

Test du "tree packing" avec un modèle de trouées

Testing the « tree packing » hypothesis with a gap model

Xavier Morin

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Journées CAQSIS – Aix-en-Provence 26-28 mars 2019

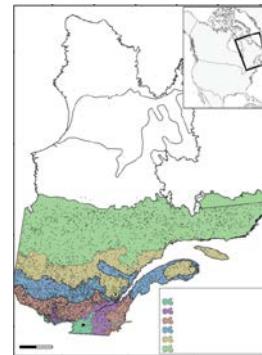
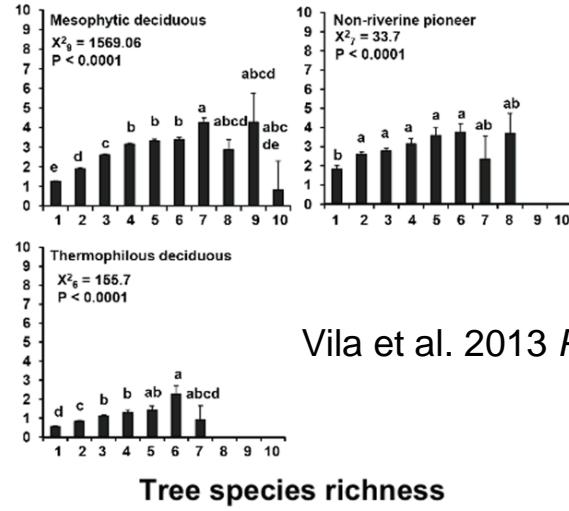
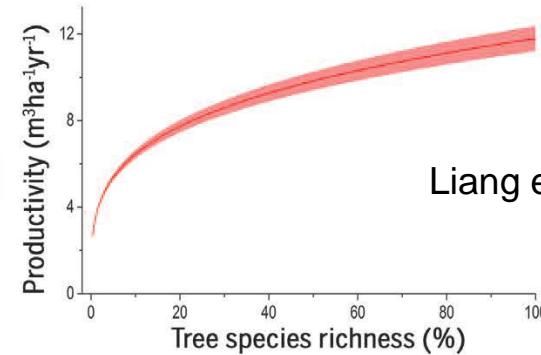
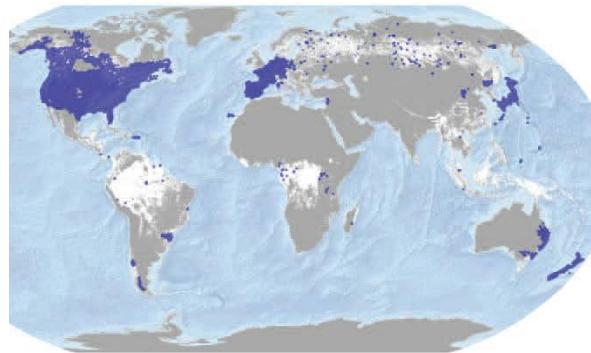


The diversity-productivity relationship in forest ecosystems

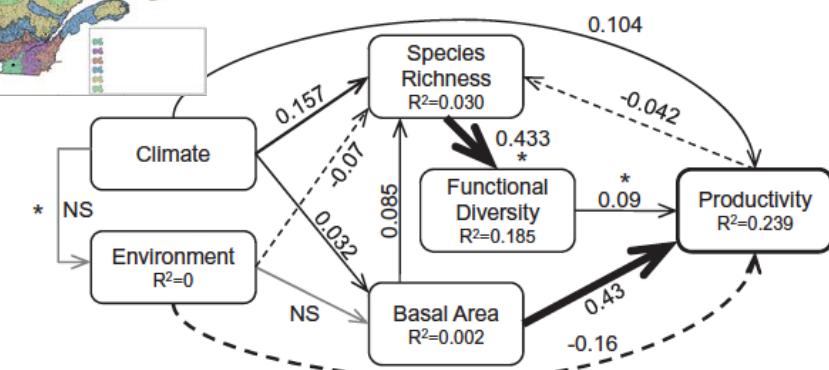
The diversity-productivity relationship in forest ecosystems

Observations

NFI data = empirical



Paquette & Messier 2011
Global Ecol. & Biog.

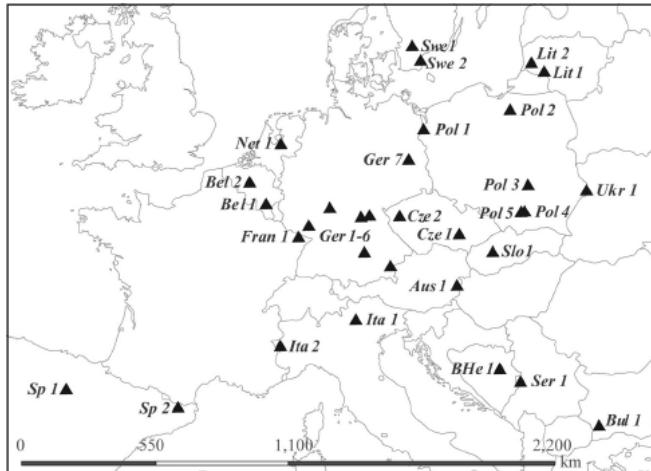
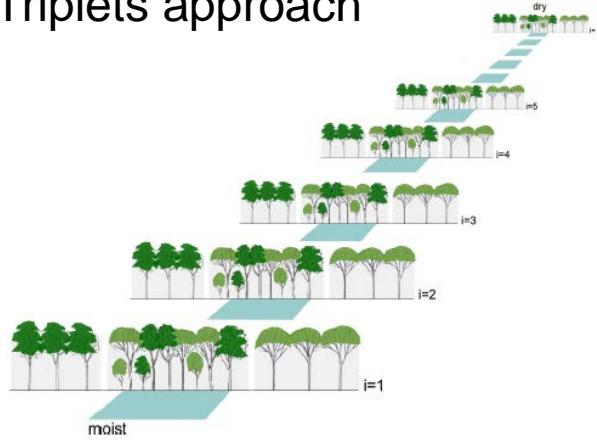


The diversity-productivity relationship in forest ecosystems

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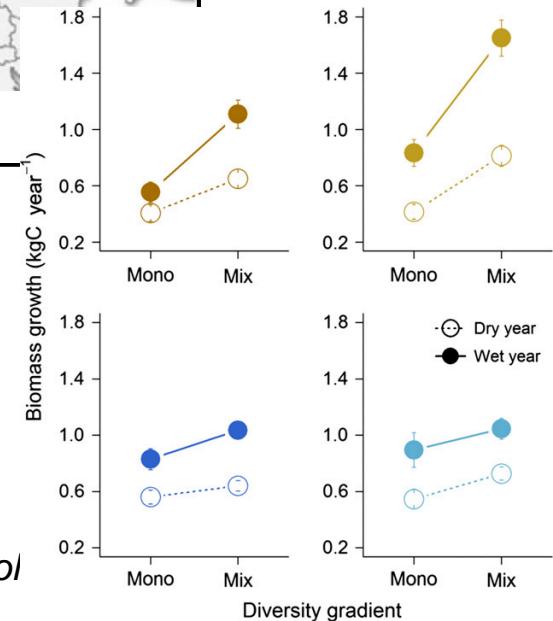
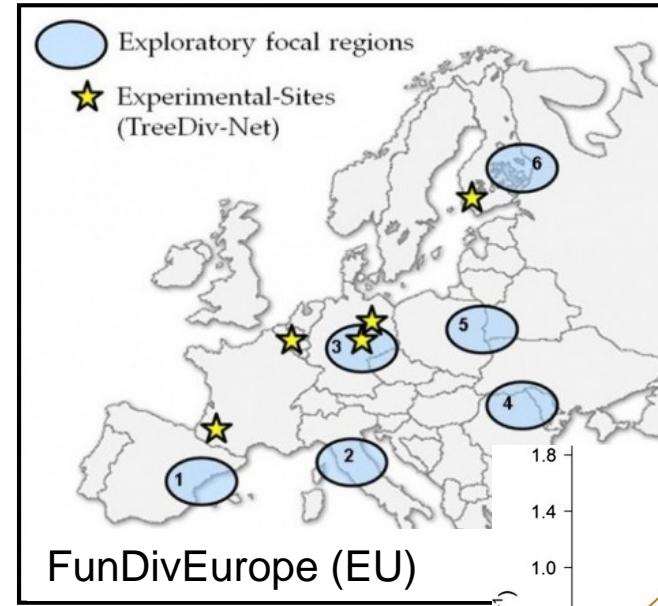
Semi-experimental plots

Triplets approach



Pretzsch et al. 2015 *Eur. J. For. Res.*

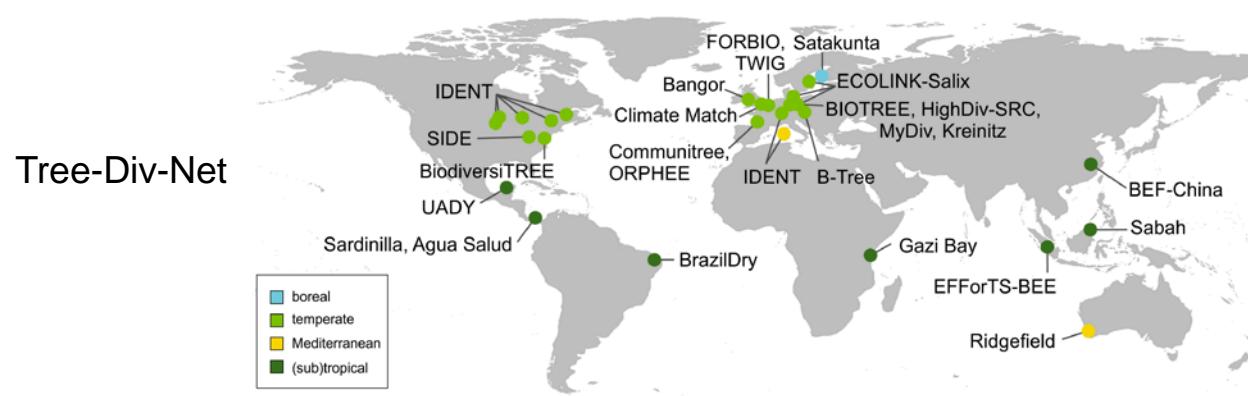
« Exploratory » plots



Jucker et al. 2014 *J. Ecol.*

The diversity-productivity relationship in forest ecosystems

Experiments



ORPHEE Experiment – Pierroton (FR)

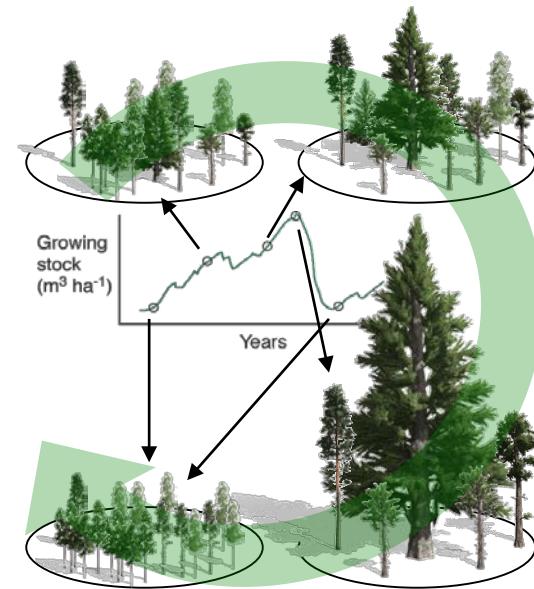


The diversity-productivity relationship in forest ecosystems

Simulations

- Gap models rely on key hypotheses in Forest Ecology
Succession niche
- Cyclical successions on small patches of land
- Quantitative description of tree population dynamics
Establishment / Growth / Mortality
- Optimal growth limited by environmental factors
Climate / Competition for light

Gap models

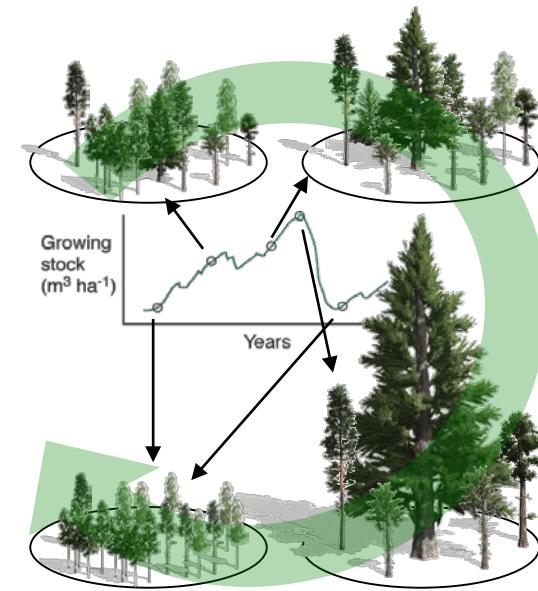


The diversity-productivity relationship in forest ecosystems

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

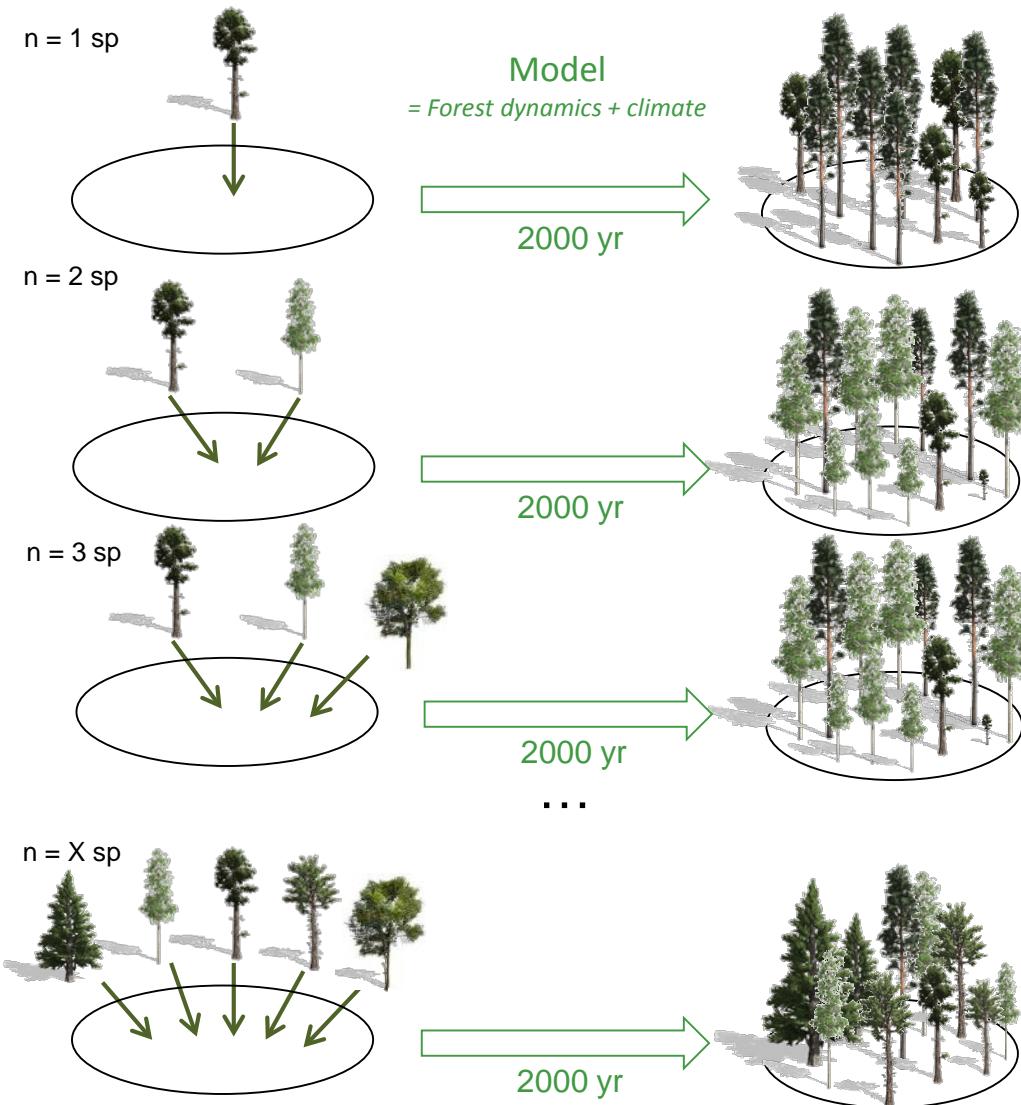
Gap models



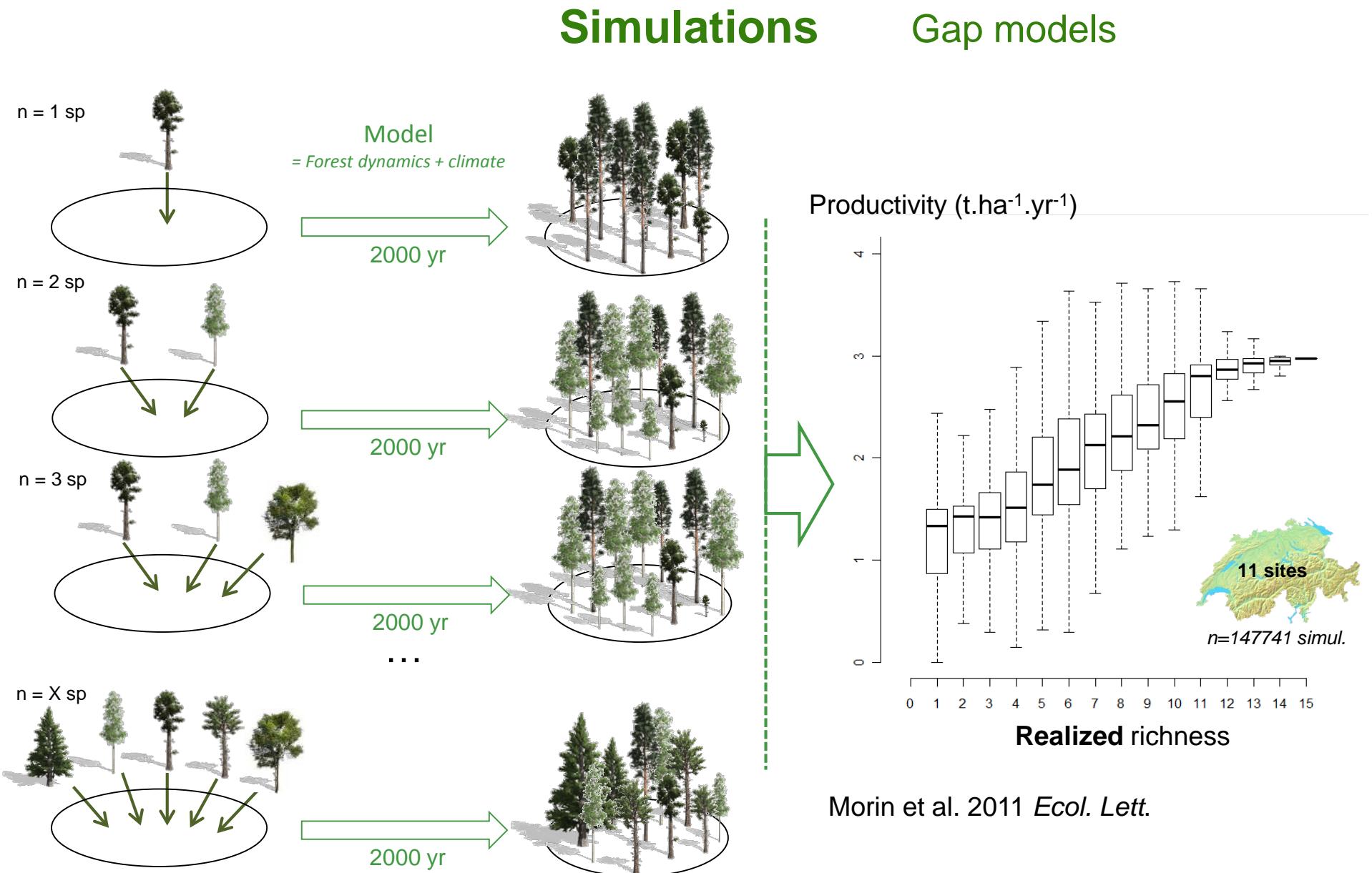
The diversity-productivity relationship in forest ecosystems

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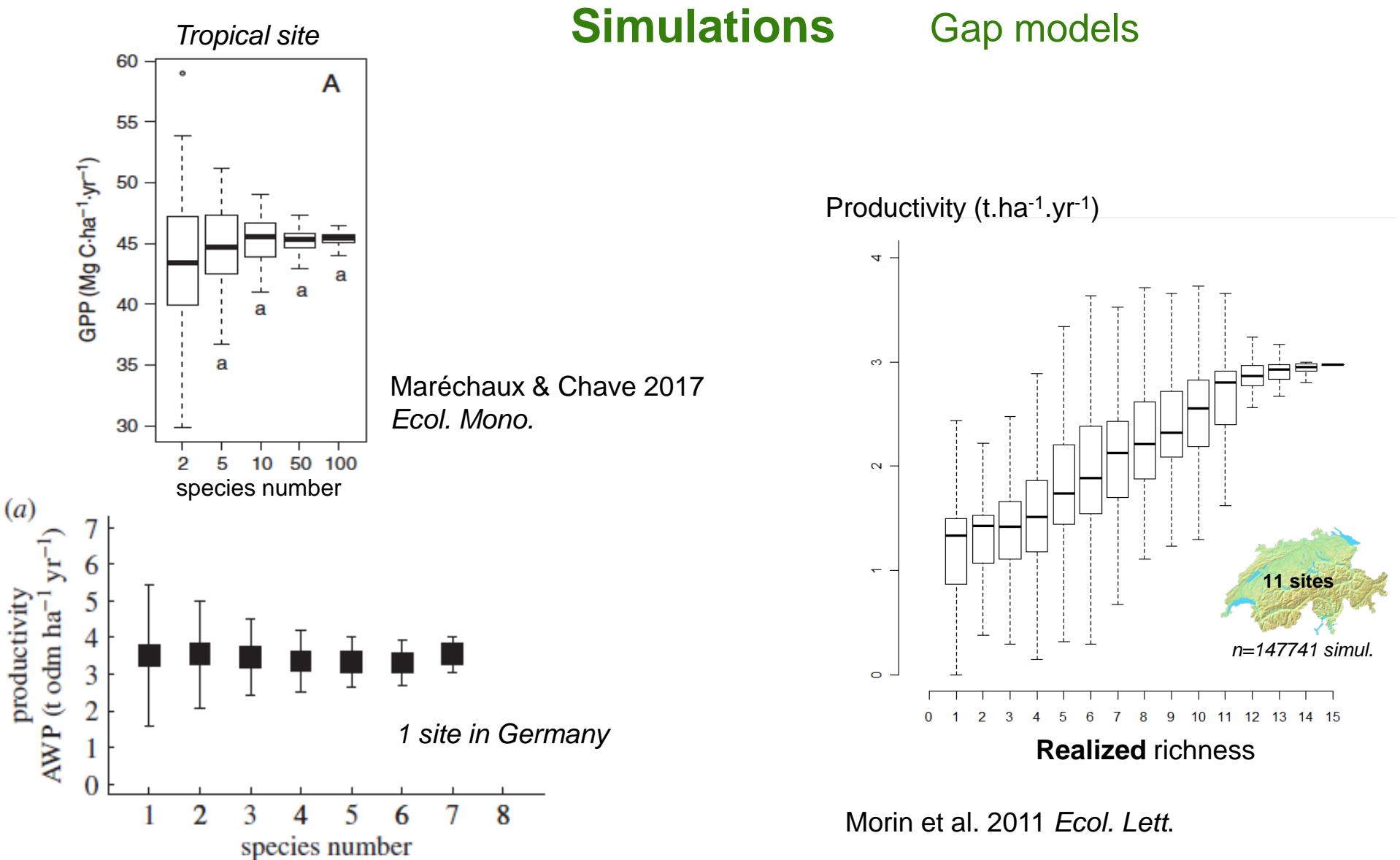
Gap models



The diversity-productivity relationship in forest ecosystems



The diversity-productivity relationship in forest ecosystems



The diversity-productivity relationship in forest ecosystems

What mechanisms?

Resource partitioning

Space

The diversity-productivity relationship in forest ecosystems

What mechanisms?

Resource partitioning

Space

Tree level

Community level

The diversity-productivity relationship in forest ecosystems

What mechanisms?

Resource partitioning

Space

Tree level

Community level

Nutrients

Differentiation in tolerance
or requirements

Water

Rooting stratification
Rooting plasticity



Root segregation

Light

Vertical stratification
Crown plasticity

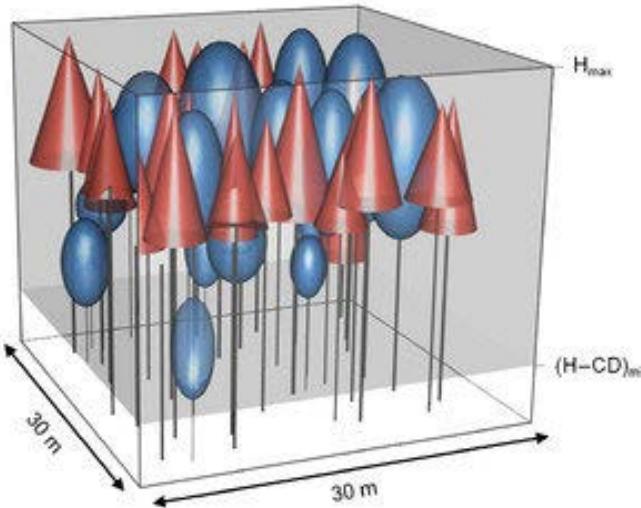


Canopy packing

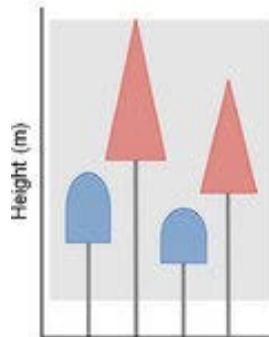
The diversity-productivity relationship in forest ecosystems

Canopy packing = one of the main mechanisms proposed to explain diversity-productivity effects in forests

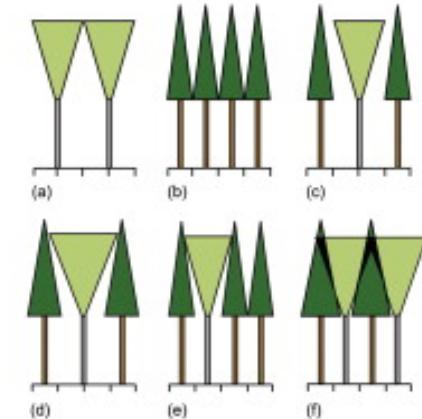
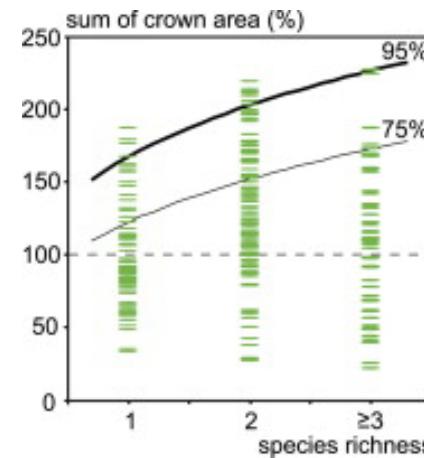
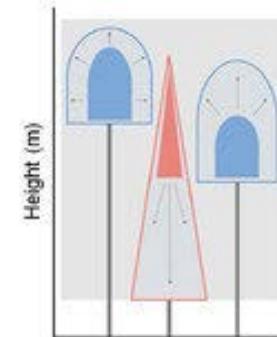
(a) Canopy packing



(b) Vertical stratification



(c) Crown plasticity



Pretzsch et al. 2014 *For. Ecol. & Manag.*

The diversity-productivity relationship in forest ecosystems

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Canopy packing

Number of trees

The diversity-productivity relationship in forest ecosystems

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Canopy packing

Number of trees

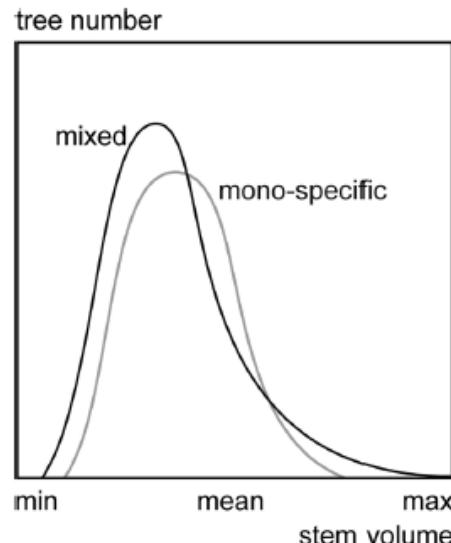
= Can diverse forest « accept » more trees?
Consequences for EF?

The diversity-productivity relationship in forest ecosystems

More trees in mixed stands?

Triplets

Interaction with stem size



Pretzsch & Schütze 2016
Eur. J. For. Res.

