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

Ph.D. defence of

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realised under the supervision of

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at IRSTEA Grenoble - TEGR

Context

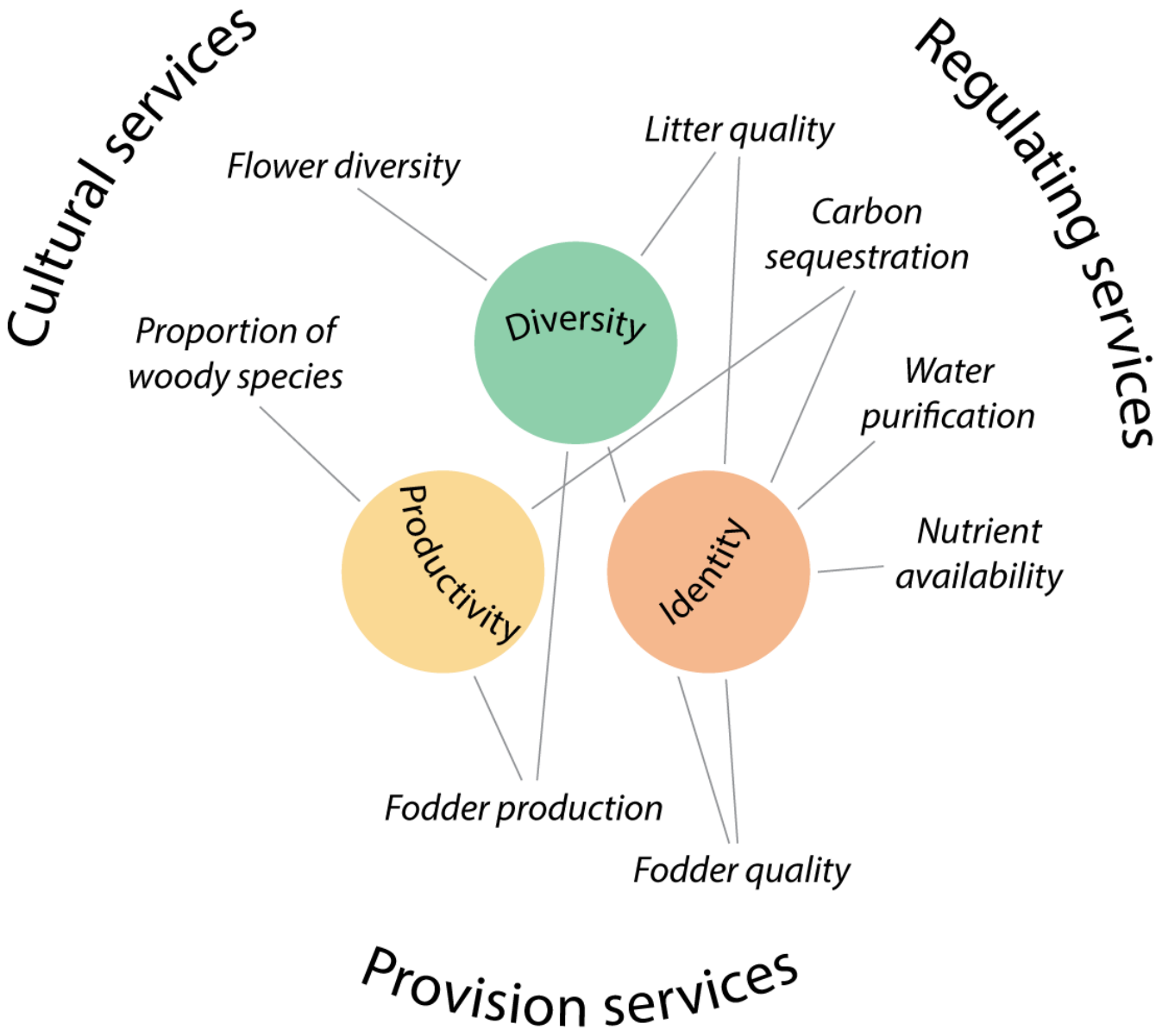
Mountain grasslands in a changing world

The value of mountain grasslands' diversity.

Ecosystem services

Benefits that humans freely gain from the natural environment

- Argument for nature conservation
- Tool for management

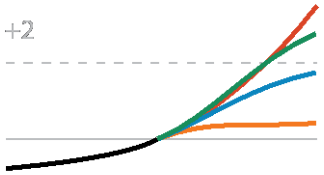


Assessing grassland ecosystem services

Trait: morphological, anatomical, biochemical, physiological or phenological features of individuals or their component organs or tissues - TRY database

Drivers

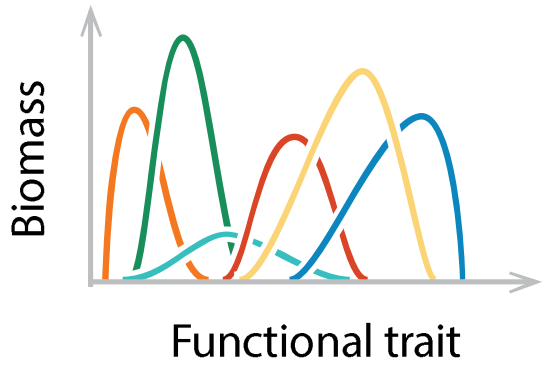
Climate



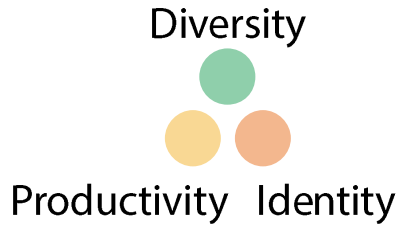
Land-use

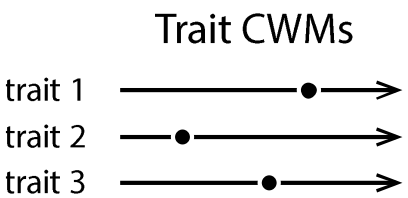
Soil

Description of community



Summary statistics

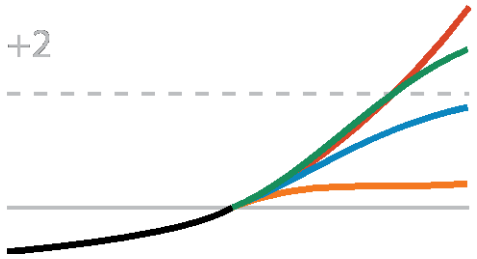


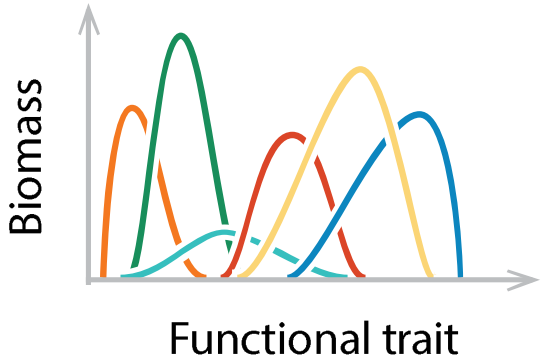


Services

Measure → Model → Compute → Estimate

Drivers, global change and services





Summary statistics

Diversity

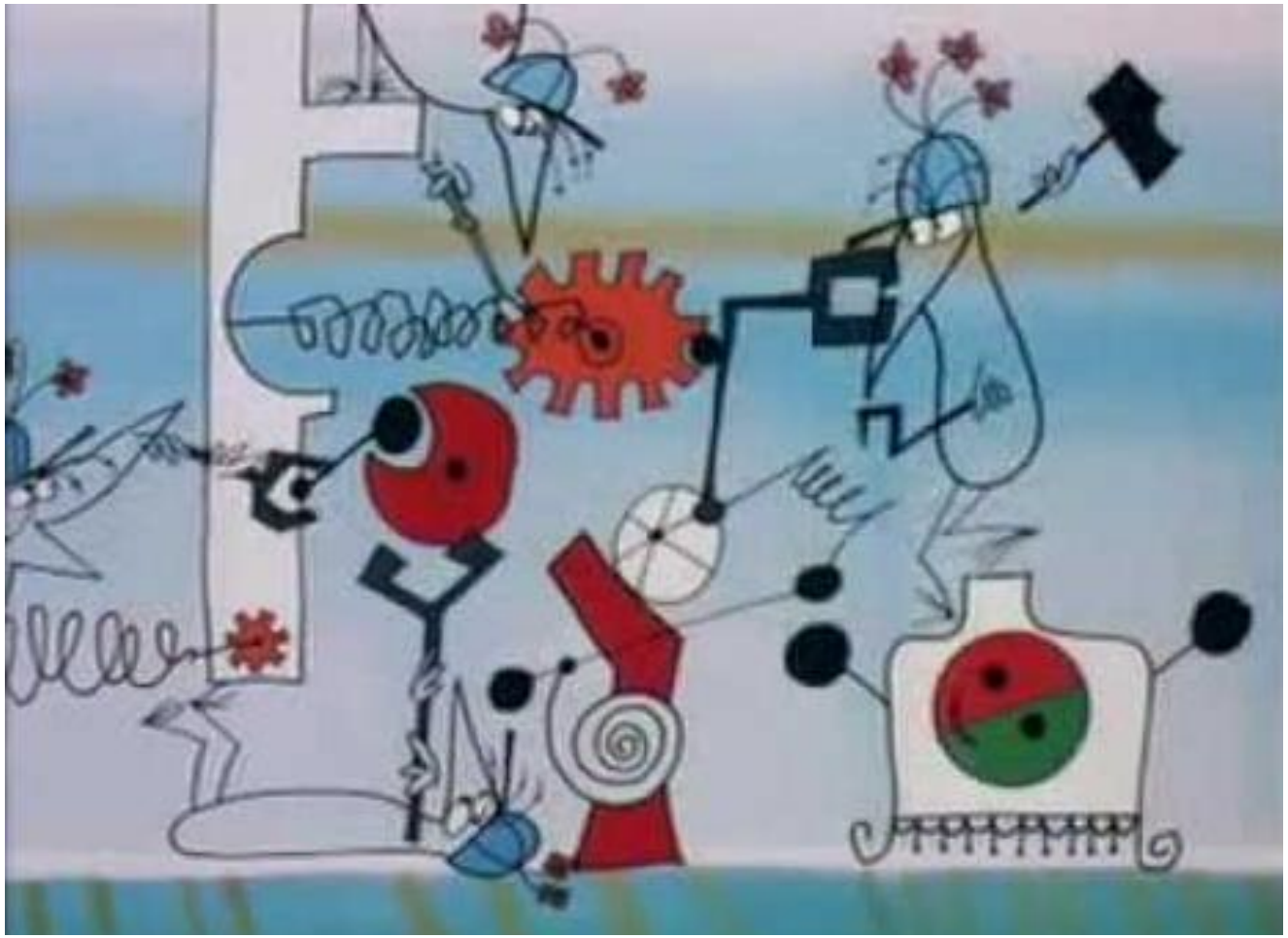
Productivity Identity

Trait CWMs

trait 1
trait 2
trait 3

Project → Model → Compute → Estimate

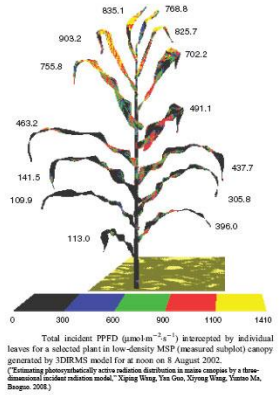
Models to understand and predict



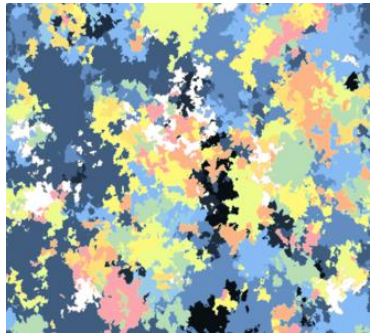
- Understanding by explaining
- Emerging behaviour
- Allow exrtapolations
- Experiment at low cost

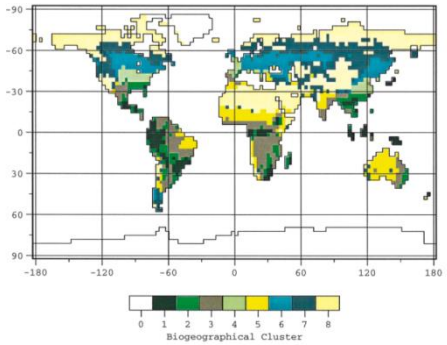
A gap to fill

Combine the species diversity and ecological processes of large scale models with the plant level processes of small scale models.



