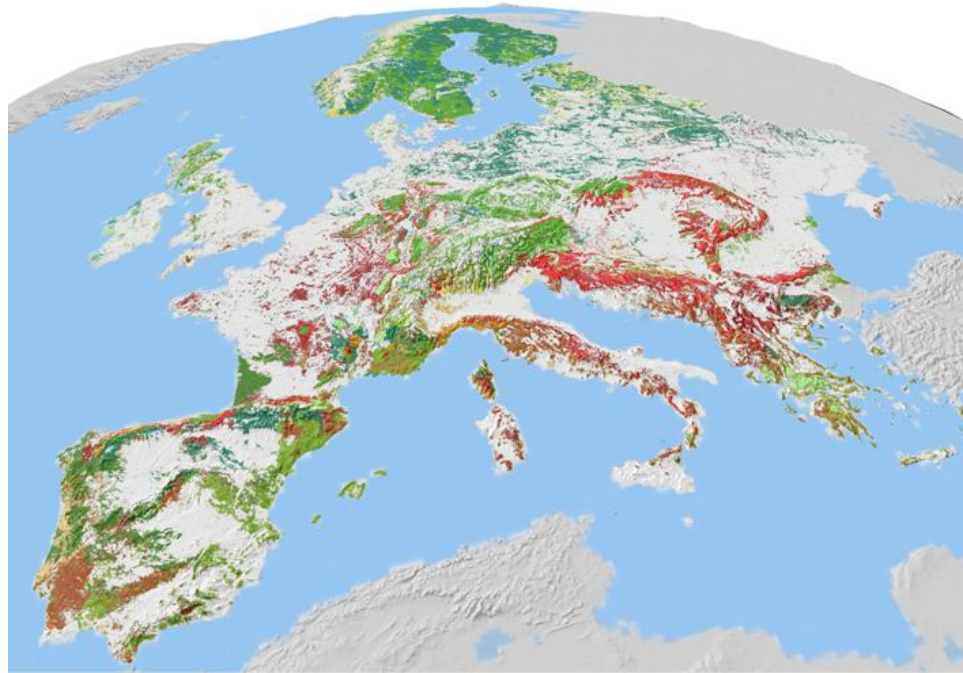


How will climate change affect the relationship between tree diversity and productivity in European temperate forests?



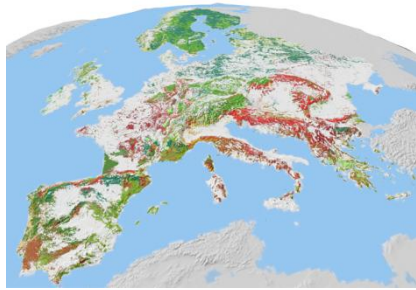
Xavier Morin

CEFE – CNRS
Montpellier

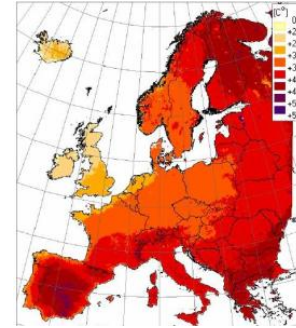
TOURS 2012



Impacts of global change on forests



Global Change



Local extinctions
Colonizations

Species range

CO₂ fertilization

*Temperature and precipitation
increase/decrease*

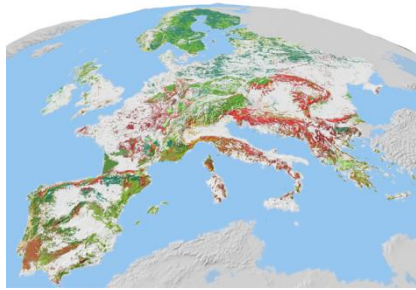
*Photosynthetic and
respiration rates*

Community composition

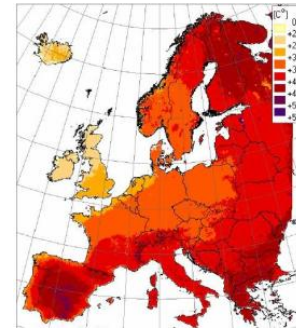
Ecosystem functioning



Impacts of global change on forests



Global Change



Local extinctions
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Species range

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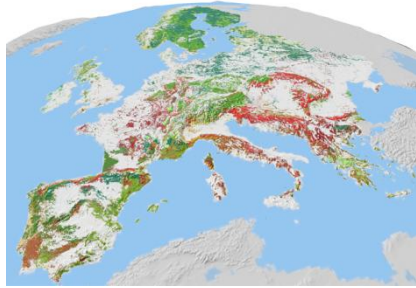
*Photosynthetic and
respiration rates*

Community composition

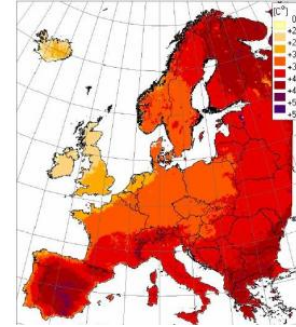
Ecosystem functioning



Impacts of global change on forests



Global Change



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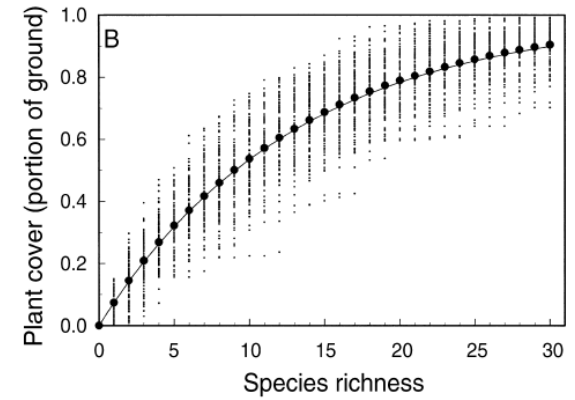
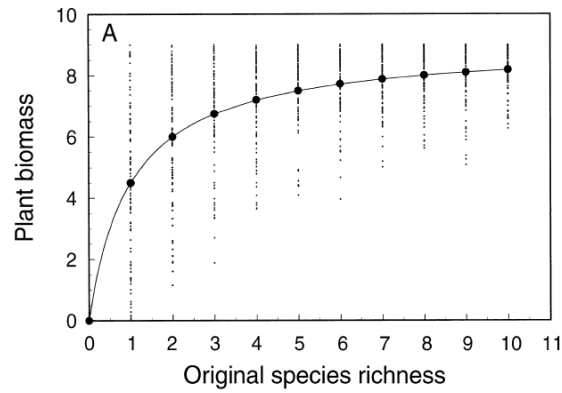
Species richness
Functional diversity



Productivity

The *Diversity-Productivity* relationship

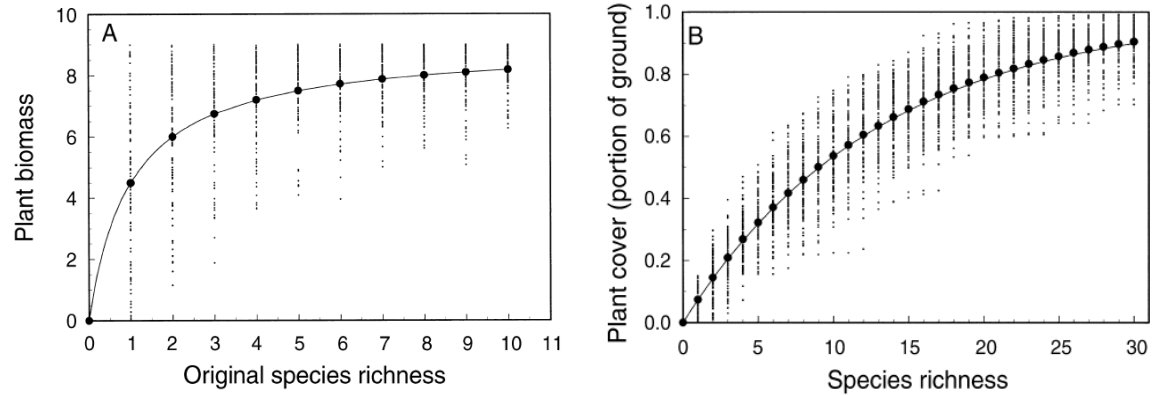
- Theoretical work



Hooper *et al.* 2005 *Ecol. Monographs*

The *Diversity-Productivity* relationship

- Theoretical work



Hooper *et al.* 2005 *Ecol. Monographs*

➔ Positive relation *specific richness - productivity*, but not necessarily

Loreau 1998 *PNAS*

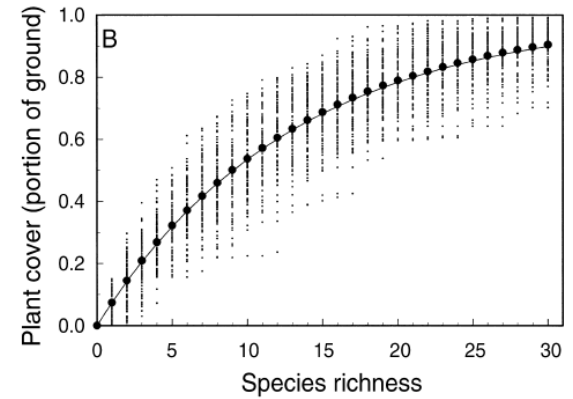
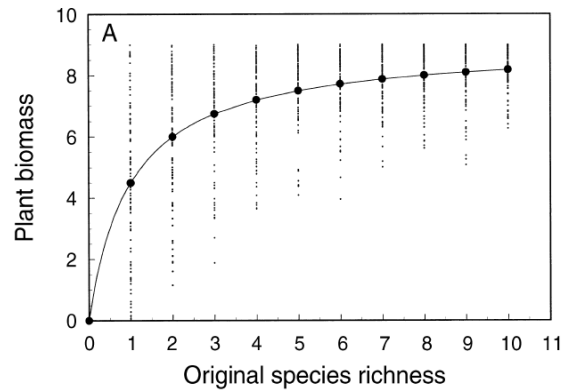
➔ Combination of two effects: *selection and complementarity*

Loreau *et al.* 2001 *Science*

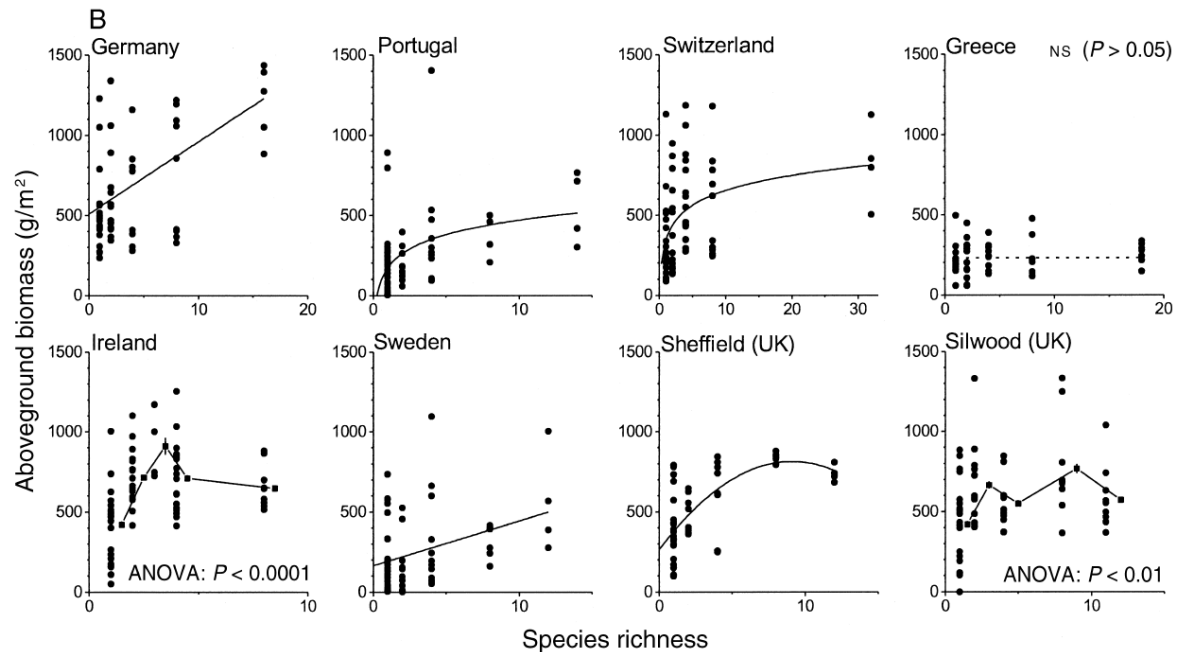
The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests

*For terrestrial ecosystems
= mostly grasslands*



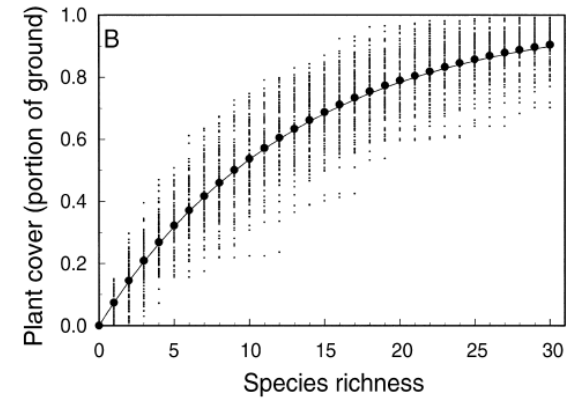
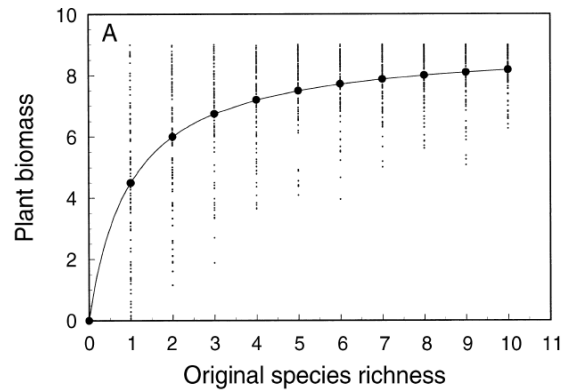
Hooper *et al.* 2005 *Ecol. Monographs*



The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests

*For terrestrial ecosystems
= mostly grasslands*



Hooper *et al.* 2005 *Ecol. Monographs*



➔ **Confirming trends predicted by theoretical works**

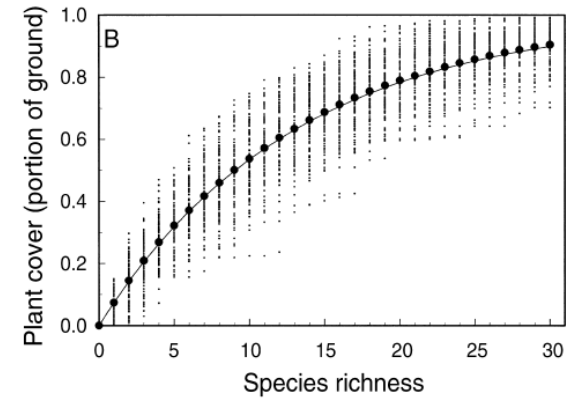
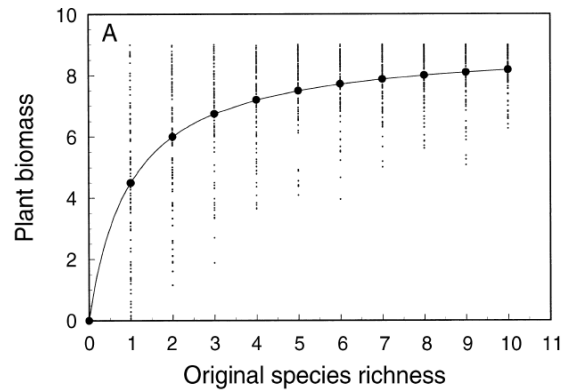
Cardinale *et al.* 2007 *PNAS*



The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests

*For terrestrial ecosystems
= mostly grasslands*



Hooper *et al.* 2005 *Ecol. Monographs*



➔ Confirming trends predicted by theoretical works

Cardinale *et al.* 2007 *PNAS*

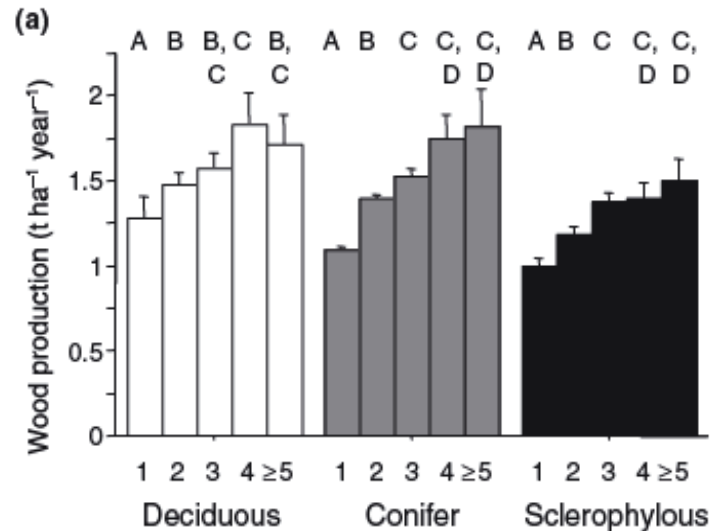
BUT

- no general pattern
- random assemblages of species
- few tested combinations
- necessarily in the short-term
- validity for other ecosystems? (such as forests...)



The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests
- Empirical measures in the field



Vila *et al.* 2007 *Ecol. Lett.*

- ➔ Forests: only way to study adult trees
Non random diversity
BUT confounding factors in the field...

The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests
- Empirical measures in the field
 - ➔ *Relationship in the long-term?*
 - ➔ *Impact of environmental conditions?*
 - ➔ *Weak knowledge for forests...*

The *Diversity-Productivity* relationship

- Theoretical work
- Experimental tests
- Empirical measures in the field

➔ *Relationship in the long-term?*

➔ *Impact of environmental conditions?*

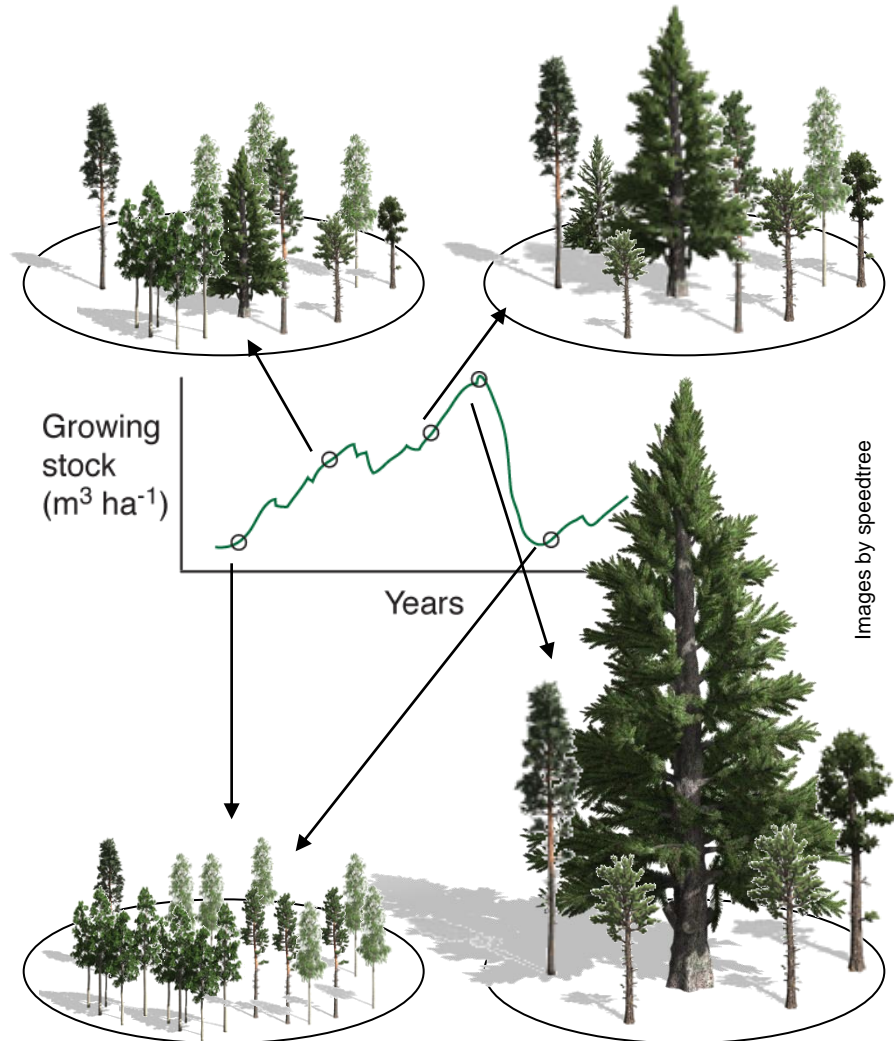
➔ *Weak knowledge for forests...*

- **Model of forest dynamics**

- independent tool to study the *diversity-productivity* relationship
- “real” species : parameters = derived from measured traits
- realized specific richness in the long term
- much greater number of testable combinations

