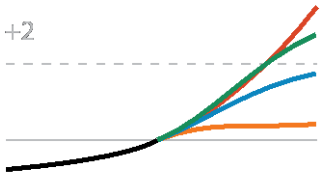
Land-use

Soil

Assessing grassland ecosystem services

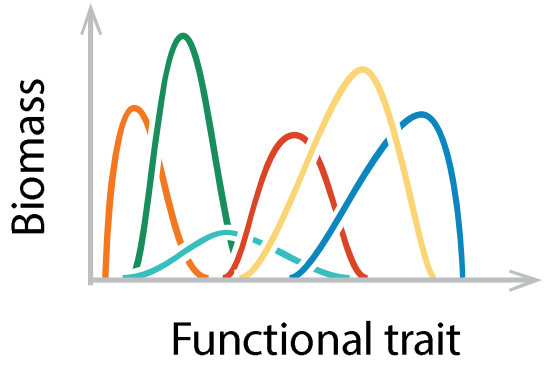
Drivers → Community structure → Summary statistics → Services

Climate



Land-use

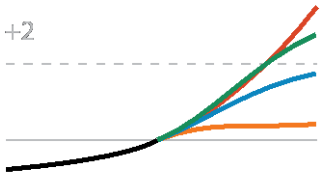
Soil



Assessing grassland ecosystem services

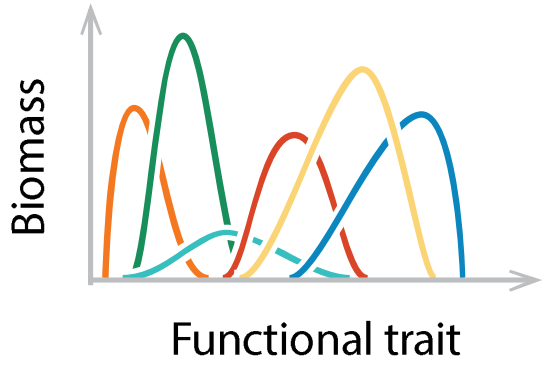
Drivers → Community structure → Summary statistics → Services

Climate



Land-use

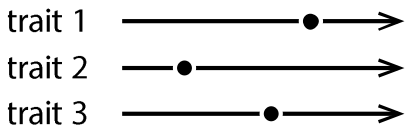
Soil



Diversity

Productivity Identity

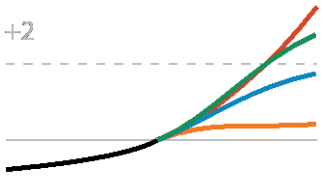
Trait CWMs



Assessing grassland ecosystem services

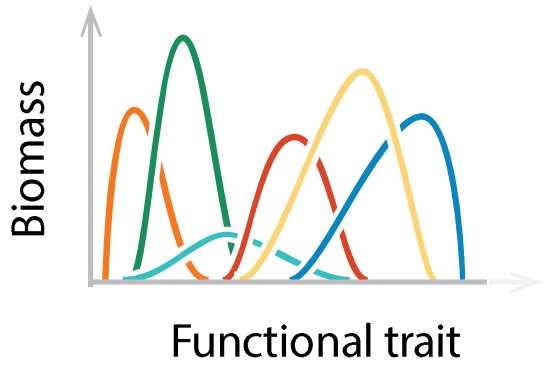
Drivers → Community structure → Summary statistics → Services

Climate



Land-use

Soil

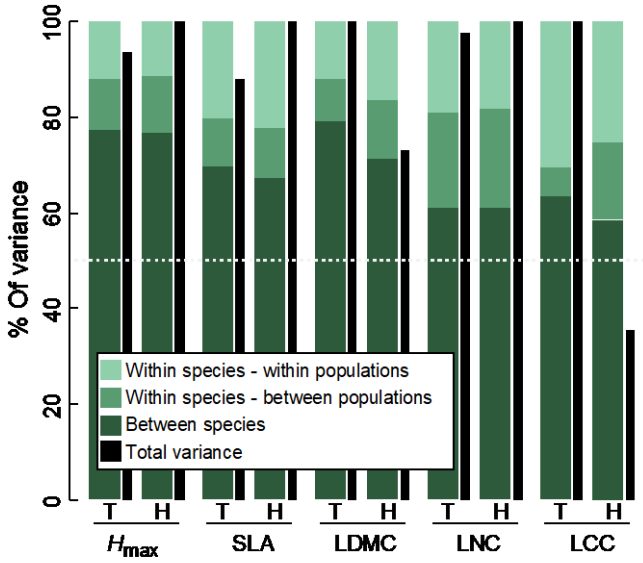


Diversity

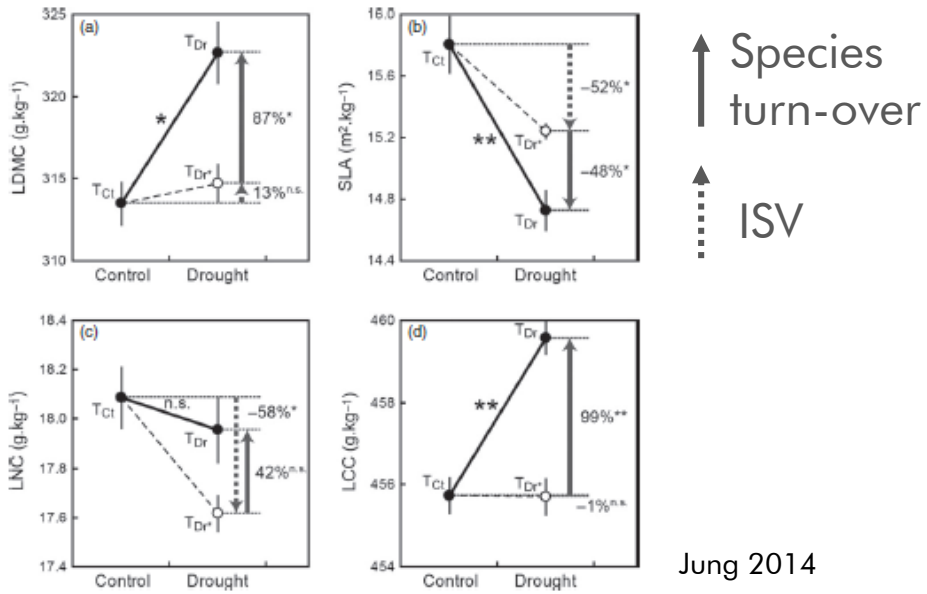
Productivity Identity

Trait CWMs

Intra-specific variability matters and impacts the community responses



Variance decomposition into the different levels.
From Albert and al. 2010.



Jung 2014

Up to 40% of the total variability of some traits.

Strong impact on community response

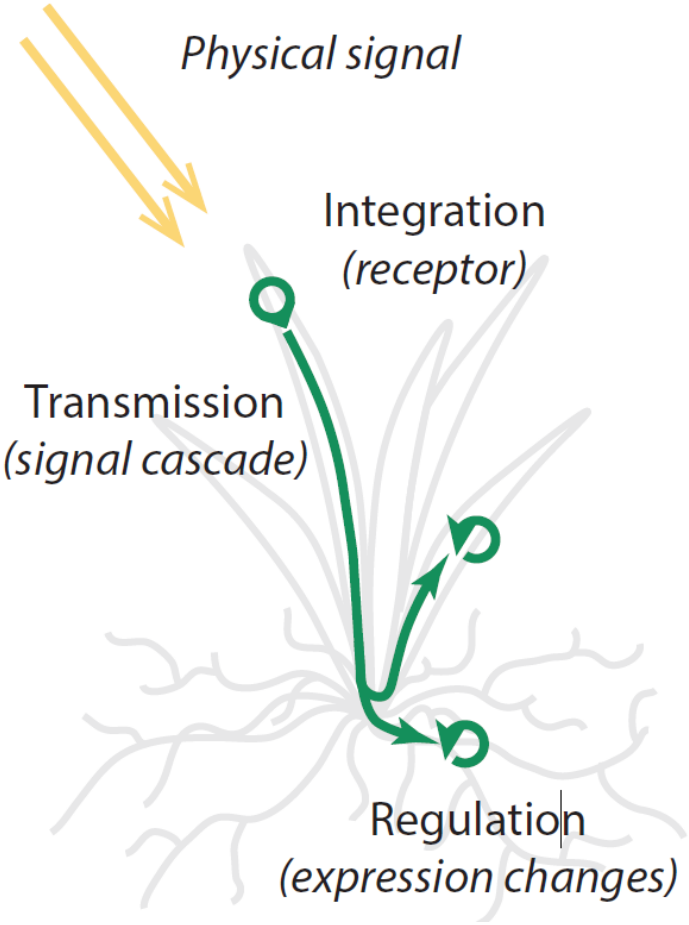
Should be considered in:

- ES assessments
- Dynamic models

The phenotypic plasticity: one source of variation

Genetic variation

Phenotypic plasticity



The phenotypic plasticity: one source of variation

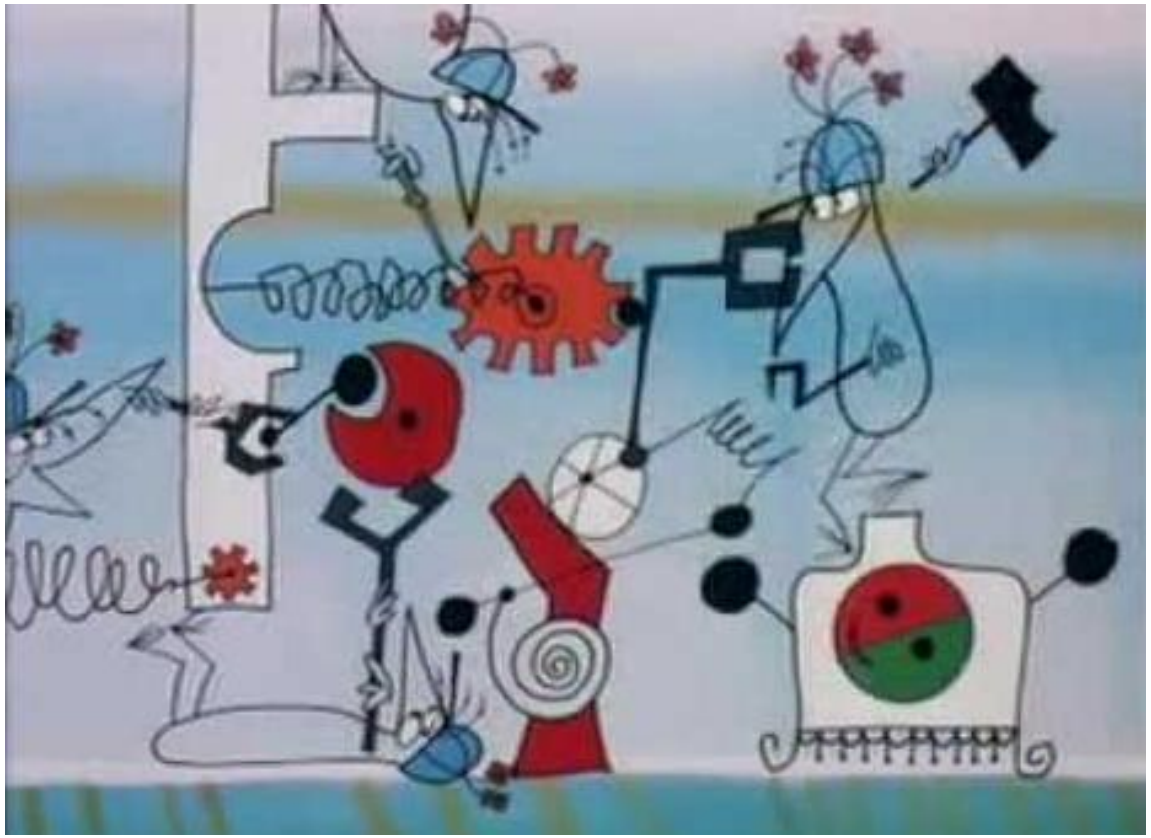
Genetic variation

Phenotypic plasticity

Rapid response to driver variations

Often overlooked because hard to study in empirical experiments

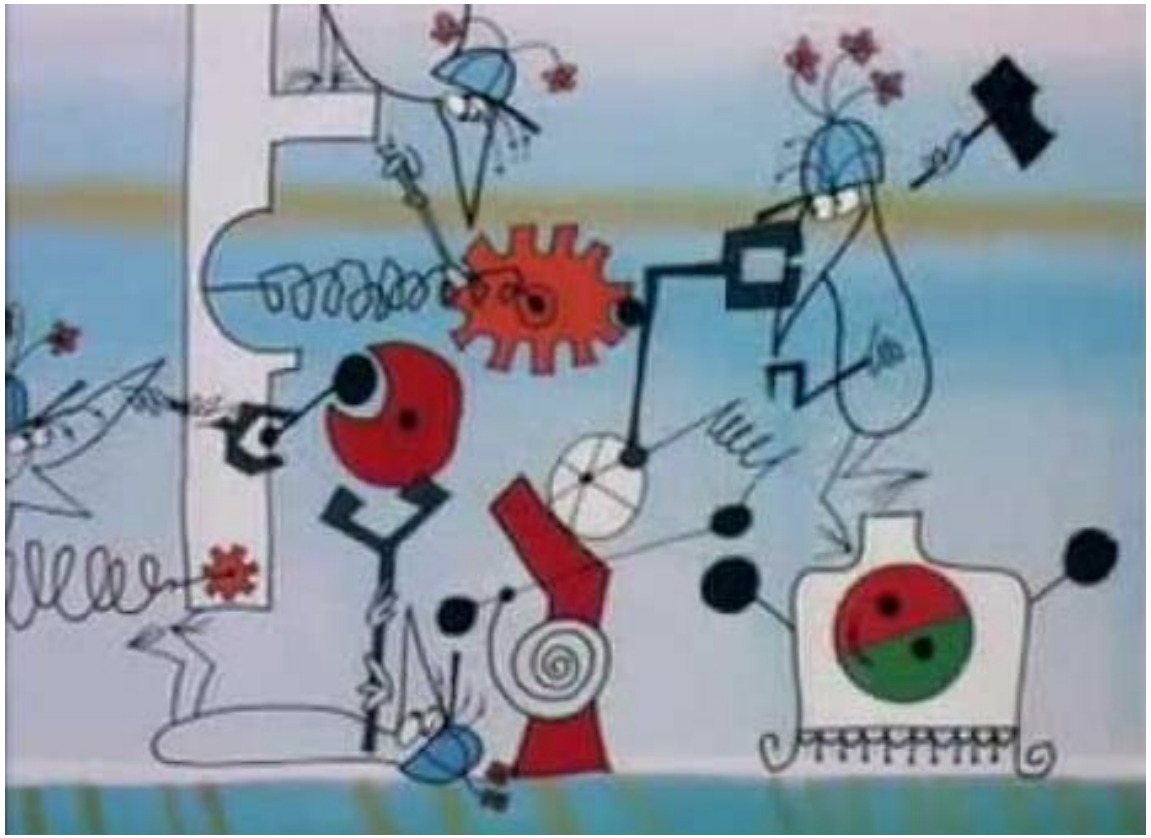
Mechanistic models to understand



Explicit link with drivers

Experiment at low cost

Mechanistic models to understand



Explicit link with drivers

Experiment at low cost

But often limited to a few species or functional types in a discrete manner

How does phenotypic plasticity impact grassland community properties?

How does phenotypic plasticity impact grassland community properties?

Species diversity and dominant strategies

How model diverse plant communities integrating phenotypic plasticity?

How does phenotypic plasticity impact grassland community properties?