Tree species mixing can increase maximum stand density¹

Hans Pretzsch and Peter Biber

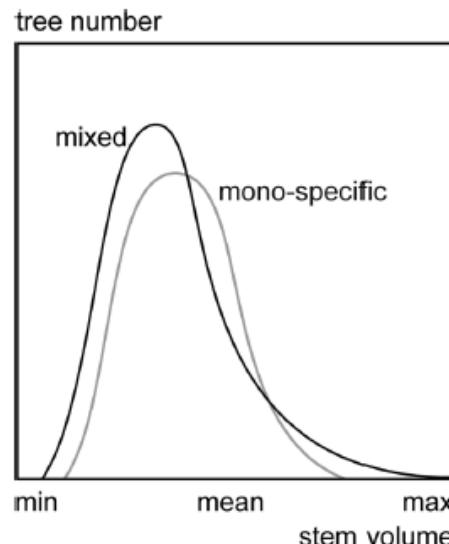
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The diversity-productivity relationship in forest ecosystems

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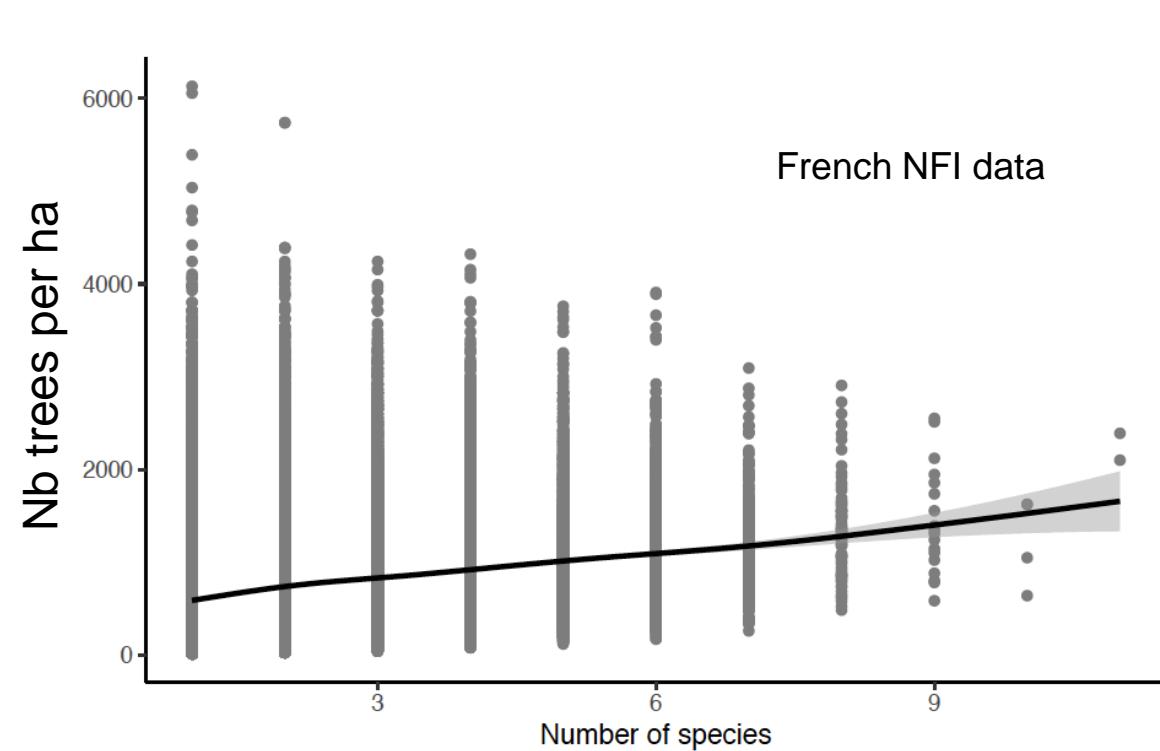
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NFI data



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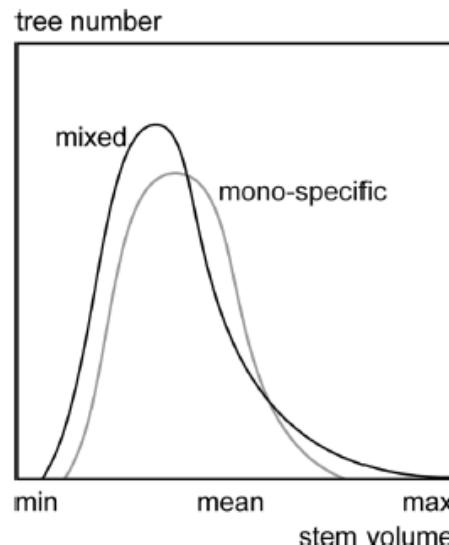
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The diversity-productivity relationship in forest ecosystems

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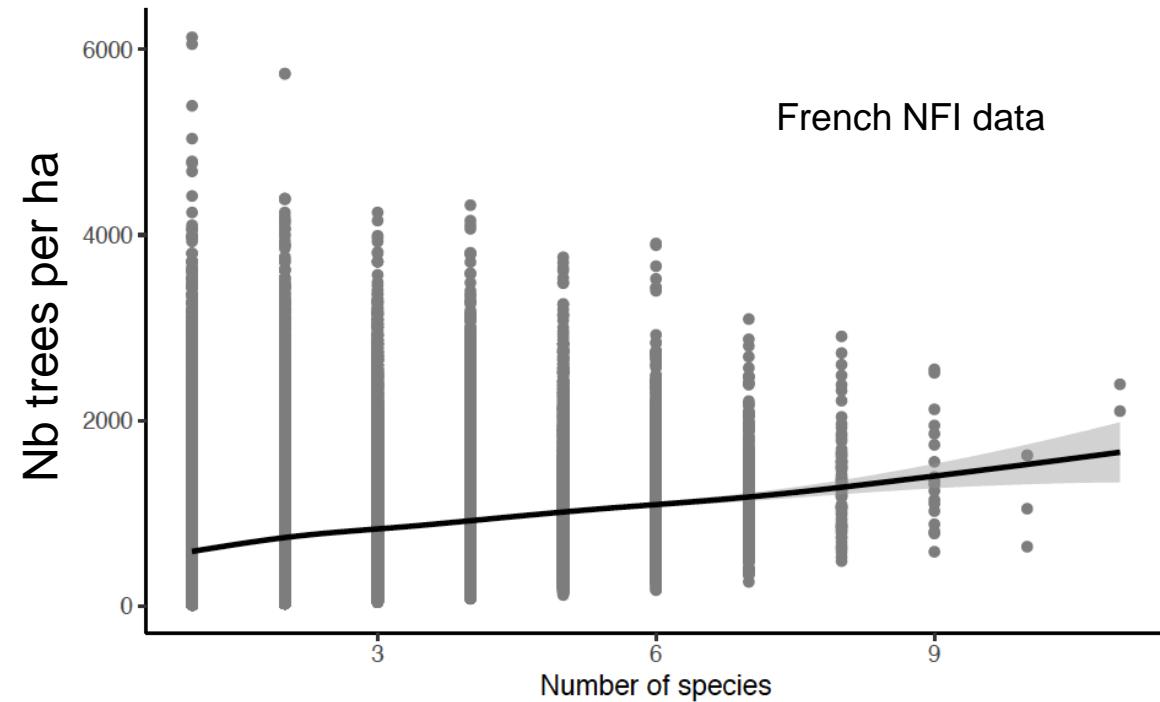
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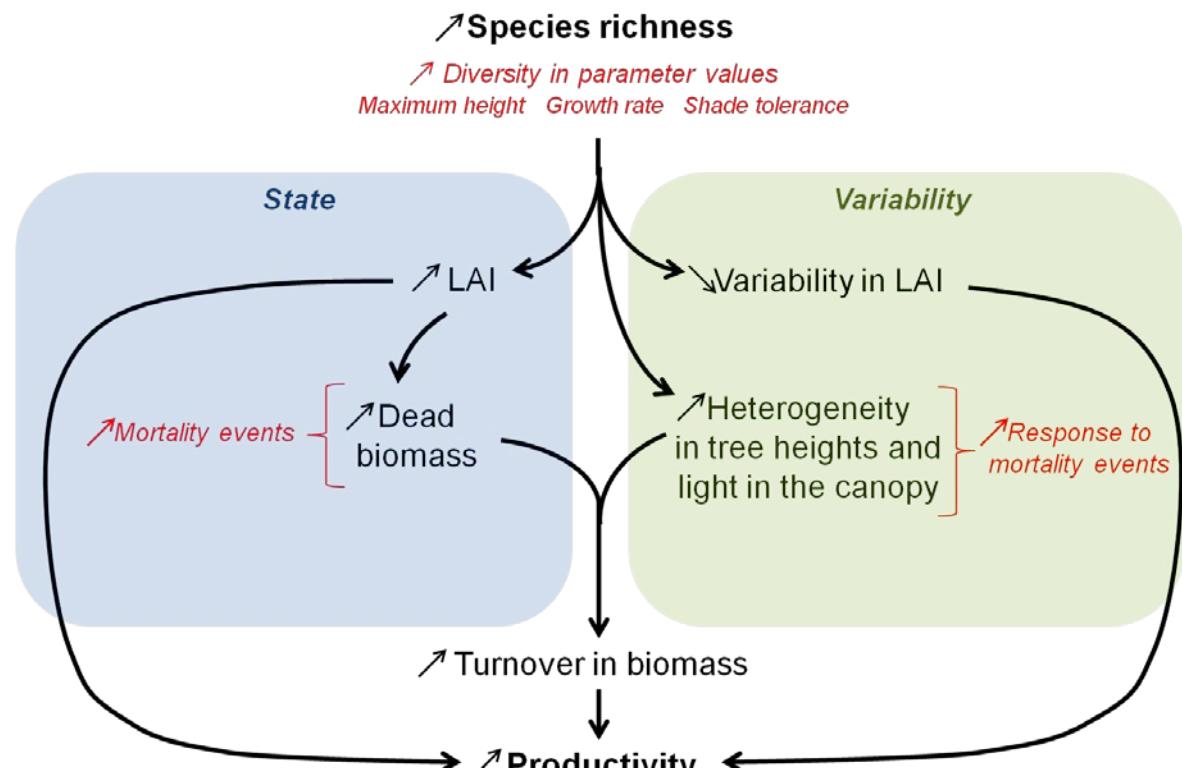
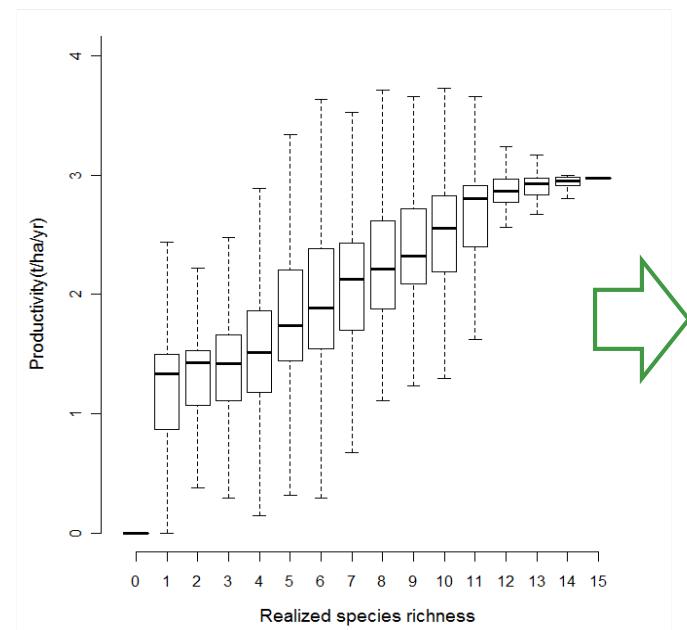
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Consistent pattern, but unclear...

Importance for ecosystem productivity?

The diversity-productivity relationship in forest ecosystems

What mechanisms?

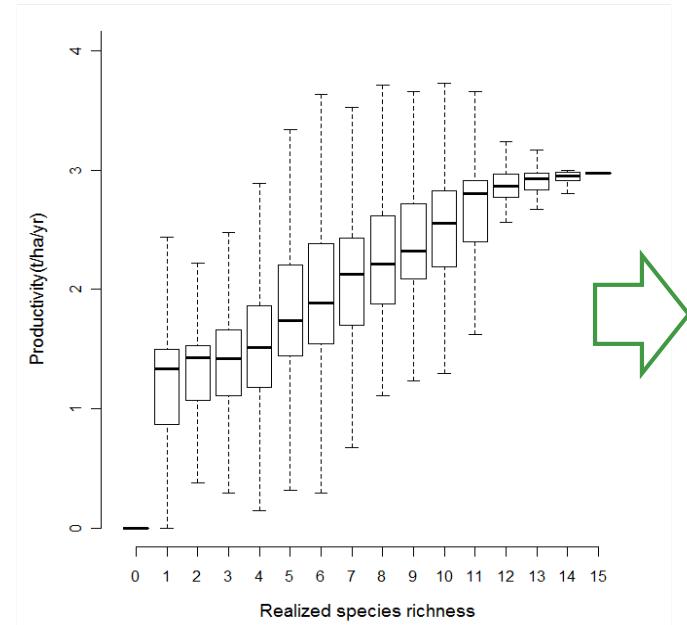


Morin et al. 2011

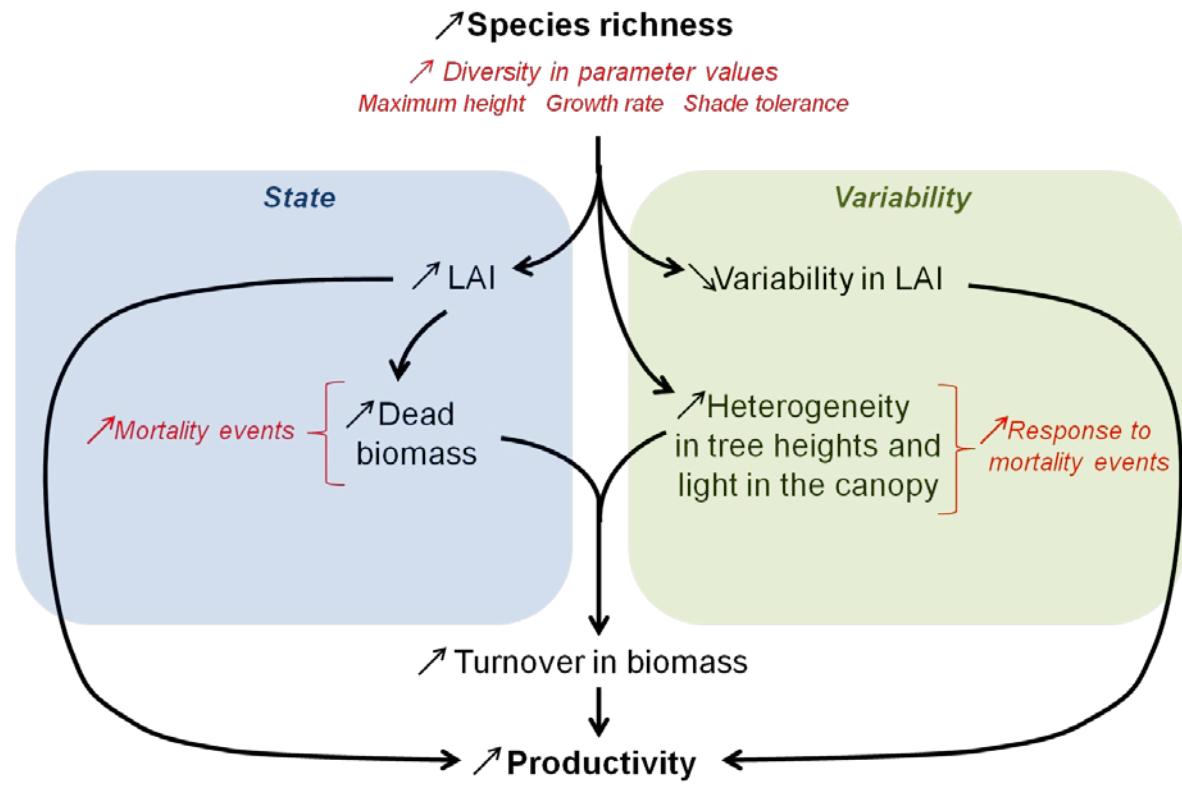
≈ Canopy packing

The diversity-productivity relationship in forest ecosystems

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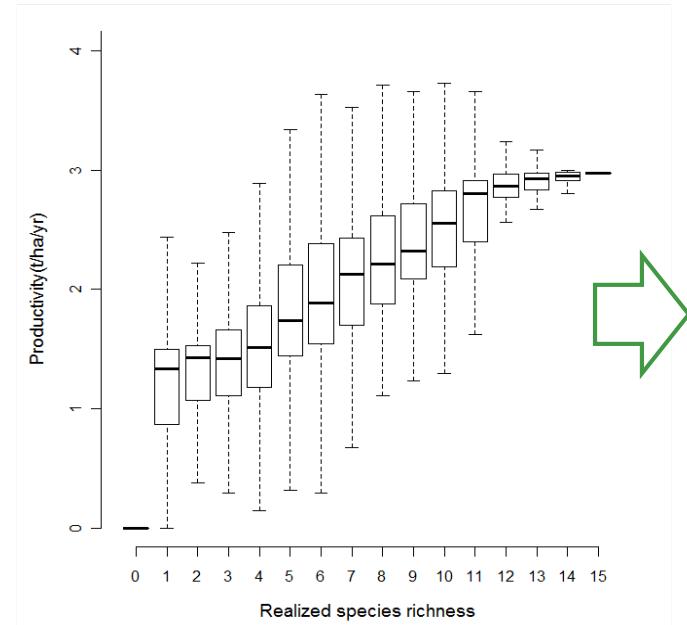
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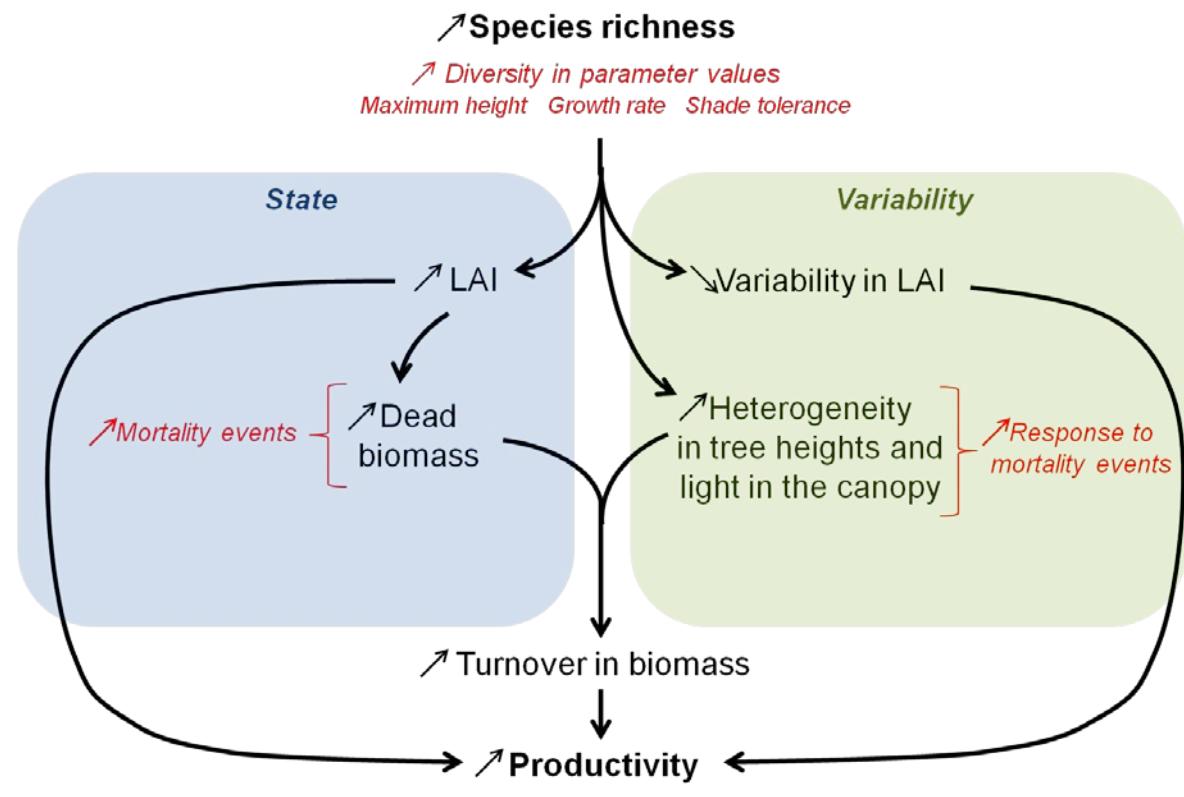
Yet, when focusing on individual growth = the effect was much weaker

The diversity-productivity relationship in forest ecosystems

What mechanisms?



Morin et al. 2011



≈ Canopy packing

Yet, when focusing on individual growth = the effect was much weaker

→ In the simulations, part of the net diversity effect on productivity was due to an increased nb of trees in mixed forests (tree packing) = **general pattern?**

Questions

- Using the same modelling approach used to test BEF in forests, can we confirm and quantify this « more trees hypothesis » ?
- What is its importance on ecosystem functioning?

To do list

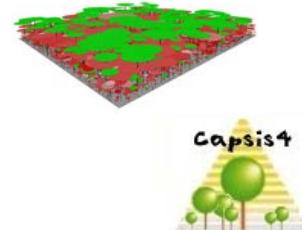
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- 1- Calibrating the model for French forests
- 2- Simulating BEF relationships

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The ForCEEPS model

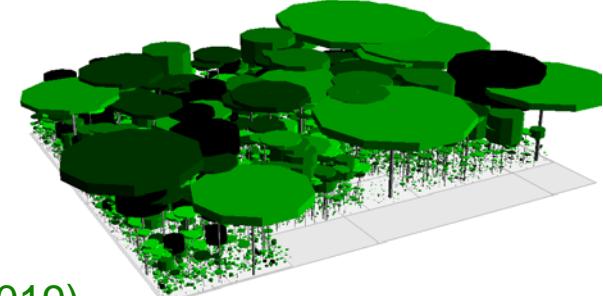
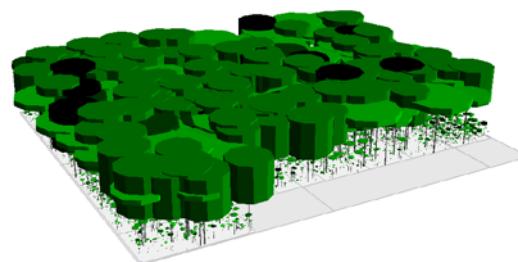
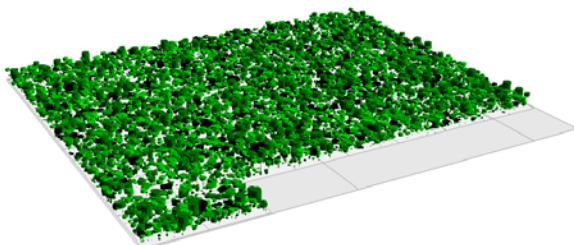
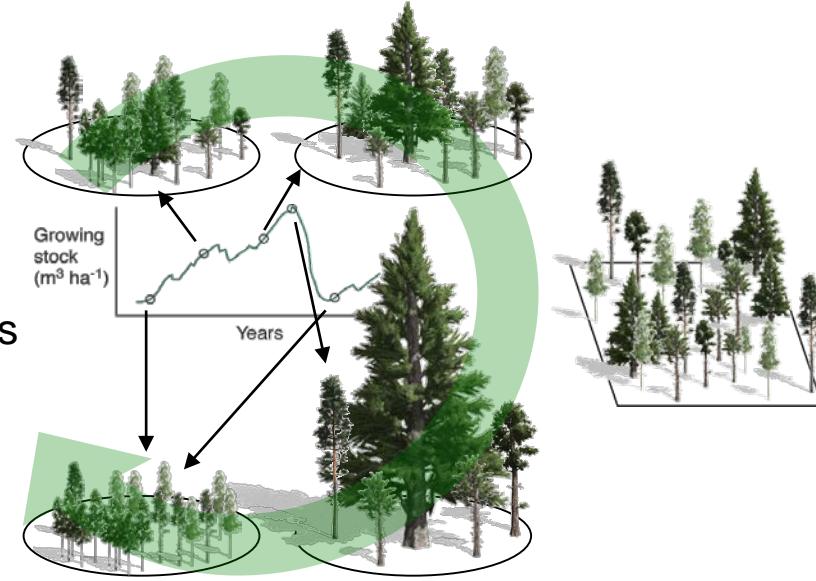
= FORest Community Ecology and Ecosystem ProcesseS

= a classic gap model

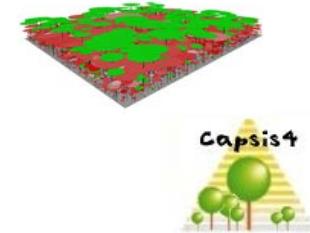
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- Cyclical successions on small patches of land
- Quantitative description of tree population dynamics
 - Establishment / Growth / Mortality*
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Morin et al.

http://capsis.cirad.fr/capsis/help_en/forceeps



Competition for light with 2D crowns (since 2019)

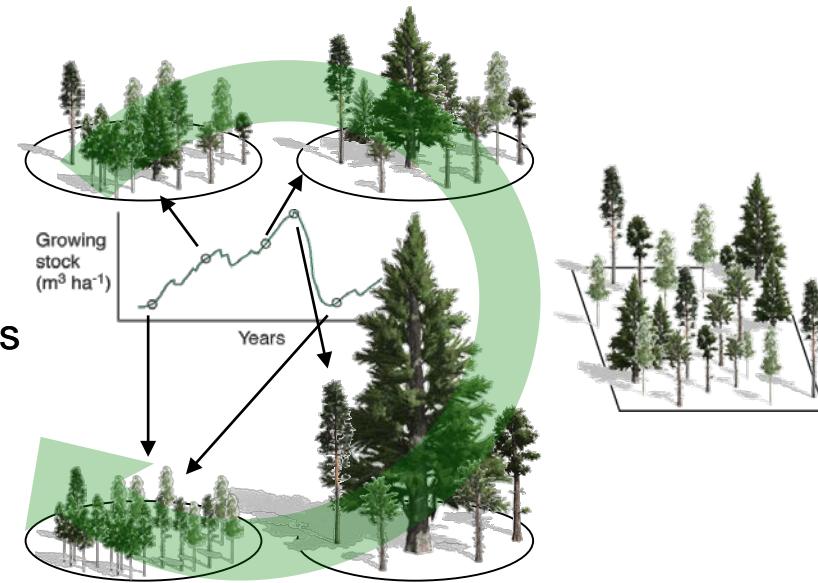


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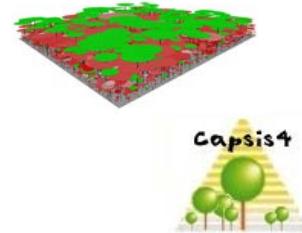
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BUT: Gap models are usually not *a priori* constrained in terms of number of trees

- Switching off recruitment = plantation
- But what about long term-dynamics?

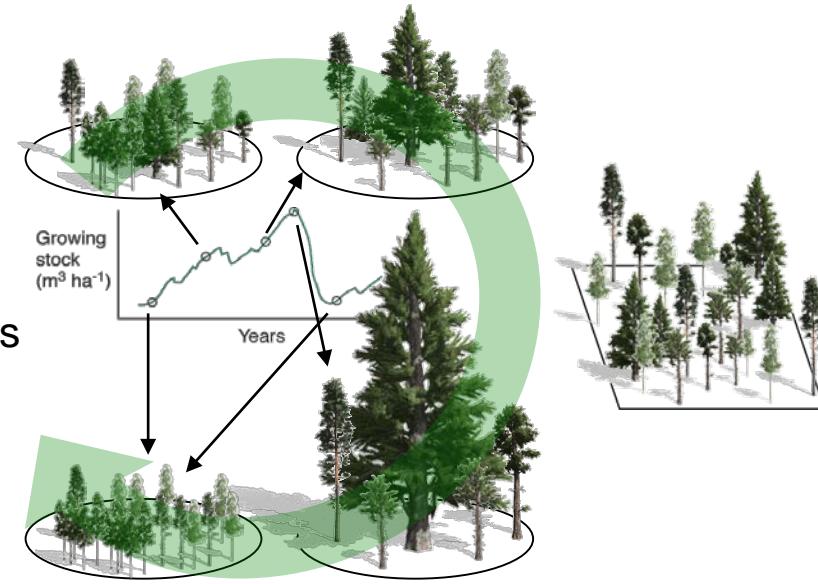


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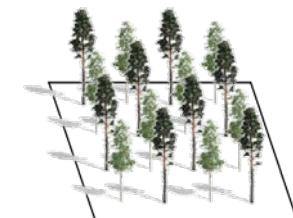
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BUT: Gap models are usually not *a priori* constrained in terms of number of trees

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- But what about long term-dynamics?

- In ForCEEPS, patch occupancy can be controlled



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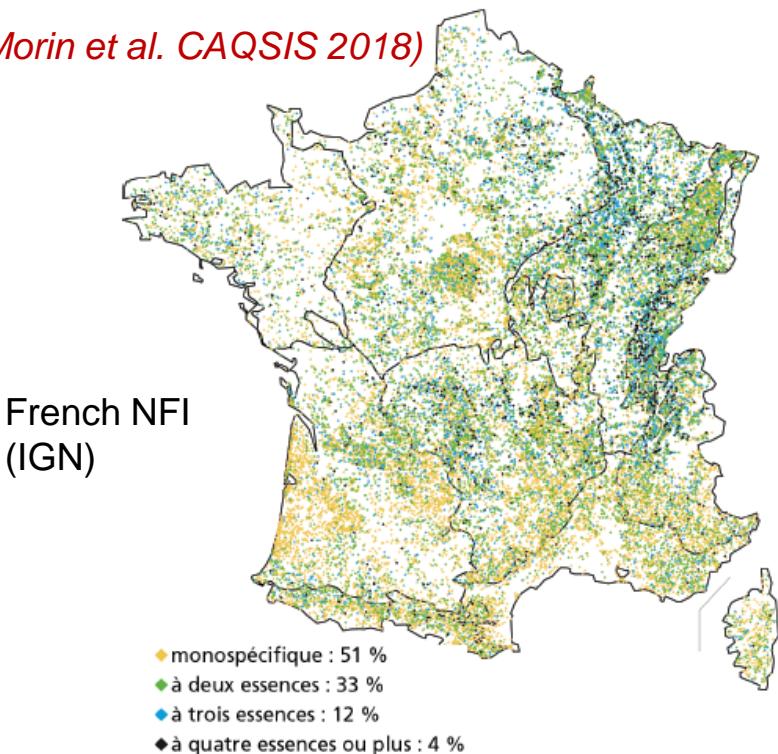
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Can ForCEEPS simulate forest productivity with enough accuracy? *(and not « only » biomass...)*

Calibration

(Morin et al. CAQSI 2018)



French NFI
(IGN)

Individual tree data
for many species & for a wide range of cond.



