# 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

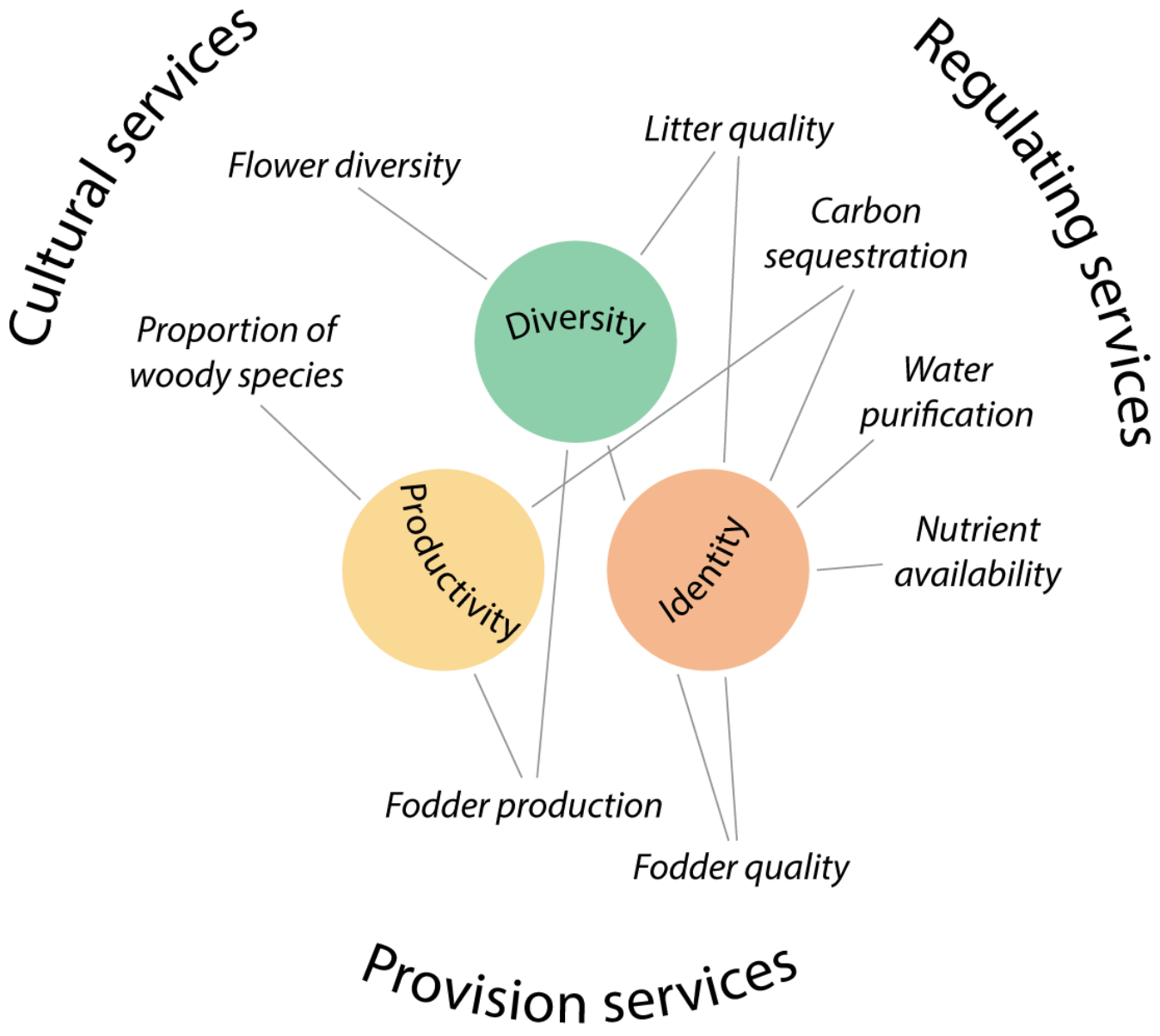
Mountain grasslands in a changing world

# The value of mountain grasslands' diversity.

# Ecosystem services

Benefits that humans freely gain from the natural environment

- Argument for nature conservation
- Tool for management

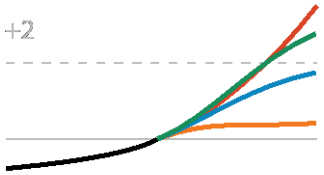


# Assessing grassland ecosystem services

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

Drivers

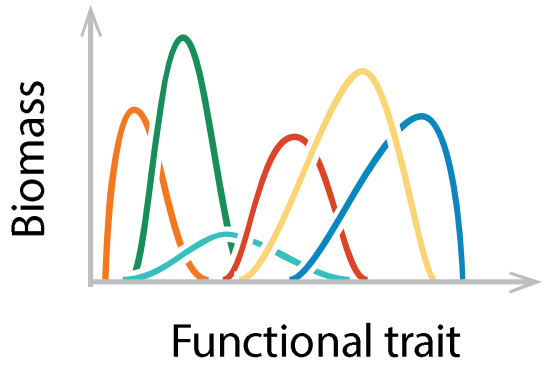
Climate



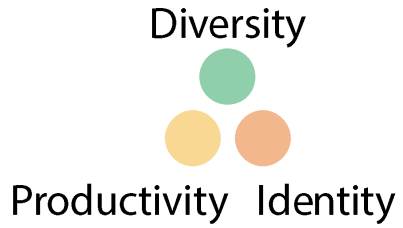

Land-use

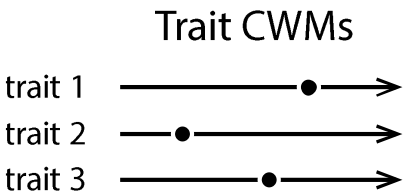
Soil

Description of community




Summary statistics

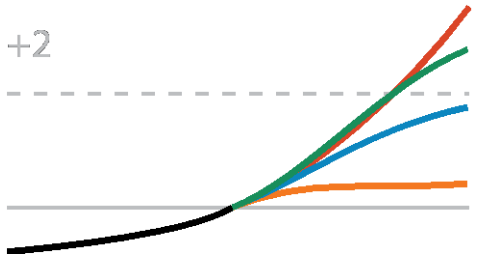


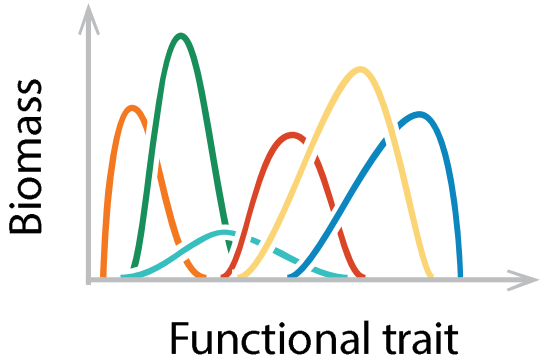




Services

Measure → Model → Compute → Estimate

# Drivers, global change and services




Summary statistics

Diversity

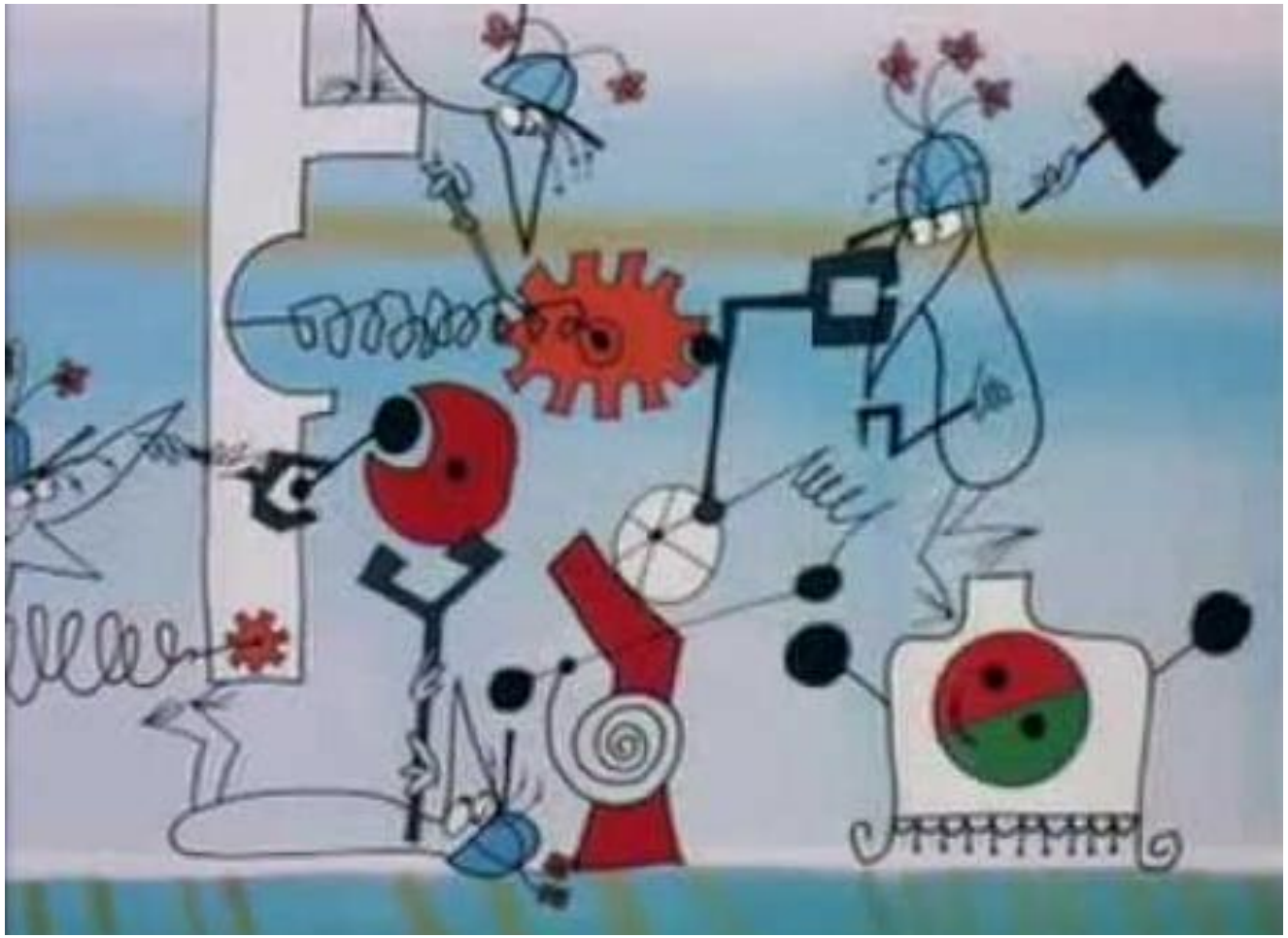
Productivity Identity

Trait CWMs

trait 1
trait 2
trait 3

Project → Model → Compute → Estimate

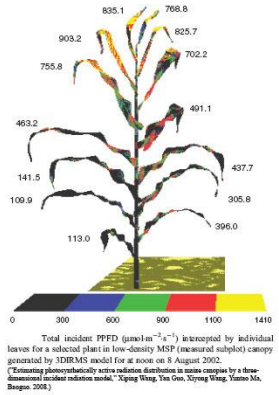
# Models to understand and predict



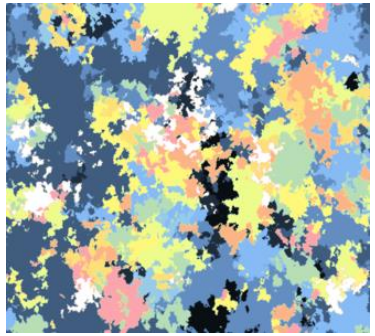
- Understanding by explaining
- Emerging behaviour
- Allow exrtapolations
- Experiment at low cost

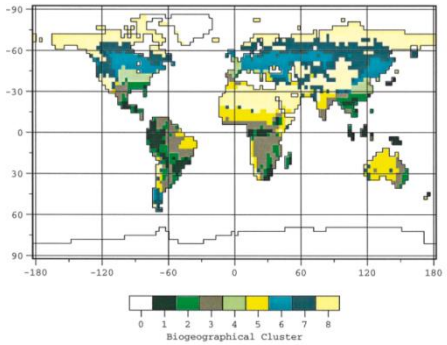
# A gap to fill

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.)



