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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Introduction

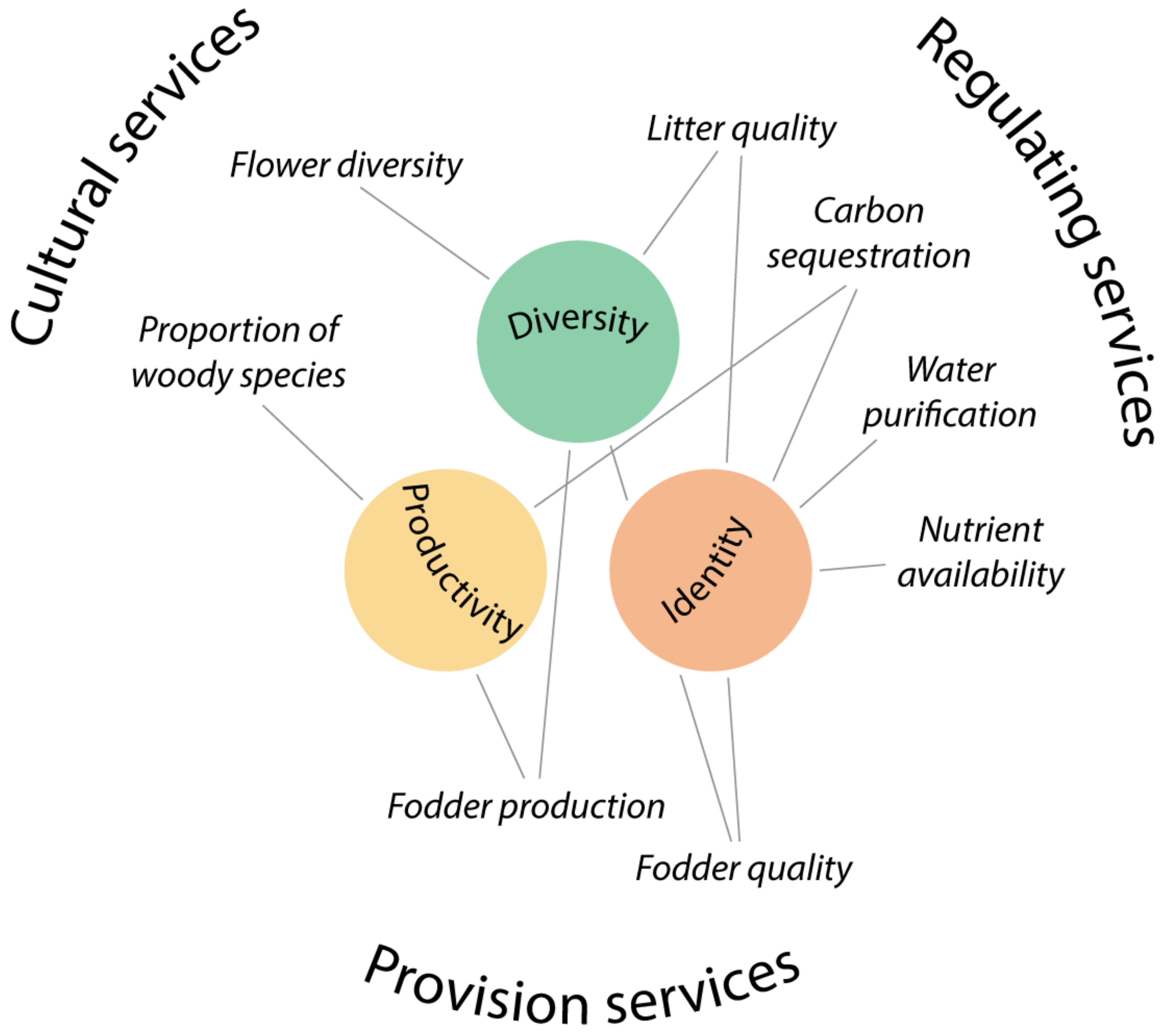
From context to questions

The value of mountain grasslands' diversity.

Ecosystem services

Benefits that humans freely gain from the natural environment

- Argument for nature conservation
- Tool for management

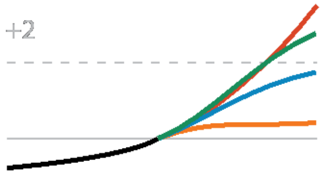


Assessing grassland ecosystem services

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

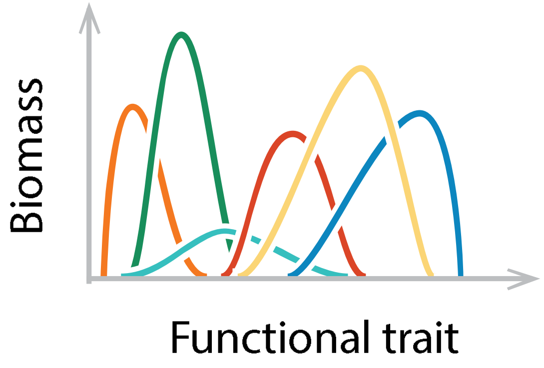
Drivers → Description of community → Summary statistics → Services

Climate

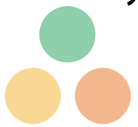


Land-use

Soil

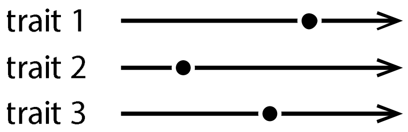


Diversity

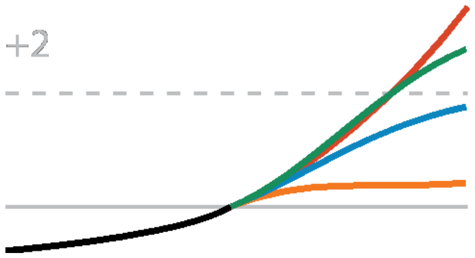


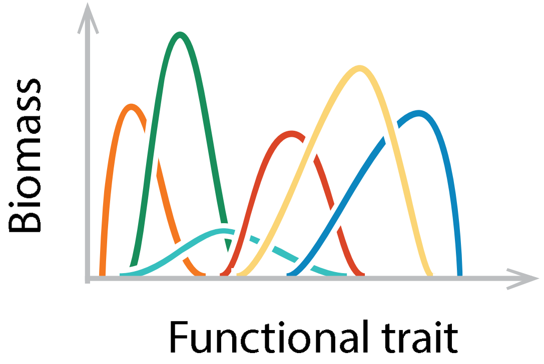
Productivity Identity

Trait CWMs

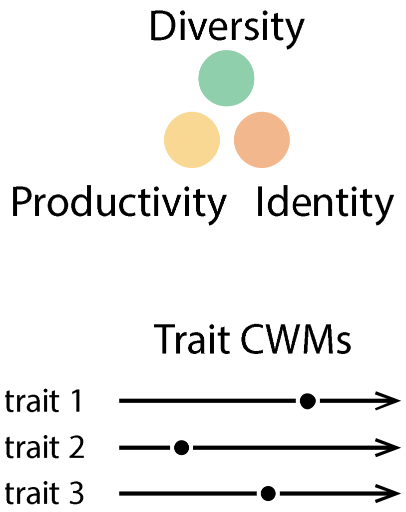


Drivers, global change and services



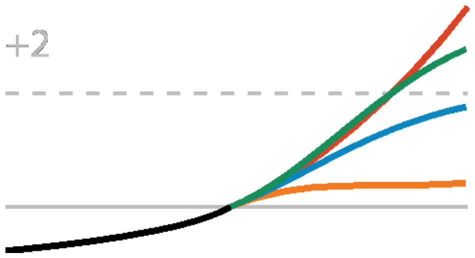


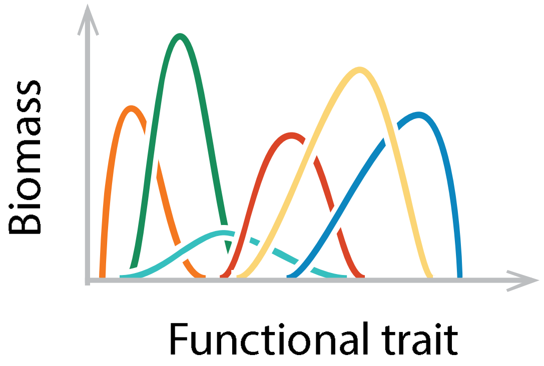
Summary statistics

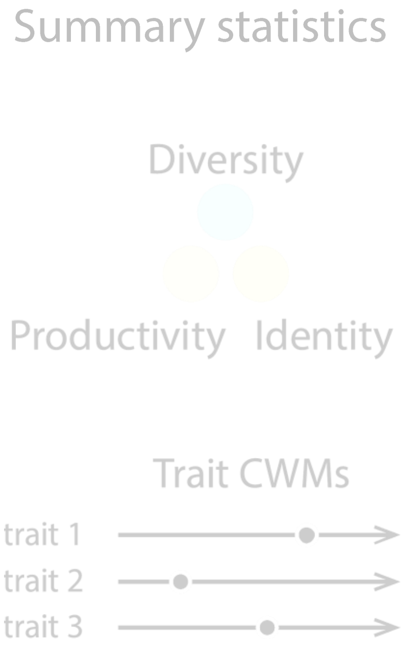


Project → Model → Compute → Estimate

Drivers, global change and services

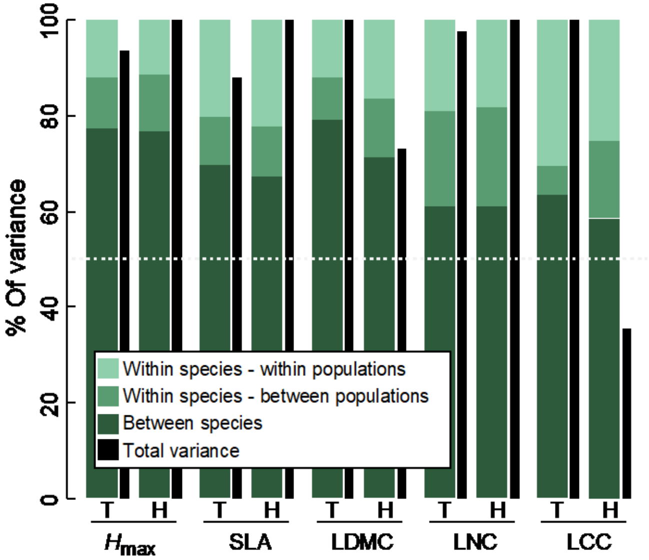






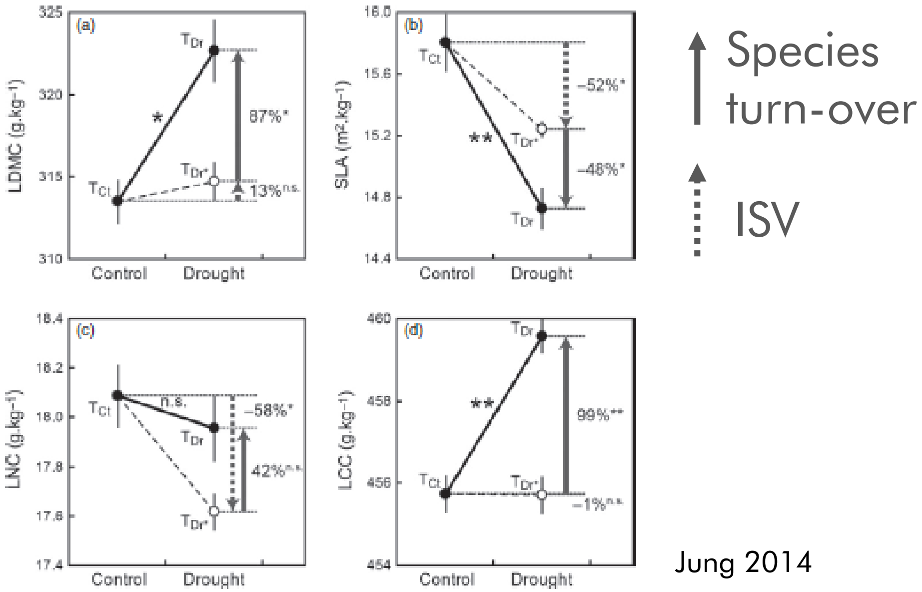
Project → Model → Compute → Estimate

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

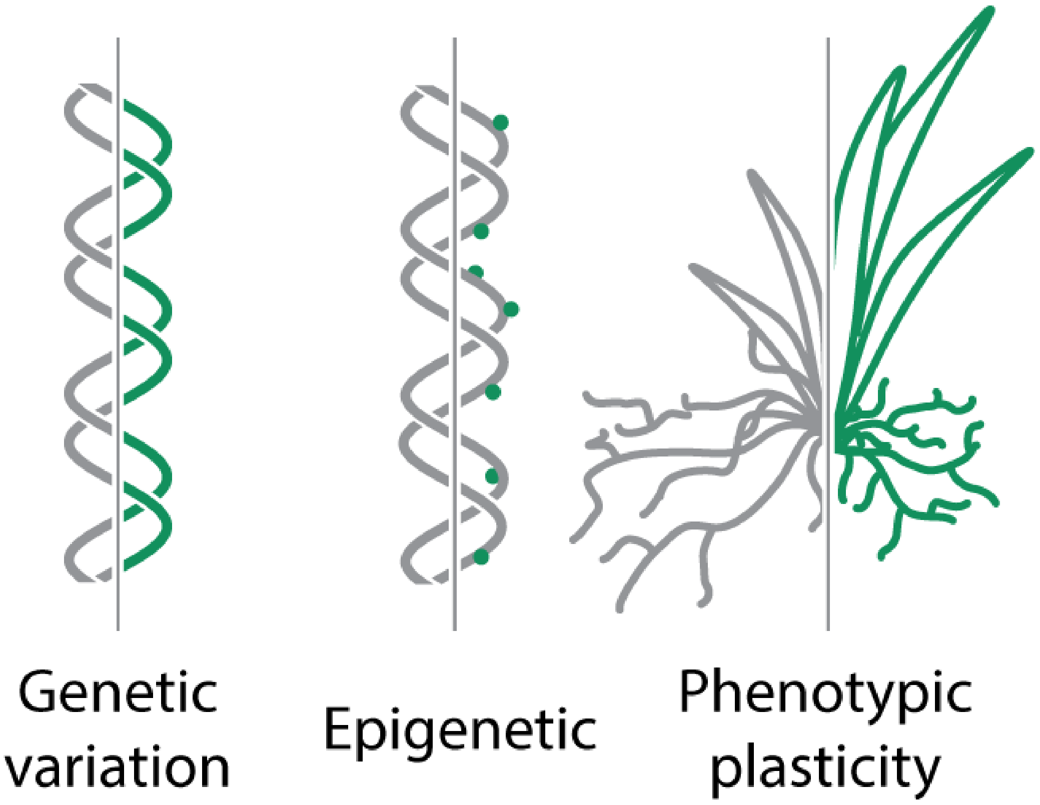
Strong impact on community response

Should be considered in:

- ES assessments

- Dynamic models

Phenotypic plasticity, one source of variation



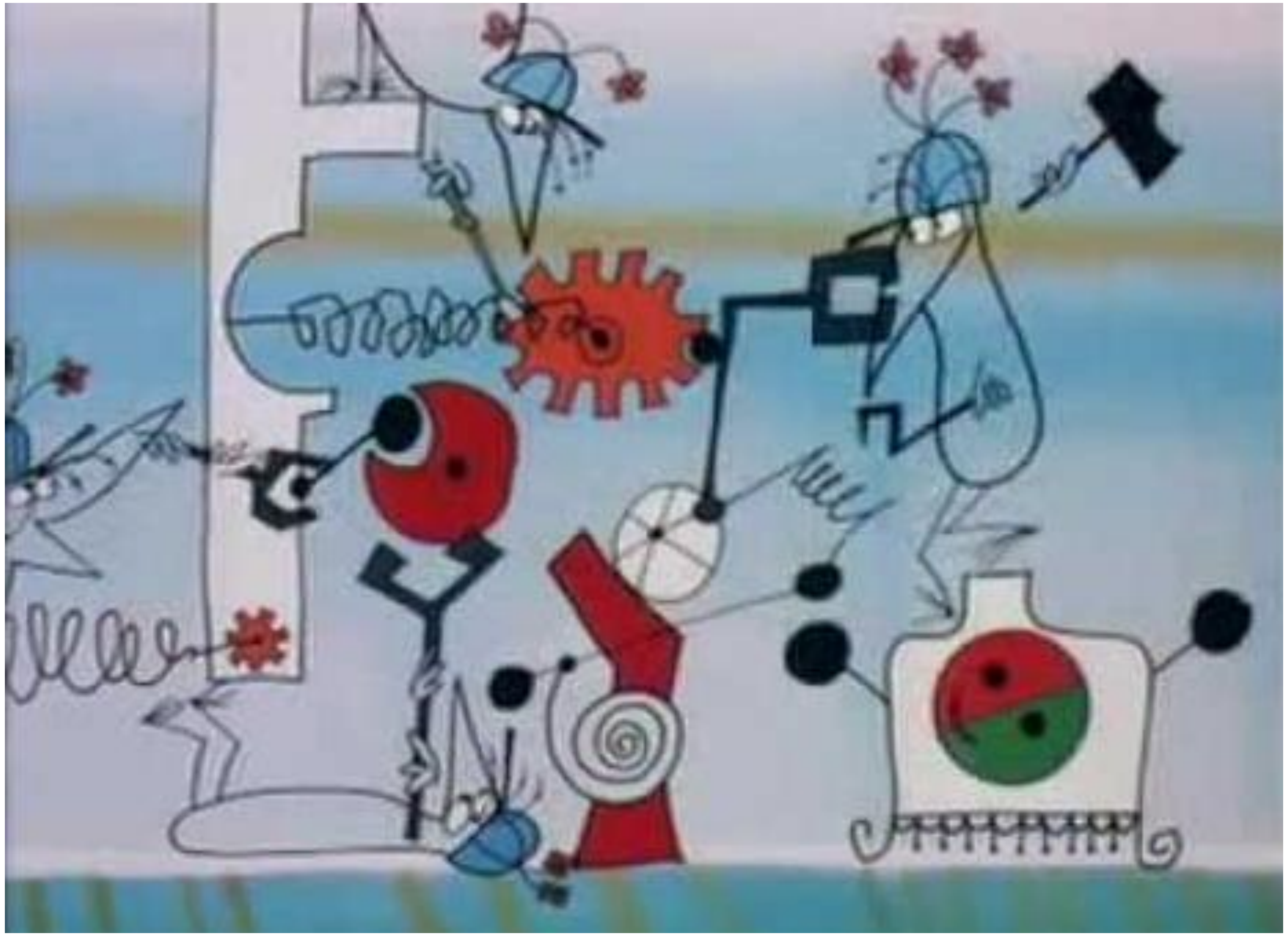
Plasticity

Potential for:

- Important role in response to drivers;
- rapid adaptation to global change.

Often overlooked because hard to study in empircal experiment.

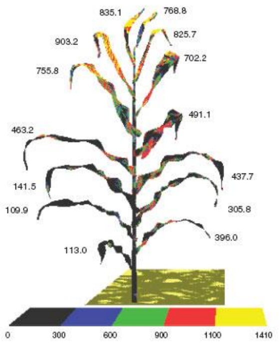
Mechanistic models to understand



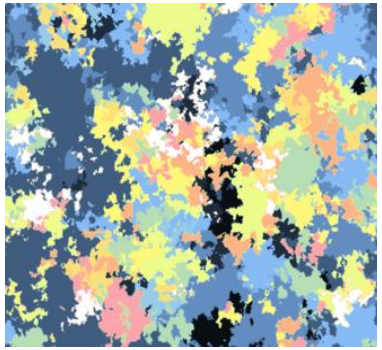
- More complex, but explicit link with drivers
- Understanding by explaining
- Emerging behaviour
- Experiment at low cost

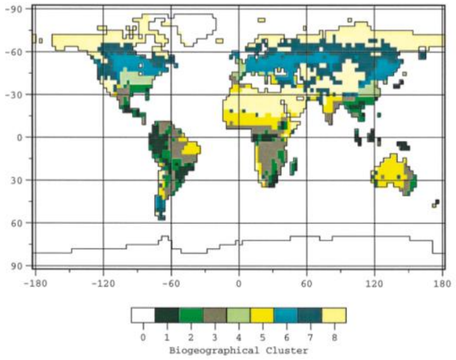
A gap to fill

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



Total incident PPFD (µmol·m^{-2}·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, Xiyong Wang, Yuntao Ma, Baoguo. 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**

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?

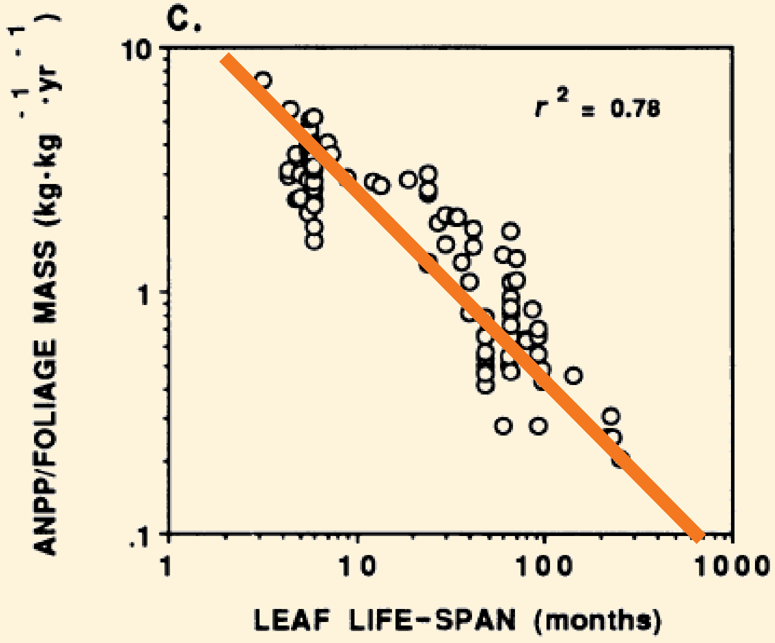
Concepts

From ecological concepts to the model *MountGrass*

Competition for resources

The Leaf Economic Spectrum

Active phenotypic plasticity



P. Reich (1992)

Competition

Shapes communities by affecting the niche

Is the main plant interaction mechanism

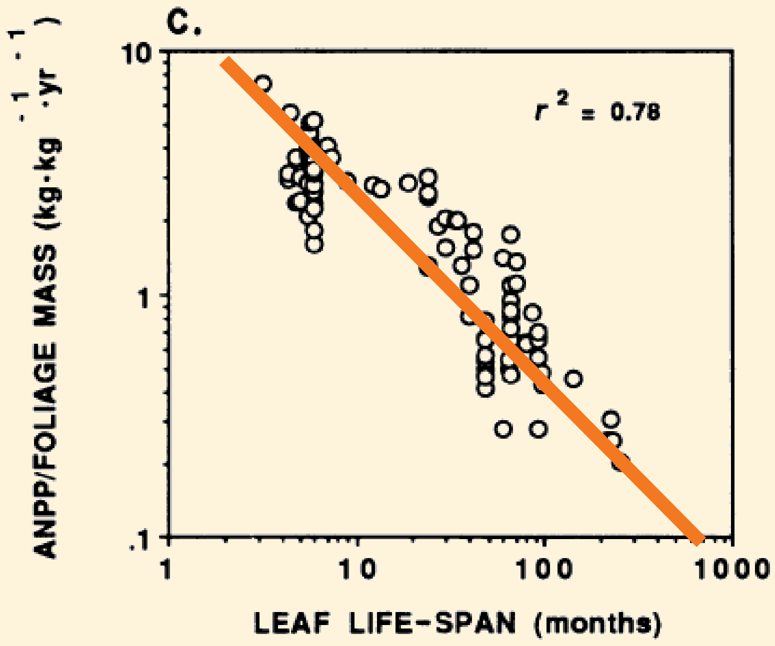
Depends on plant strategies

Leaf Economic spectrum

Leaf traits are correlated

Dimension reduction of resource-use in leaves strategies to a continuum

Depends mainly on the type of tissues the plant invests in



P. Reich (1992)

Active plasticity

Response to environmental cues

Anticipatory and integrated mechanism: often adaptive

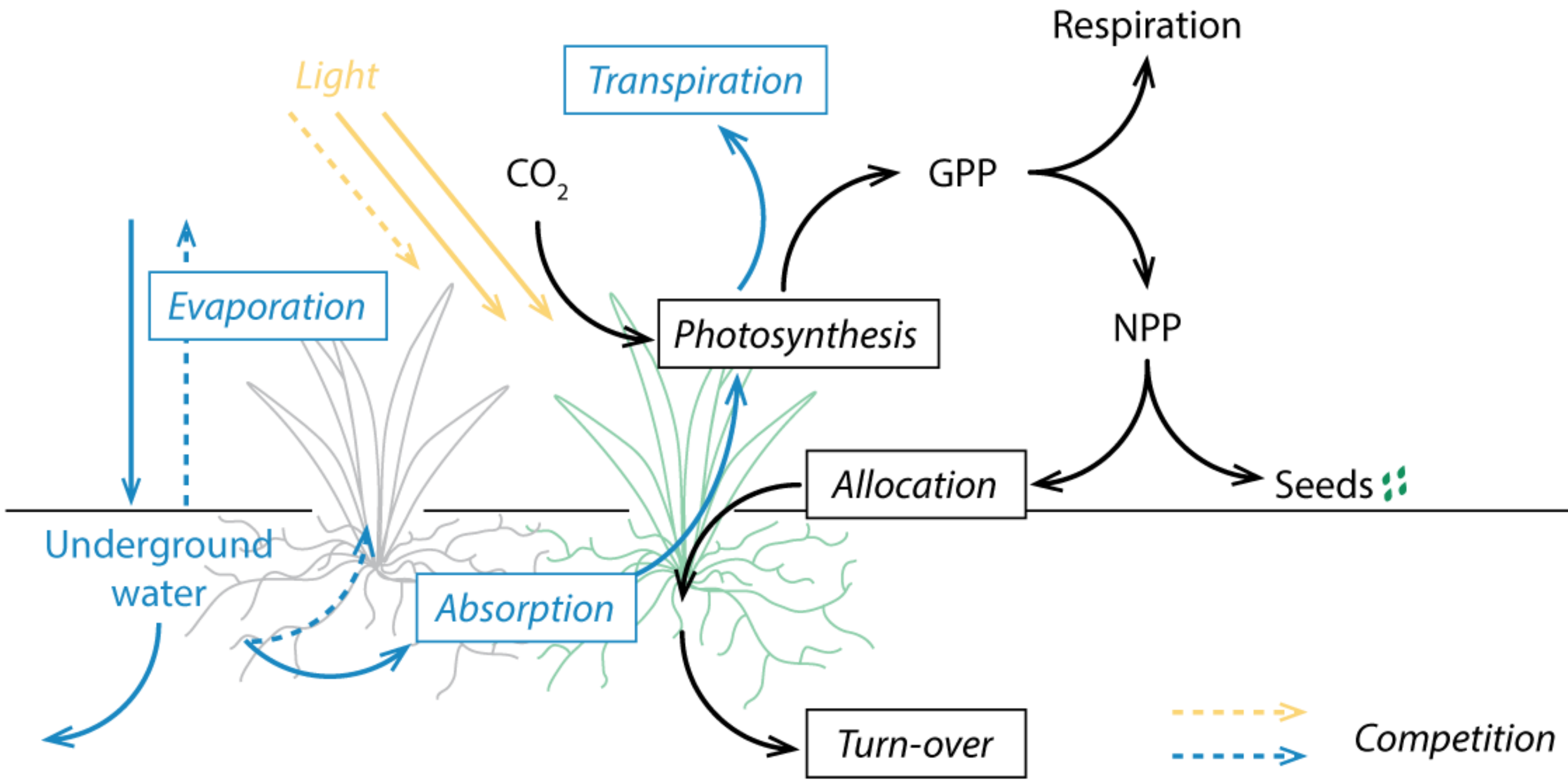
Alters morphology and allocation patterns