2

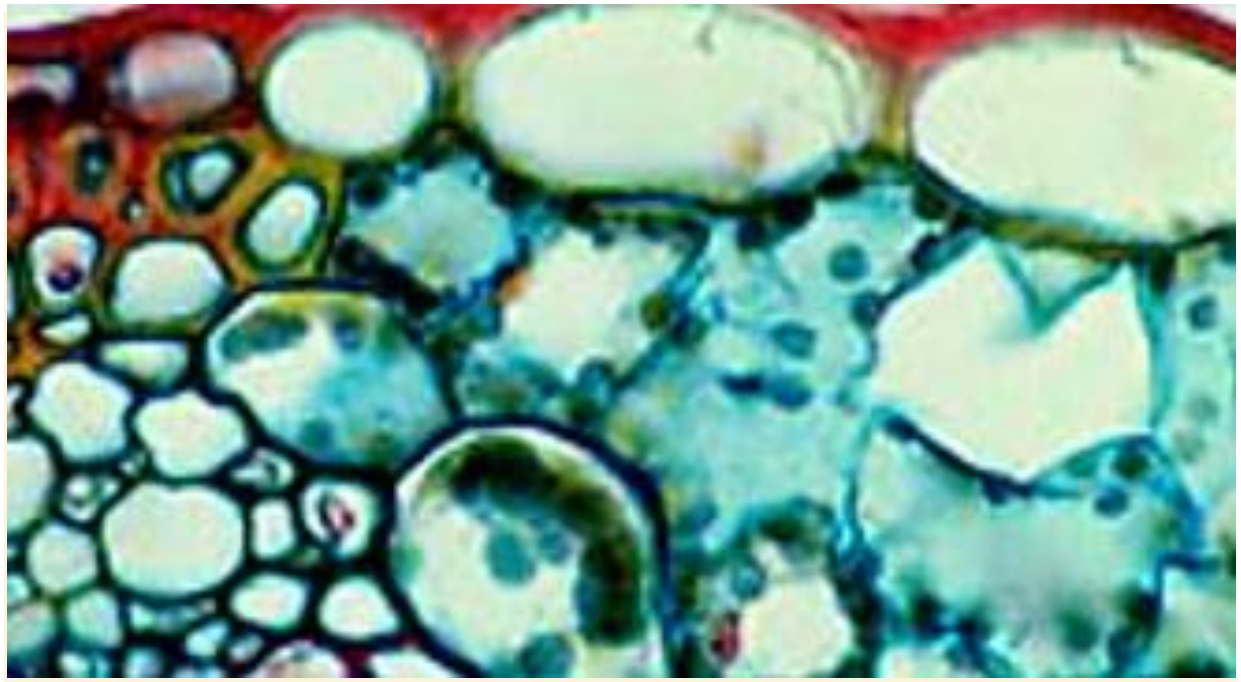
Concepts

From ecological concepts
to the model *MountGrass*

Niche and variability

Competition for resources

Strategy trade-offs

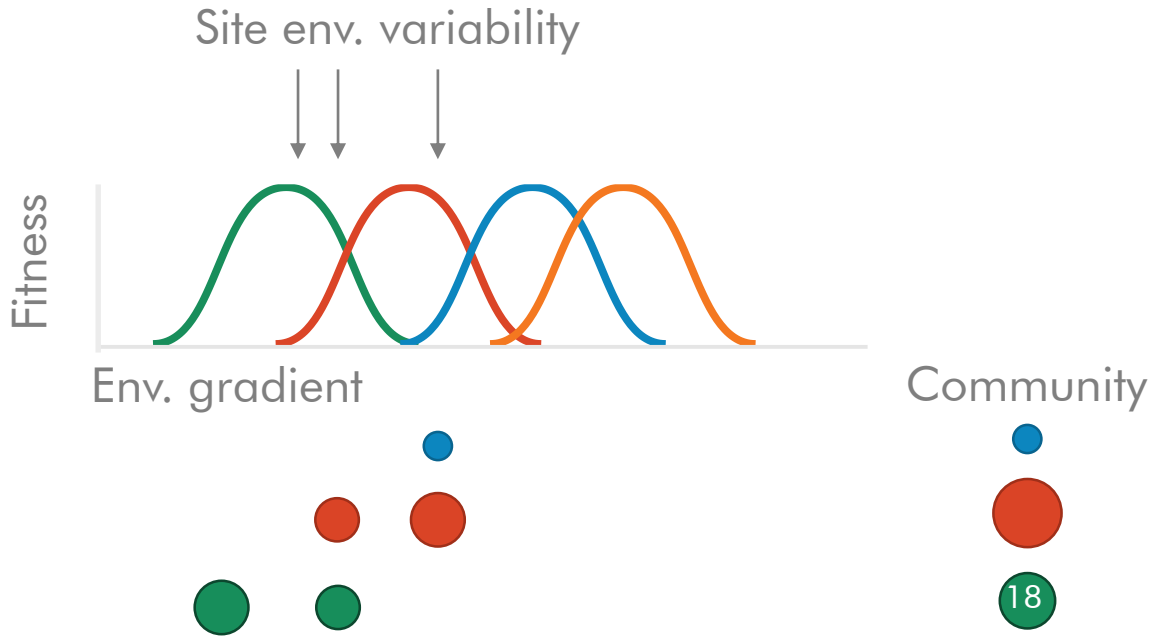


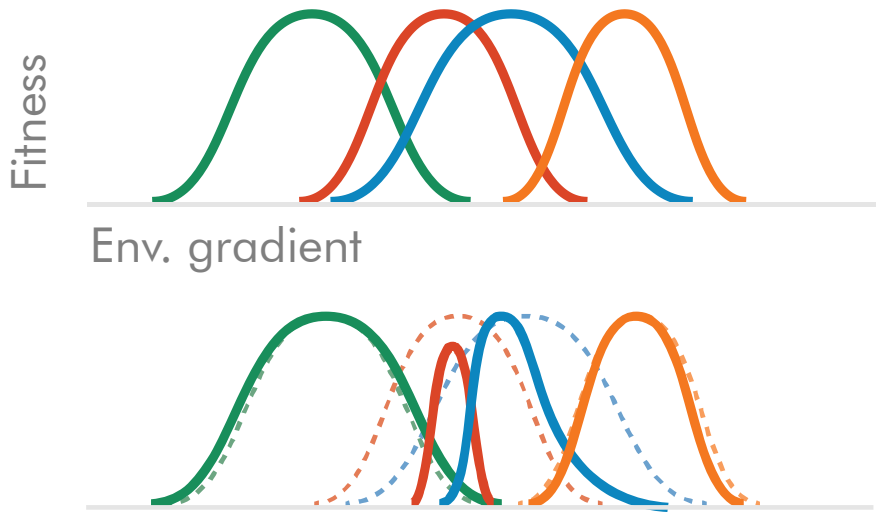
Niche & variability

Fit of a species under specific environmental conditions

Variability promotes coexistence

True for spatial and temporal variability

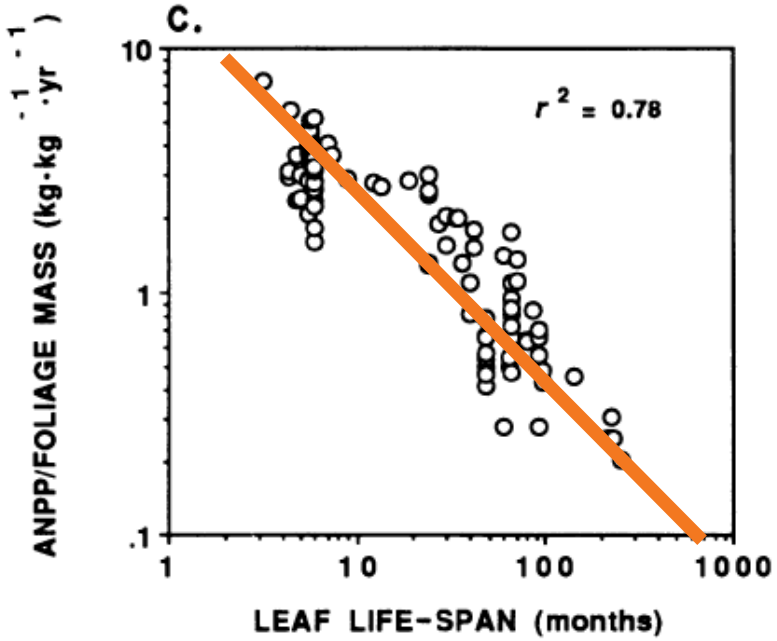




Competition for resources

- Main plant interaction mechanism
- Shapes communities by affecting the realised niches
- Depends on plant strategies

Leaf Economic Spectrum



Strategy trade-offs

Plant strategies are constrained

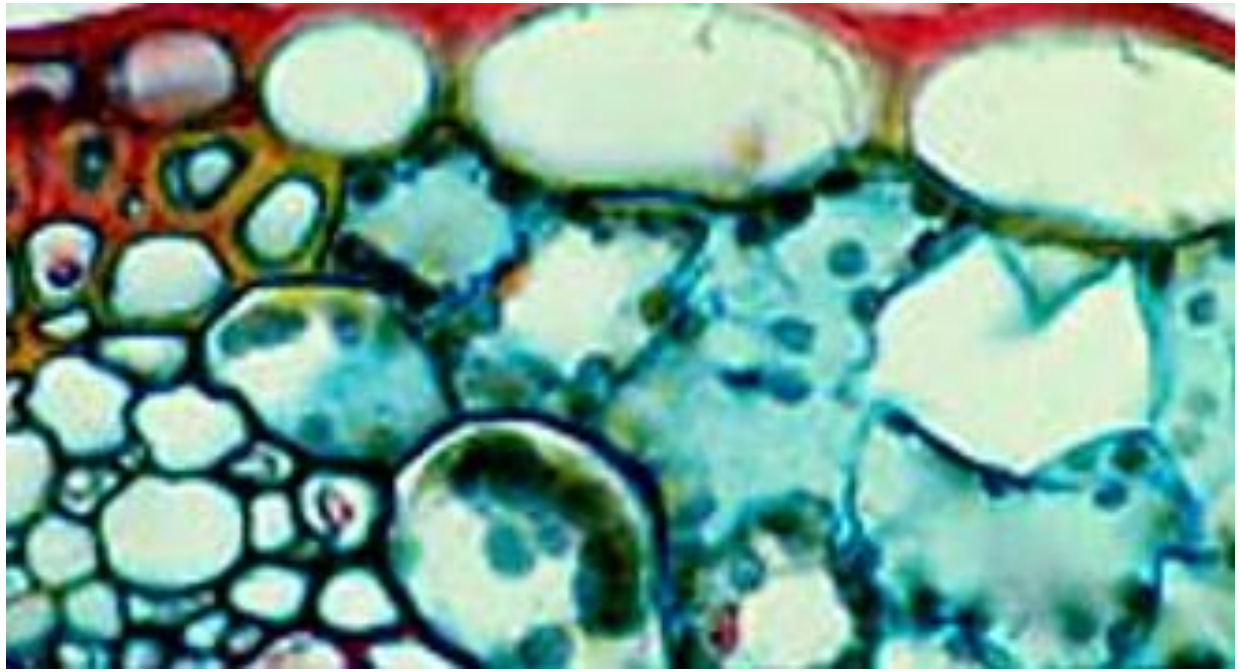
→ Dimension reduction

Continuum of plant strategies

Build a strategy space

Depends on allocation

P. Reich (1992)



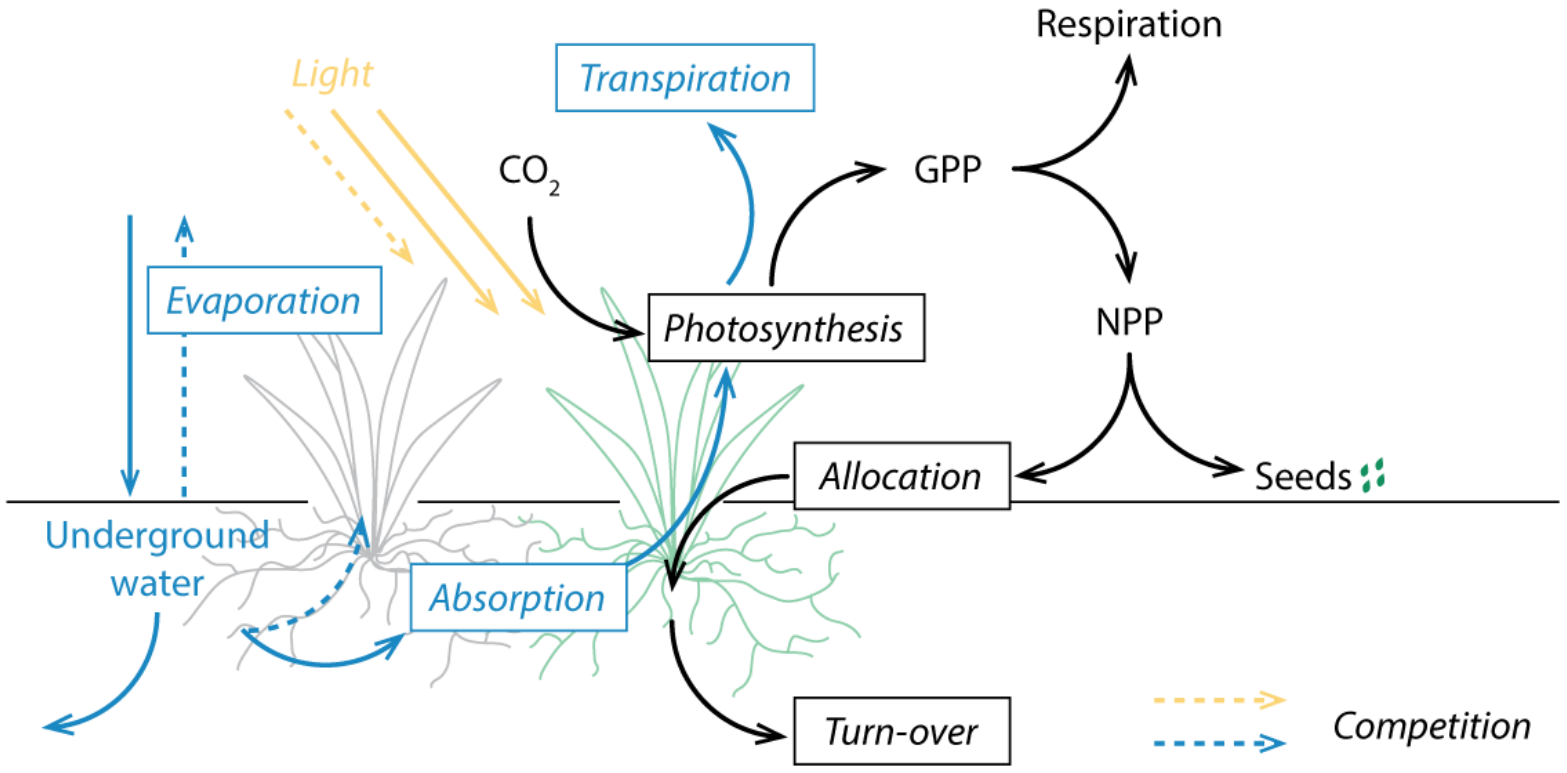
The model *MountGrass*

MountGrass' processes

Response to drivers: physiological processes.

Above and belowground competition: light and water cycles.

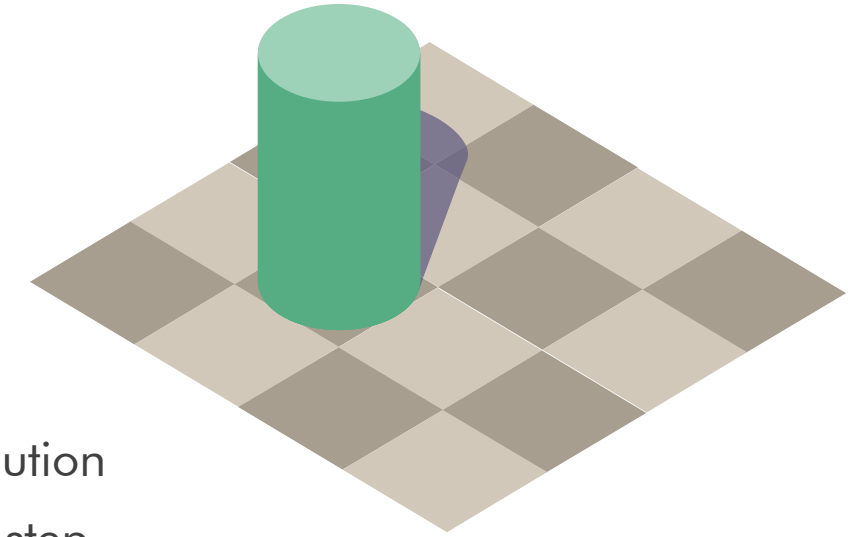
Strategies: carbon allocation trade-offs.