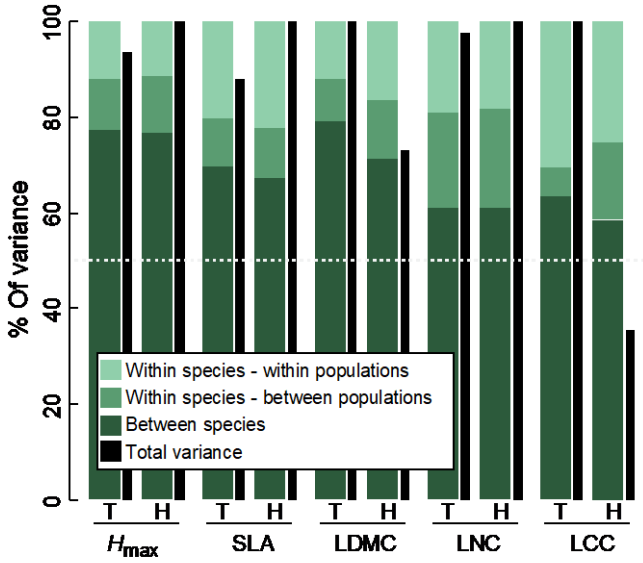



Molécular — Organ — Individual — **Communuty** — Landscape

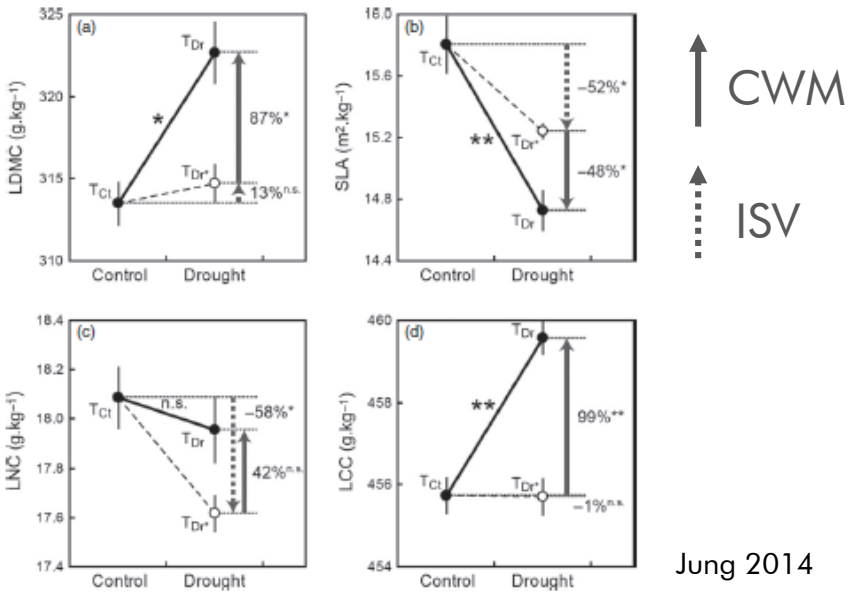
S< — s, min / mm — h, j / cm — j / **cm, m** — j, week / m, km

**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.




Jung 2014

Should be considered in:

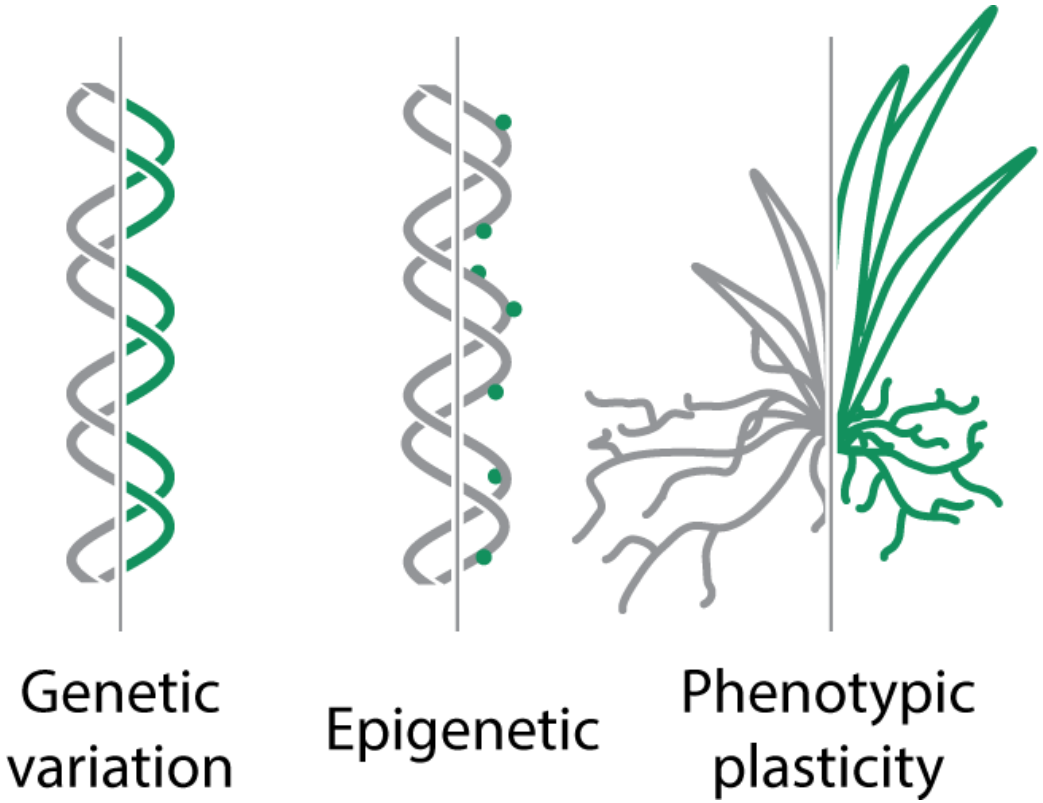
- Dynamic models

- ES assessments

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

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.

# 2

# 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?

# 3

# Introduction

State of the art and concepts

# The concept of niche

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

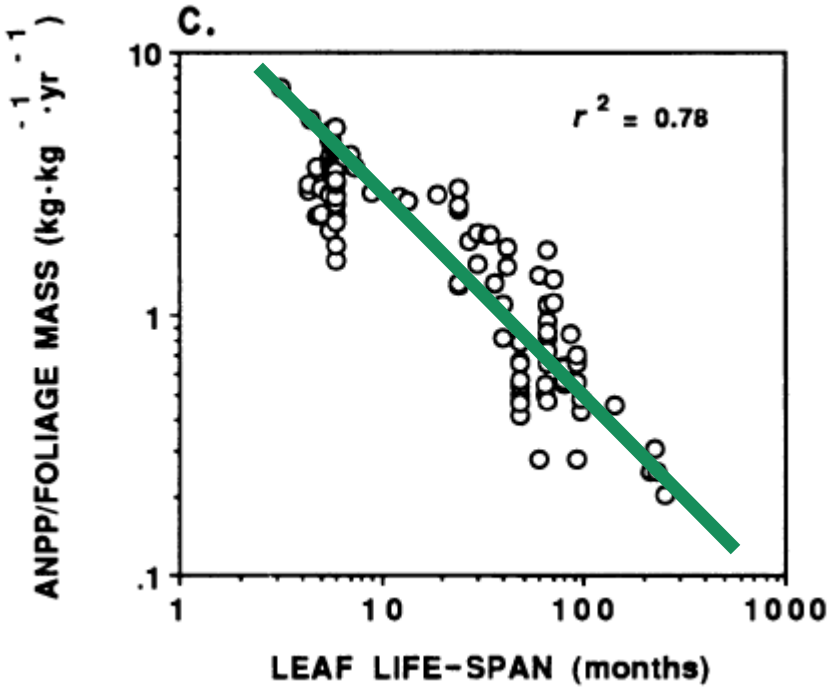
Hutchinton: n-dimension volume.

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?

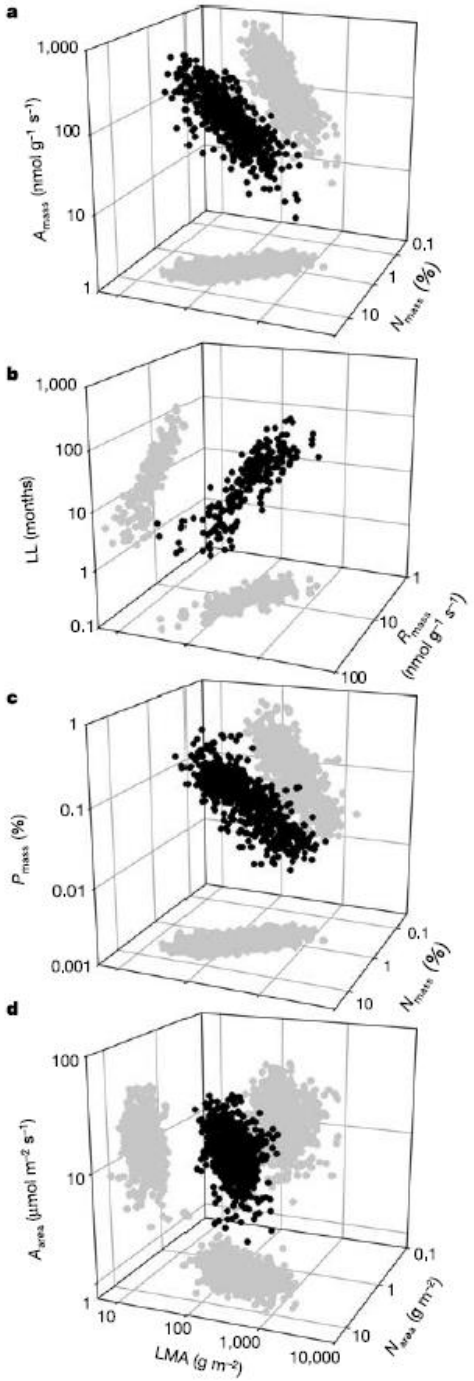
# The leaf economic spectrum

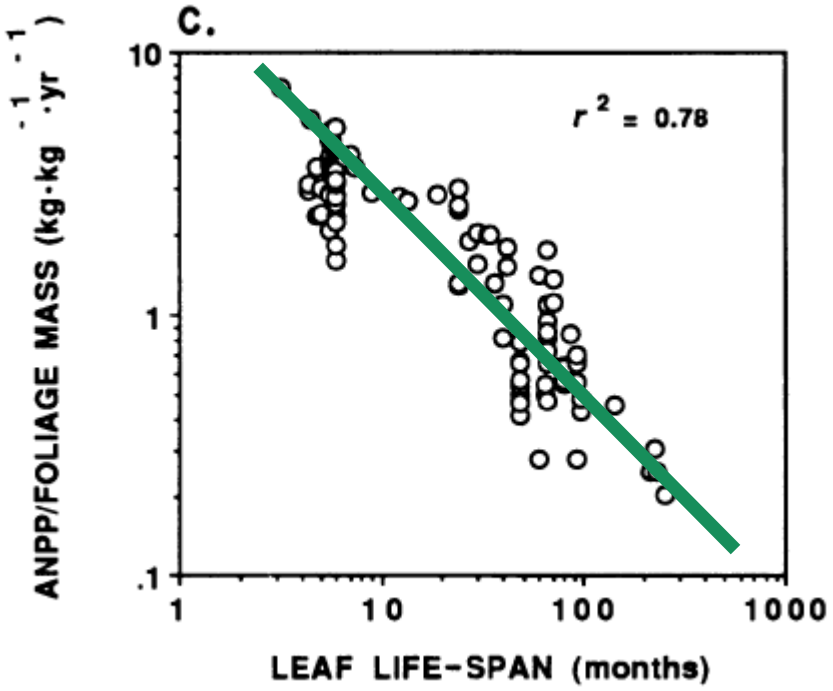



P. Reich (1992)

Wright et al. (2003)

# The leaf economic spectrum

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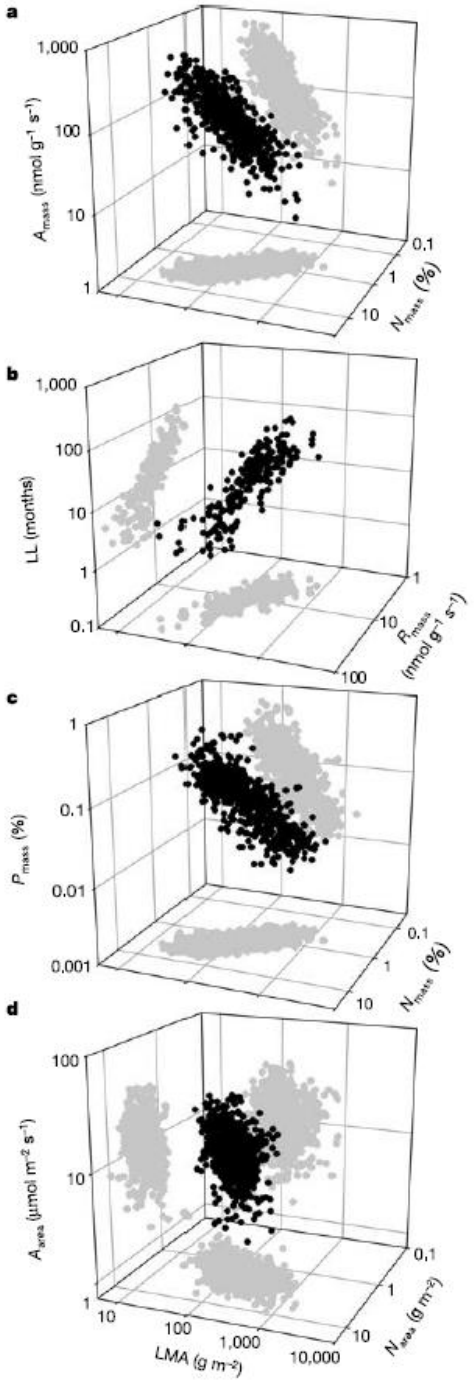
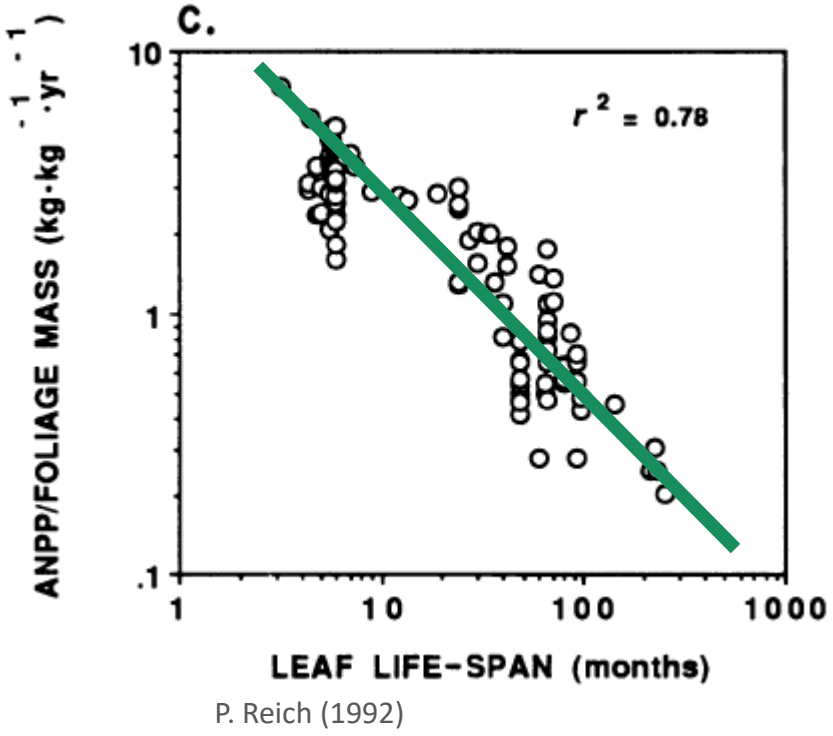
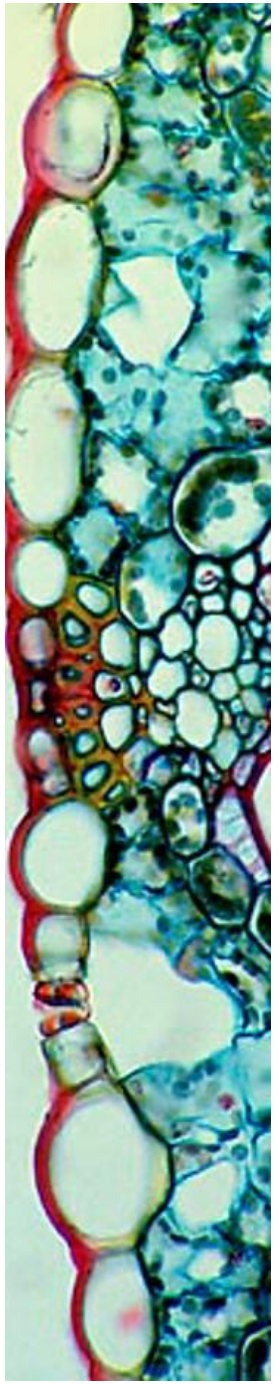