**Calibrating optimal tree growth
for most tree species in FR
+ literature data**

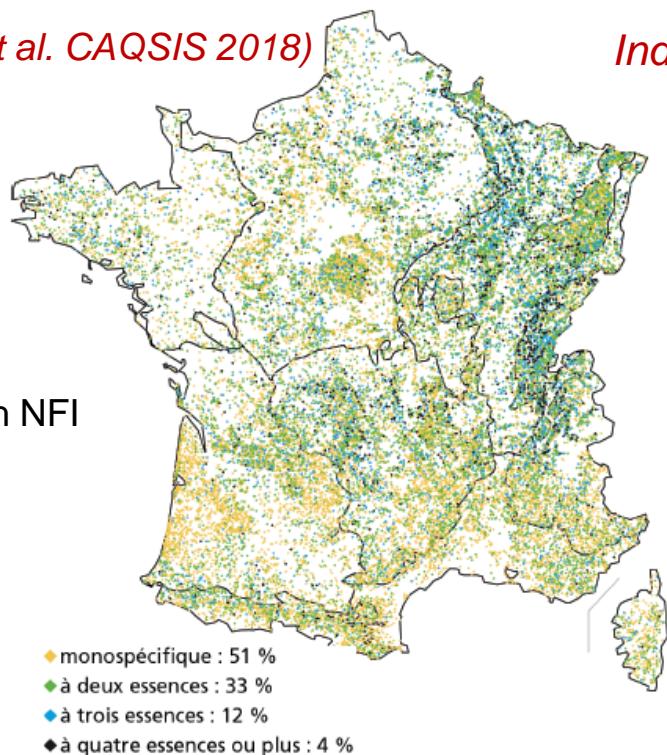
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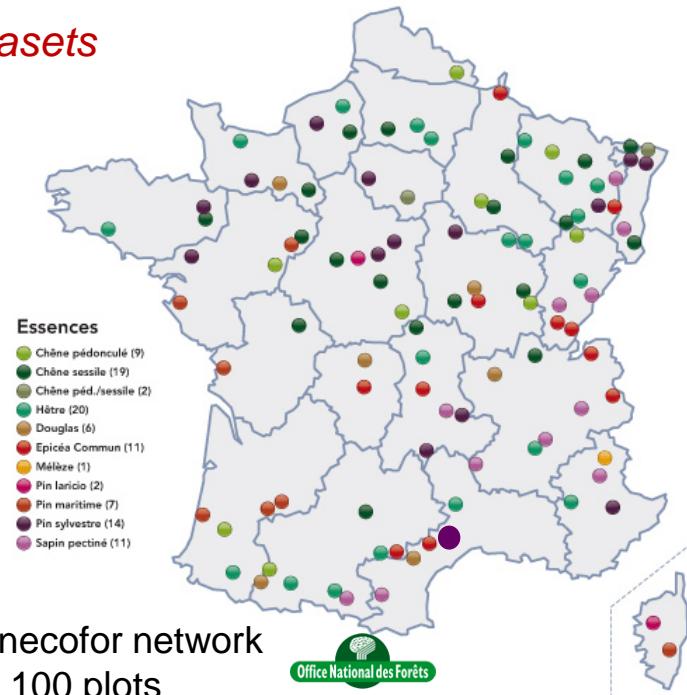
Individual tree data
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Validation

Independent datasets



Long-term data of productivity (diameter incr.)
at both tree level & stand level



Validating stand productivity
for 8 species

Can ForCEEPS simulate forest productivity with enough accuracy?

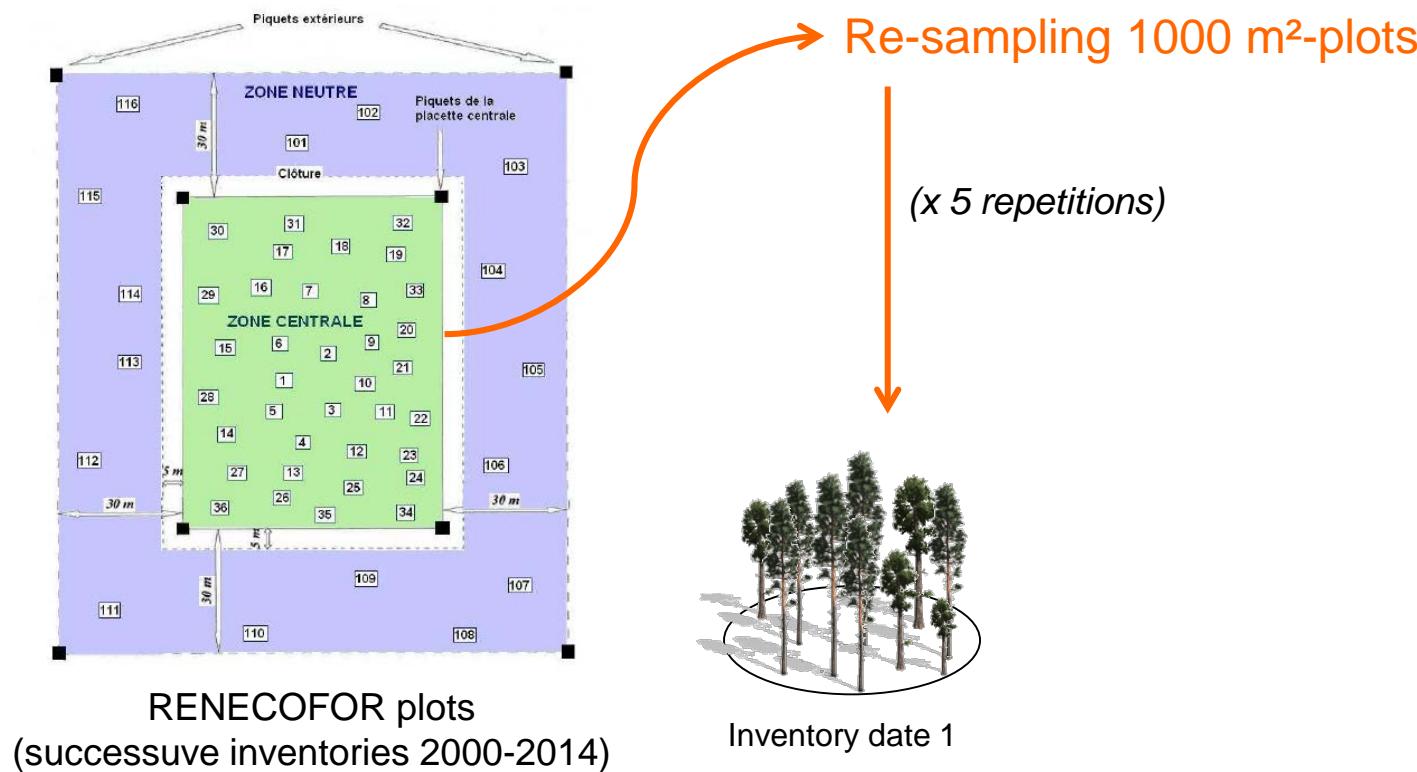
RENECOFOR = mostly monospecific stands  *Emerging properties in mixed stands(?)*

Validation on stand basal area and its increment

Can ForCEEPS simulate forest productivity with enough accuracy?

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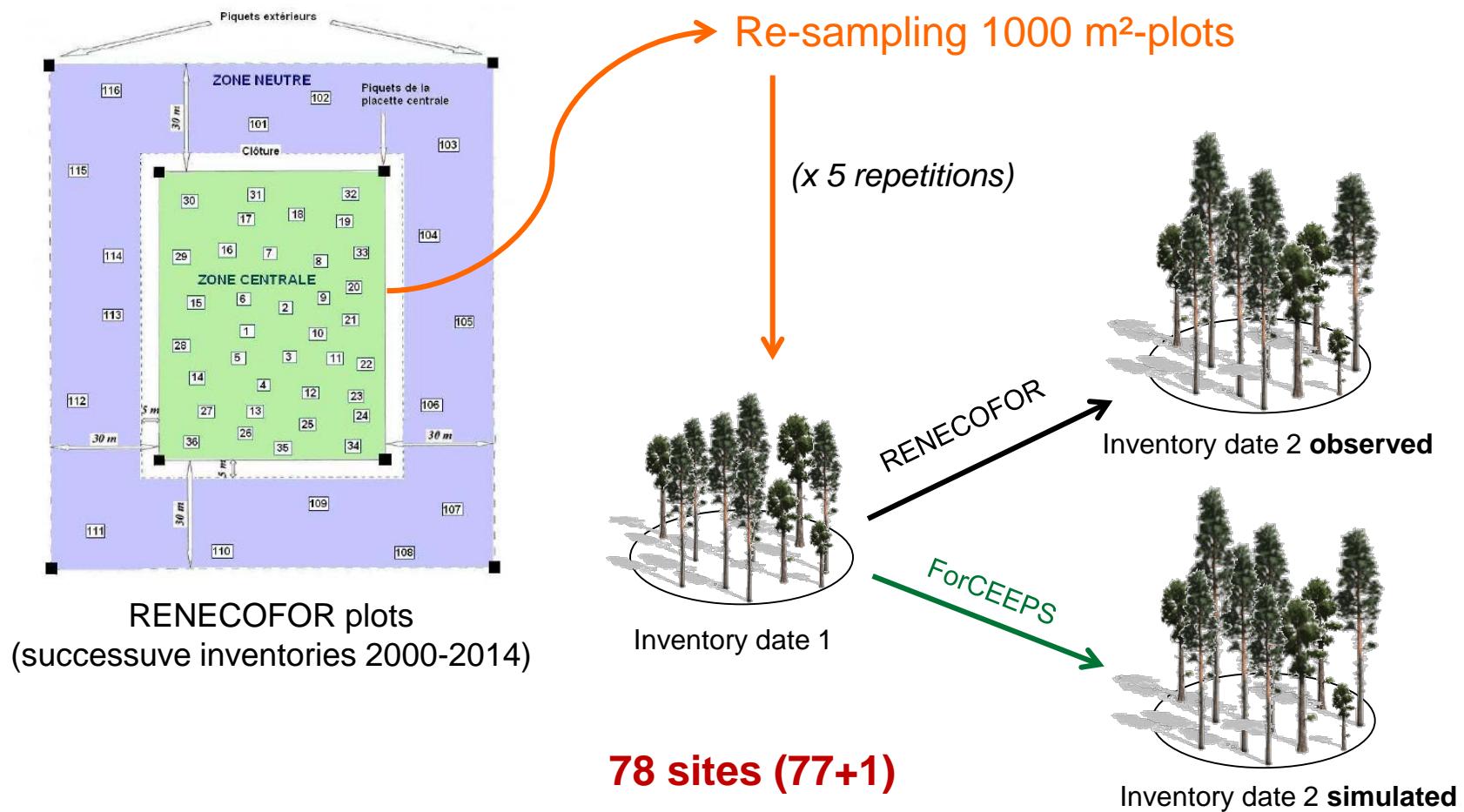
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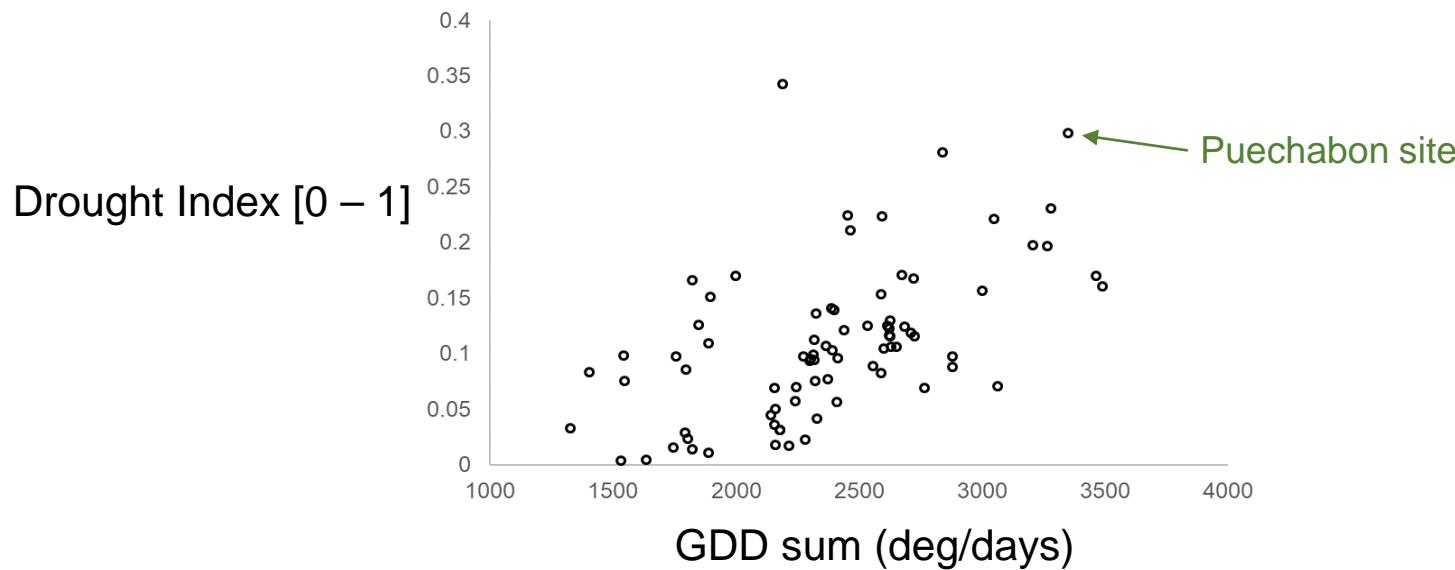
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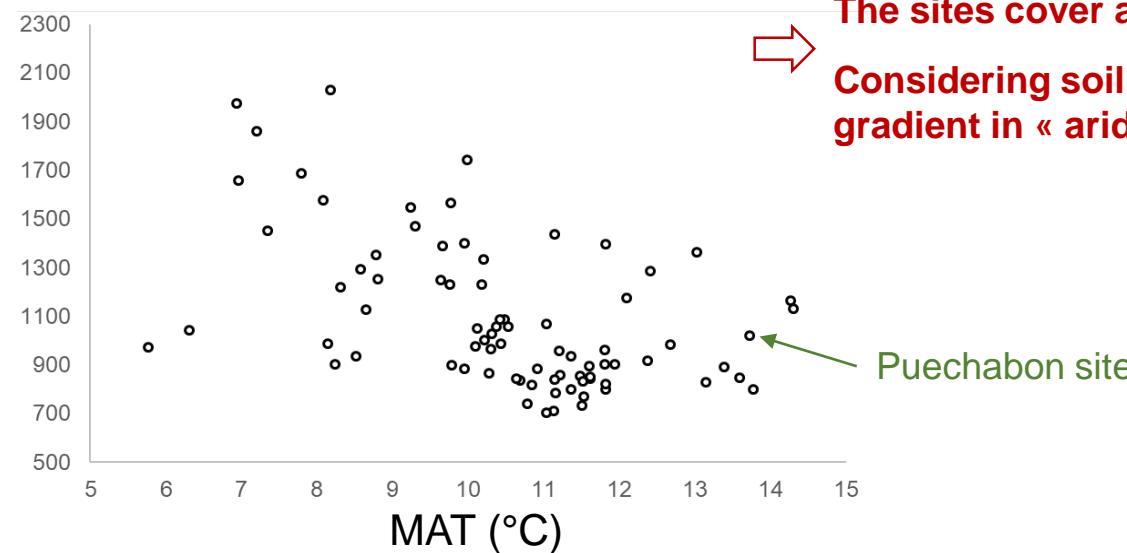
Range of climatic conditions covered by the sites for validation



Annual Precipitation Sum (mm)

The sites cover a large climatic range

Considering soil characteristics, the gradient in « aridity » is relatively large



Results

Final basal area per tree (m²)

Results

Final basal area per tree (m^2)

$r^2 = 0,98$

Coef. = 1.001

Spearman = 0.78 ***

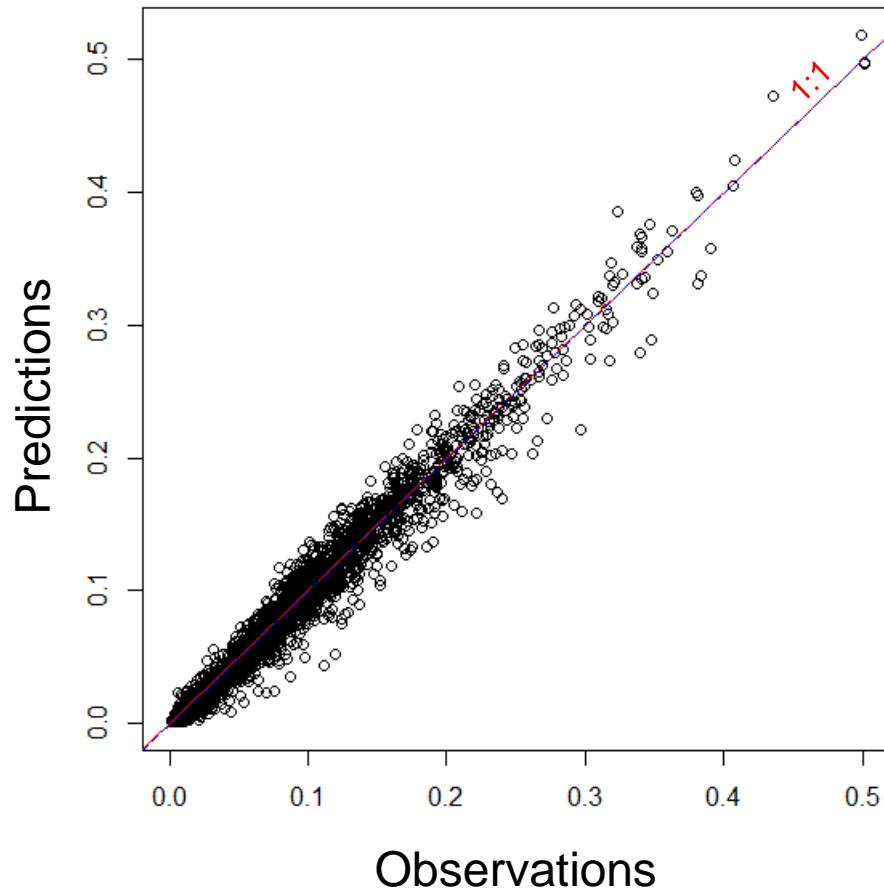
Rmse = 11.1

$N_{\text{plots}} = 78$

$N_{\text{trees}} = 3585$



Weak test !



Results

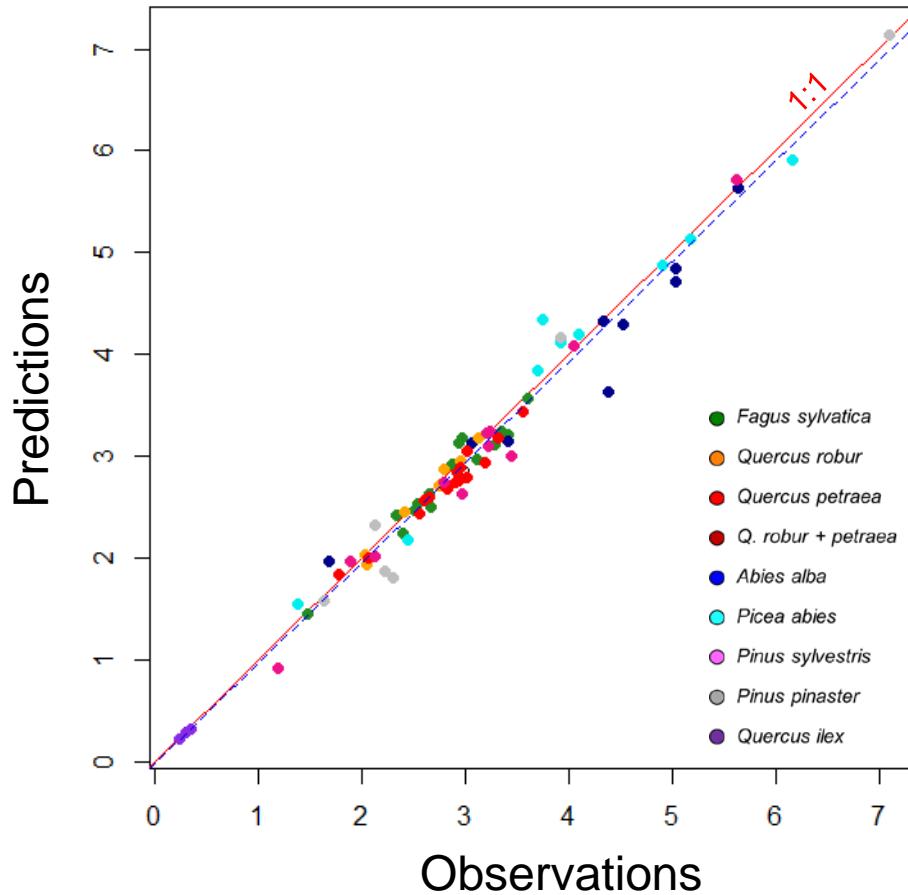
$r^2 = 0,98$
Coef. = 0.99
Spearman = 0.98 ***
Rmse = 24.6

$N_{plots} = 78$
 $N_{trees} = 3585$



Weak test !

Final basal area per plot (m^2)



Results

Mean annual productivity (BAI) per tree (m^2)

$r^2 = 0,57$

Coef. = 0.78

Spearman = 0.78 ***

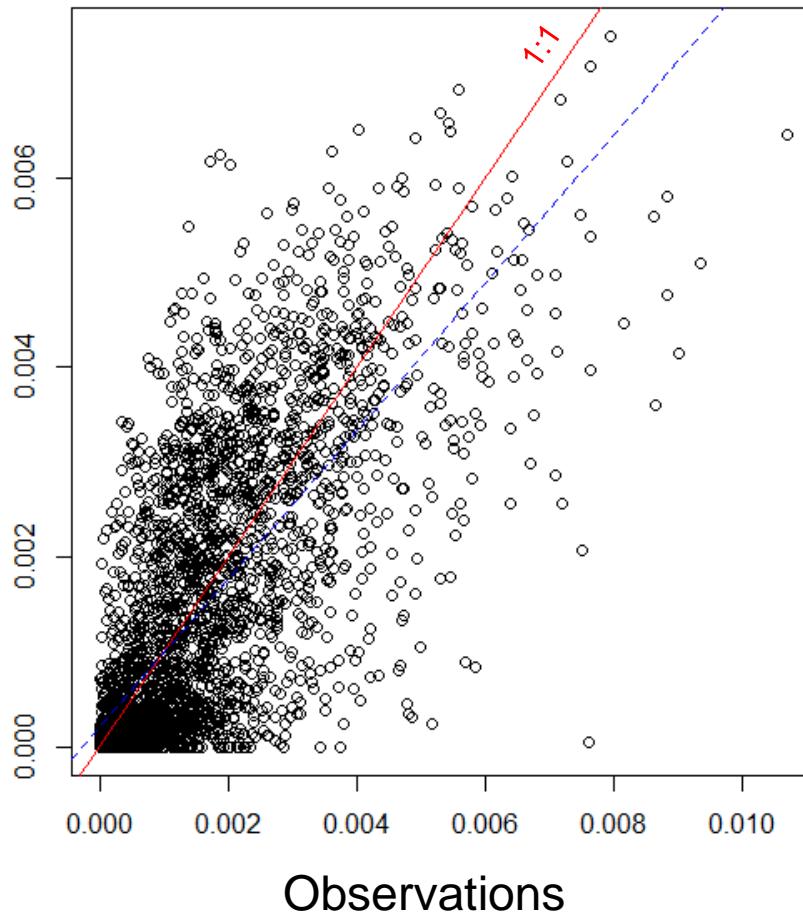
rmse = 2.46

$N_{\text{plots}} = 78$

$N_{\text{trees}} = 3585$

= stronger test

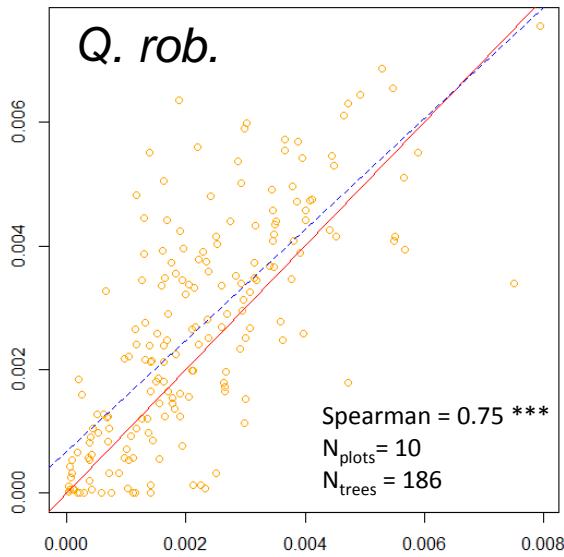
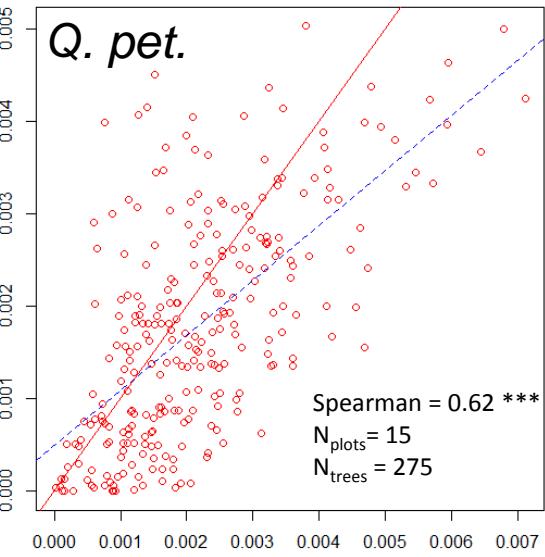
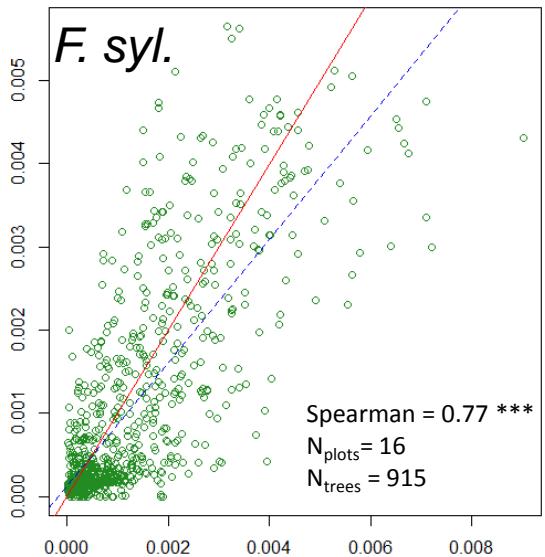
Predictions



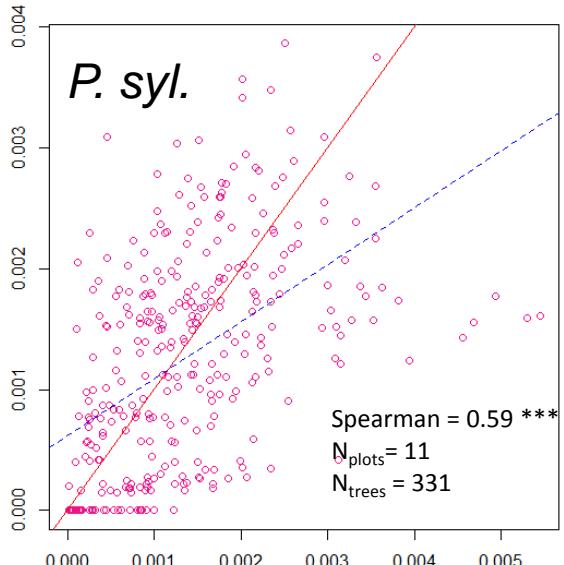
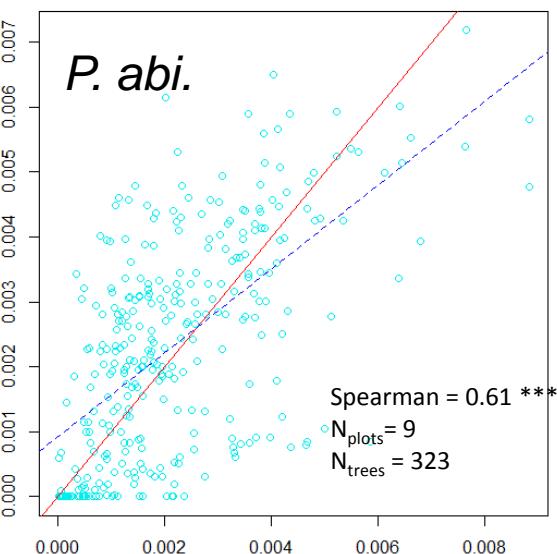
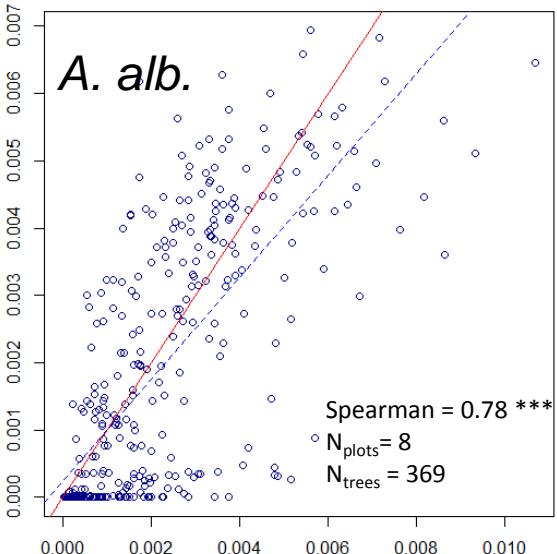
Validating the ForCEEPS model for French forests

Mean annual productivity (BAI) per tree (m^2)

Per species

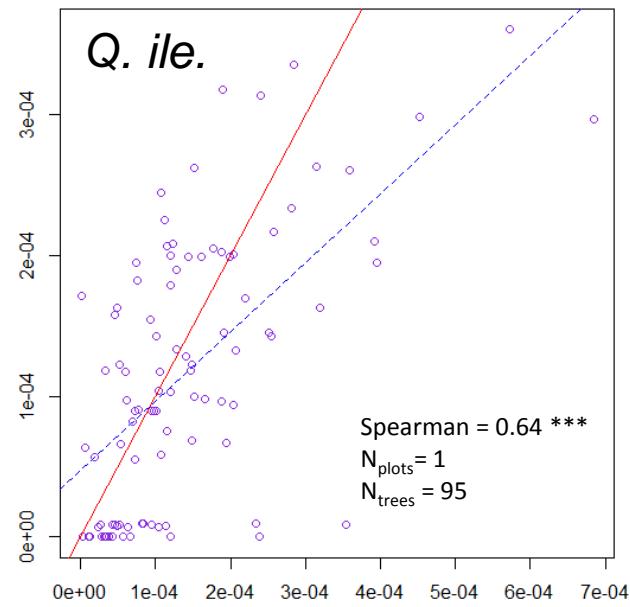
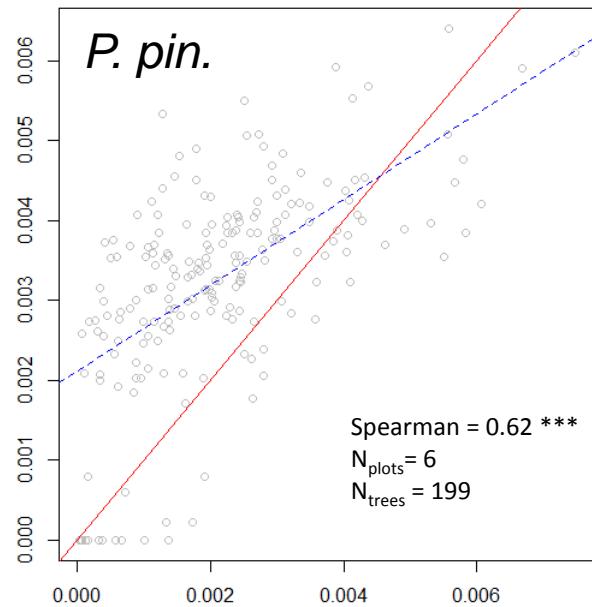