Studying the *diversity-productivity* relationship with a forest succession model

- Forest gap models: cyclical succession on small patches of land
- Basis: Theories by A.S. Watt, H.A. Gleason
- Quantitative description of tree population dynamics
- cf. Review article (Bugmann 2001)



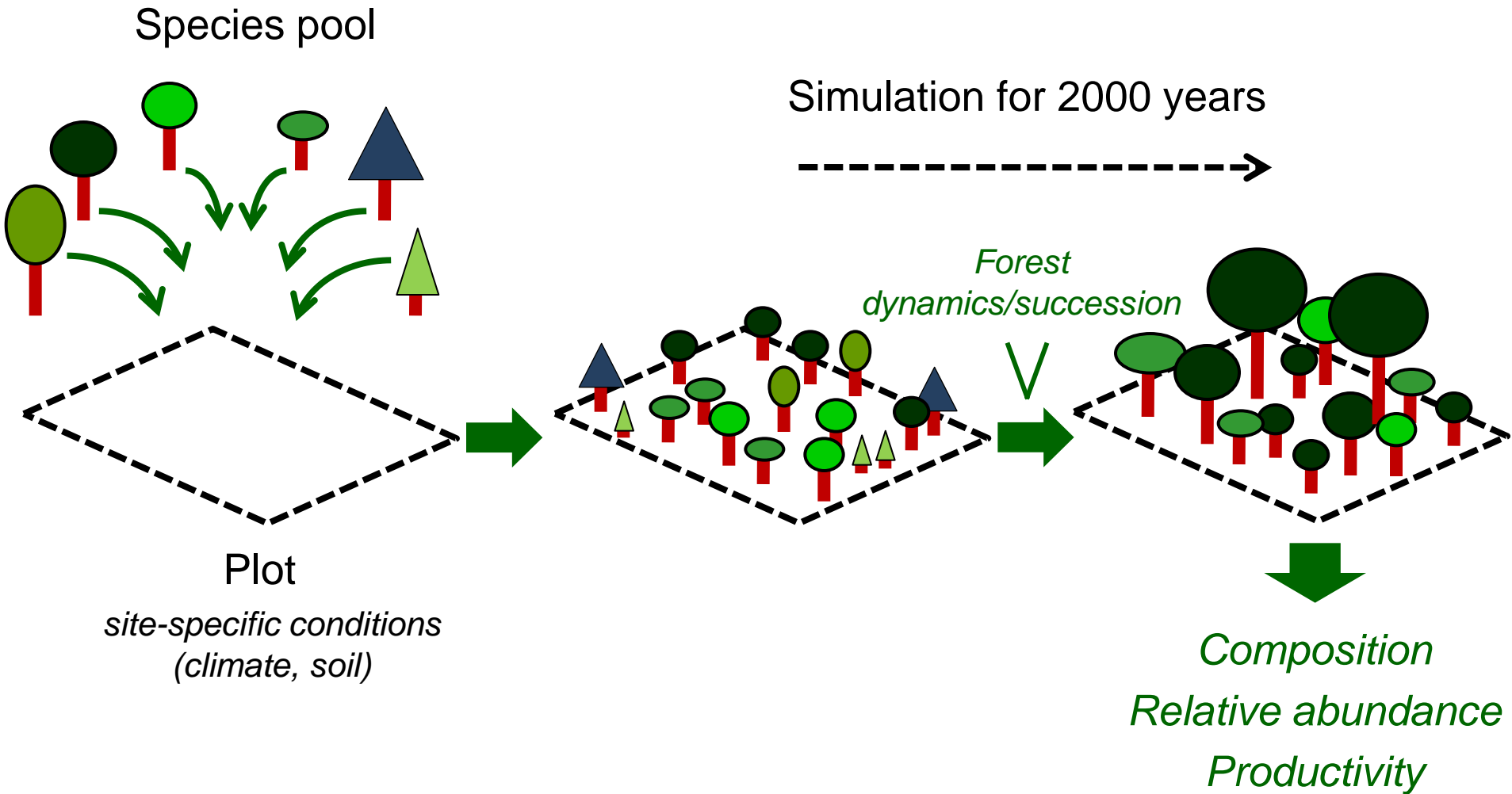
Exploring the *sp. richness-productivity* relationship with a forest succession model

ForClim

- Validated along a large climatic gradient (11 sites)
- Parameterized for 30 tree species

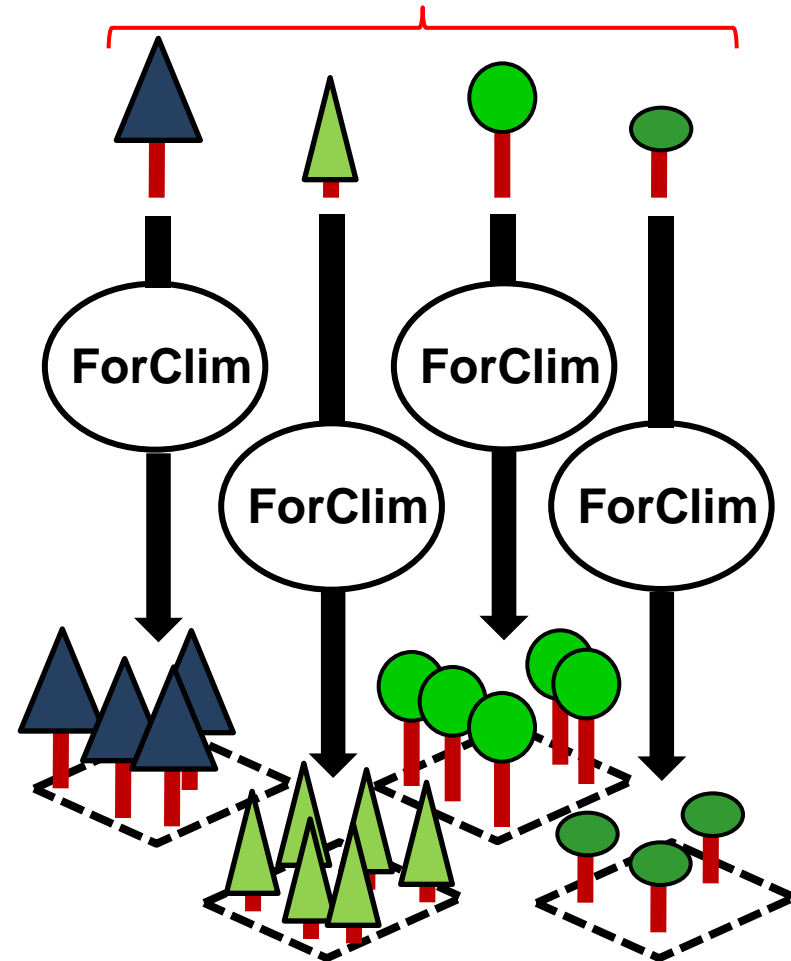
➡ *Virtual experiments on the gradient*

Virtual experiments: principle



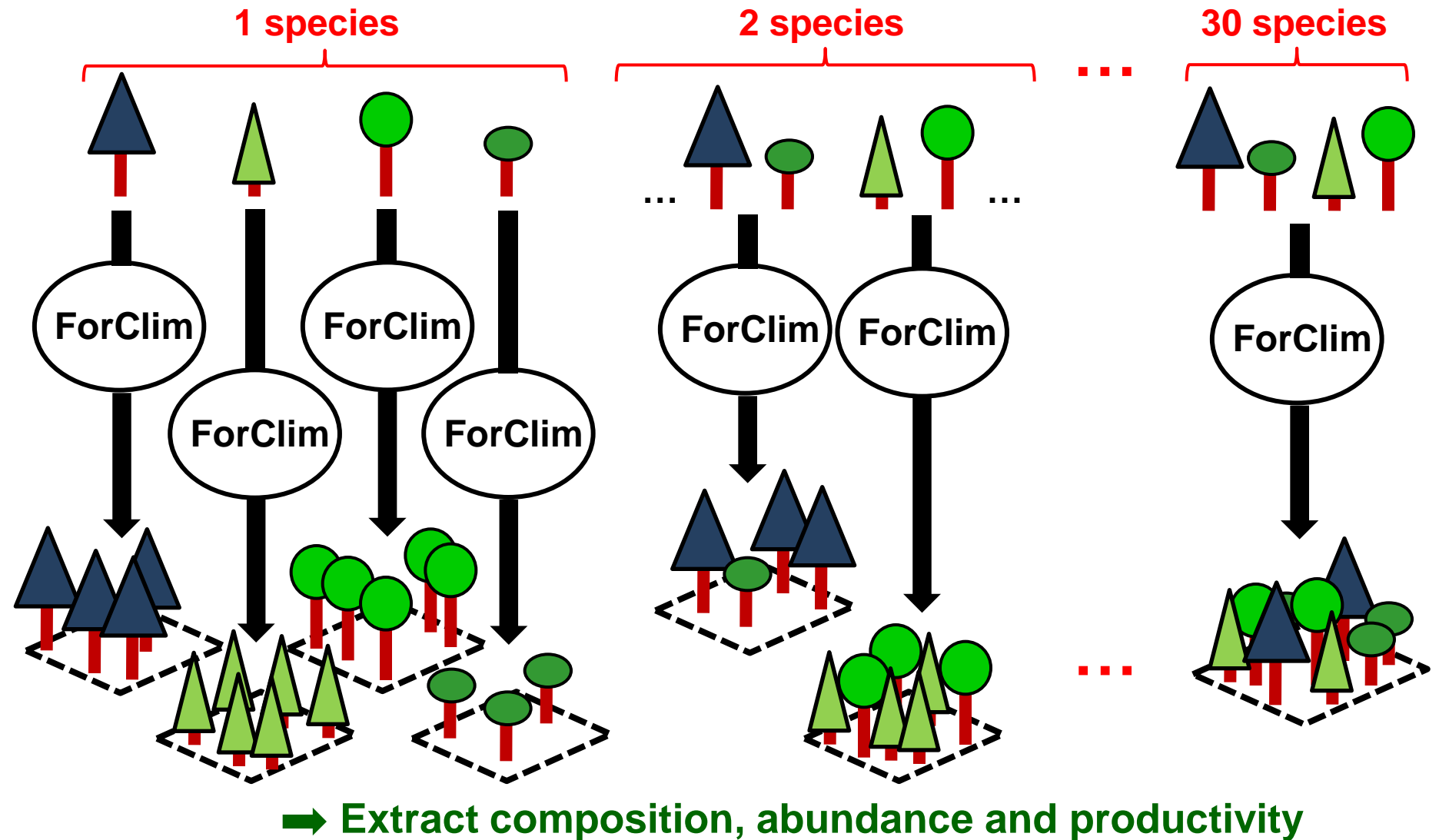
Virtual experiments: principle

1 species



= 30 « monocultures »

Virtual experiments: principle



Exploring the *sp. richness-productivity* relationship with a forest succession model

ForClim

- Validated along a large climatic gradient (11 sites)
- Parameterized for 30 tree species

➔ *Virtual experiments* on the gradient

Problem

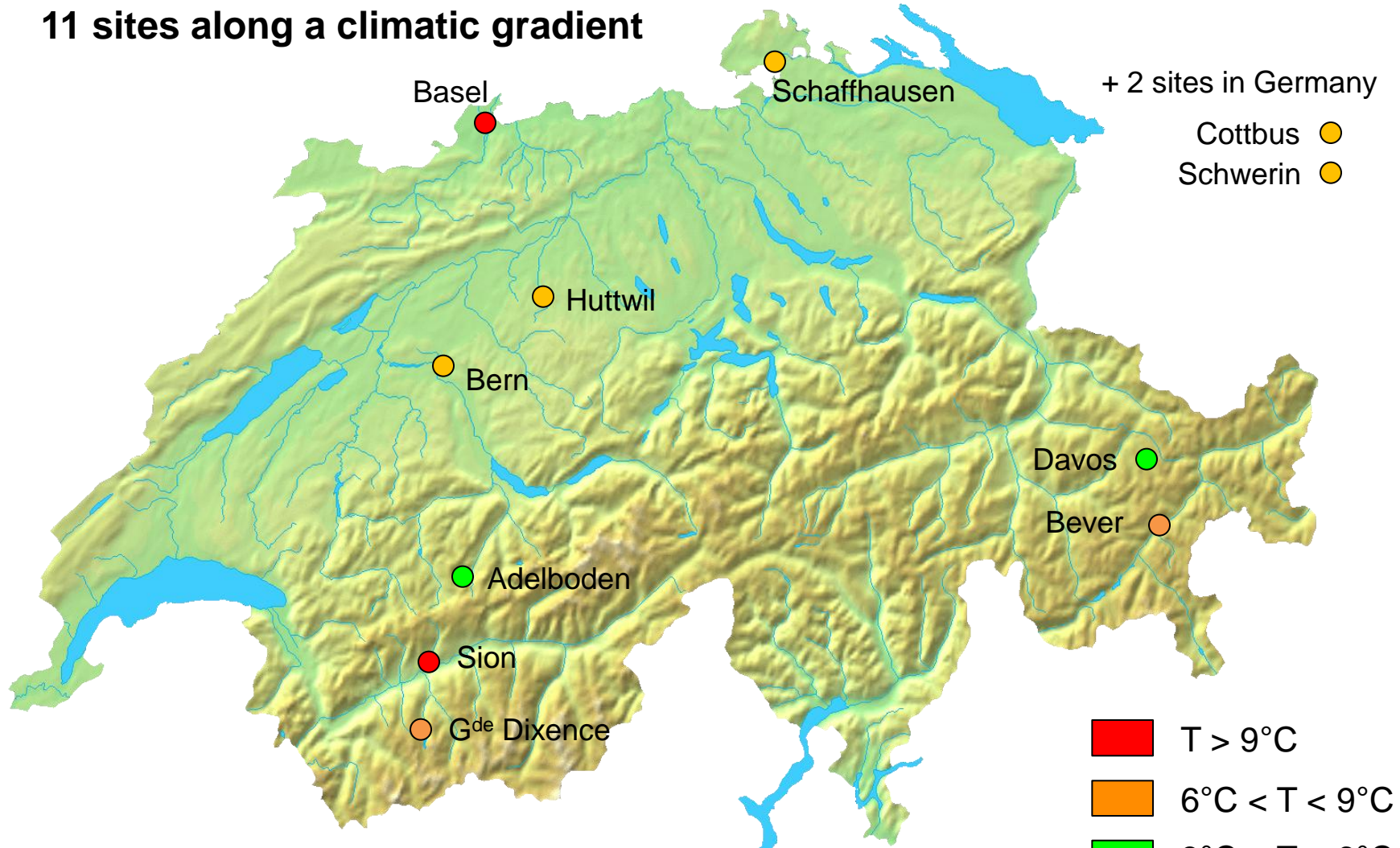
30 species ➔ >1 billion combinations

$$\binom{30}{1} = 30 \quad \binom{30}{2} = 435 \quad \dots \quad \binom{30}{28} = 435 \quad \binom{30}{29} = 30 \quad \binom{30}{30} = 1$$
$$\binom{30}{15} = 155,117,520$$

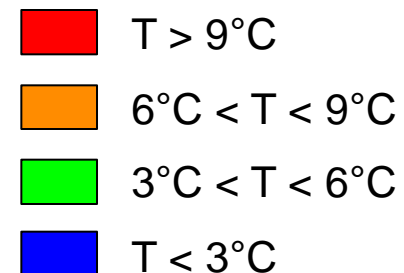
➔ Reducing the number of simulations
= 500 simulations max per richness level

Exploring the *sp. richness-productivity* relationship with a forest succession model

11 sites along a climatic gradient



In each site 13414 tested combinations → ~ 150,000 simulations in total

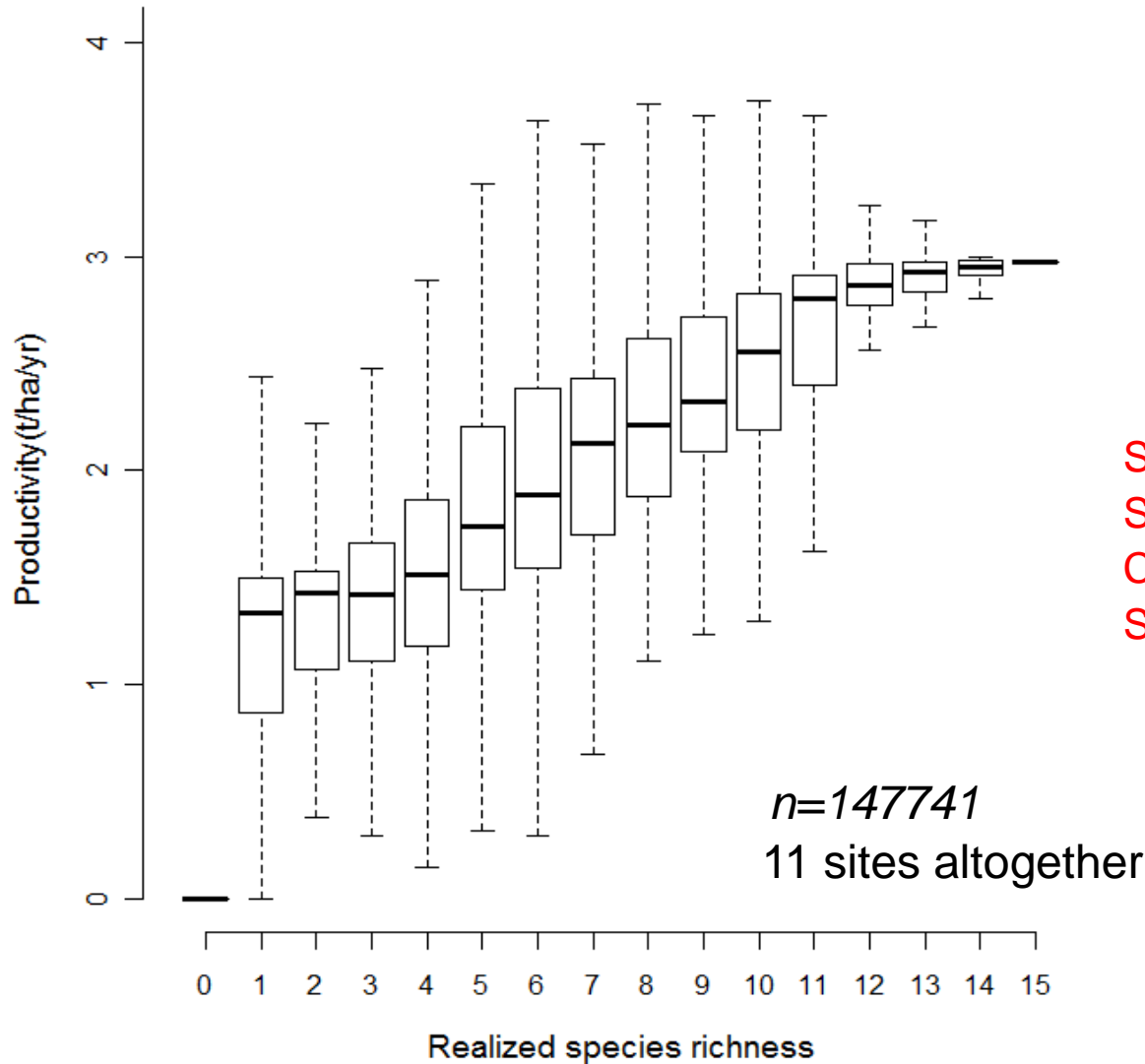


Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

A positive trend across sites

Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

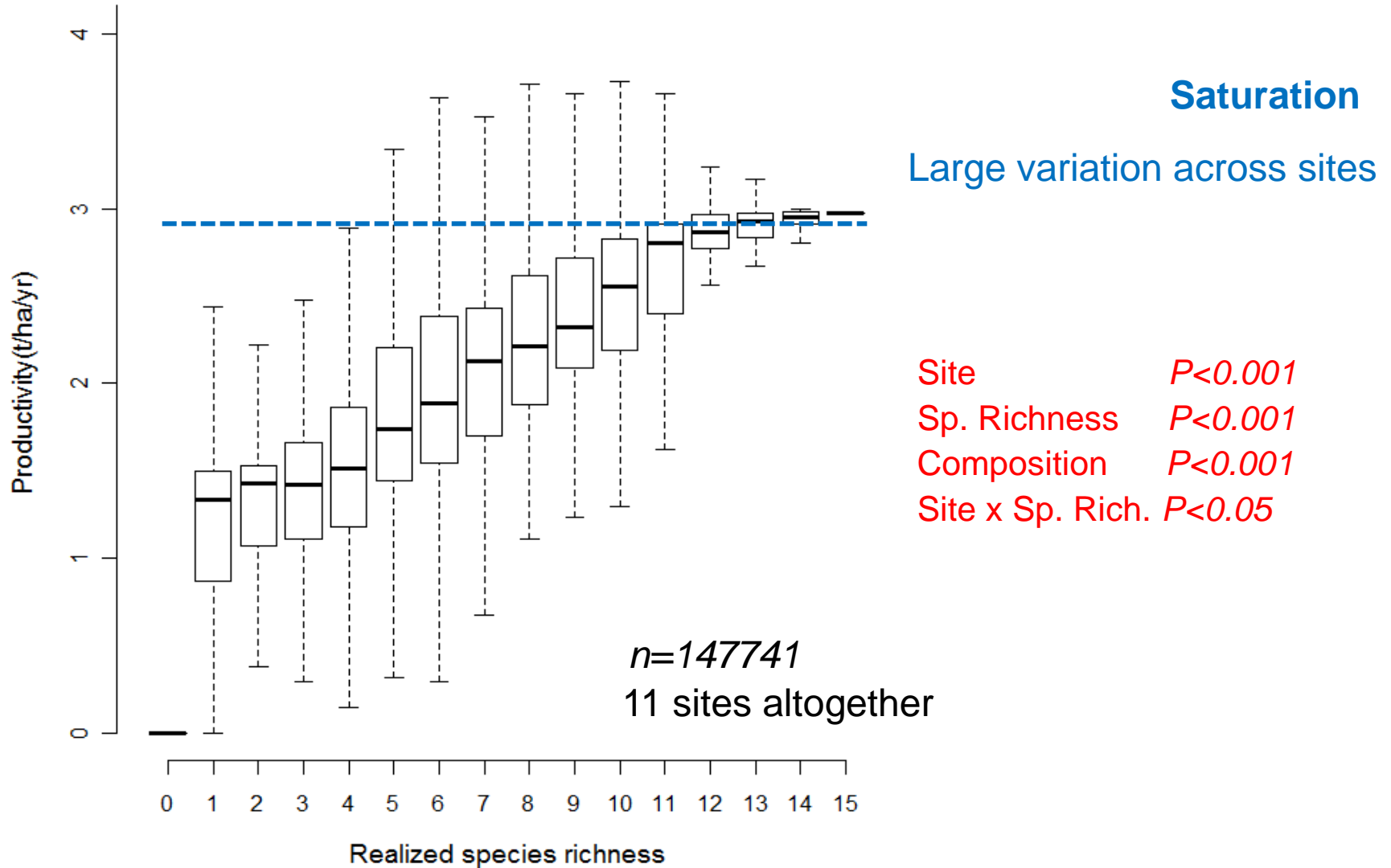
A positive trend across sites



Site $P < 0.001$
Sp. Richness $P < 0.001$
Composition $P < 0.001$
Site x Sp. Rich. $P < 0.05$