Wright et al. (2003)

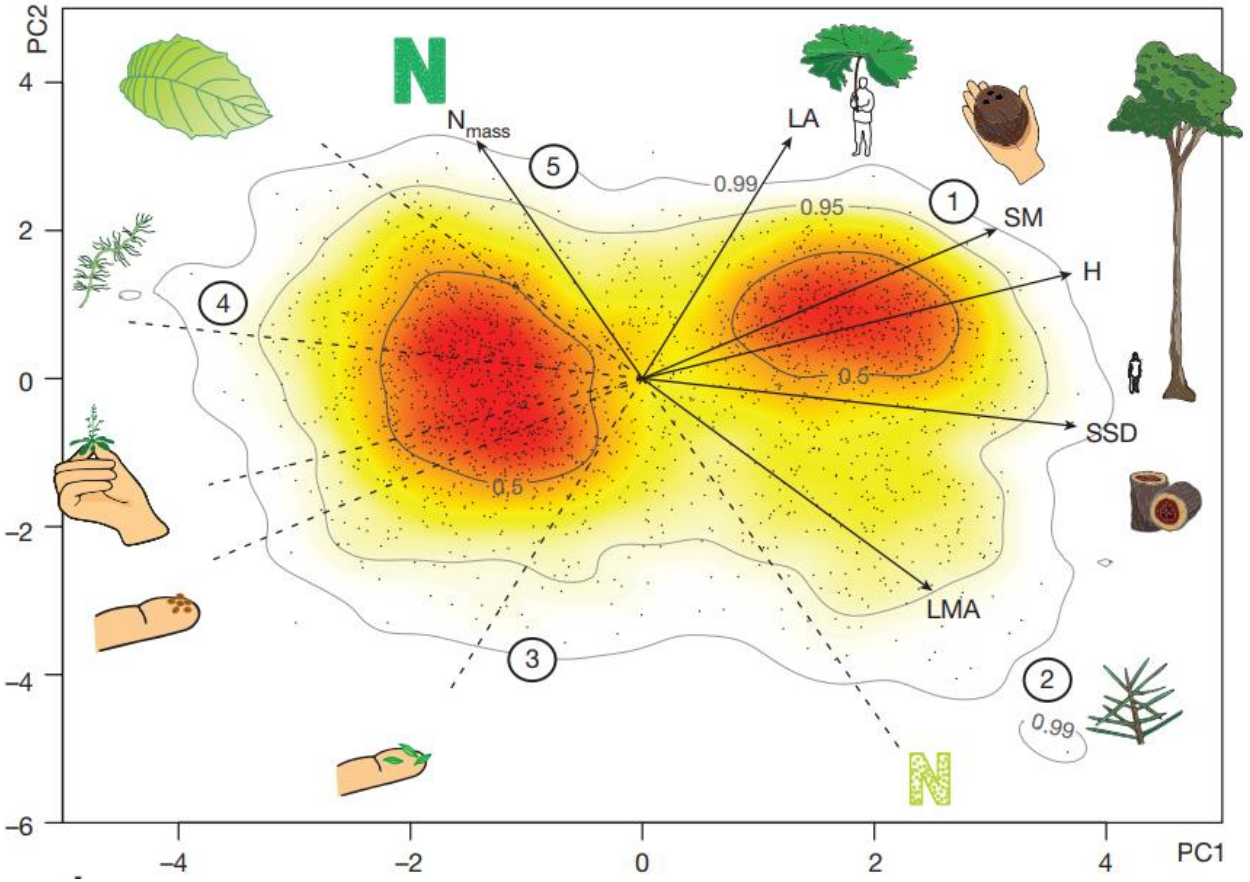



P. Reich (1992)

- Exchange are per mass unit
- Dimension reduction
- Cell wall/cell volume



# Trade-offs and strategy space




Diaz et al. (2015)

Dimension reduction → generalise trade-offs to other processes: reproduction, geometry, etc...

Continuous traits and growth forms:

→ same functioning but species differences

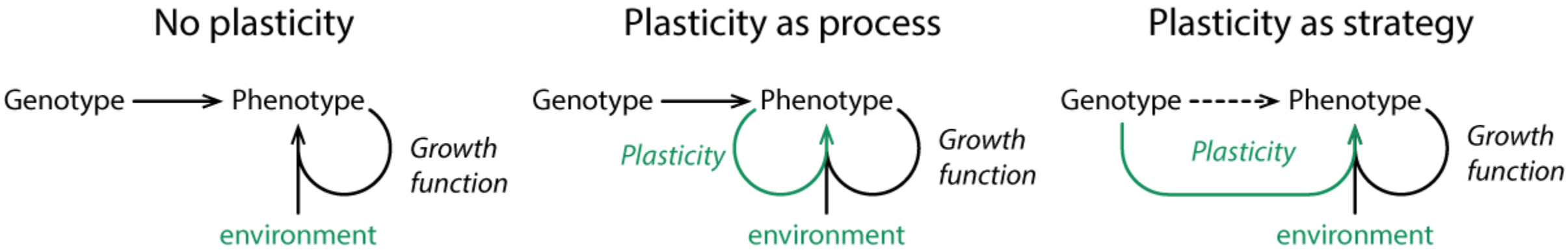
→ diversity of processes

→ allows plasticity

- 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

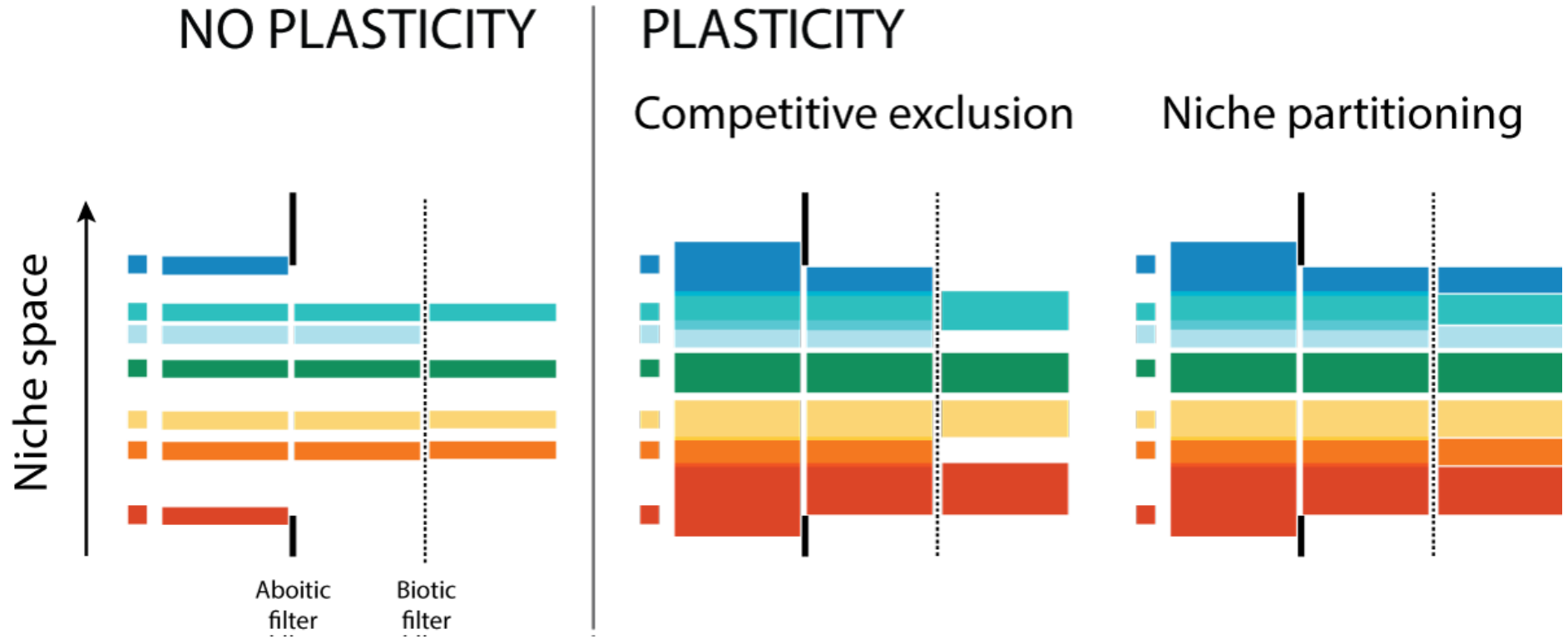
Plasticity in models: dimensions, objectives and assumptions

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?