(Spearman correlation)



Mean annual productivity (BAI) per tree (m^2)

Per species



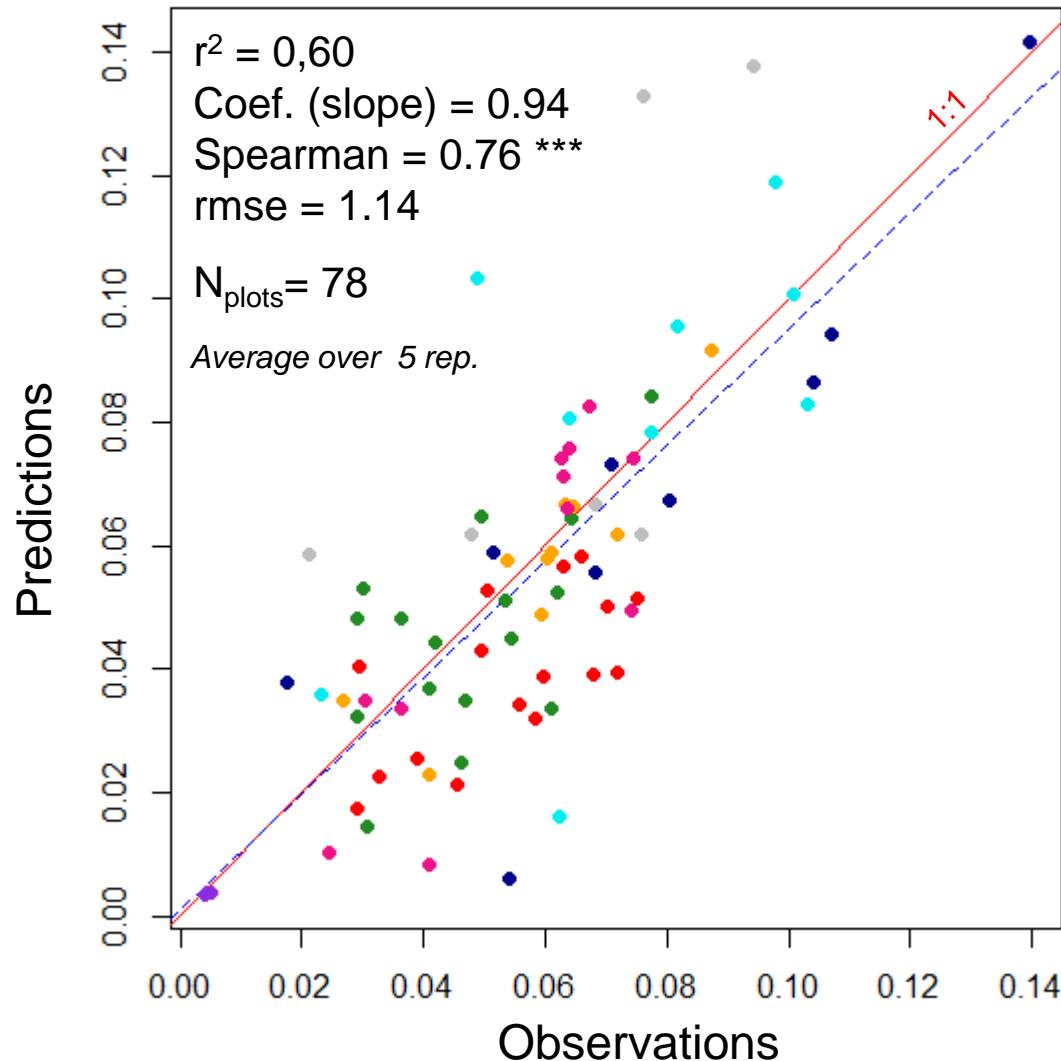
➡ Predictions at the tree level seem « good enough » on average
Tendency to underestimate the largest growths

Results

Mean annual productivity (BAI) per stand (m^2)

- *Fagus sylvatica*
- *Quercus robur*
- *Quercus petraea*
- *Q. robur + petraea*
- *Abies alba*
- *Picea abies*
- *Pinus sylvestris*
- *Pinus pinaster*
- *Quercus ilex*

- = stronger test

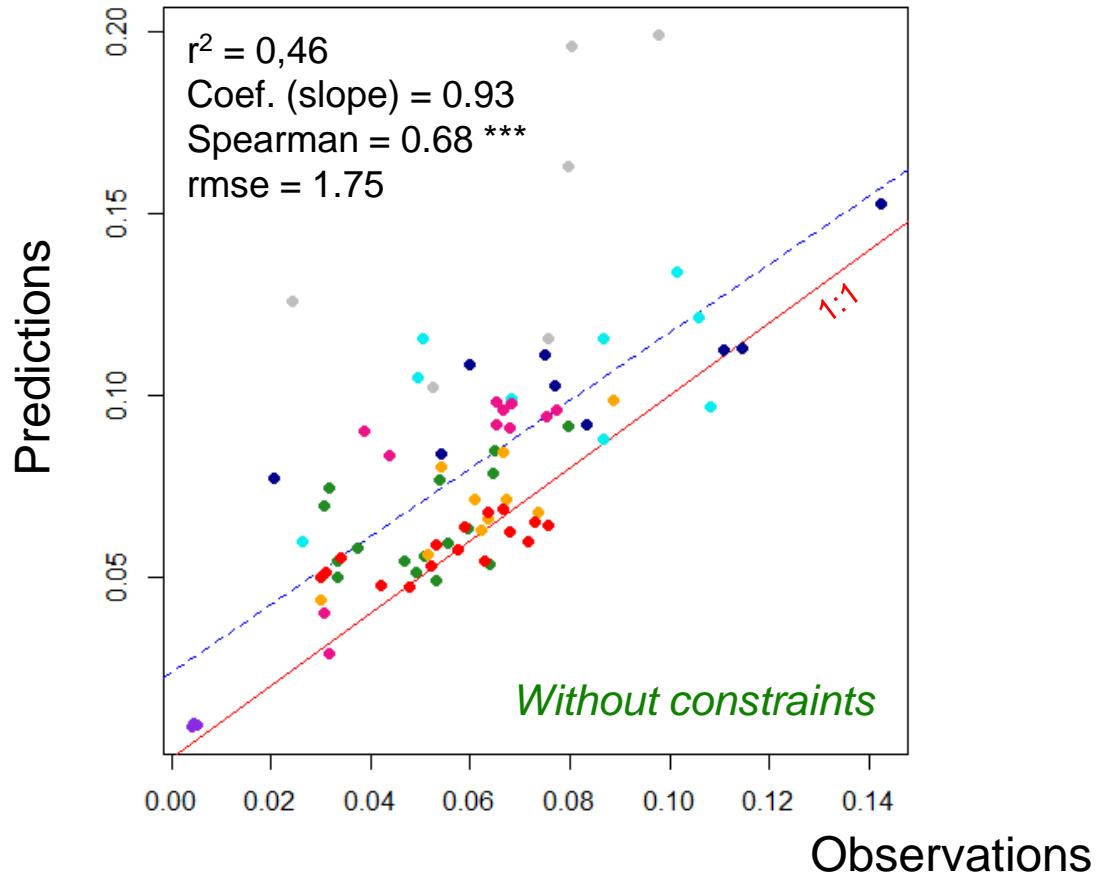


Ccl: the explained variance appears « satisfactory » (when compared to what other kinds of models may predict, eg. ecophysiological models)

Results

Testing the model's ability **to represent the climatic constraints on growth**
= same simulations than before, but with « non-stressful climate »

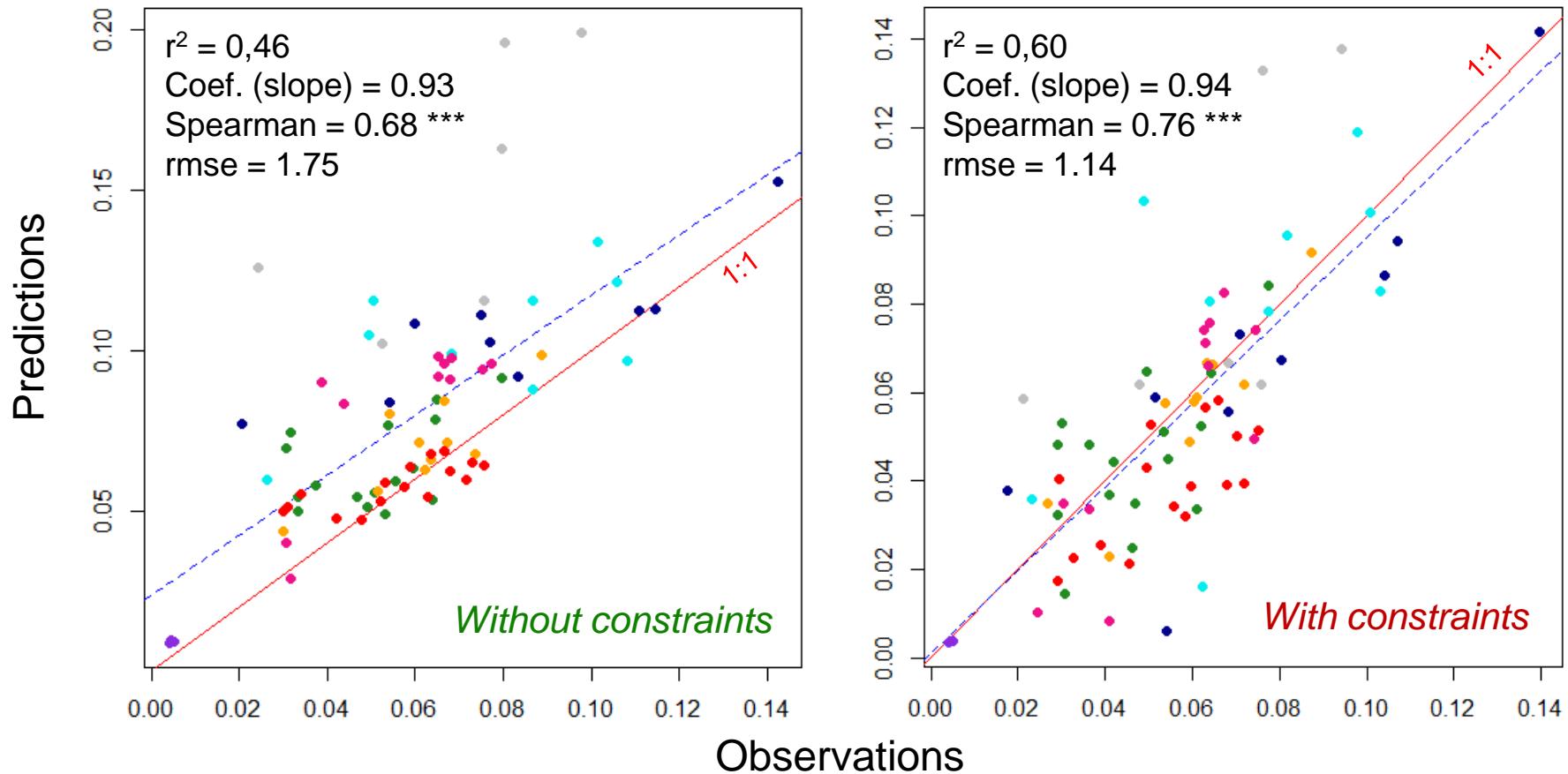
Mean annual productivity (BAI) per stand (m^2)



Results

Testing the model's ability **to represent the climatic constraints on growth**
= same simulations than before, but with « non-stressful climate »

Mean annual productivity (BAI) per stand (m^2)



- Ccl: - The version *with* constraints is significantly « better » (=> difference in RMSE)
 - However the difference is not large, probably because the plots have **not** been selected
in extreme conditions for each species

Questions

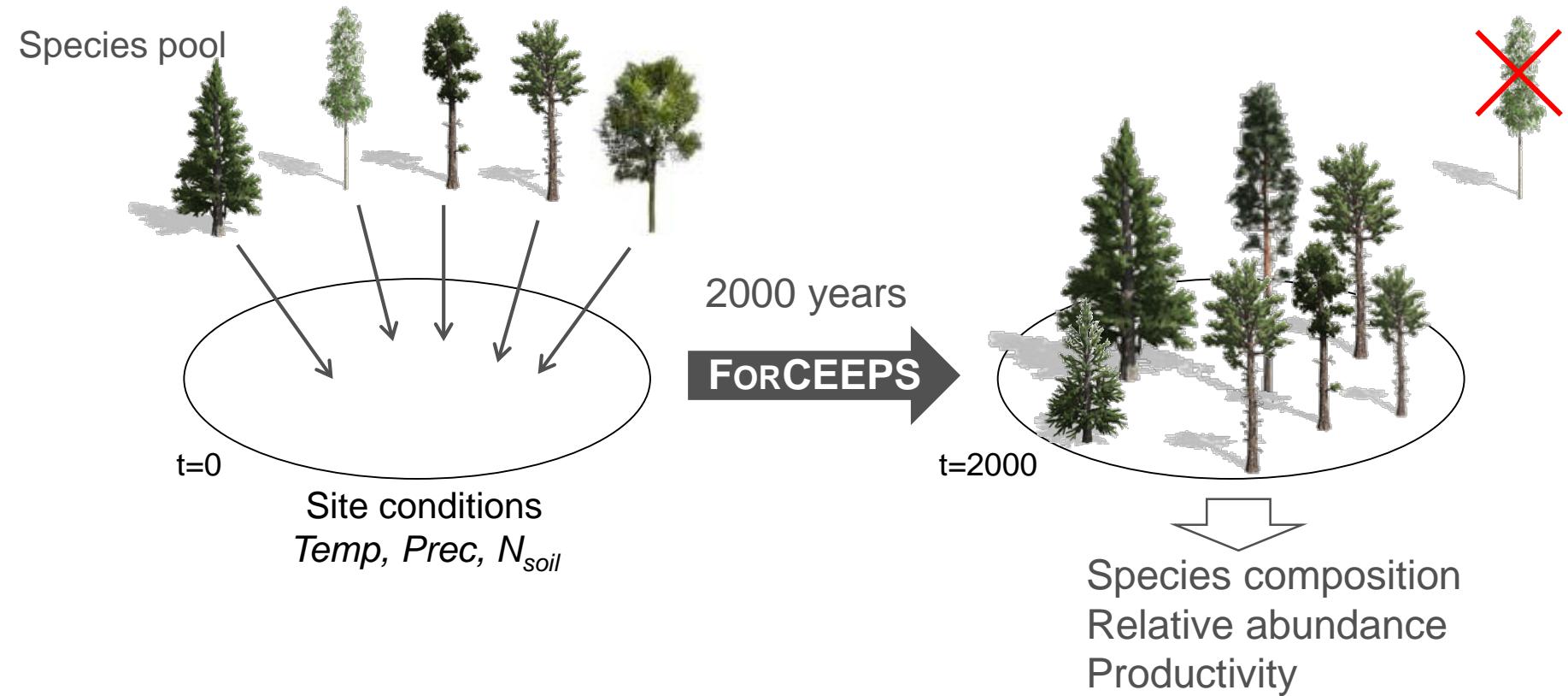
- Using the same modelling approach used to test BEF in forests, can we confirm and quantify this « more trees hypothesis » ?
- What is its importance on ecosystem functioning?

To do list

- 0- Developing the model ForCEEPS to allow testing the « more trees hypothesis »
- 1- Calibrating the model for French forests
- 2- Simulating BEF-relationships

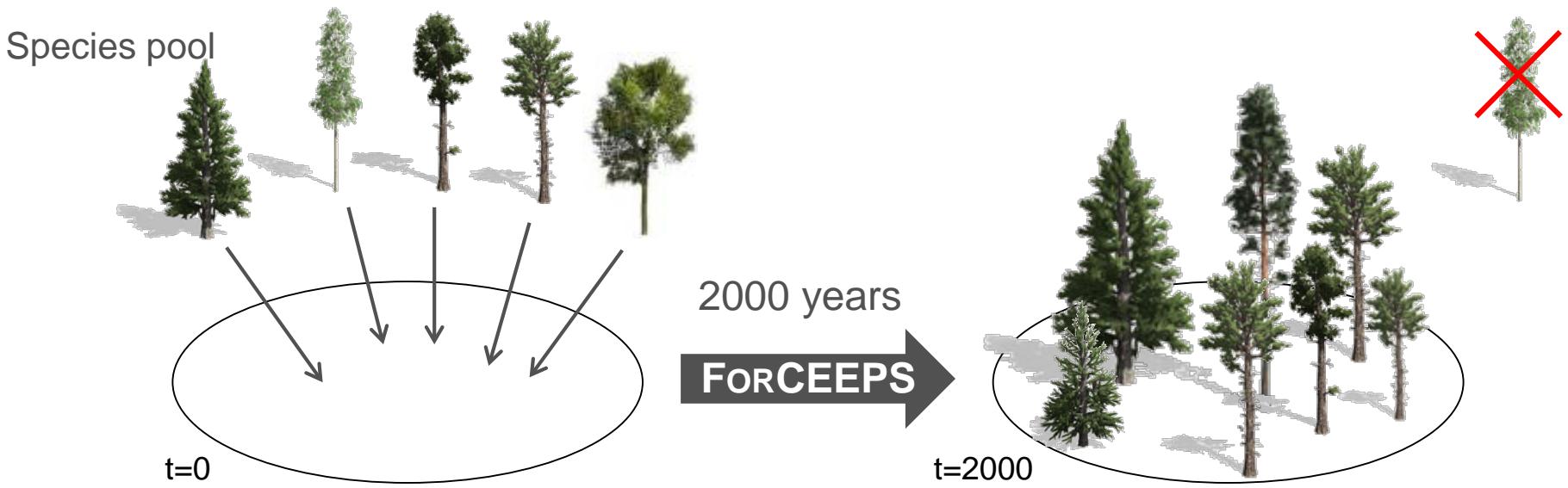
Simulating diversity-productivity relationships in forests

Gap model ForCEEPS = Forest dynamics + climate

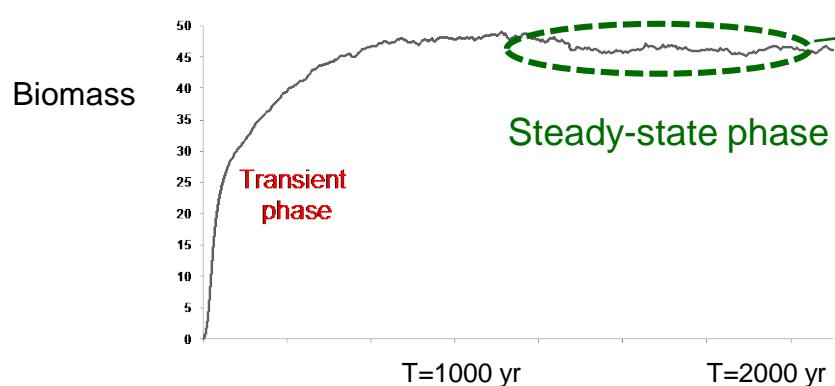


Simulating diversity-productivity relationships in forests

Gap model ForCEEPS = Forest dynamics + climate

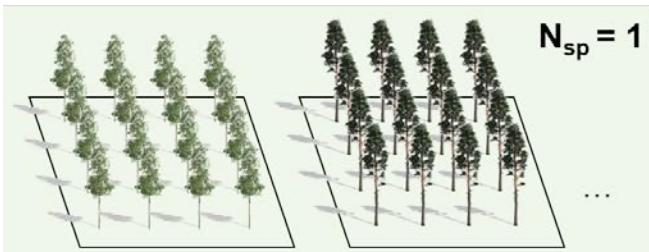


Species composition
Relative abundance
Productivity

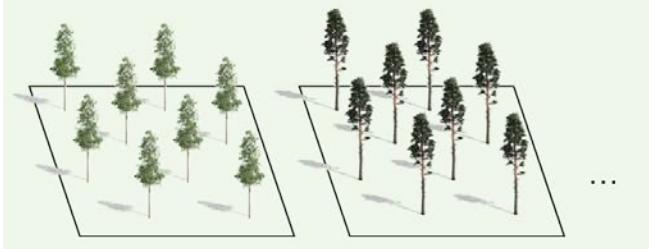


Simulation design

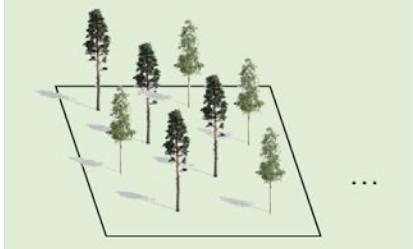
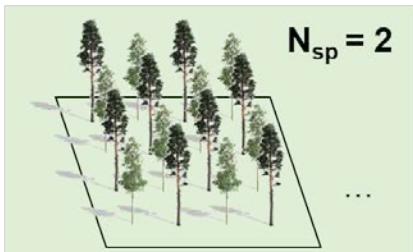
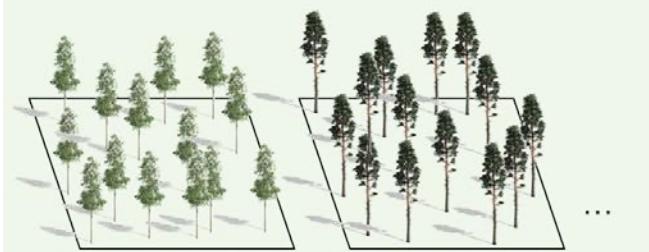
Density
 2500 trs.ha^{-1}



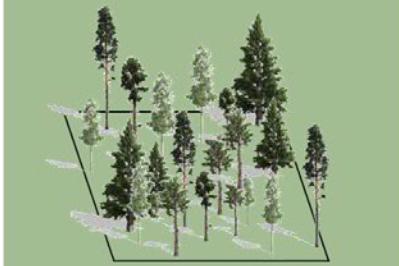
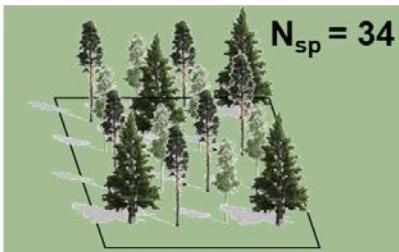
Density
 625 trs.ha^{-1}



No constraint

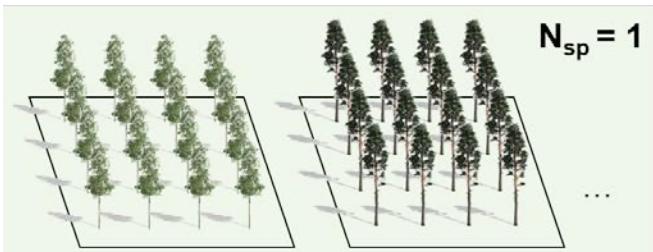


$N_{sp} = X$

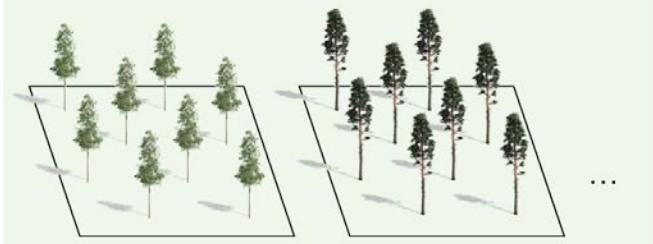


Simulation design

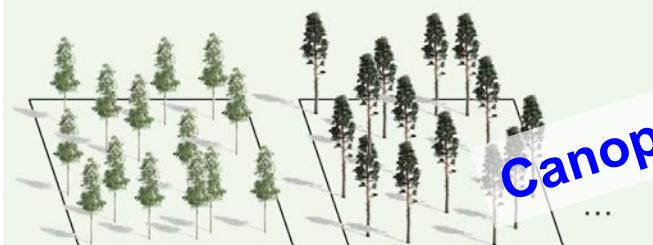
Density
 2500 trs.ha^{-1}



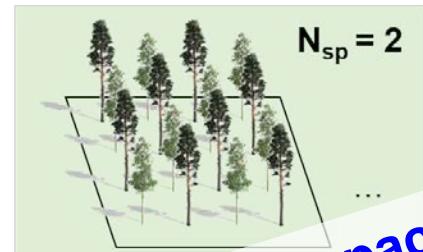
Density
 625 trs.ha^{-1}



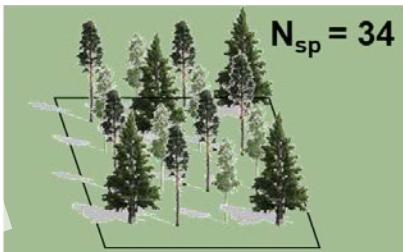
No constraint



Only canopy packing...



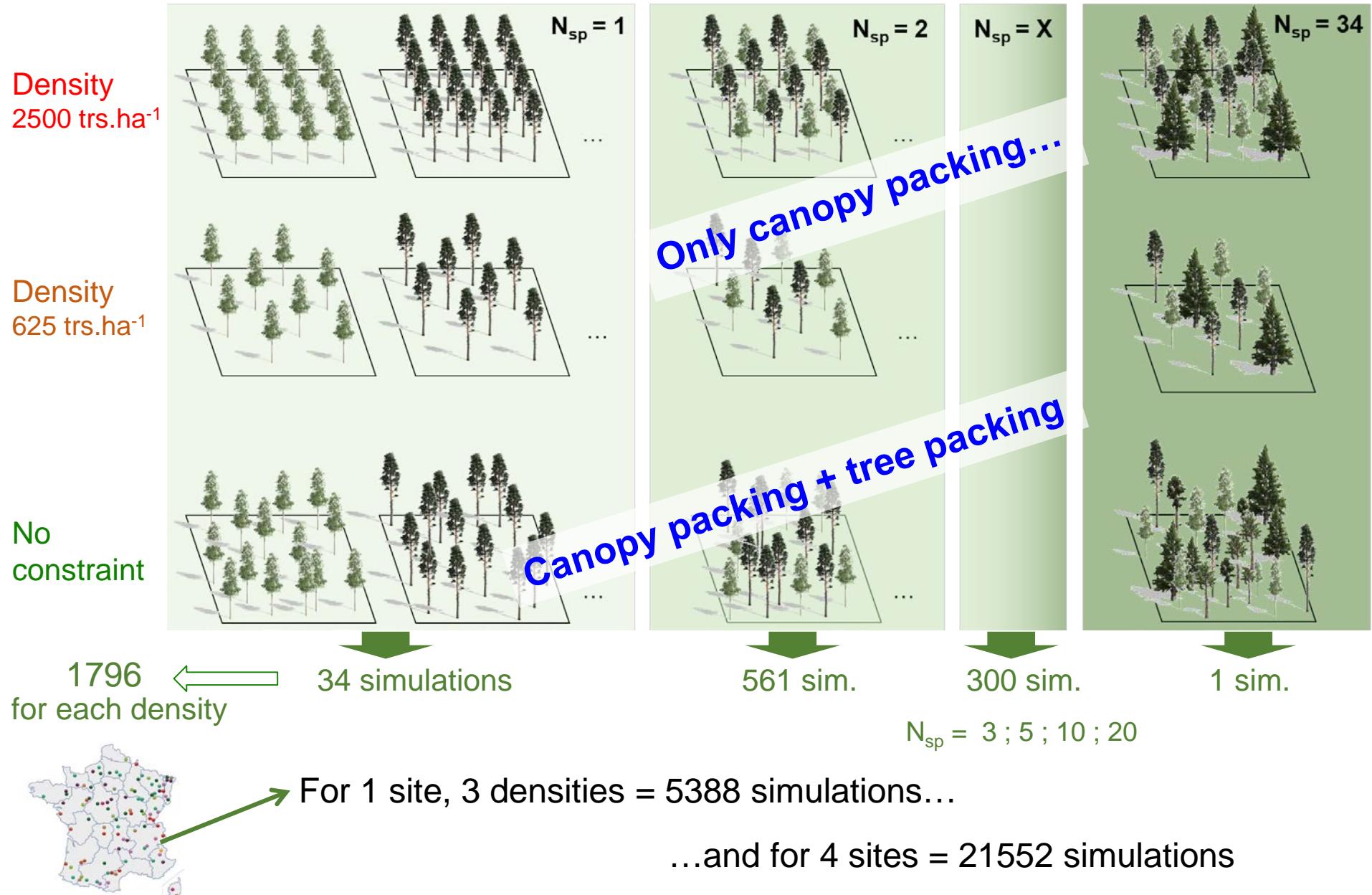
$N_{sp} = X$



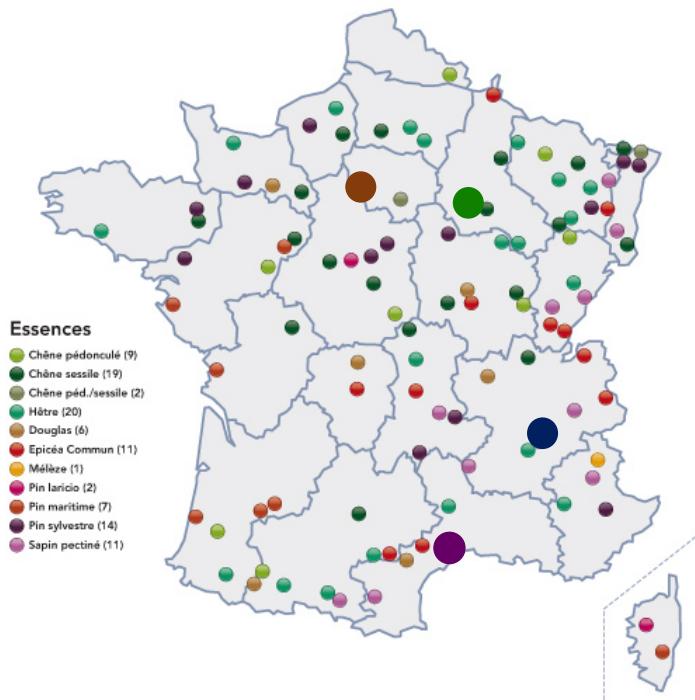
Canopy packing + tree packing



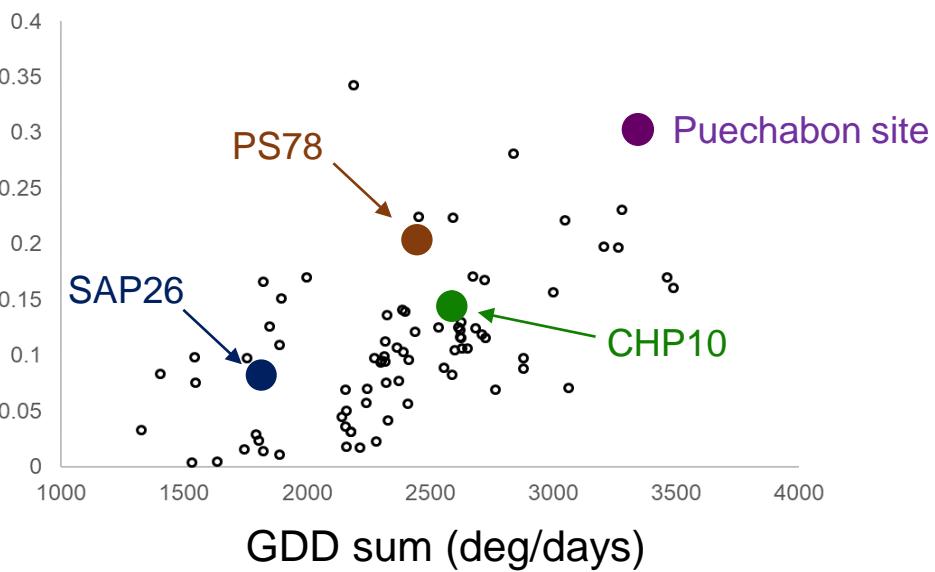
Simulation design



What sites?