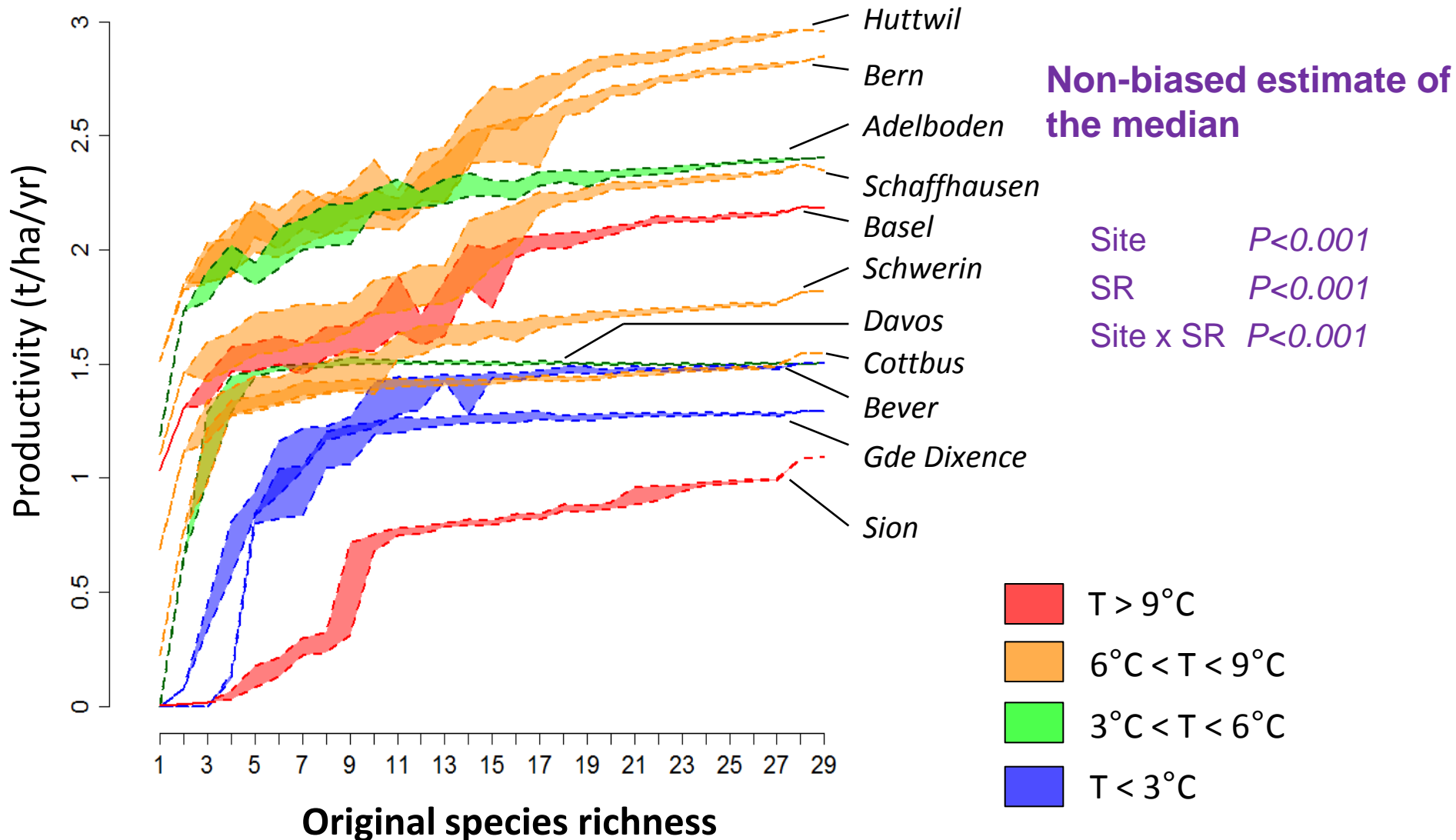
Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

A positive trend across sites



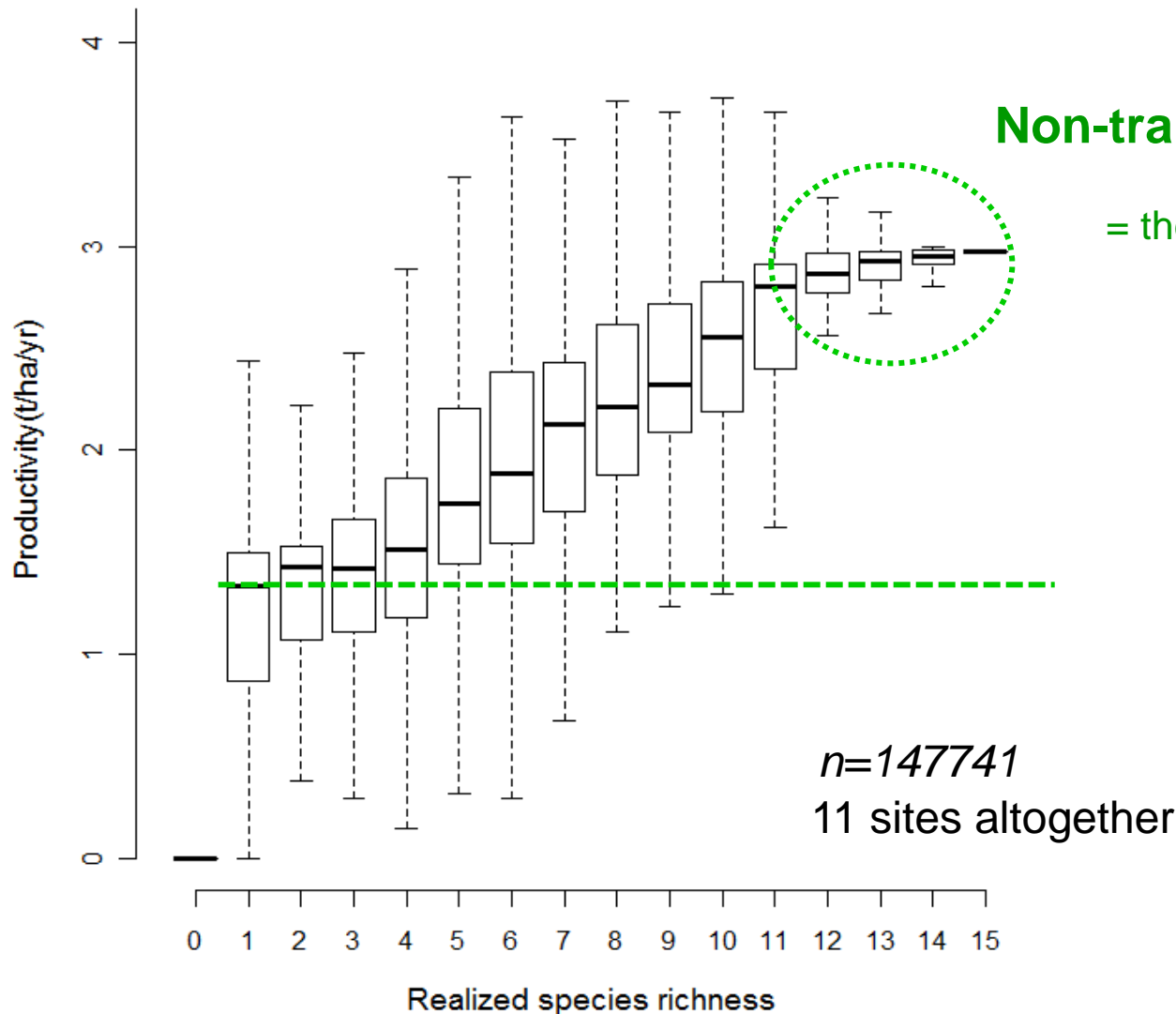
Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

A positive trend at each site



Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

Diverse forests are more productive than monocultures



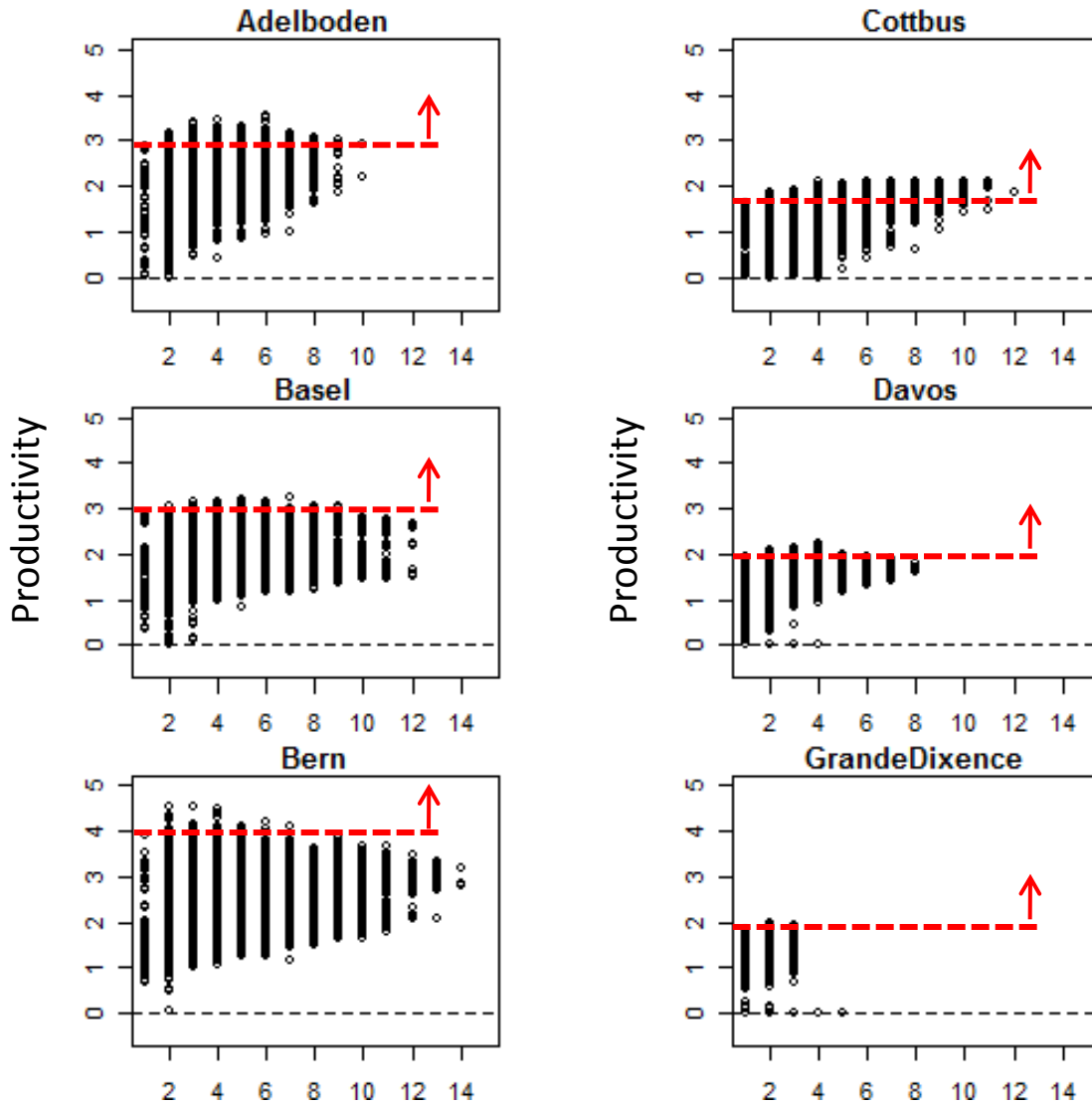
Non-transgressive overyielding

= the most diverse forests are more productive than the averaged monocultures

93% of simulations

Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

Diverse forests are more productive than monocultures



Transgressive overyielding

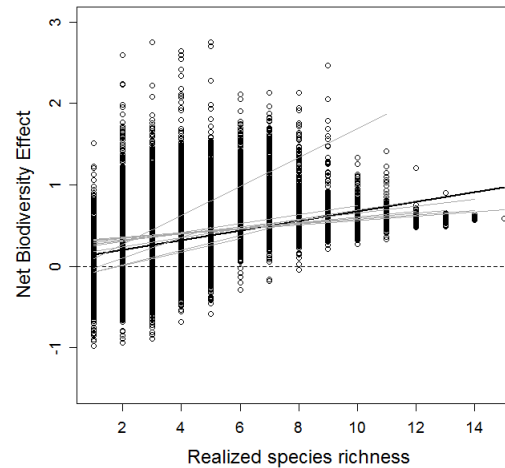
Average per site
11% of simulations

Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

The positive trend is caused by complementarity between species

$\Delta Y =$ Net biodiversity effect

Partitioning method
Loreau and Hector (2001)



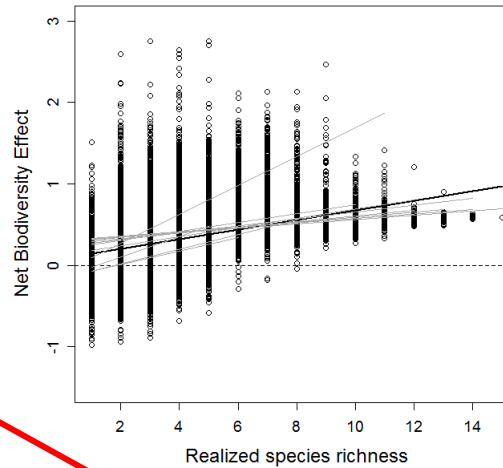
⇒ Overyielding

Exploring the *SR-Productivity* relationship with a forest succession model: Results

The positive trend is caused by complementarity between species

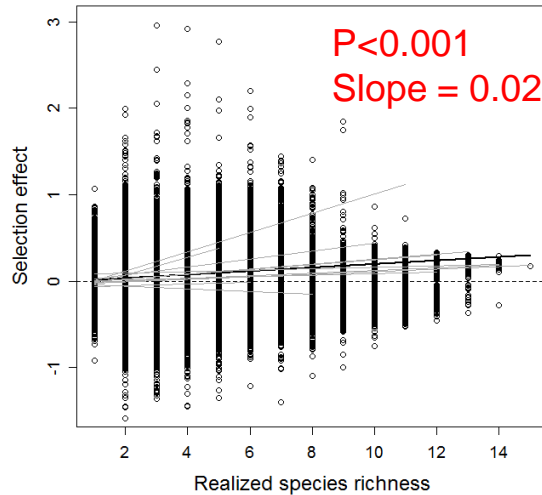
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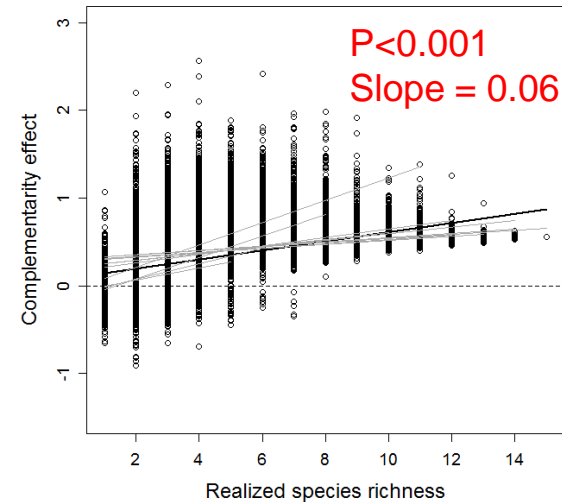
⇒ Overyielding

Selection



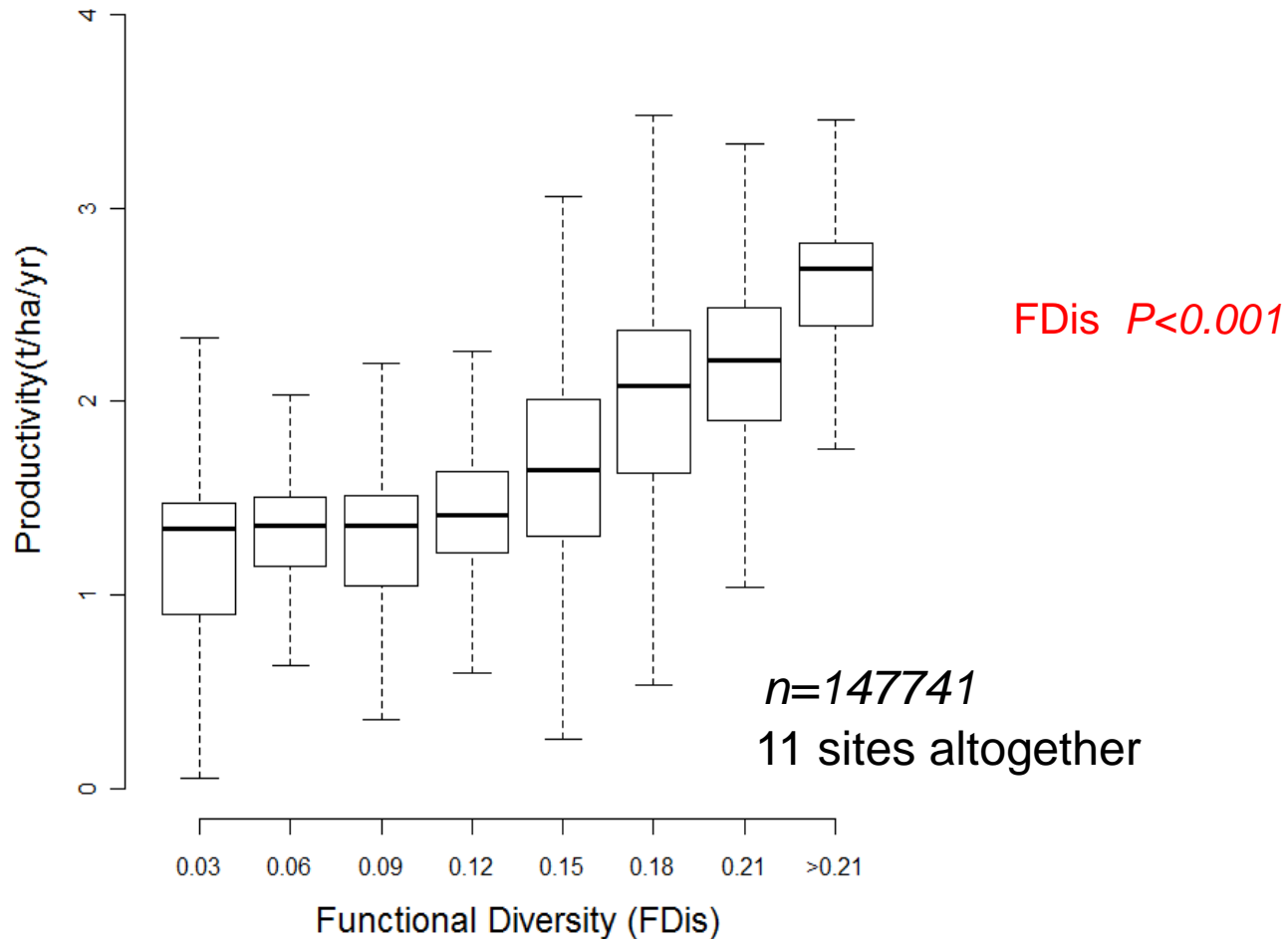
(in 80% of cases)

