UCLouvain

Earth and Life Institute (ELI)

Exploring climate adaptation pathways through forest ecosystem modelling

Mathieu Jonard

Symposium OPTIMix

11 June 2026

UCLouvain

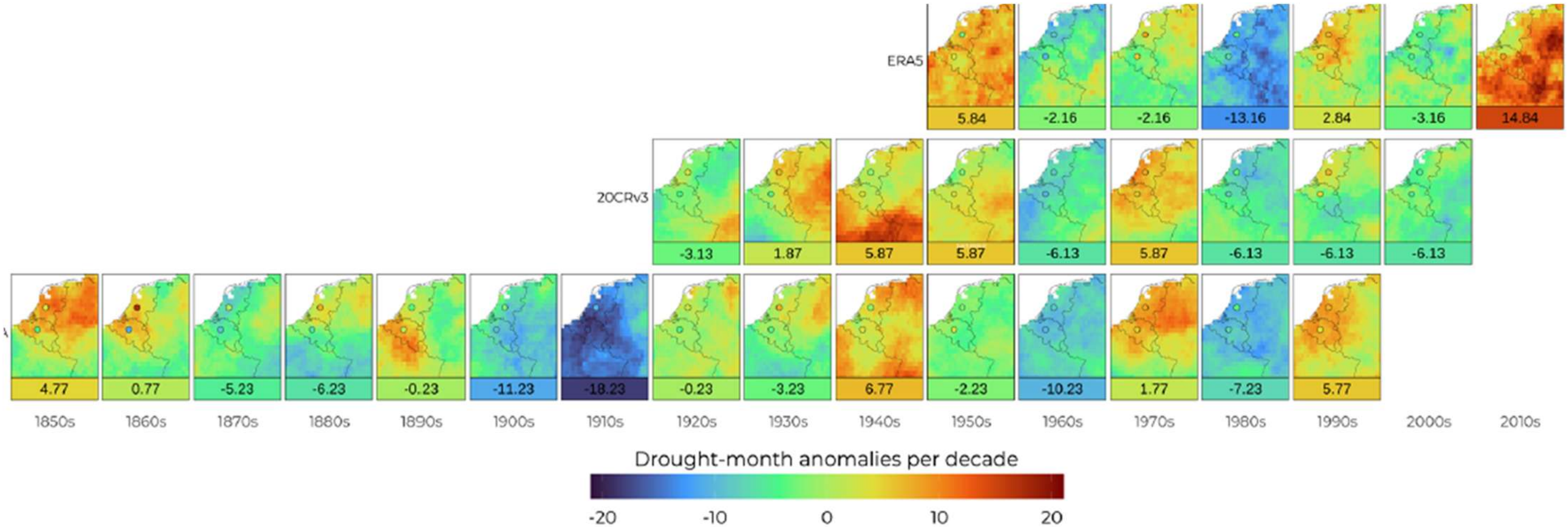
Earth and Life Institute (ELI)

1. Forests in a changing climate:

vulnerabilities, risks and adaptation needs

Current climate change and forest vulnerabilities

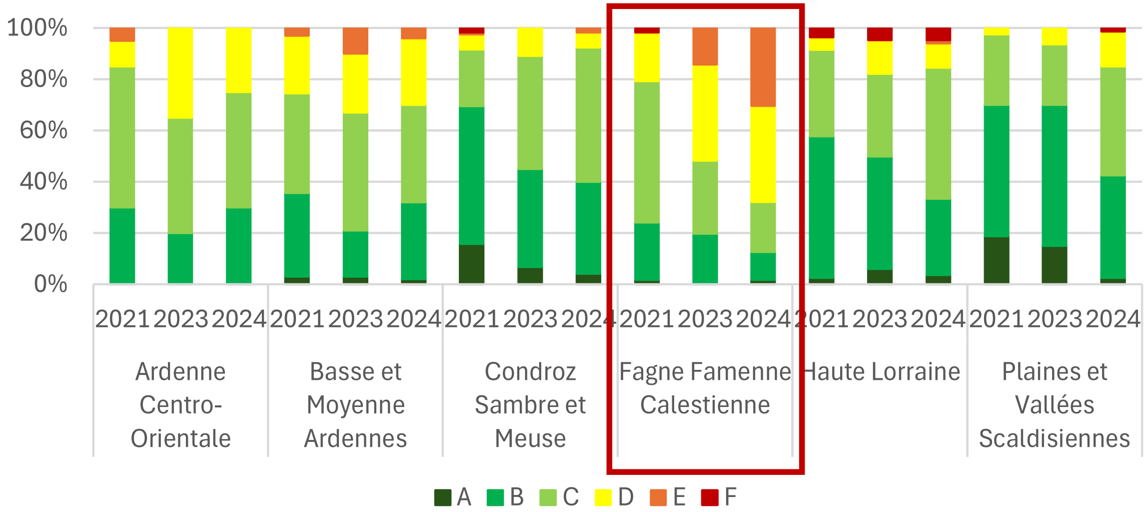
SPEI-based decadal drought index in western Central Europe