Drought Index [0 – 1]



= Simulation in 4 sites with contrasted environmental conditions

VERY PRELIMINARY !!!

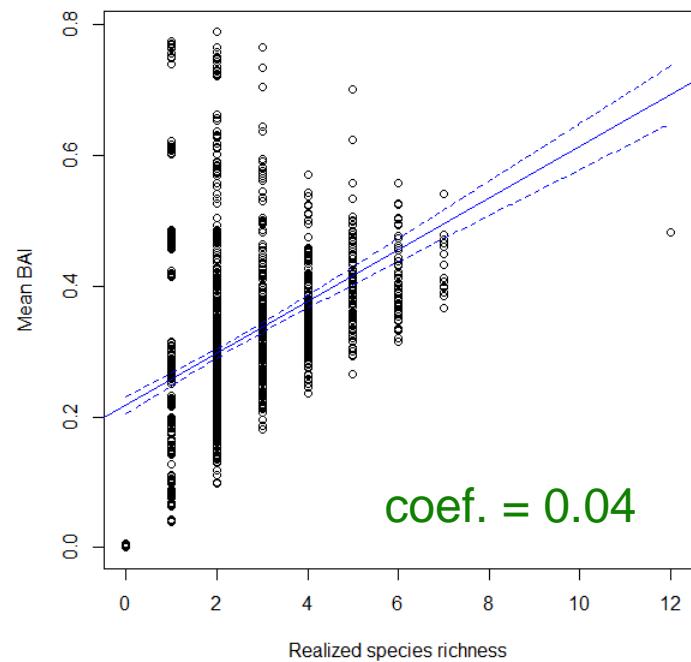
Results

Results

VERY PRELIMINARY !!!

CHP10

No constraint

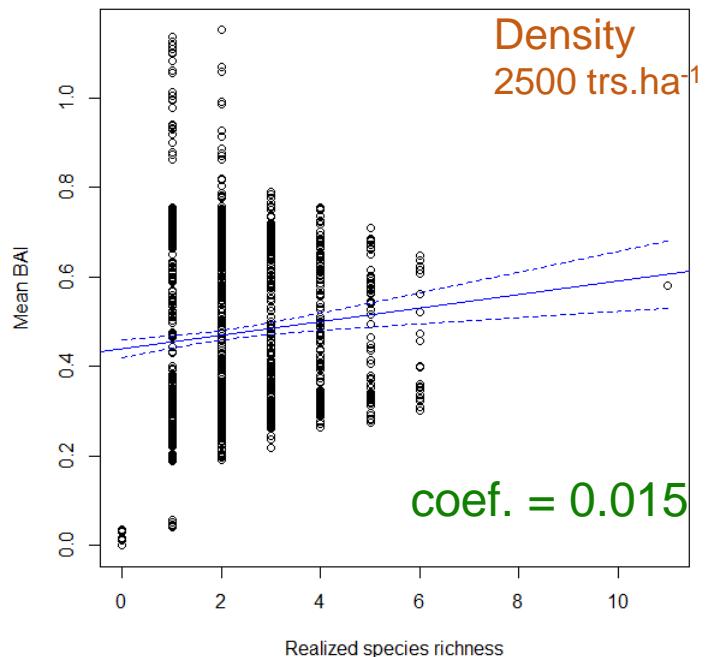
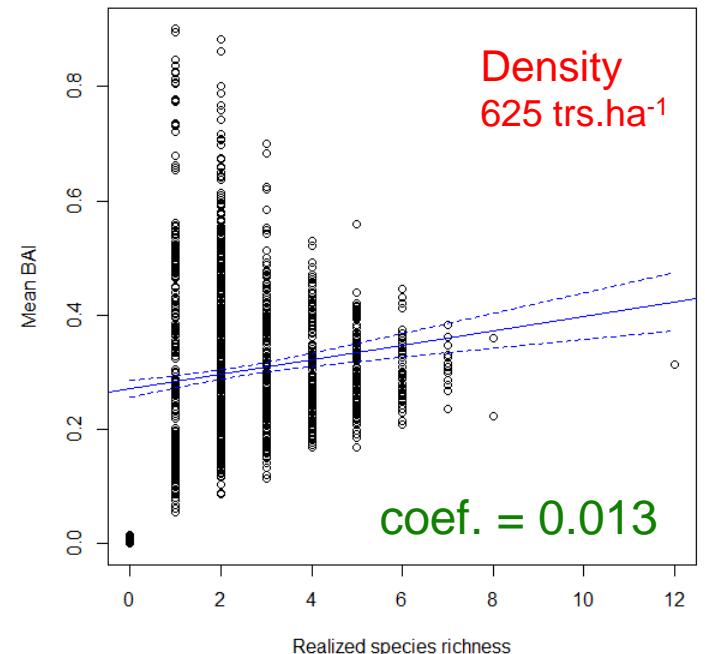
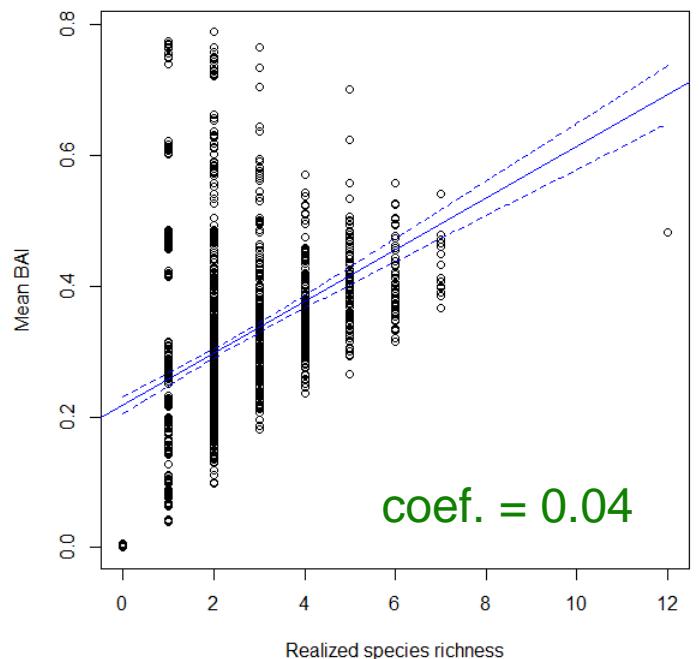


Results

VERY PRELIMINARY !!!

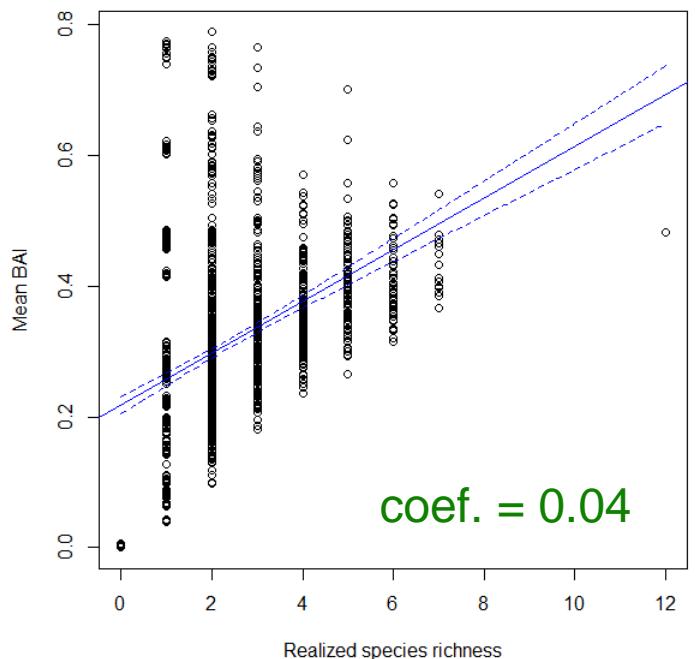
CHP10

No constraint



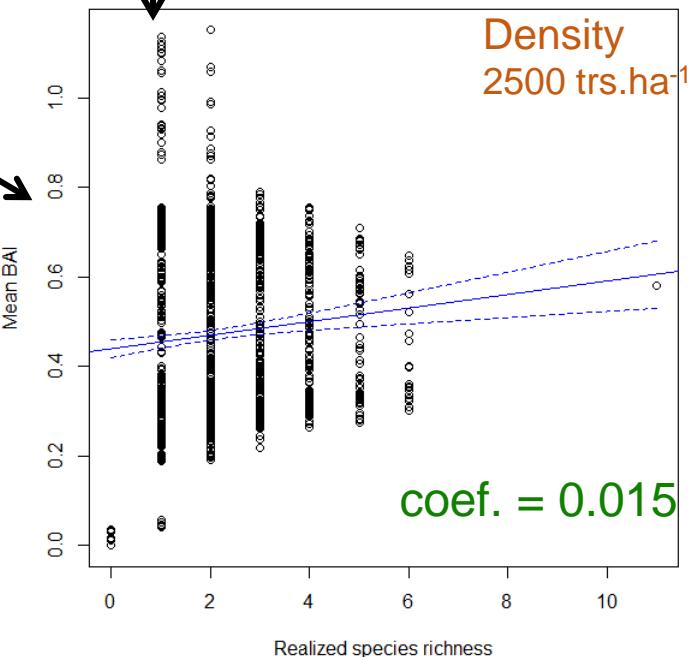
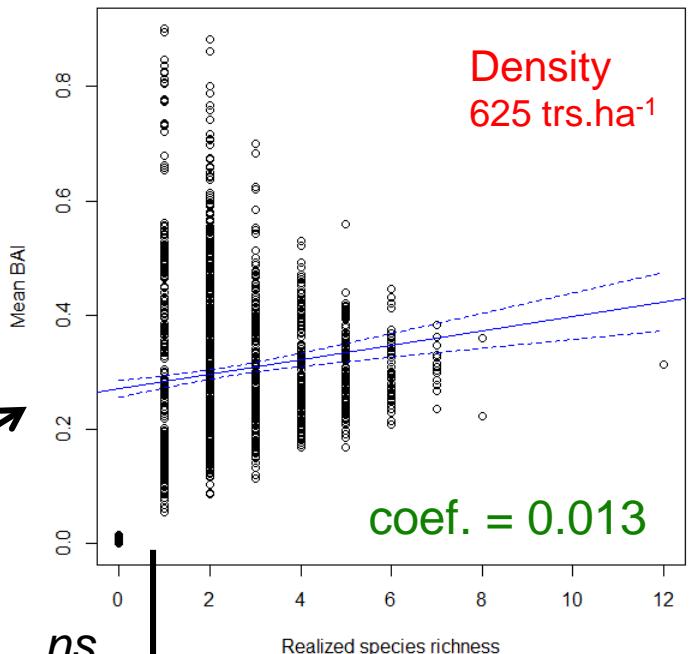
VERY PRELIMINARY !!!

Results

CHP10**No constraint**

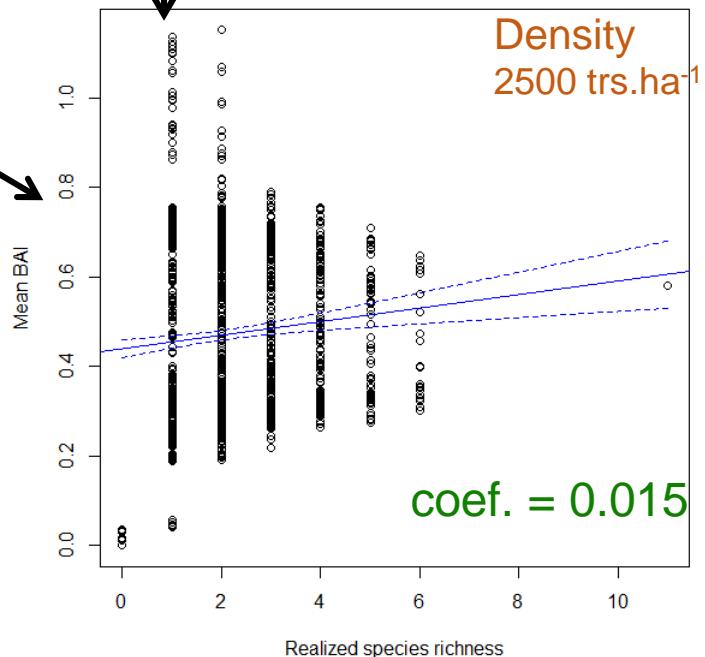
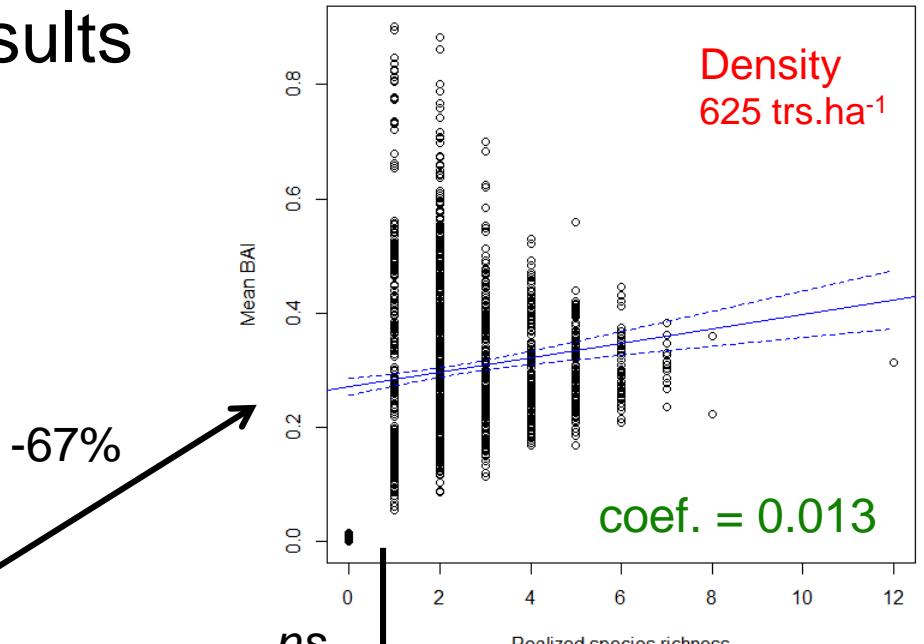
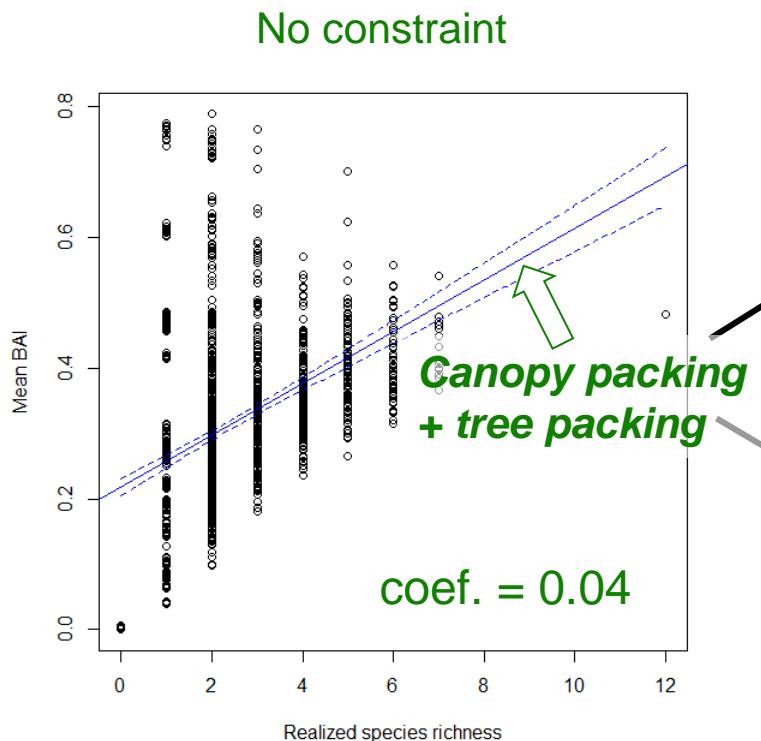
-67%

-63%

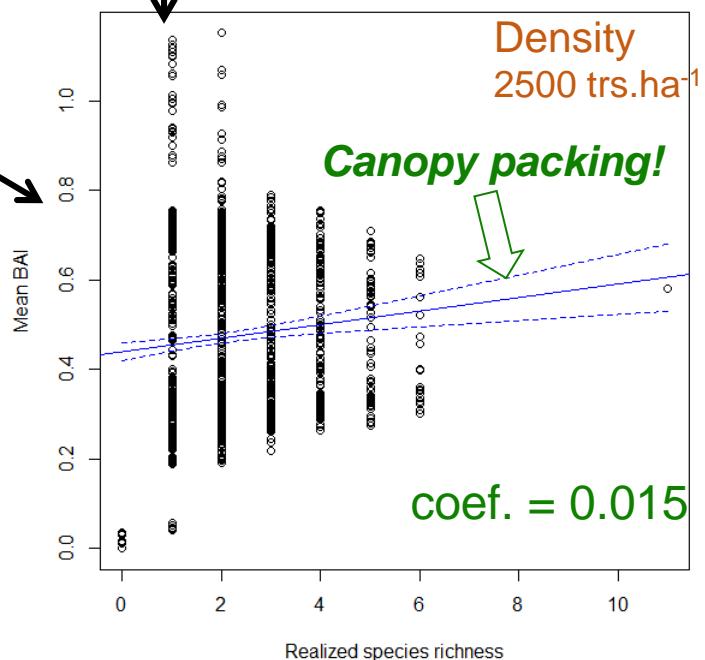
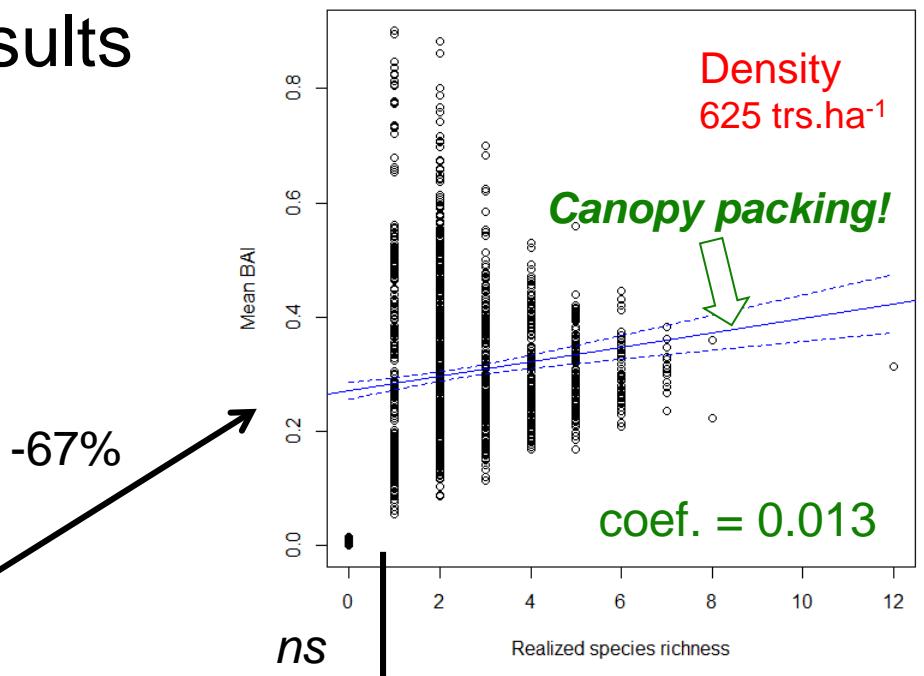
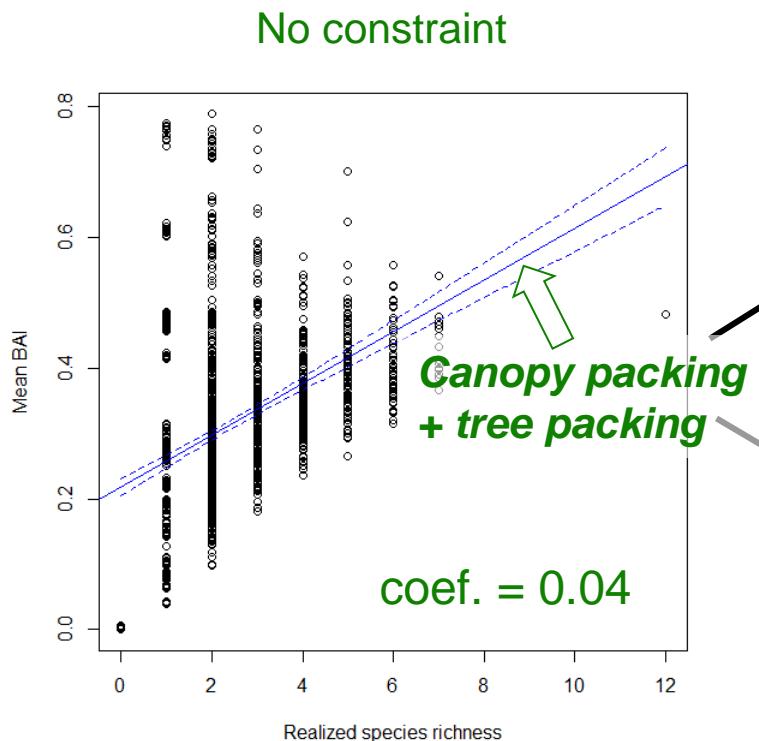


VERY PRELIMINARY !!!

Results

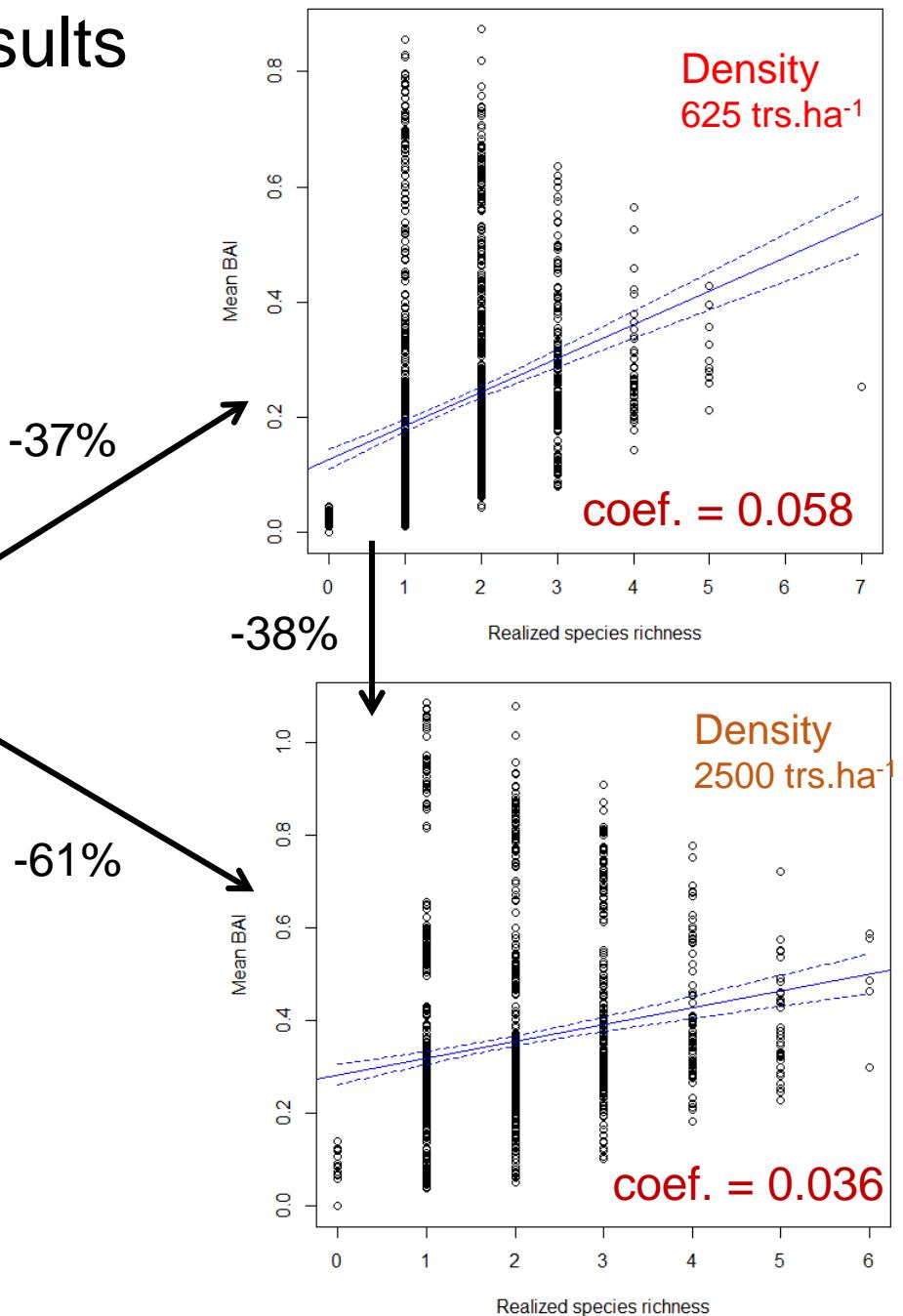
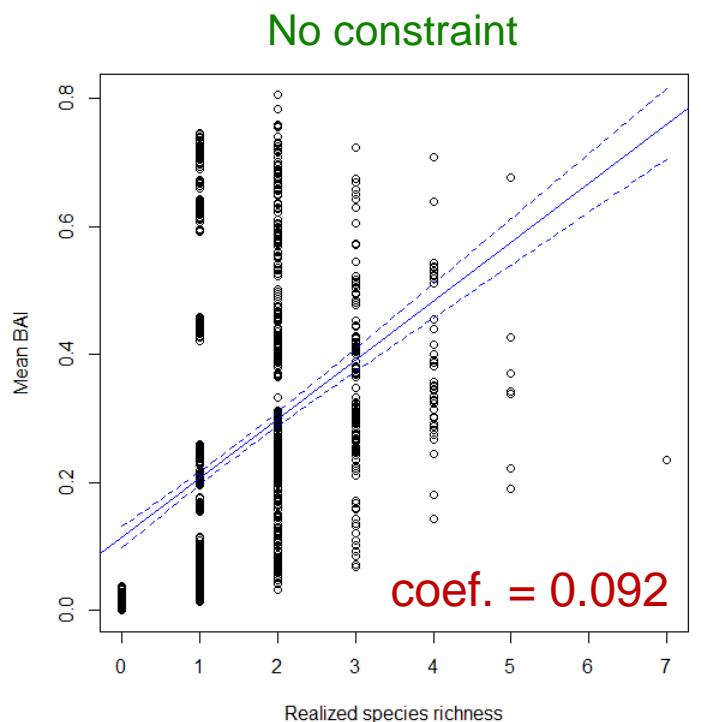
CHP10**-67%****-63%**

Results

VERY PRELIMINARY !!!**CHP10****-67%****-63%****ns**

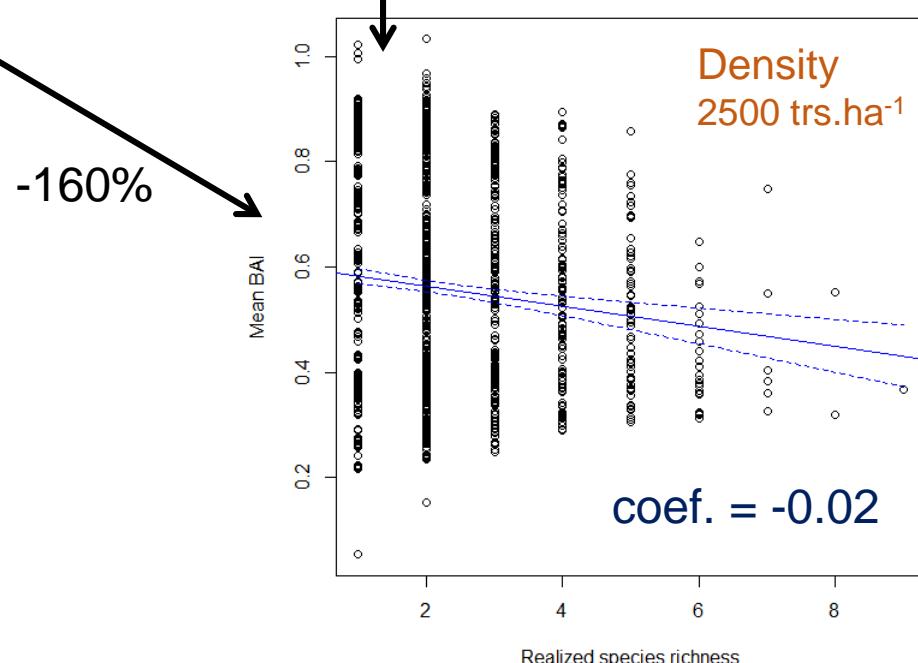
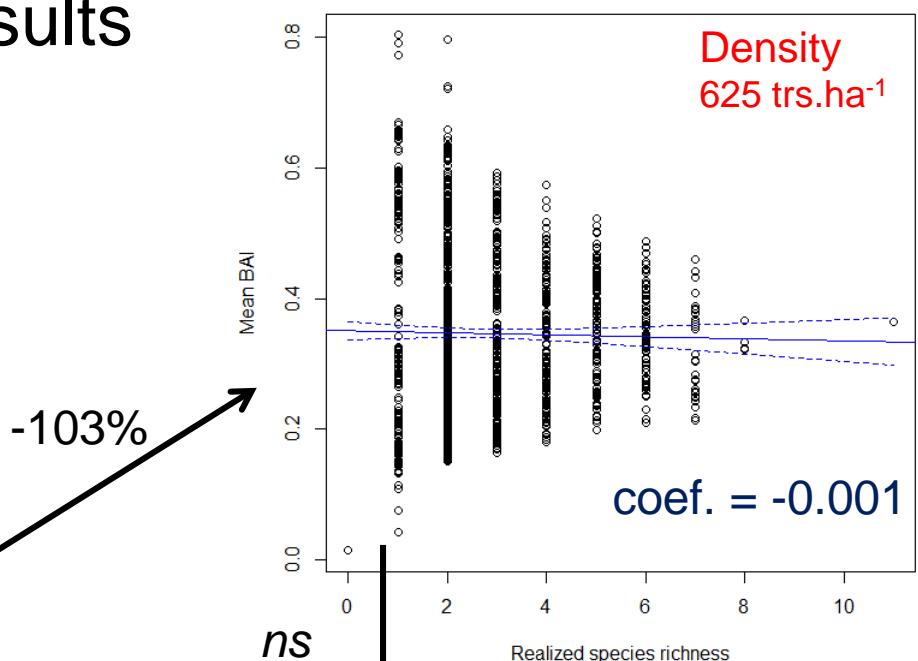
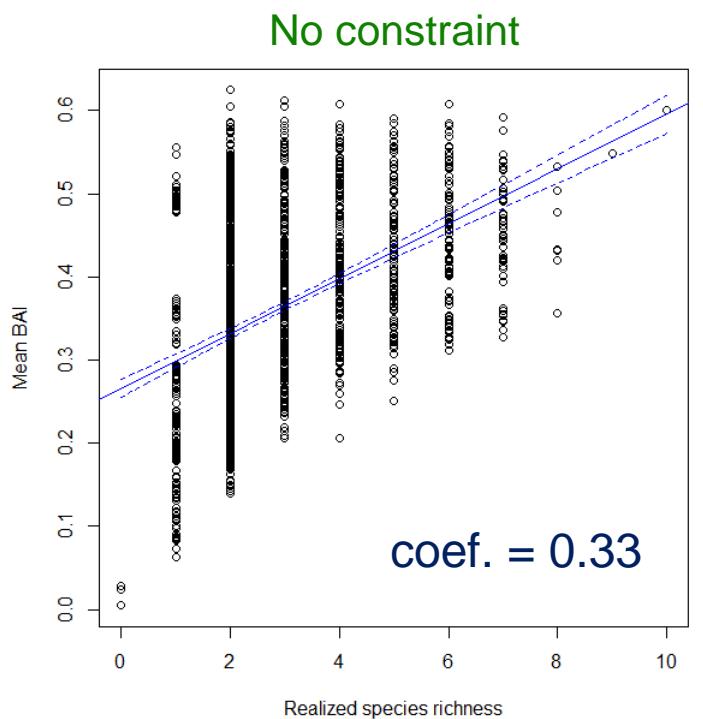
VERY PRELIMINARY !!!