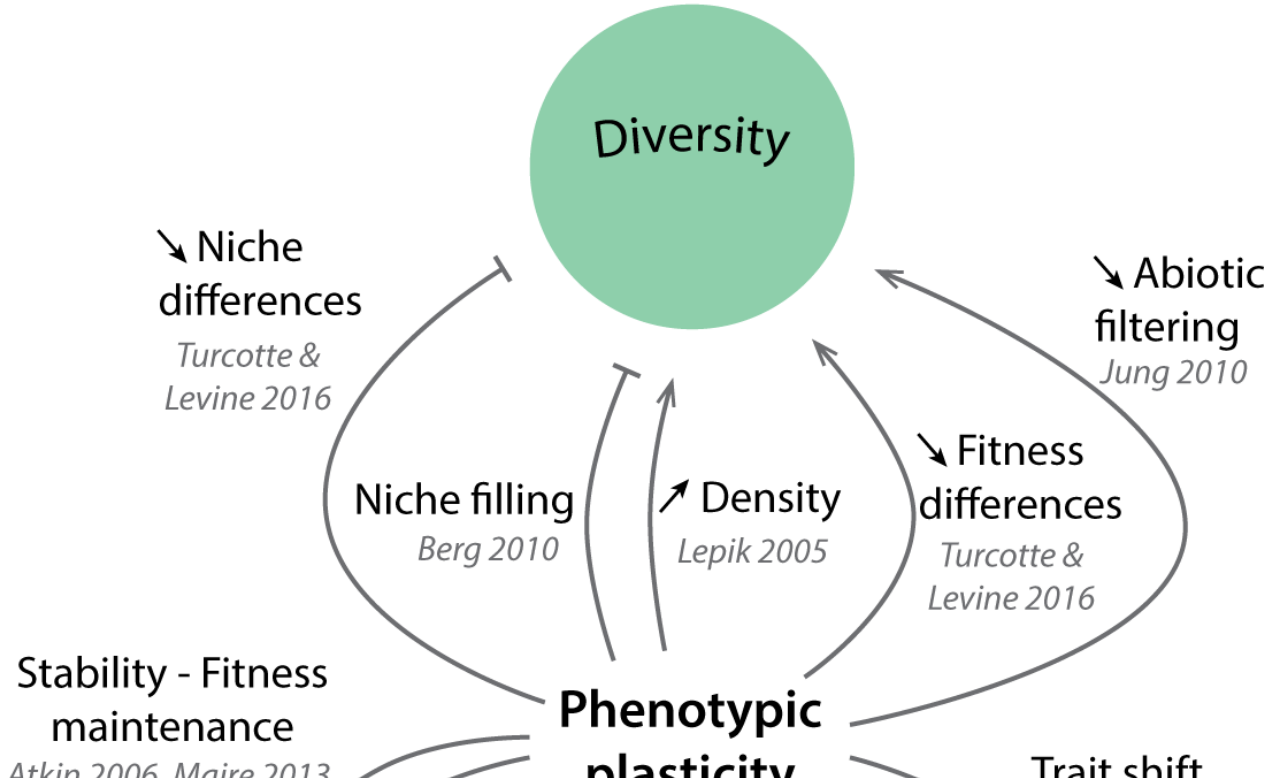
# Effect on community's diversity

Niche partitionning vs competitve exclusion



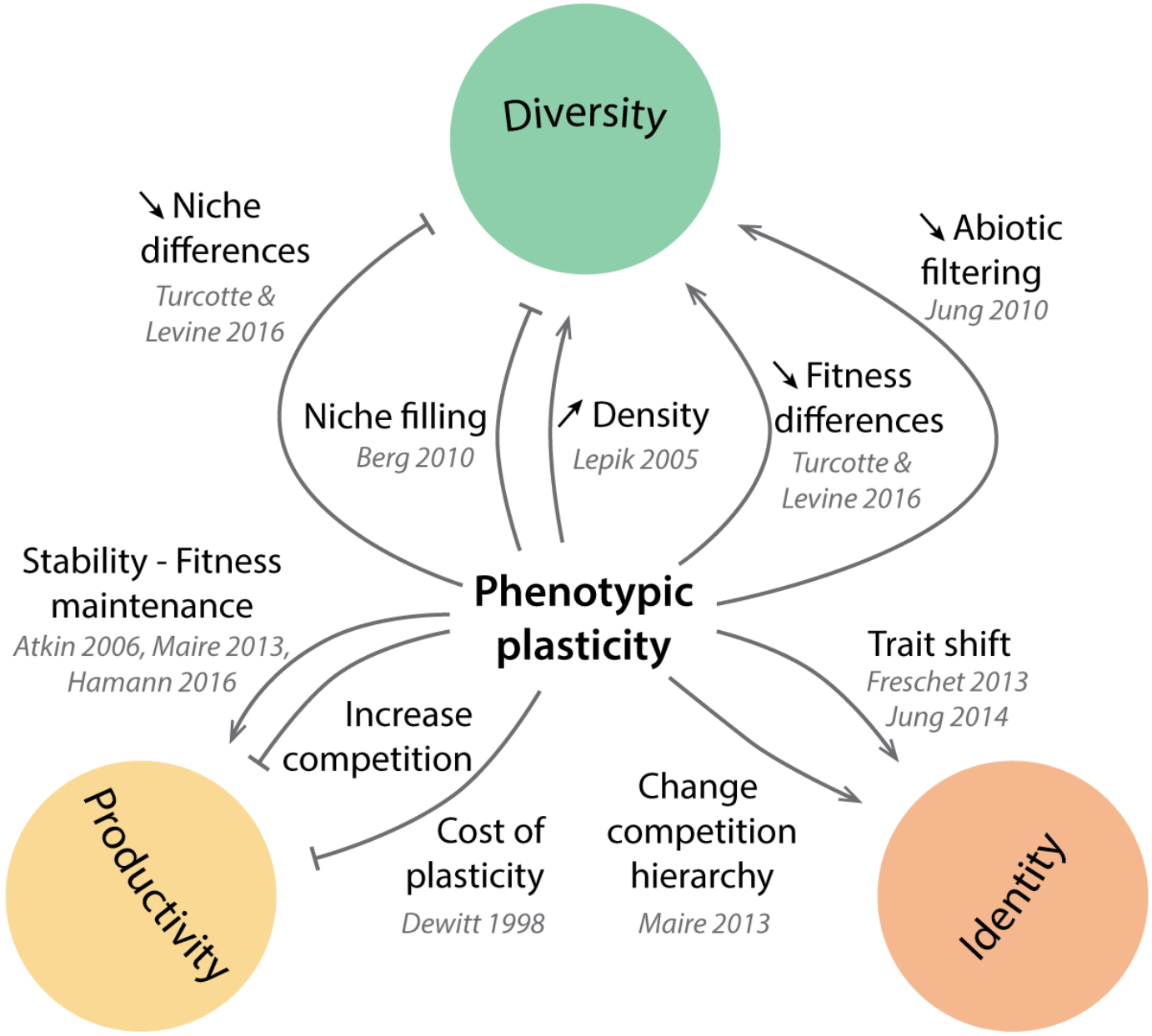
# We do not agree, yet

All effects



# We do not agree, yet

## All effects



# 4

# Results

Presentation of *MountGrass*

Individual- and community-level effects of plasticity

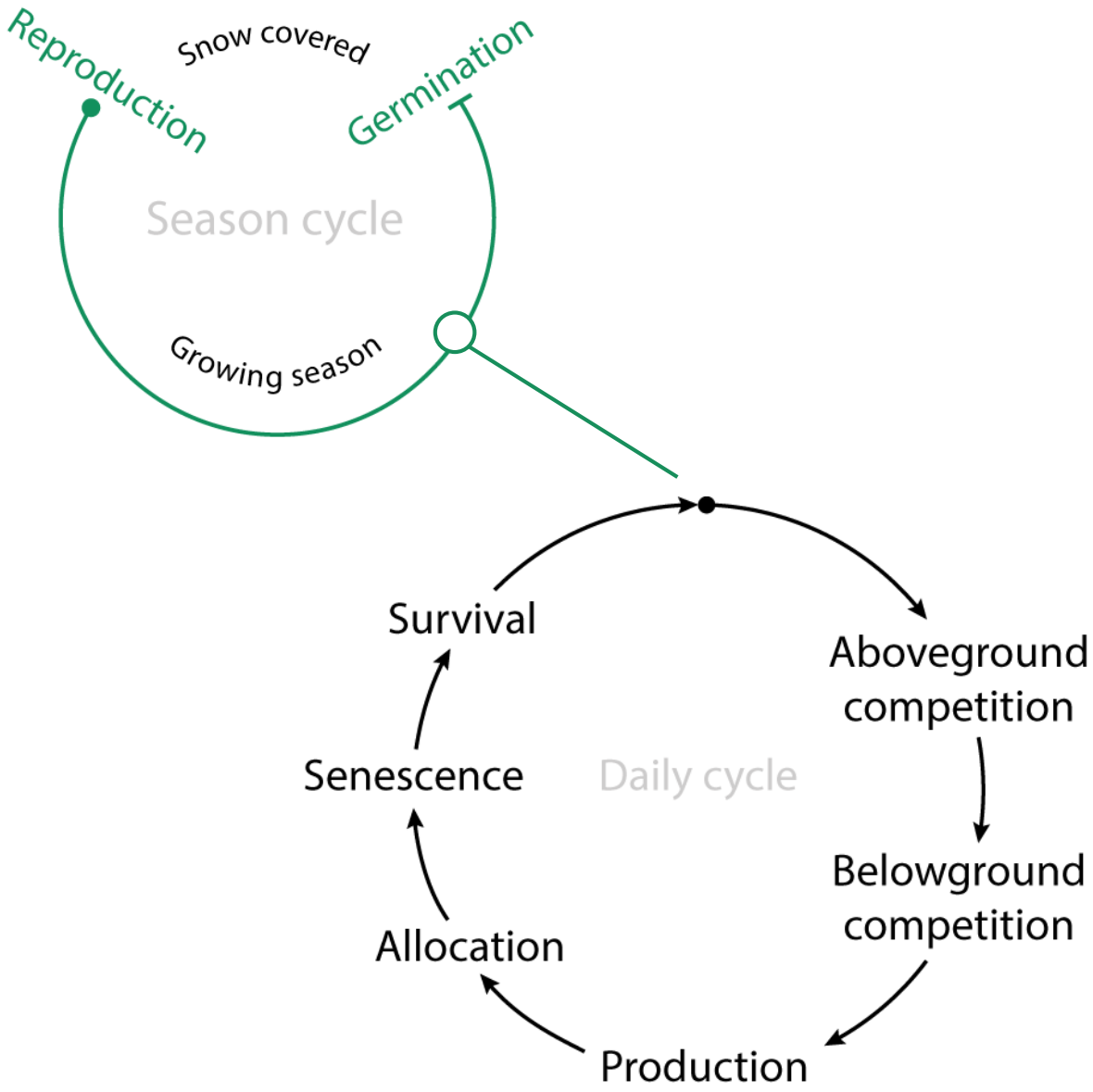
# Model overview

# *MountGrass*' world representation

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

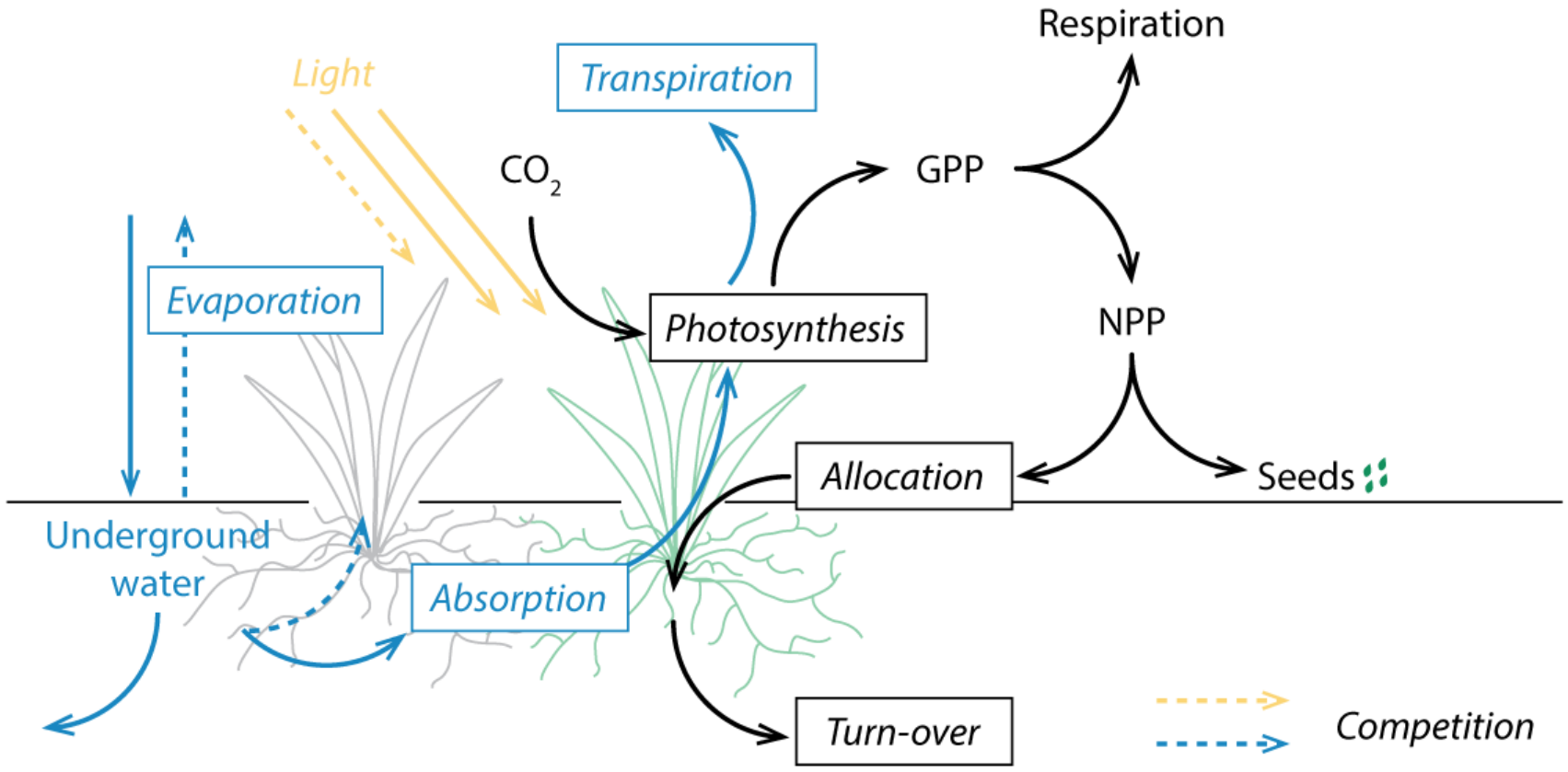
IBM spatially explicit

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

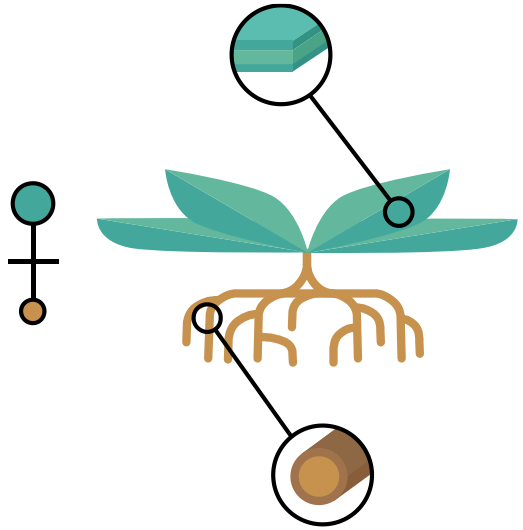


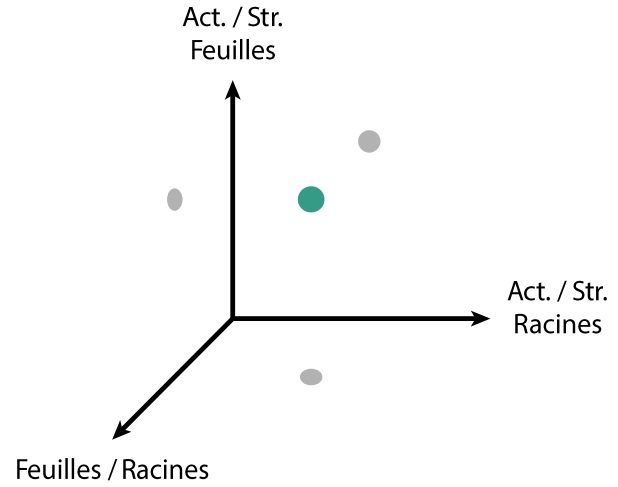
# *MountGrass*' processes

- Main processes



# Plant representation







Based on trade-offs and strategy space