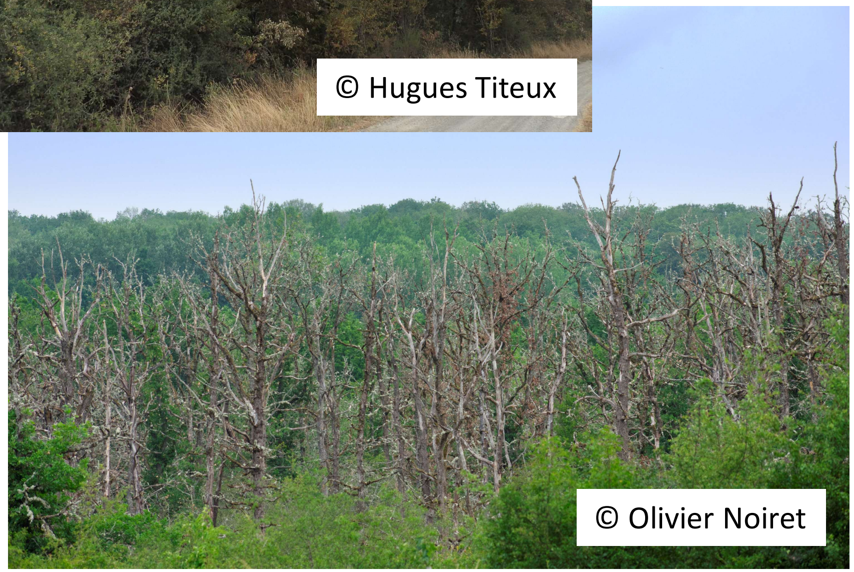
Neimry *et al.* (accepted)

Current climate change and forest vulnerabilities

Recent crown condition changes in pedunculate oak across bioclimatic zones
(DEPERIS method)

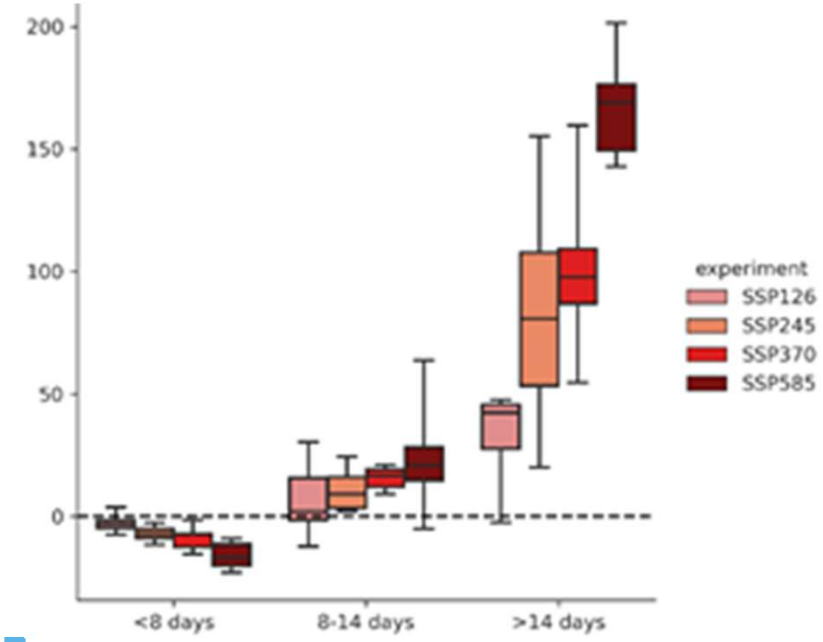


Observatoire Wallon de la Santé des Forêts (2025)