MountGrass' processes

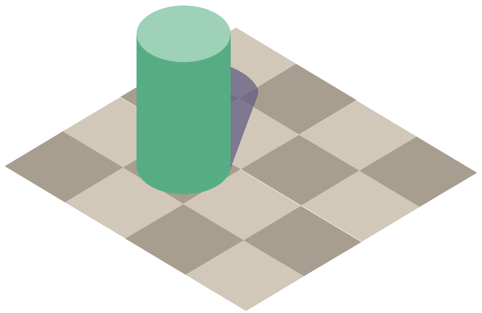
Response to drivers: physiological processes.

Above and belowground competition: light and water cycles.

Strategies: carbon allocation trade-offs.



MountGrass' space and time: individual plant scale

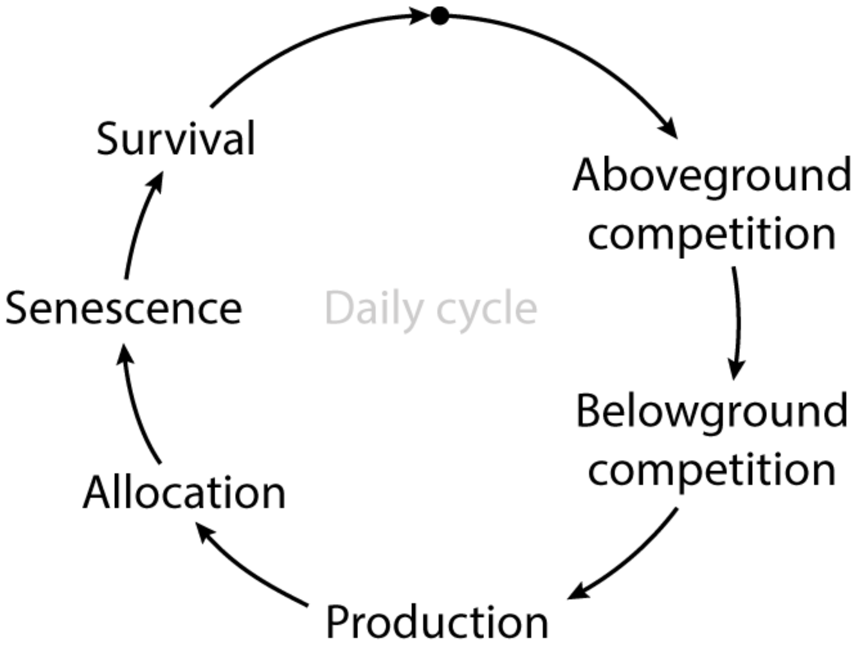


Scale: metter

Resolution: cm

Variability: water content saturation

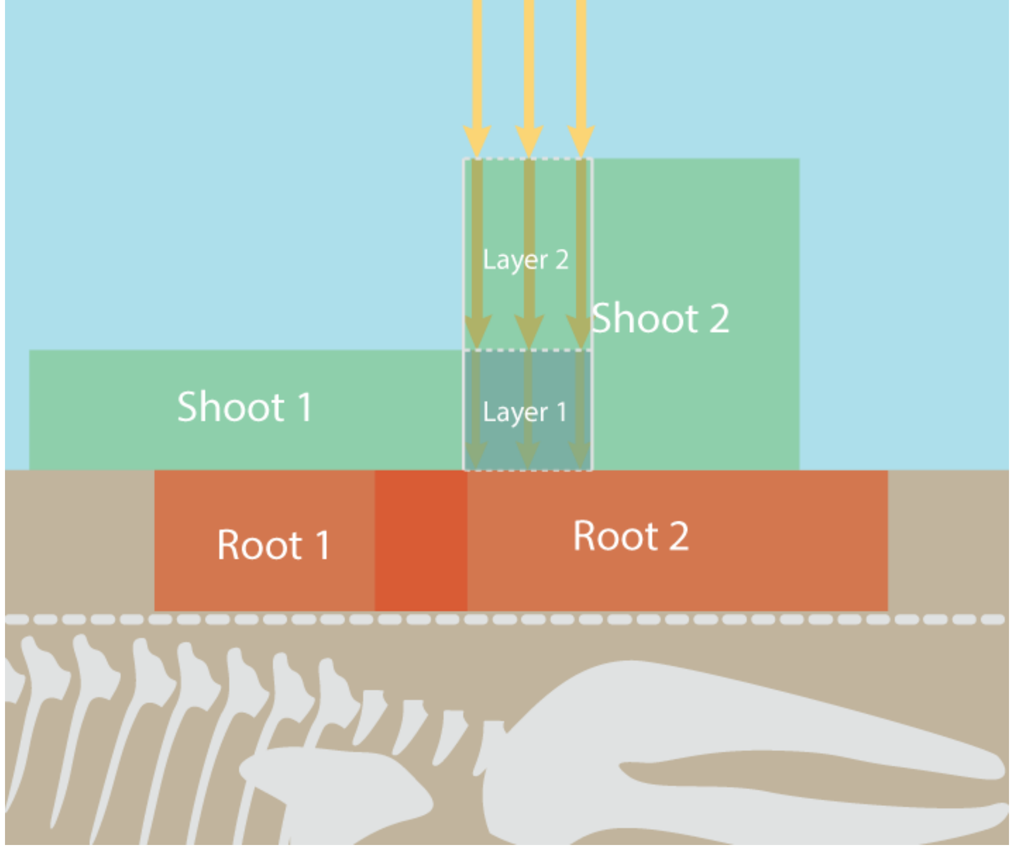
Individual-based model, spatialy explicit



Scale: season

Resolution: daily cycle

Variability: daily averages (T°, prec., radiations)

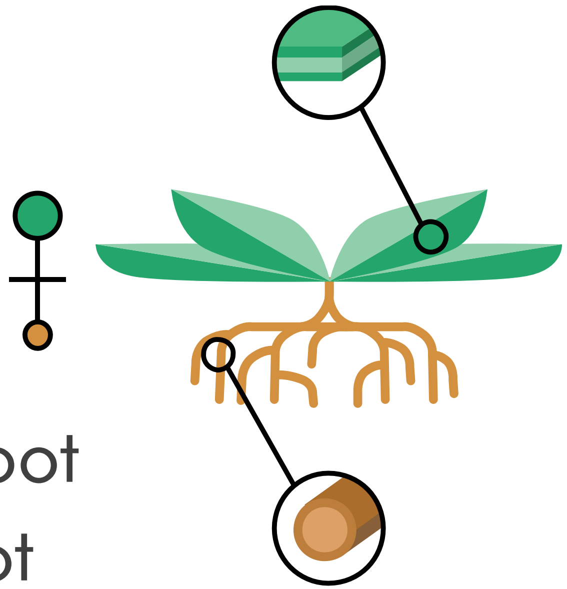


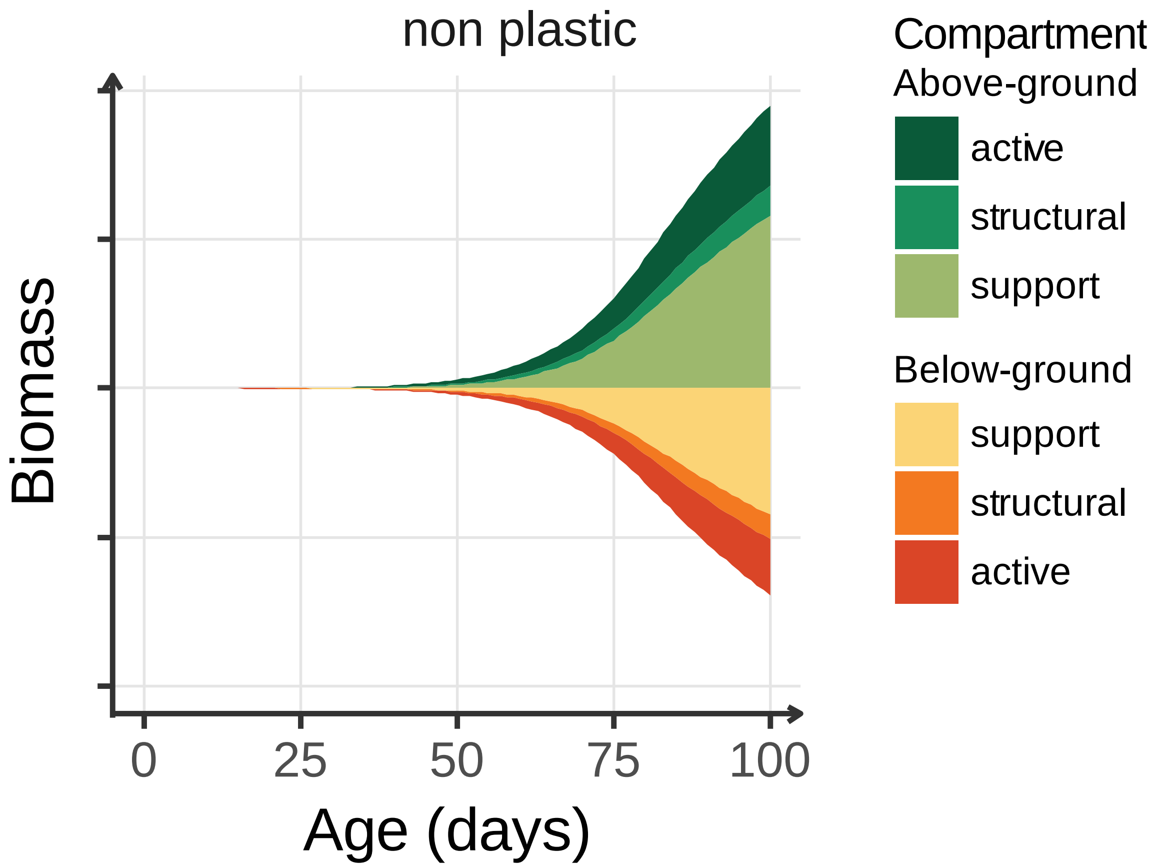
Plant carbon pools and allocation trade-offs