Total incident PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) intercepted by individual leaves for a selected plant in low-density MSP (measured subplot) canopy generated by 3DIRMS model for at noon on 8 August 2002.
("Estimating photosynthetically active radiation distribution in maize canopies by a three-dimensional incident radiation model." Xiping Wang, Yan Guo, Xiyang Wang, Yunnes Ma, Baogue. 2008.)



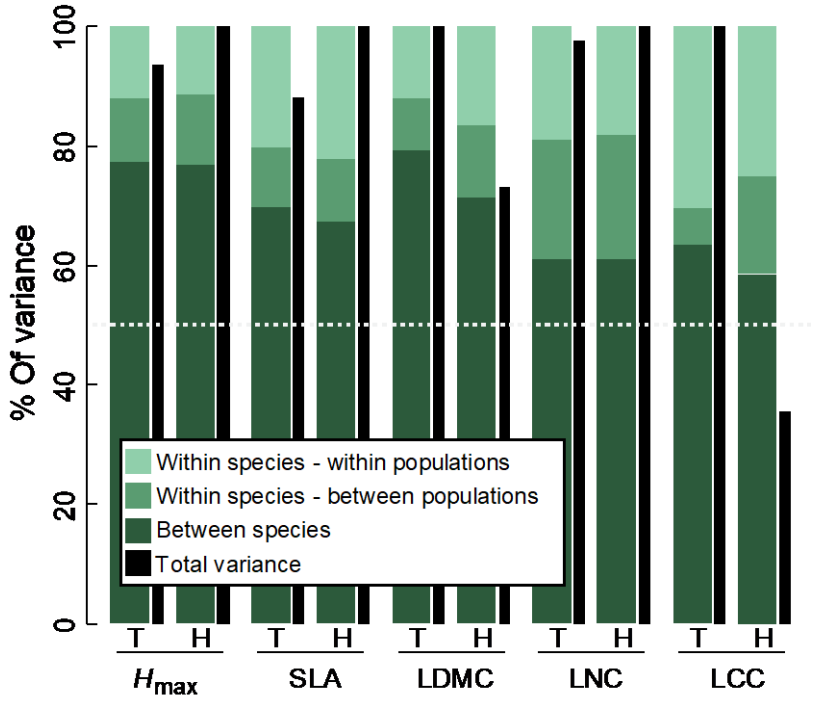


Molécular — Organ — Individual — **Communuty** — Landscape

S< — s, min / mm — h, j / cm — j / **cm, m** — j, week / m, km

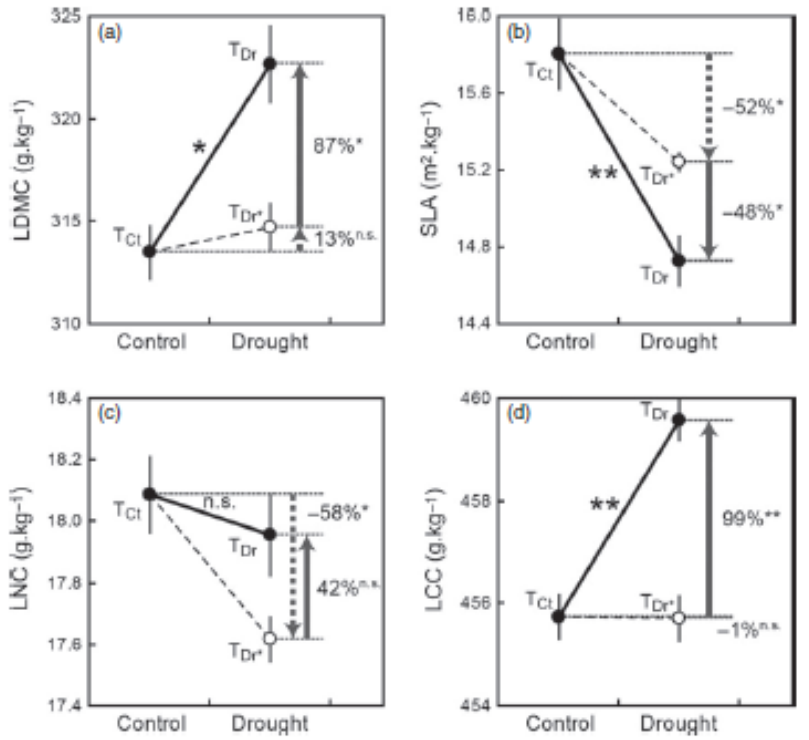
Physiological model — **Growth/development model** — **DGVMs**

Intra-specific variability matters and impacts the community responses



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

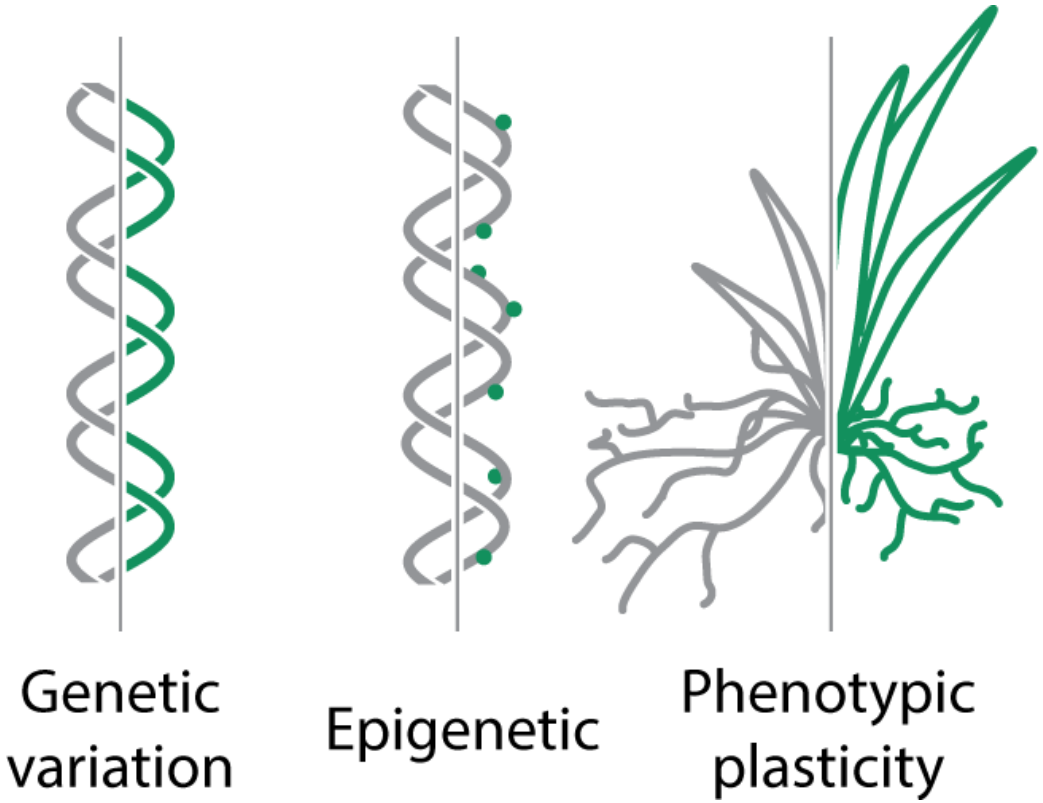
Up to 40% of the total variability of some traits.



Jung 2014

Strong impact on community response

Phenotypic plasticity, one source of variation



Plasticity

Often overlooked.

Hard to study in empircal studies.

Potential for rapid adaptation to climate change.

Potential for mitigation of the effects of environmental variability.

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Questions

Technical and scientific interrogations

How does phenotypic plasticity impact grassland community properties & dynamics?

How model diverse plant communities integrating phenotypic plasticity?

How does phenotypic plasticity impact grassland community properties?

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Introduction

State of the art and concepts

The concept of niche

How a species fit in a set of env. conditions.

Hutchinton: n-dimension volume.

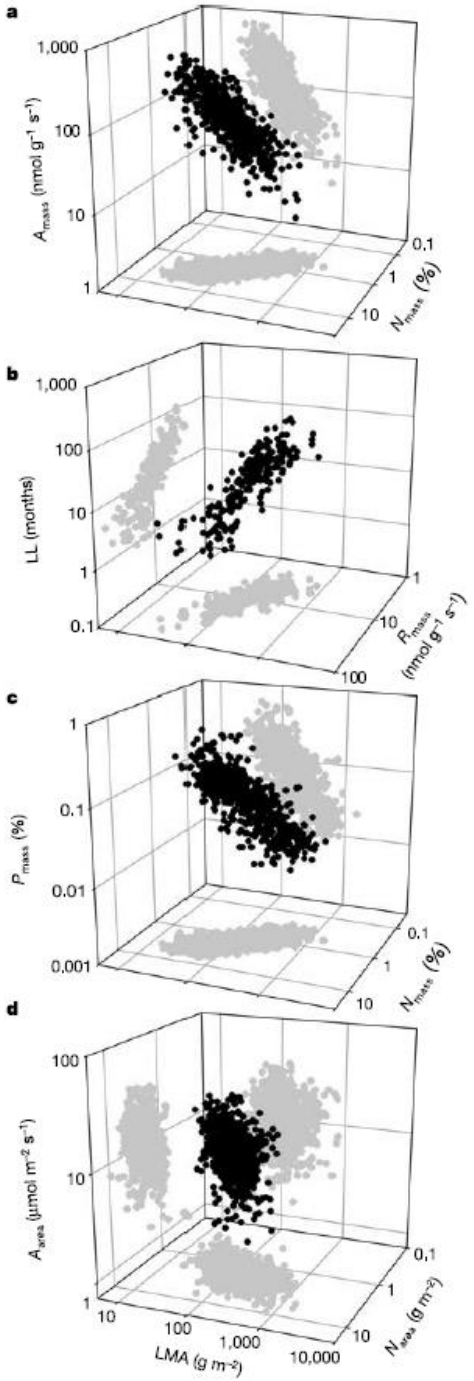
Translate the impact of an environmental factor on the fitness function (growth, survival and reproduction)

Affected by biotic condition fundamental → realised

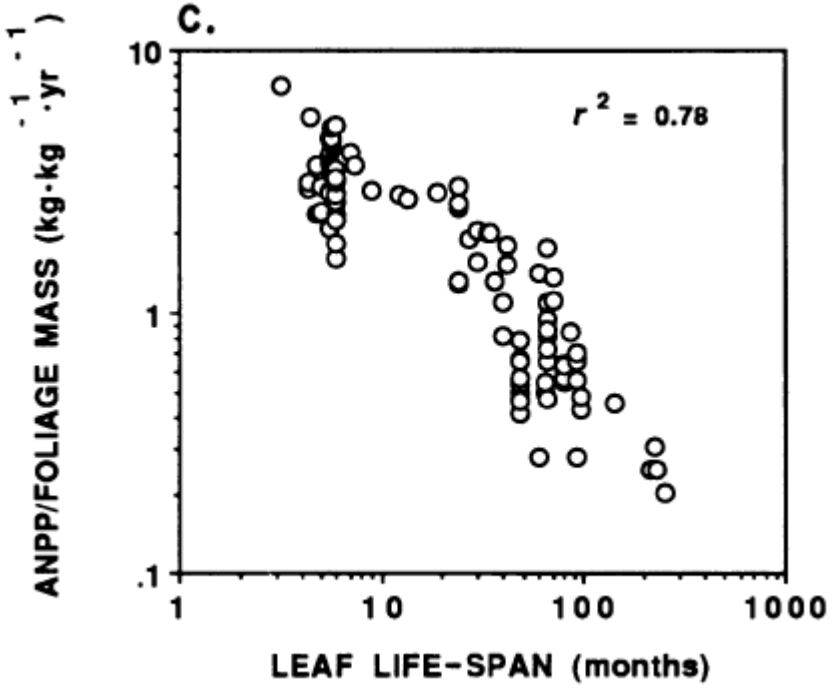
Despite the similar functioning

Why do not plant share the same niche?

The leaf economic spectrum

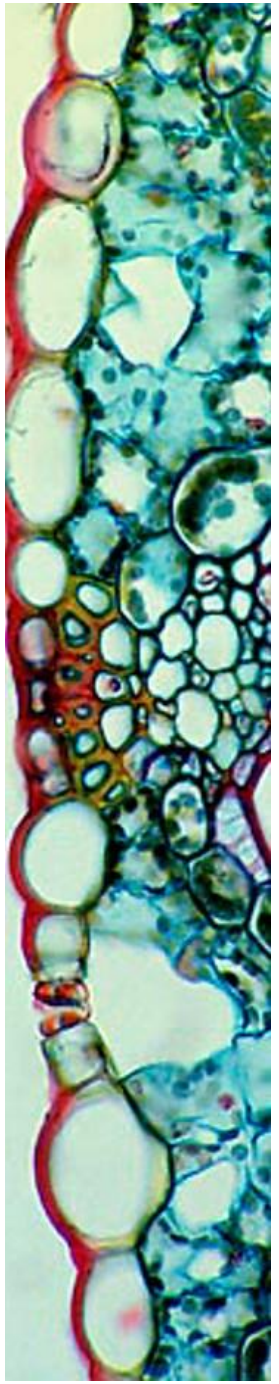


Wright et al. (2003)



P. Reich (1992)

- Variation in structure and resource use
- Emerge from ecological and biological constraints
- Allow simplification of plant classification
- Partly explain by the trade-off between active and structural tissues



Trade-offs and strategy space

Strategy space.