Projected climate change and associated risks

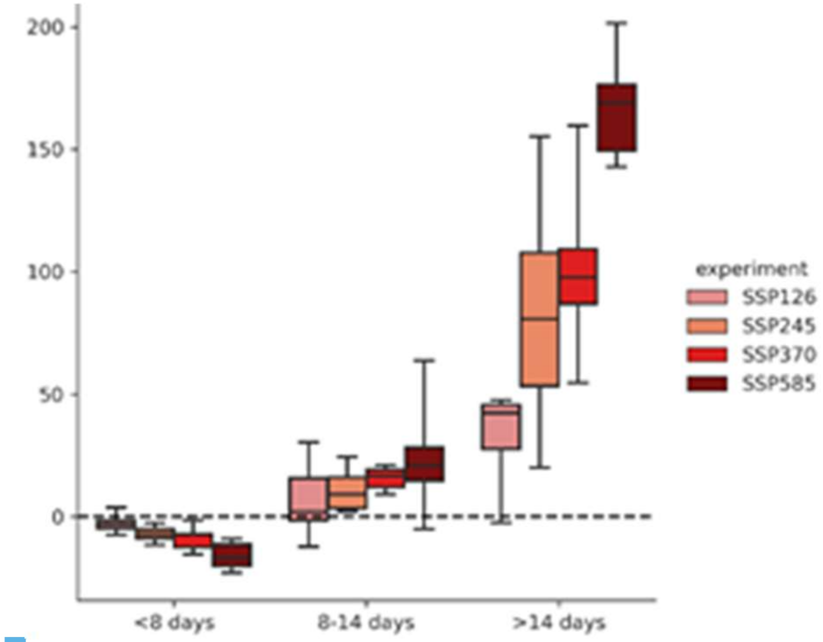
Relative change in drought length (%) from 1976-2014 to 2071-2100



Marchi *et al.* (2024)

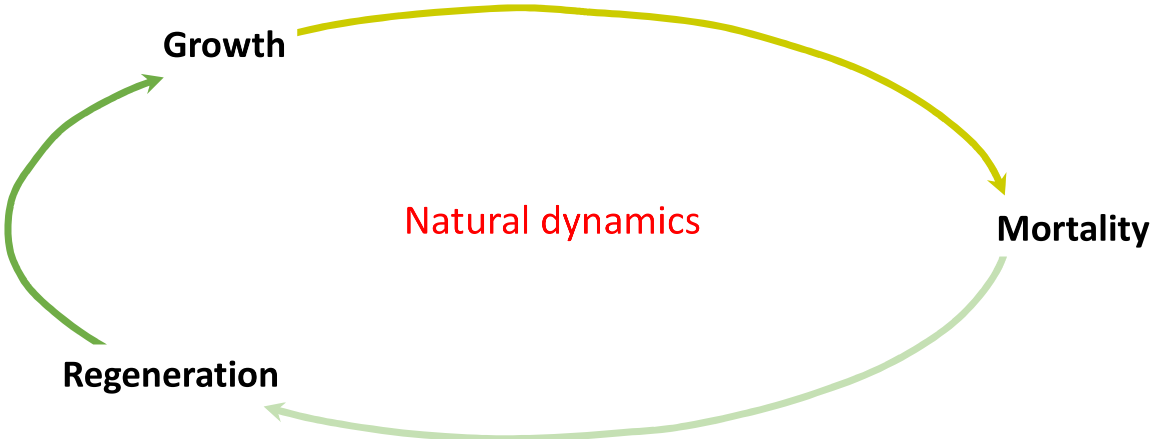
Projected climate change and associated risks

Relative change in drought length (%) from 1976-2014 to 2071-2100



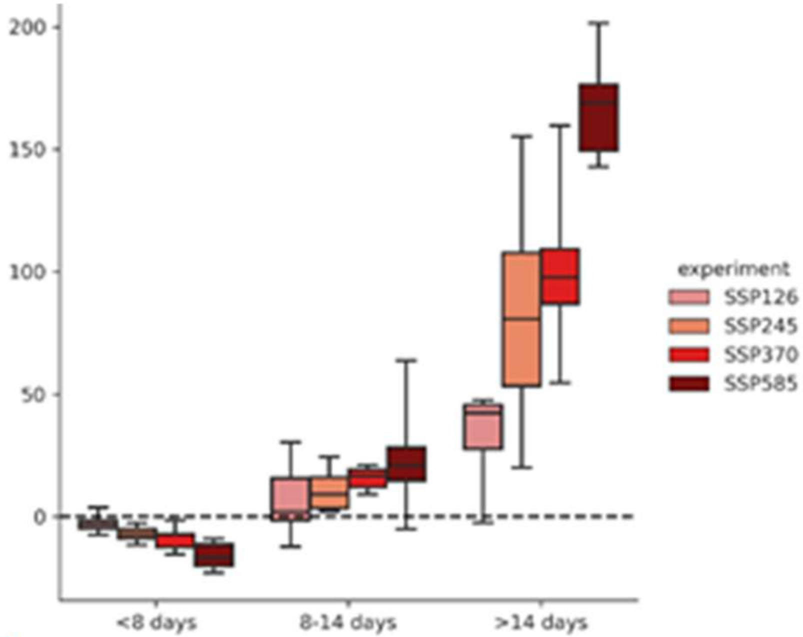
Marchi *et al.* (2024)