6 vegetative pools

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

Allocation trade-offs
→ strategic trade-offs





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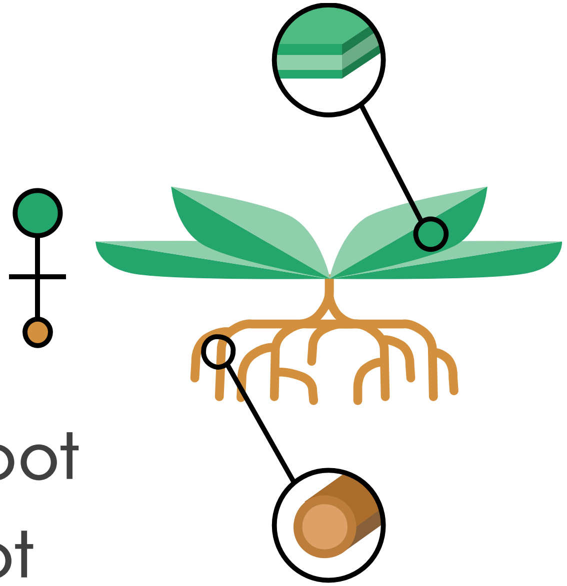
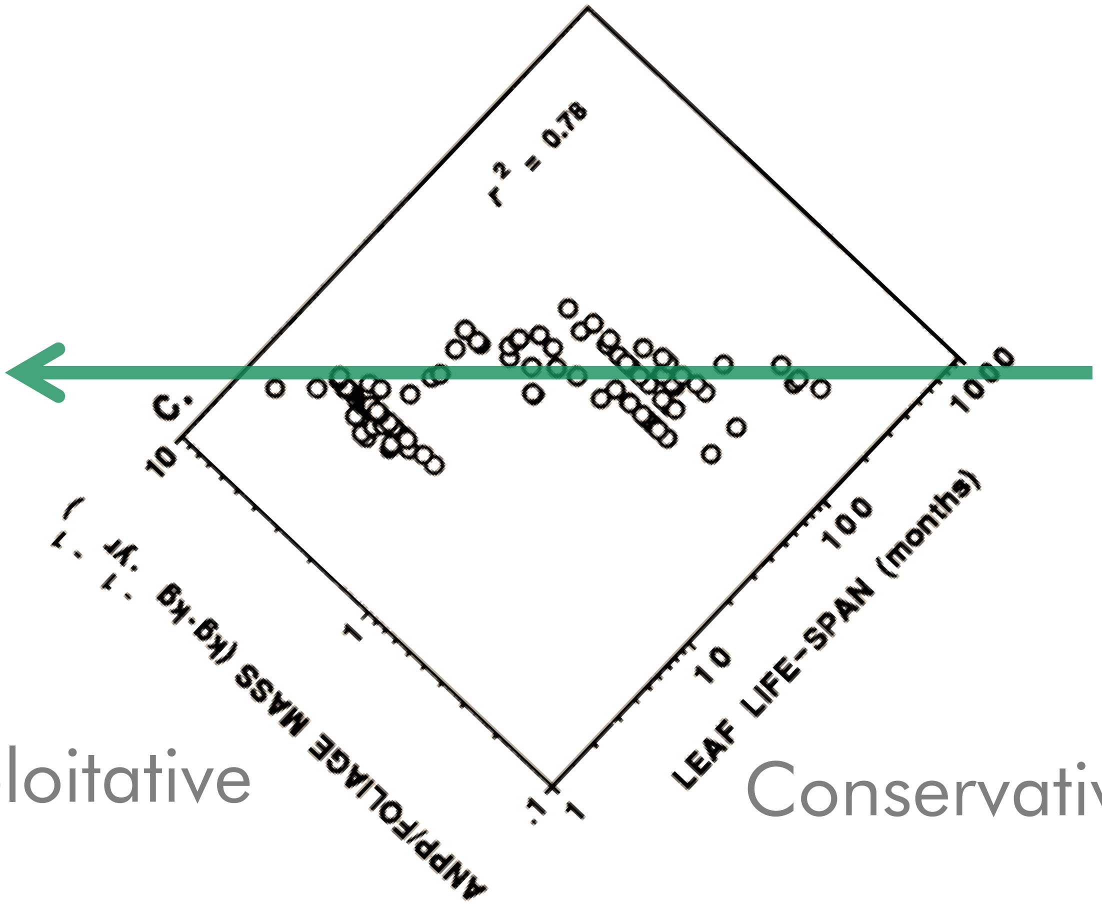


Allocation trade-offs
→ strategic trade-offs

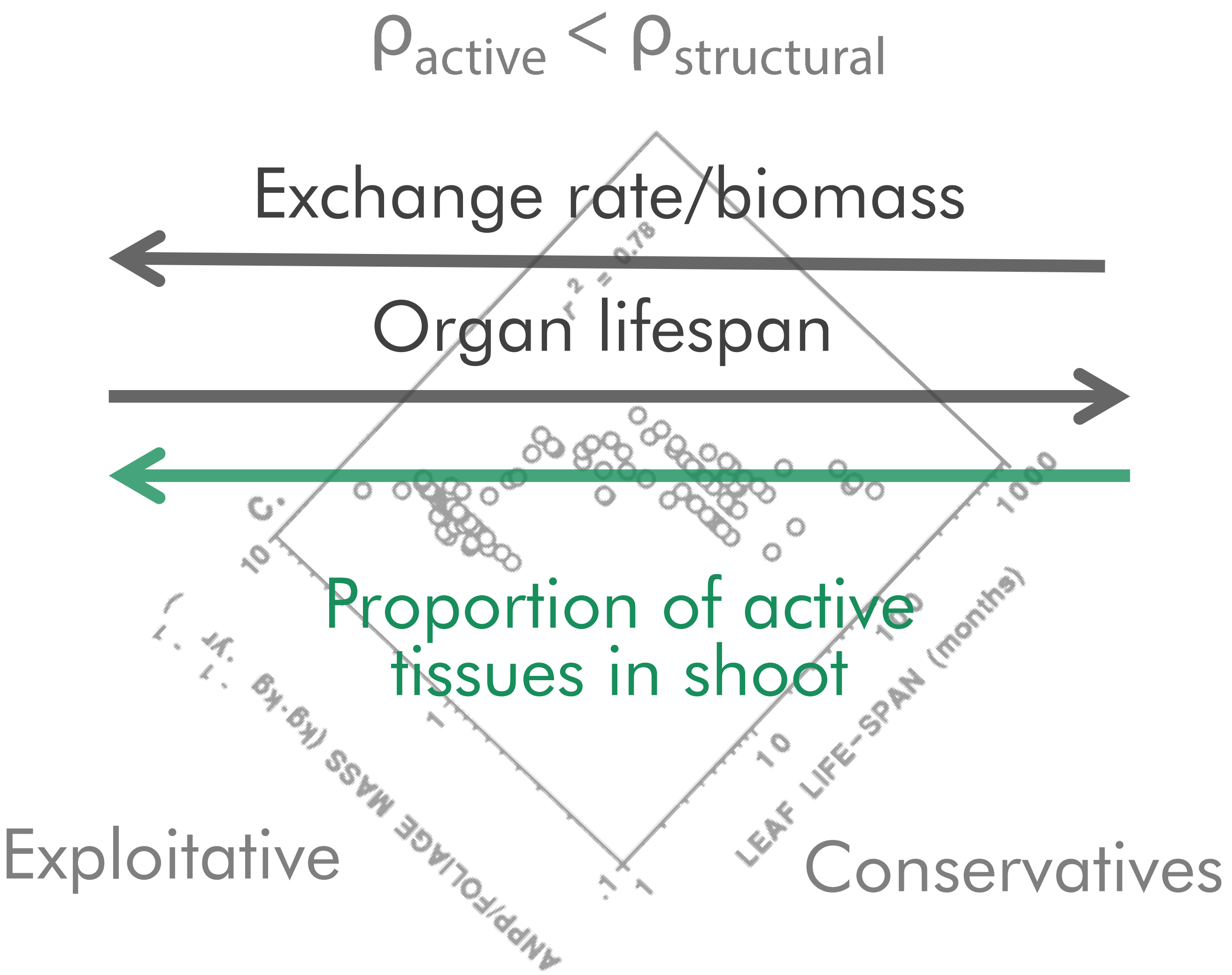


Plant carbon pools and allocation trade-offs

Strategic trade-offs

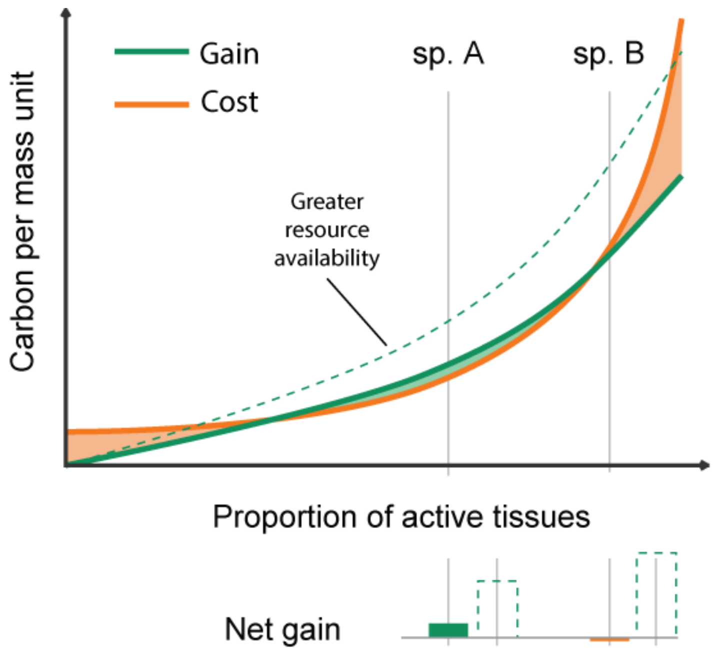
=closed strategy space

→Generate diversity but
with no « super-species »