Complementarity



Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

A positive functional diversity – productivity relationship

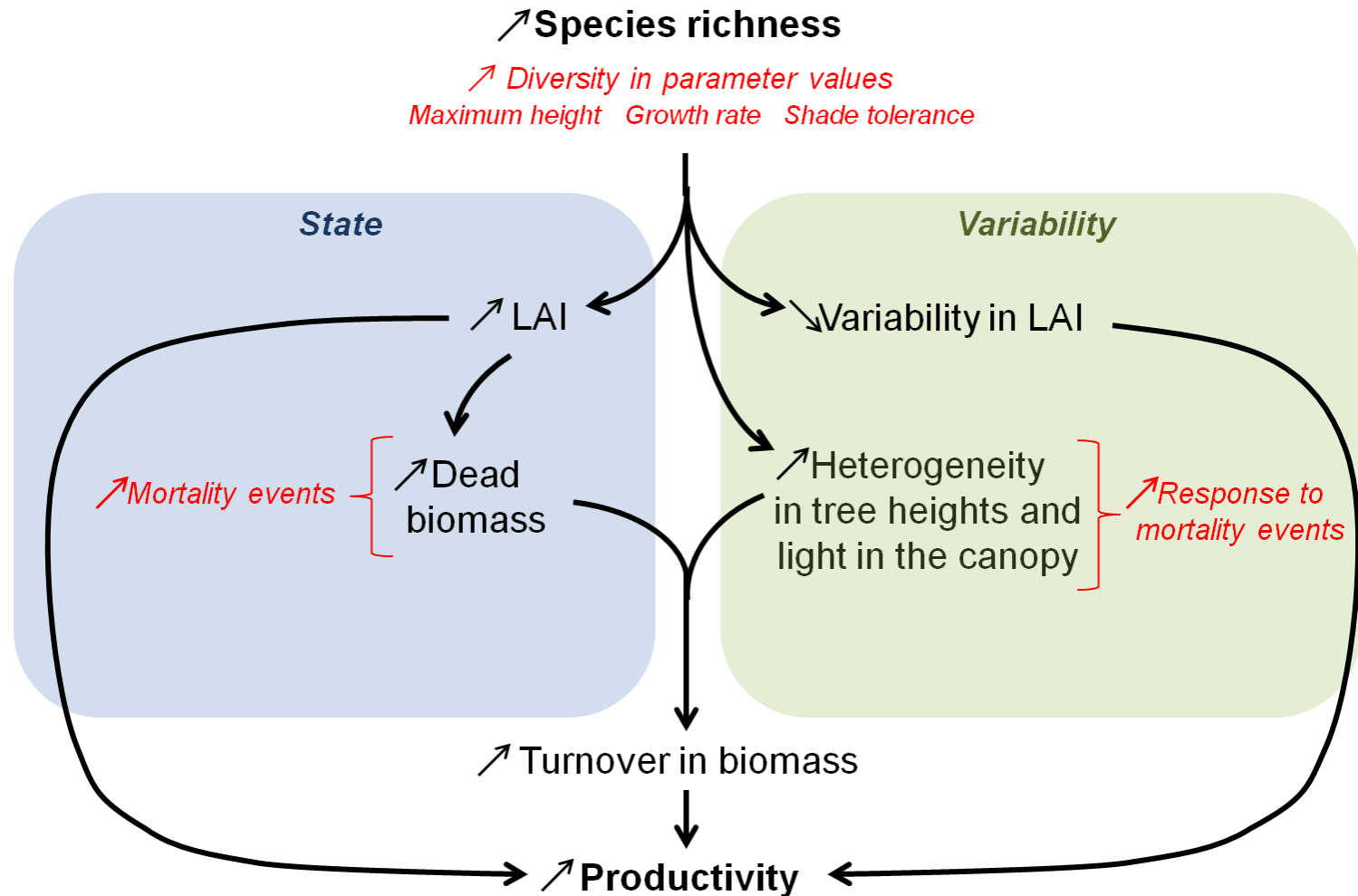


Exploring the *SR-Productivity* relationship
with a forest succession model: **Results**

WHY?

Exploring the *SR-Productivity* relationship with a forest succession model: **Results**

WHY?



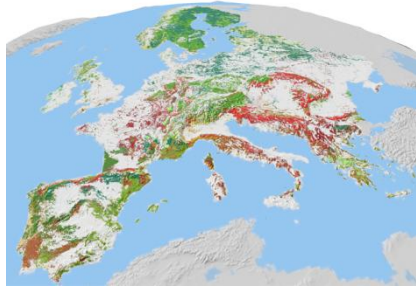
Conclusions 1

- 1st attempt to use a forest succession model to explore the *diversity-prod.* Relationship
- Consistent results with biodiversity experiments (herbaceous species)
 - ➡ Linking theory and experiments
 - ➡ A model with few interactions shows that a strong complementarity can emerge
 - ➡ Importance of functional diversity
- Importance of biomass turn-over and response ability of more diverse forests
 - ⇒ Morin *et al.* Ecology Letters (2011)

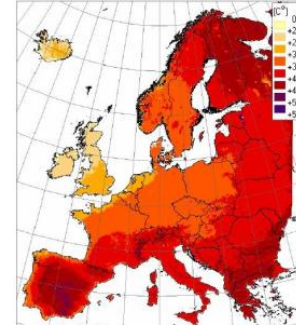
Conclusions 1

- 1st attempt to use a forest succession model to explore the *diversity-prod.* Relationship
- Consistent results with biodiversity experiments (herbaceous species)
 - ➡ Linking theory and experiments
 - ➡ A model with few interactions shows that a strong complementarity can emerge
 - ➡ Importance of functional diversity
- Importance of biomass turn-over and response ability of more diverse forests
- Role of functional diversity => needs deeper exploration
- Positive *diversity-stability* relationship

Impacts of global change on forests



Global Change



Local extinctions
Colonizations

Species range

CO₂ fertilization

*Temperature and precipitation
increase/decrease*

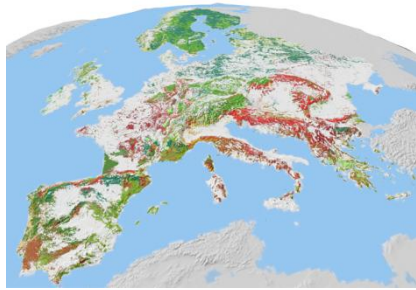
*Photosynthetic and
respiration rates*

Community composition

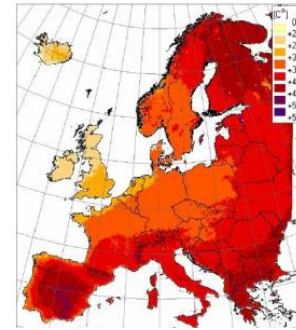
Ecosystem functioning



Impacts of global change on forests



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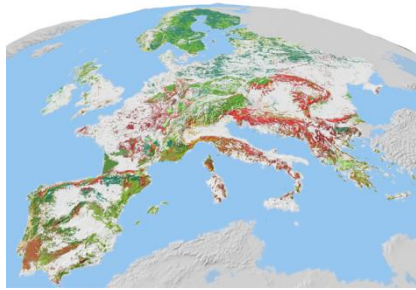
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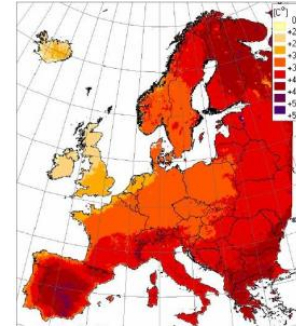
Ecosystem functioning



Impacts of global change on forests



Global Change



How will the *SR-Productivity* relationship change with new climatic conditions?

Community composition



Ecosystem functioning



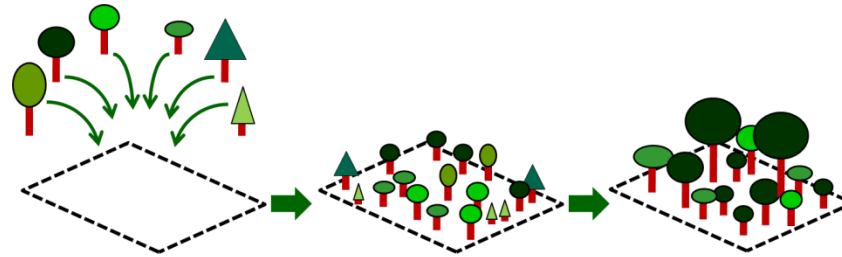
Local ex
Coloniza

ation
and
s

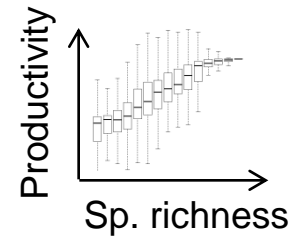
CO₂ fertilization

Using ForClim to investigate the interplay between climate change, diversity, and forest productivity

Current conditions

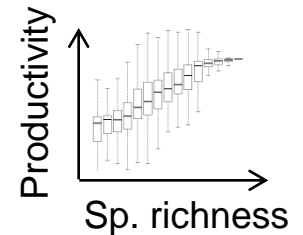
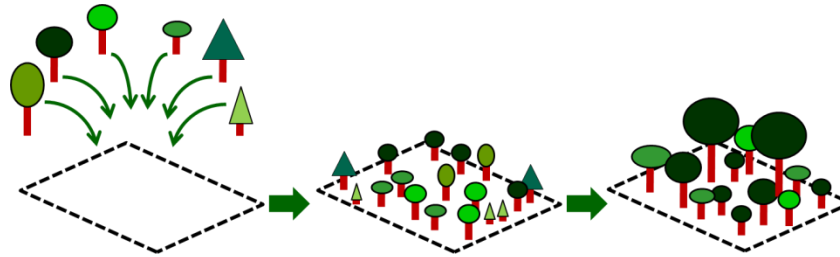


3 RCMs 2090-2100
A1b scenario



Using ForClim to investigate the interplay between climate change, diversity, and forest productivity

Current conditions



3 RCMs 2090-2100
A1b scenario

KNMI – RACMO2

+3.5 °C
-18% precip.

MPI – CLM

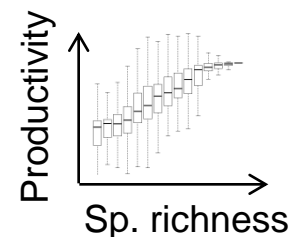
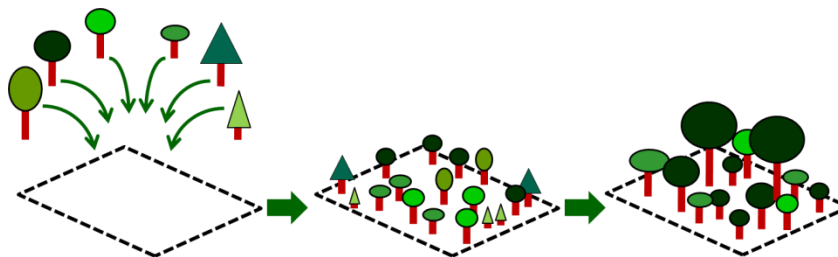
+4.2 °C
-16% precip.

SHMI – RCA30

+4.1 °C
-21% precip.

Using ForClim to investigate the interplay between climate change, diversity, and forest productivity

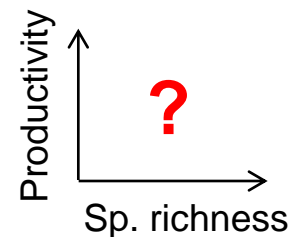
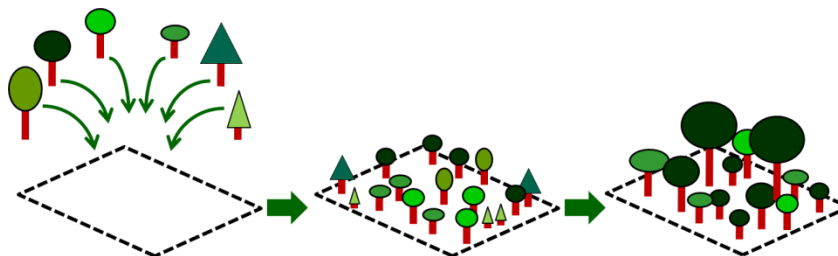
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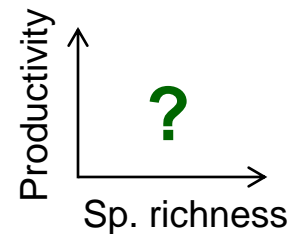
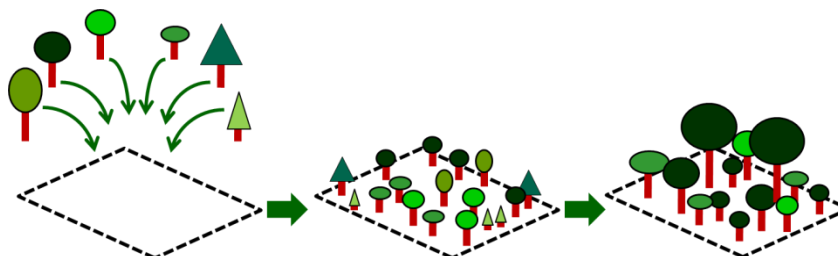
KNMI – RACMO2

+3.5 °C
-18% precip.



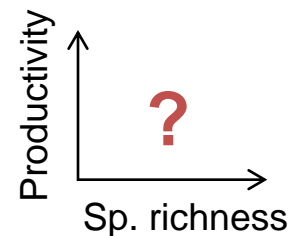
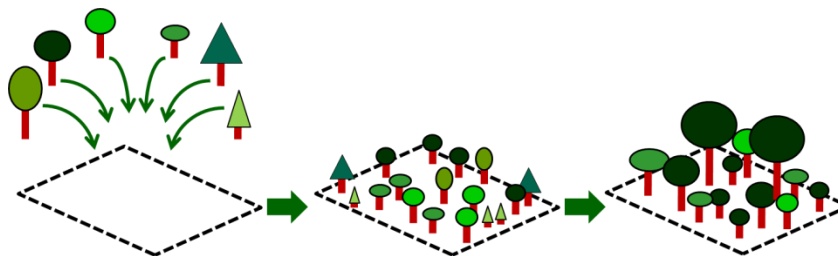
MPI – CLM

+4.2 °C
-16% precip.



SHMI – RCA30

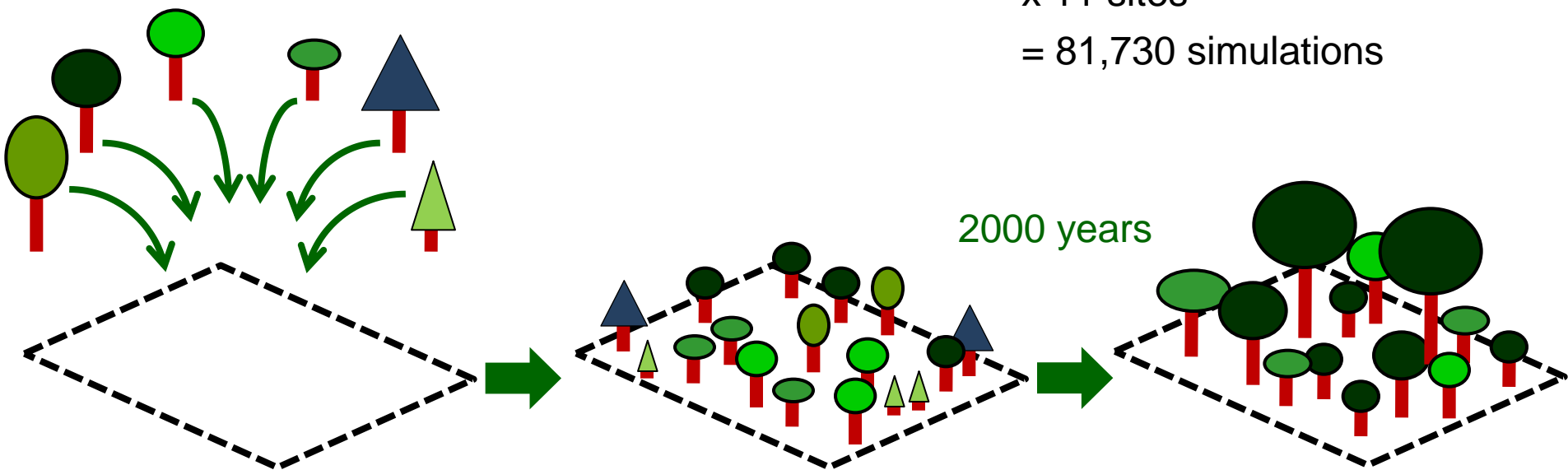
+4.1 °C
-21% precip.



Using ForClim to investigate the interplay between climate change, diversity, and forest productivity

Levels of richness simulated:

$N = 1, 2, 3, 5, 7, \dots, 25, 27, 28, 29, 30$ \implies 7,430 tested combinations
x 11 sites
= 81,730 simulations

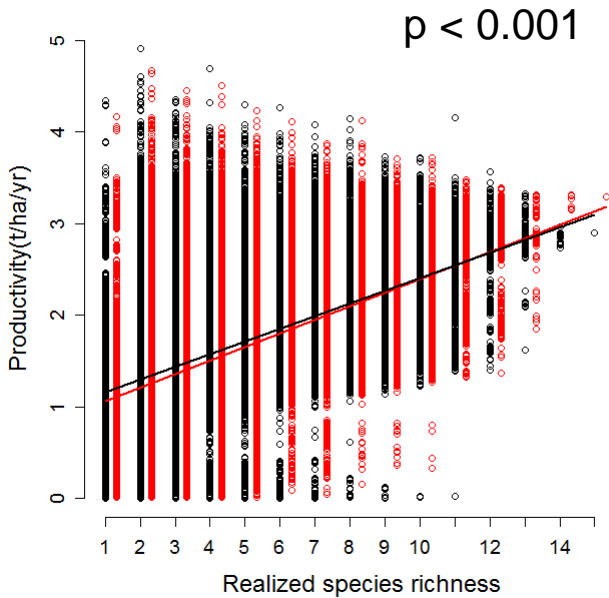


Current conditions + 3 RCMs \implies 326,920 simulations

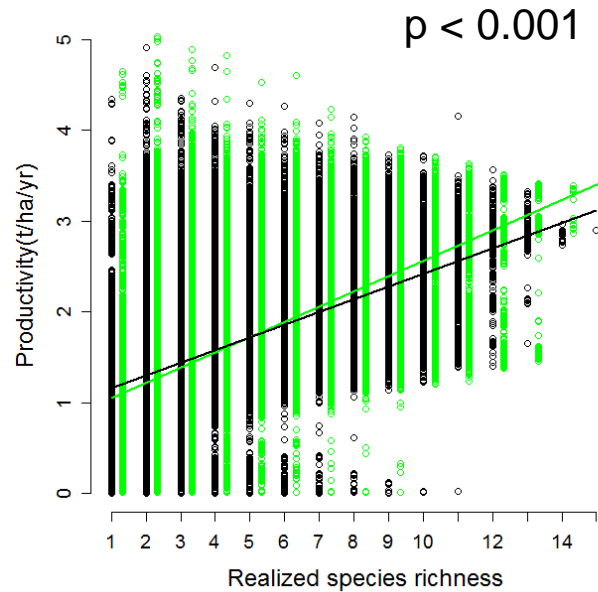
**A positive impact of climate change on the
SR-Productivity rel. across all sites**

A positive impact of climate change on the *SR-Productivity* rel. across all sites