Results

PS78

VERY PRELIMINARY !!!

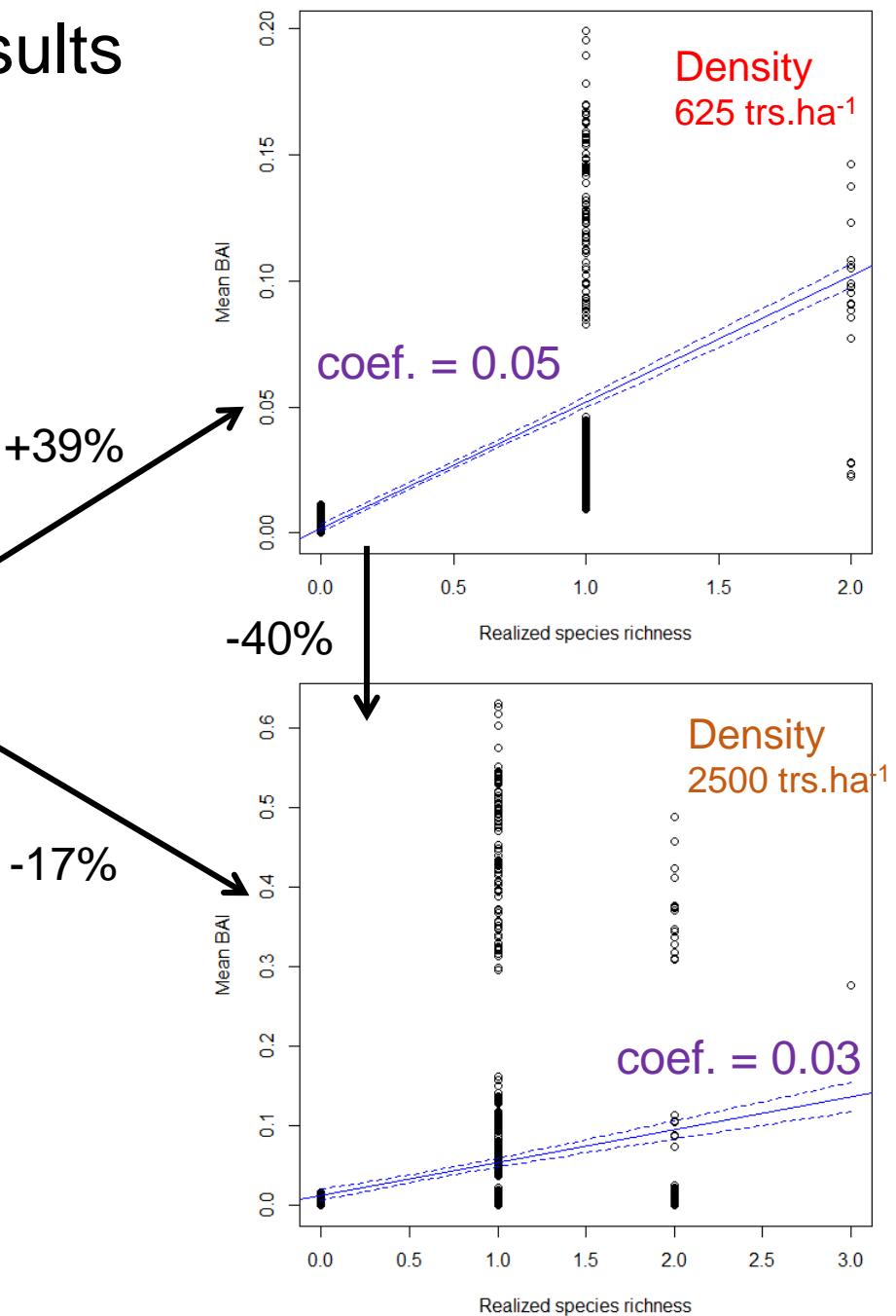
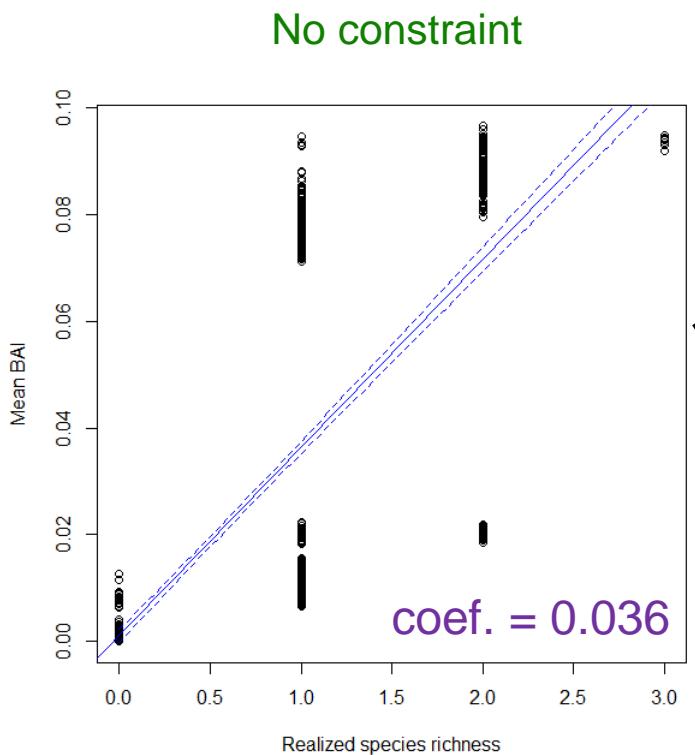
Results

SAP26

VERY PRELIMINARY !!!

Results

Puéchabon



VERY PRELIMINARY !!!

Results

- Controlling for tree density seems to strongly reduce the effect of diversity on productivity
 - ➡ **Evidence for a tree packing effect**
- The canopy packing effect can still emerge from the simulations

VERY PRELIMINARY !!!

Results

- Controlling for tree density seems to strongly reduce the effect of diversity on productivity
 - ➡ **Evidence for a tree packing effect**
- The canopy packing effect can still emerge from the simulations
- But complementary analyses are required
(= mean individual productivity, importance of mortality events...)
- ...To be continued (=> 15 sites across the climatic gradient)

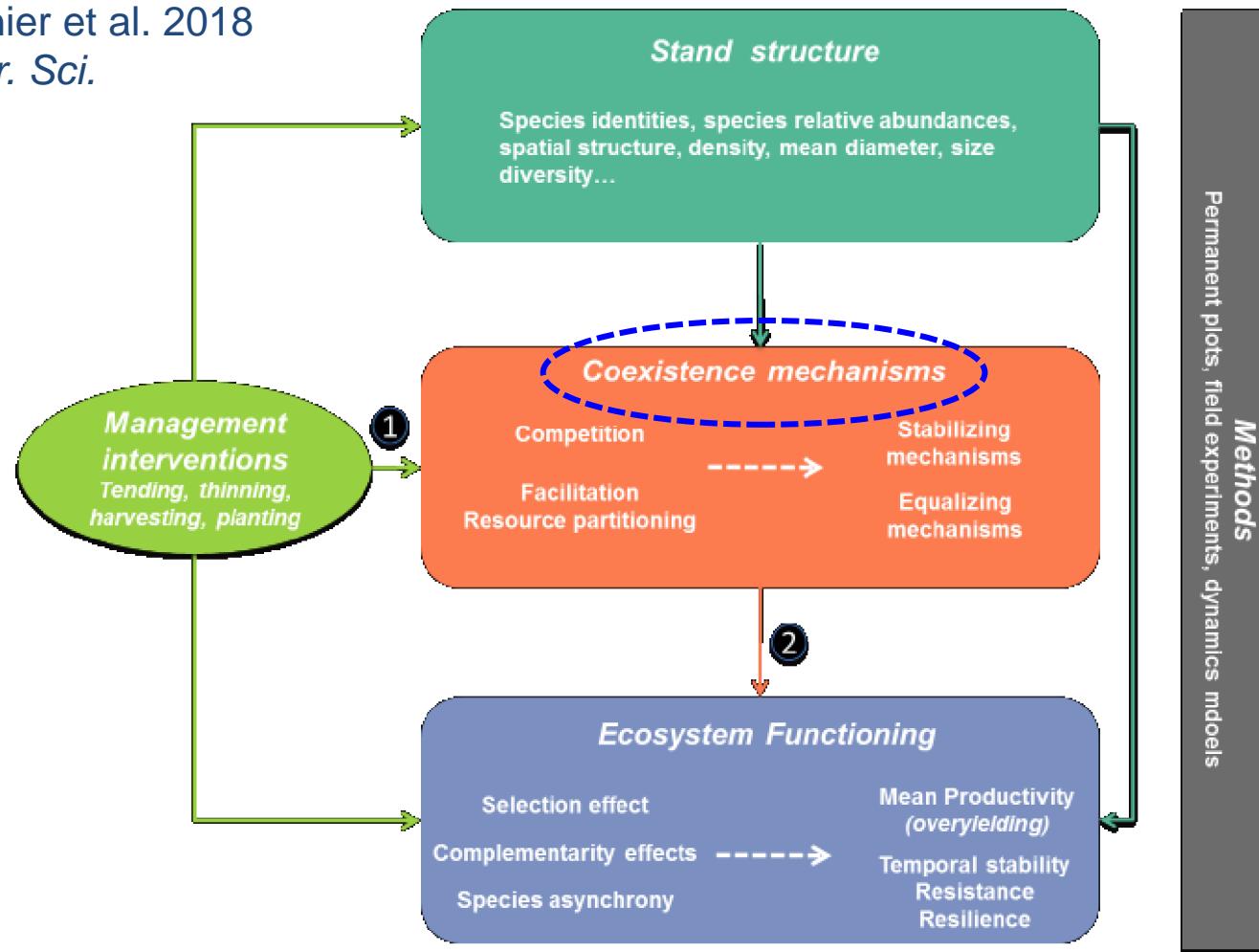
Take-home messages

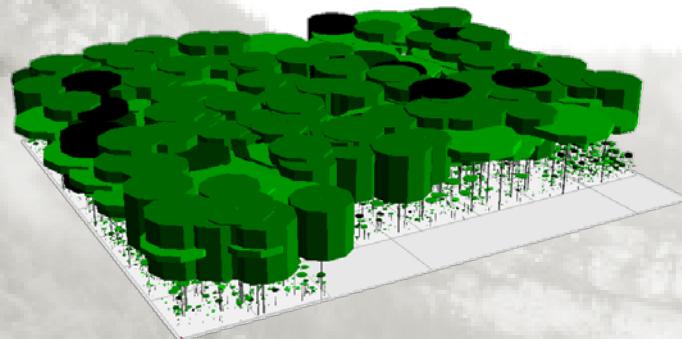
- The model ForCEEPS can simulate forest productivity in FR with reliable accuracy, considering main tree species
- These simulations suggest that BEF relationships in natural forests may be explained:
 - by canopy packing
 - by the fact that more trees may co-exist in mixed forests
- *To be confirmed!!!*
 - more analyses to be done
 - comprehensive simulation design to be completed (eg. 15 sites)
 - reliability across environmental gradients? Link with stress gradient hyp.?
- Link with analysis of the role of coexistence processes with ForCEEPS

Understanding the role of coexistence processes

= key to better understand BEF relationships,
species identity effects,
climate effects?

Cordonnier et al. 2018
Ann. For. Sci.



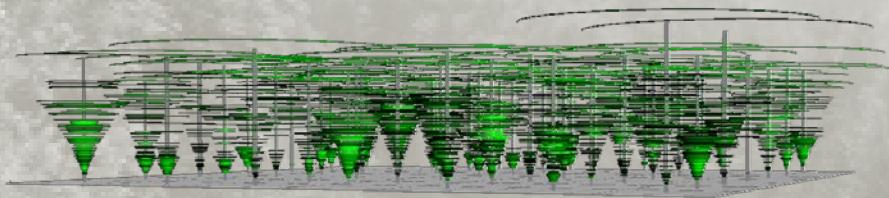


Merci !



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Philippe Dreyfus
Lorenz Fahse
Harald Bugmann
Myriam Legay
Hervé Jactel
Manuel Nicolas et le réseau RENECAFOR
IGN-IFN



MINISTÈRE
DE L'AGRICULTURE
DE L'AGRO-ALIMENTAIRE
ET DE LA FORÊT



The diversity-productivity relationship in forest ecosystems

What mechanisms?

Selection

Complementarity

The diversity-productivity relationship in forest ecosystems

What mechanisms?

Selection

Dominance
Sampling

Complementarity

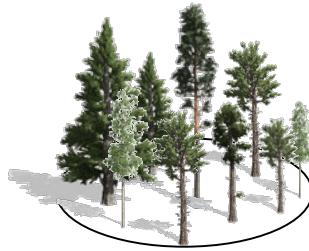
Resource partitioning
Abiotic facilitation
Biotic feedbacks

The diversity-productivity relationship in forest ecosystems

What mechanisms?

Selection

Dominance
Sampling



Individual tree level

Complementarity

Resource partitioning
Abiotic facilitation
Biotic feedbacks

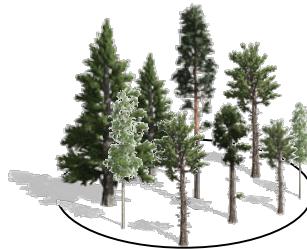
Community level

The diversity-productivity relationship in forest ecosystems

What mechanisms?

Selection

Dominance
Sampling



Complementarity

Resource partitioning
Abiotic facilitation
Biotic feedbacks

Individual tree level

Fixed plant responses = differences in fundamental niche
=> **additive effects**

Phenotypic changes = different response of trees in pure vs. mixed communities => **non-additive effects**

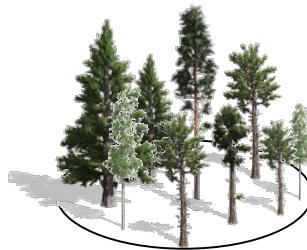
Community level

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Resource partitioning
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Biotic feedbacks

Fixed plant responses = differences in fundamental niche
=> **additive effects**

Phenotypic changes = different response of trees in pure vs. mixed communities => **non-additive effects**

Community level

Link with ecosystem functioning...

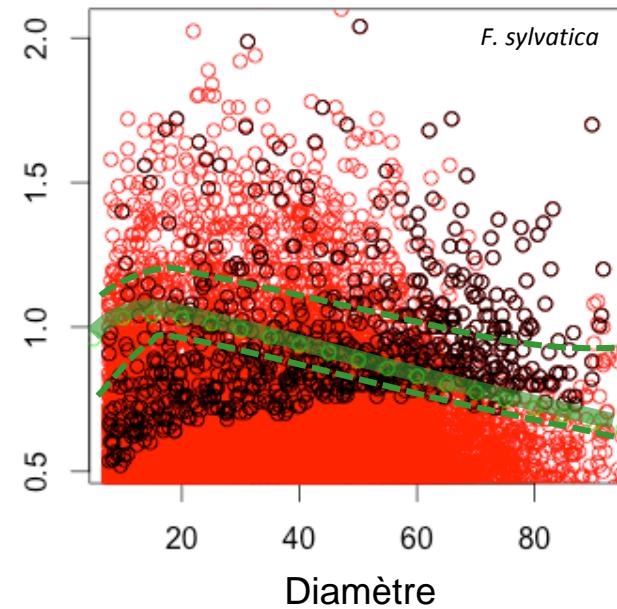
Modéliser la croissance « optimale » d'un arbre

2- Calibration paramètre de croissance optimale en diamètre = g

Ajustement sur les arbres ayant les plus fortes croissance pour un diamètre donné

Incrément annuel
en diamètre

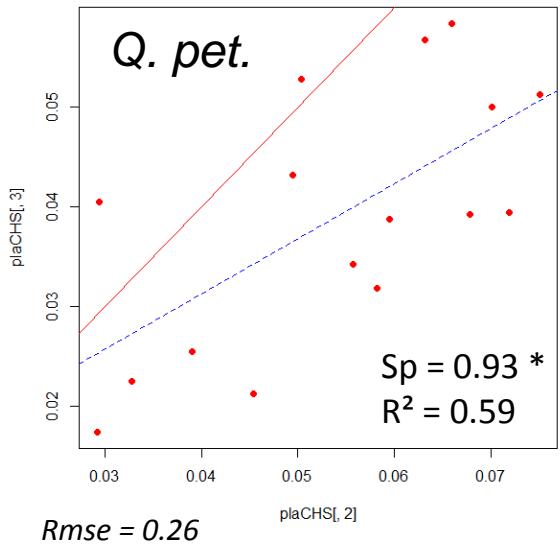
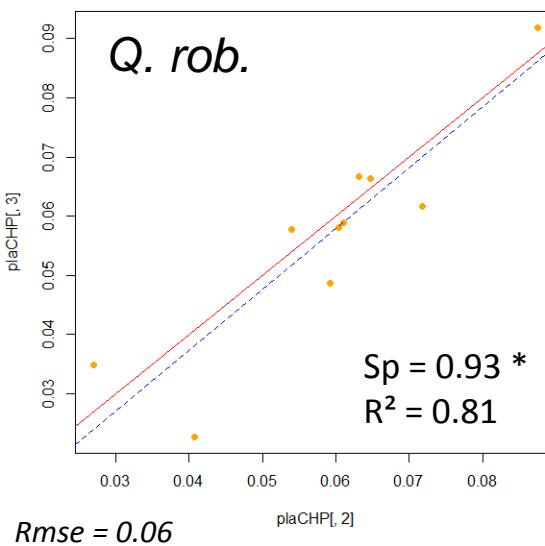
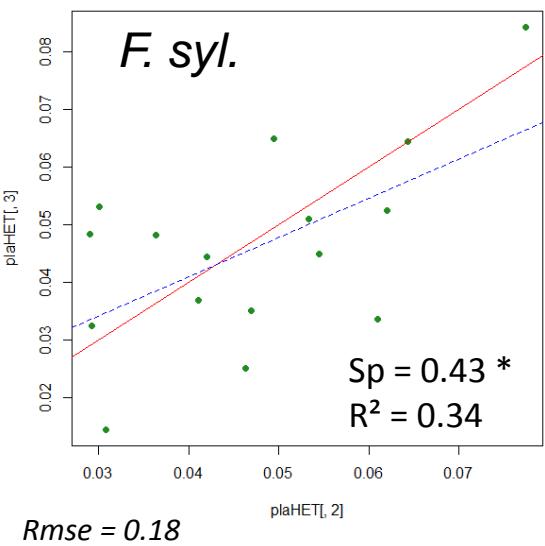
Données IFN → pour 10 espèces



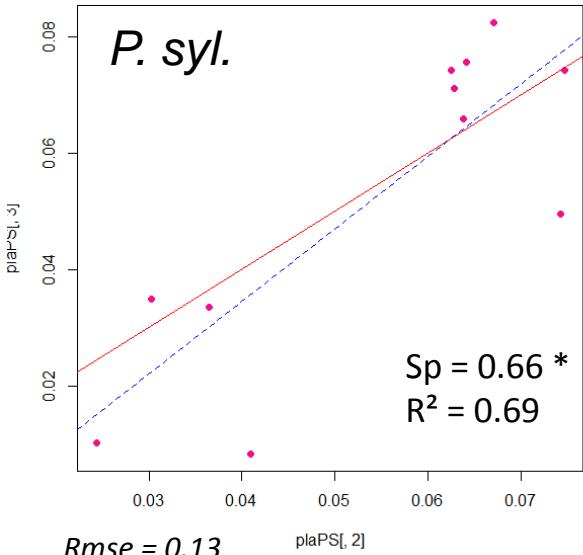
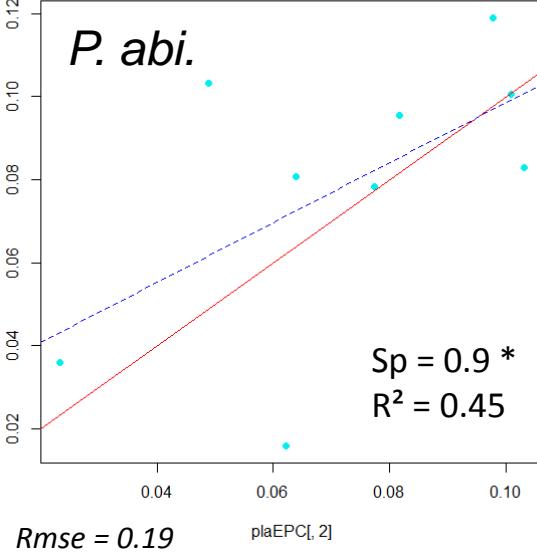
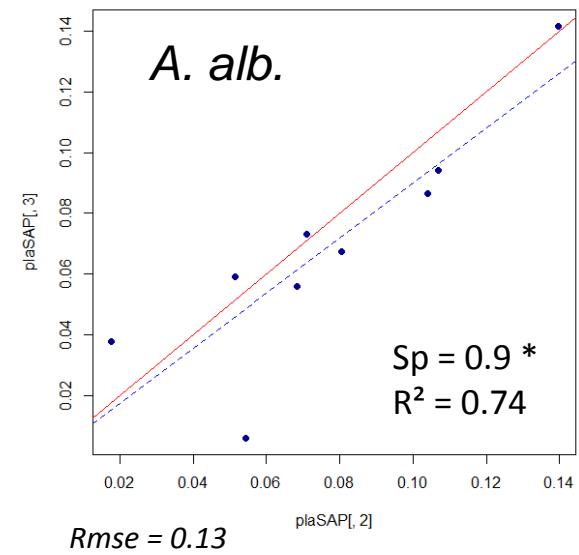
Validating the ForCEEPS model for French forests

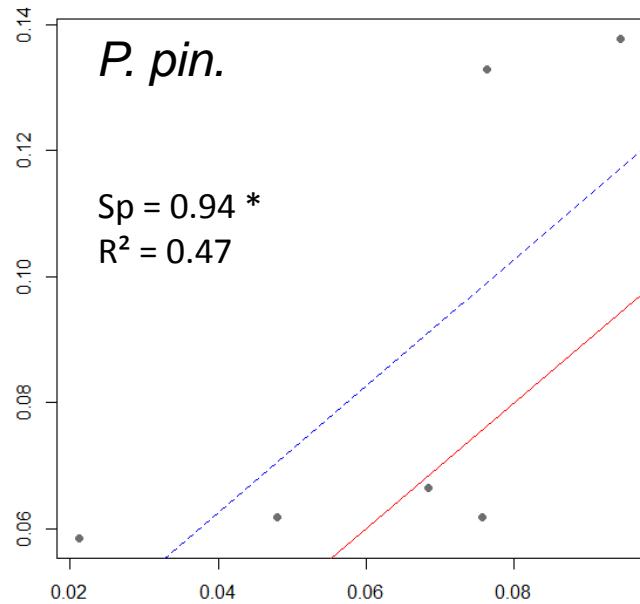
Mean annual productivity (BAI) per stand (m^2)

Per species



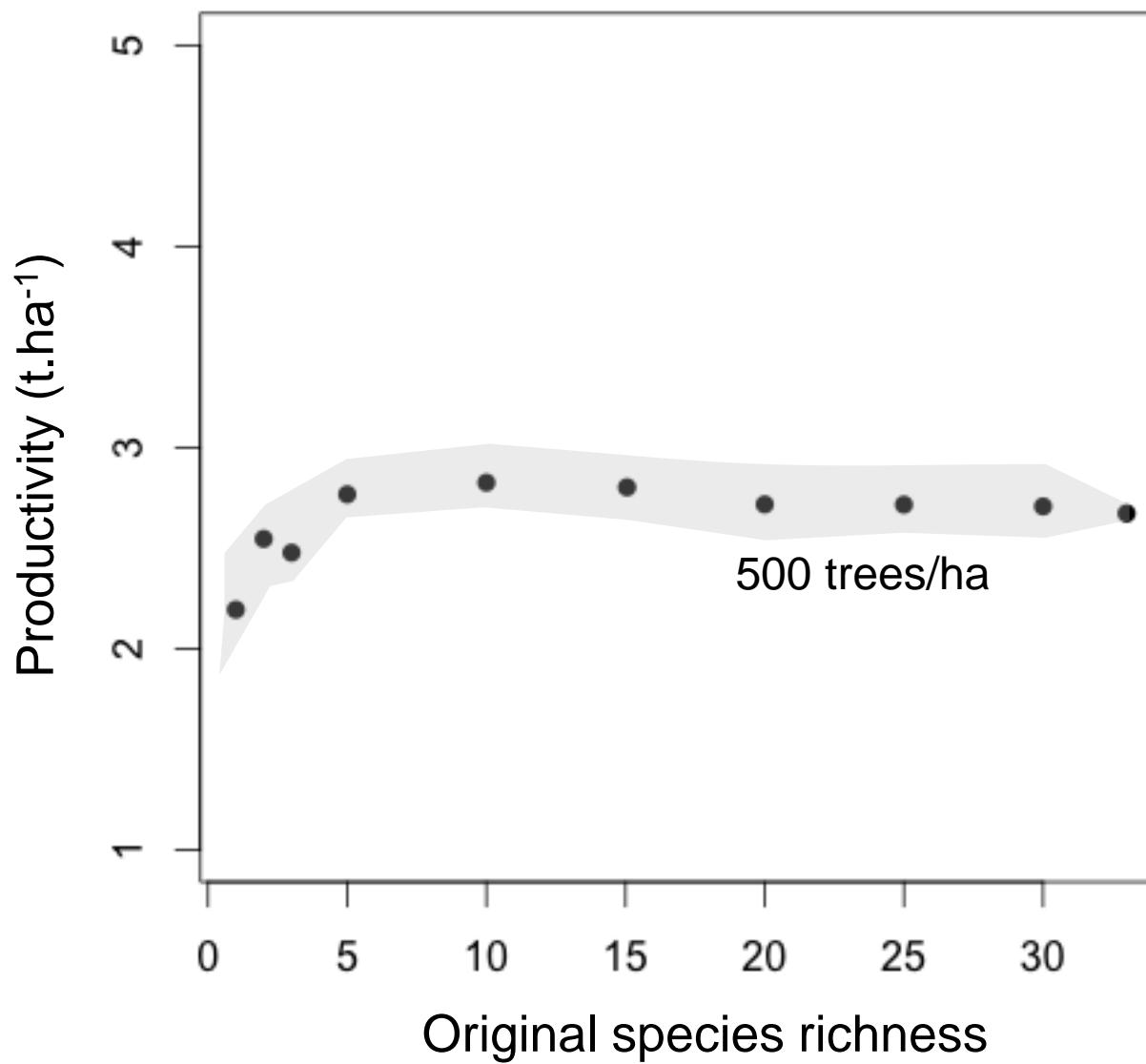
(Sp = Spearman correlation)



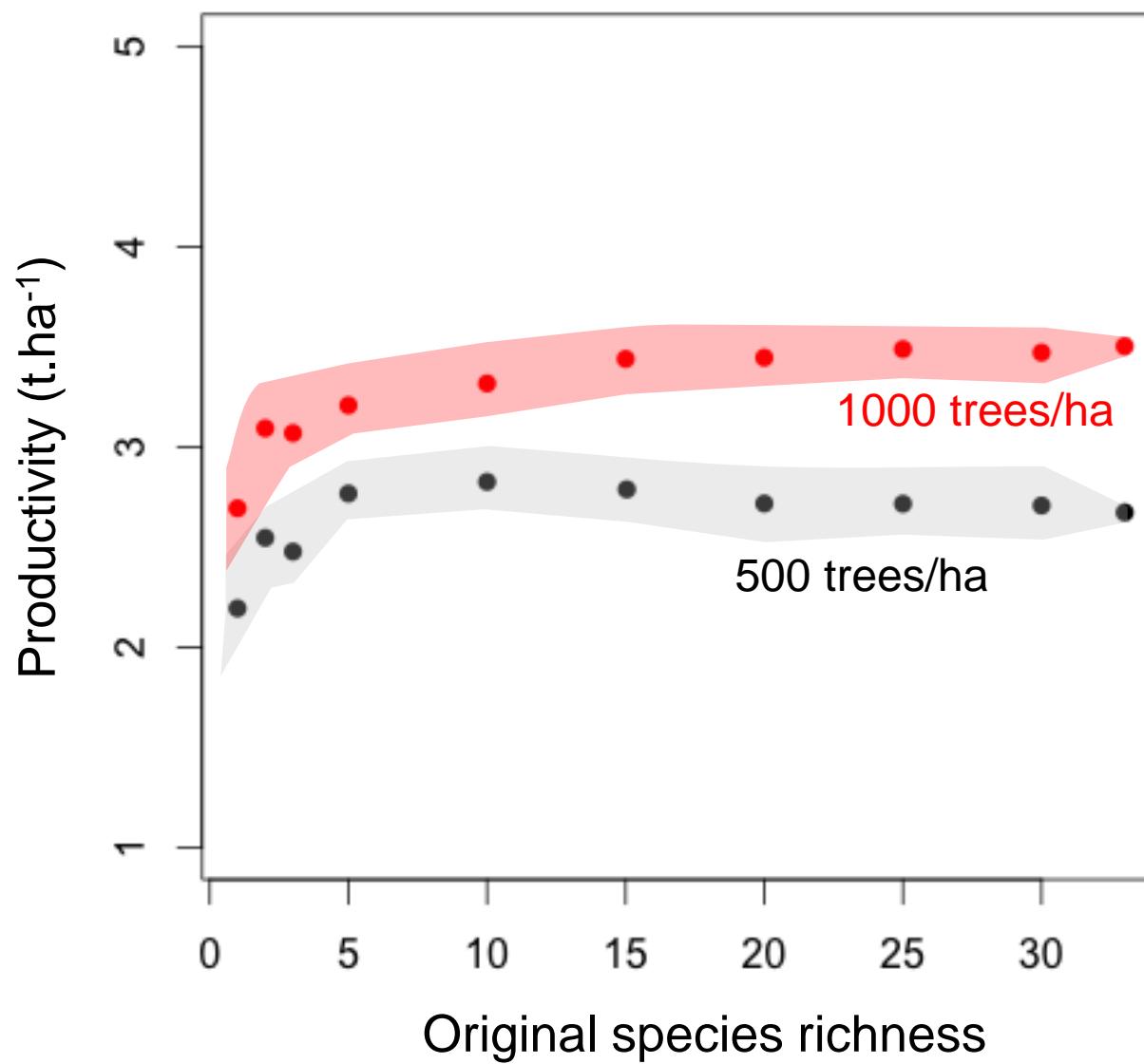
Mean annual productivity (BAI) per stand (m^2)*Per species*

+ *Q. ilex* = seulement 1 site...