Space & time: the individual plant scale

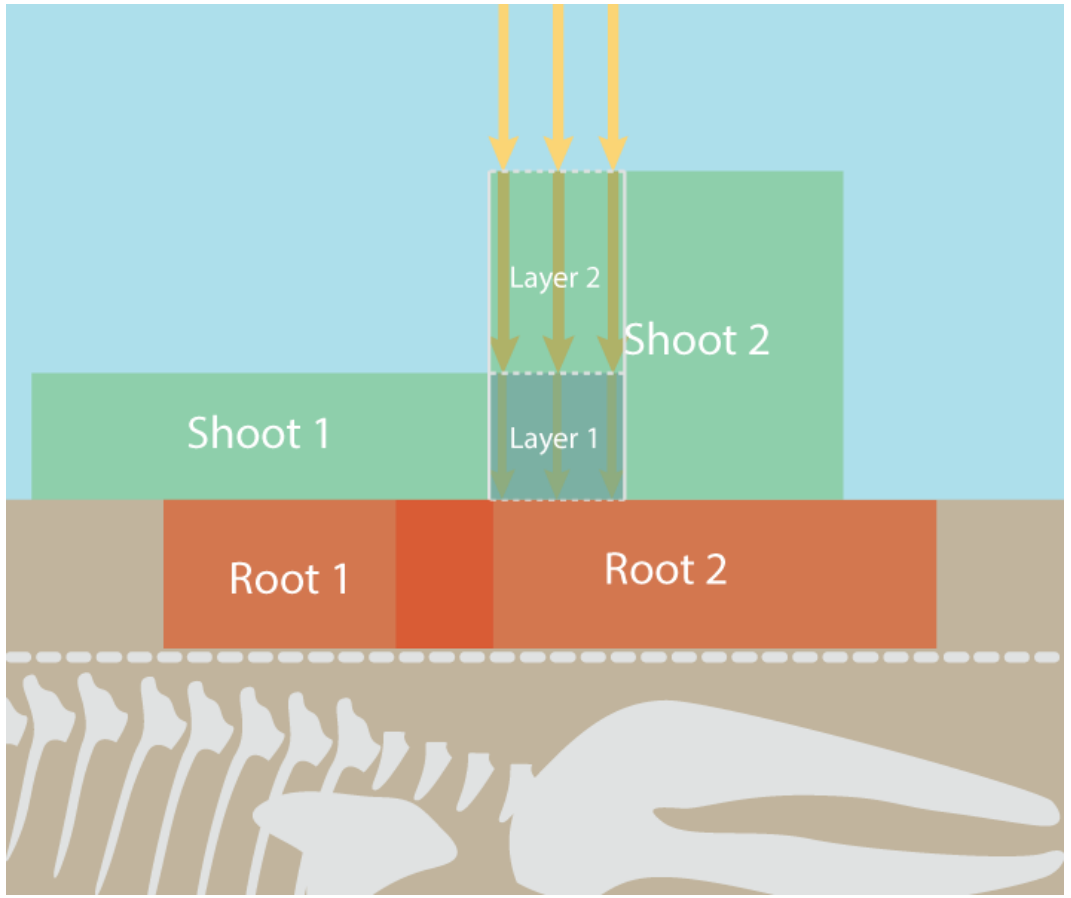
Individual-based model

spatialy explicit: explicit competittion



1 cm resolution

daily time-step

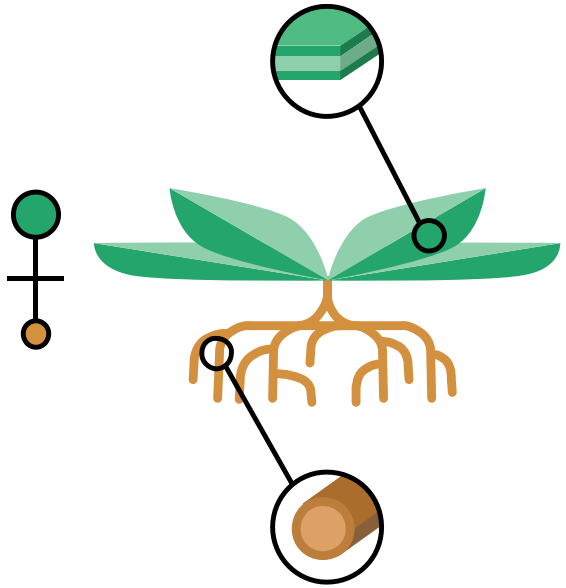


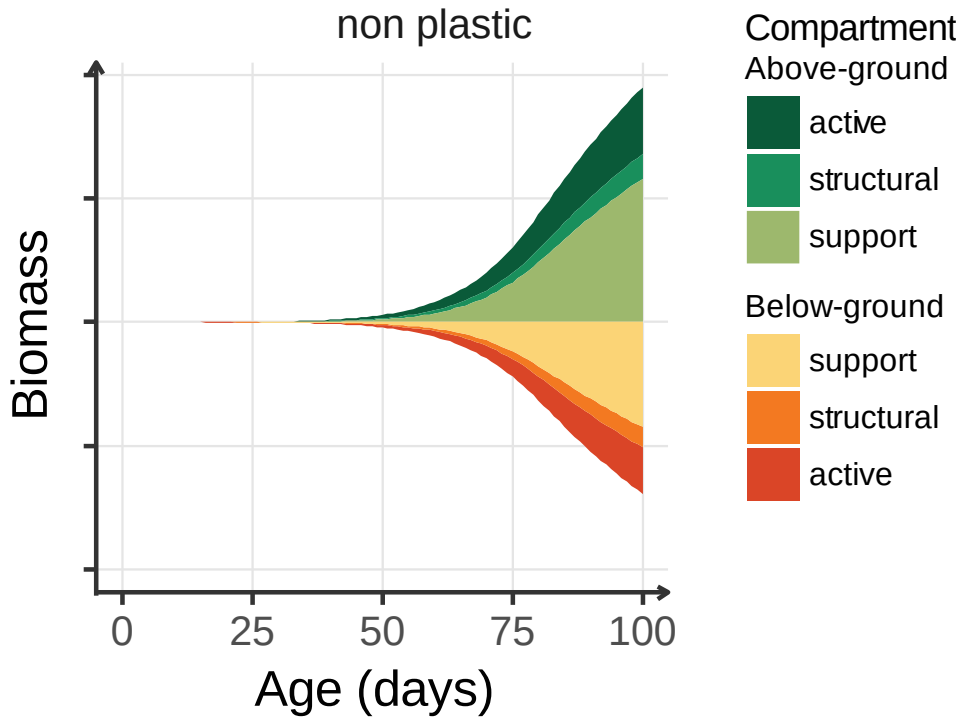
Plant carbon pools and allocation trade-offs

6 vegetative pools

3 dimensions:
- Root:shoot ratio
- Prop. active in shoot
- Prop. active in root

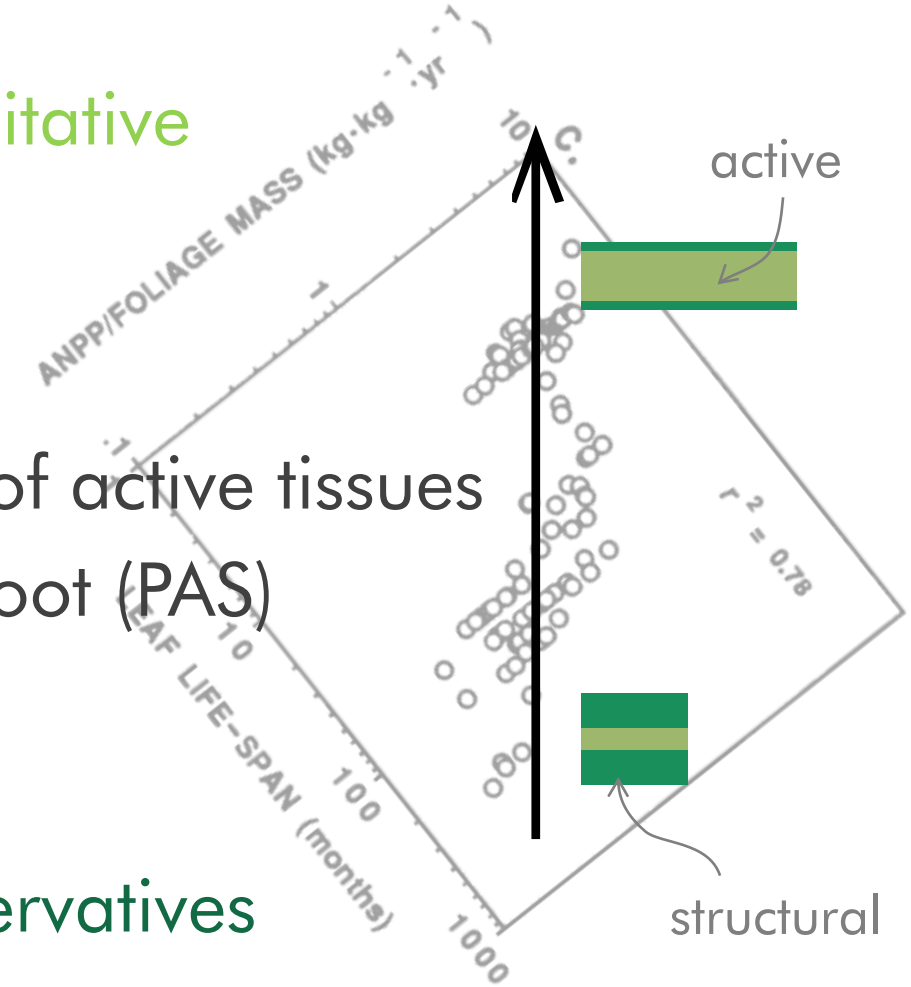
Allocation trade-offs
→ strategic trade-offs





Allocation trade-off into strategic trade-off

Exploitative



Proportion of active tissues in shoot (PAS)