4 vegetative compartments

Par, pas, r:s

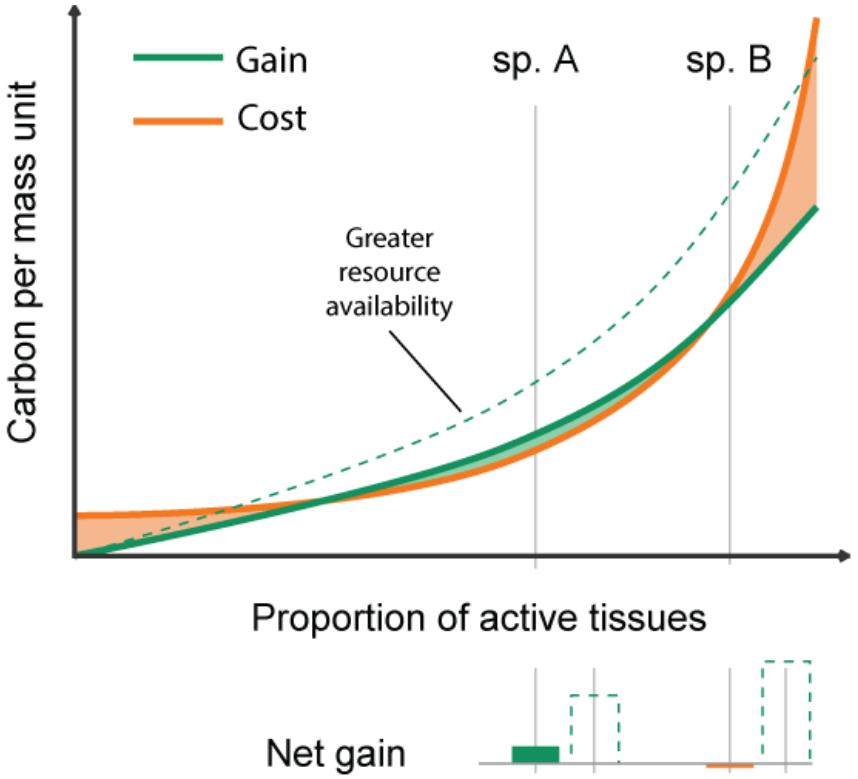
Different dry volumic masses → Change the cost of exchange area

But also alters turn-over and respiration

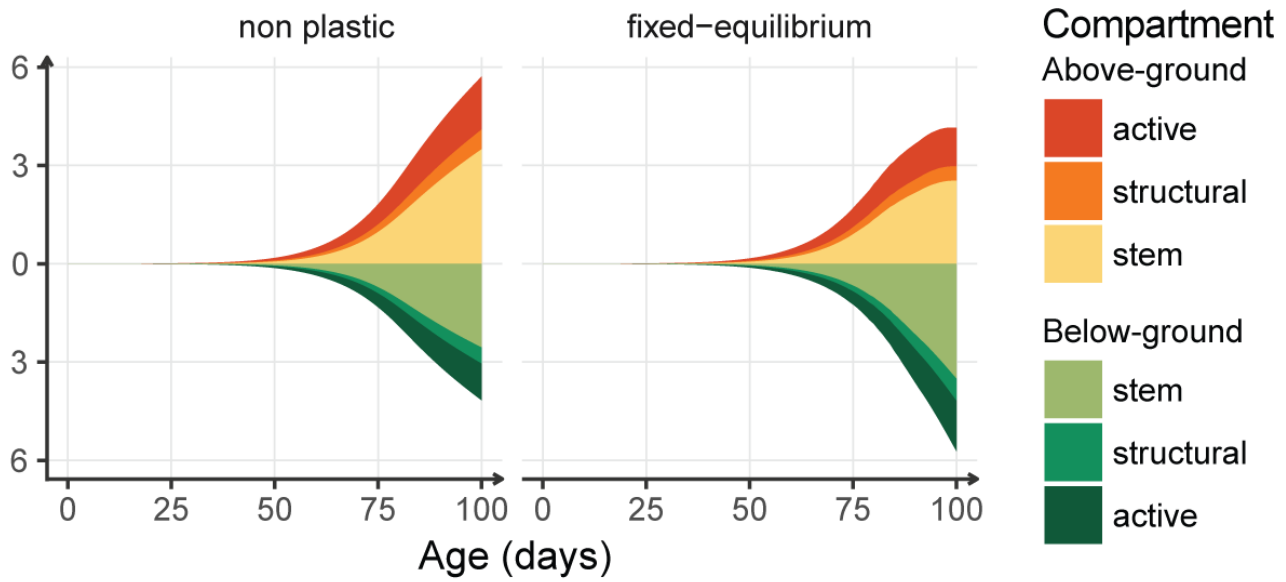
How does the phenotype impact the plant growth?

# The components of plant growth

## TISSUE EFFICIENCY



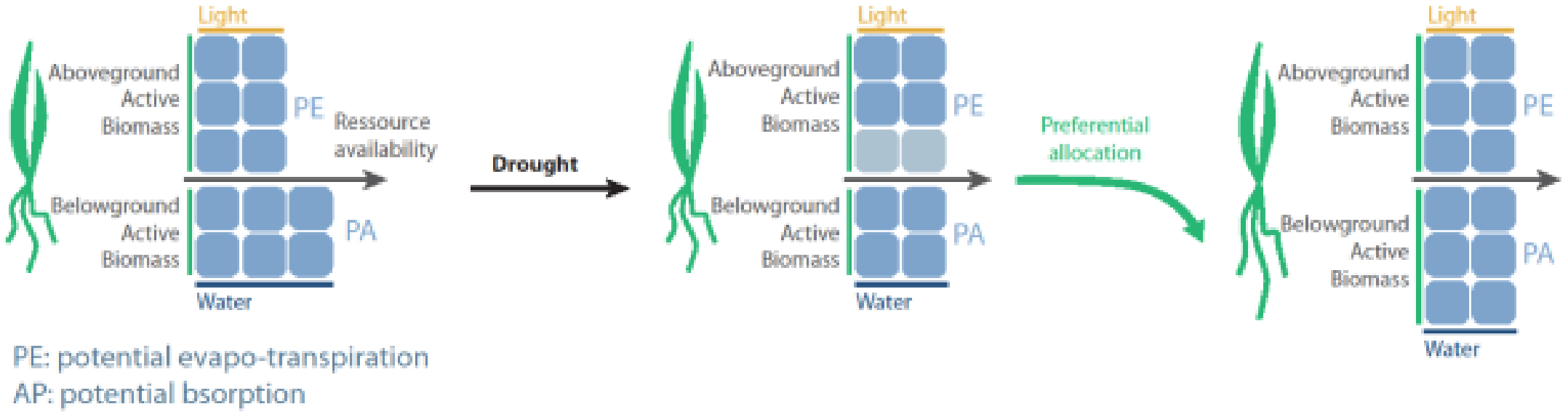

## BALANCE




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

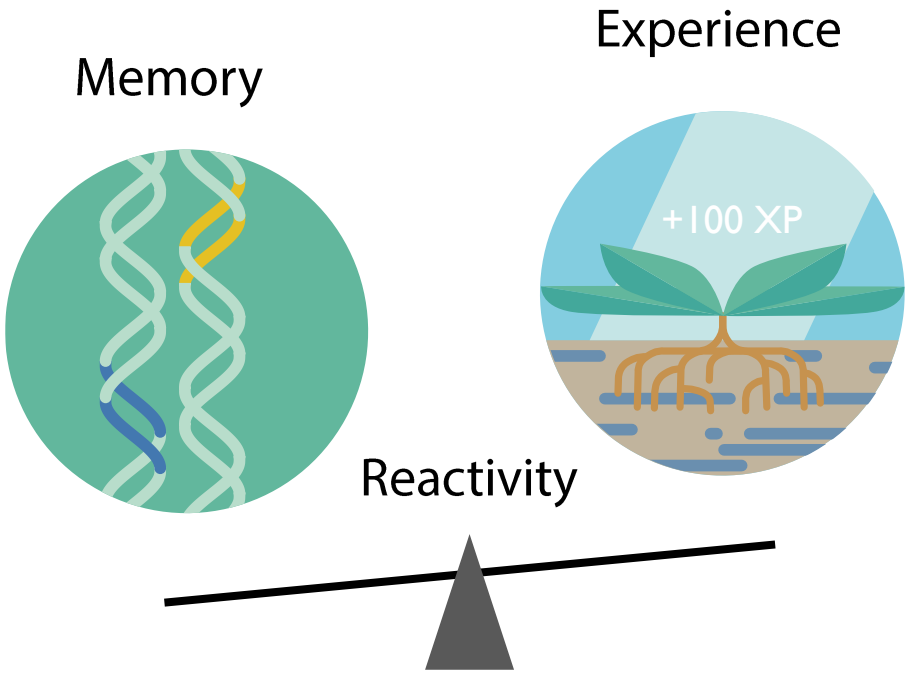
Just rules, not a strategy

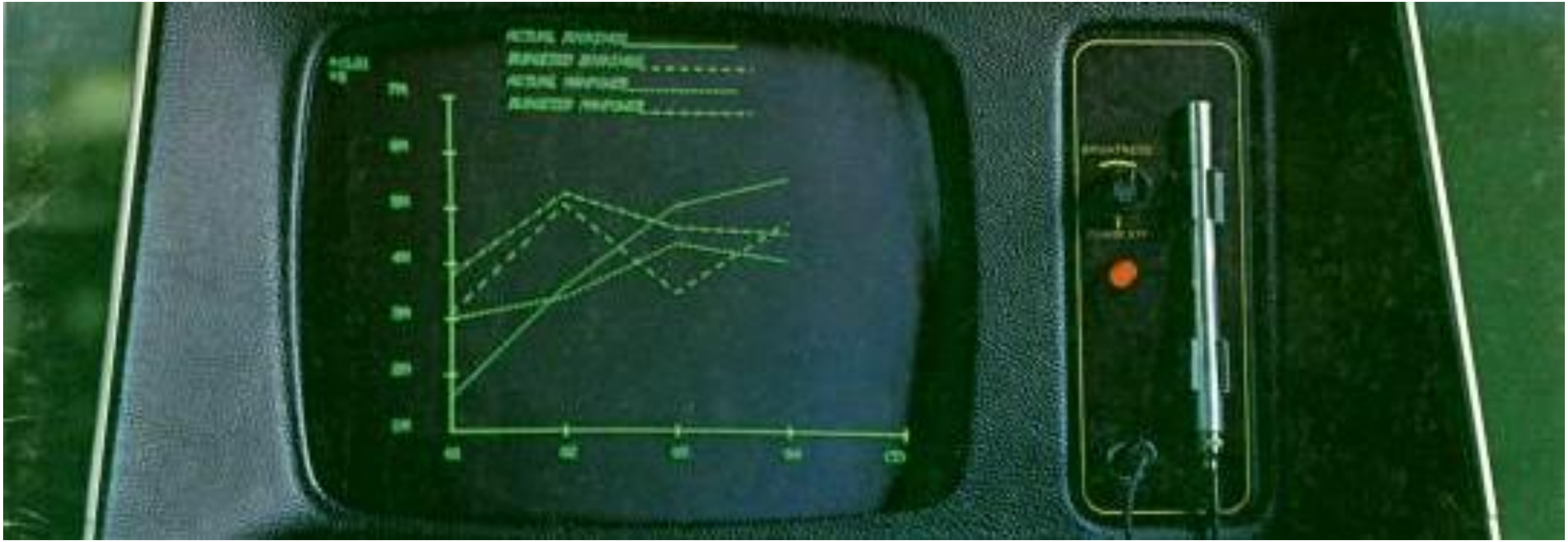
# The future: between species memory and individual experience

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

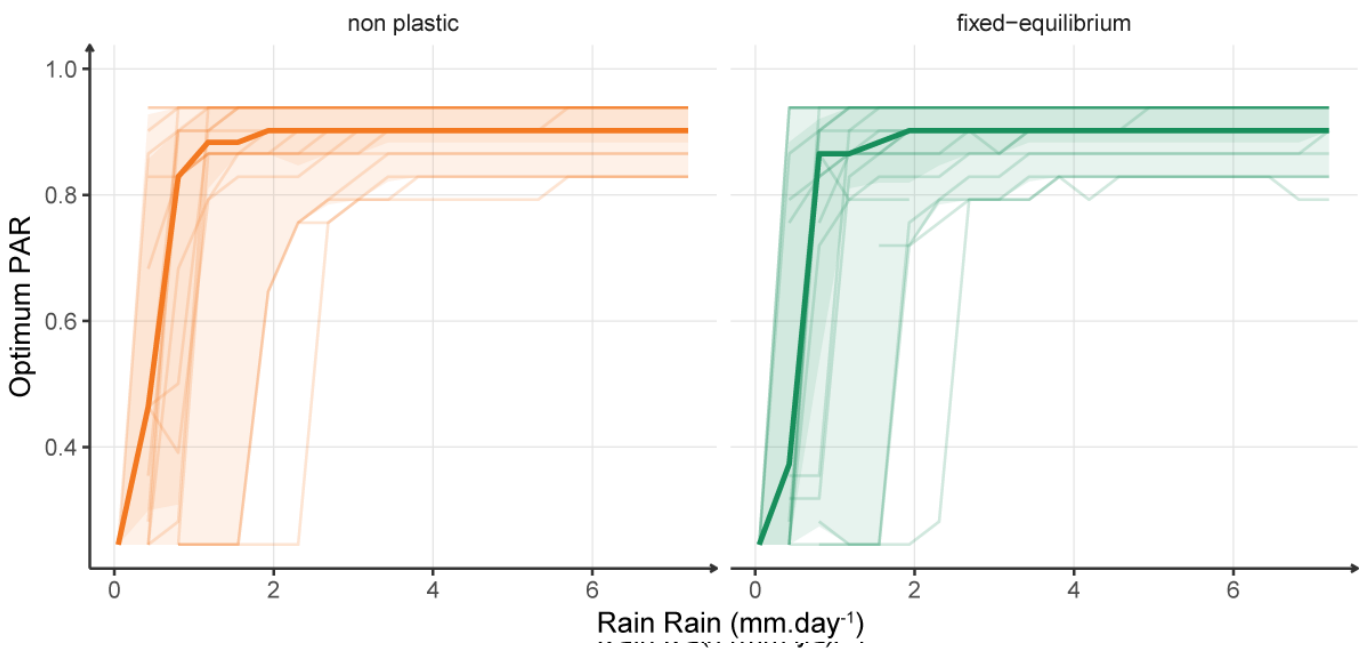
- 20 Parameter sets
- Plastic and non plastic
- Gradient of water availability
- N * m phenotypes