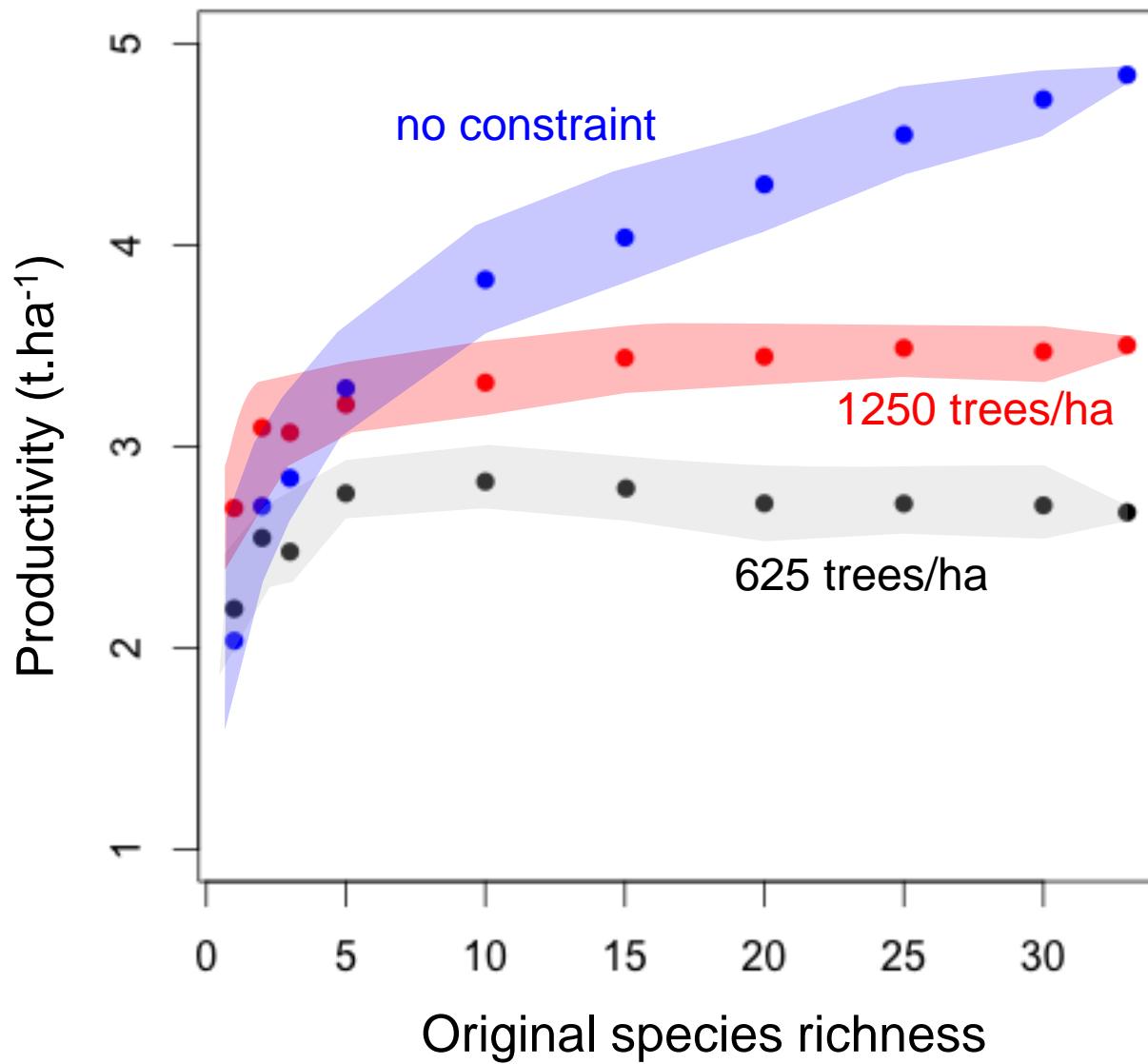
Results



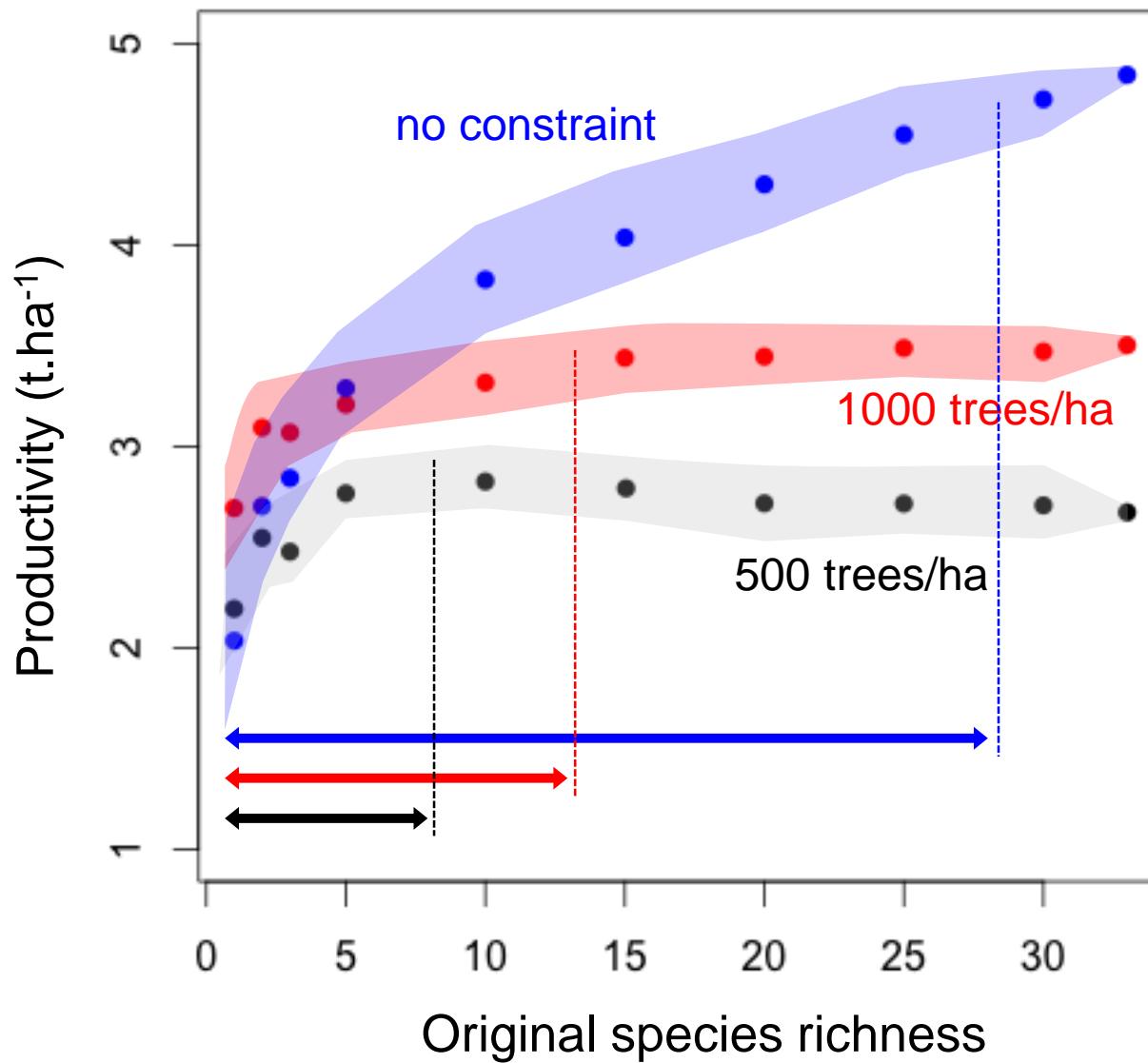
Results



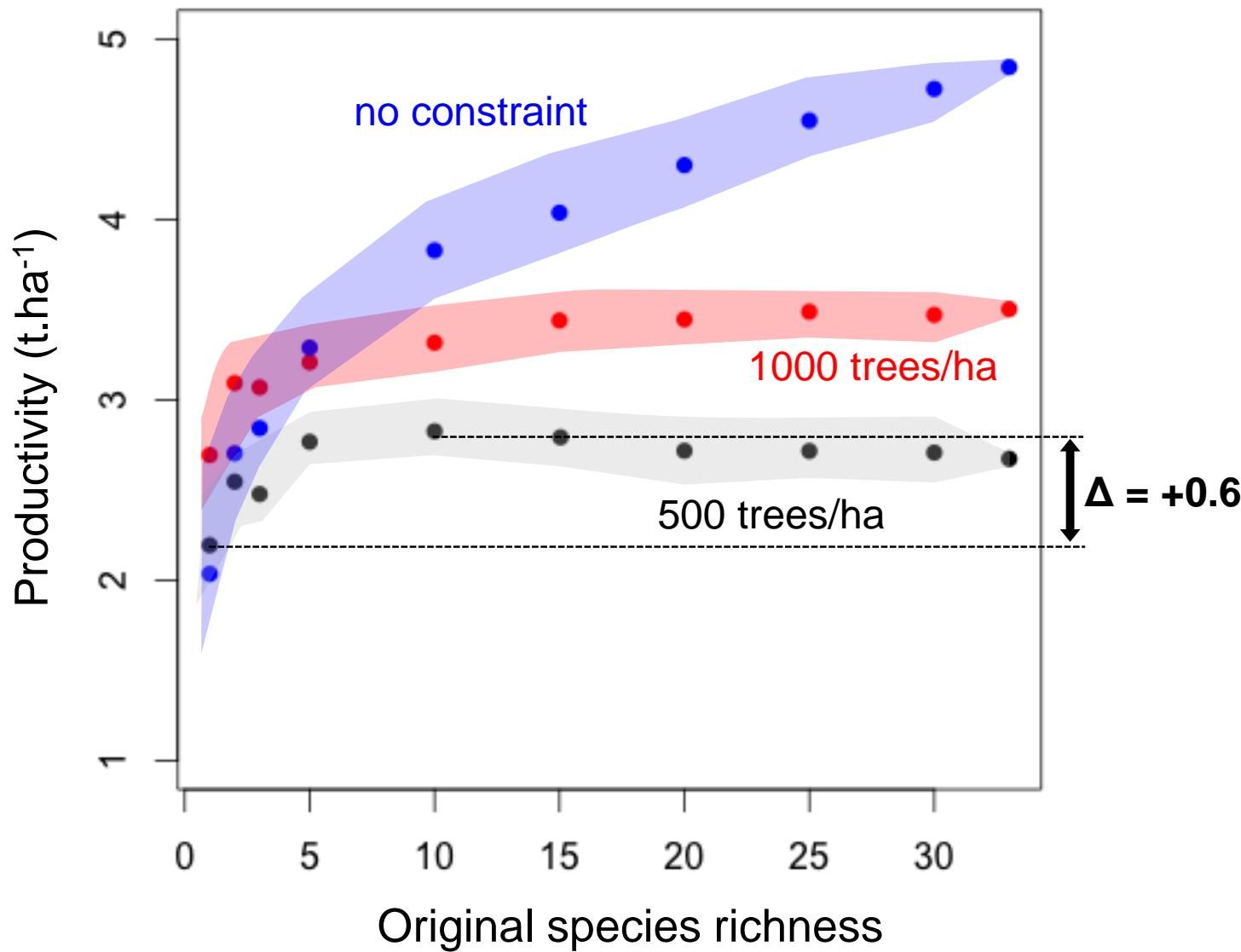
Results



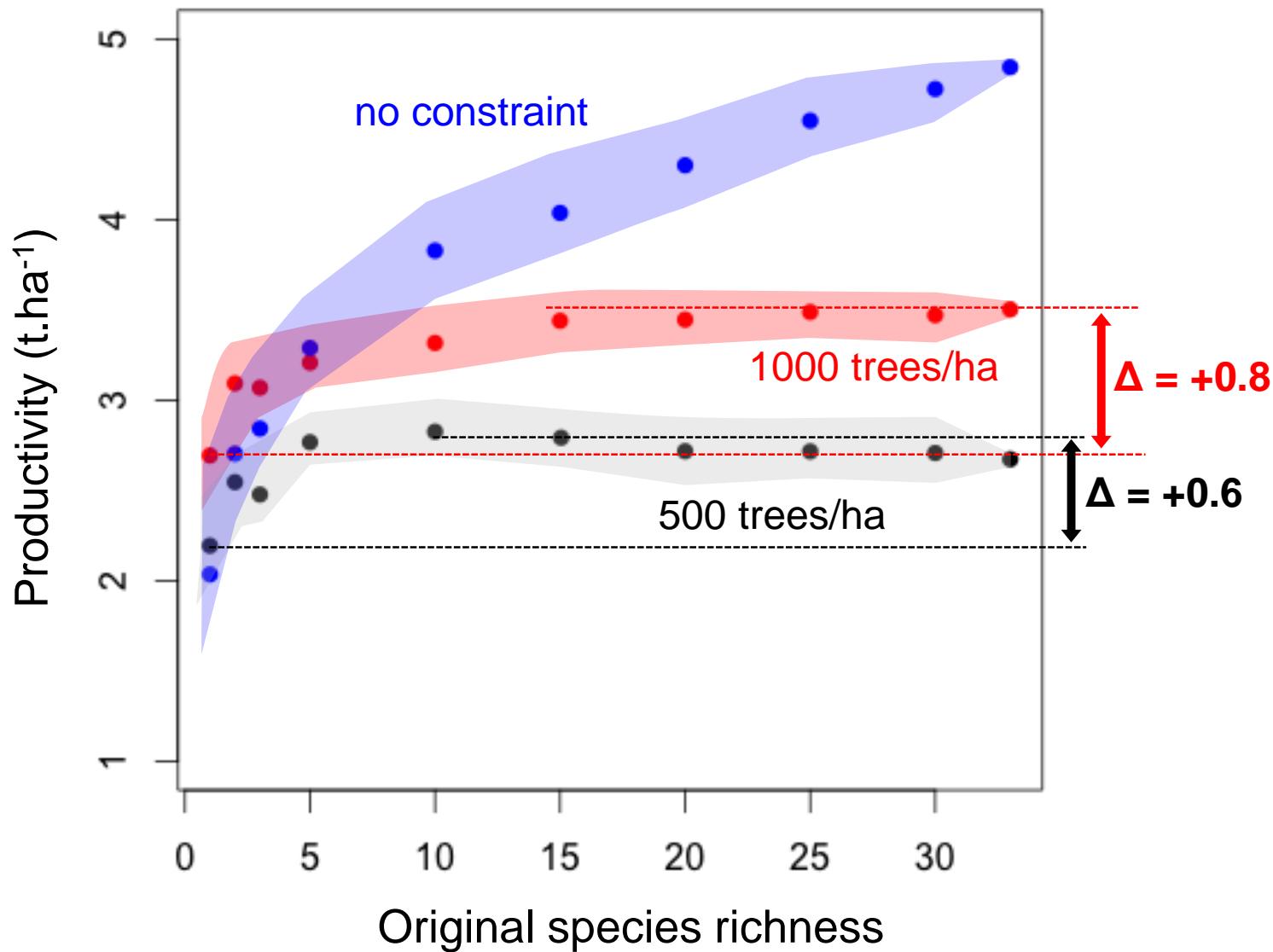
Results



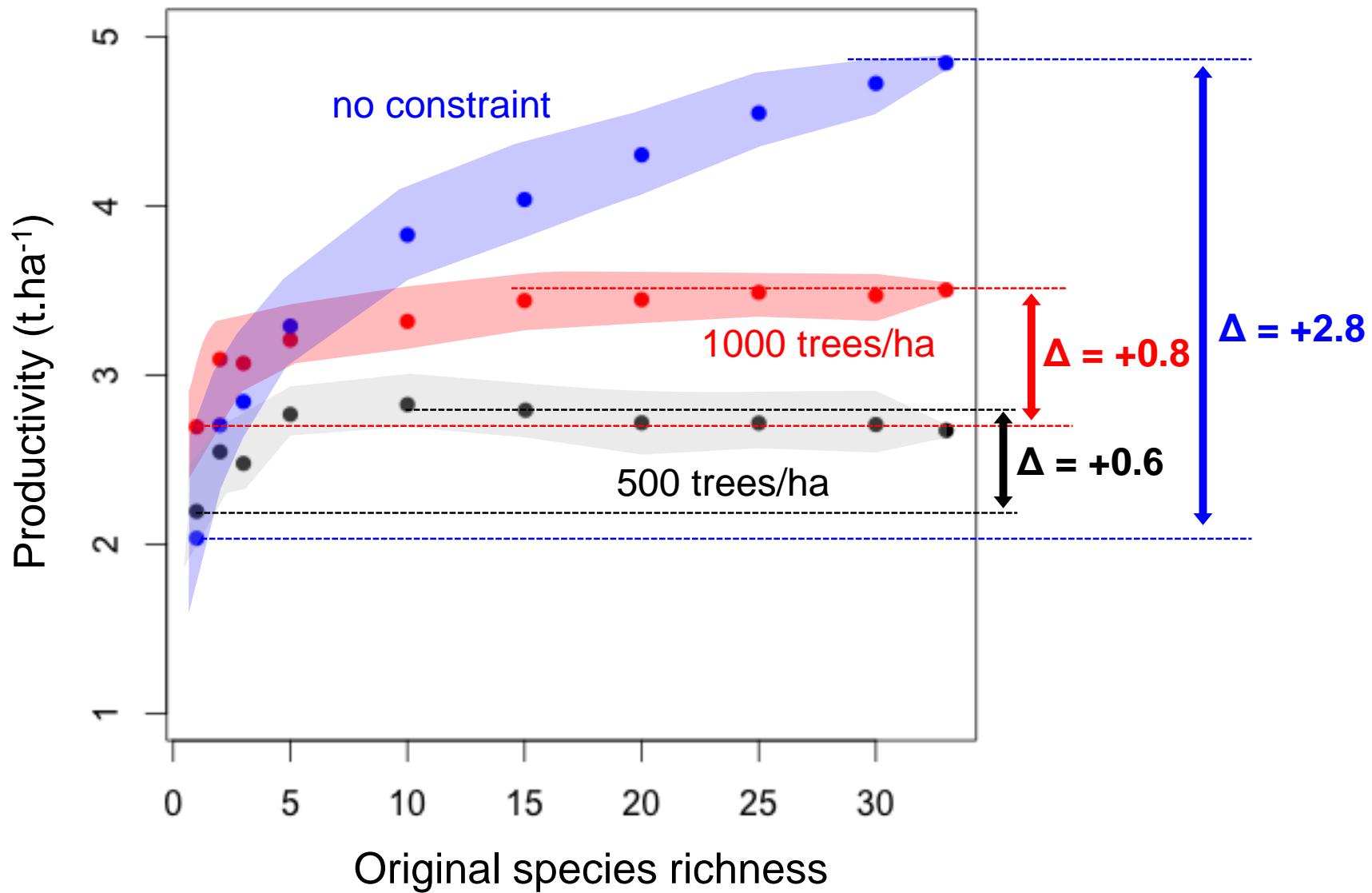
Results



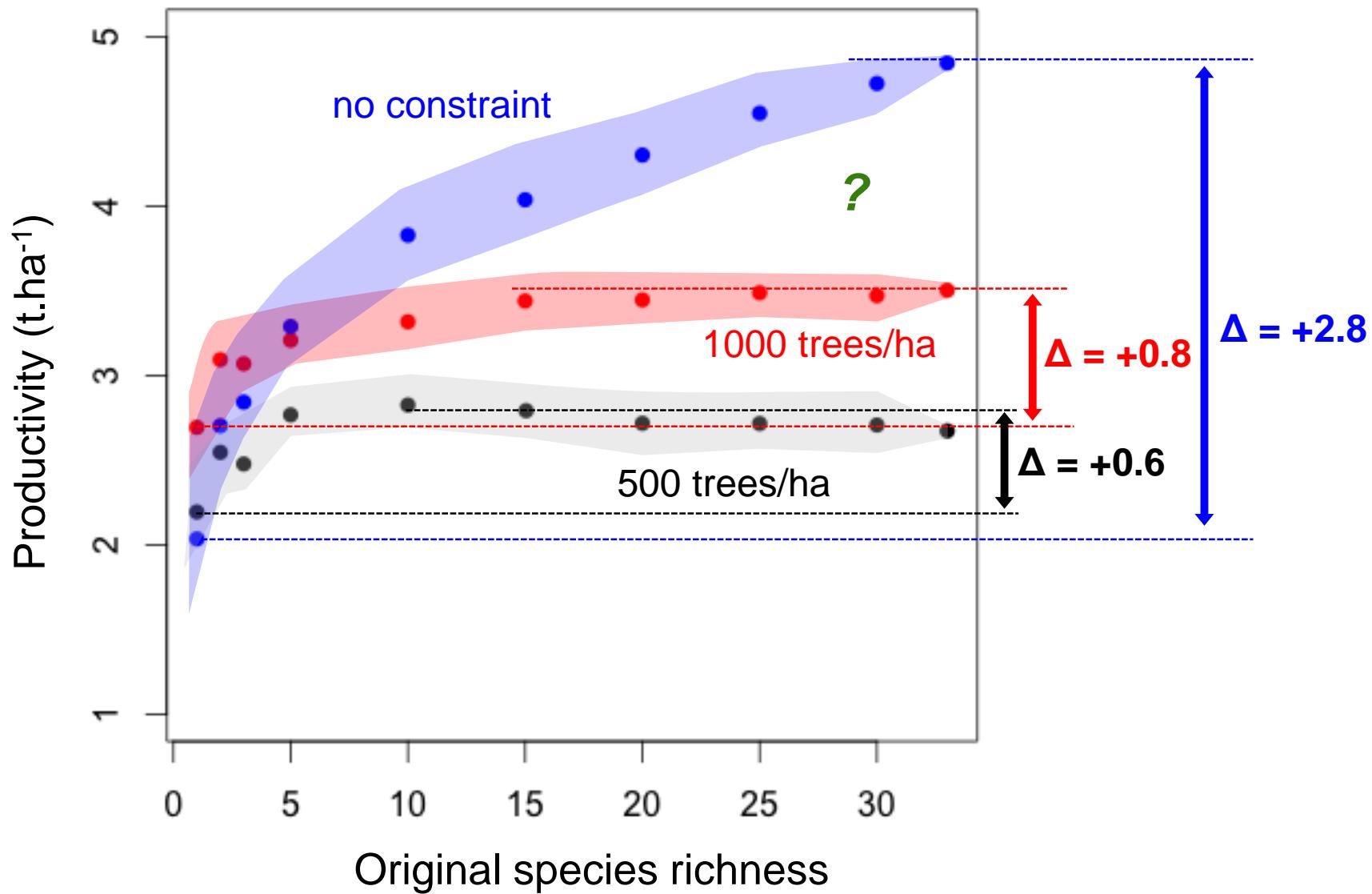
Results



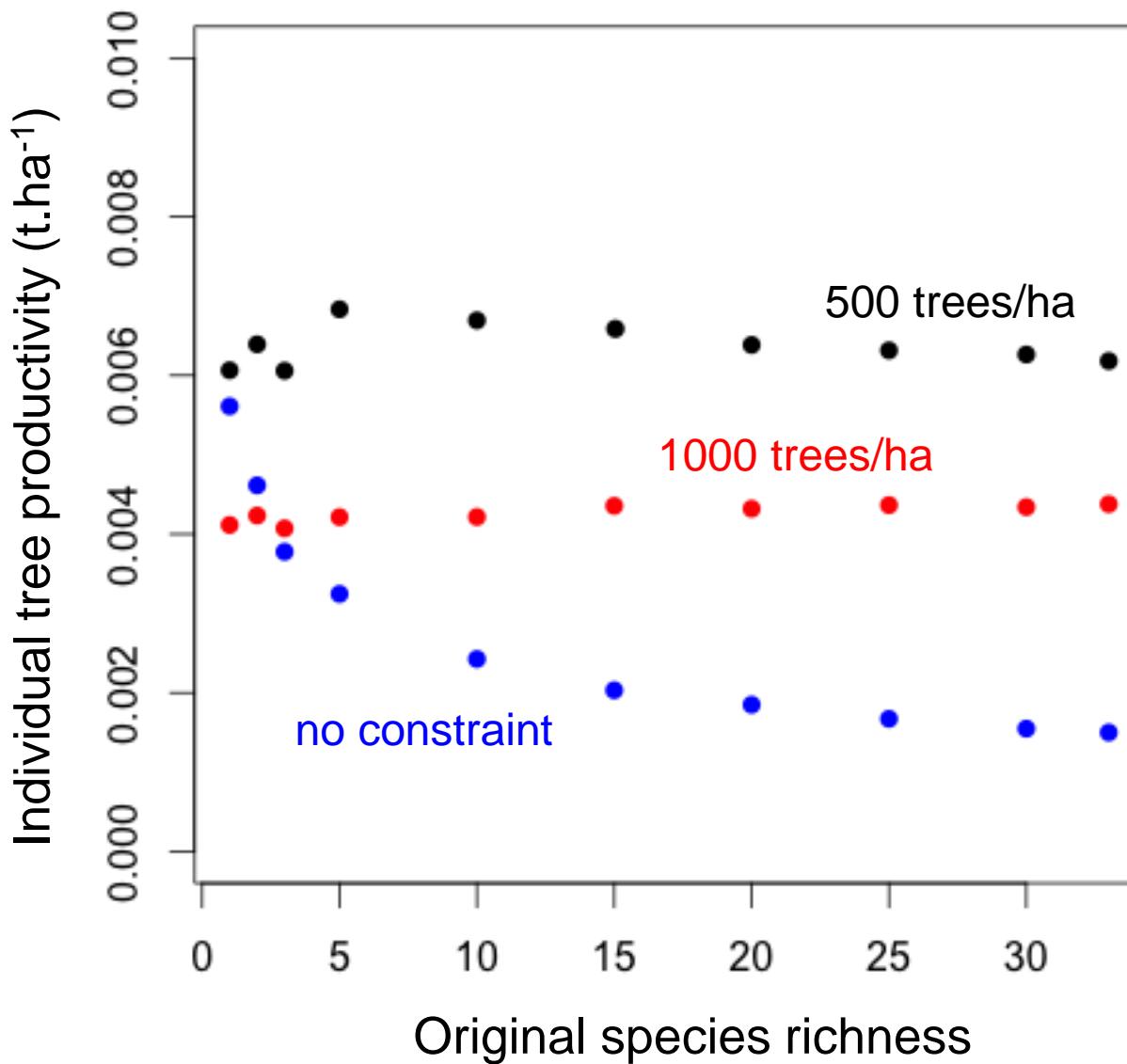
Results



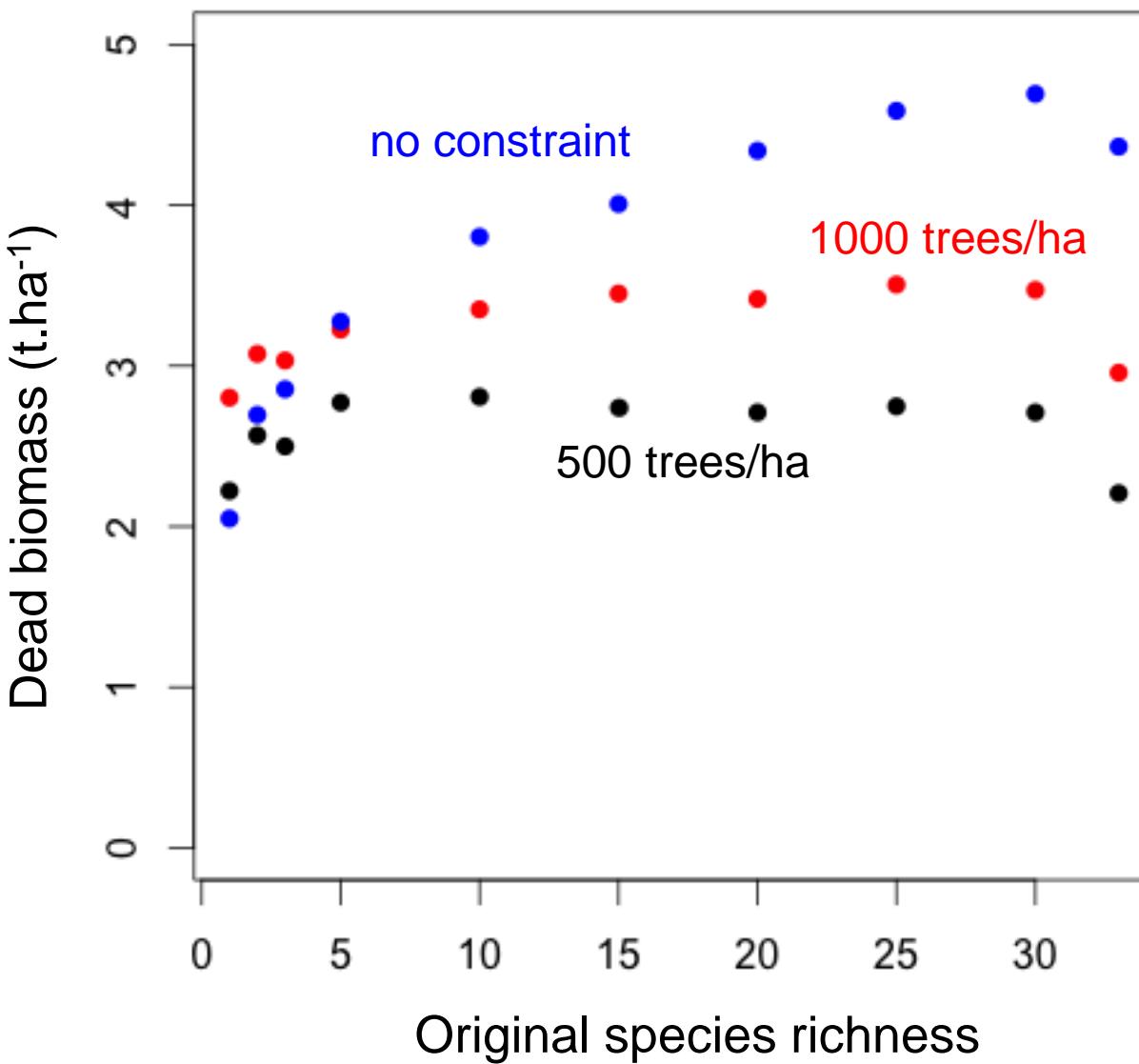
Results



Results

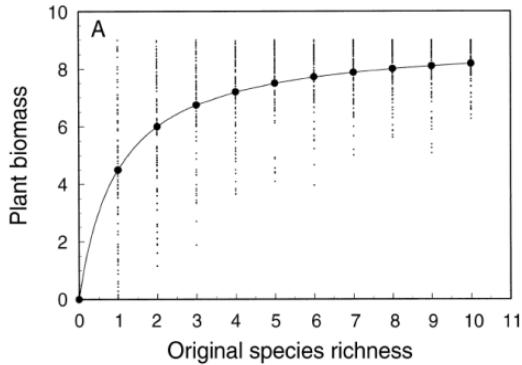


Results



Diversity-productivity, a review of evidence

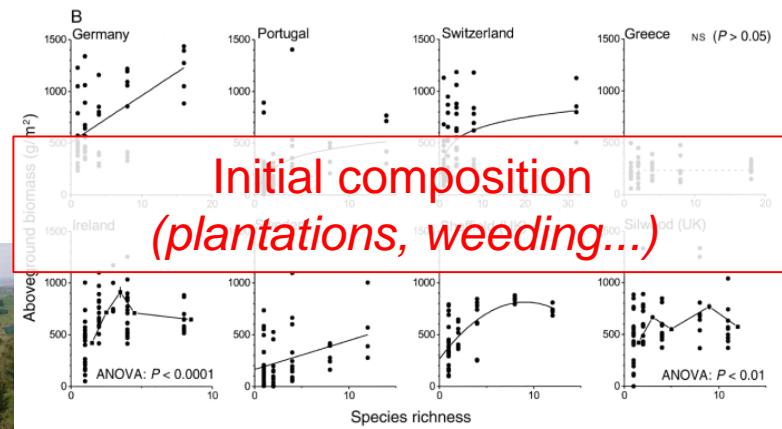
Theoretical works



Loreau 1998



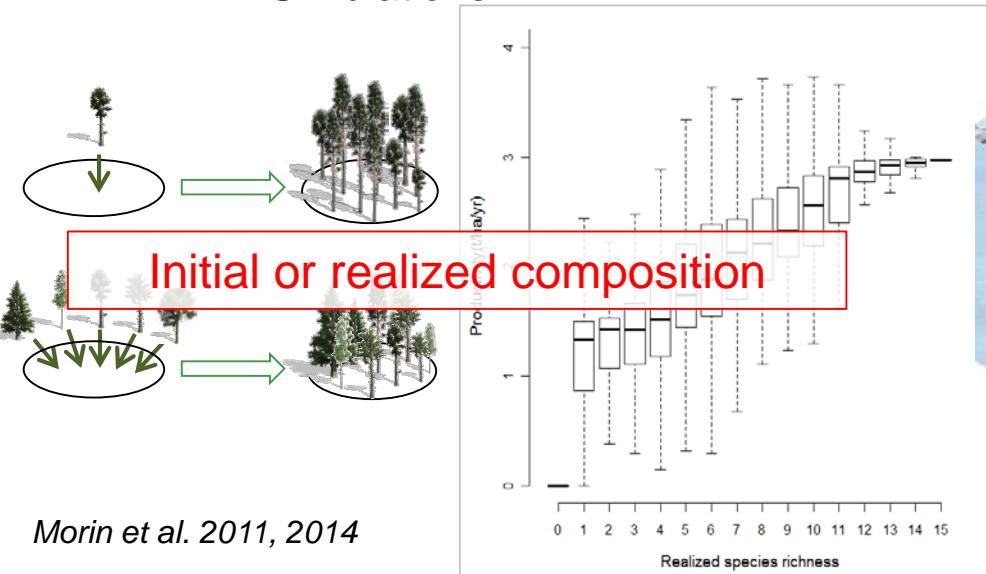
Experiments



Hector et al. 1999

Forest ecosystems

Simulations



Initial or realized composition

Morin et al. 2011, 2014

Observations

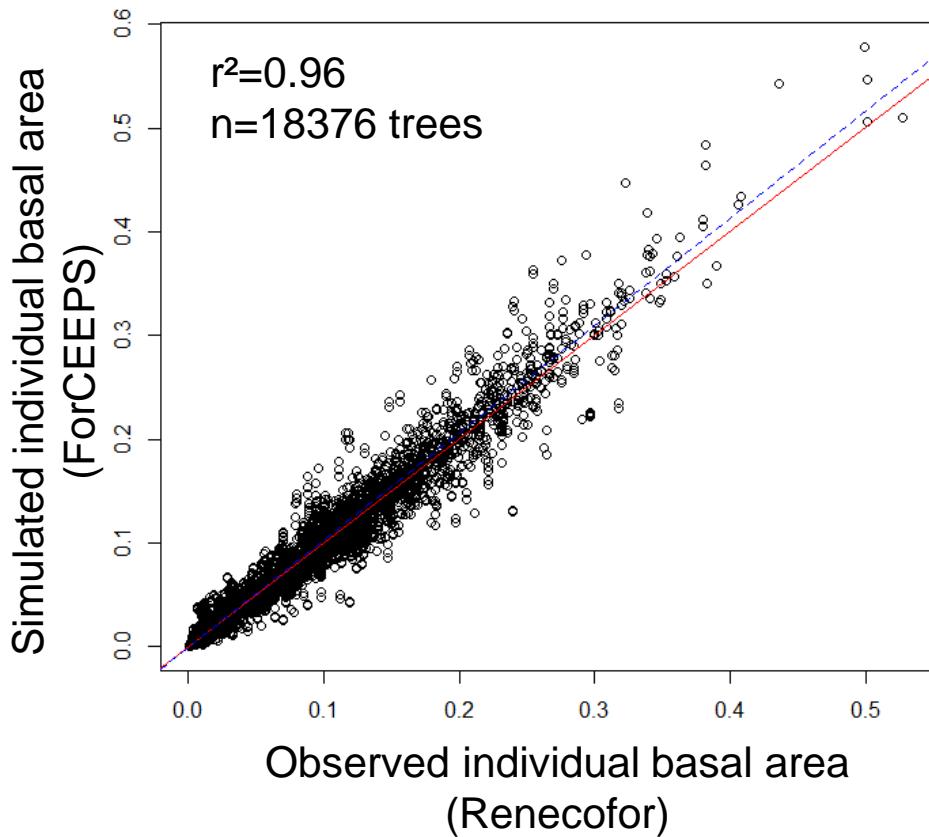
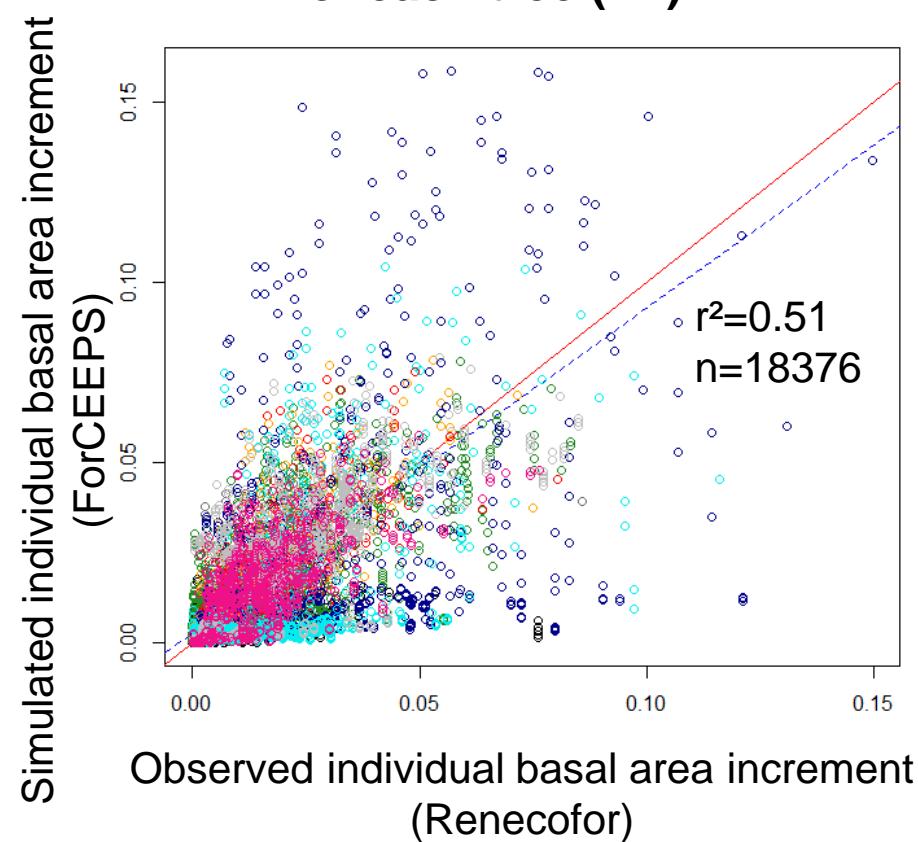


Realized composition

Liang et al. 2016

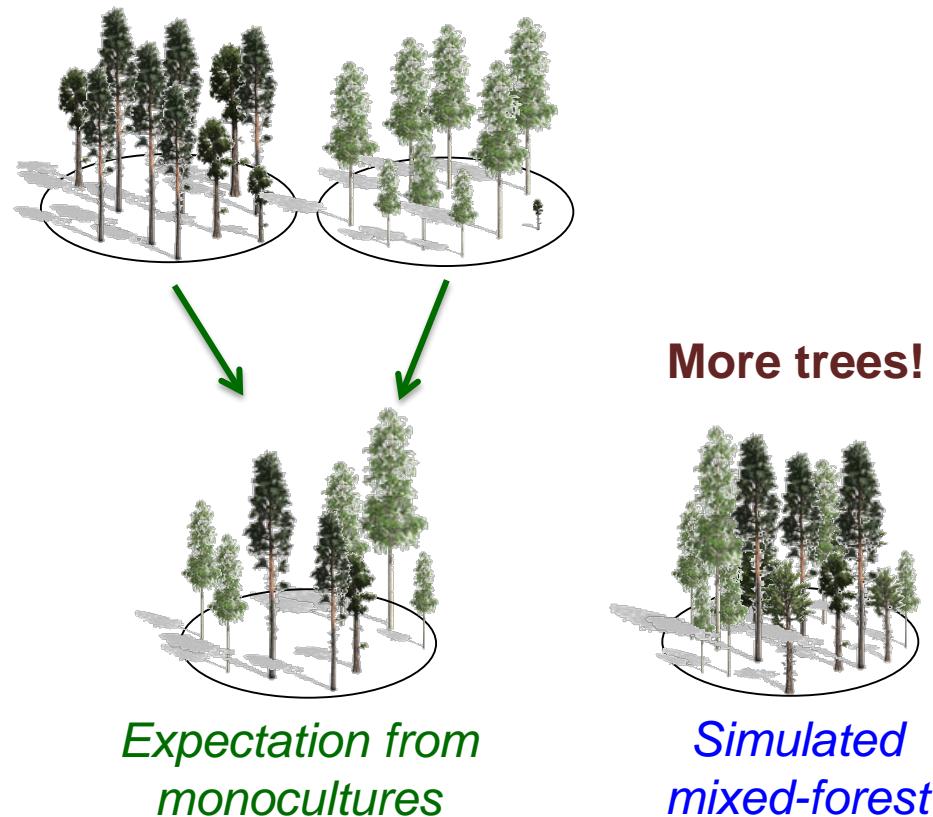
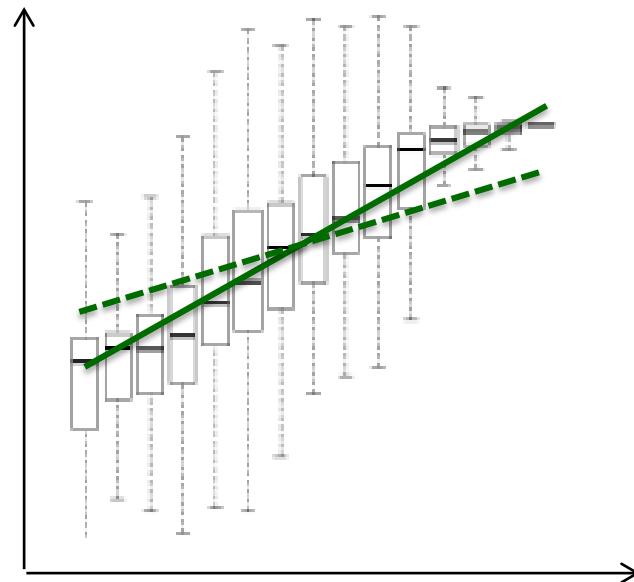
Vila et al. 2013

Paquette & Messier 2011

Final tree basal area (m^2)**Cumulative basal area increment of each tree (m^2)**

The diversity-productivity relationship in forest ecosystems

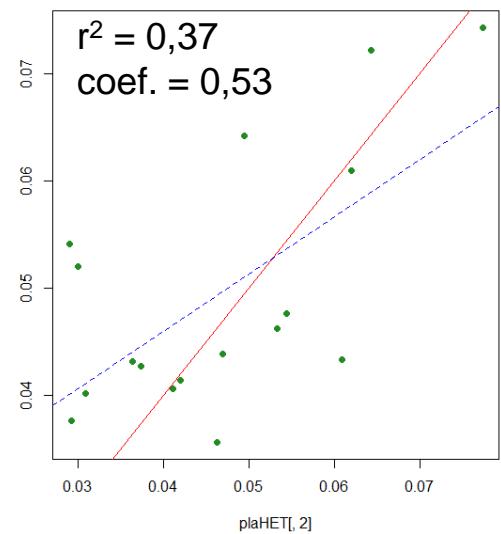
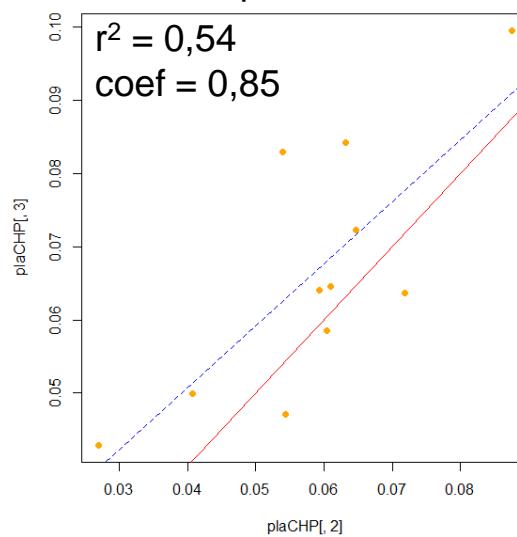
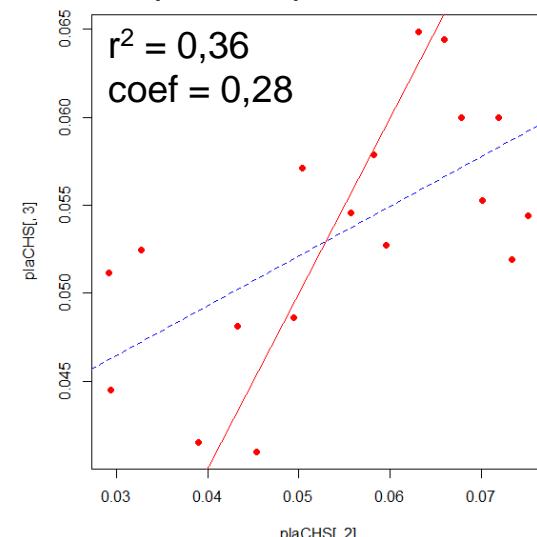