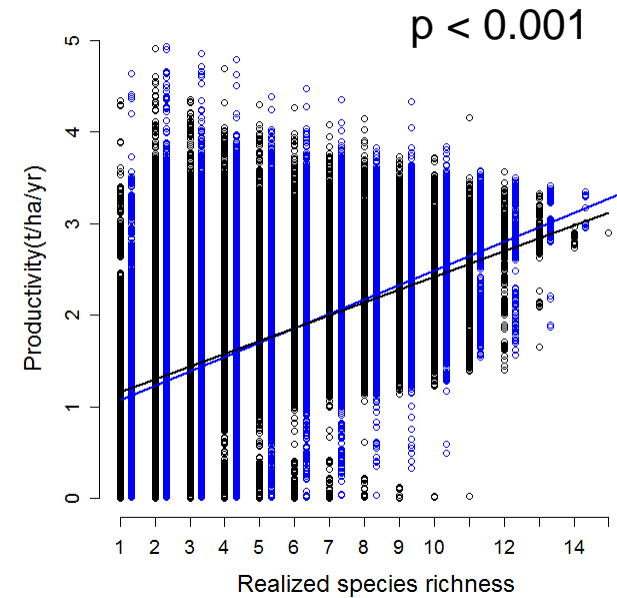
KNMI – RACMO2



MPI – CLM



SHMI – RCA30



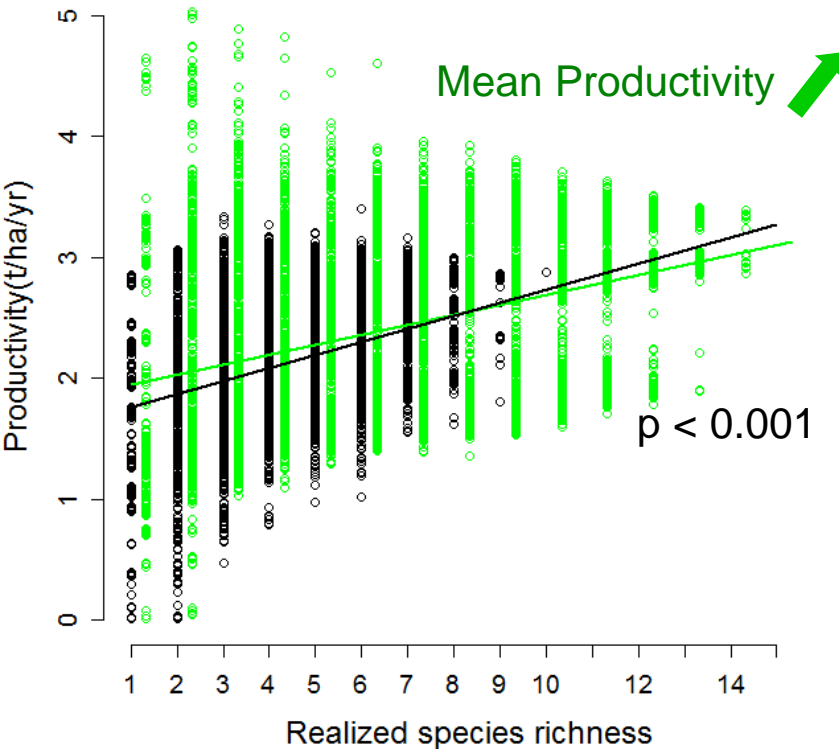
— Current pattern

With all RCMs data, slope of the *SR-Prod.* rel. under CC conditions are significantly steeper than under current conditions

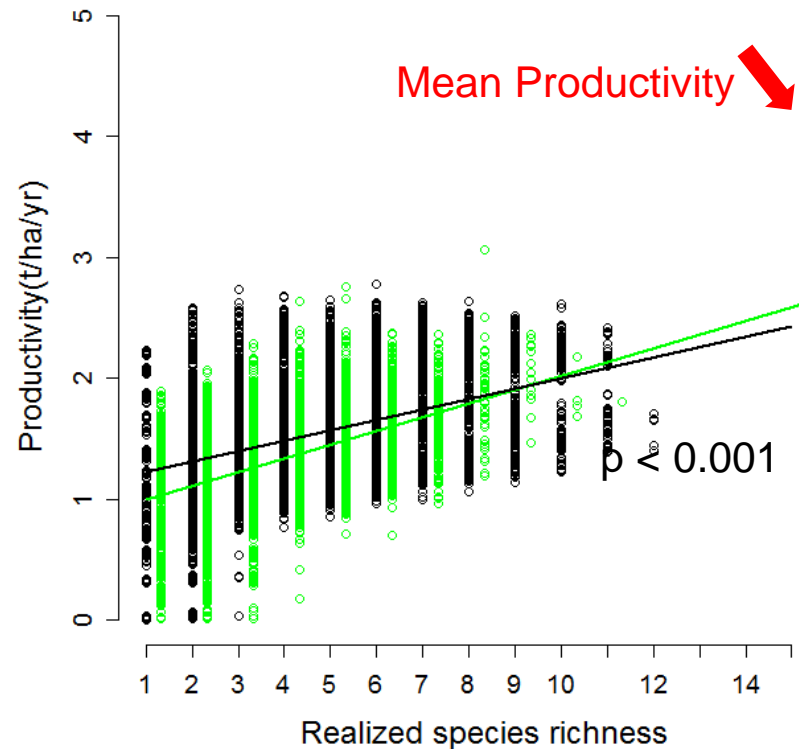
... to be confirmed with an analysis at each site

— MPI – CLM
— Current conditions

Adelboden = « cold site »



Schwerin = « dry site »



Confirmation of the pattern (?)

Causes:

- « extension » of the relationship = « statistical effect »
- In harsher conditions diversity is more important = « diversity effect »

... to be confirmed with an analysis at each site

Change
in mean productivity

Adelboden



Basel



Bern



Bever



Cottbus



Davos



Grande Dixence



Huttwil



Schaffhausen






































Schwerin



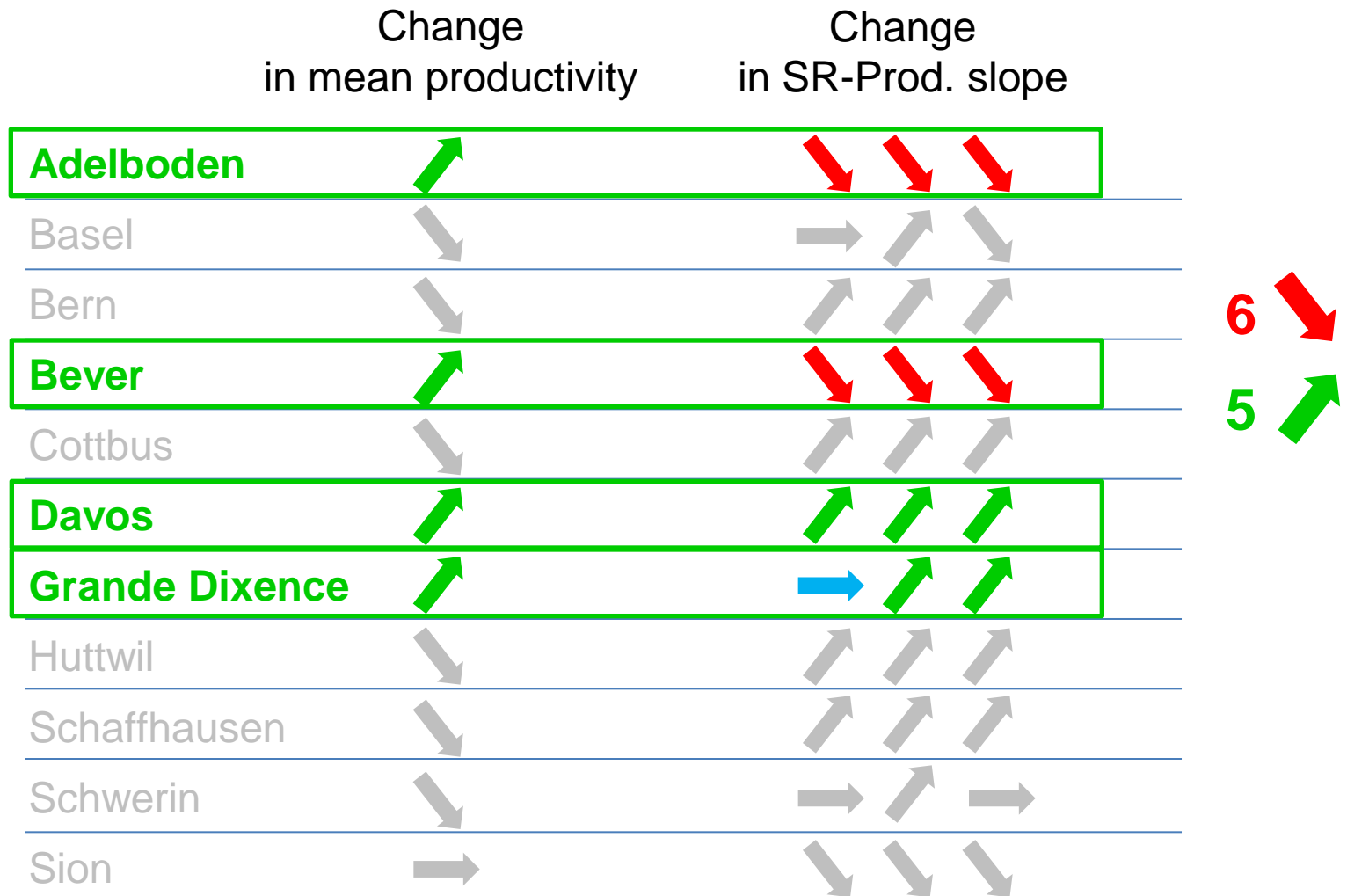
Sion



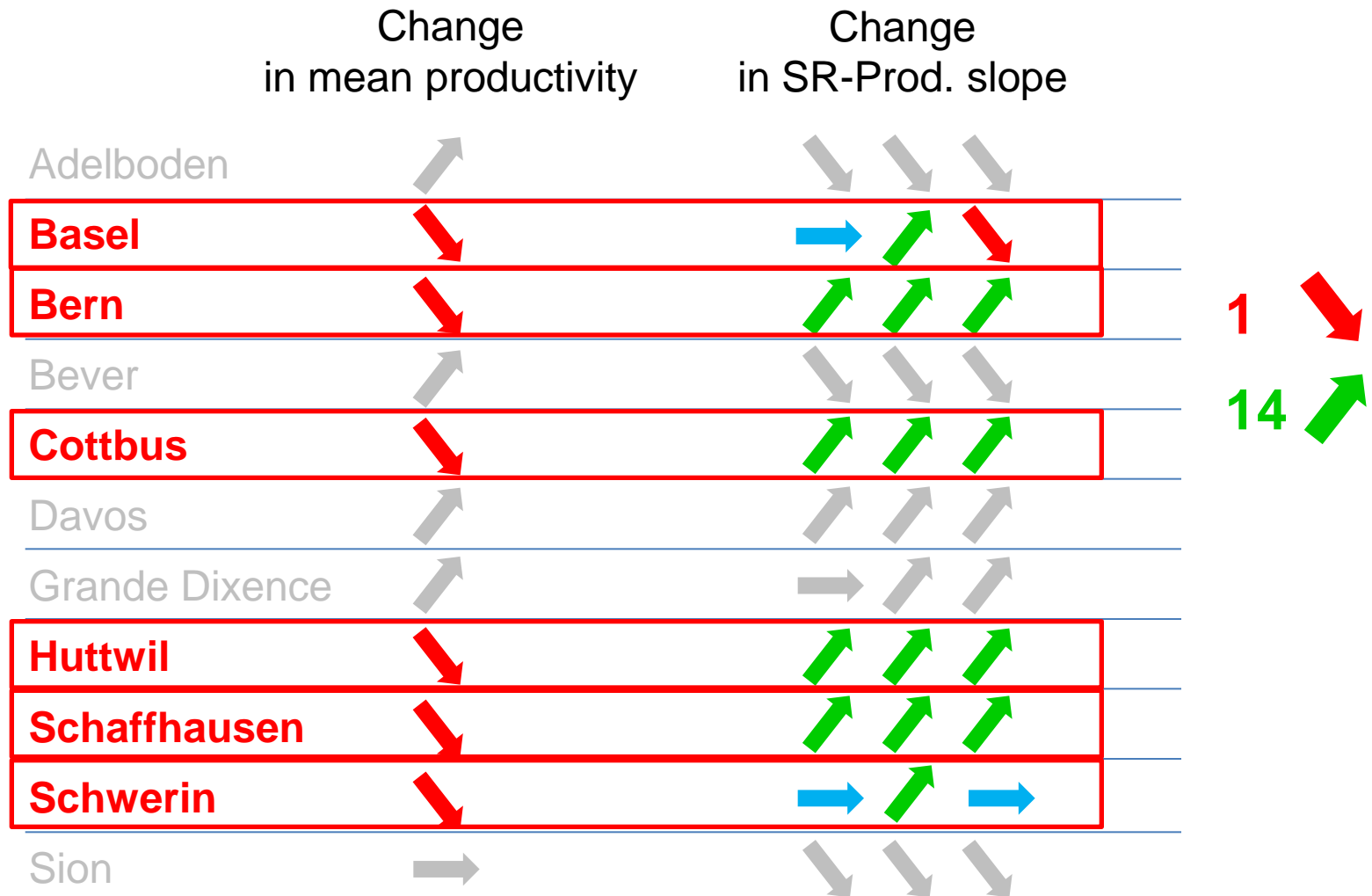
... to be confirmed with an analysis at each site

	Change in mean productivity	Change in SR-Prod. slope		
Adelboden				
Basel				
Bern				
Bever				
Cottbus				
Davos				
Grande Dixence				
Huttwil				
Schaffhausen				
Schwerin				
Sion				

... to be confirmed with an analysis at each site



... to be confirmed with an analysis at each site



Conclusions 2

- 1st exploration of the impact of climate change on the diversity-productivity relationship
- Stronger impact of change in species richness on forest productivity??
 - ➔ Especially in sites with conditions getting harsher in the future?
- To be confirmed at the site level

What's next?

- Mechanisms? (e.g. greater complementarity between species in sites with harsher conditions?)
- Same pattern for stability in ecosystem functions?

Thanks!

Harald Bugmann

Lorenz Fahse

BACCARA partners (WP 3-4)

Forest Ecology Group ETHZ

Michael Scherer-Lorenzen

Georges Kunstler

Hervé Jactel

Michel Loreau

Tanya Handa

Alain Paquette

MariCarmen Ruiz-Jaen

Jurgis Sapijanskas

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Bernhard Schmid

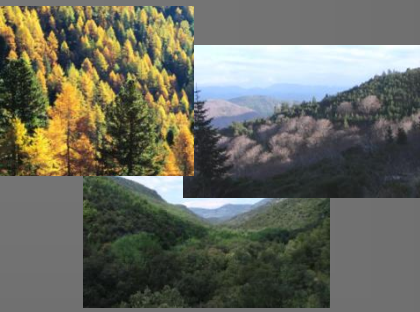
Niklaus Zimmermann



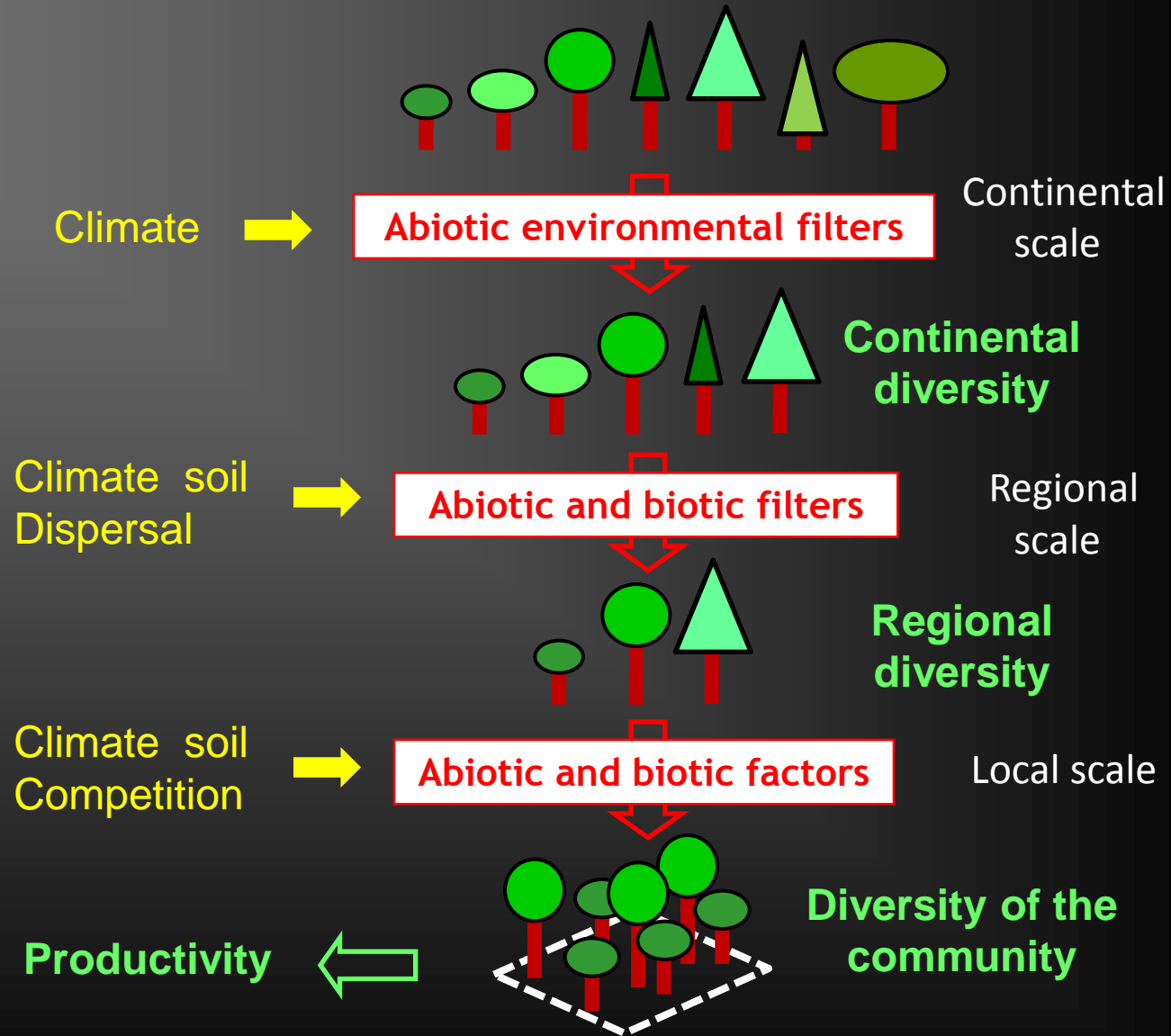
ETH

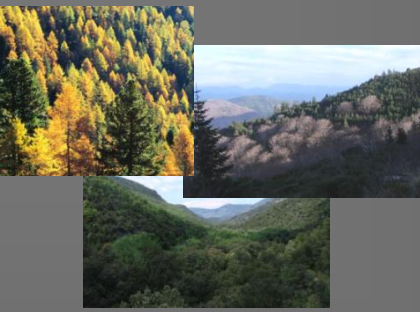
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich





Linking climate, biodiversity and ecosystem functioning

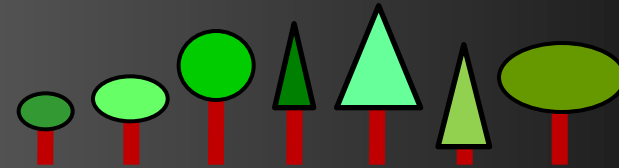




Linking climate, biodiversity and ecosystem functioning

Process-based models (DGVM)

Climate →



Abiotic environmental filters

Continental scale

Habitat-based models

Process-based models

Climate soil
Dispersal →

Abiotic and biotic filters

Continental diversity

Regional scale

Forest succession model

Climate soil
Competition →

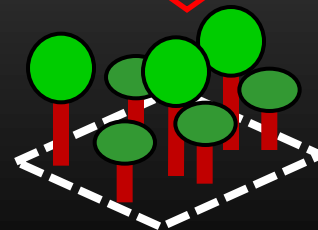
Abiotic and biotic factors

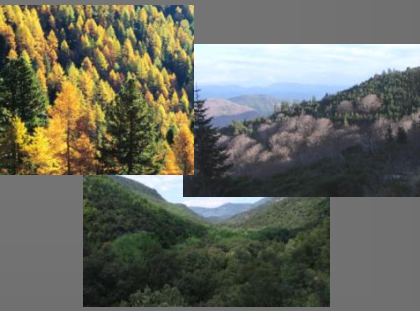
Regional diversity

Local scale

Productivity ←

Diversity of the community

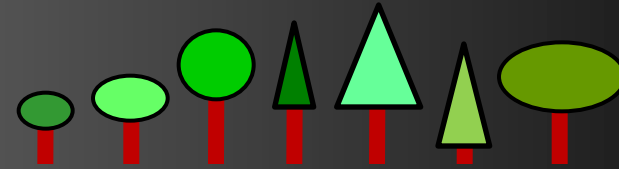




Linking climate, biodiversity and ecosystem functioning

Process-based models (DGVM)