Impact on forest dynamics



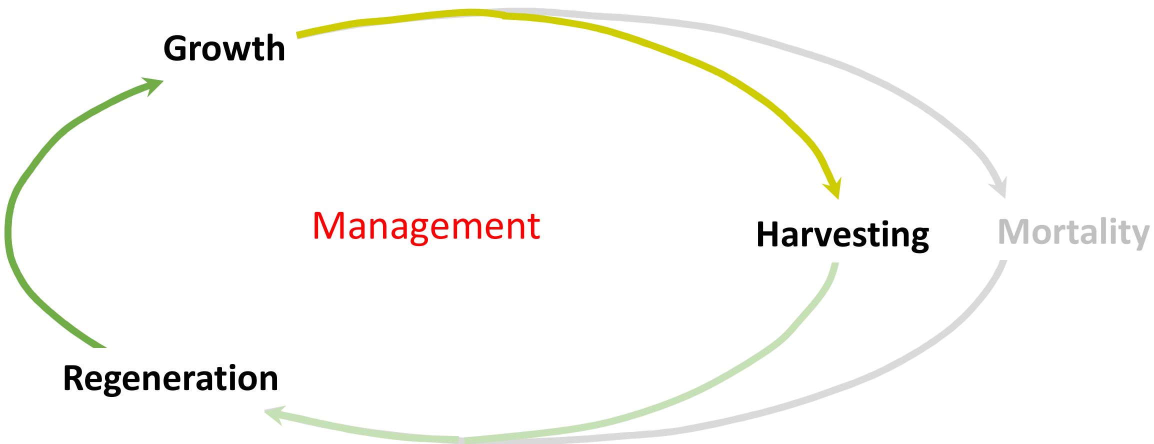
Projected climate change and associated risks

Relative change in drought length (%) from 1976-2014 to 2071-2100



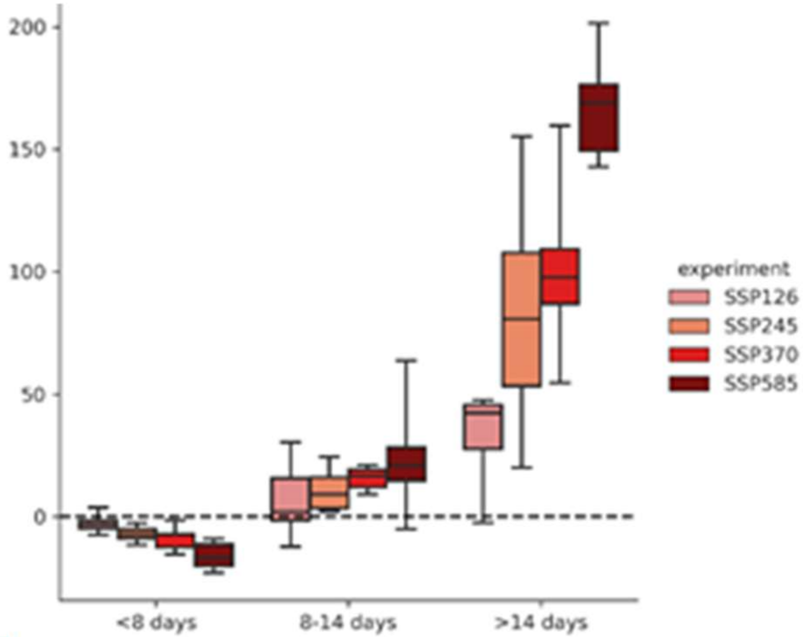
Marchi *et al.* (2024)

