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

Xavier Morin
CEFE – CNRS
Montpellier
Impacts of global change on forests

Global Change

Species range

Local extinctions
Colonizations

Community composition

Ecosystem functioning

$CO_2$ fertilization

Temperature and precipitation increase/decrease

Photosynthetic and respiration rates
Impacts of global change on forests

Global Change

Species range

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CO$_2$ fertilization
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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

- Species richness
- Functional diversity

Ecosystem functioning

- Productivity
The *Diversity-Productivity* relationship

- Theoretical work

Hooper *et al.* 2005 *Ecol. Monographs*
The *Diversity-Productivity* relationship

- Theoretical work

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

Combination of two effects: *selection* and *complementarity*

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

Loreau 1998 *PNAS*

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

![Graph A](image.png)  

![Graph B](image.png)

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...)

![Image](image.png)
The *Diversity-Productivity* relationship

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

Forest: 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 $sp. \textit{richness}$-$\textit{productivity}$ relationship with a forest succession model

ForClim

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

$\rightarrow$ \textit{Virtual experiments} on the gradient
Virtual experiments: principle

Species pool

Plot
site-specific conditions (climate, soil)

Simulation for 2000 years
Forest dynamics/succession

Composition
Relative abundance
Productivity
Virtual experiments: principle

1 species

= 30 « monocultures »
Virtual experiments: principle

Extract composition, abundance and productivity
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

\[
\begin{align*}
\binom{30}{1} &= 30 \quad \binom{30}{2} = 435 \\
\binom{30}{28} &= 435 \quad \binom{30}{29} = 30 \quad \binom{30}{30} = 1 \\
\binom{30}{15} &= 155,117,520
\end{align*}
\]

⇒ 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 $\rightarrow \sim 150,000$ 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

![Box plot showing productivity vs. realized species richness across 11 sites, with statistical significances for Site, Sp. Richness, and Composition, and a trend for Site x Sp. Rich.]

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

$n=147741$

11 sites altogether
Exploring the $SR$-$Productivity$ relationship with a forest succession model: Results

A positive trend across sites

Saturation

Large variation across sites

$n=147741$
11 sites altogether

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 at each site

<table>
<thead>
<tr>
<th>Site</th>
<th>T &gt; 9°C</th>
<th>6°C &lt; T &lt; 9°C</th>
<th>3°C &lt; T &lt; 6°C</th>
<th>T &lt; 3°C</th>
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<tr>
<td>Huttwil</td>
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<tr>
<th>Site</th>
<th>P&lt;0.001</th>
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<tr>
<td>SR</td>
<td>P&lt;0.001</td>
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<tr>
<td>Site x SR</td>
<td>P&lt;0.001</td>
</tr>
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</table>

Non-biased estimate of the median
Exploring the \( SR\)-Productivity relationship with a forest succession model: Results

Diverse forests are more productive than monocultures

Non-transgressive overyielding

\[ n=147741 \]

11 sites altogether

= 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

\[ \Delta Y = \text{Net biodiversity effect} \]

Partitioning method
Loreau and Hector (2001)
Exploring the \textit{SR-Productivity} relationship with a forest succession model: Results

The positive trend is caused by complementarity between species

\( \Delta Y = \text{Net biodiversity effect} \)

\( \Rightarrow \text{Overyielding} \)

\textit{Partitioning method}

Loreau and Hector (2001)

\textbf{Selection}

\( P<0.001 \)

Slope = 0.02

\textbf{Complementarity}

(in 80\% of cases)

\( P<0.001 \)

Slope = 0.06
Exploring the *SR-Productivity* relationship with a forest succession model: Results

A positive functional diversity – productivity relationship

![Boxplot showing the relationship between Functional Diversity (FDi) and Productivity (t/ha/yr).](image)

- **FDi** $P < 0.001$
- $n = 147741$
- 11 sites altogether
Exploring the \textit{SR-Productivity} relationship with a forest succession model: \textbf{Results WHY?}
Exploring the \textit{SR-Productivity} relationship with a forest succession model: \textbf{Results}

\textbf{WHY?}

\textasciitilde \textit{Species richness}

\textasciitilde \textit{Diversity in parameter values}
  \textit{Maximum height} \textit{Growth rate} \textit{Shade tolerance}

\textbf{State}

\textasciitilde \textit{LAI}

\textasciitilde \textit{Dead biomass}

\textasciitilde \textit{Mortality events}

\textbf{Variability}

\textasciitilde \textit{Variability in LAI}

\textasciitilde \textit{Heterogeneity in tree heights and light in the canopy}

\textasciitilde \textit{Response to mortality events}

\textasciitilde \textit{Turnover in biomass}

\textasciitilde \textit{Productivity}
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

CO₂ fertilization
Temperature and precipitation increase/decrease
Photosynthetic and respiration rates

Species range

Local extinctions
Colonizations

Community composition

Ecosystem functioning
Impacts of global change on forests

Global Change

CO₂ fertilization
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Local extinctions
Colonizations
Species range
Community composition
Ecosystem functioning
Impacts of global change on forests

Global Change

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

- Local extinctions
- Colonizations
- CO₂ fertilization
- Temperature and precipitation increase/decrease
- Photosynthetic and respiration rates