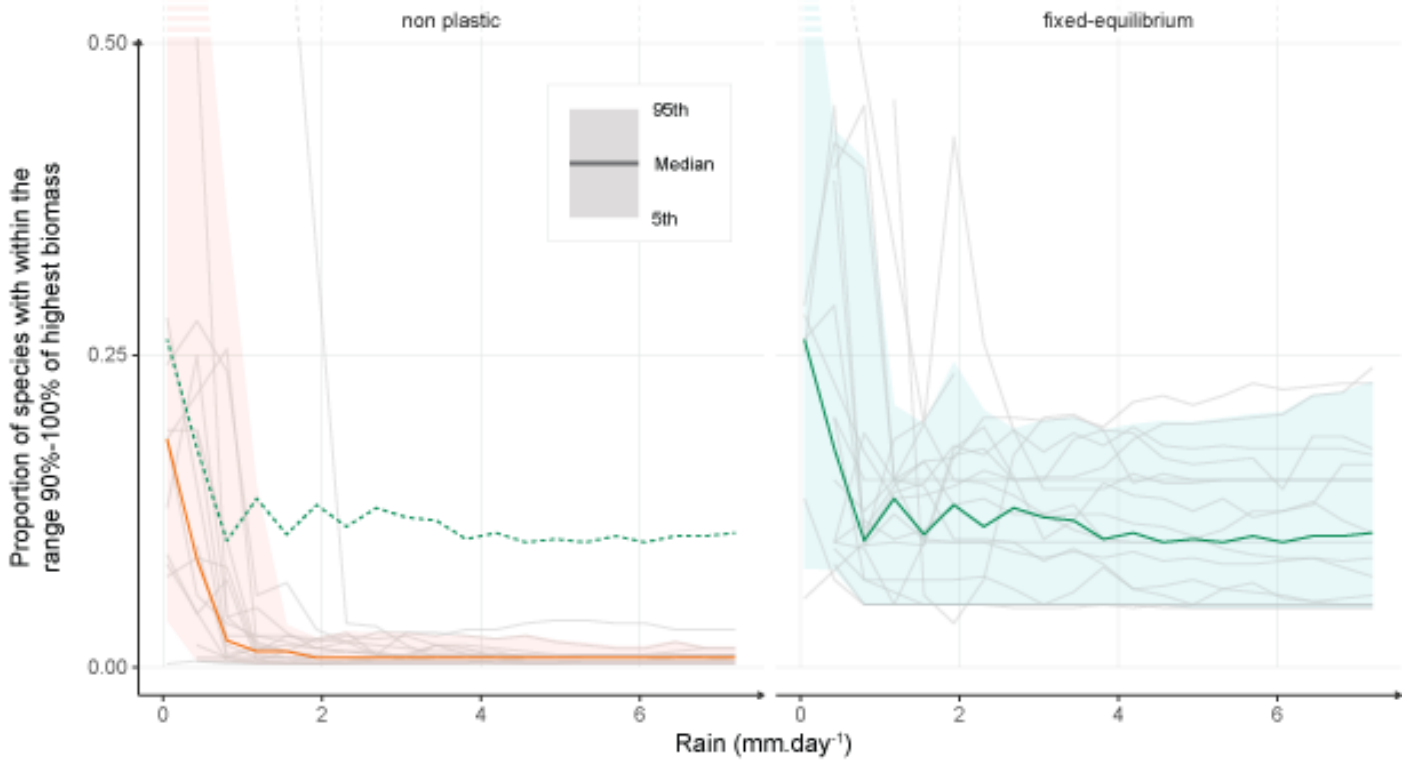
Each simulation

- Size/lenght

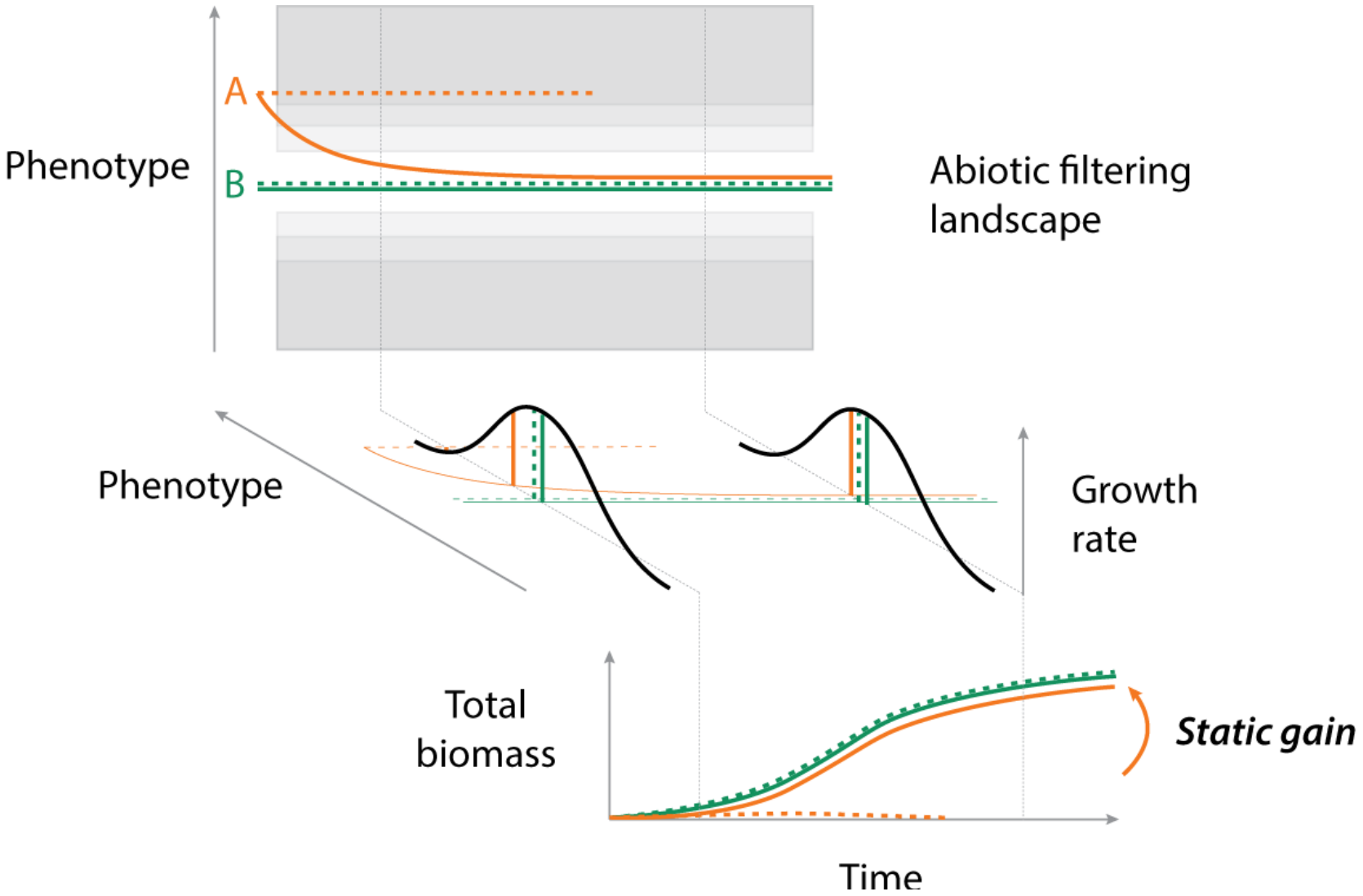
# Homogeneous conditions & static gain

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



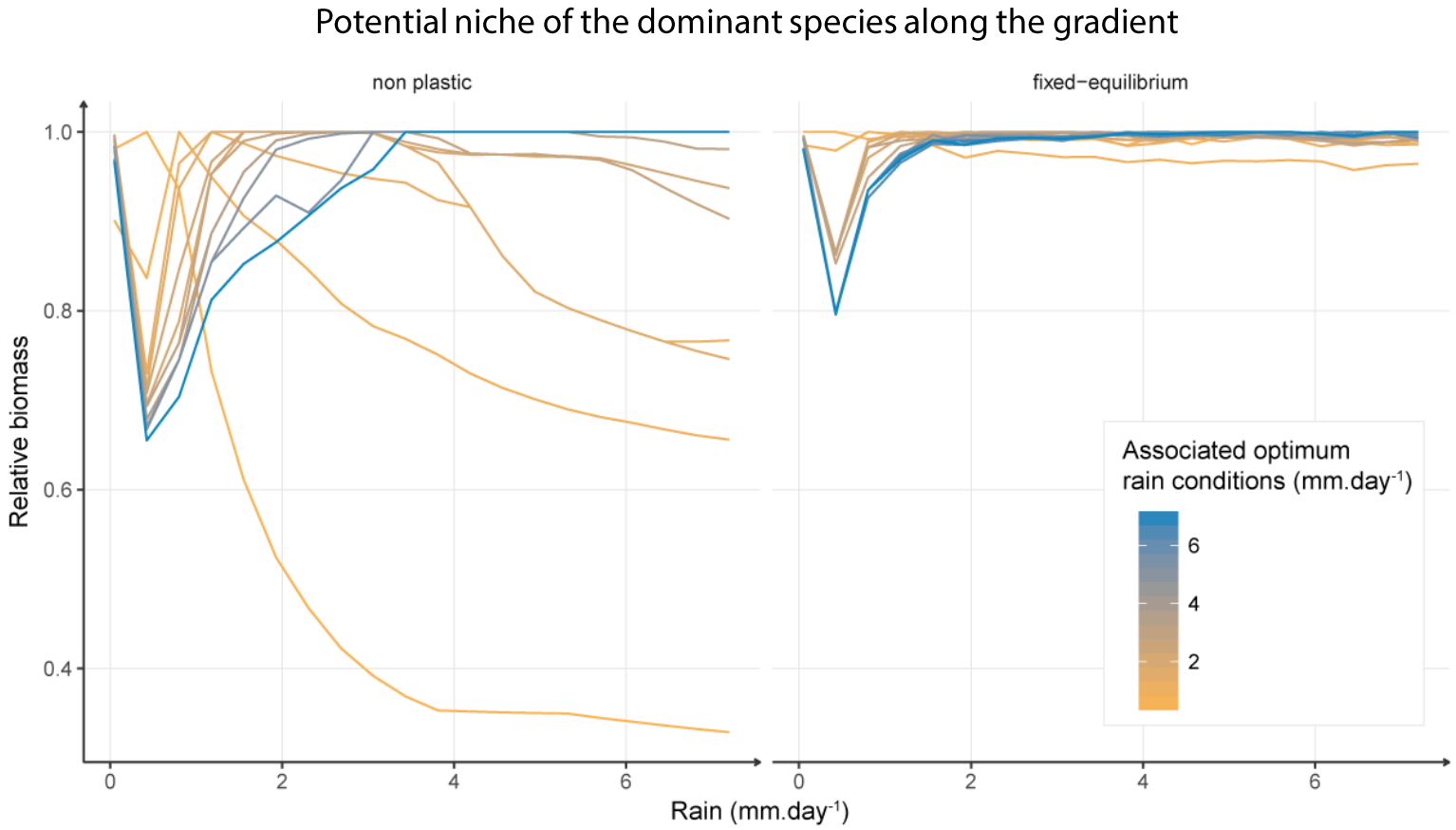



# Static gain


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

# Widenning of the potential niche

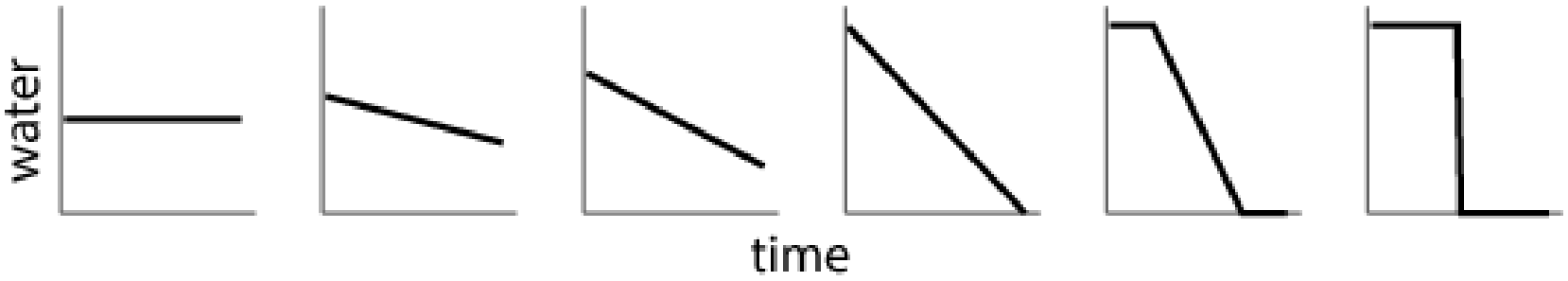
- Increase in potential species diversity
- But not functional diversity
- No change in dominant strategies