Conservatives

density

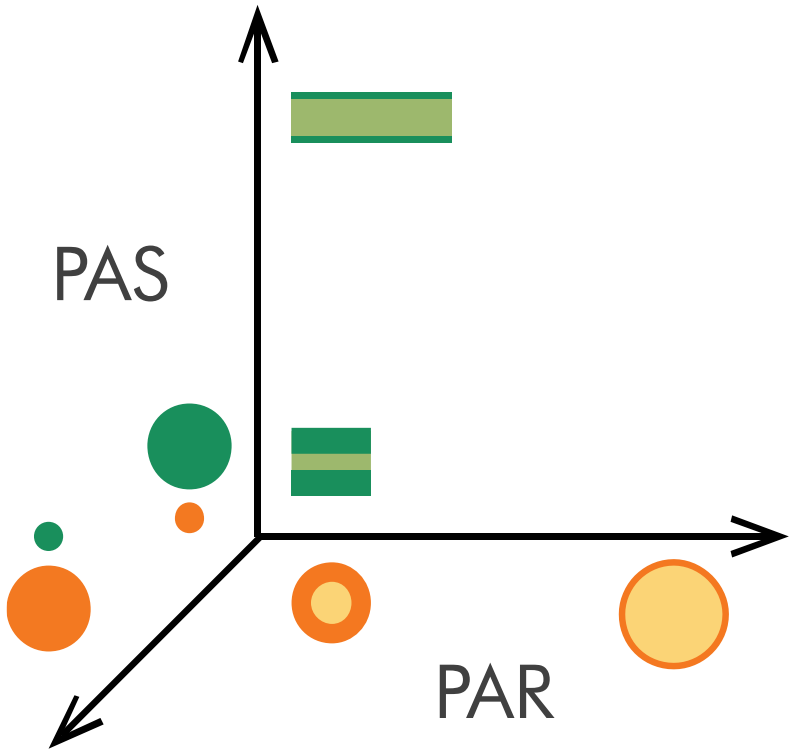
lifespan

area

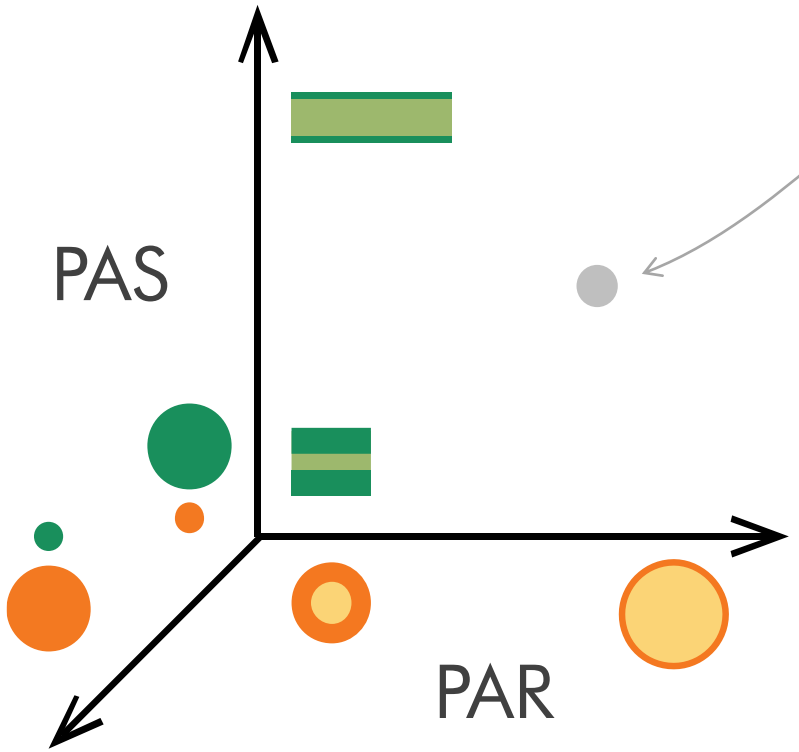
biomass

respiration

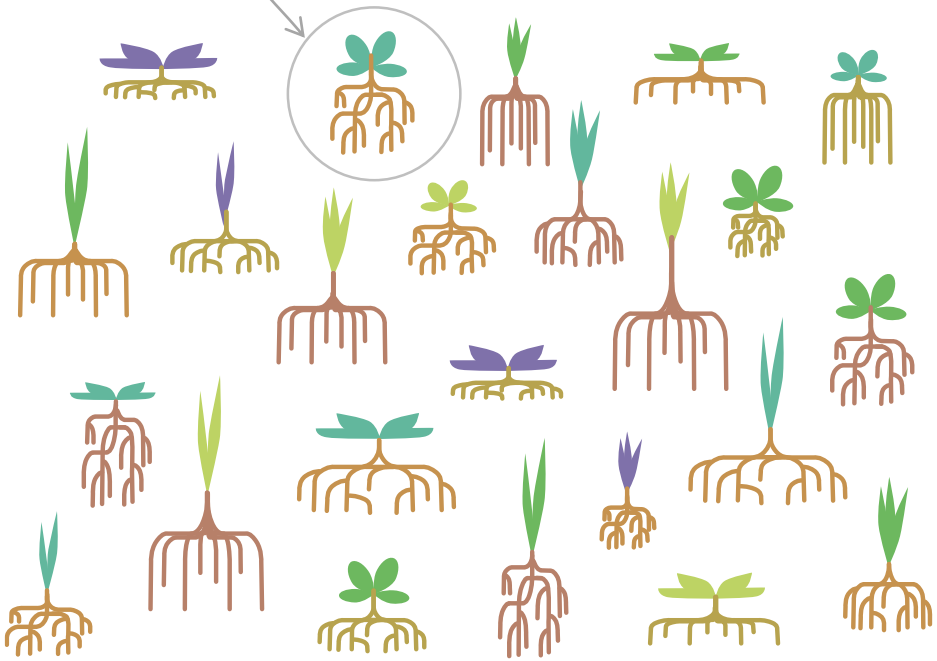
Phenotypes and strategies



Phenotypes and strategies

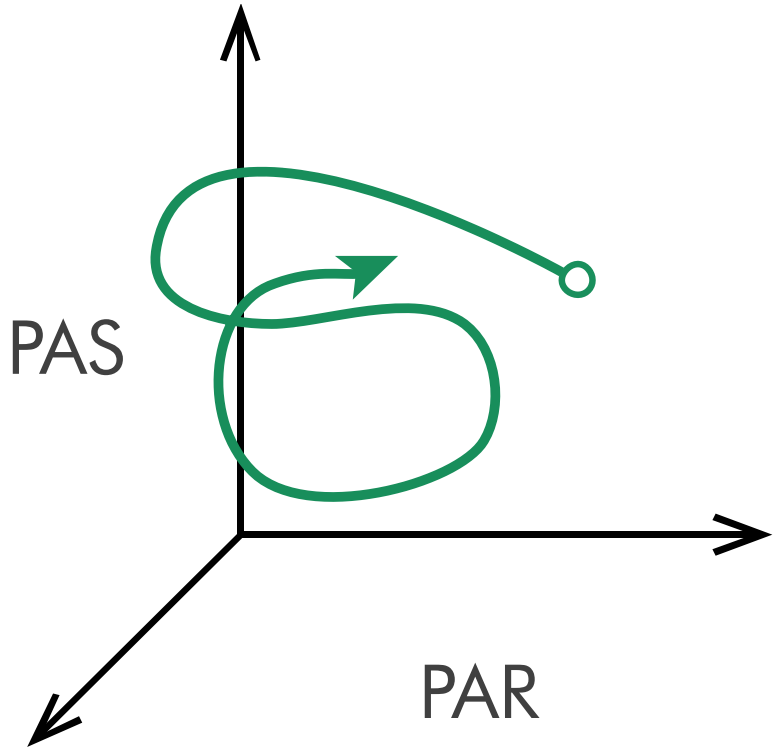


Each point is a valid strategy



→ sample diverse strategies in a continuous space

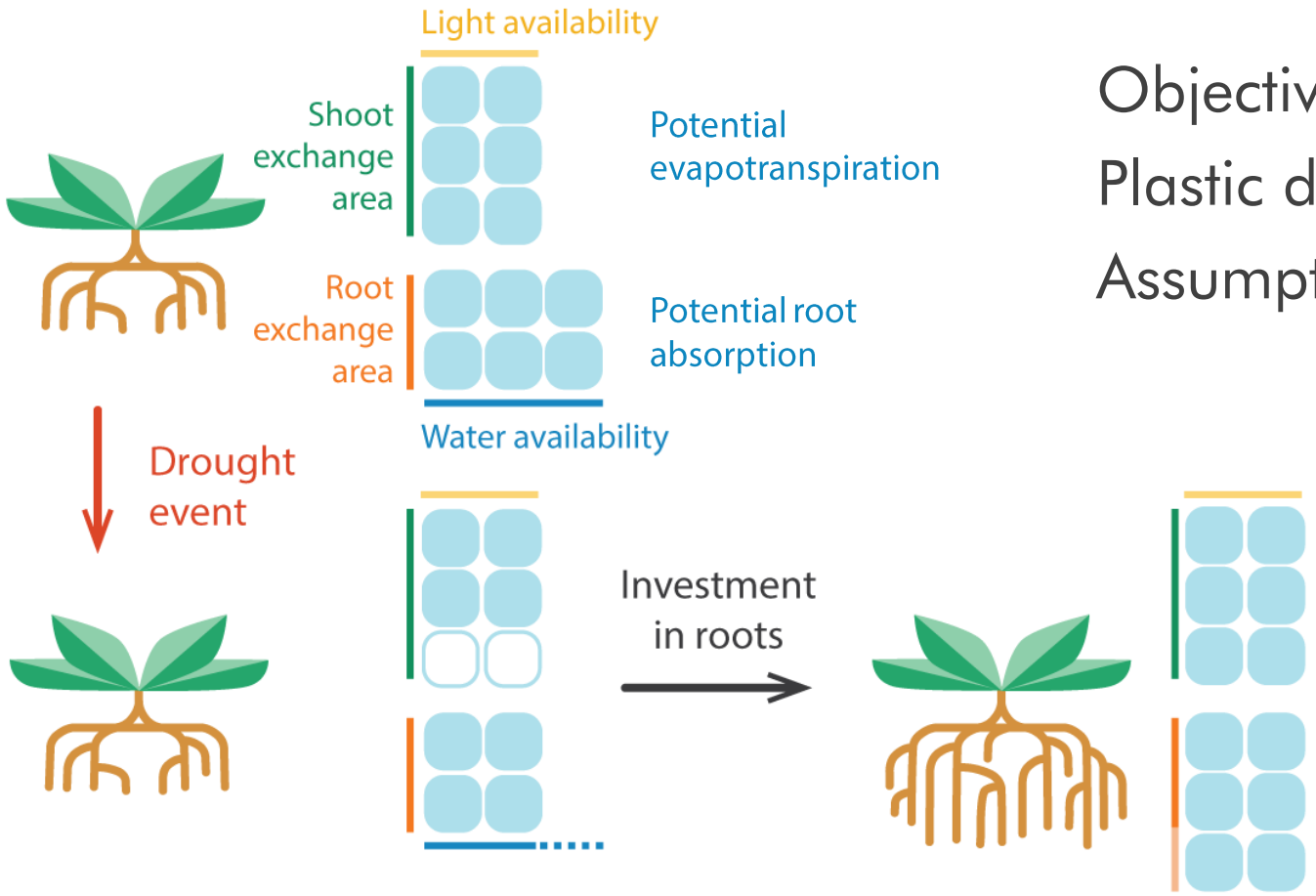
Phenotypes and strategies



Plasticity allows plant to move within this closed space,

but it needs rules.

Plasticity: the functional equilibrium



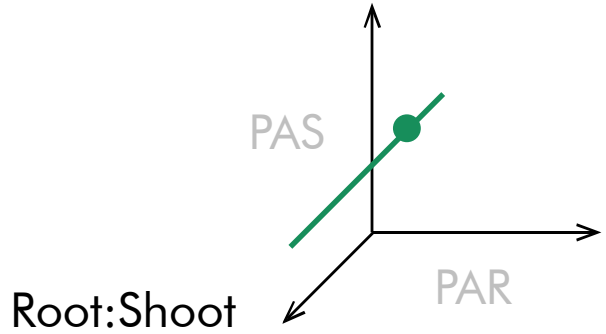
Objective function: root activity = shoot activity

Plastic dimension: Root:Shoot ratio

Assumption: tomorrow same as today

« fixed-equilibrium »

= changes in Root:Shoot only



Results

Individual- and community-level effects of plasticity

111 days

fixed T° & irradiance

12*12*90 cm pots

Parameter filtering

31 parameters

Pot growth patterns in 2 treatments of watering

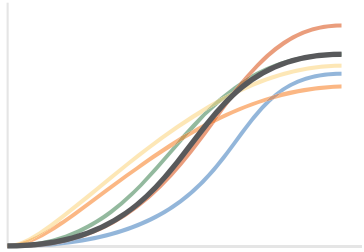
→ Selection of a subset of parameter sets for simulations

1 parameter set = 31 values

Accepted sets

Simulation sets

Trend from multiple simulations



fixed T° & irradiance

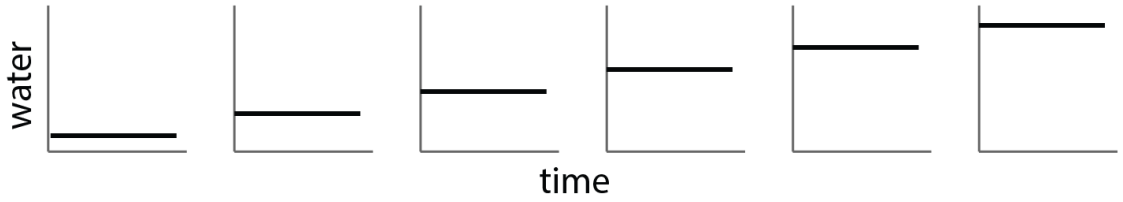
12*12*90 cm pots

100 days

Individual-level simulations

How does plasticity affect community response to spatial and temporal variability?

Individual growth along an availability gradient (spatial)



fixed T° & irradiance

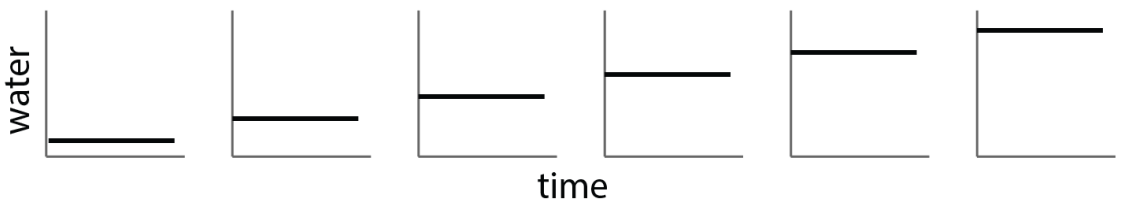
12*12*90 cm pots

100 days

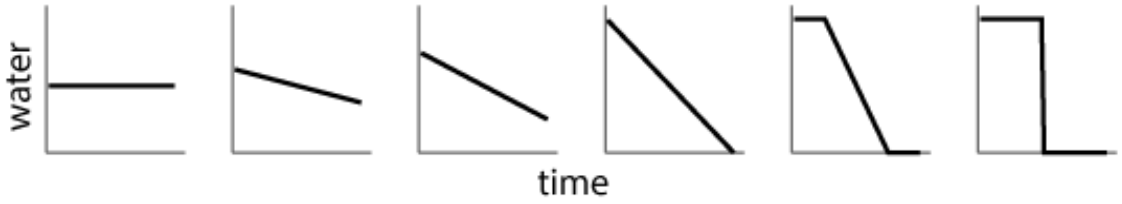
Individual-level simulations

How does plasticity affect community response to spatial and temporal variability?

Individual growth along an availability gradient (spatial)



Individual growth along an variability gradient (temporal)



fixed T° & irradiance

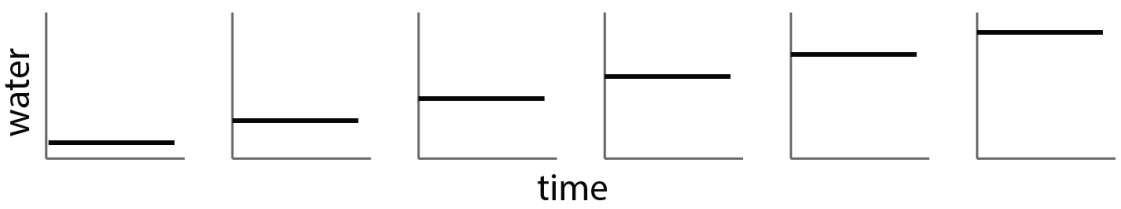
12*12*90 cm pots

100 days

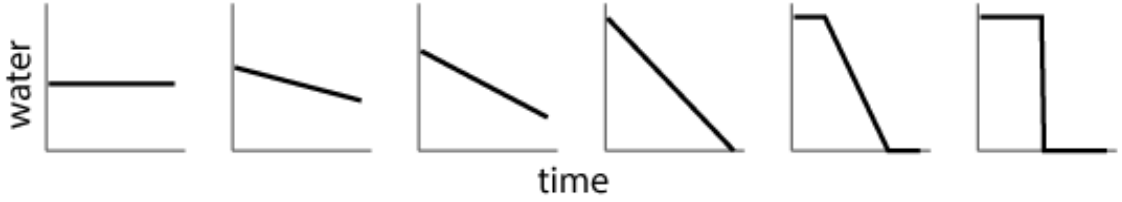
Individual-level simulations

How does plasticity affect community response to spatial and temporal variability?

Individual growth along an availability gradient (spatial)



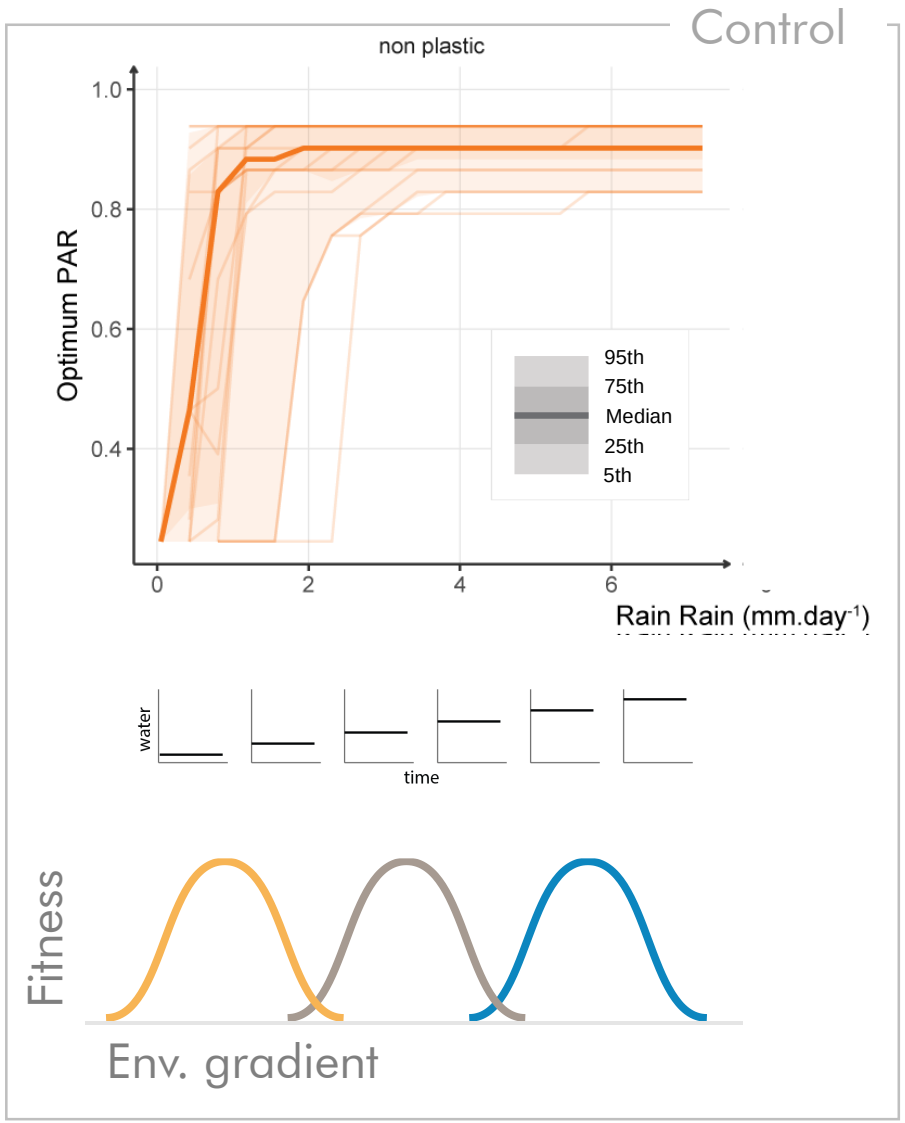
Individual growth along an variability gradient (temporal)



1 resource: water → observe the effect of plasticity on biomass and optimum root strategy (PAR)