Impact on forest dynamics



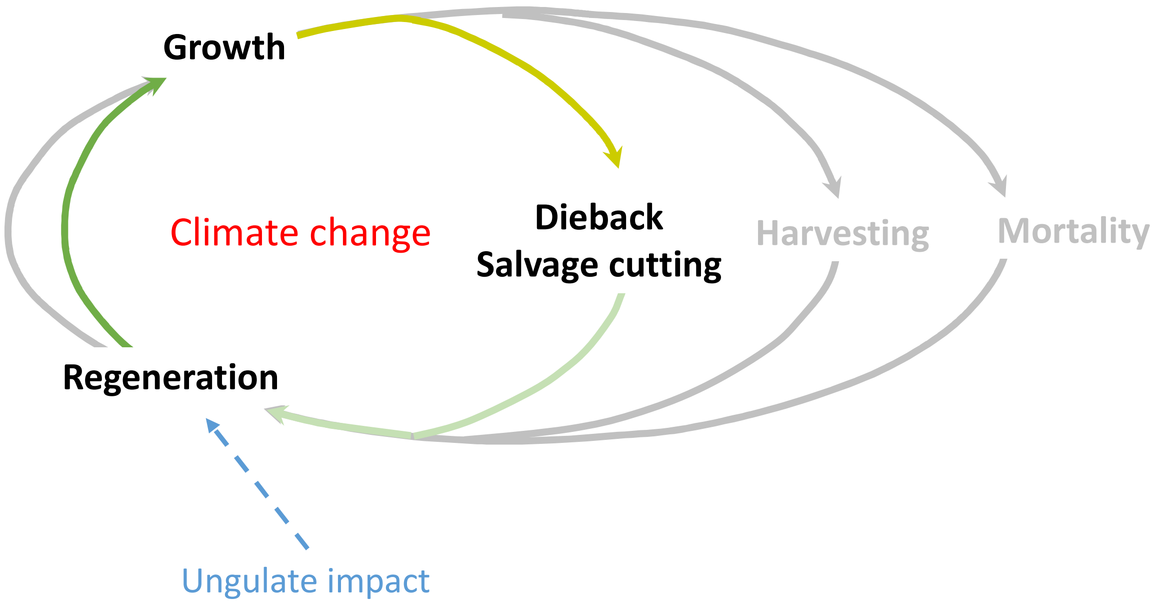
Projected climate change and associated risks

Relative change in drought length (%) from 1976-2014 to 2071-2100



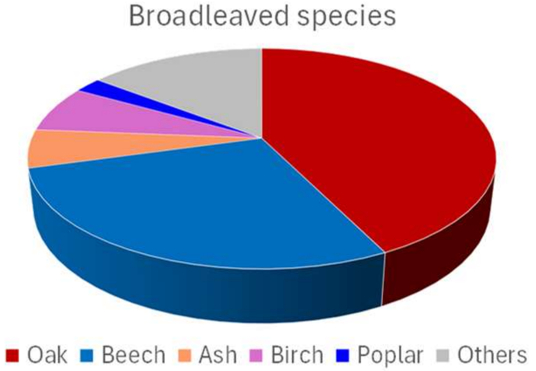
Marchi *et al.* (2024)

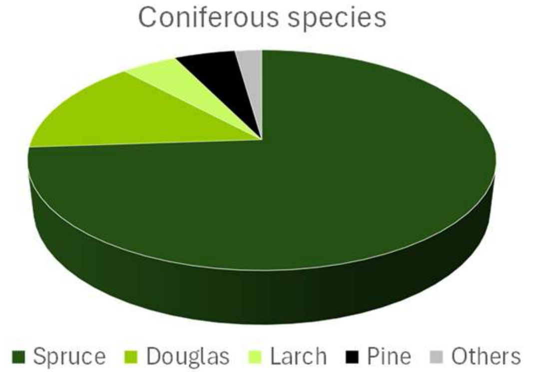
Impact on forest dynamics



Improving forest resilience: an urgent necessity!

Forest tree species in Wallonia

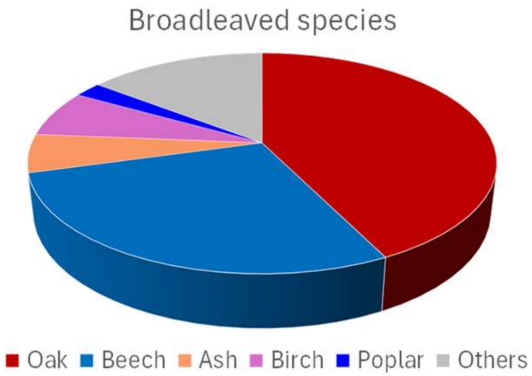


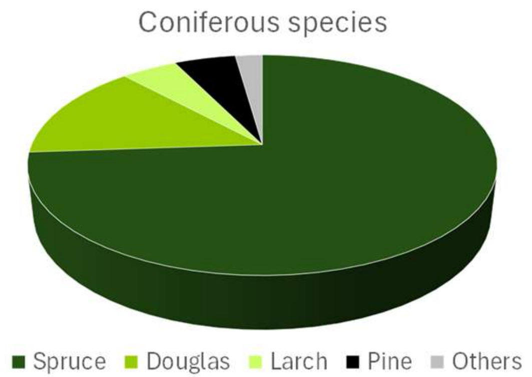


Panorabois (2024)

Improving forest resilience: an urgent necessity!