Climate



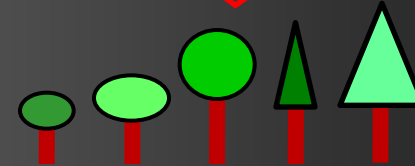
Abiotic environmental filters

Continental scale

Habitat-based models

Process-based models

Climate soil
Dispersal



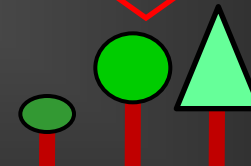
Abiotic and biotic filters

Continental diversity

Regional scale

Forest succession model

Climate soil
Competition



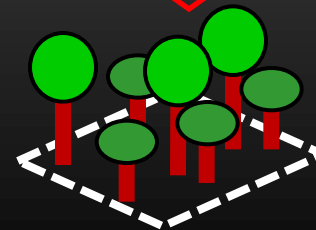
Abiotic and biotic factors

Regional diversity

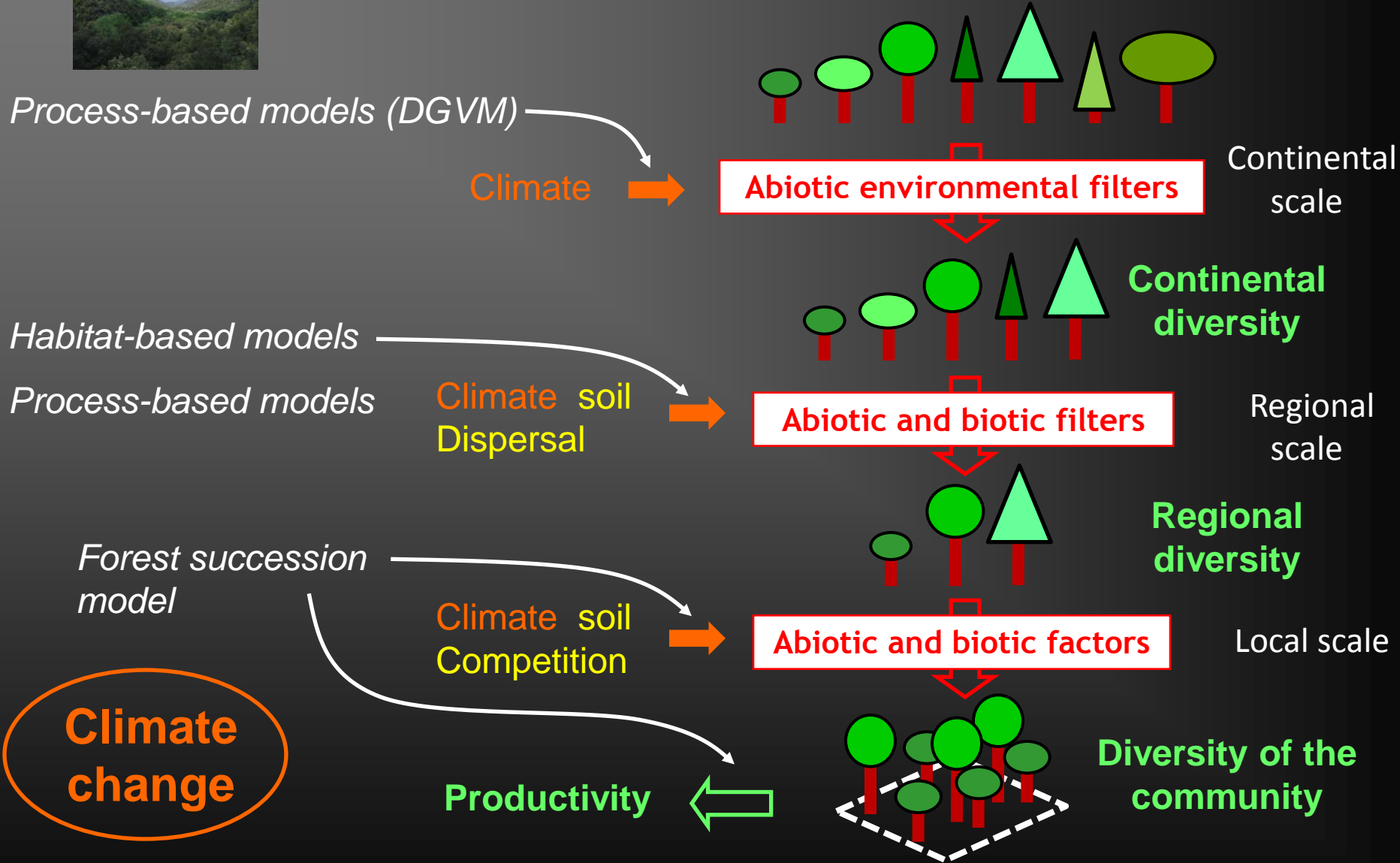
Local scale

Climate change

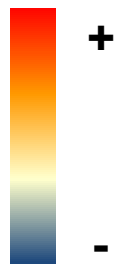
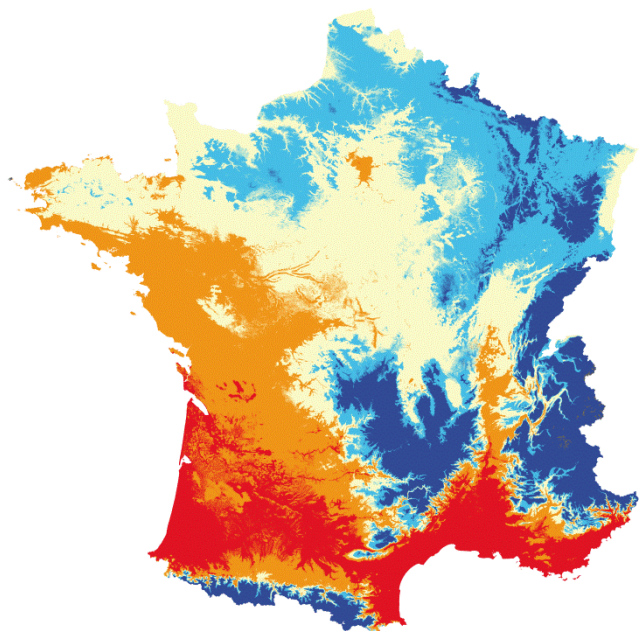
Productivity



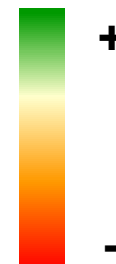
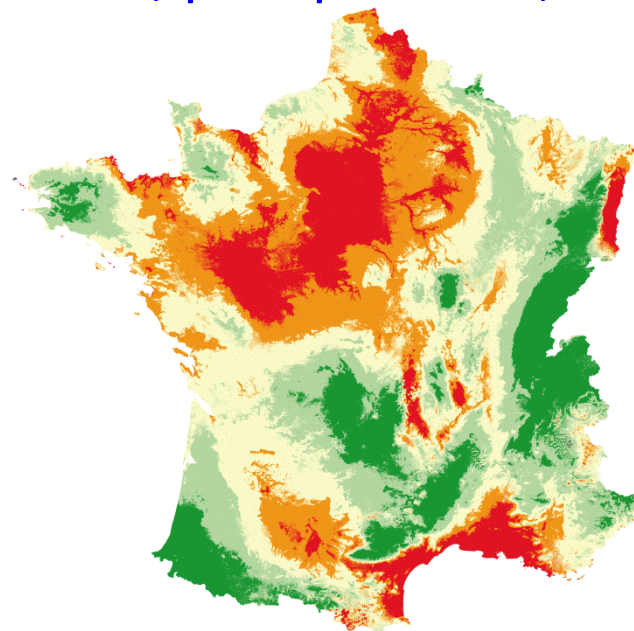
Diversity of the community



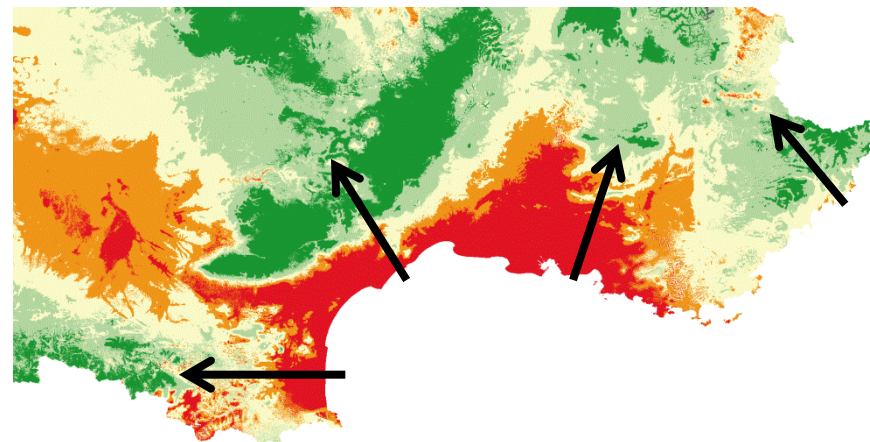
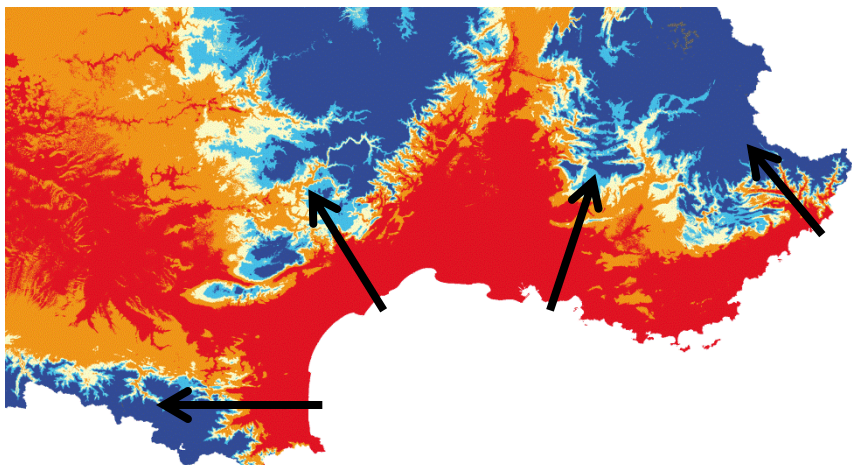
Zone méditerranéenne = forts gradients environnementaux
(température, précipitations, altitude)



Temp. moy annuelle



Somme Prec. annuelle



Gradients environnementaux en zone méditerranéenne

- ⇒ Mesure de composition de communautés, de traits des ind.
- ⇒ Validation de prédictions (composition, productivité...)
- ⇒ Implémentation var. intrasp. dans les modèles

Gradients régionaux



Gradients environnementaux en zone méditerranéenne

- ⇒ Mesure de composition de communautés, de traits des ind.
- ⇒ Validation de prédictions (composition, productivité...)
- ⇒ Implémentation var. intrasp. dans les modèles



Gradients environnementaux en zone méditerranéenne

- ⇒ Mesure de composition de communautés, de traits des ind.
- ⇒ Validation de prédictions (composition, productivité...)
- ⇒ Implémentation var. intrasp. dans les modèles



Site-test = Mont Aigoual



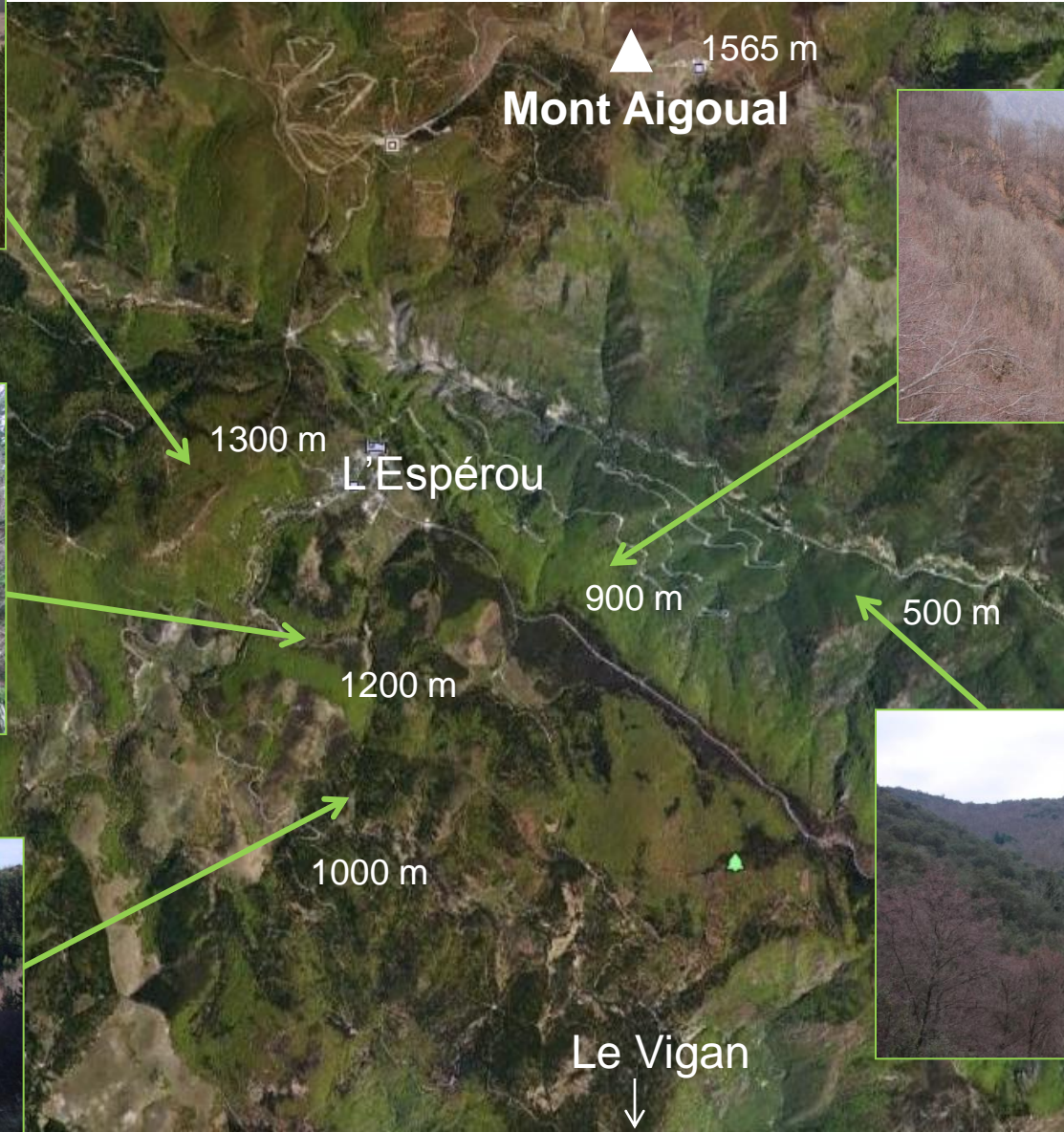
Fagus sylvatica
Picea abies
Pinus uncinata



Fagus sylvatica
Abies alba *Picea abies*



Fagus sylvatica
Pinus nigra *Pinus sylvestris* *Picea abies*



Fagus sylvatica
Castanea sativa

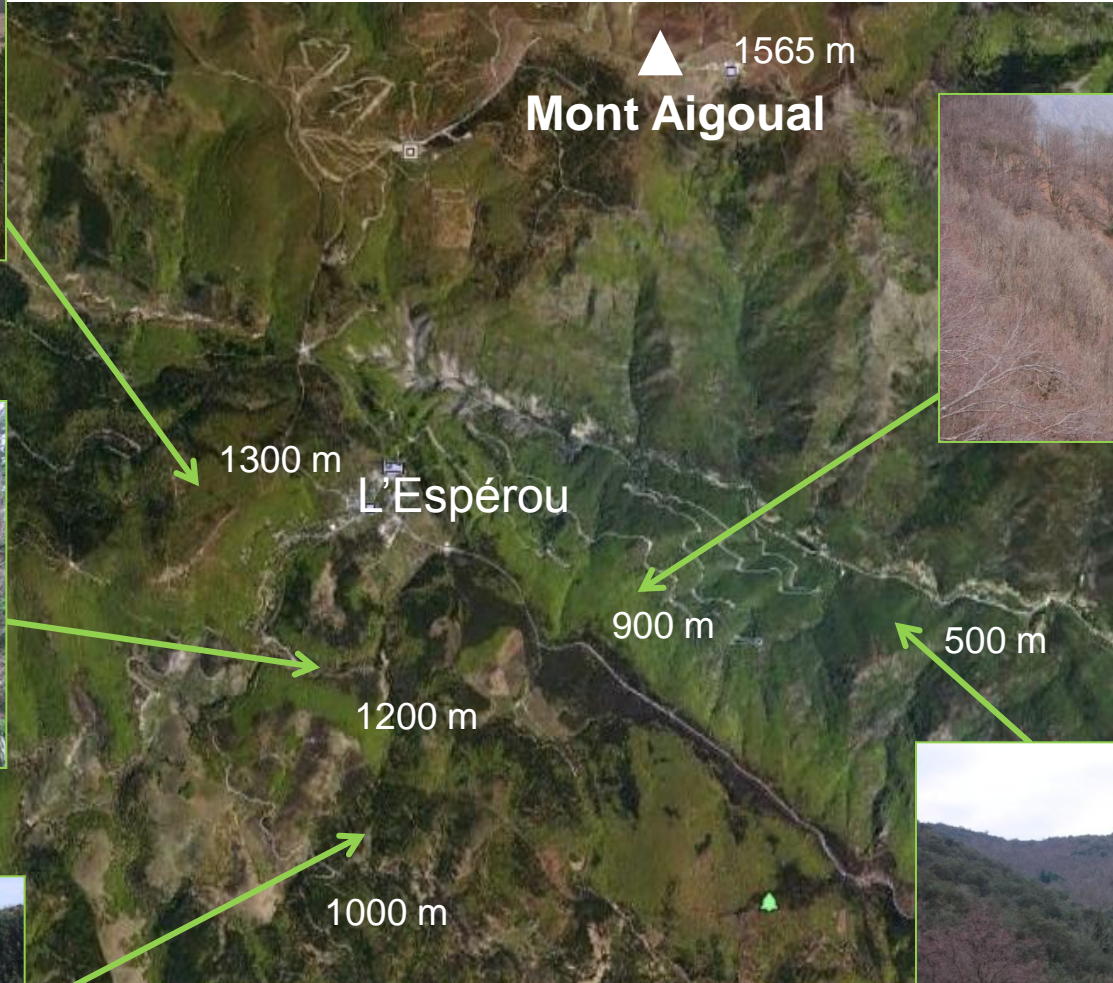


Quercus ilex
Castanea sativa

Site-test = Mont Aigoual



Fagus sylvatica
Picea abies
Pinus uncinata



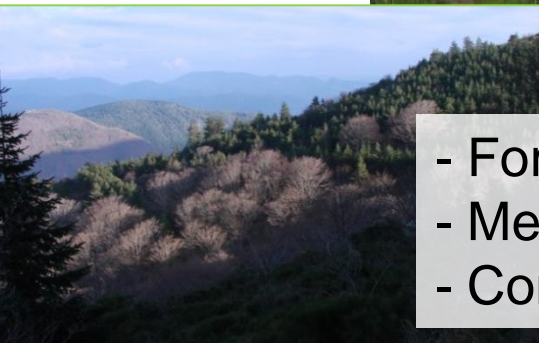
Fagus sylvatica
Castanea sativa



Fagus sylvatica
Abies alba *Picea abies*



Quercus ilex
Castanea sativa



Fagus sylvatica
Pinus nigra *Pinus sylvestris* *Picea abies*

- Forêts mono et pluri-spécifiques
- Mesures de traits (var. intra- et inter-spécifique)
- Composition arbres et arbustes

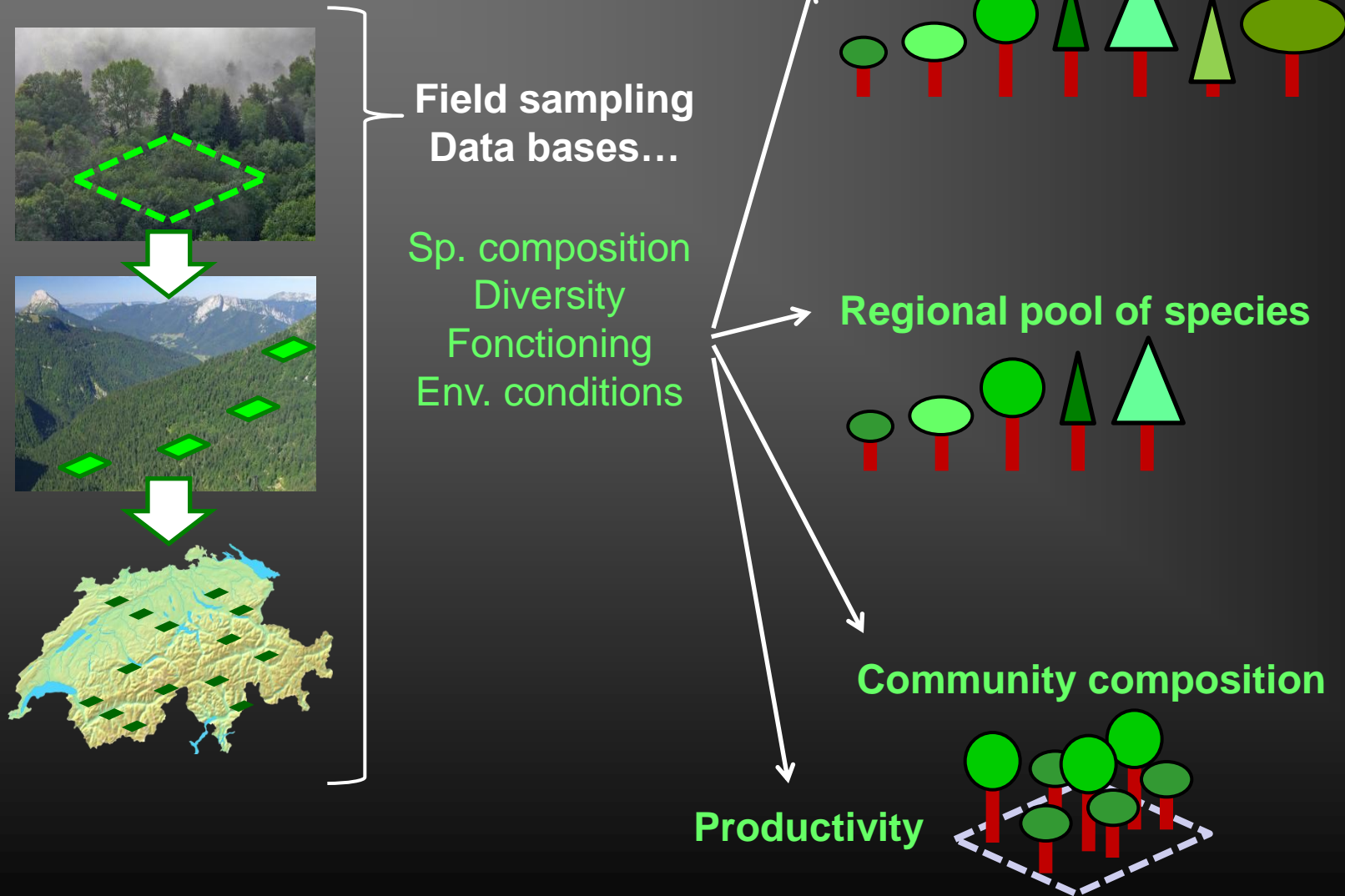
Gradients environnementaux en zone méditerranéenne

- Mise en place de placettes pour suivi à moyen/long terme
- Elargissement...
- Autres niveaux trophiques (herbivorie, décomposition...)