Plasticity effect in homogeneous conditions

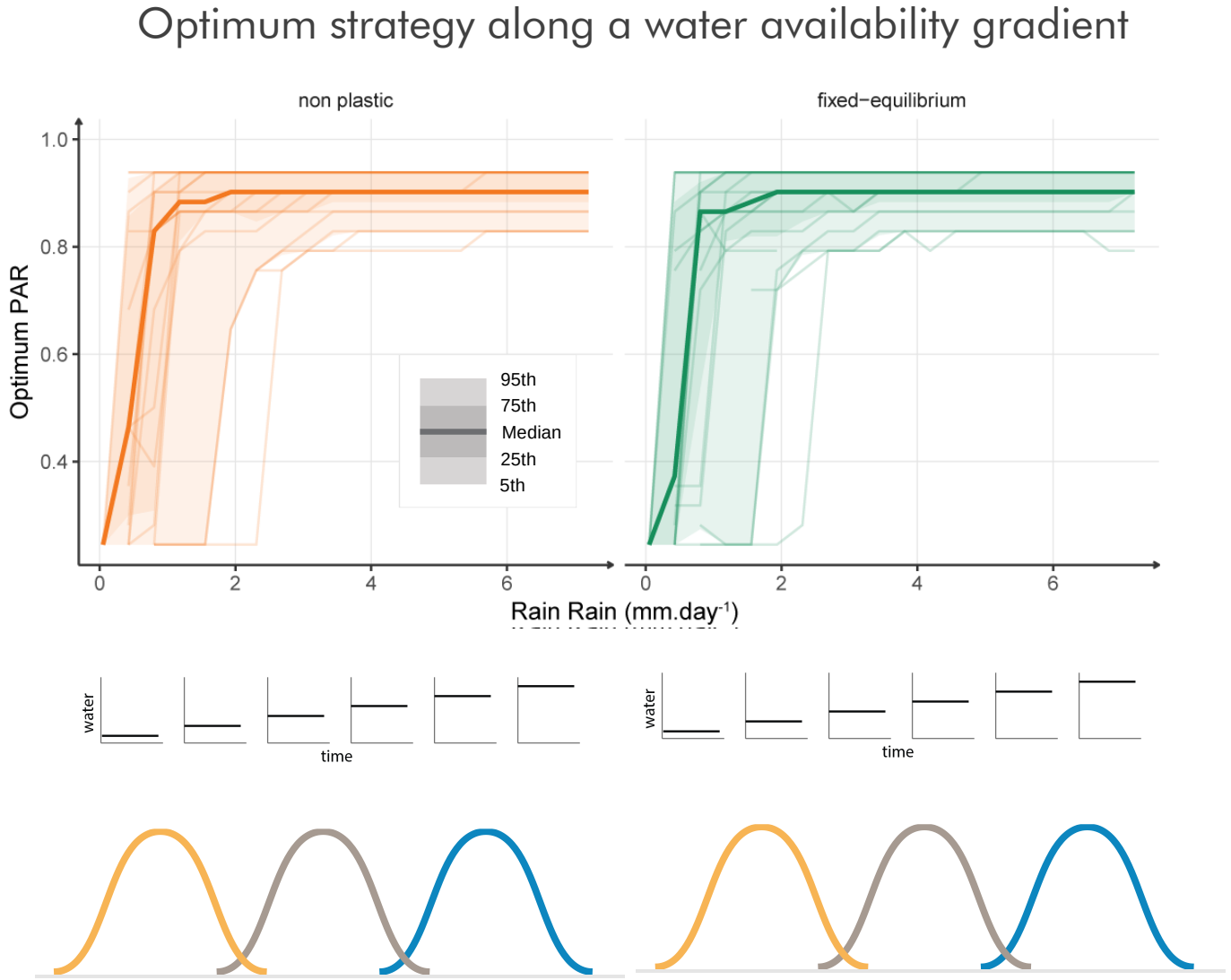
Optimum strategy along a water availability gradient



Plasticity effect in homogeneous conditions

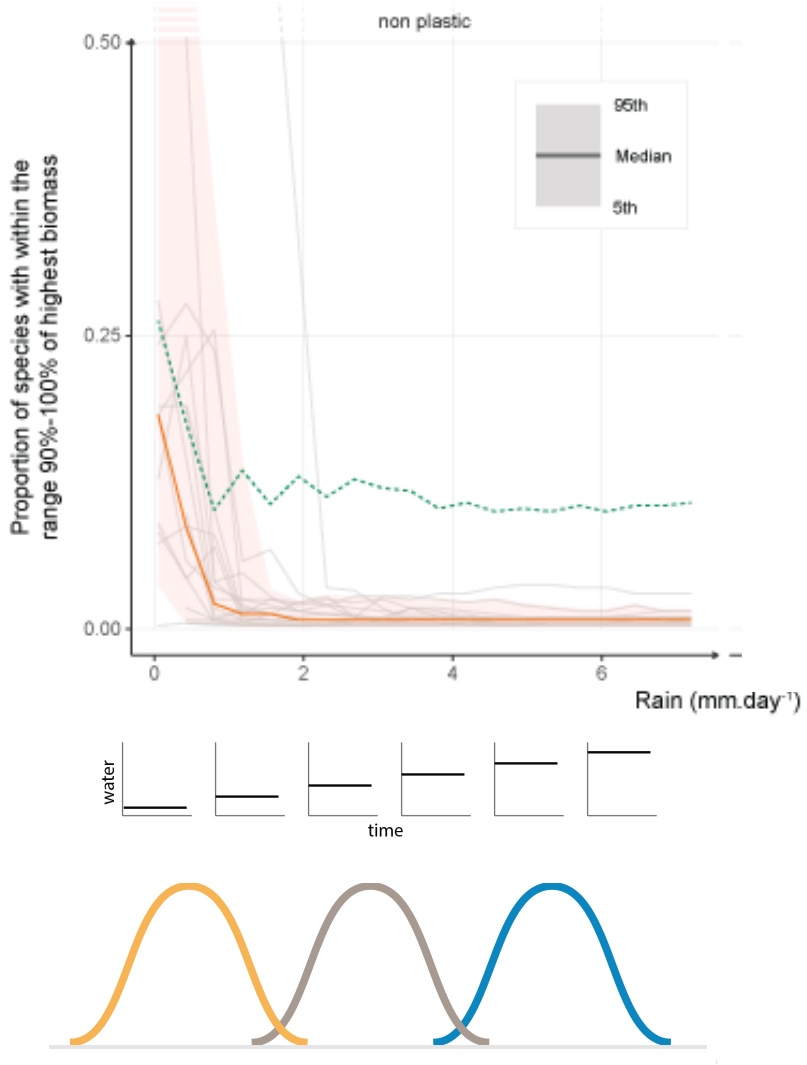
- No shift in best strategy
- No change in maximum biomass