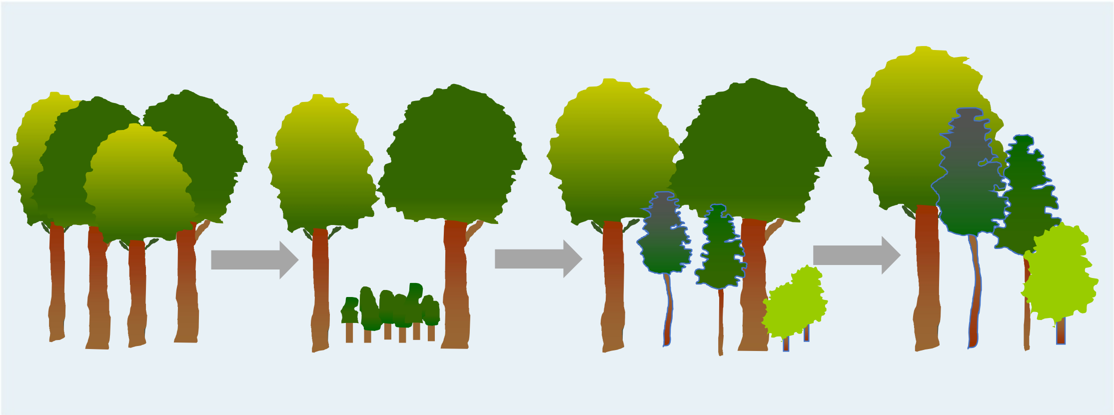
Forest tree species in Wallonia





Panorabois (2024)

Diversification in tree age and species composition



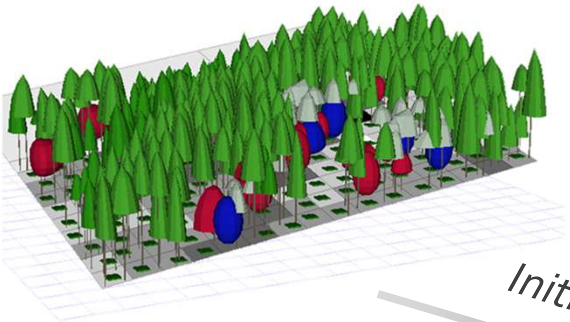
2. Forest dynamics modelling:

anticipating stress

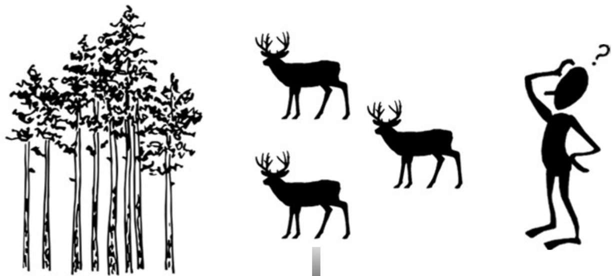
& evaluating silvicultural strategies

Using a model to build climate-resilient forests

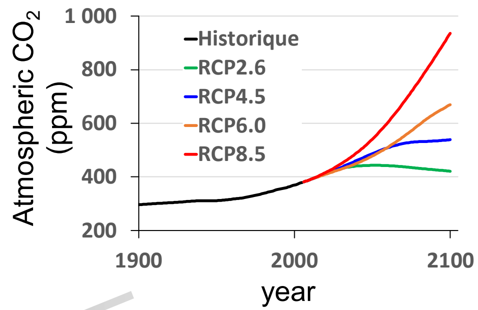
Case studies



Forest management



Climate scenarios



Initialisation

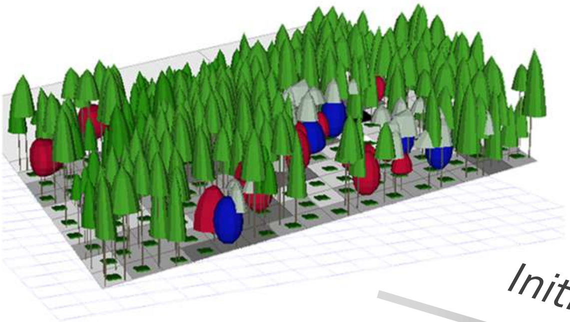
Process-based forest dynamics model

Simulation analysis

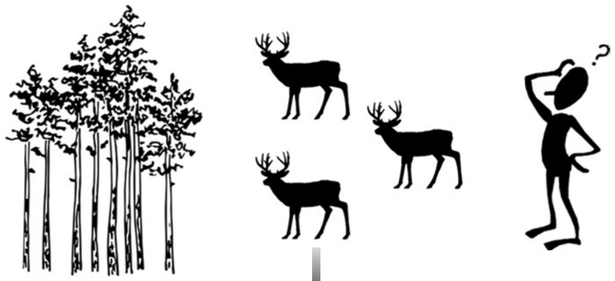
- Water stress
- Ecosystem services
- Resilience
- Sustainability