Generalise trade-offs to other processes: roots exchanges, reproductions, etc…

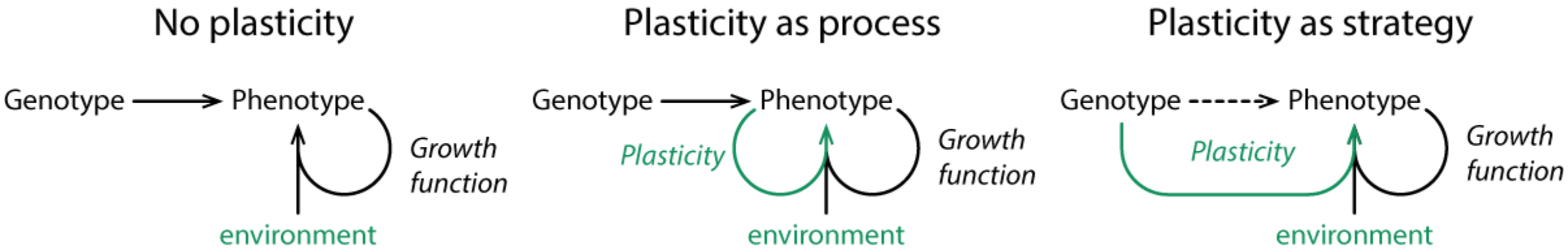
Continuous axis, convenient for modelling

→Same functioning framework but species differences

- How does plasticity fits in this framework ?

Plasticity as a strategy

Active plasticity: anticipatory, and often highly integrated, phenotypic changes in response to some environmental cue



Modelling plasticity

Finalist perspective

Plasticity in models: dimensions, objectives and assumptions

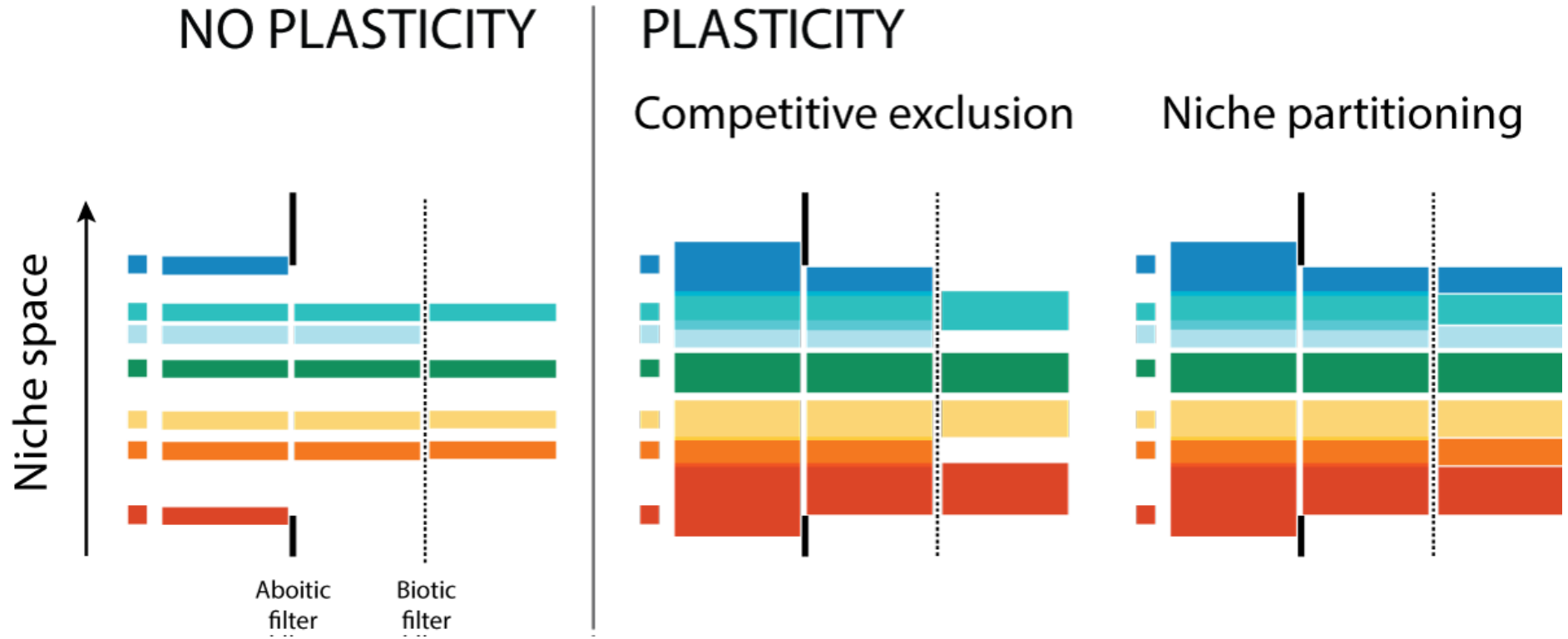
Dimensions: what traits are plastic,
Objective: what drives the changes,
Assumptions: implicit or explicit rules

How does palsticity impact properties and dynamics of plant communities?