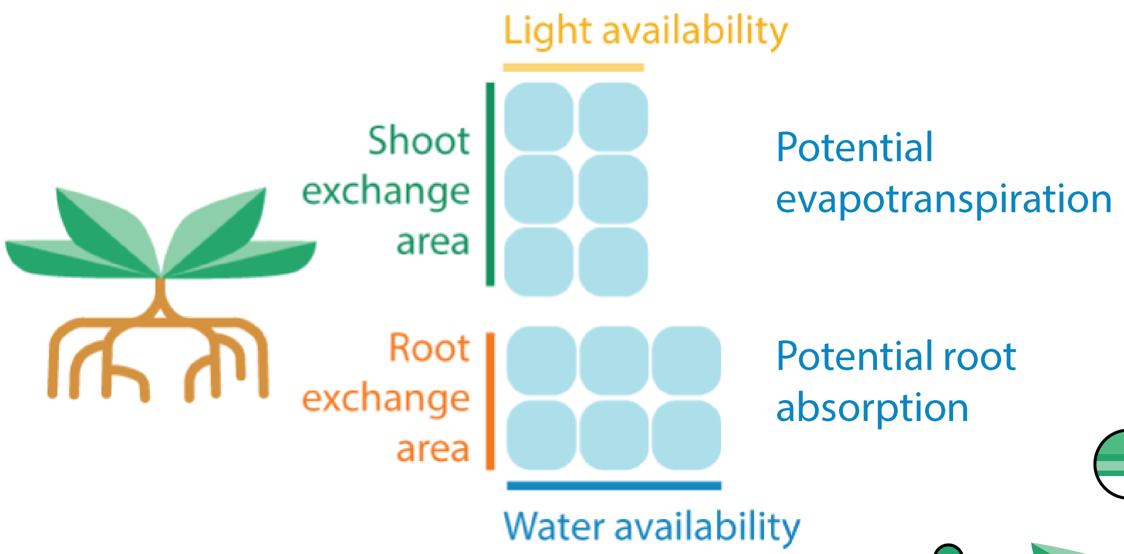


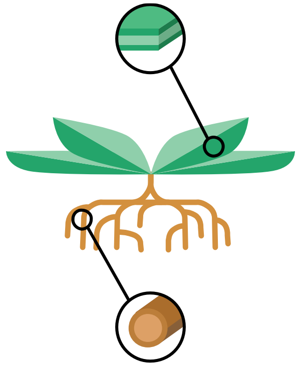
The components of plant growth

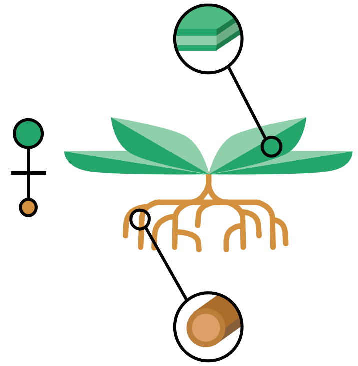
Tissue potential efficiency



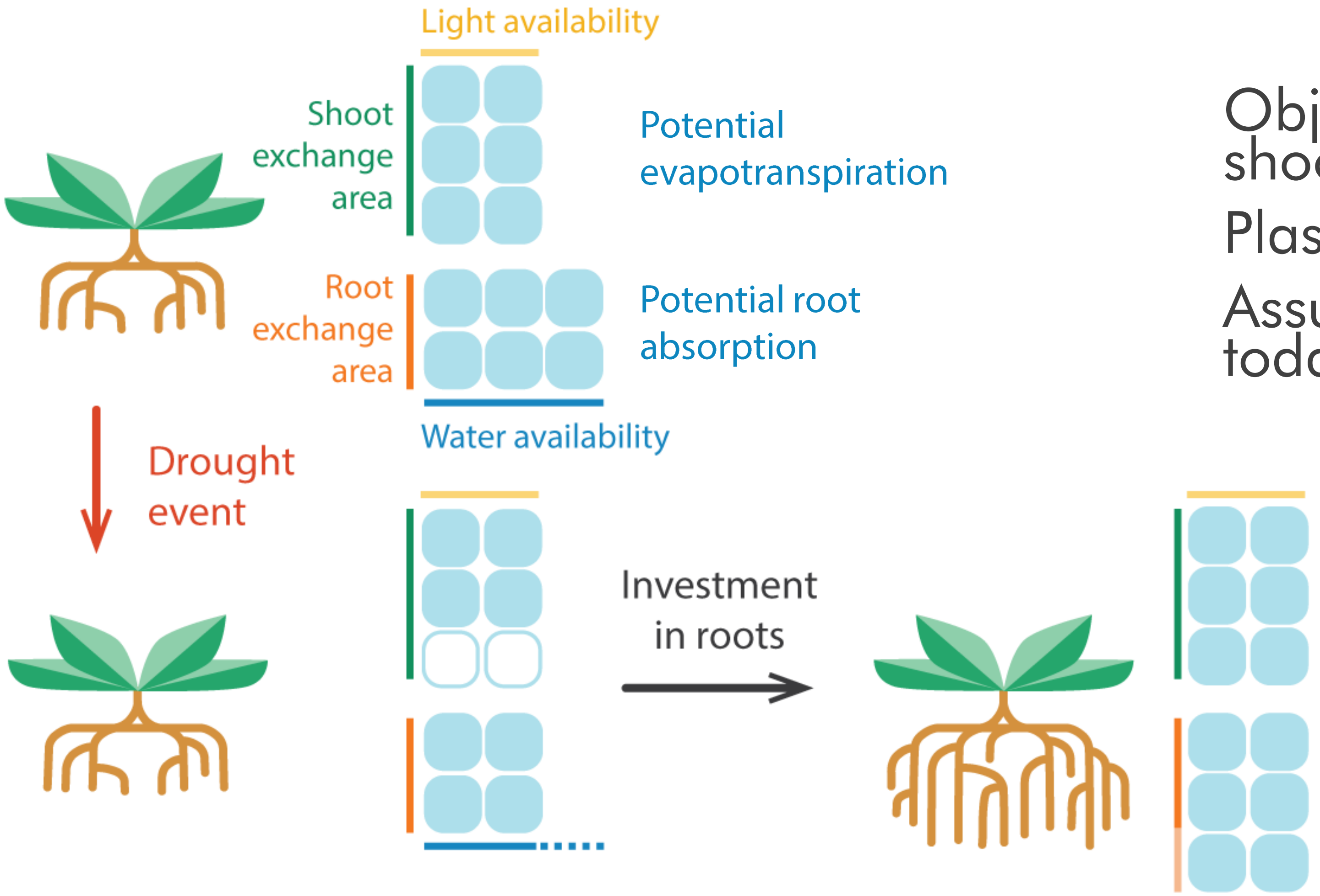
Balance







Plasticity: the functional equilibrium



Objective function: root activity = shoot activity

Plastic dimension: Root:shoot ratio

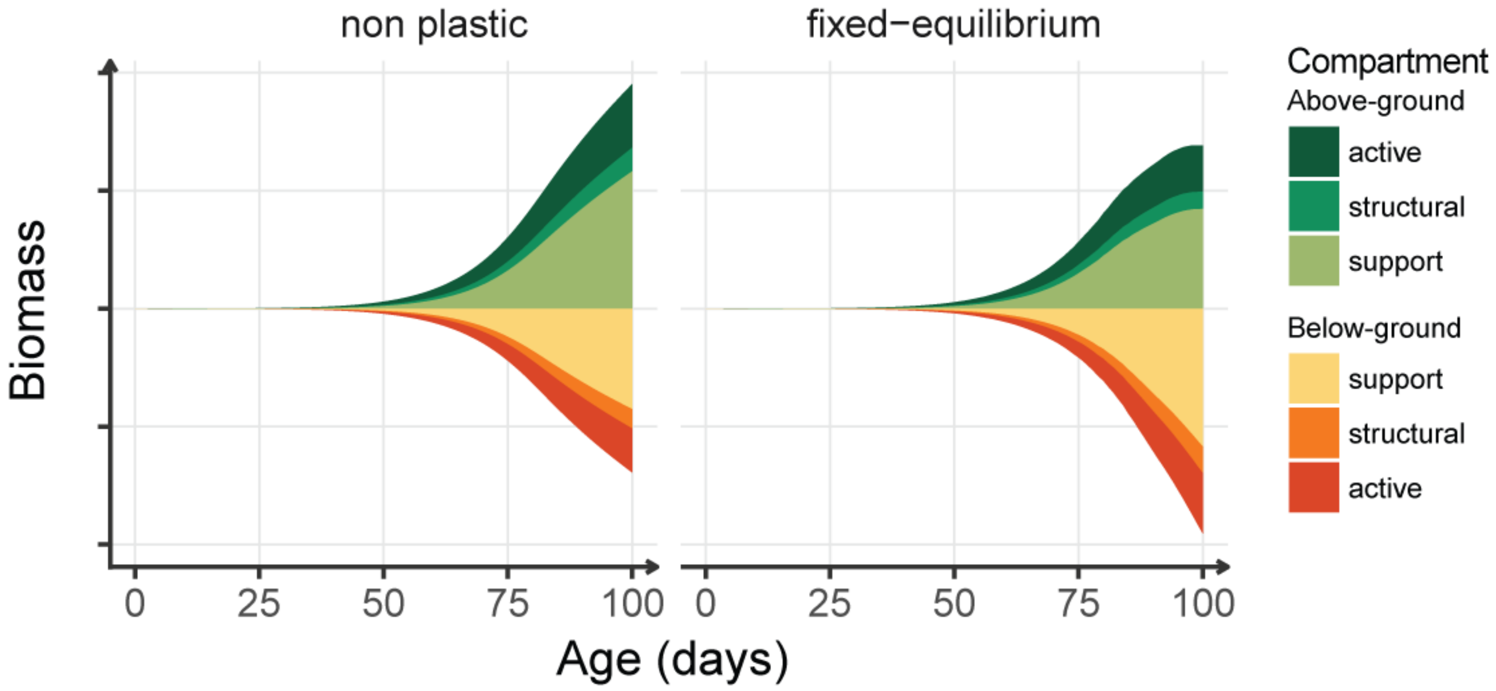
Assumption: tomorrow same as today

« fixed-equilibrium »

= no changes in proportion of active tissues

Plasticity in action

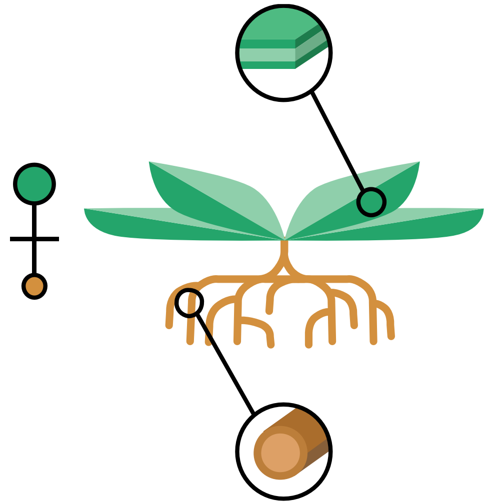
Water limiting at the end of the simulation → investment in root tissues



« fixed-equilibrium »

= no changes in proportion of active tissues

Model summary



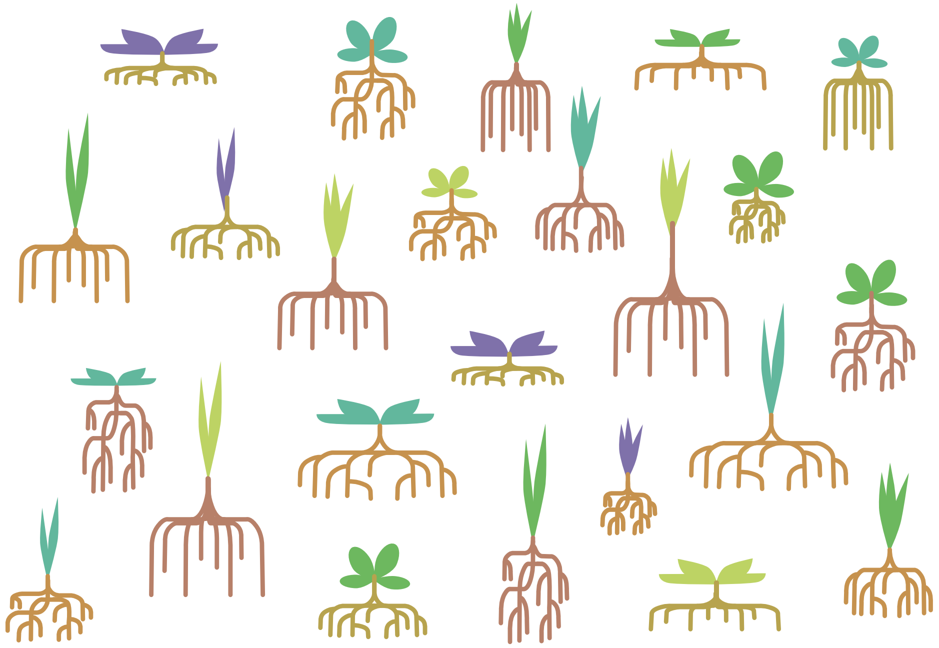
Allocation trade-off

Close continuous phenotypic space

Closed continuous strategy space

Phenotypic plasticity

Species diversity



Results

Individual- and community-level effects of plasticity

Calibration

26 parameters

5 strategic parameters

Pot growth patterns in 2 treatments of precipitation

→ Selection of a subset of parameter sets for simulations

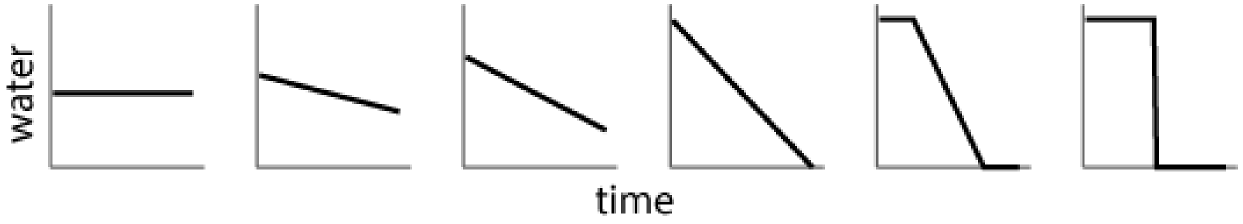
20 parameter sets 12*12*90 cm pots

100 days fixed T° & irradiance

Individual-level simulations

How does plasticity affect individual growth?

- with spatial variability: gradient of homogeneous water availability
- with temporal variability: gradient of heterogeneous water availability (but same average availability)



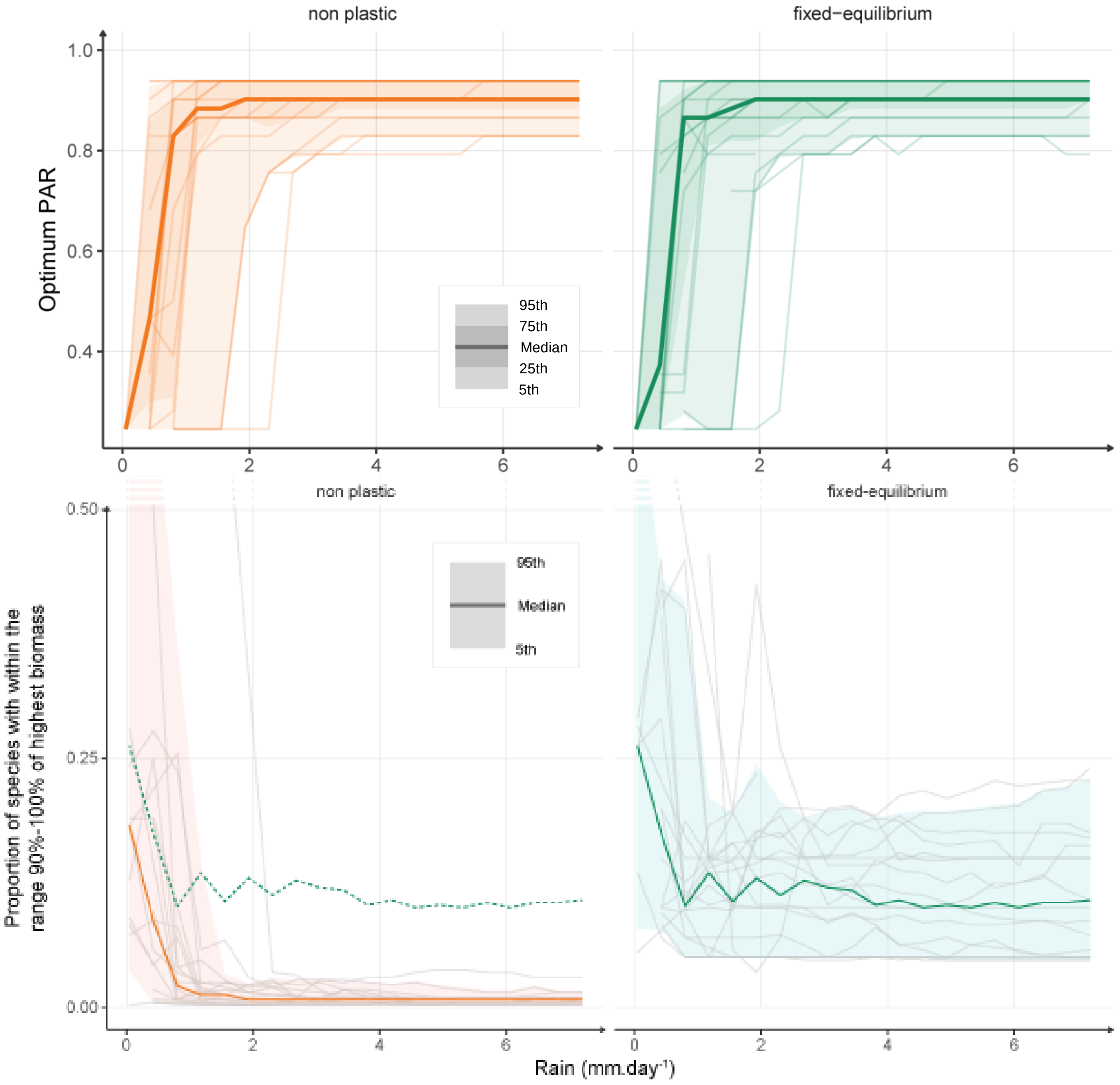
→ track biomass for diverse root strategies: maximum biomass, relative performances and dominant strategy