Community composition → Ecosystem functioning
Using ForClim to investigate the interplay between climate change, diversity, and forest productivity

Current conditions

3 RCMs 2090-2100 A1b scenario

Productivity

Sp. richness
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

Current conditions

3 RCMs 2090-2100 A1b scenario

- **KNMI – RACMO2**
  - +3.5 °C
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- **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,..., 25, 27, 28, 29, 30 → 7,430 tested combinations x 11 sites = 81,730 simulations

Current conditions + 3 RCMs → 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

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

Adelboden = « cold site »

Schwerin = « dry site »

Confirmation of the pattern (p < 0.001)

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Change in Mean Productivity</th>
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<tbody>
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... to be confirmed with an analysis at each site

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Change in mean productivity: Arrows pointing downwards indicate decreases.

Change in SR-Prod. slope: Arrows pointing upwards indicate increases.

- Adelboden: No change
- Basel: Increase in SR-Prod. slope
- Bern: Increase in mean productivity
- Bever: Increase in mean productivity
- Cottbus: Decrease in mean productivity, increase in SR-Prod. slope
- Davos: Increase in mean productivity
- Grande Dixence: Increase in mean productivity
- Huttwil: Increase in SR-Prod. slope
- Schaffhausen: Increase in mean productivity
- Schwerin: Increase in SR-Prod. slope
- Sion: Increase in mean productivity
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
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Hervé Jactel
Michel Loreau
Tanya Handa
Alain Paquette
MariCarmen Ruiz-Jaen
Jurgis Sapijanskas
Andy Hector
Bernhard Schmid
Niklaus Zimmermann
Abiotic and biotic factors

Abiotic environmental filters

Continental scale

Abiotic and biotic filters

Continental diversity

Climate and soil
Dispersal

Regional scale

Climate and soil
Competition

Regional diversity

Productivity

Local scale

Diversity of the community

Linking climate, biodiversity and ecosystem functioning
Abiotic and biotic factors

Abiotic environmental filters

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Local scale

Diversity of the community

Process-based models (DGVM)

Climate

Abiotic and biotic filters

Climate  soil

Climate

Dispersal

Competition

Habitat-based models

Process-based models

Forest succession model

Productivity

Process-based models

Climate soil

Climate

Dispersal
**Abiotic and biotic factors**

- **Abiotic environmental filters**
  - Continental scale
- **Abiotic and biotic filters**
  - Regional diversity
  - Continental diversity
- **Abiotic and biotic factors**
  - Local scale

**Habitat-based models**

- Process-based models (DGVM)
  - Climate
  - Soil
  - Dispersal
  - Competition

**Process-based models**

- Habitat-based models
  - Forest succession model

**Climate change**

- Productivity

**Linking climate, biodiversity and ecosystem functioning**
Zone méditerranéenne = forts gradients environnementaux (température, précipitations, altitude)
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

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Massif de l’Aigoual

Massif du Canigou

Massif du Ventoux

Projet BioProFor
Site-test = Mont Aigoual

- 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…)

Gradients locaux (altitudinaux)

Gradients régionaux
Project

Field validation

Linking climate, biodiversity and ecosystem functioning

- Continental pool of species
- Regional pool of species
- Community composition
- Productivity

Field sampling
Data bases...

Sp. composition
Diversity
Functioning
Env. conditions
Linking climate, biodiversity and ecosystem functioning

Continental pool of species

Regional pool of species

Community composition

Productivity

Sp. composition
Diversity
Fonctioning
Env. conditions

Field sampling
Data bases…

Project
Field validation
Regional pool of species

Community composition

Continental pool of species

Field sampling
Data bases...

Sp. composition
Diversity
Fonctioning
Env. conditions

Phylogenetic clustering?

Phylogenetic overdispersion?

Productivity

Linking climate, biodiversity and ecosystem functioning

Project
Field validation
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
1 billion ha
25% Europe surface
Stability of forest productivity = 1/CV(Productivity)

Stability in productivity over time increases with species richness

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

Morin et al. in prep.
Future project...
Global Change

Future project...
Future project...

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
Global Change

Environment

Distributions

Biodiversity

Ecosystem Functioning

Future project...

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

1. **Continental species pool**
   - **Environmental filter**
   - **Regional species pool**
   - **Biotic interactions**
   - **Community composition**

**Spatial scale**
- **Abiotic factors**
  - Abiotic and biotic factors

**Future project...**

**Environment**
- Distributions
  - Biodiversity

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

Spatial scale

Continental species pool

Abiotic factors

Abiotic and biotic factors

Regional species pool

SDMs

Forest dynamics model

Community composition

Productivity

Environment Distributions

Biodiversity

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

Future project...

1. Spatial scale
   - Continental species pool
     - Species phylogenetically close?
     - Functional convergence?
   - Regional species pool
     - Species phylogenetically distant?
     - Functional divergence?
   - Community composition
     - Test of community ecology hypotheses

Abiotic factors

Abiotic and biotic factors

Biodiversity

Environment

Distributions
Future project...

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

a) Modelling
- Site 1
- Site i
- Site n

b) Empirical validation

= Diversity-productivity rel. according to environmental gradients