Widenning niches

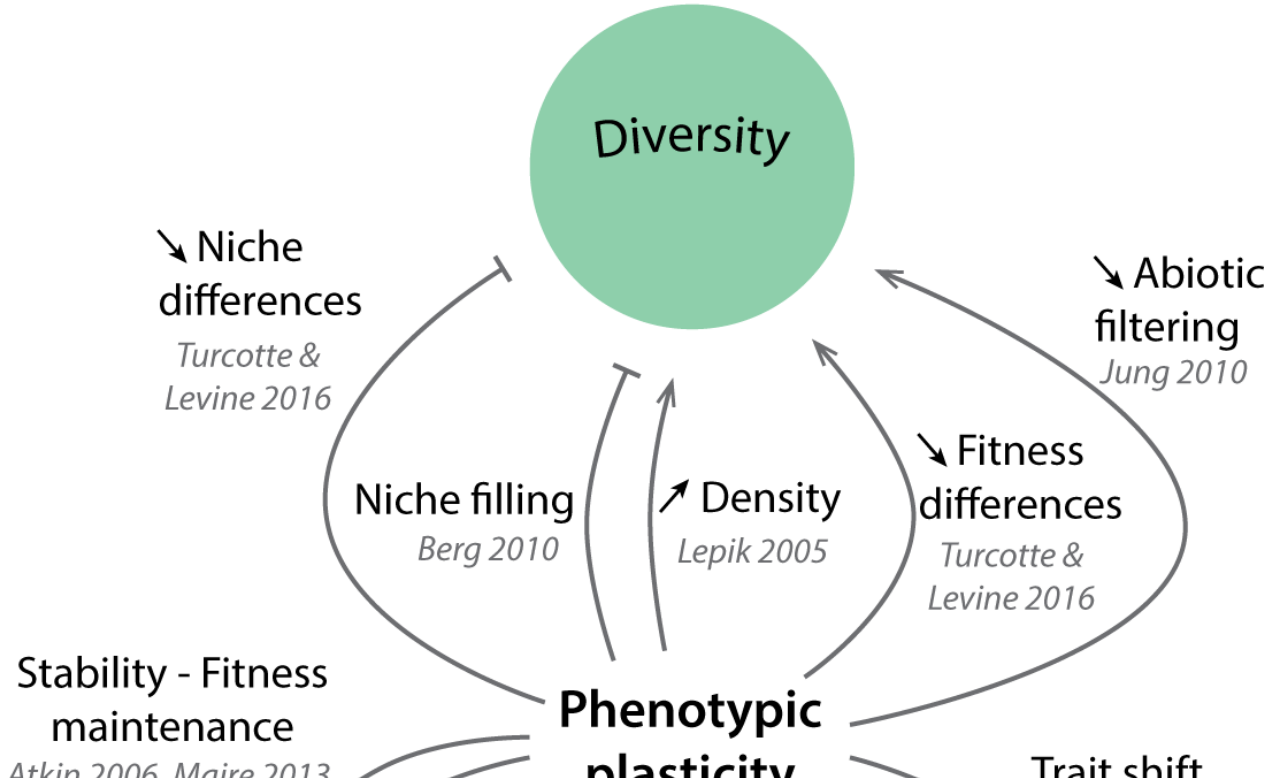
Effect on community's diversity

Niche partitionning vs competitve exclusion



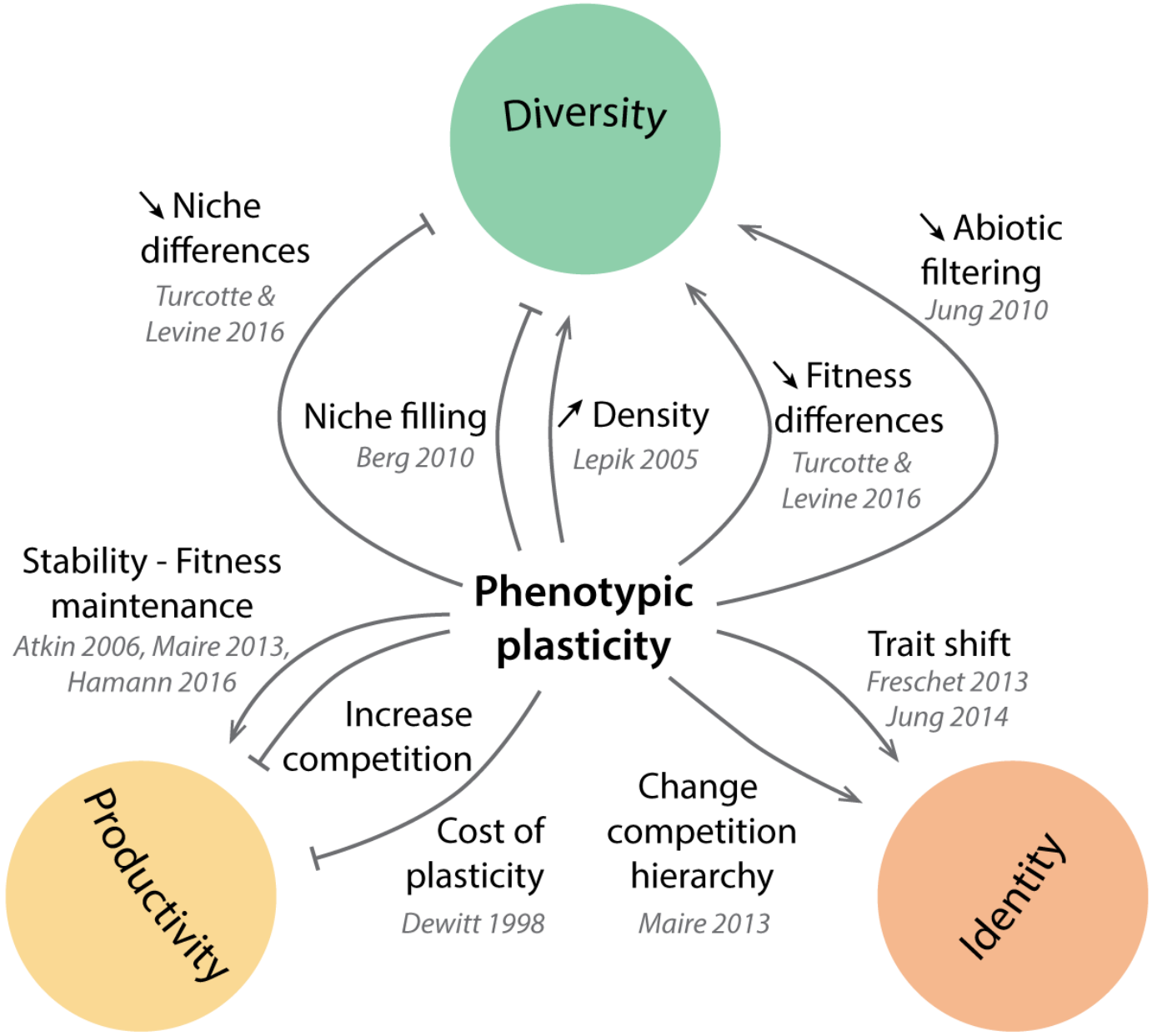
We do not agree, yet

All effects



We do not agree, yet

All effects



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Results

Presentation of *MountGrass*

Individual- and community-level effects of plasticity

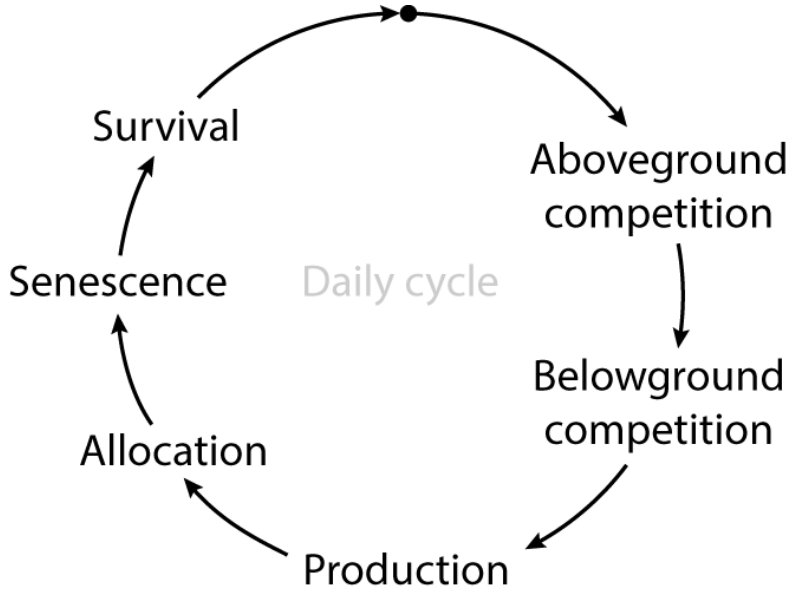
Model overview

MountGrass' world representation

Obj: community properties and dynamics emerge from plant fcting. → individual

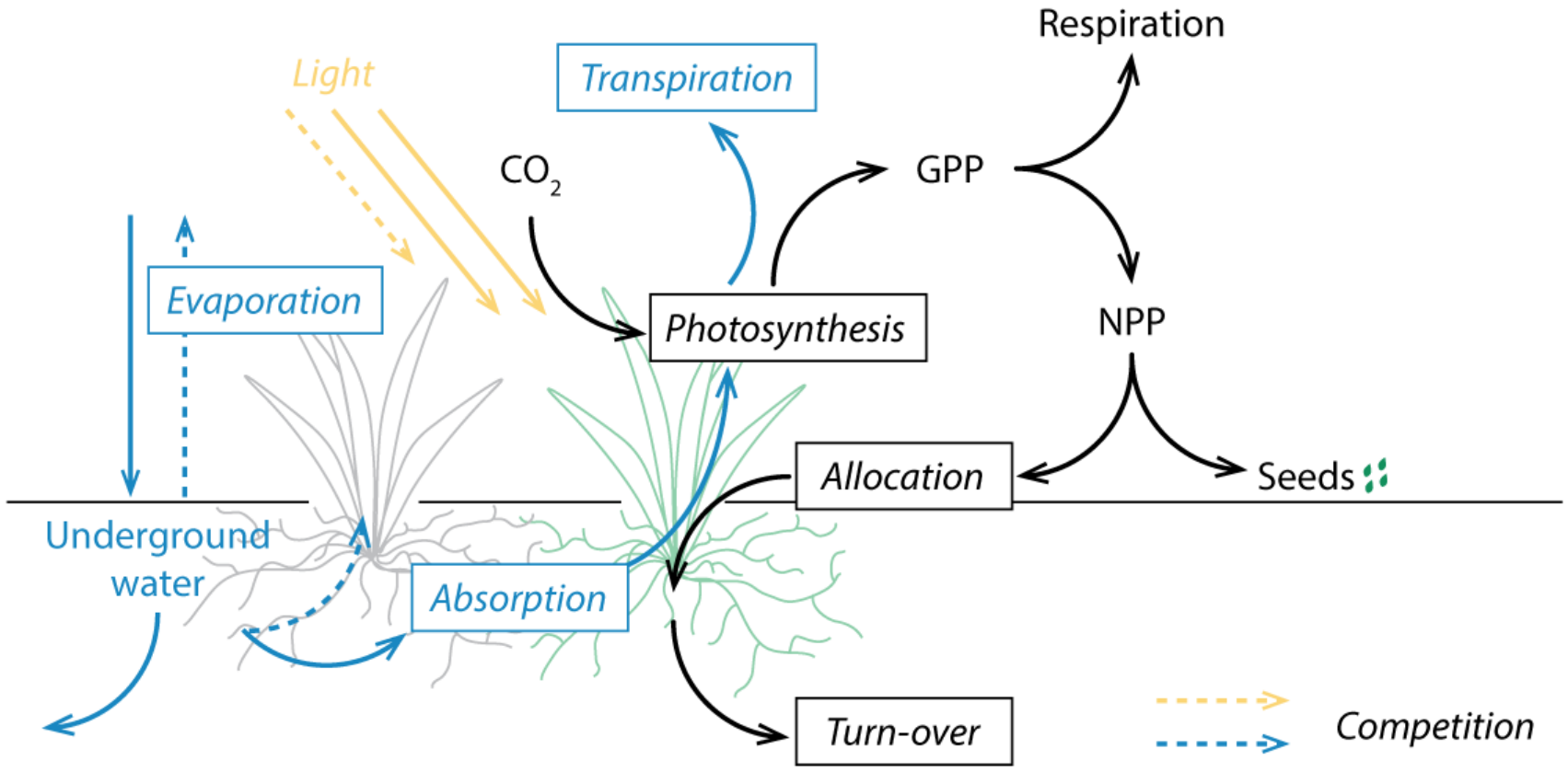
IBM spatially explicit

- Scales and resolutions
- Cm, day
- Seasons
- Grid

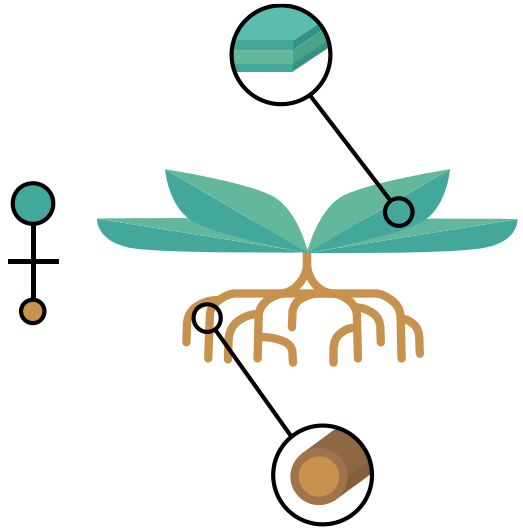


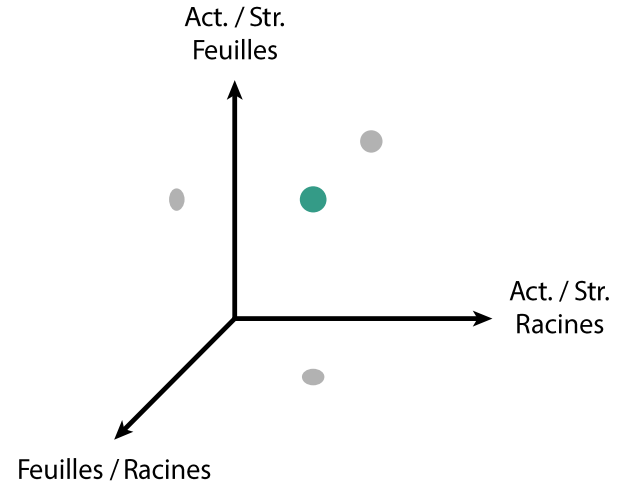
MountGrass' processes

- Main processes



Plant representation





Based on trade-offs and strategy space

4 vegetative compartments

Par, pas, r:s

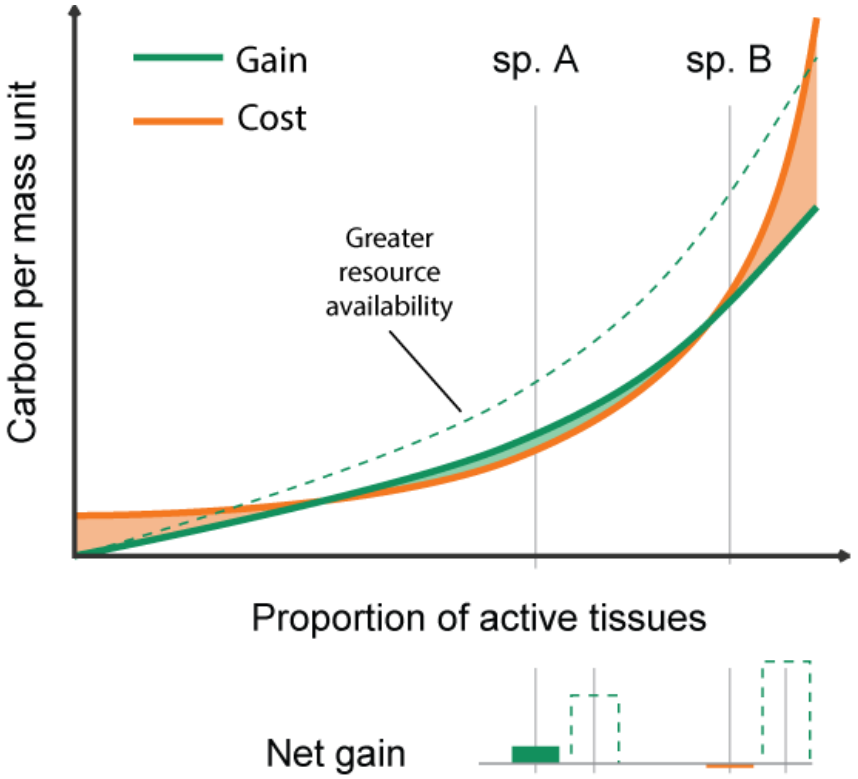
Different dry volumic masses → Change the cost of exchange area

But also alters turn-over and respiration

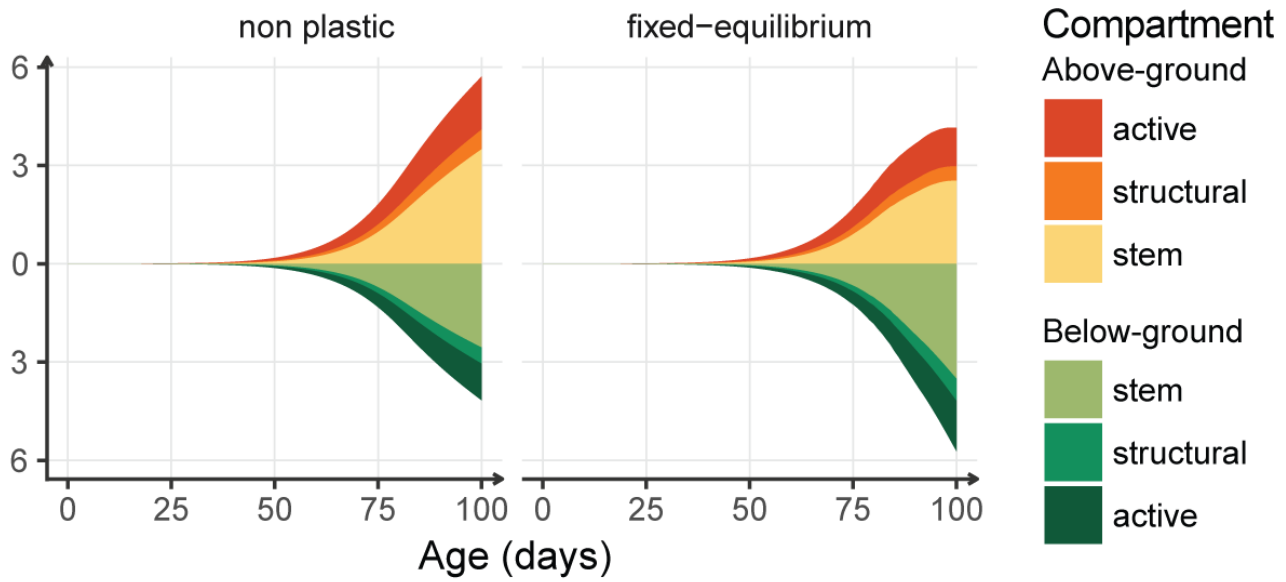
How does the phenotype impact the plant growth?