Plasticity effect in homogeneous conditions

- No shift in best strategy
- Reduction of growth differences

→niche widening

→ no improvment of the dominant species

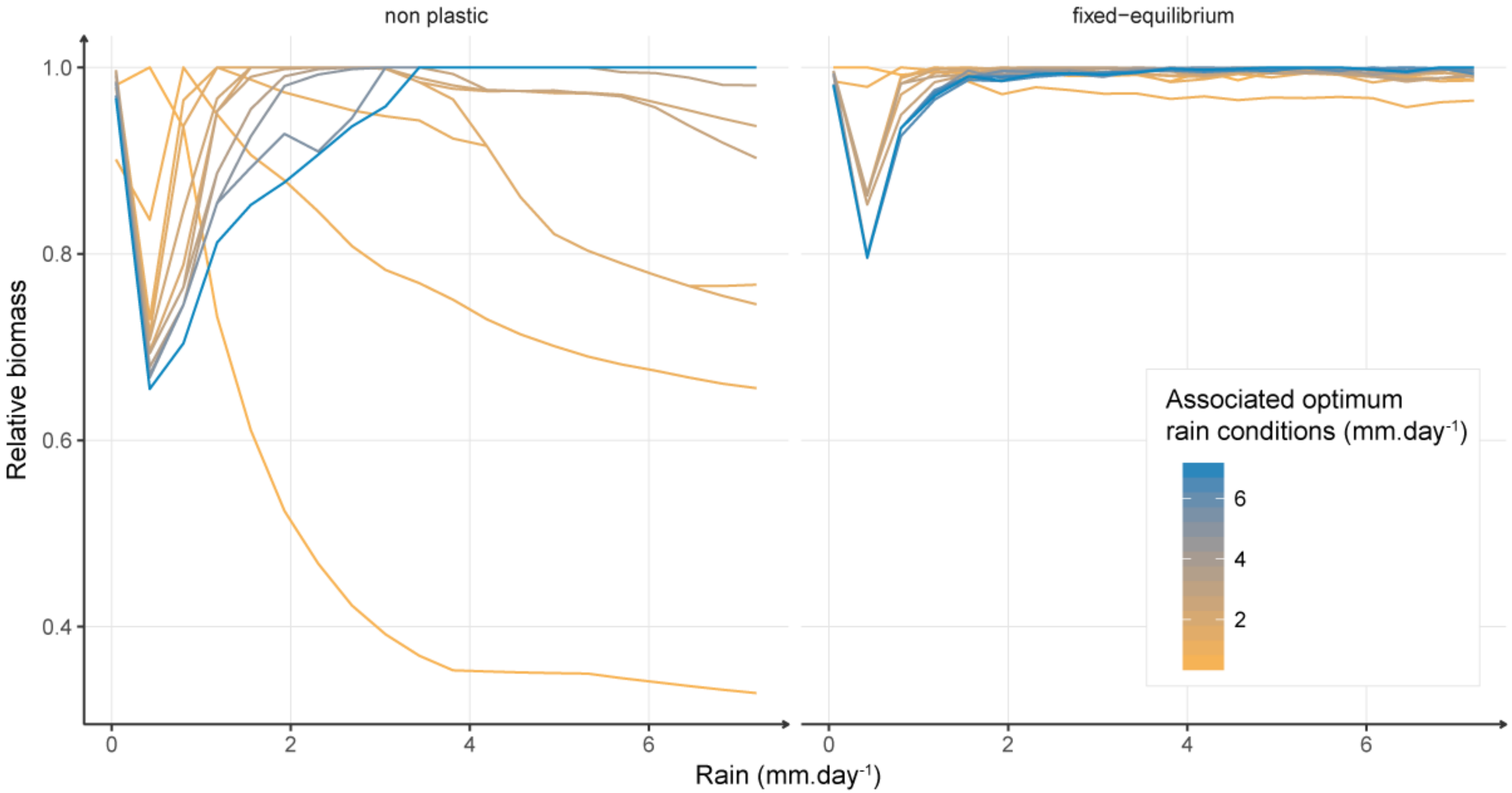


Niche widening in homogeneous conditions

for 1 parameter set

Performance of the best species of each condition

Plasticity → increases relative biomass in non optimum conditions

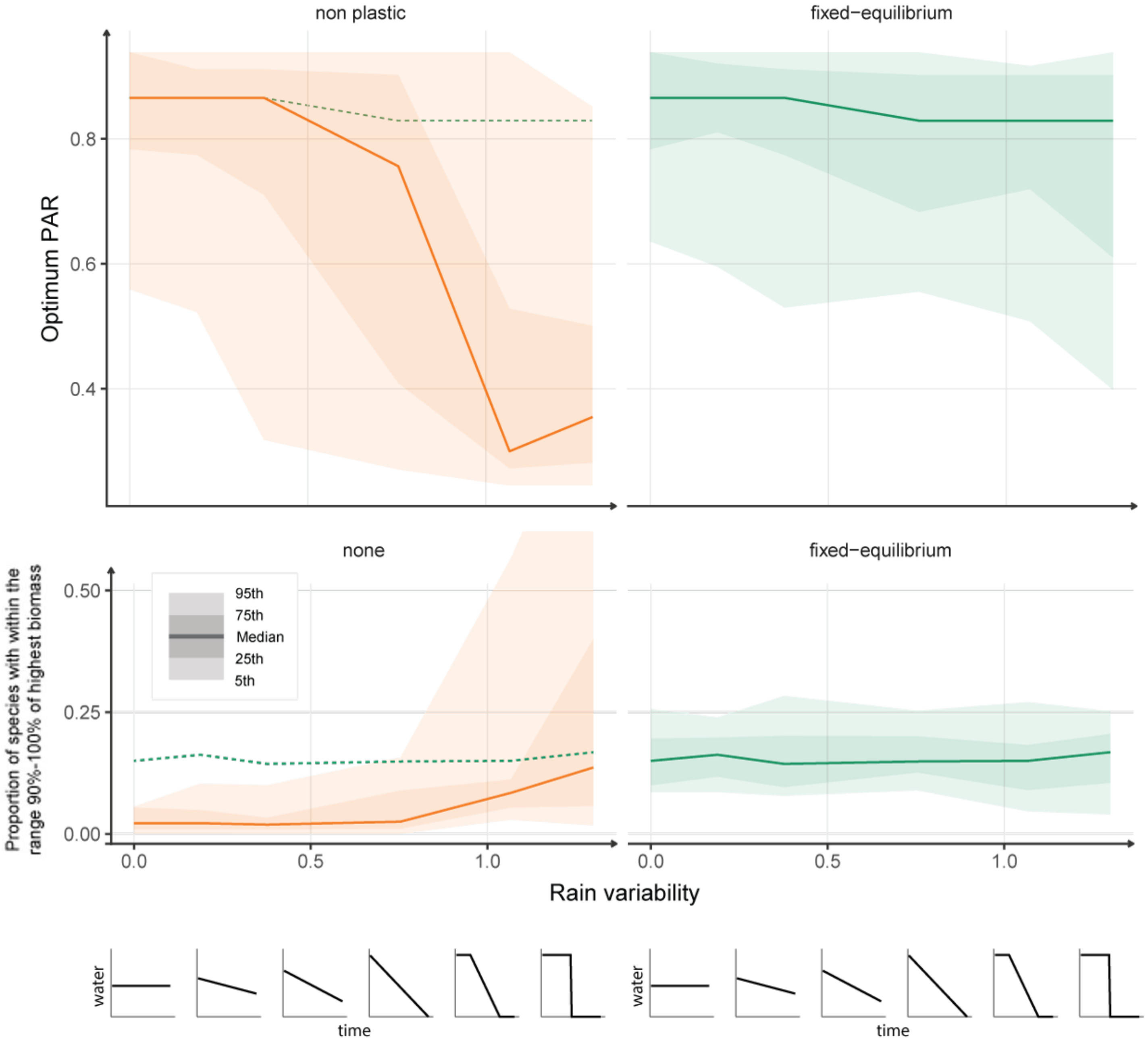


Plasticity effect in heterogeneous conditions

- Changes in dominant strategy in favour of dominant species
- Reduction of growth differences
- Increase of relative BM
  (not shown)

→ niche widening

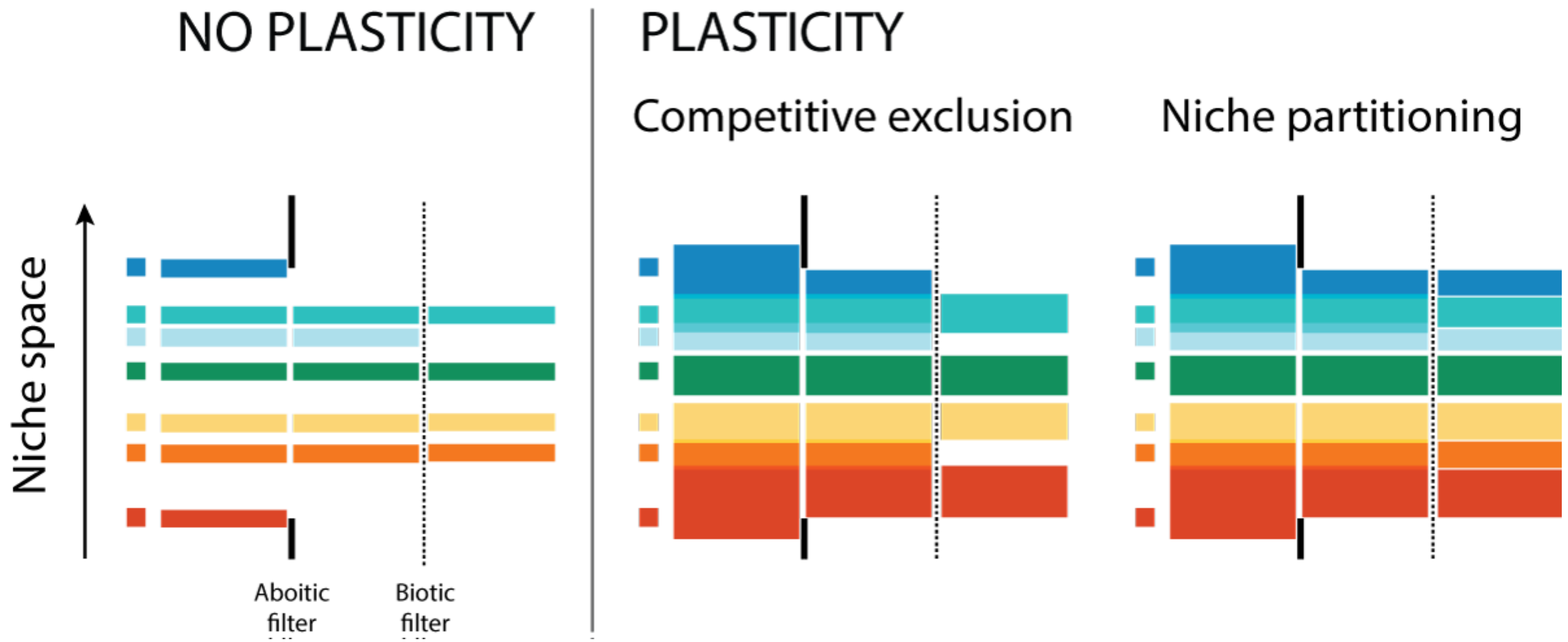
→ assymetric gain (+exploitative strategies)



Consequences at the community level ?

Niche widening = reduction of abiotic filtering

- higher potential species diversity



Assymetric gain

- Competitive exclusion by exploitative species?
- Shift in dominant strategy?