# Simulation set-up

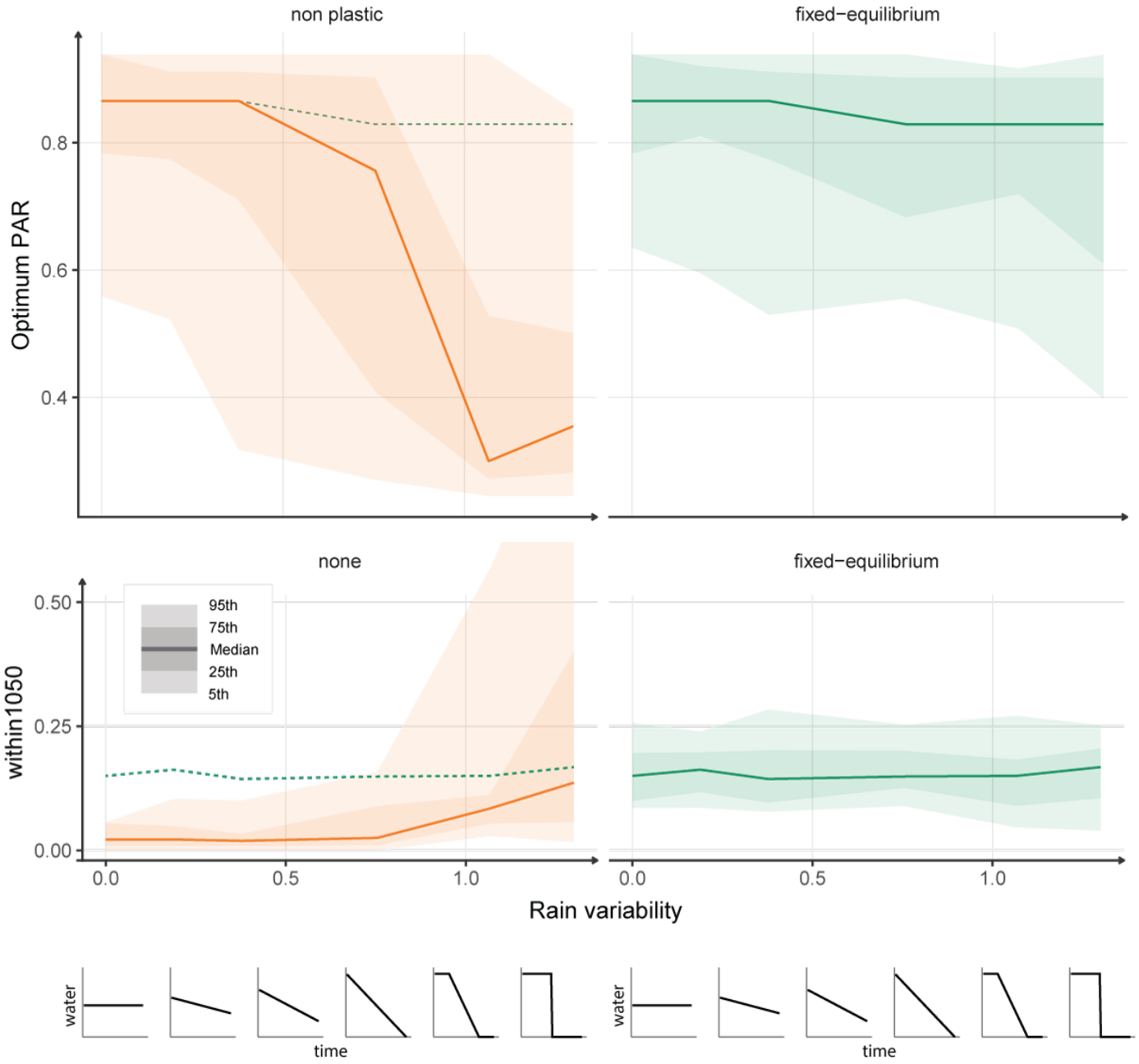
- Simulation
- N Parameter sets
- M conditions
- 2 algorithms