Using a model to build climate-resilient forests

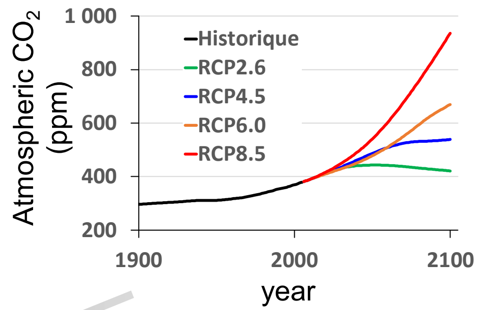
Case studies



Forest management



Climate scenarios



Initialisation

Process-based forest dynamics model

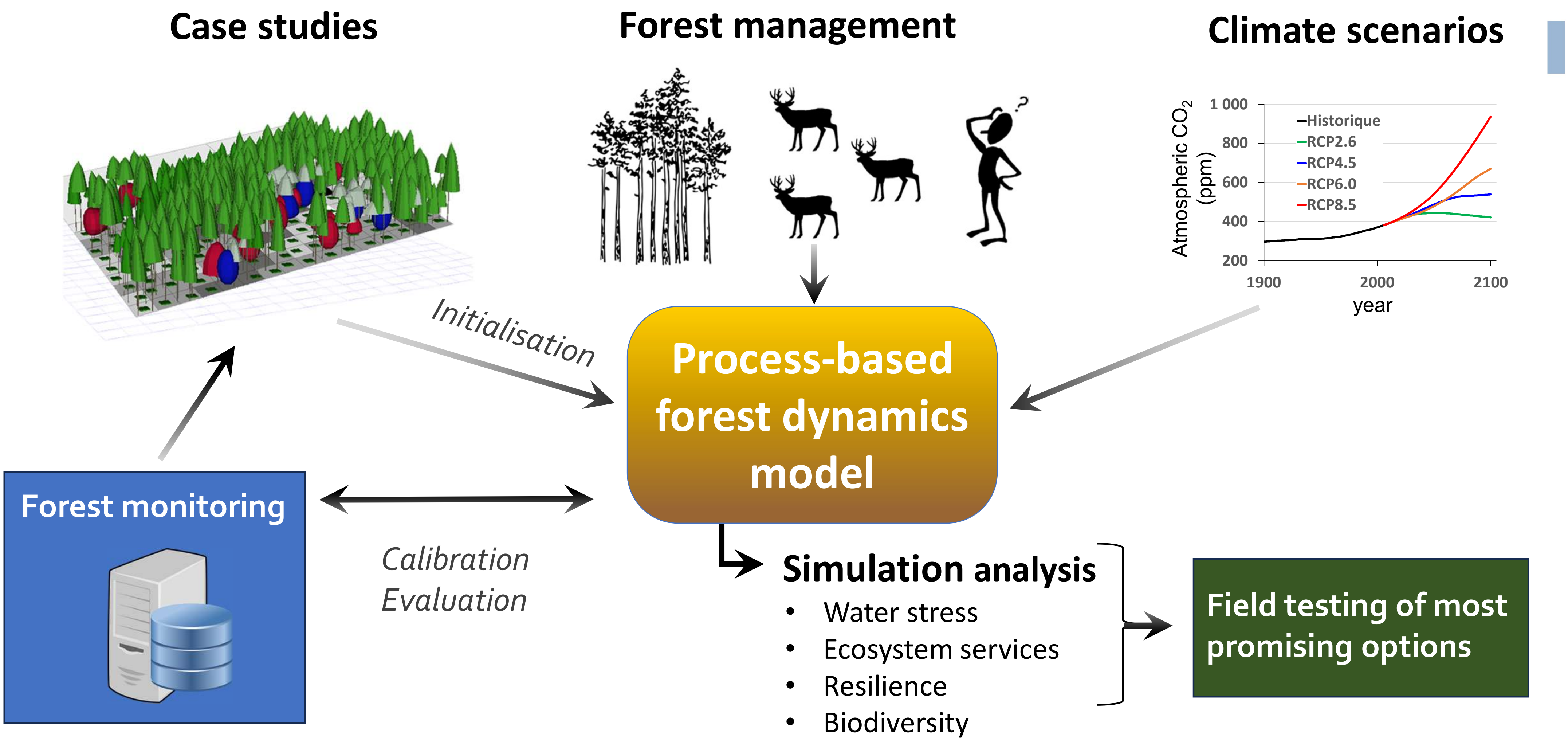
Forest monitoring

Calibration
Evaluation

Simulation analysis

- Water stress
- Ecosystem services
- Resilience
- Sustainability

Using a model to build climate-resilient forests



3. Inside HETEROFOR:

building a model for forest management in a changing climate

Why a new model?