The components of plant growth

TISSUE EFFICIENCY



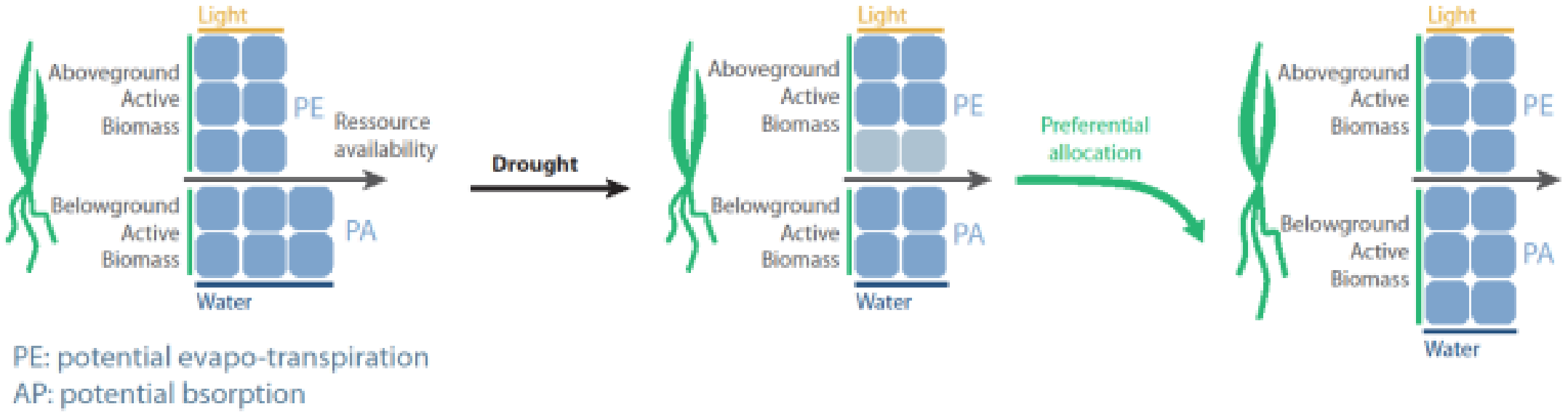
BALANCE



How does plasticity fit this representation and drive the phenotype ?

Algorithms

- Objective functions
- Plastic dimensions
- Assumptions



PE: potential evapo-transpiration
AP: potential bsorption

- Objective function: equilibrium, axis: root:shoot ratio
- One among 3

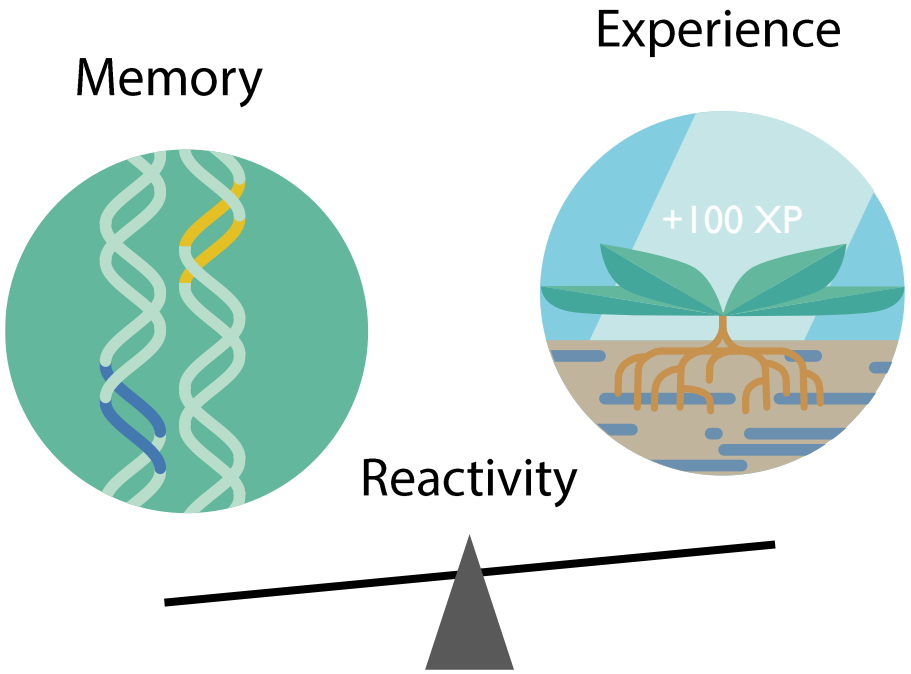
Just rules, not a strategy

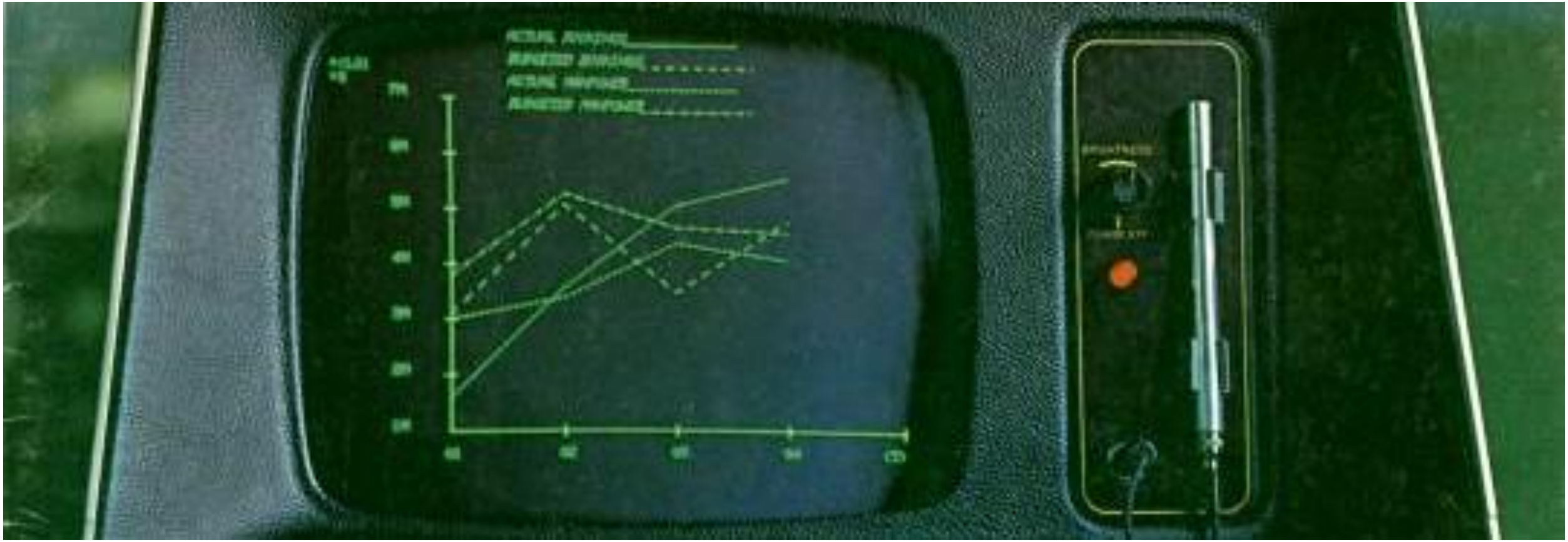
The future: between species memory and individual experience

How make it a strategy, and not only a process ? Make the projection definition species specific

Memory: genetic memory of the species

Reactivity: relative weight given to the individual experience





Simulation results

Individual-level simulations

The plasticity and the potential niche

Simulation set-up

Simulations

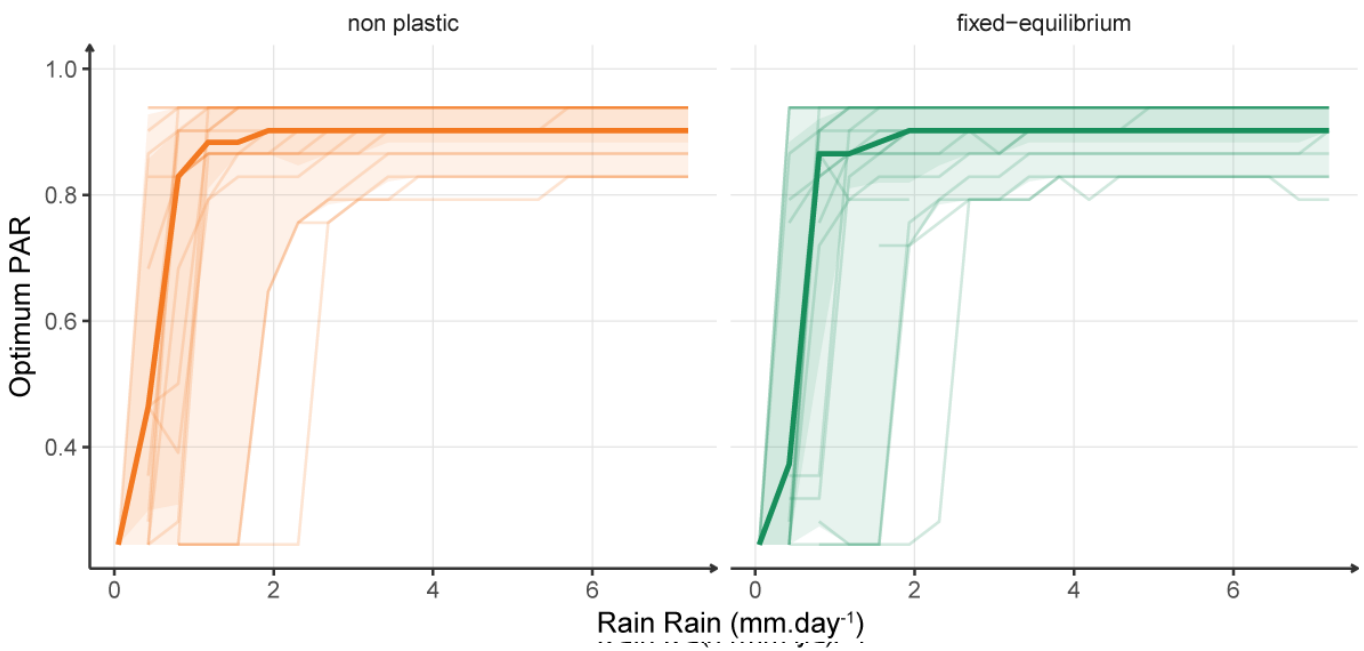
- 20 Parameter sets
- Plastic and non plastic
- Gradient of water availability
- N * m phenotypes