- Each simulation
- Size, length, …

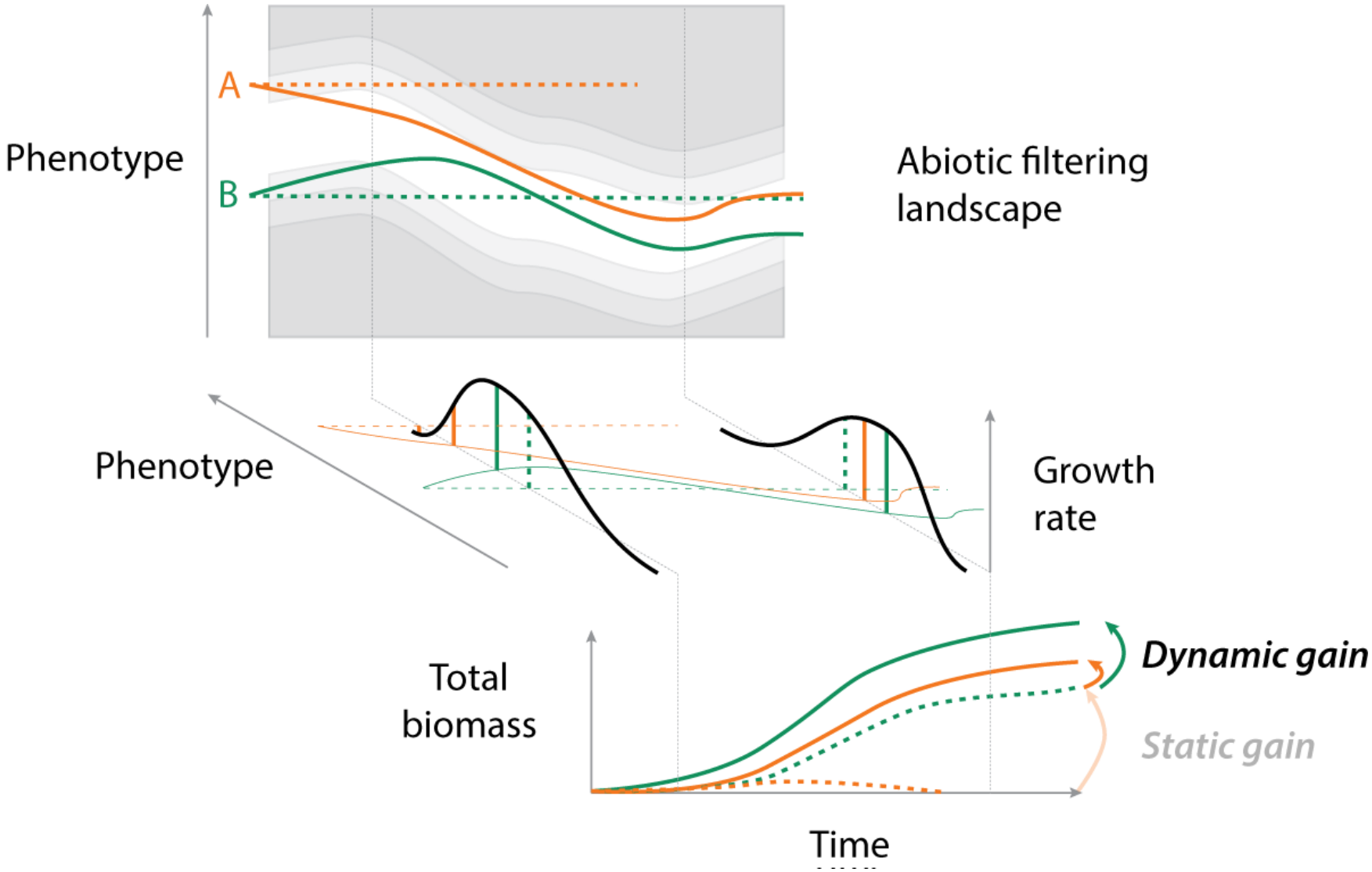


# Heterogeneous conditions & dynamic gain

- 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

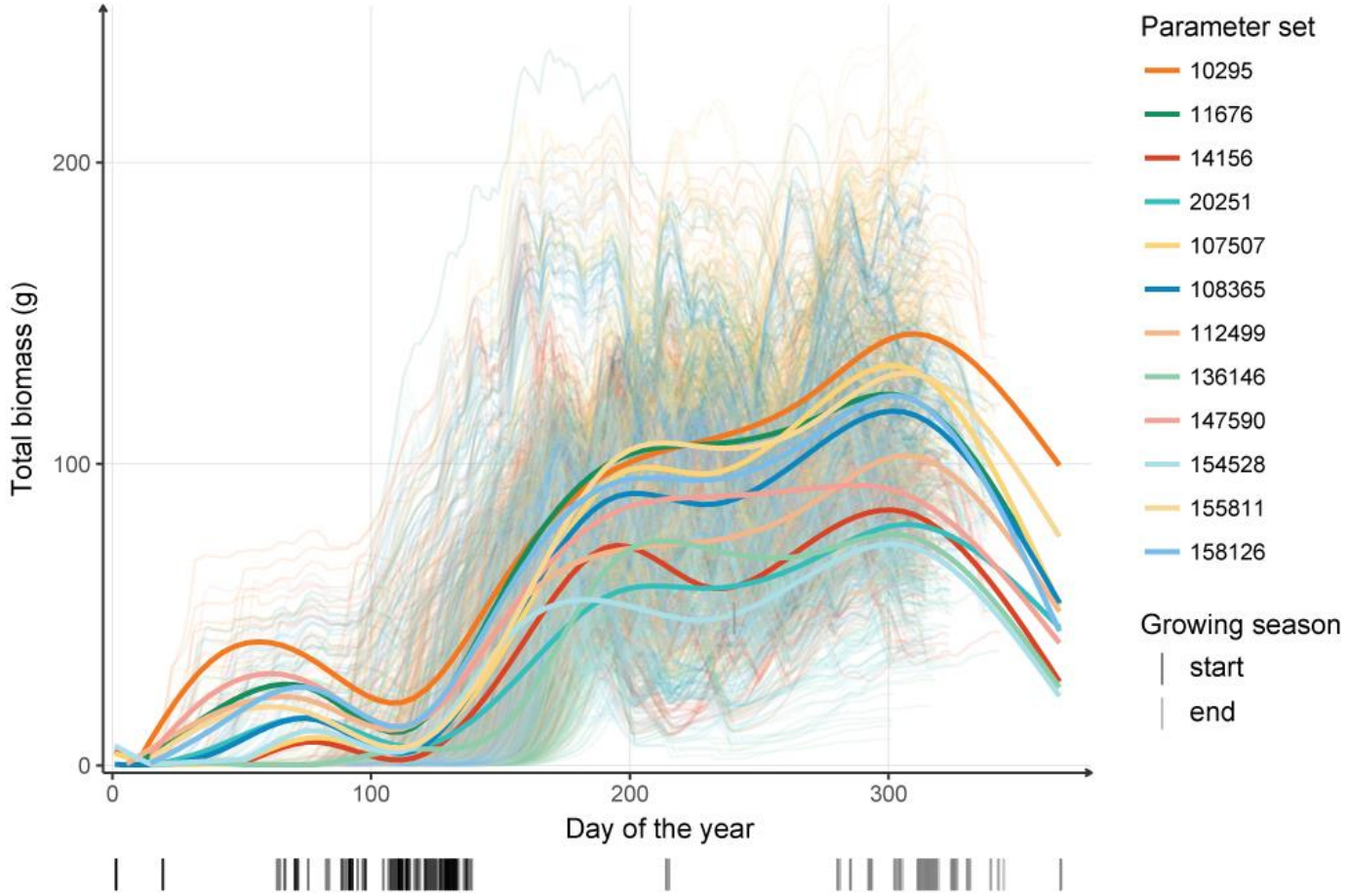
Community structure and diversity

The realised balance between mechanisms

# Simulation set-up

12 parameter sets
300 years
400 phenotypes
6 sites

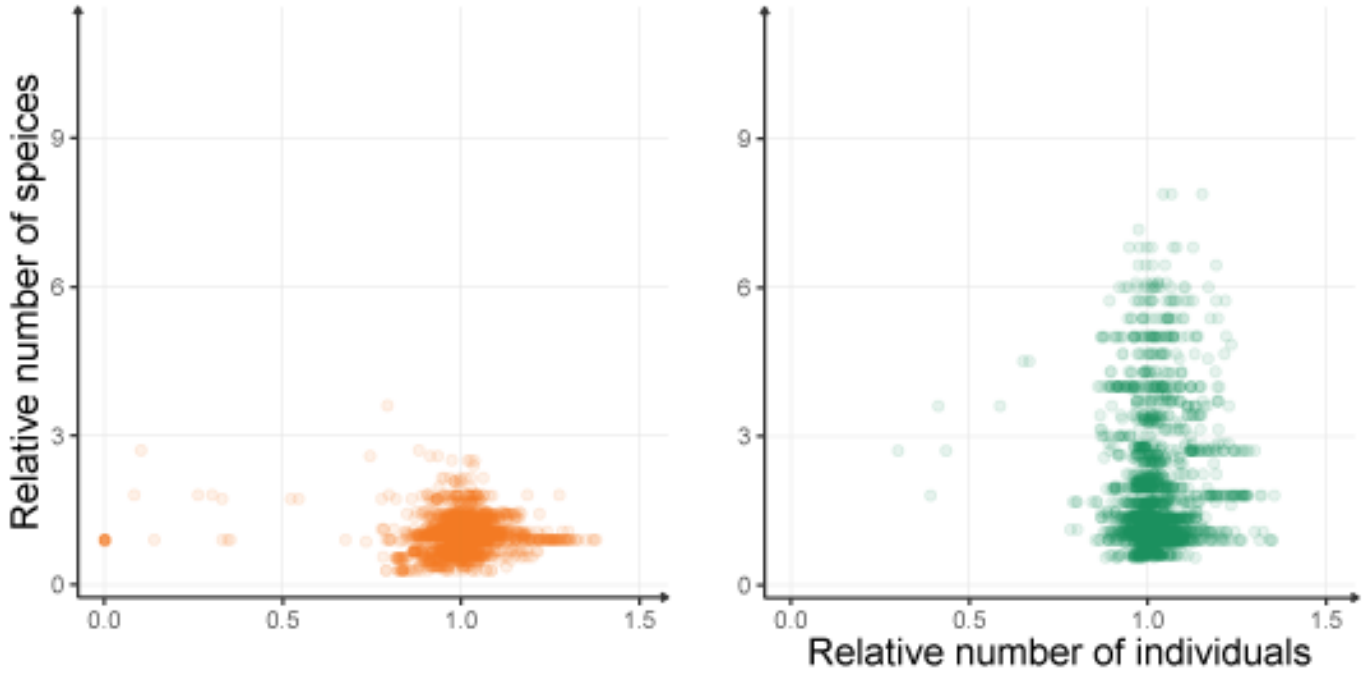
Partially shared seedbank



# Effect of the niche widening on diversity

- reduction of fitness differences >> reduction of niche differences

- Toward neutral situation

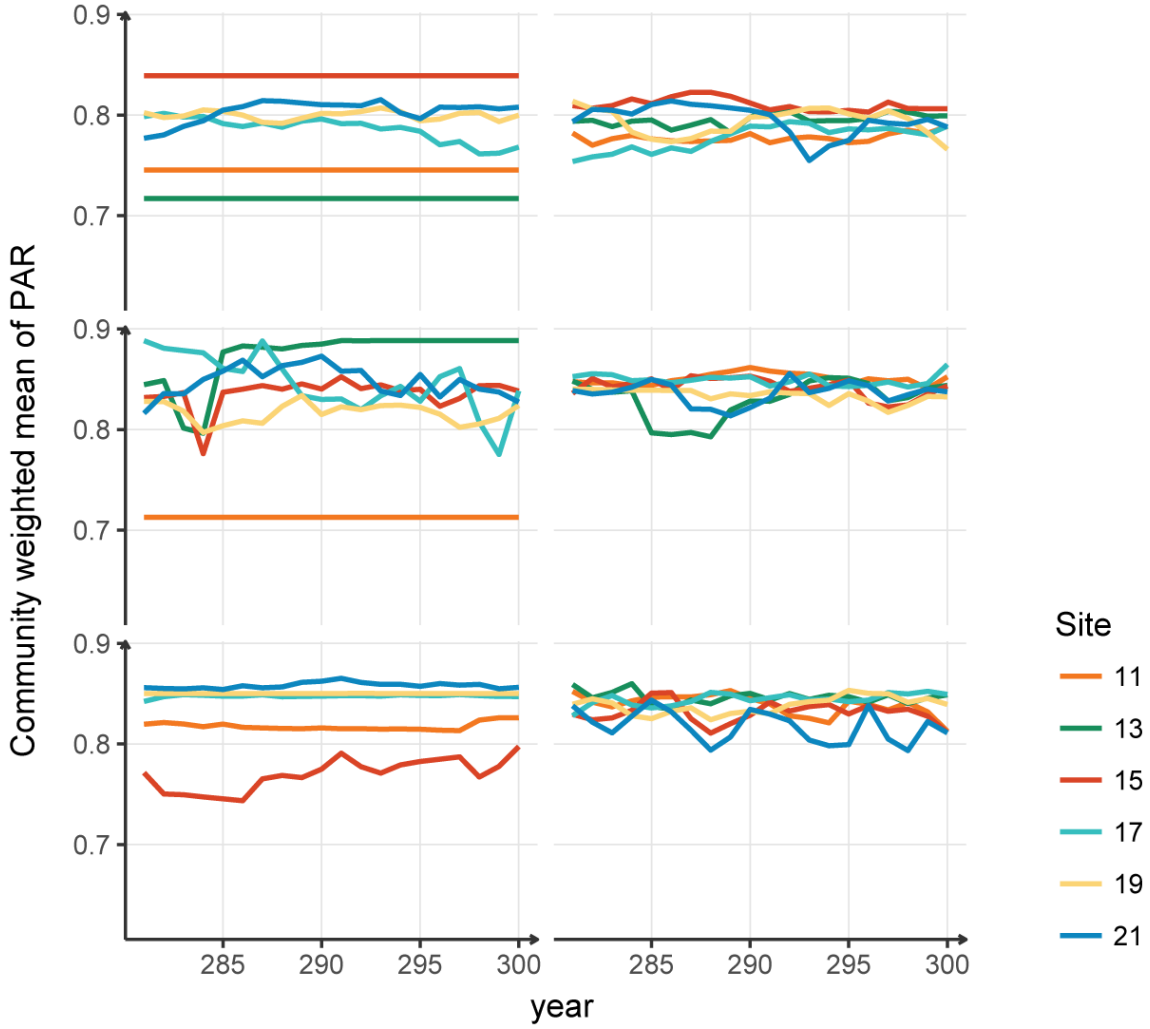



Effect on dominant strategy (asymmetric gain) ?

# Dominant strategies variability

Effects on dominant strategy << effects on community structure

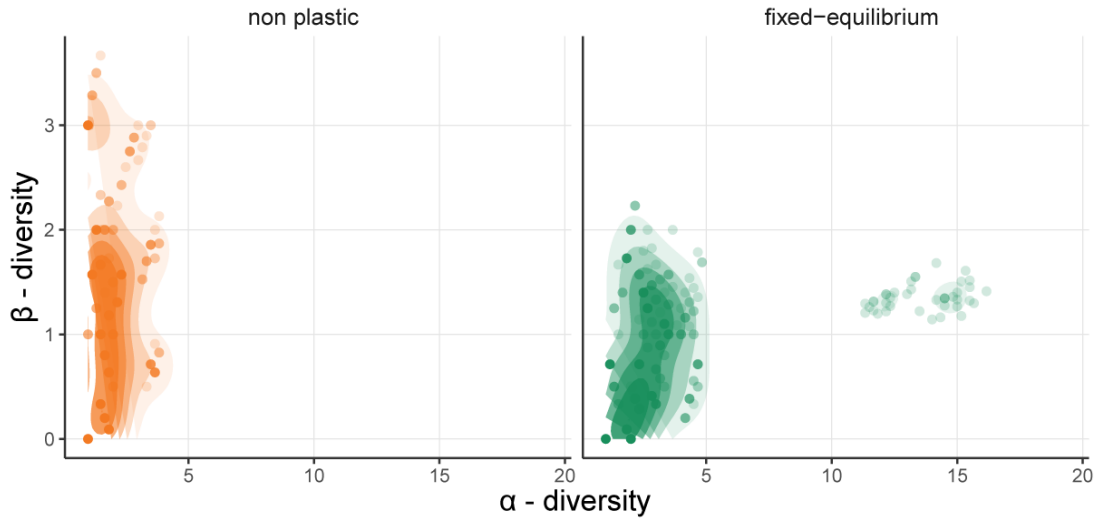
Yet, some differences should emerge (extended simulations needed)

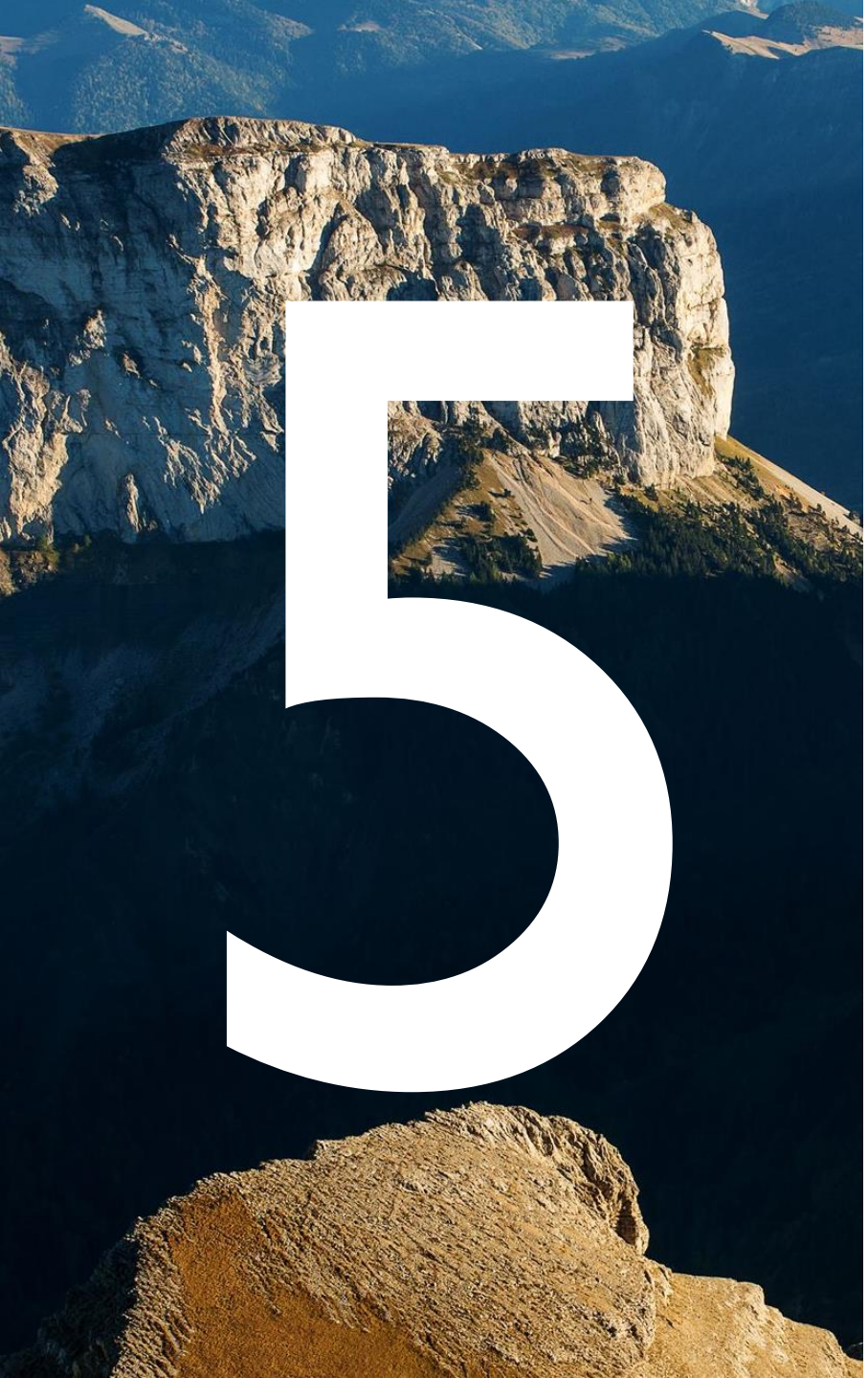



Different meta-community structure

# 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 (static gain > dynamic gain)





# 5

# Discussion

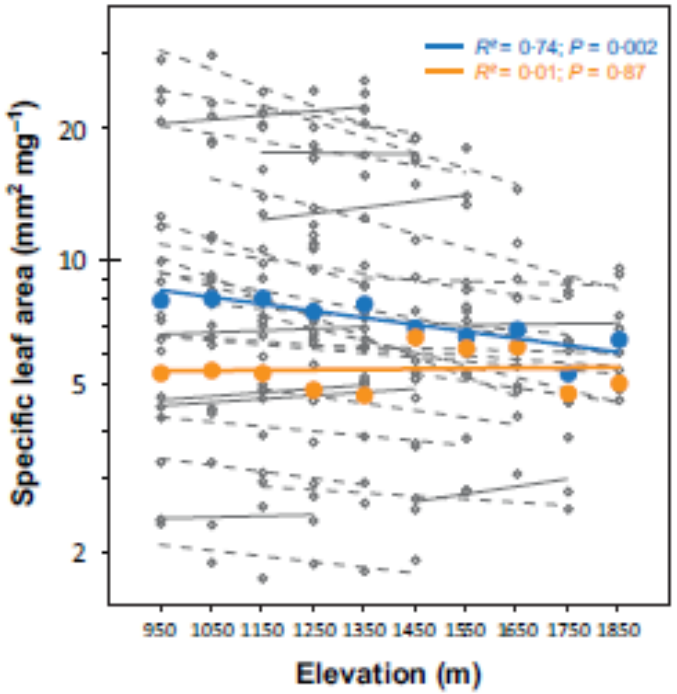
Impact on community dynamics and community modelling

# 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




Niche differentiation

Avoidance vs resistance vs resilience

Solution:

Change assumptions

2 dimensions to plasticity as strategy

…but increase model complexity

# 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

# Challenge the gaussian

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

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

→ Multi-risk plasticity framework

- Stability/invasibility
- Epigenetics

# Thank you