12 parameter sets 100*100cm plots

6 sites: variable T°, prec. & irradiance

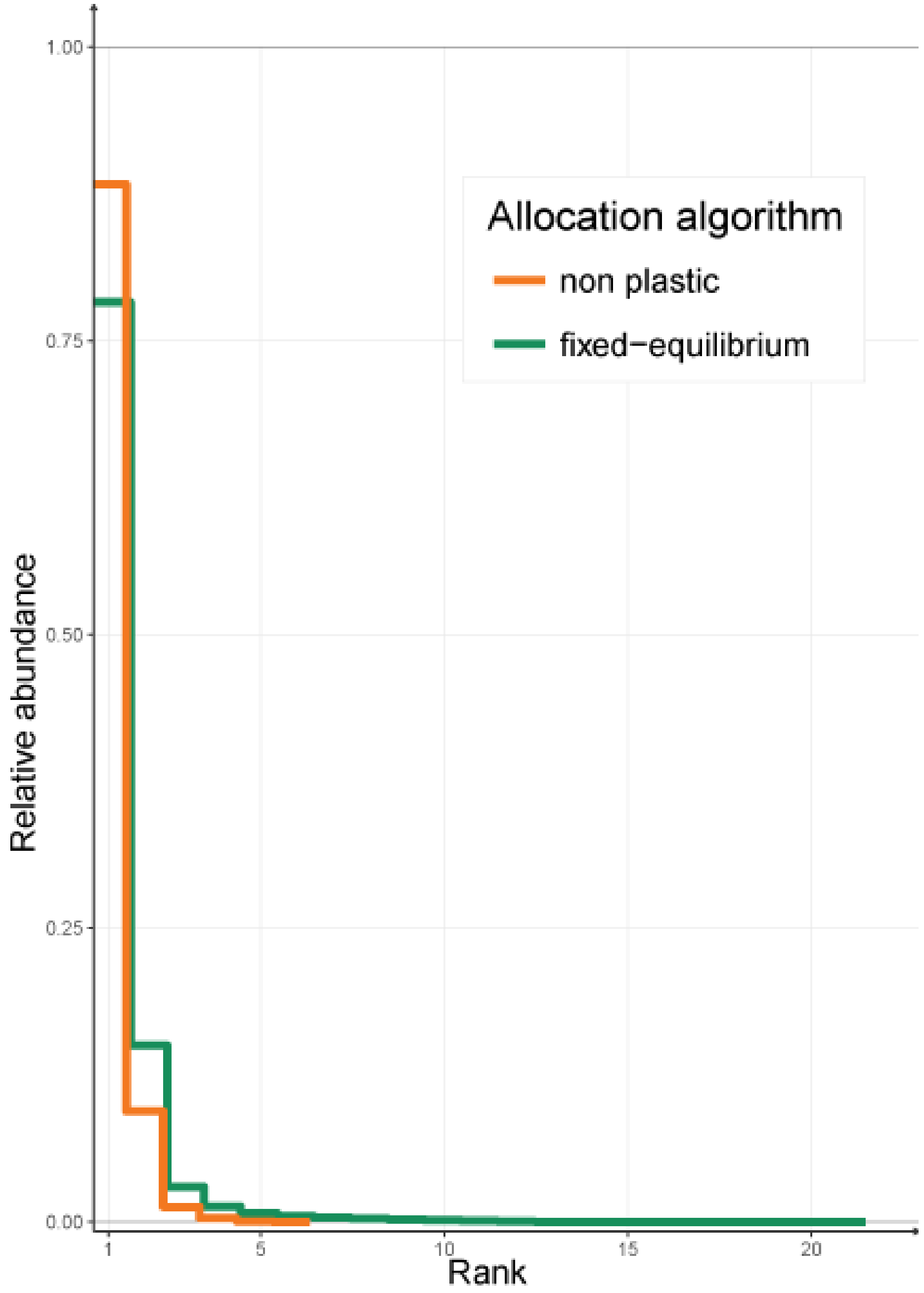
Community-level simulations

How are plasticity effects transfering to community level:

Is competitive exclusion effect larger than the niche widening?

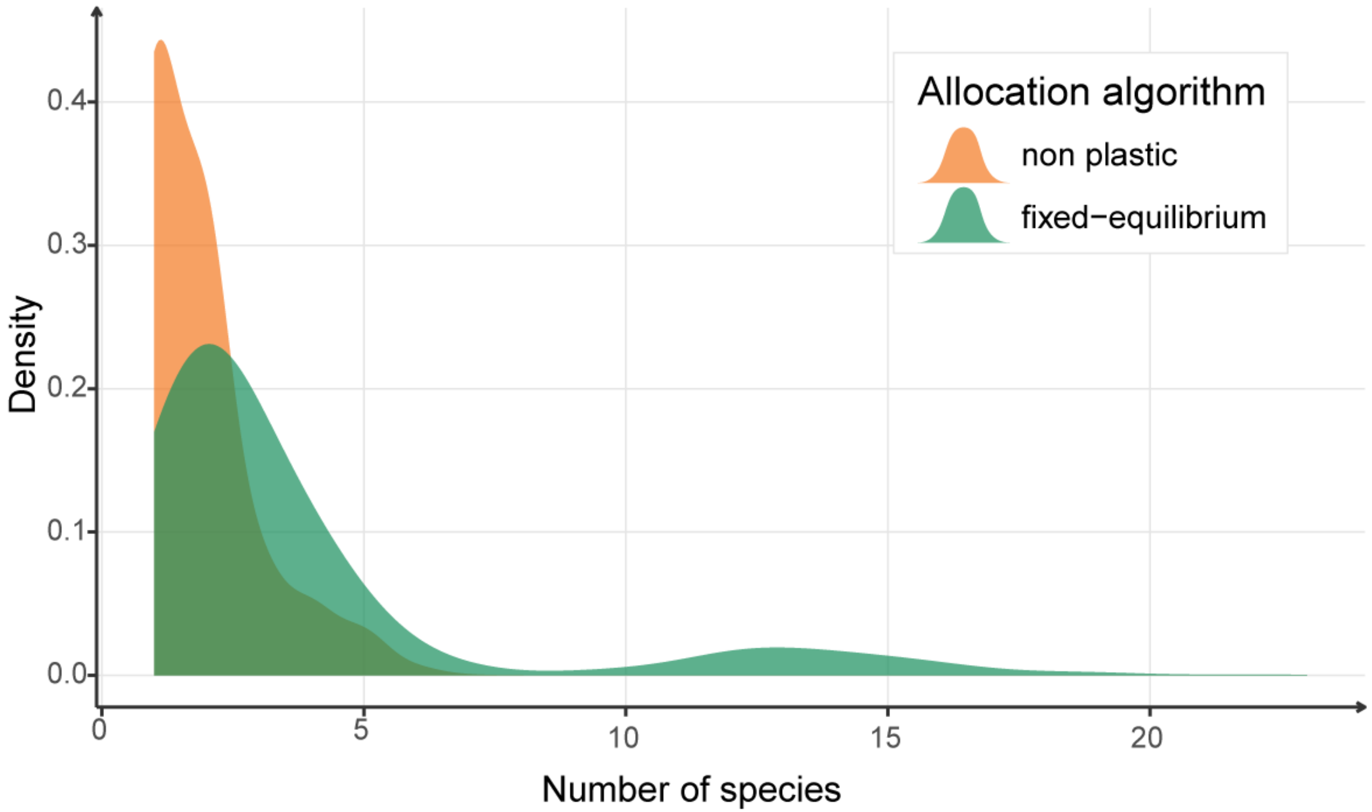
Is there a shift in the dominant strategy?

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



Effects of plasticity on species diversity

Niche widening > competitive exclusion

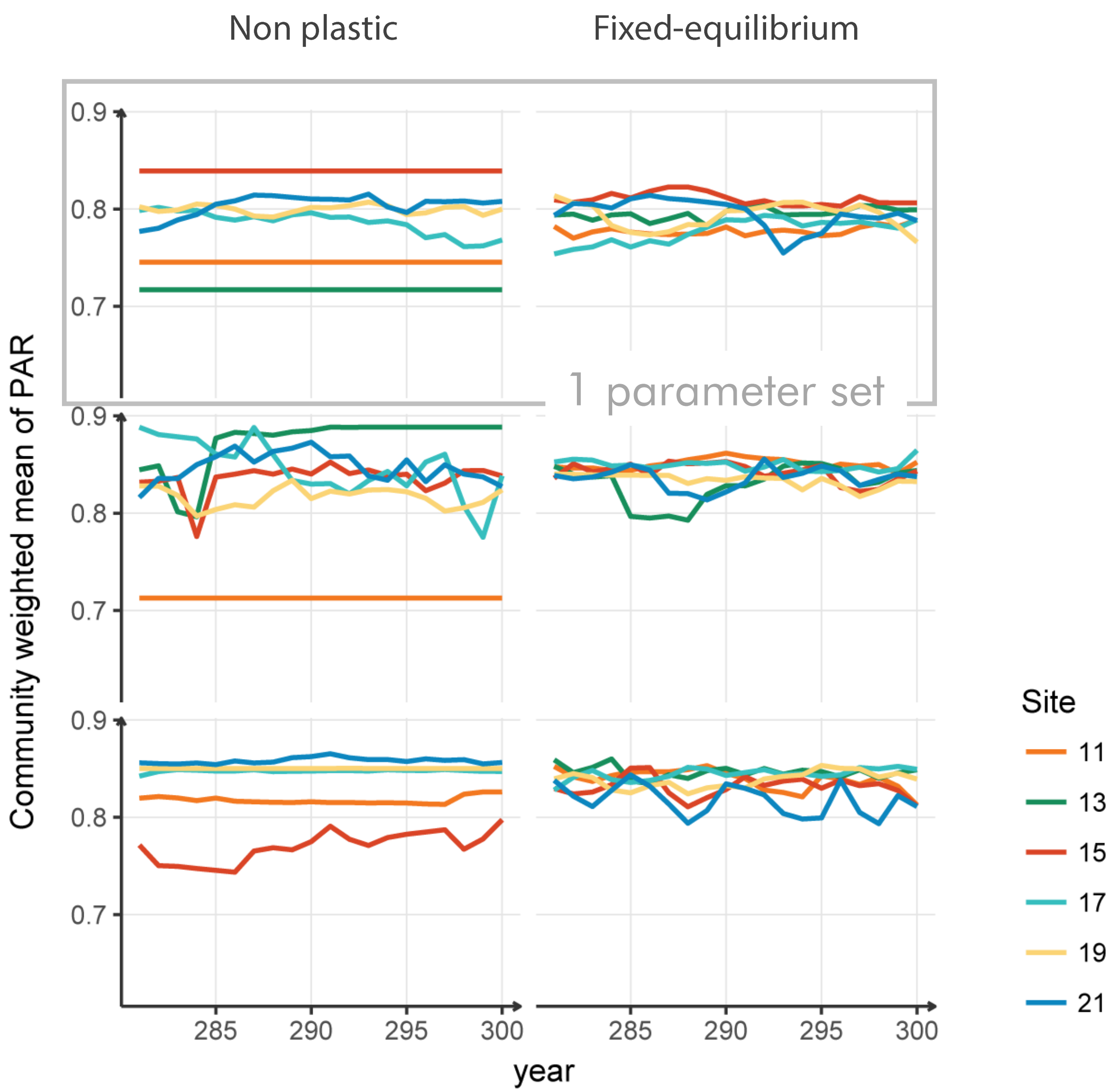


Effects of plasticity on dominant strategy

From inter-site variability to inter-season variability

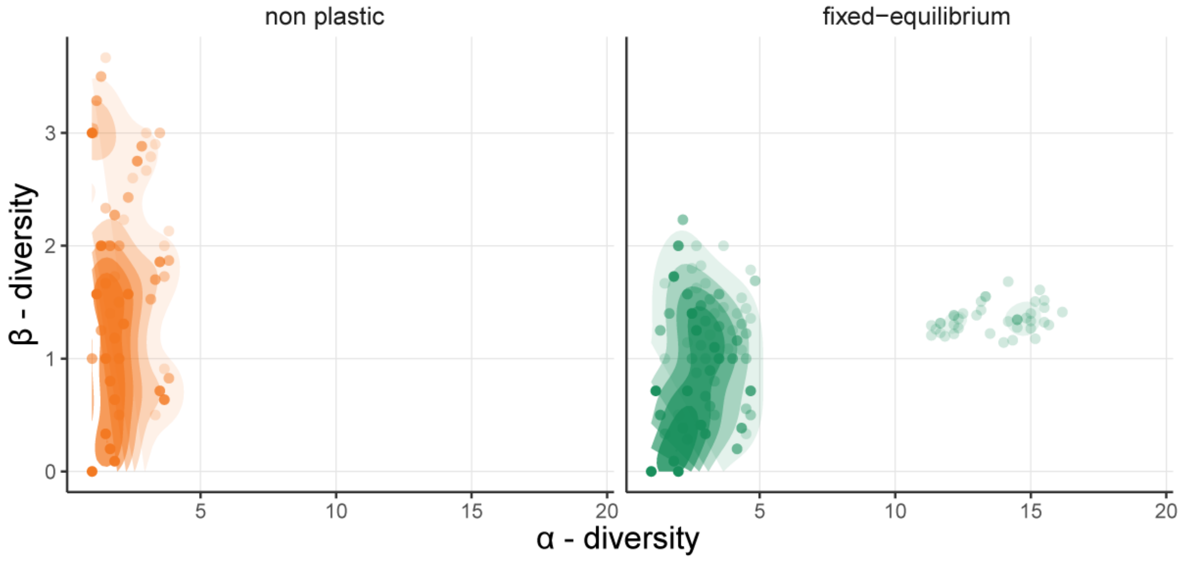
Plasticity reduces functional diversity (meta-community scale)