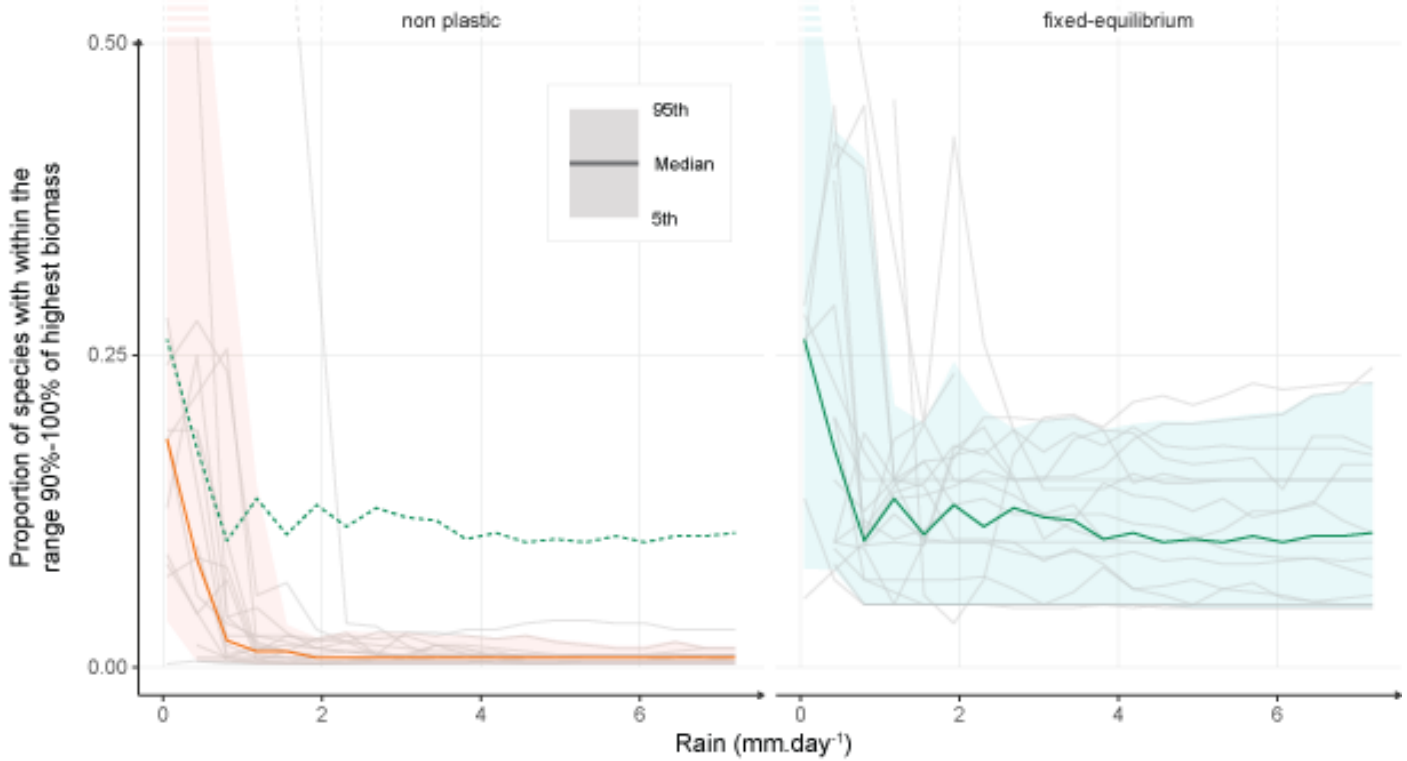
Each simulation

- Size/lenght

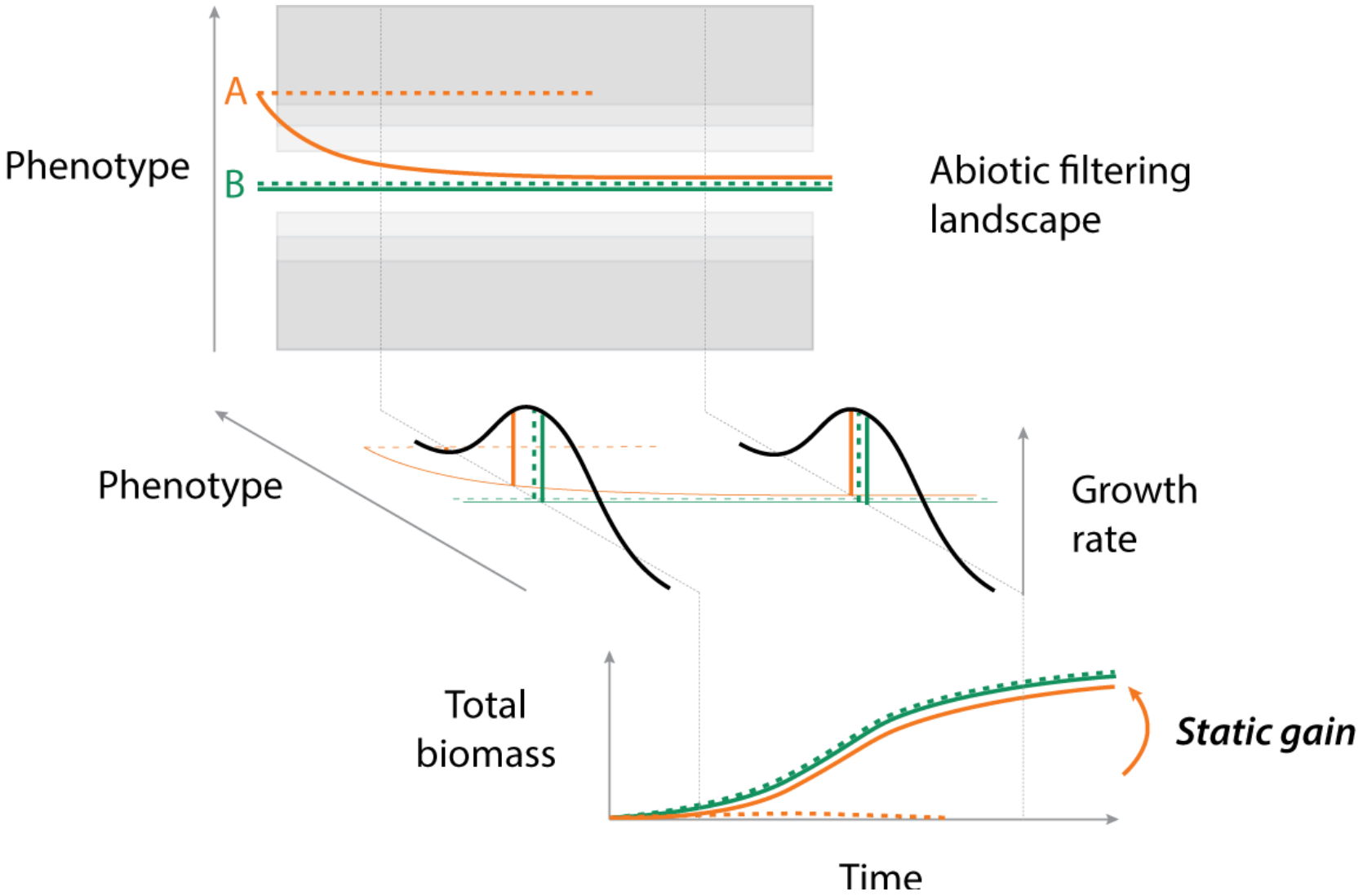
Homogeneous conditions & static gain

- No shift in best strategy (proportion of active tissues)
- Reduction of growth differences (not shown)
- Little change in maximum biomass



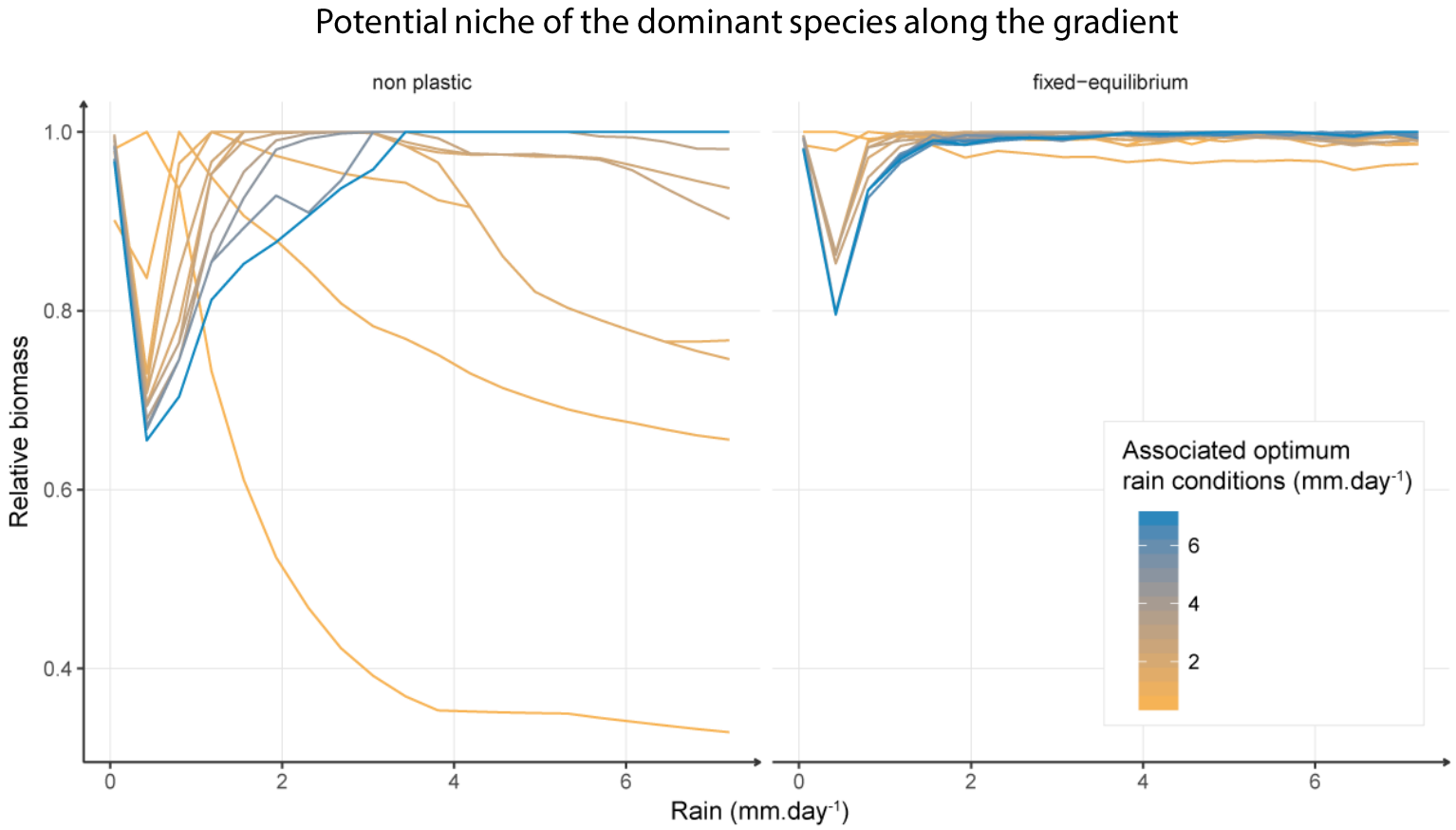


Static gain


A
B
Phenotype
Abiotic filtering landscape
Phenotype
Growth rate
Total biomass
Static gain
Time

Widenning of the potential niche

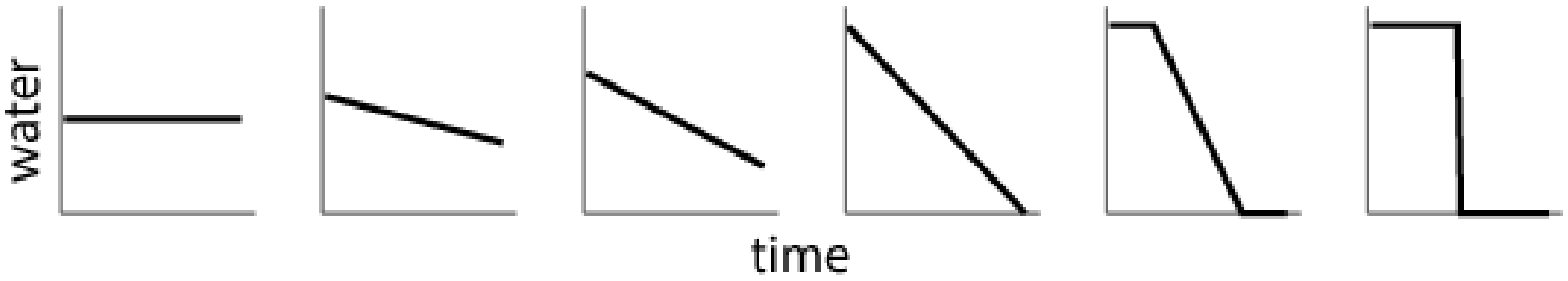
- Increase in potential species diversity
- But not functional diversity
- No change in dominant strategies



Simulation set-up

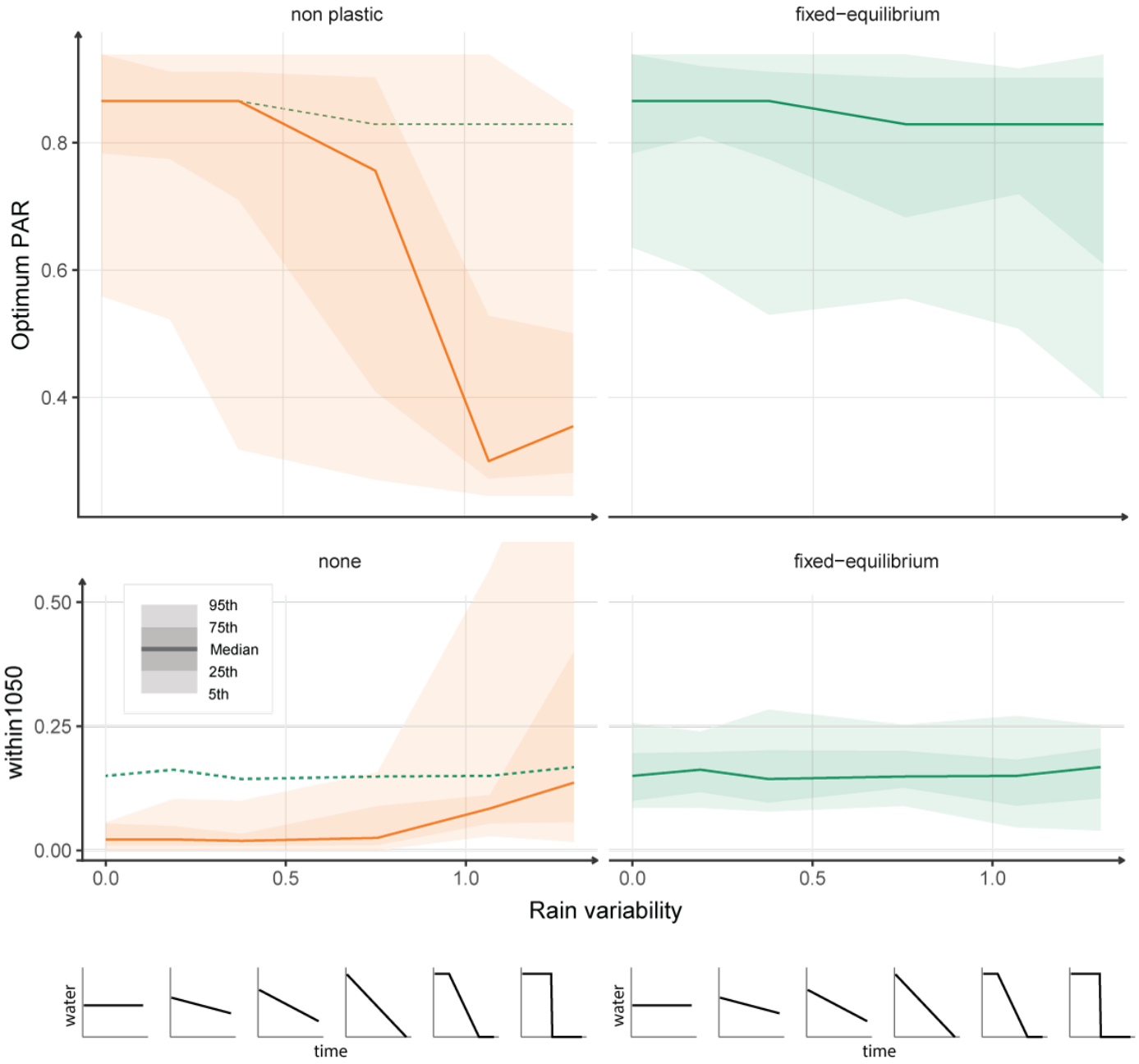
- Simulation
- N Parameter sets
- M conditions
- 2 algorithms