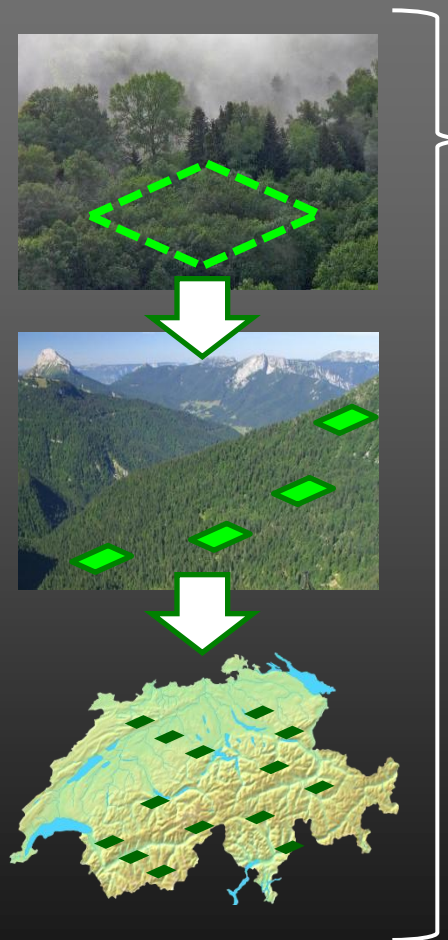


Linking climate, biodiversity and ecosystem functioning





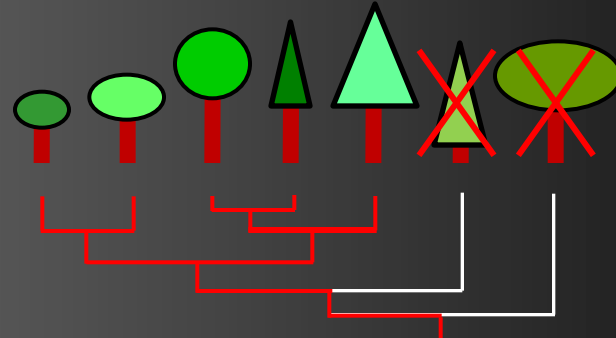
Linking climate, biodiversity and ecosystem functioning



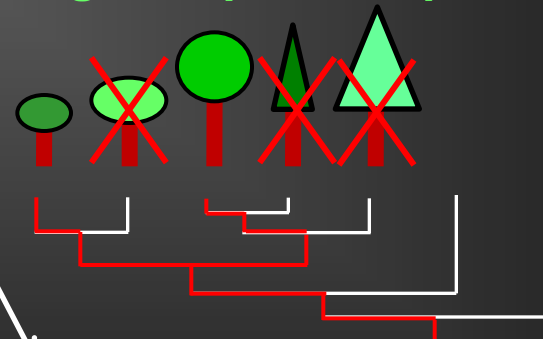
Field sampling
Data bases...

Sp. composition
Diversity
Functioning
Env. conditions

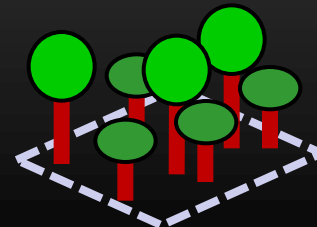
Continental pool of species



Regional pool of species



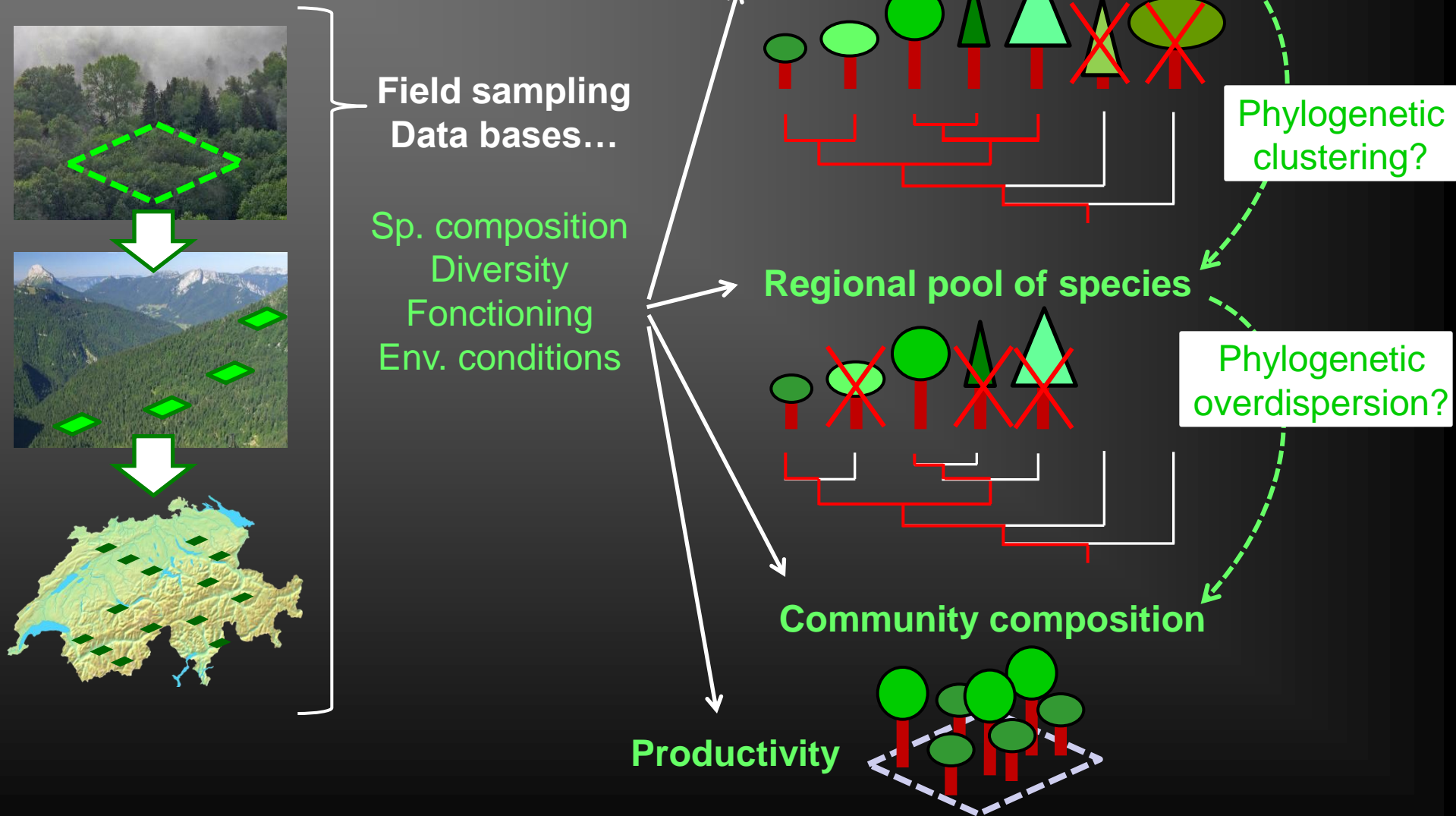
Community composition



Productivity



Linking climate, biodiversity and ecosystem functioning



Impacts of global change on forests

**Changement
climatique**

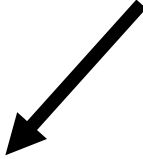


Facteurs abiotiques { *Climat Sol*

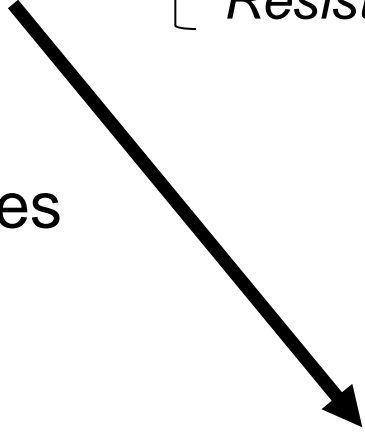


Physiologie

{ *Croissance
Phénologie
Résistance au stress*



Répartition des espèces



Composition des
communautés

*Richesse spécifique
Diversité fonctionnelle*



Fonctionnement
des écosystèmes

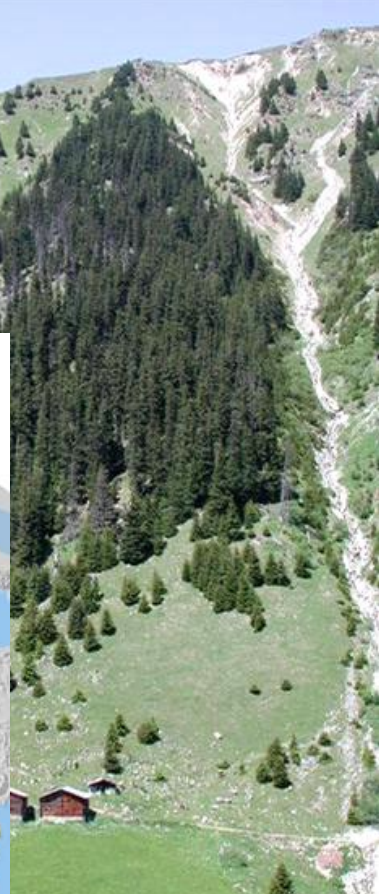
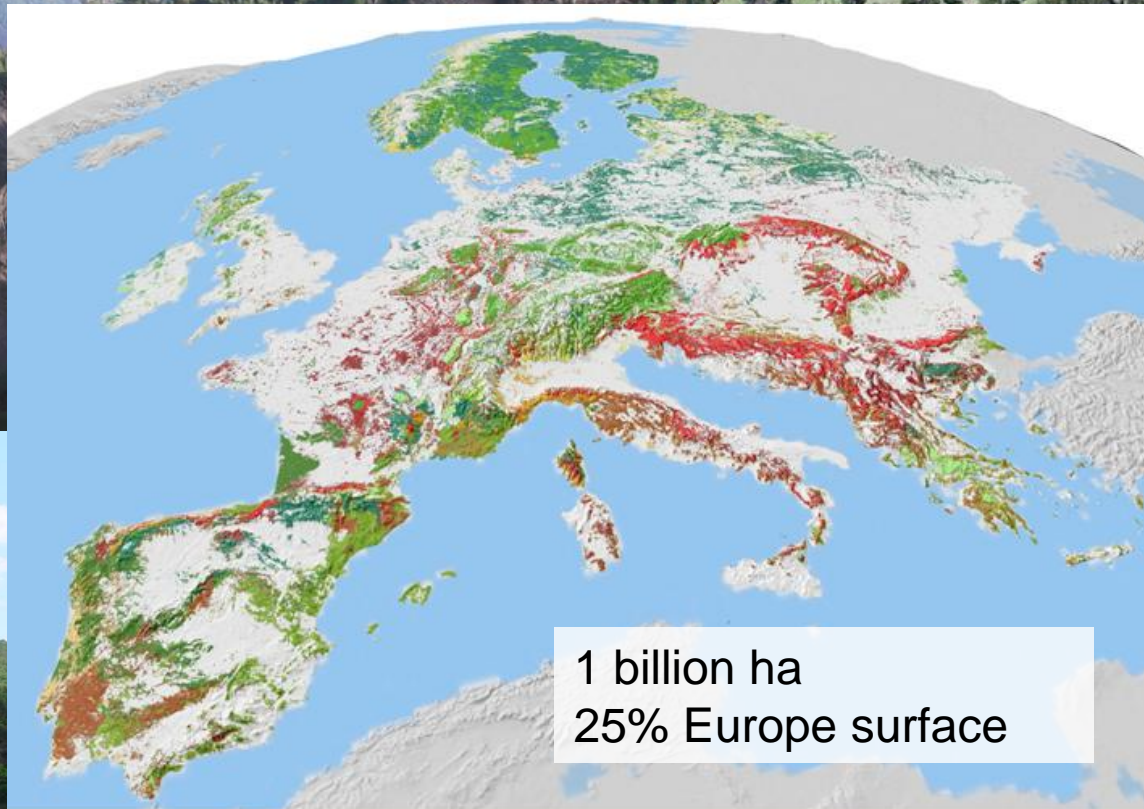
Productivité



Échelle
continentale/régionale

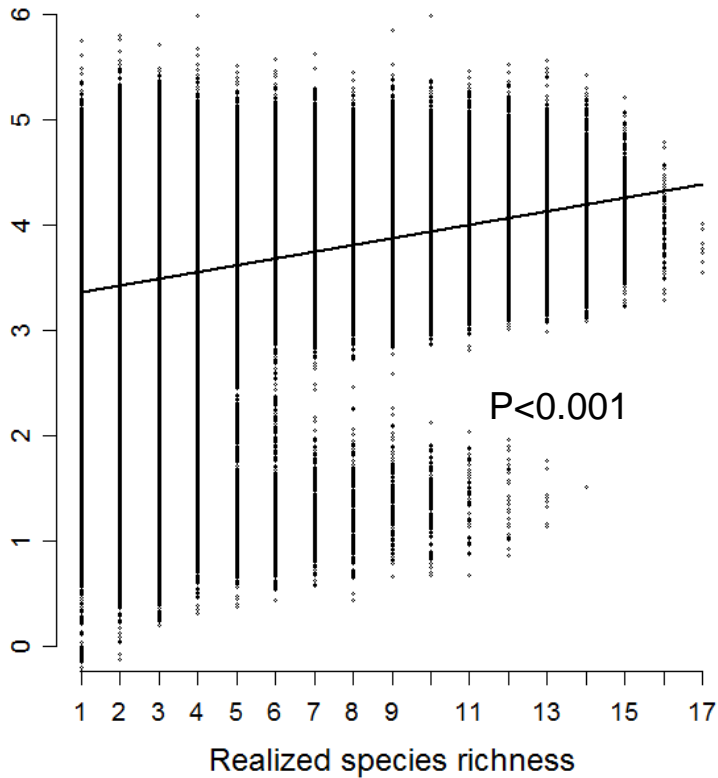
Échelle locale





Stability in productivity over time increases with species richness

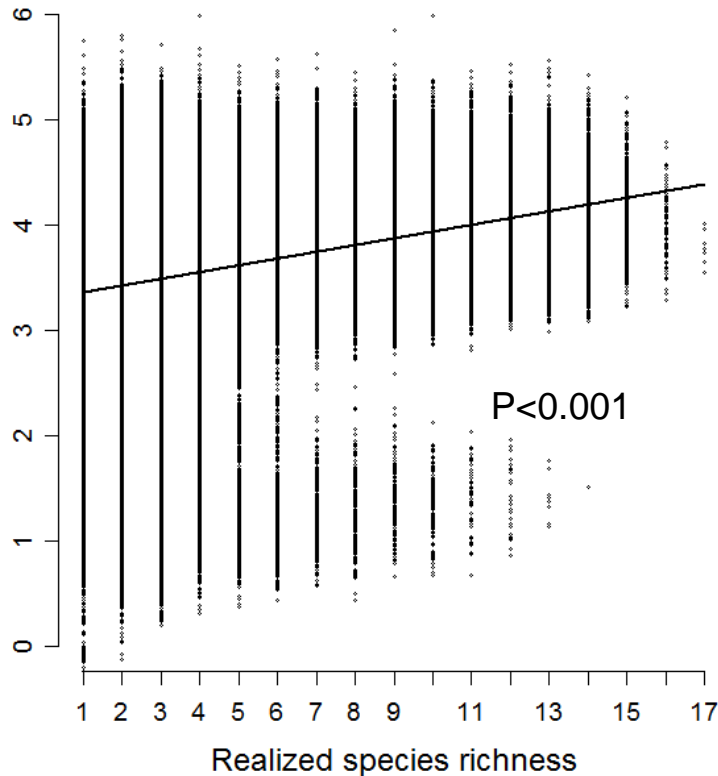
Stability of forest productivity = $1/\text{CV}(\text{Productivity})$



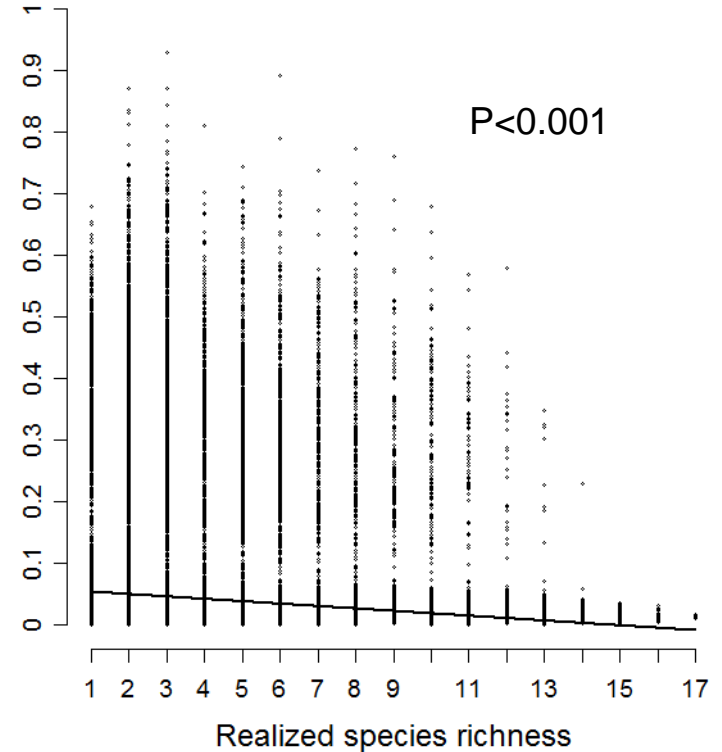
- More diverse forests have a stronger temporal stability than less diverse forests