→No shift in the dominant species



Plasticity effect in homogeneous conditions

Proportion of species with high performances along a water availability gradient

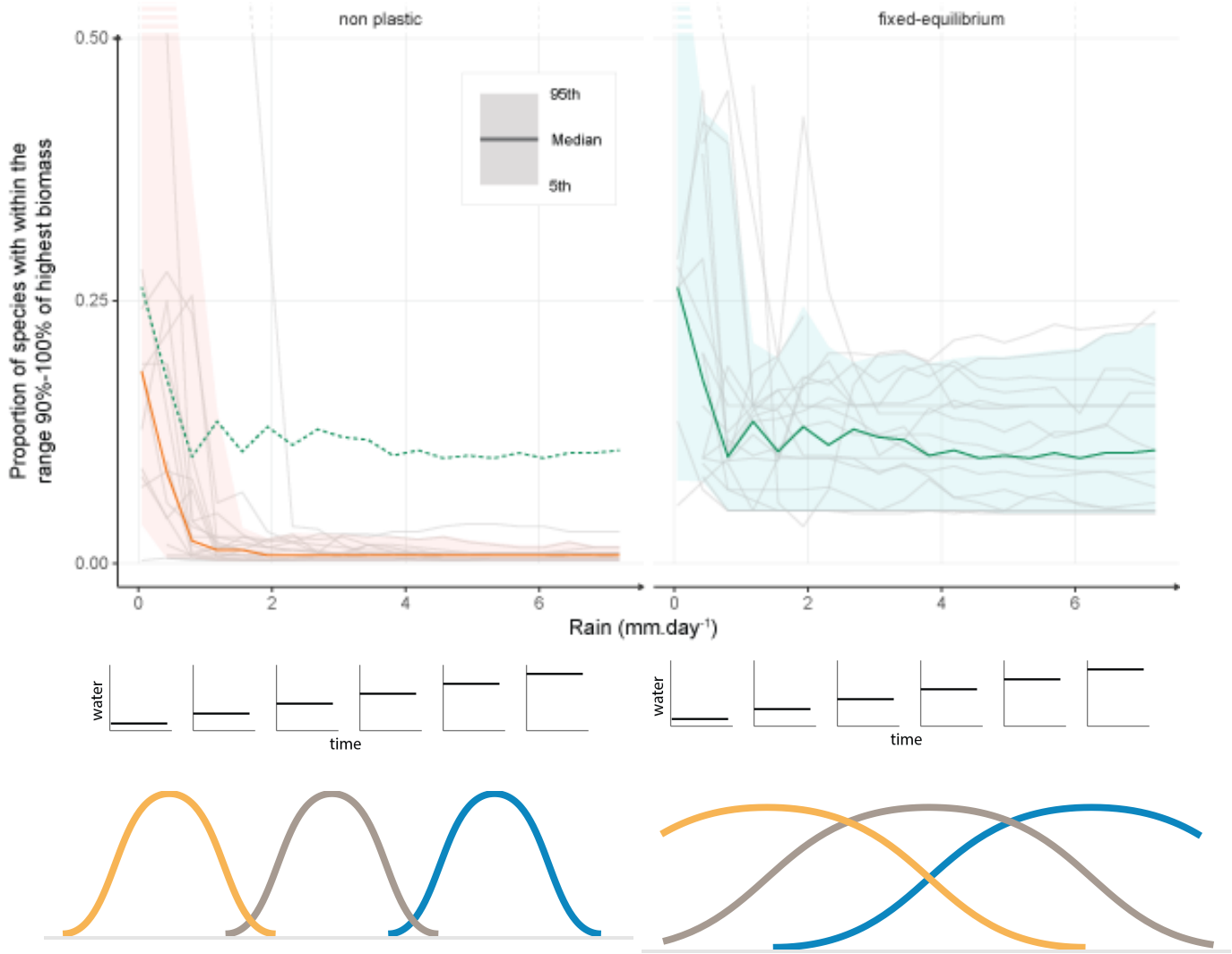


Plasticity effect in homogeneous conditions

- Reduction of growth differences

→Niche widening

Proportion of species with high performances along a water availability gradient

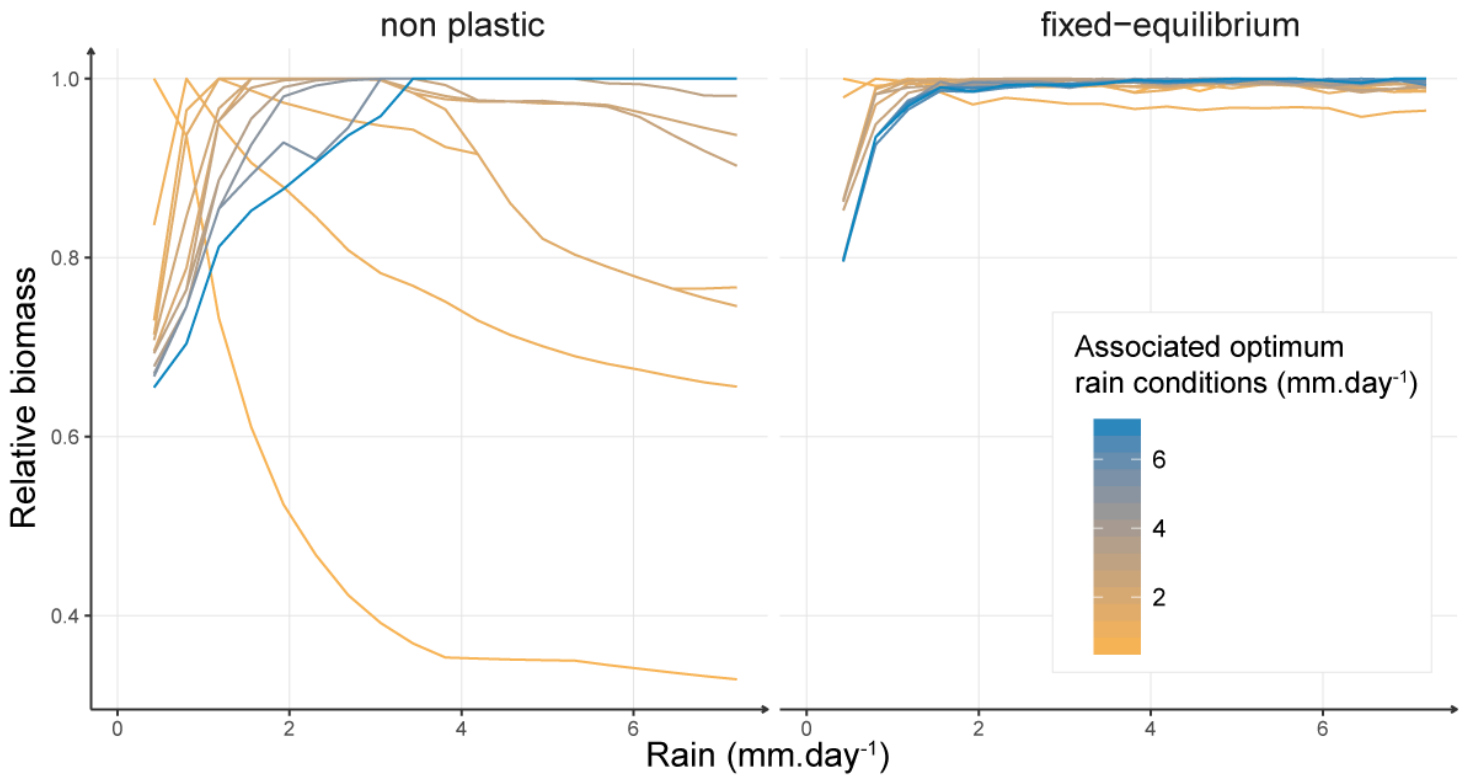


Niche widening in homogeneous conditions

Plasticity

→ increases relative biomass in non optimum conditions

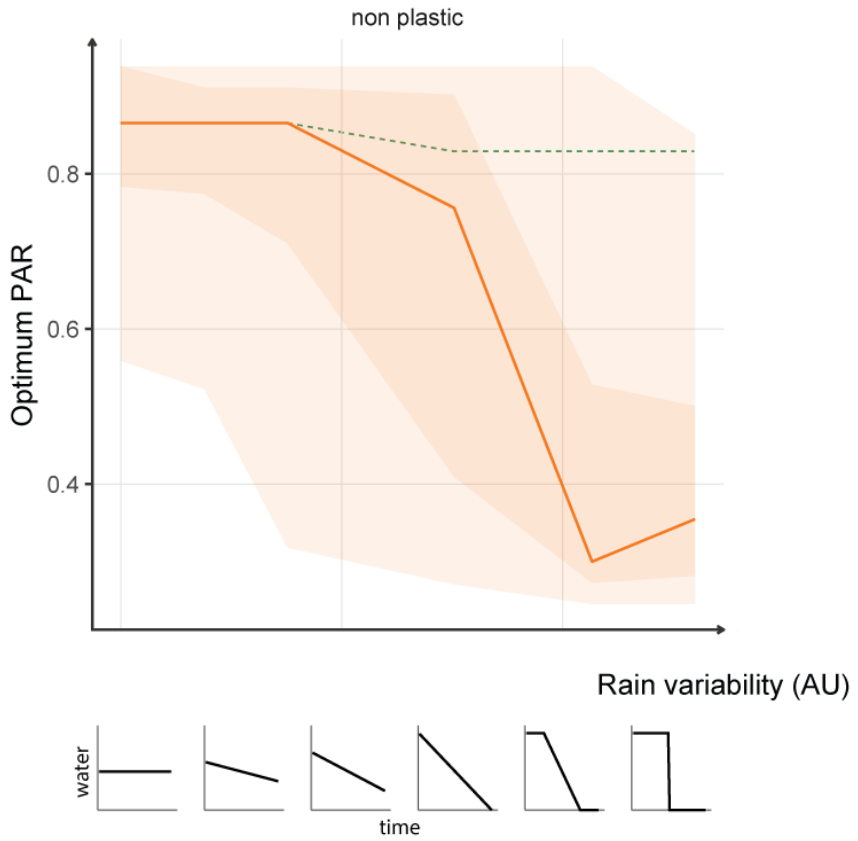
Potential niche of best species



for 1 parameter set

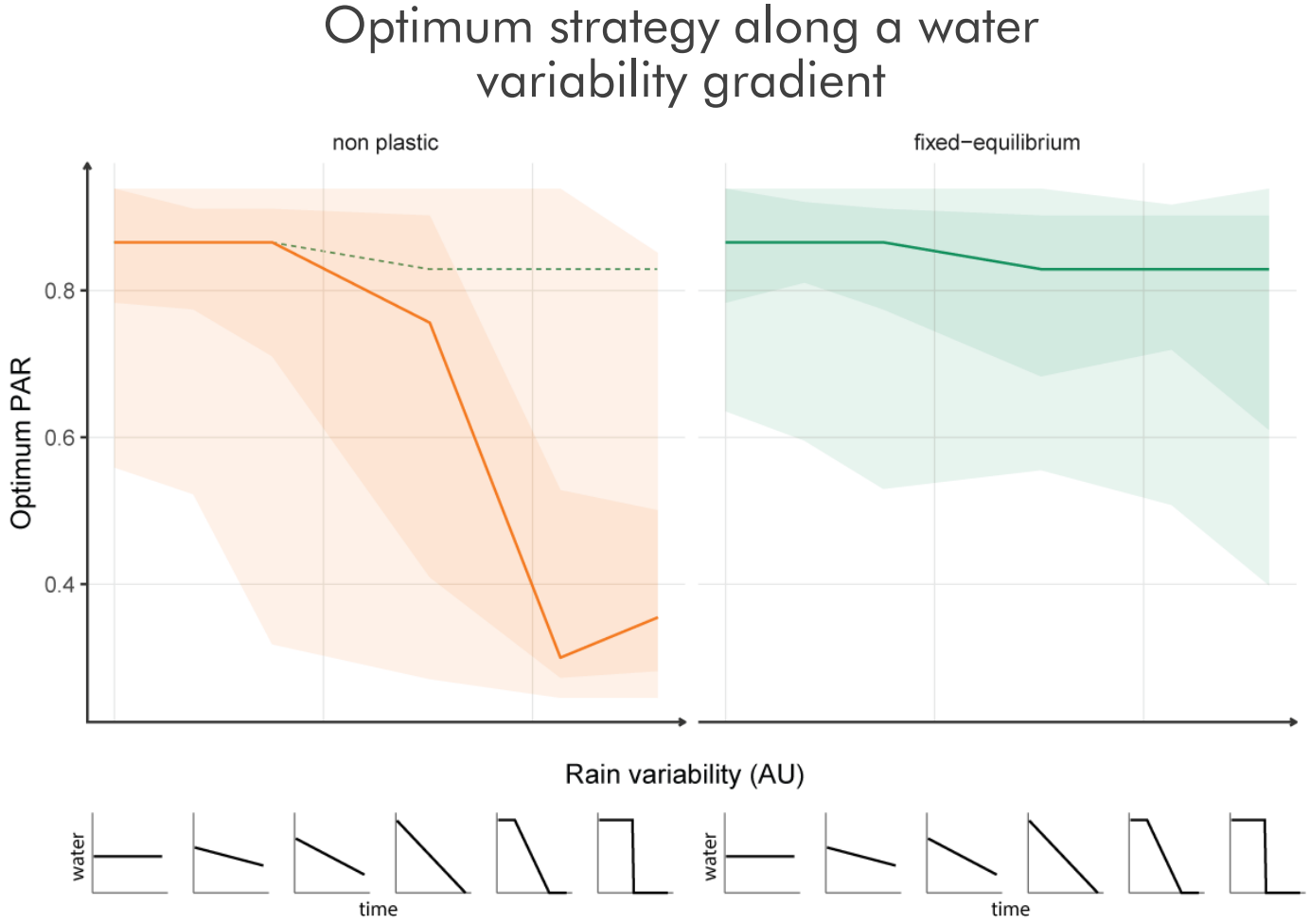
Plasticity effect in heterogeneous conditions

Optimum strategy along a water variability gradient



Plasticity effect in heterogeneous conditions

- Changes in dominant strategy in favour of exploitative species
- Reduction of growth differences
- Increase of relative BM

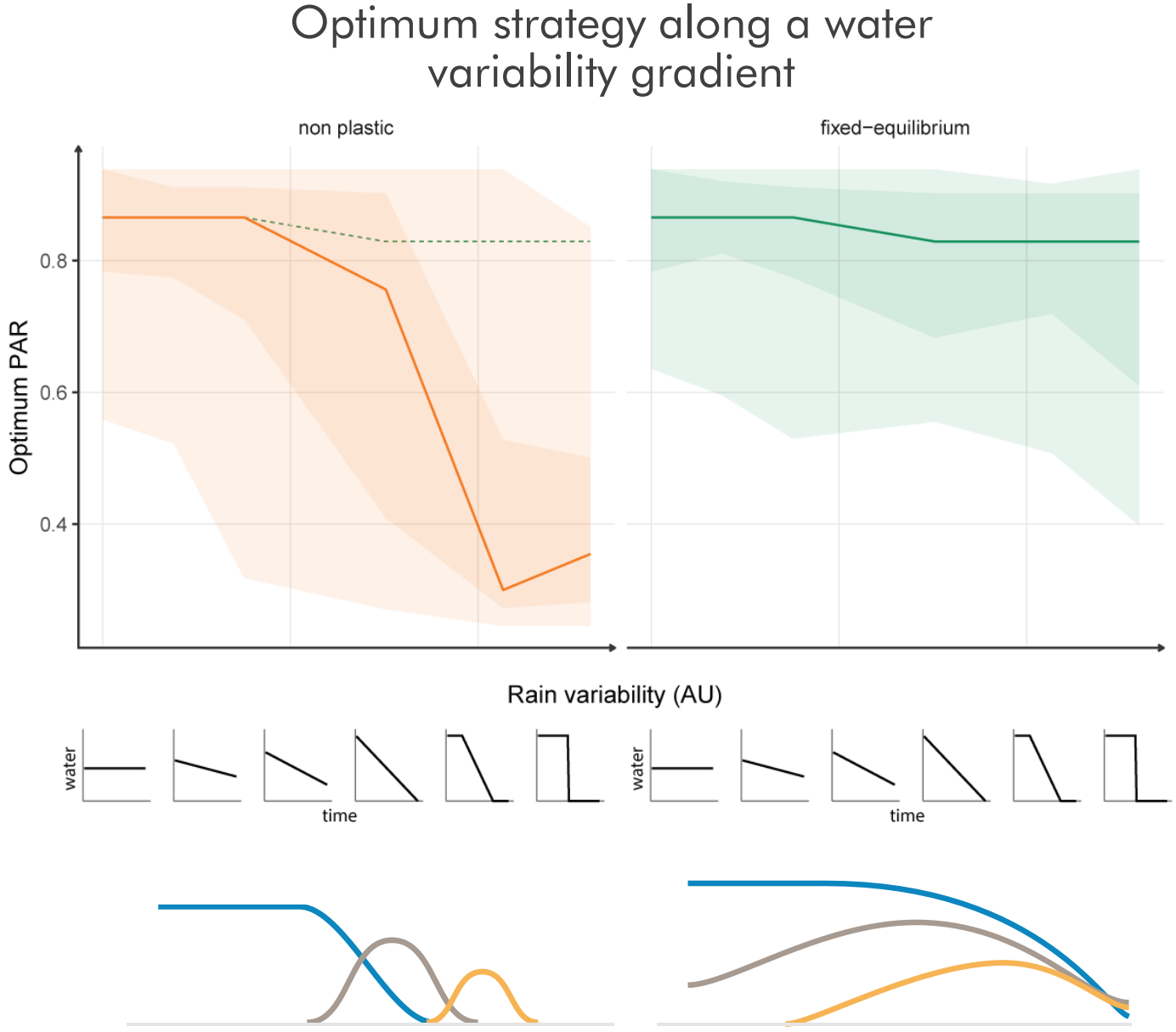


Plasticity effect in heterogeneous conditions

- Changes in dominant strategy in favour of exploitative species
- Reduction of growth differences
- Increase of relative BM

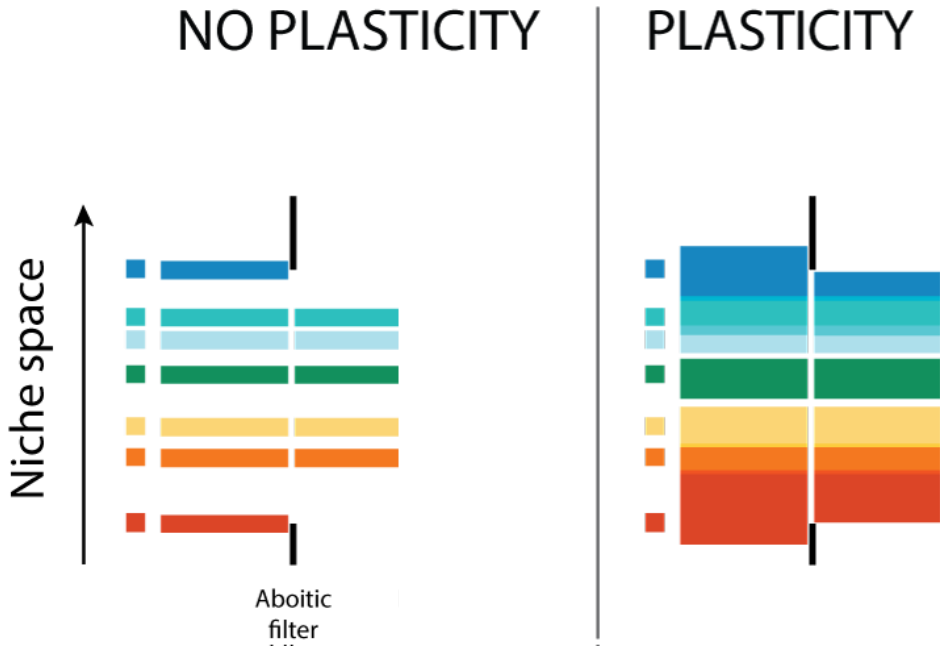
→ Asymmetric gain (+exploitative strategies)

→Niche widening



Consequences at the community level ?

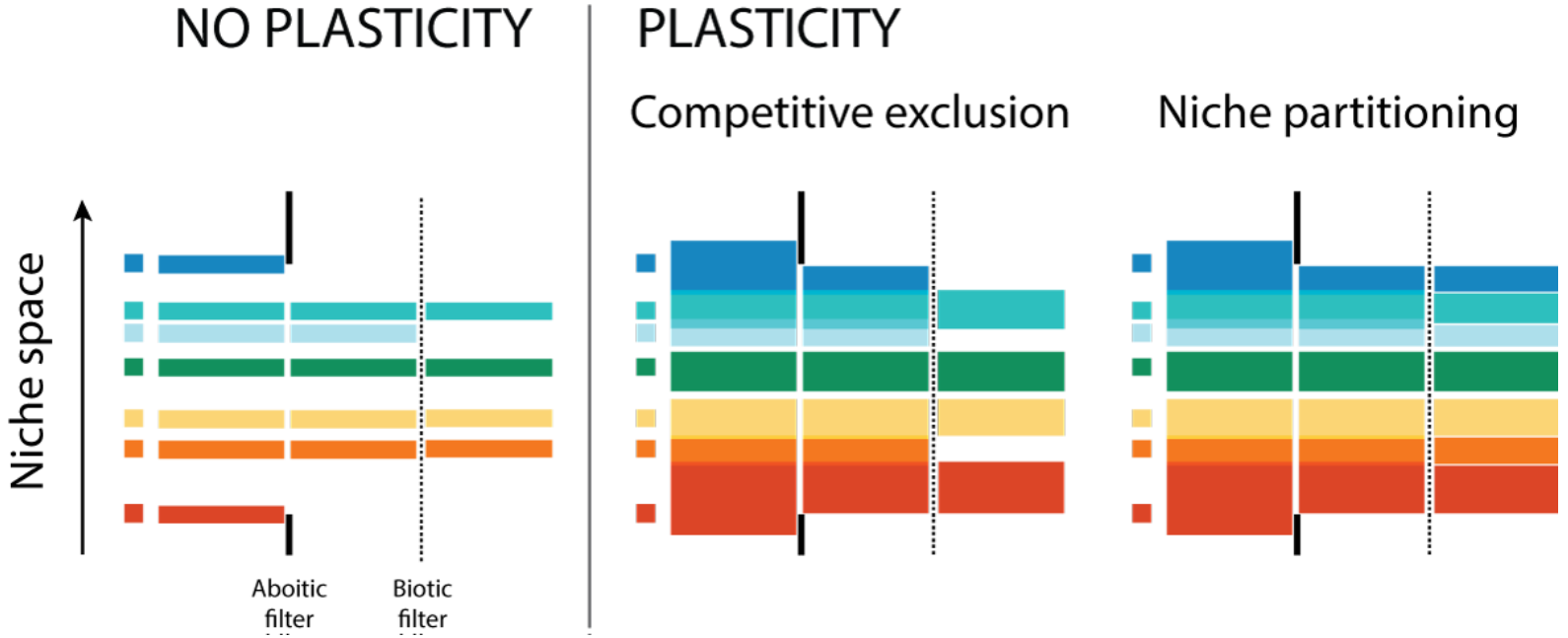
Niche widening = reduction of abiotic filtering + reduction of fitness differences



Consequences at the community level ?

Niche widening = reduction of abiotic filtering

- higher potential species diversity



Asymmetric gain

- Competitive exclusion by exploitative species?