- Each simulation
- Size, length, …

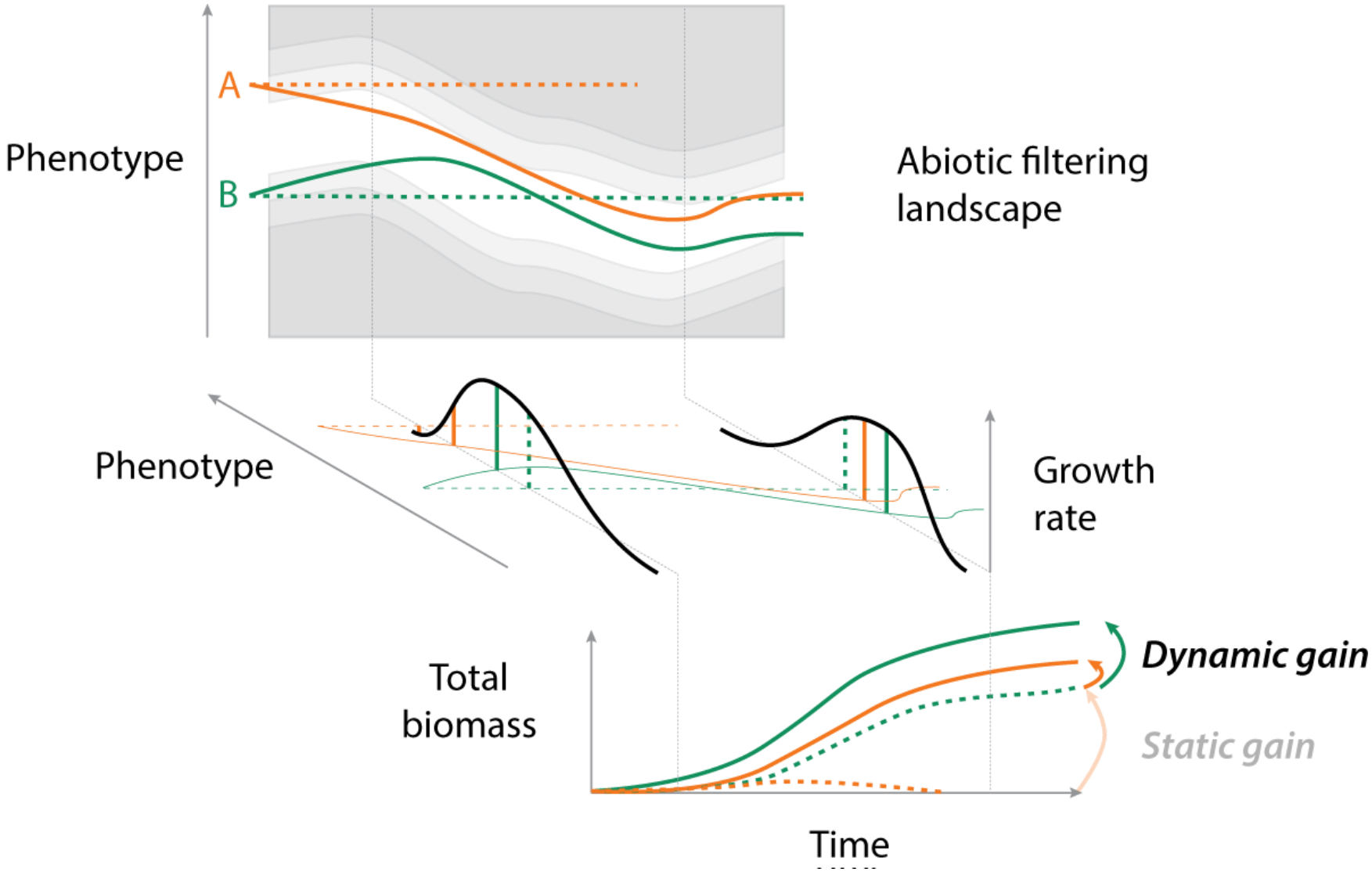


Heterogeneous conditions & dynamic gain

- Increase of relative BM (~ n%)
- Changes in dominant strategy (assymetric gain)
- Reduction of growth differences



Dynamic gain



Consequences at the community level ?

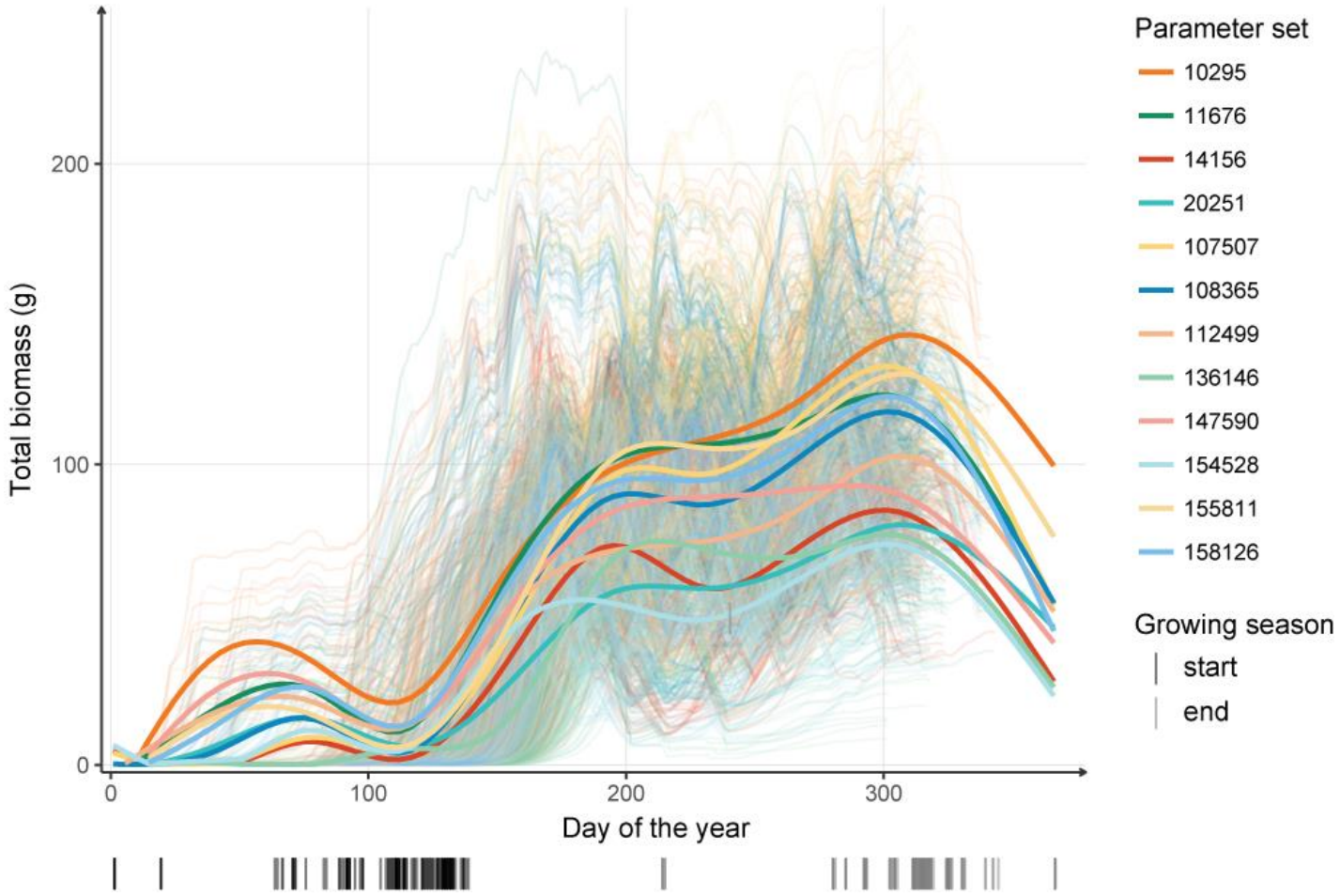
- Shift in dominant strategy
- Higher potential species diversity
- Competitive exclusion by exploitative species?