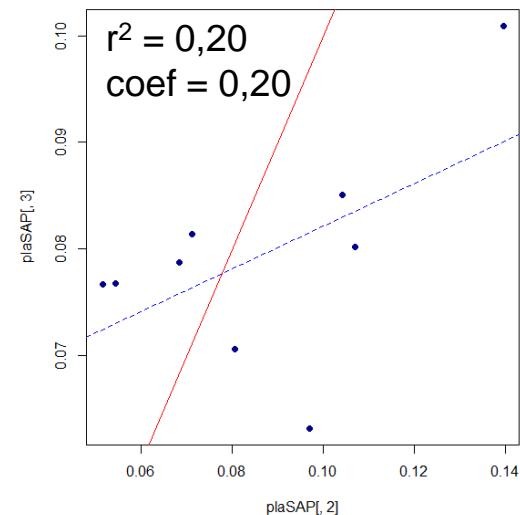
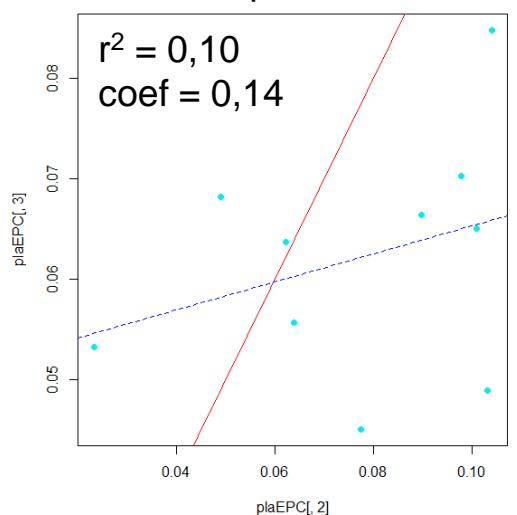
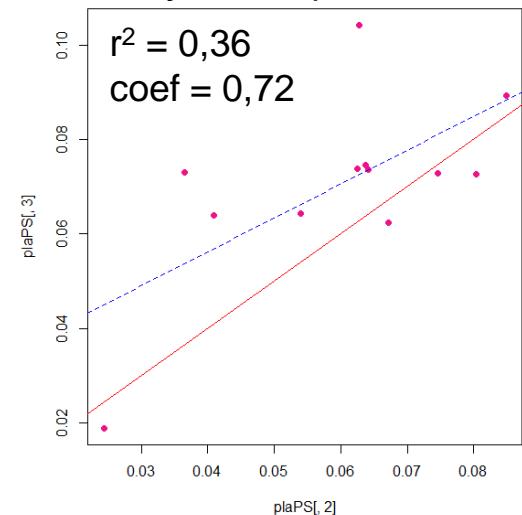
When focusing on individual growth = the effect is much weaker



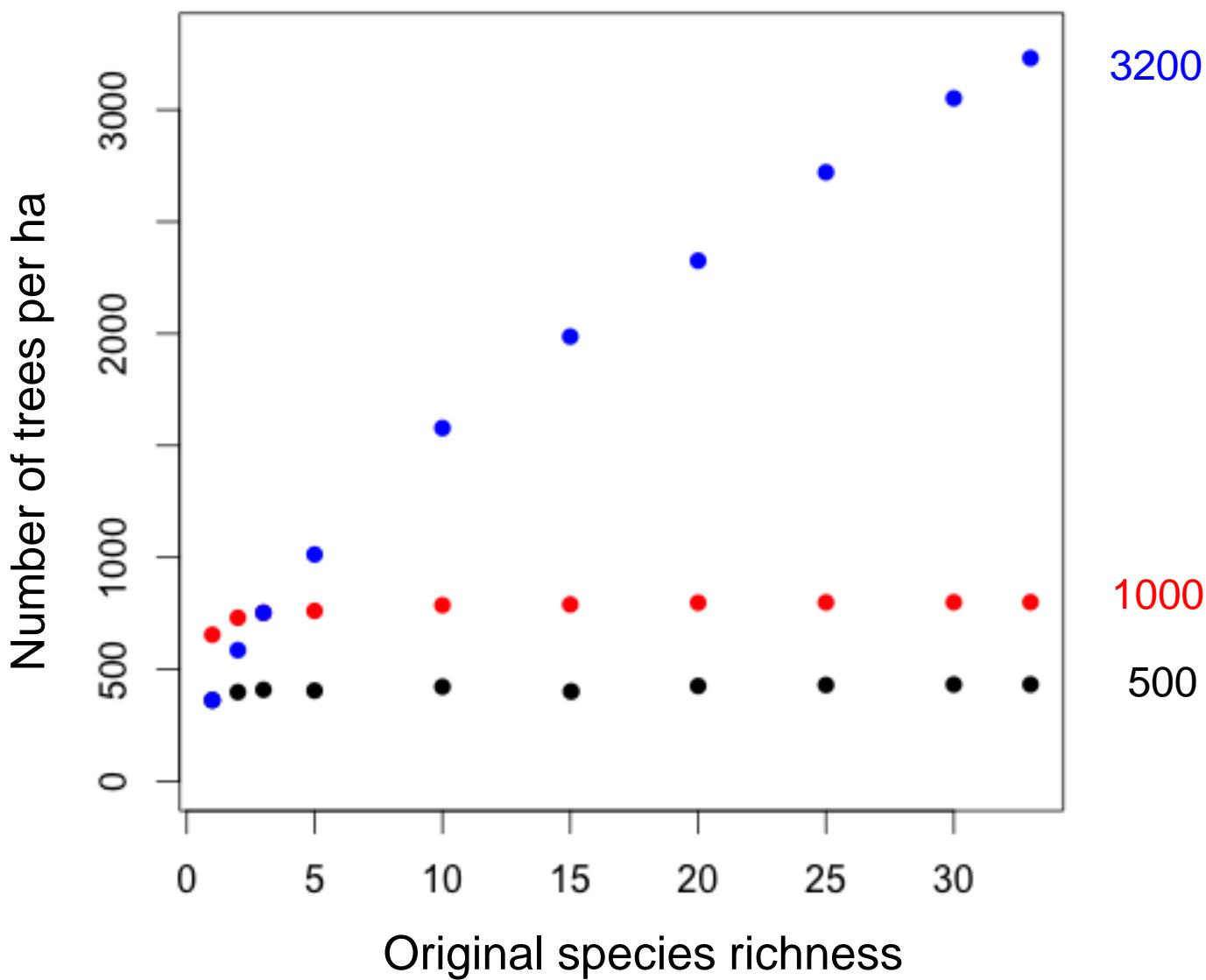
→ A part of the net diversity effect found is due to a greater occupancy of space (*niche packing*)

Consistent with French NFI data...

Can ForCEEPS simulate forest productivity with enough accuracy?

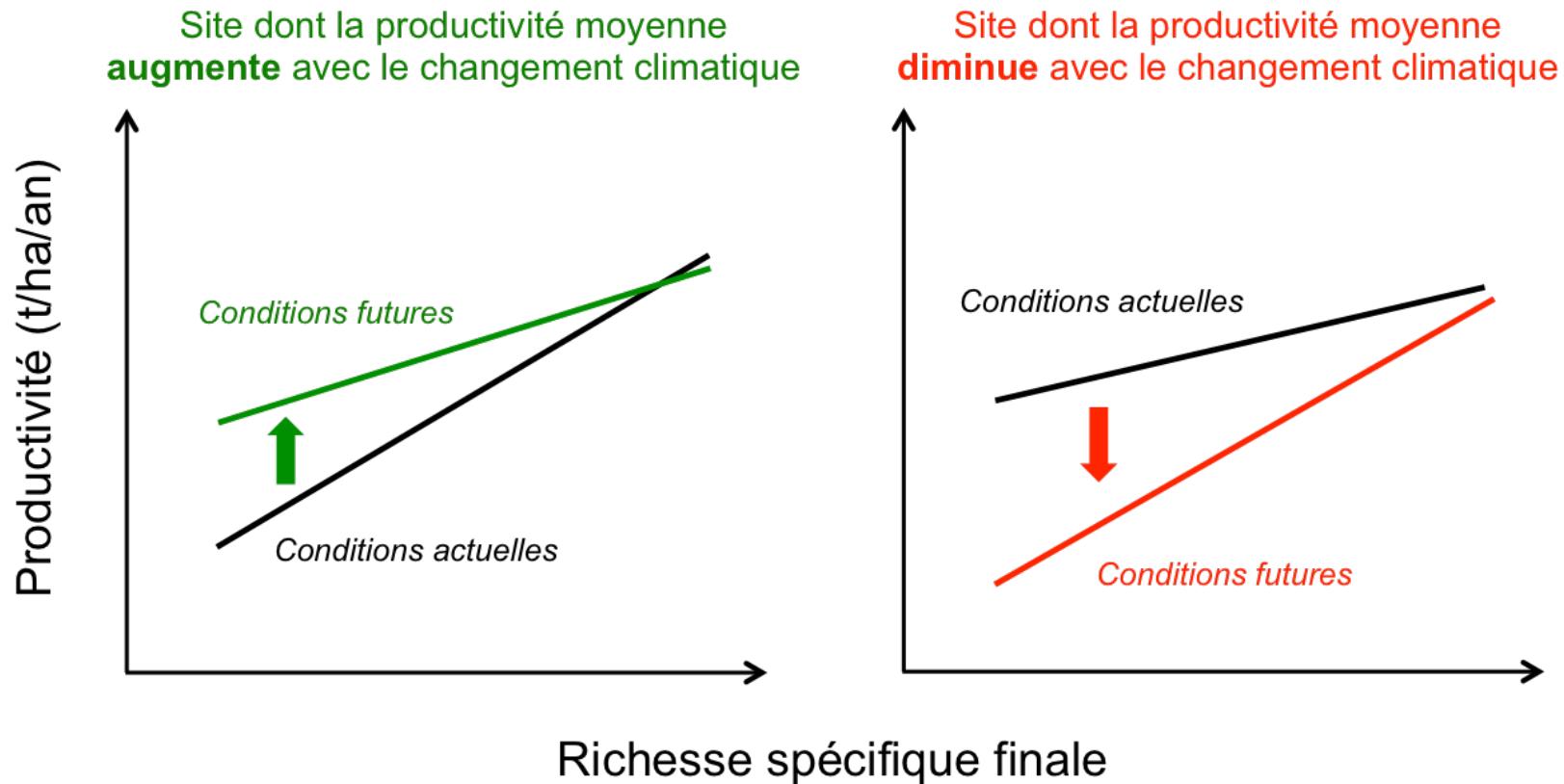
Annual plot basal area increment ($\text{m}^2 \cdot \text{yr}^{-1}$)*F. sylvatica* plots*Q. robur* plots*Q. petraea* plots*A. alba* plots*P. abies* plots*P. sylvestris* plots

Simulating diversity-productivity relationships



4 Impacts du changement climatique ?

Réaction de l'effet de la diversité au changement climatique ?  Modélisation

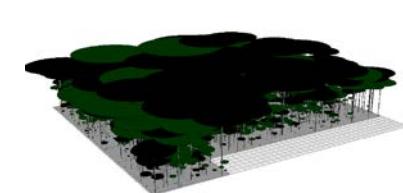
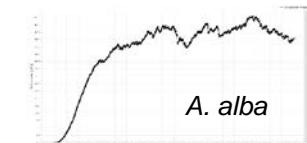
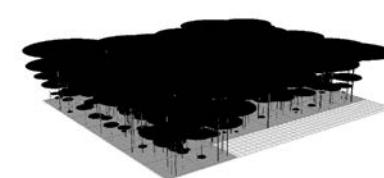
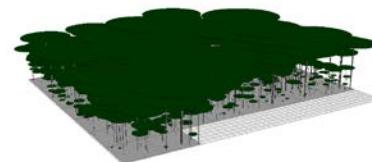
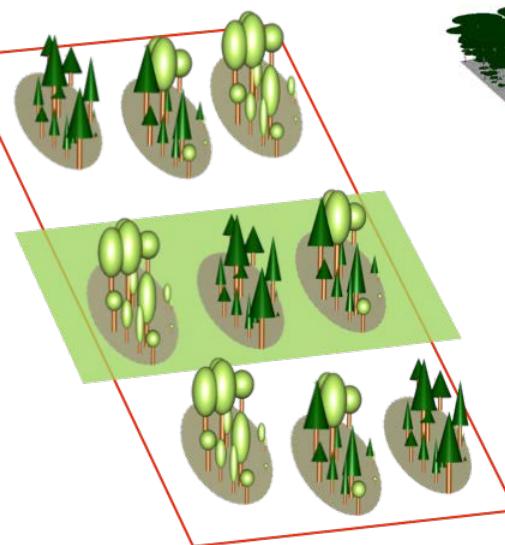


4 Impacts du changement climatique ?

Réaction de l'effet de la diversité au changement climatique ? ➔ Modélisation

Validation du modèle pour conditions tempérées et montagnardes en France

Simulation de peuplements = validation données dispositif BioProFor/Distimacc



BioProFor design

ForCEEPS