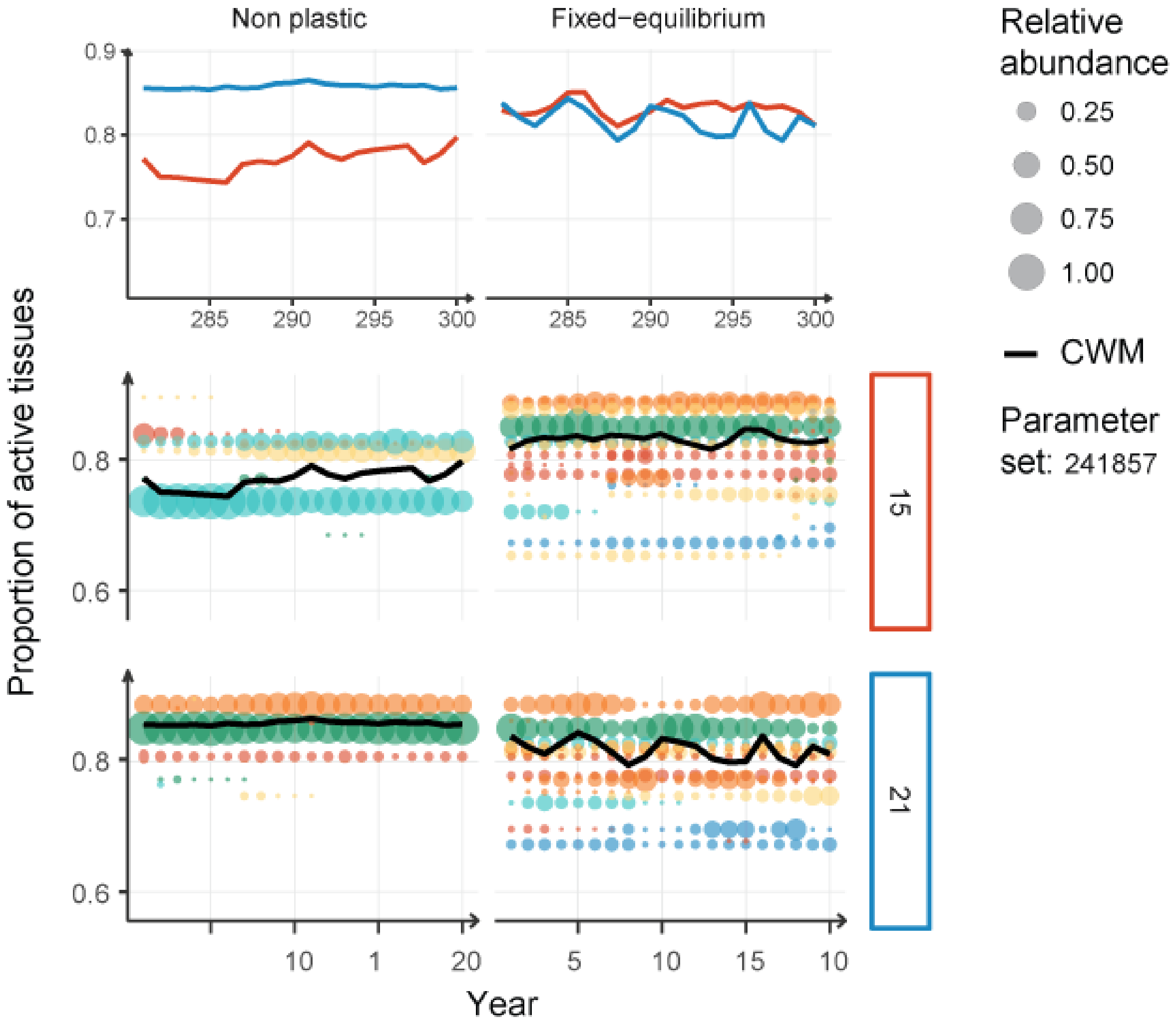
→ Investigate the structure of the meta-community



A shift in community structure

- From distinct dominated communities to diverse communities with overlap





Results summary

- Niche widening
- Assymetric gain in favour of exploitative species = loose of sensitivity to climatic conditions
- Niche widening > competitive exclusion
- Plasticity alters meta-community structure

Discussion

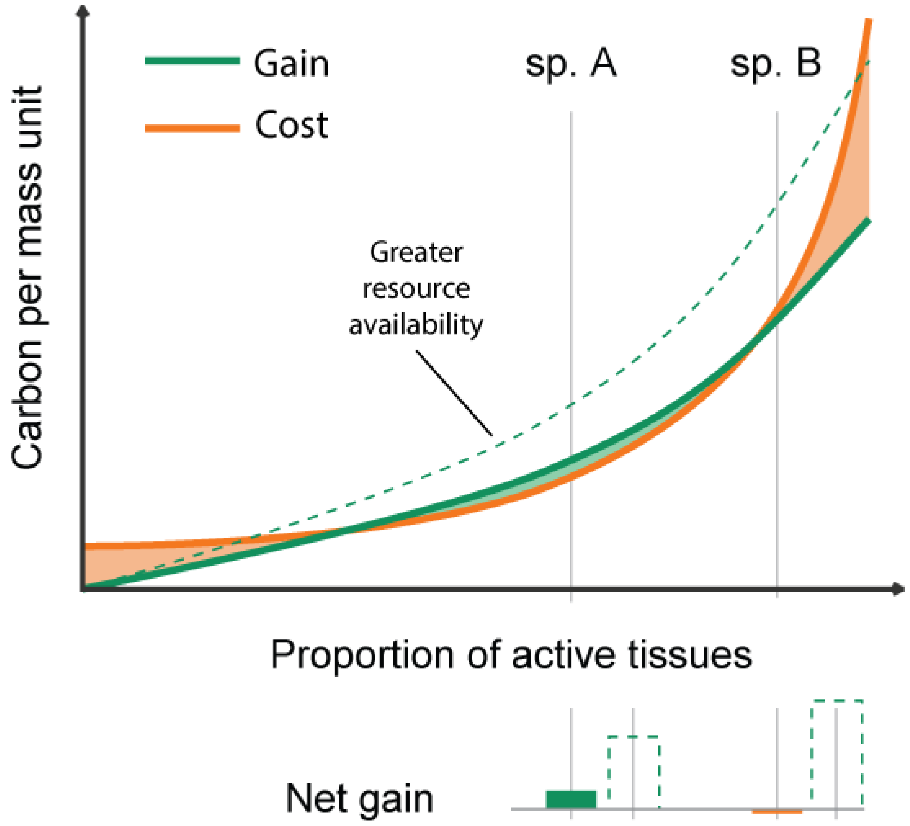
Impact on community dynamics and community modelling

How plasticity favours exploitative species?

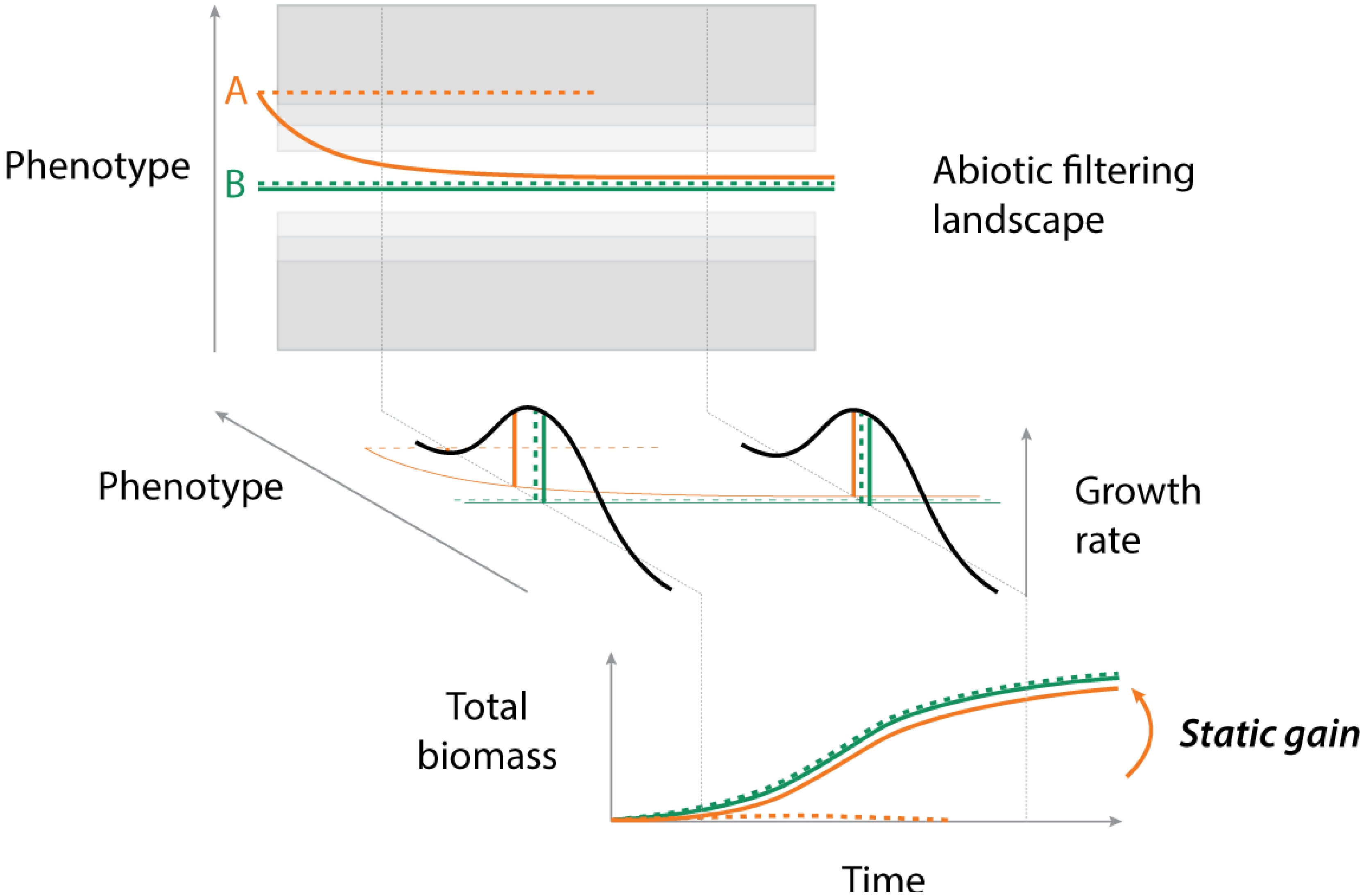
The realised tissue efficiency depends on the overall balance

Conservative species have a greater efficiency but lower rate

Plasticity ensures this balance and negates the sensitivity of exploitative species



Static gain



Plasticity widen the niche thanks to functional convergence (from 3D to 2D)

Reduced with reduced phenotypic flexibility

Linked to the mechanism of plasticity

Is there a trade-off between functional and species diversity ?

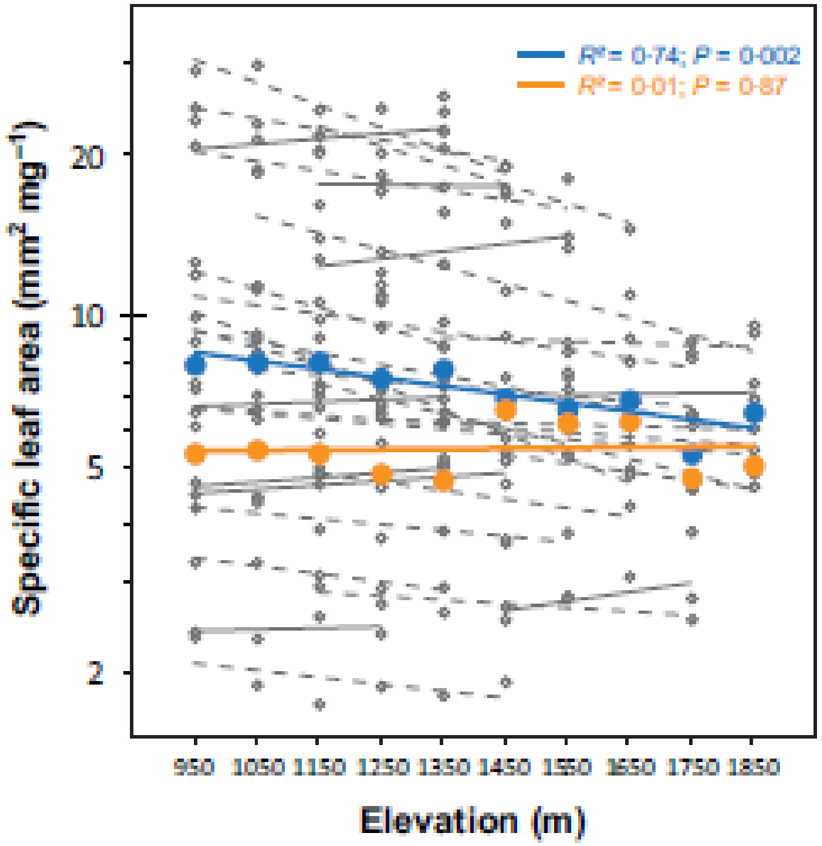
Does plasticity threaten the functional diversity?

By the reduction of the role of the abiotic filtering:

- diversity in other trait is promoted by species diversity
- part of the effect is due to strategy sampling
- part of it is assymetric gain

By the functional convergence on plastic dimensions:

- limited by the cost of plasticity
- diversify plastic strategies: avoidance vs resistance



Conclusions & Outlook

New hypothesis and simulations

Model developments

Better undertanding of plasticity

- Forms of gains: reduction of sensitivity, static gain, dynamic gain (not shown)
- Plasticity promotes the species diversity thanks to niche widening
- Plasticity may reduce the functional diversity by allowing functional convergence and reducing the abiotic filtering

Better undertanding of plasticity

- Forms of gains: reduction of sensitivity, static gain, dynamic gain (not shown)

- Plasticity promotes the species diversity thanks to niche widening

- Plasticity may reduce the functional diversity by allowing functional convergence and reducing the abiotic filtering

→ Challenge the Gaussian!

Diverse community framework

- Diverse strategies thanks to continuous strategies
- Resource dependant optimum
- Plasticity in coherent framework
- Plasticity as a strategy (not explored)

but…

- High functional convergence with plastic traits (not shown)
- Complex strategy space requiring better sampling

To go beyond

- Better calibration and strategy sampling to confirm results

- Explore the plasticity as a strategy

- Climat, management and perturbation scenarios

- New forms of plasticity

\+ exploration of other strategy axis (reproduction, frost resistance)

→ Multi-risk plasticity framework

- Epigenetics

Thank you