Stability in productivity over time increases with species richness

Stability of forest productivity = $1/\text{CV}(\text{Productivity})$

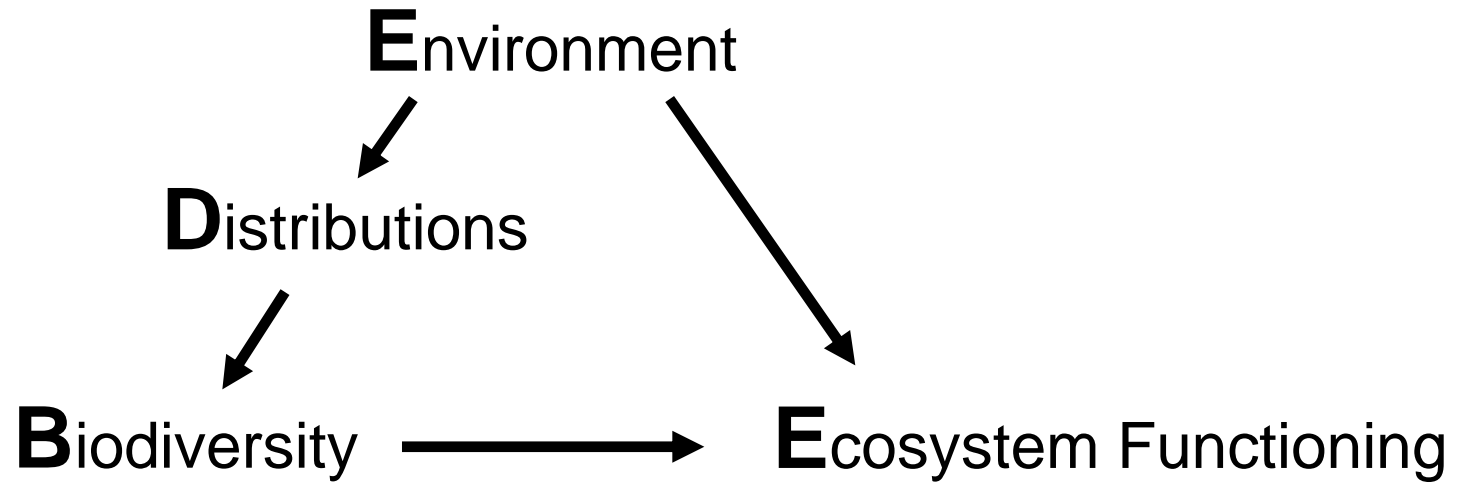
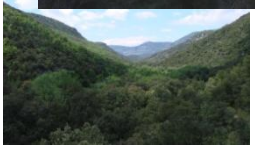


Community-wide synchrony of species productivity

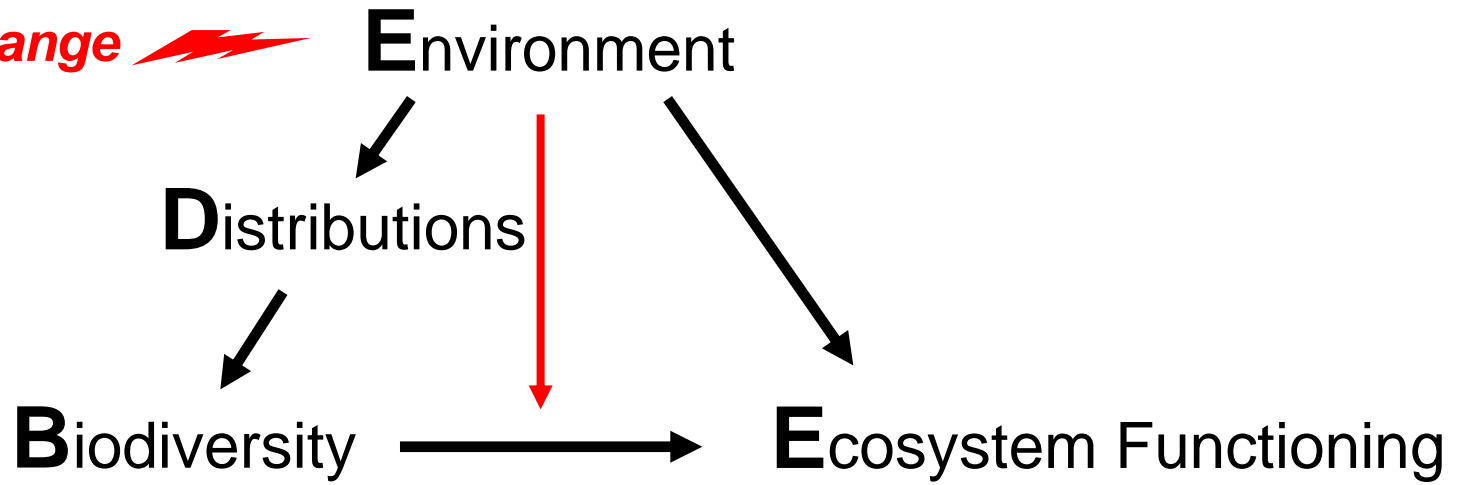


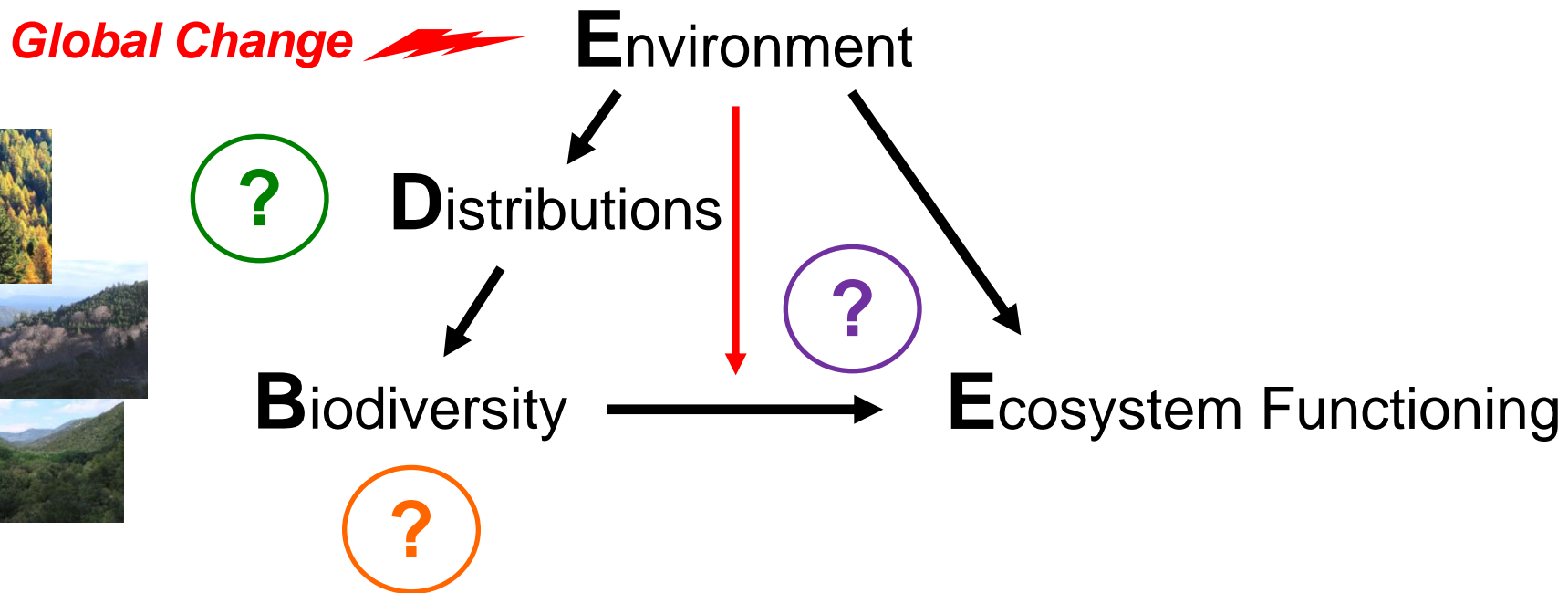
- More diverse forests have a stronger temporal stability than less diverse forests
- Diversity (SR and functional diversity) promotes temporal stability mostly because it increases species asynchrony in the community




Future project...

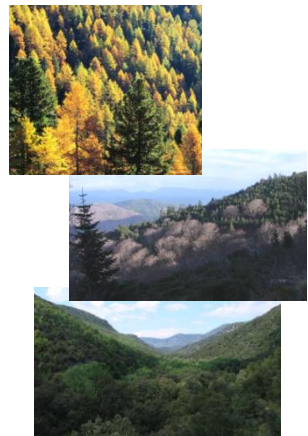


Global Change 





-  **Better understanding what rules the diversity of woody species in forest ecosystems**
-  **Predicting the impact of climate change on the relationship between diversity and forest productivity**
-  **Taking into account the role of intraspecific variability in woody species assemblages and forest productivity**



Global Change



Environment

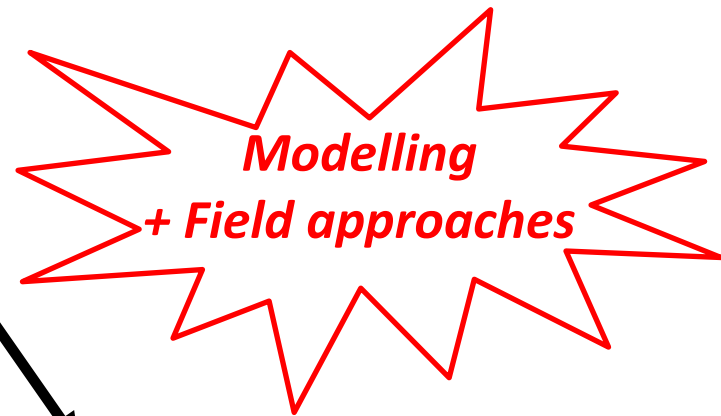


Distributions



Biodiversity

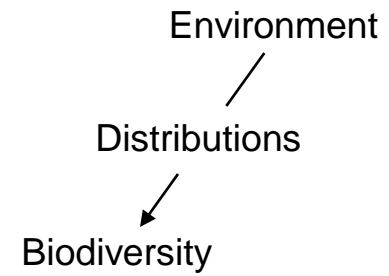
Ecosystem Functioning



- 1** Better understanding what rules the diversity of woody species in forest ecosystems
- 2** Predicting the impact of climate change on the relationship between diversity and forest productivity
- 3** Taking into account the role of intraspecific variability in woody species assemblages and forest productivity

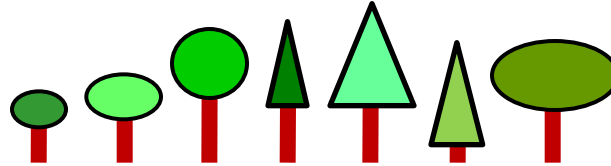
1

Better understanding what rules the diversity of woody species in forest ecosystems



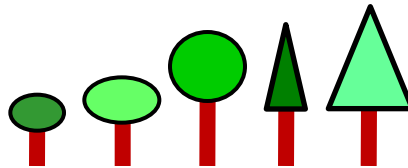
Spatial scale

Continental species pool



Environnemental filter

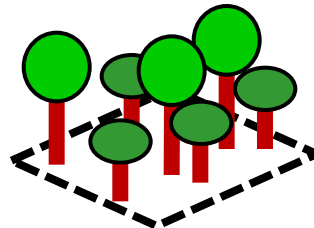
Regional species pool



Biotic interactions

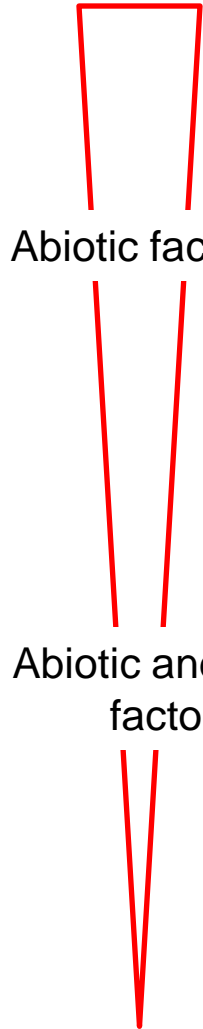
Community composition

Productivity



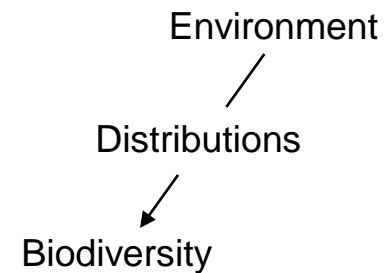
Abiotic factors

Abiotic and biotic factors



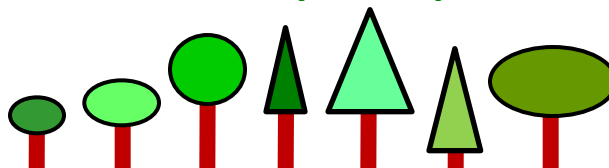
1

Better understanding what rules the diversity of woody species in forest ecosystems



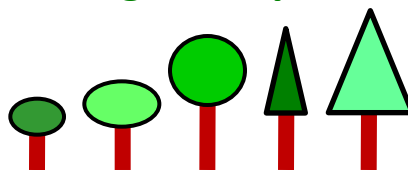
Spatial scale

Continental species pool



SDMs

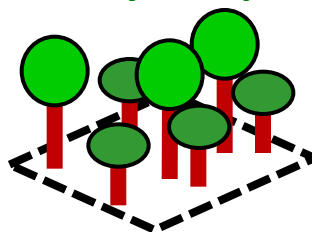
Regional species pool



Forest dynamics model

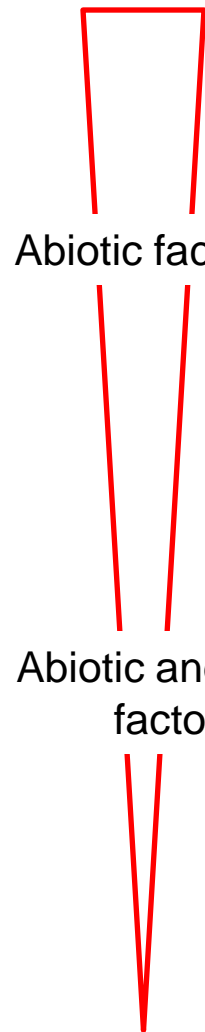
Community composition

Productivity



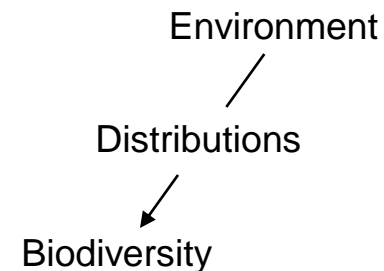
Abiotic factors

Abiotic and biotic factors

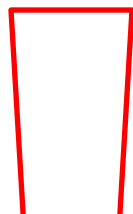


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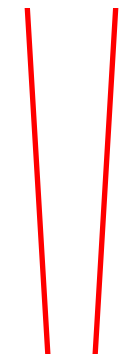
Better understanding what rules the diversity of woody species in forest ecosystems



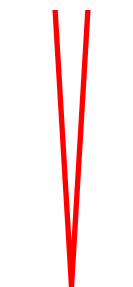
Spatial scale



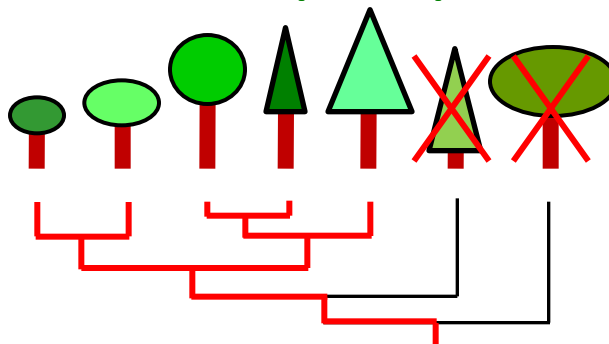
Abiotic factors



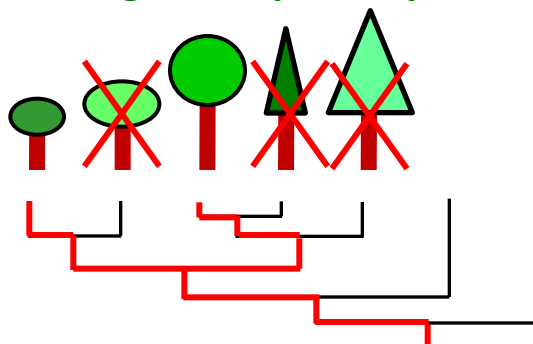
Abiotic and biotic factors



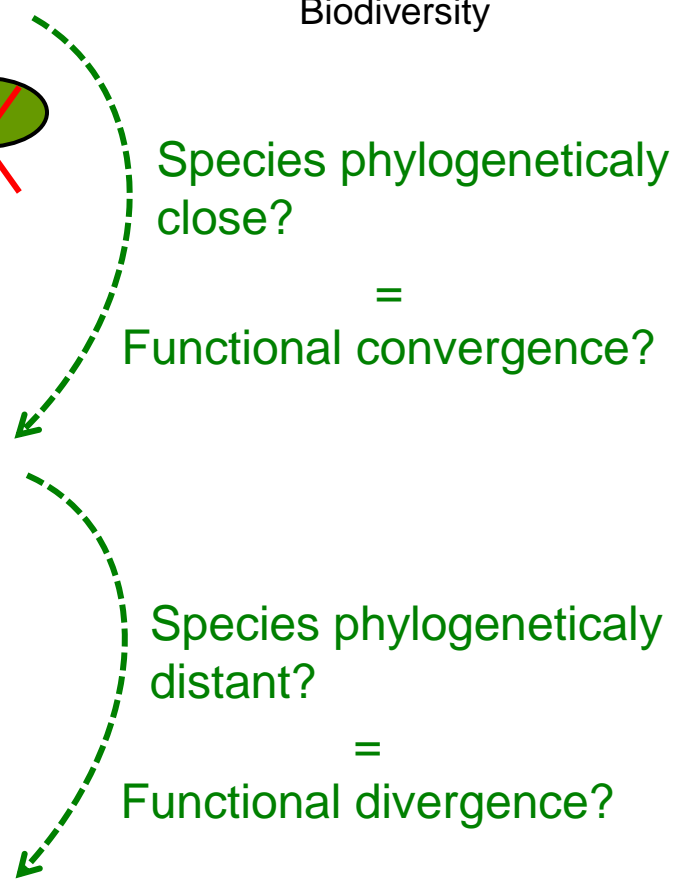
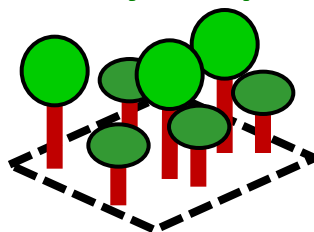
Continental species pool



Regional species pool

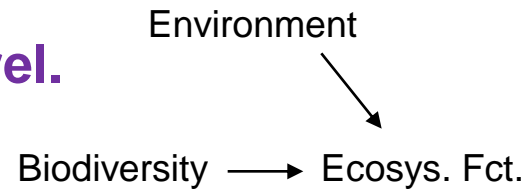


Community composition



Test of community ecology hypotheses

② Predicting the impact of climate change on the rel. between diversity and forest productivity

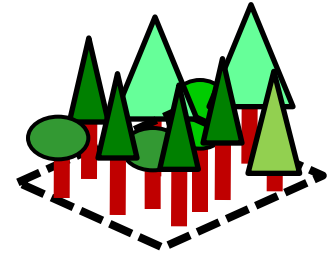
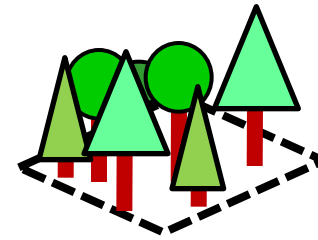
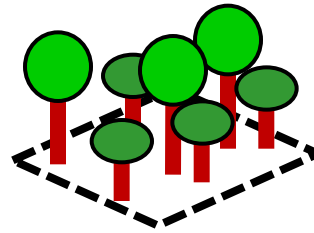


a) Modelling

● Site 1

● Site i

● Site n



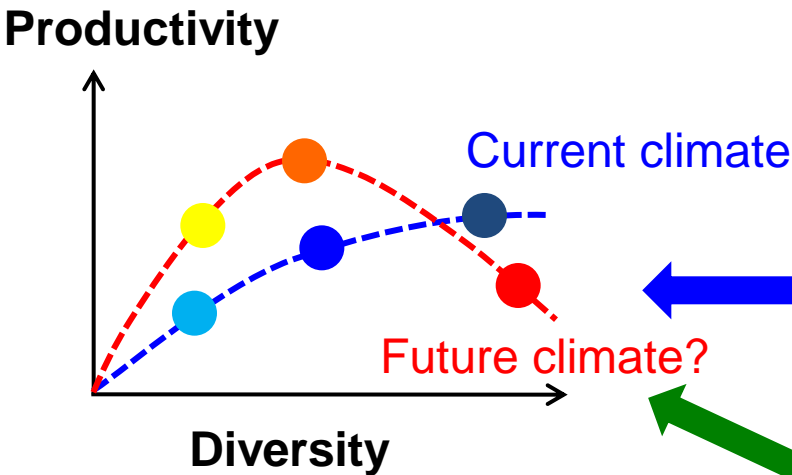
Diversity
Productivity

Diversity
Productivity

Diversity
Productivity



b) Empirical validation



Field sampling
Data bases



= Diversity-productivity rel.
according to environmental gradients