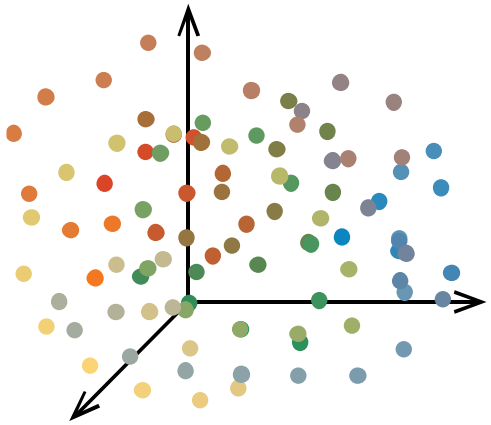
100*100cm plots

6 sites: variable T°, prec. & irradiance

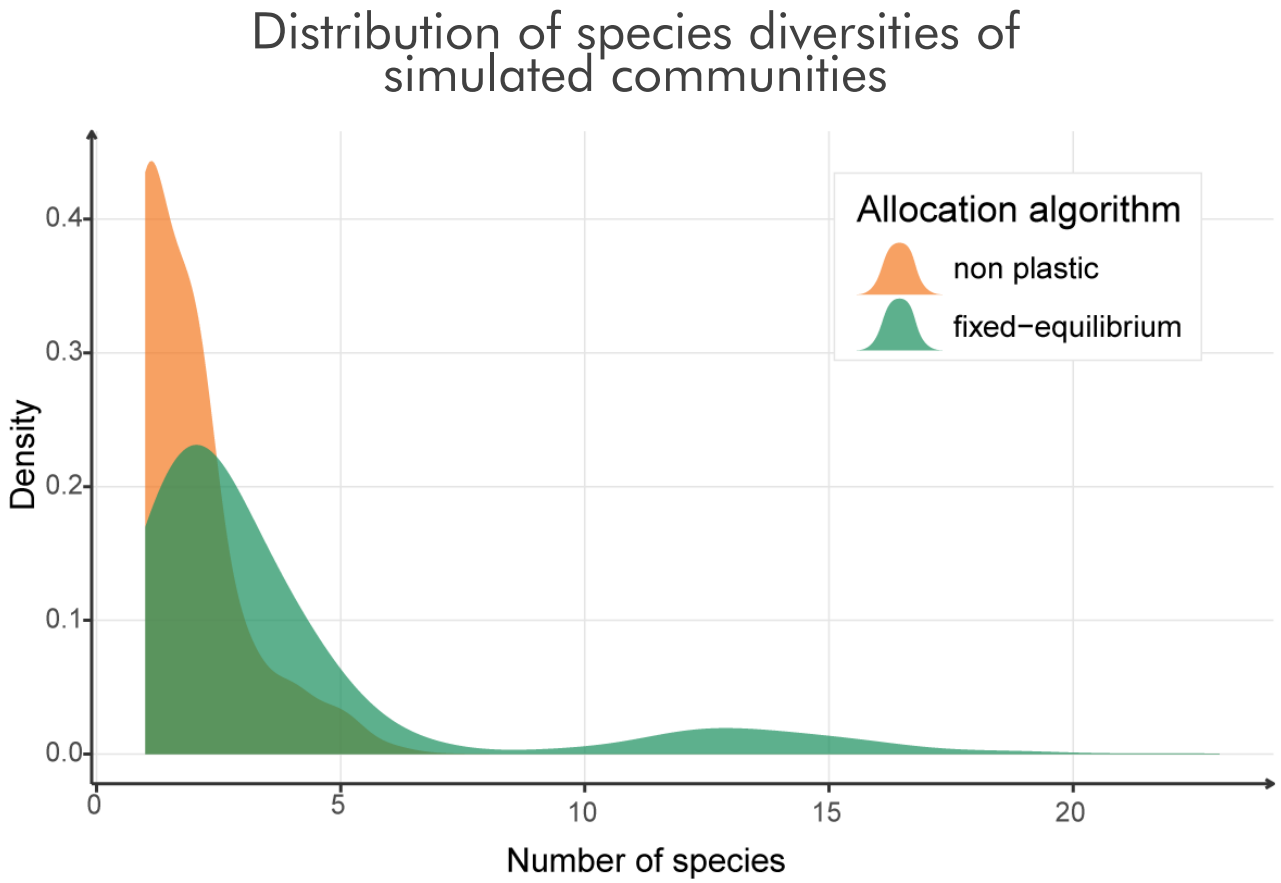
Community-level simulations

Real conditions of variability (weather data for 6 sites) + explicit competitive interactions

- Long term simulations (300 years)
- 12 stable parameter sets (reproducing individual after 50 years in non plastic conditions)
- 400 different phenotypes
- 6 sites: meta-community

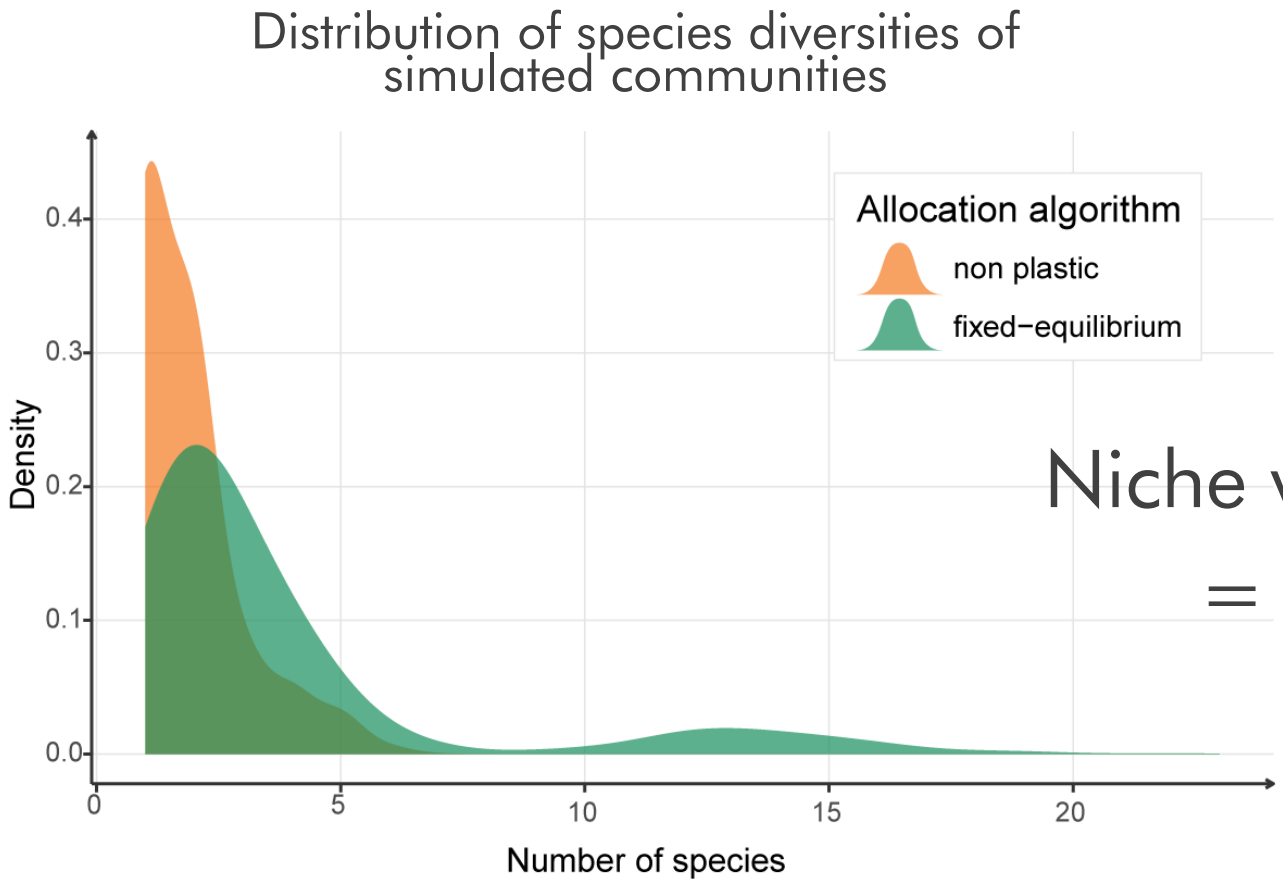


Effects of plasticity on species diversity



Higher species diversity

Effects of plasticity on species diversity



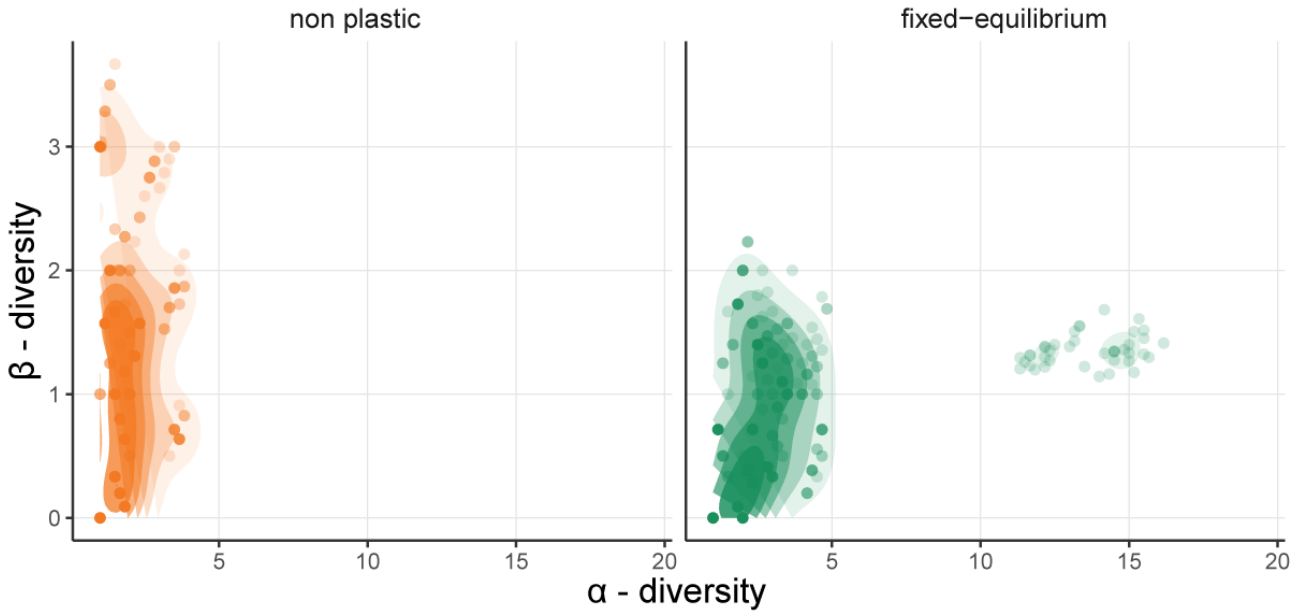
Higher species diversity

Niche widening > asymmetric gain

= better niche partitioning

A shift in meta-community structure?

Species diversity structure



Between sites

Within sites

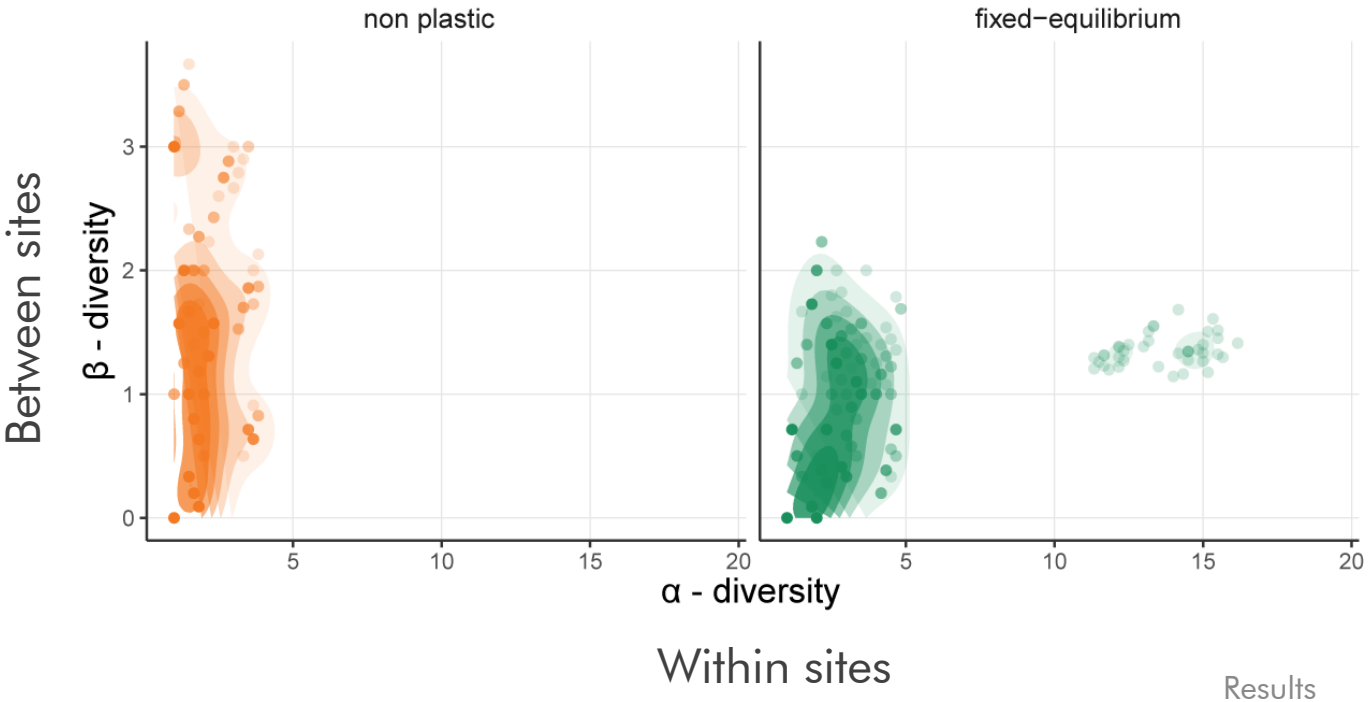
Shift in diversity structure:

- Less distinct site communities
- Richer site communities

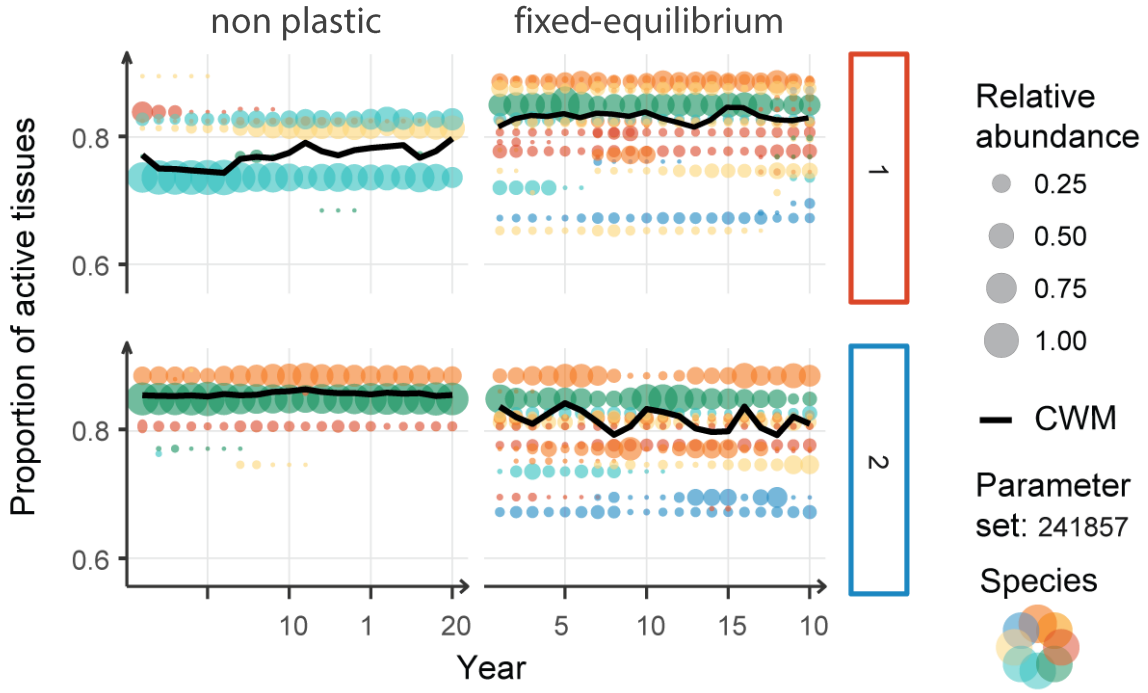
A shift in meta-community structure

More species → abundance variations but no composition shifts

Species diversity structure

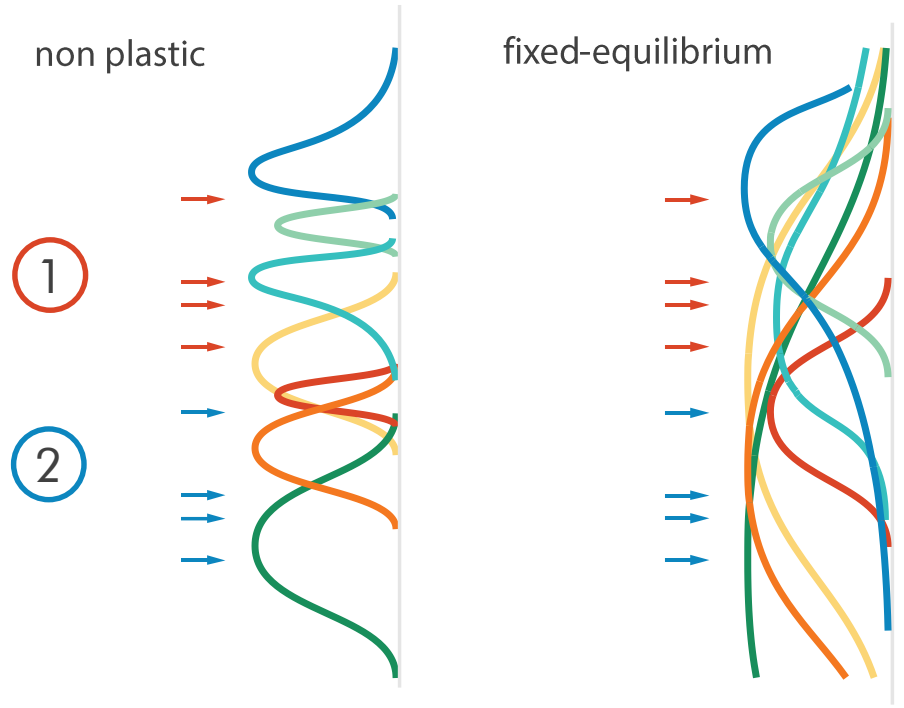


Community composition for 2 sites

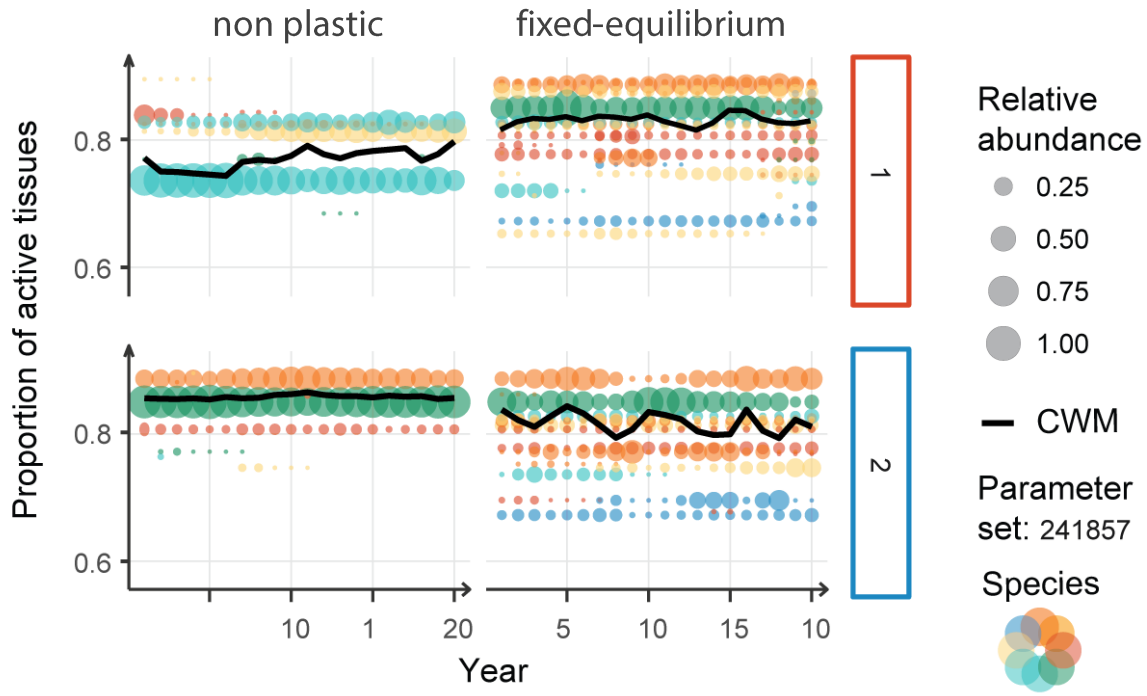


A shift in meta-community structure

More species → abundance variations but no composition shifts



Community composition for 2 sites

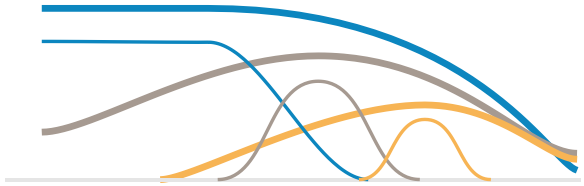


Results summary

Niche widening

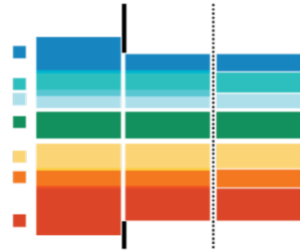
Availability gradient

Assymetric gain in favour of exploitative species = loose of sensitivity to resource variability

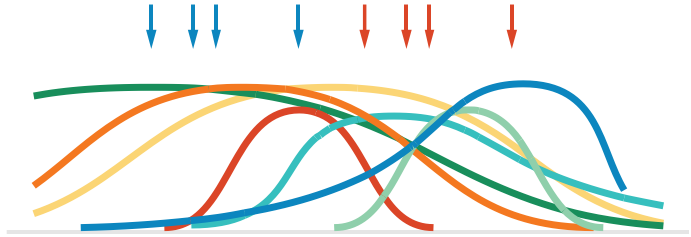


Variability gradient

Niche widening > asymmetric gain



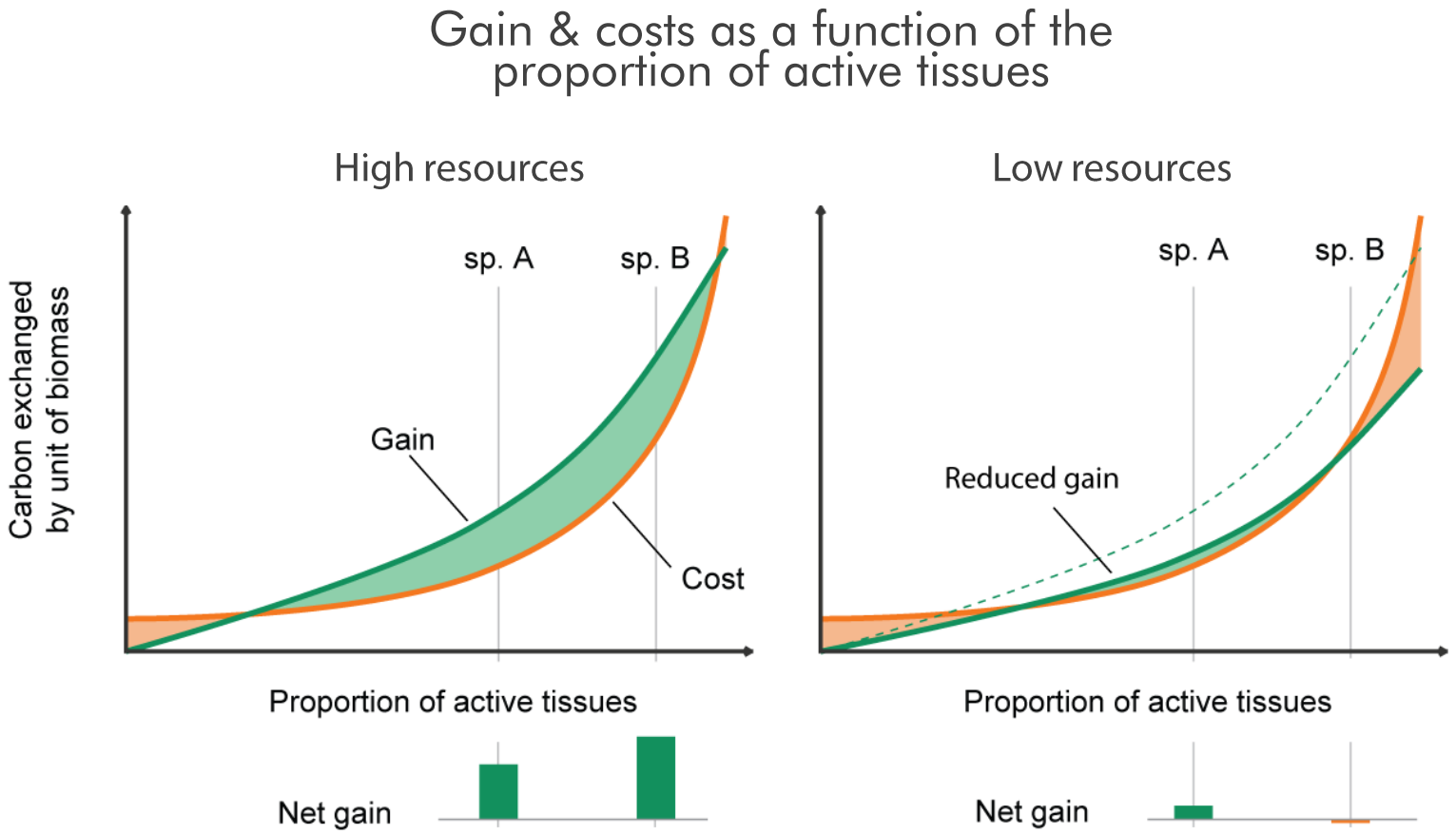
Plasticity alters meta-community structure



Discussion

Impact on community dynamics and community modelling

How plasticity favours exploitative species?



Exploitive= lower efficiency, but higher exchagne rate

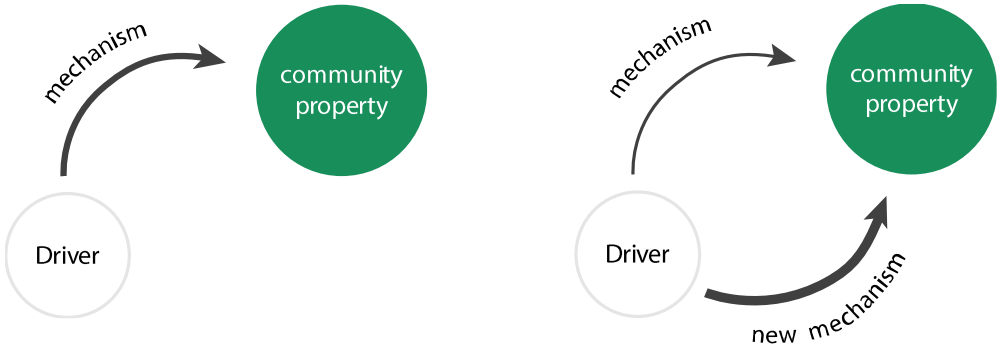
→ Sensitivity to unbalance functioning

Plasticity ensures balance and negates the sensitivity

Plasticity is a process integrated at the scale of the whole individual

Transfer to real systems?

There is not switch in reality



Is plasticity as important as it seems for diversity?

→ Cost of plasticity

→ Sampling effect

Response to specific disturbances:

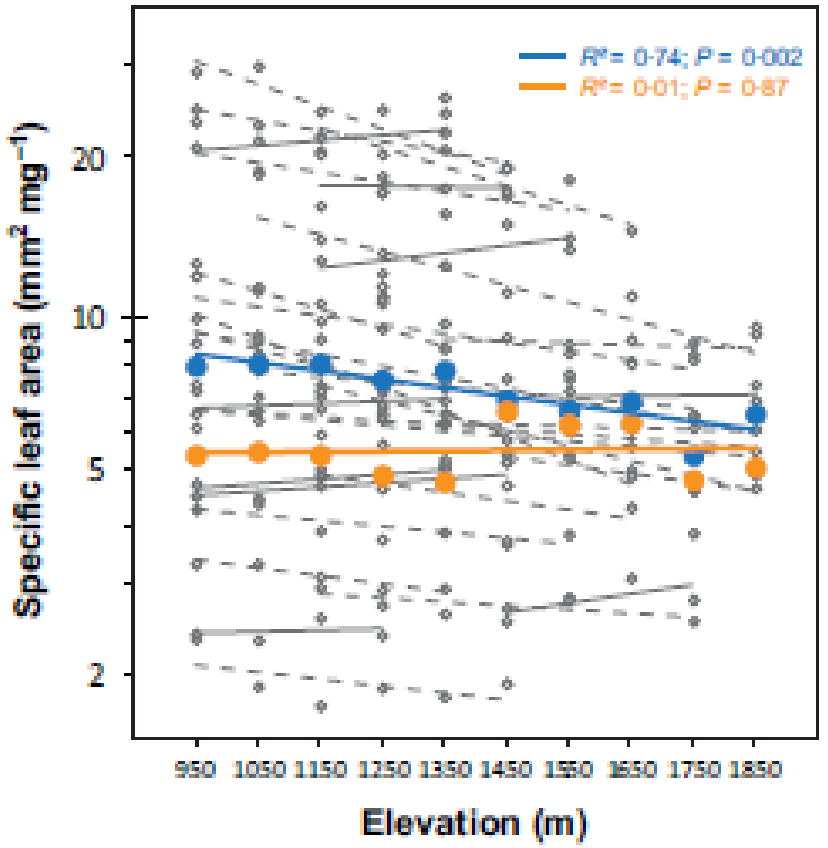
- new niche axis;
- asymmetric;

Frost & grazing

Dialogue between models & empirical experiments

MODEL	EMPIRICAL
Plasticity as a structuring process	Plastic dimensions & responses
Experiment with multiple scenarios	Cost of plasticity
Plasticity as a trait	Phenotypic flexibility

Mean specific trait along an elevation gradient



5

Conclusions & Outlook

A consistent framework for a better understanding of plasticity

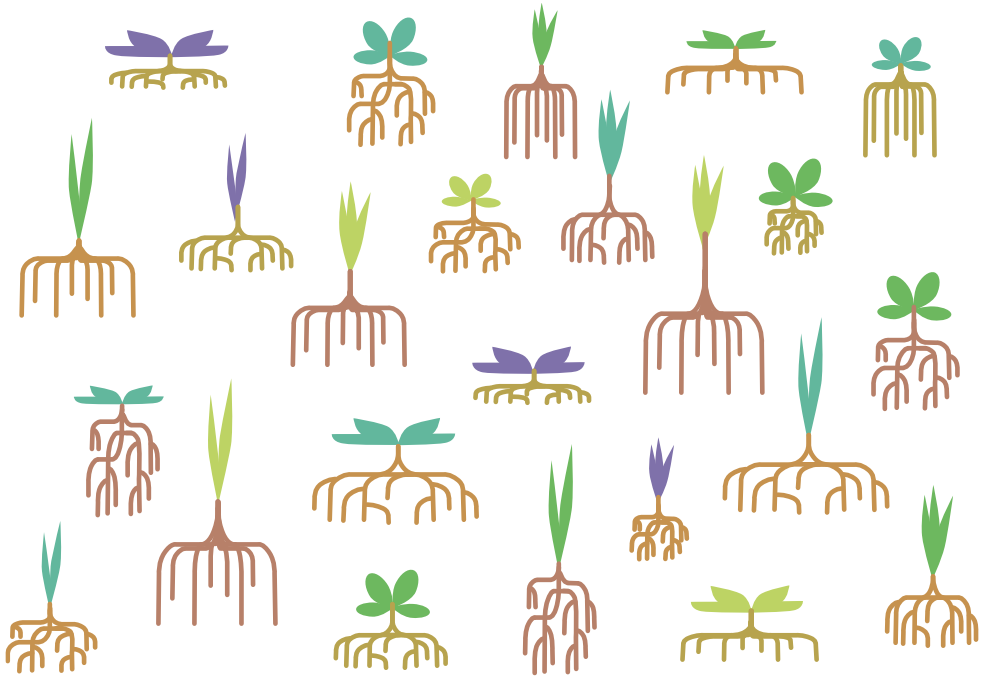
Modelling conclusions:

A diverse community framework

Diversity in strategies and species
Plasticity in coherent framework
Plasticity as a strategy (not explored)

but…

Reduce the number of parameter sets & stabilise the species
High functional convergence



Ecological conclusions:

A better undertanding of plasticity

Better understanding as an integrated growth process not just a response function

Plasticity impacts diversity via multiple mechanism at multiple scales

Plasticity is rarely symmetric (niche widening promotes subordinates species, assymetric gain favours certain strategies)

To go beyond

- Better calibration and strategy sampling to confirm results
- Climat, management and perturbation scenarios
- Explore the plasticity as a strategy

Thank you!

Merci pour votre attention.

Et merci pour l'accueil, l'aide, les rires, les discussions, les explications, les encouragements, les sorties terrains, les relectures, les photos, les pauses, les blagues, la motivation, le soutien, les distractions, les présentations, les pots, les mots gentils…

Merci !

Bonus!


FLOWERS ARE PRETTY STUPID.
SEE, IT'S A BRIGHT, SUNNY DAY OUT, RIGHT?
WELL, WITH THIS WATERING CAN, I CAN MAKE THEM THINK IT'S RAINING.
IT'S FUN TO MESS WITH THEIR MINDS.