Community-level simulations

Community structure and diversity

The realised balance between mechanisms

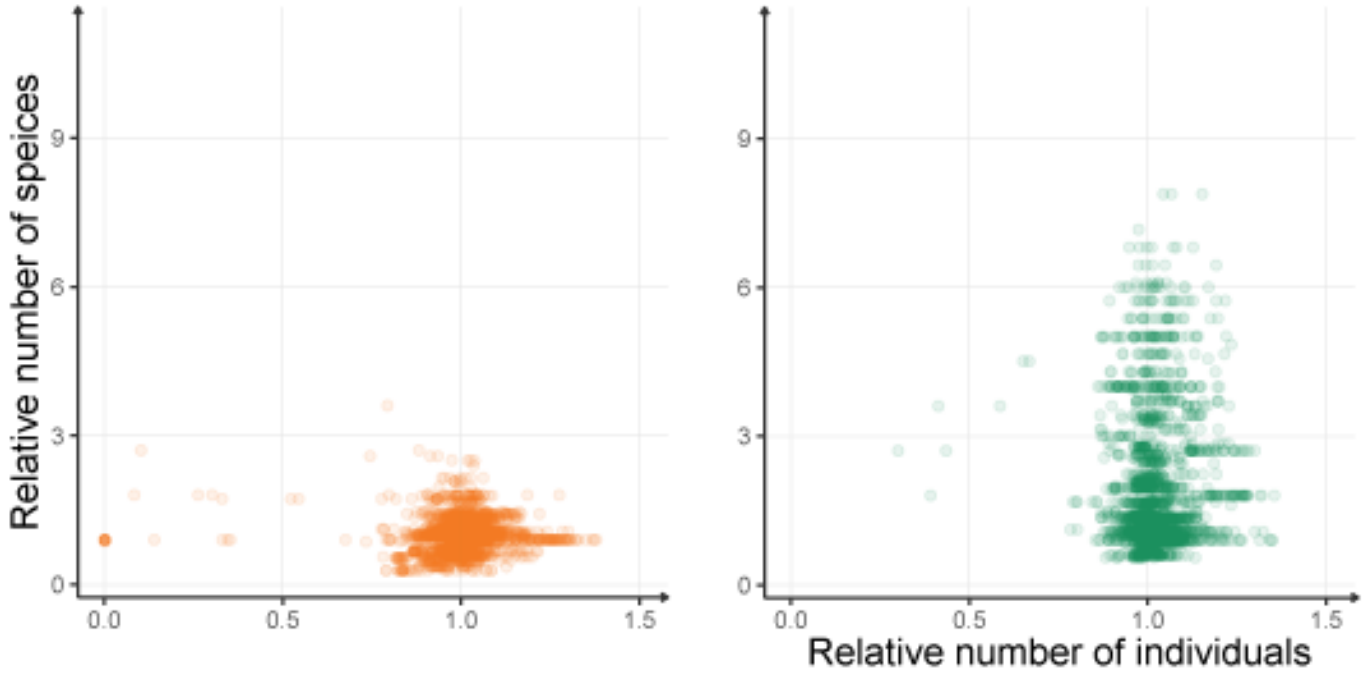
Simulation set-up



Effect of the niche widening on diversity

- reduction of fitness differences >> reduction of niche differences

- Toward neutral situation

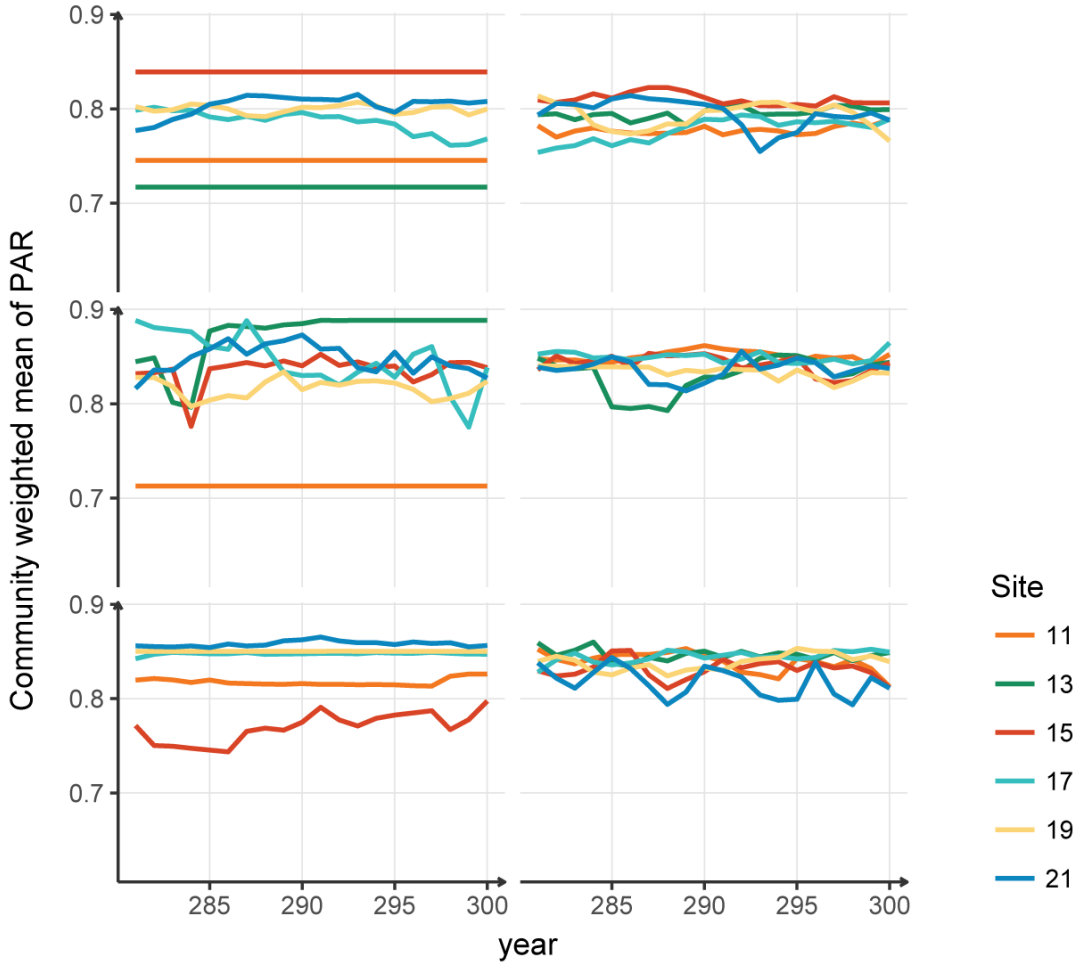


Effect on dominant strategy (asymmetric gain) ?

Dominant strategies variability

Effect on dominant strategy << effect on community structure

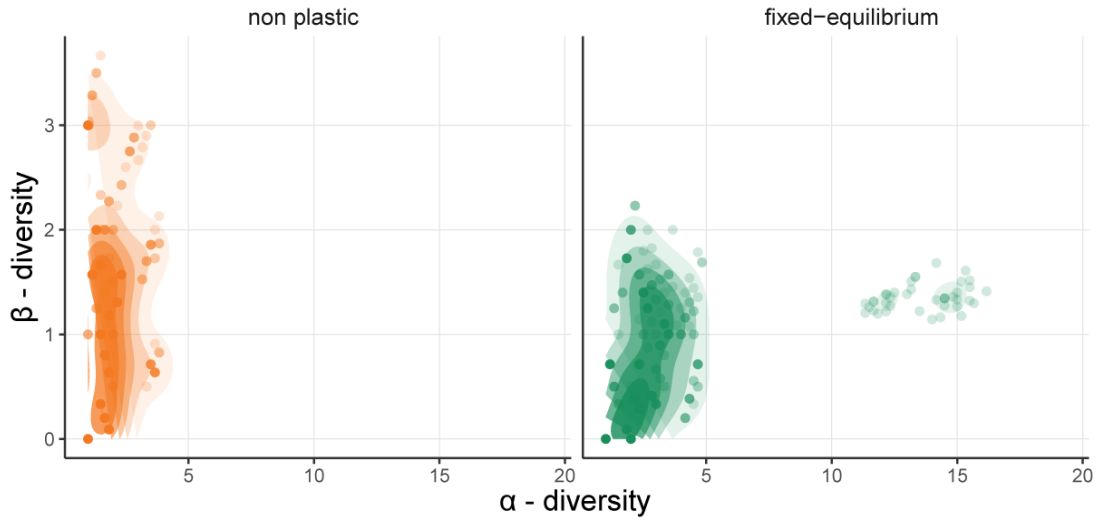
Yet, some differences should emerge (extended simulations needed)

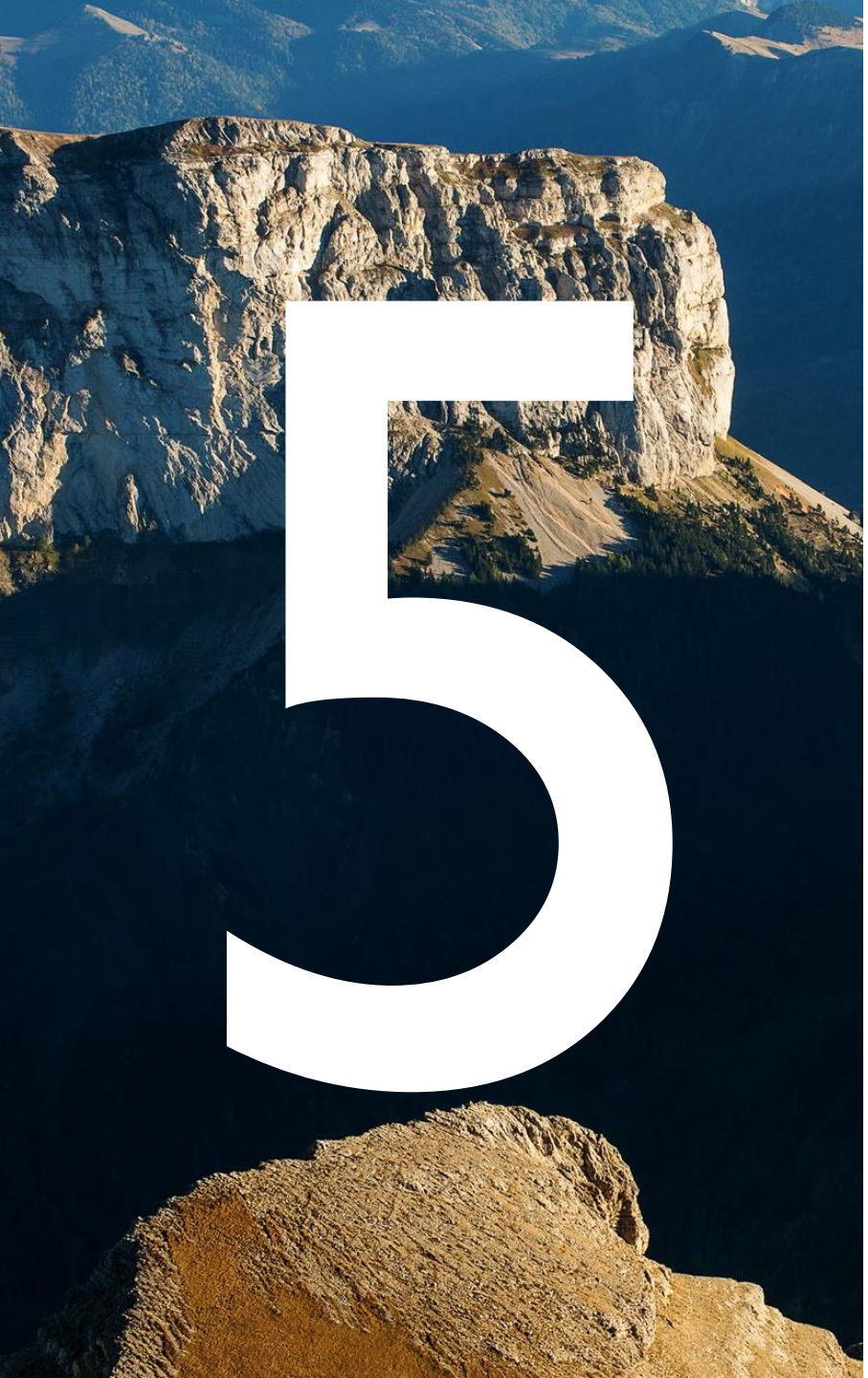


Different meta-community structure

A shift in community structure

- From distinct dominated communities to diverse communities with overlap
- Niche overlap at the meta-community scale. Tissue efficiency more important than memory.
- Reduces the importance of the Root:Shoot ratio axis → better sampling on the other two dimensions





5

Discussion

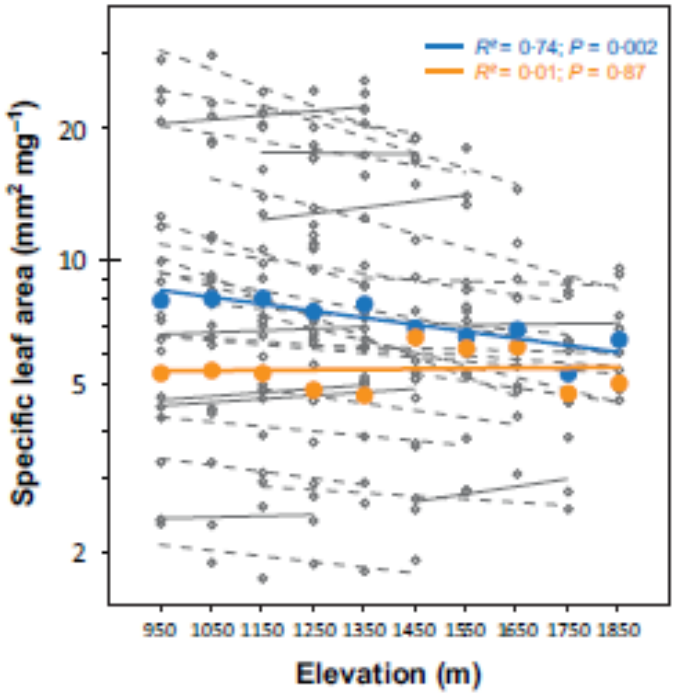
Impact on community dynamics and community modelling

Commmunity dynamics and stability

Results → hypothesis → simulation plan + limitations

Community variability and overlap → soft abundance changes, not critical transition → but need to establish stable communities (better exploration of trait space) to be sure not just sampling

Convergence vs divergence



Solution:

Change assumptions

…but increase model complexity

Niche differentiation

Avoidance vs resistance vs resilience

The frontiers of plasticity

- Traits are measures
- Plasticity is a shift in what is considered constant (allometry, growth rate, growth traits, plasticity traits → genes?)

- Measure of plasticity
- Plasticity of plasticity traits
- Plasticity = question of complexity of models
- How deep should we go in the rabbit hole
- Can we extract some general rule, behaviour that goes with the increasing complexity ?

6

Conclusion & Perspectives

New hypothesis and simulations

Model developments

Diverse community framework

- Diverse strategies
- Resource dependant optimum
- Integrated plasticity in coherent framework
- Plasticity as a strategy

but…

- Plasticity leads to high convergence, may need to diversify objective functions or assumptions…
- Strategy space must be better sampled for each parameter set

Plasticity is more than ISV

- Need to look at the process (even if not PP)
- Niche widdening and competition reduction
- Challenge strong hypotheses

To go beyond

- Better calibration to confirm results
- Explore the plasticity as a strategy
- Climate scenarios
- Management and perturbations
- Stability/invasibility

- New forms of plasticity
- + exploration of other strategy axis (reproduction, frost resistance)

→ Multi-risk plasticity framework

- Epigenetics

Thank you