Simulate long-term stand dynamics under unprecedented climate conditions for structurally-complex forests

Why a new model?

Simulate long-term stand dynamics under unprecedented climate conditions for structurally-complex forests

→ **model characteristics :**

1. Long-term stand dynamics → **regeneration, growth and mortality**

Why a new model?

Simulate long-term stand dynamics under unprecedented climate conditions for structurally-complex forests

→ model characteristics :

1. Long-term stand dynamics → **regeneration, growth and mortality**
2. Unprecedented climate conditions → **process-based (resource use: light, water, nutrients)**

Why a new model?

Simulate long-term stand dynamics under unprecedented climate conditions for structurally-complex forests

→ model characteristics :

1. Long-term stand dynamics → **regeneration, growth and mortality**
2. Unprecedented climate conditions → **process-based (resource use: light, water, nutrients)**
3. Structurally-complex forests → **individual-based and spatial-explicit**

Modeling forest dynamics in three phases

Regeneration

cohort approach

→

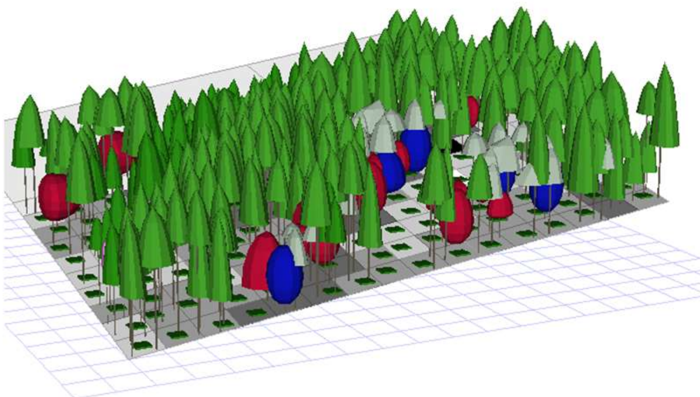
Growth

a spatially explicit and individual-based approach

→

Mortality

multiple possible mechanisms

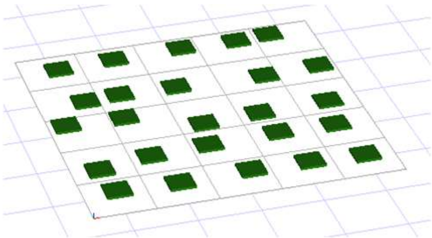


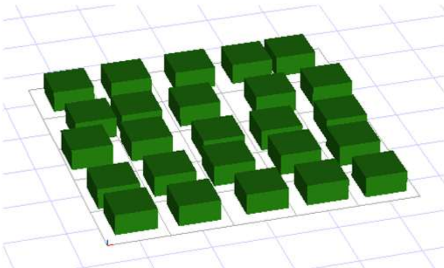
Regeneration

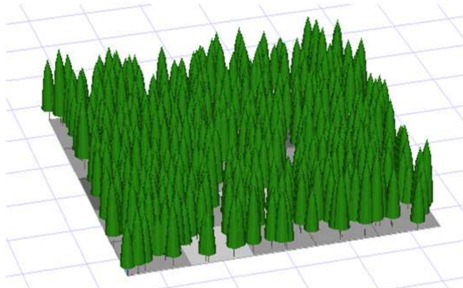
seeds → cohorts → trees

Plantation

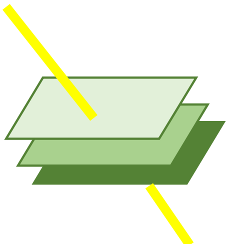
recruitment

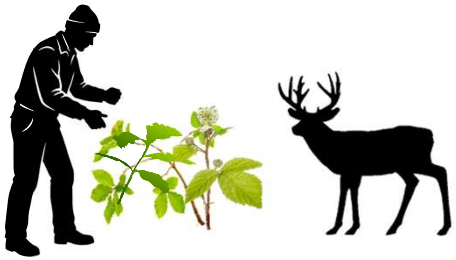




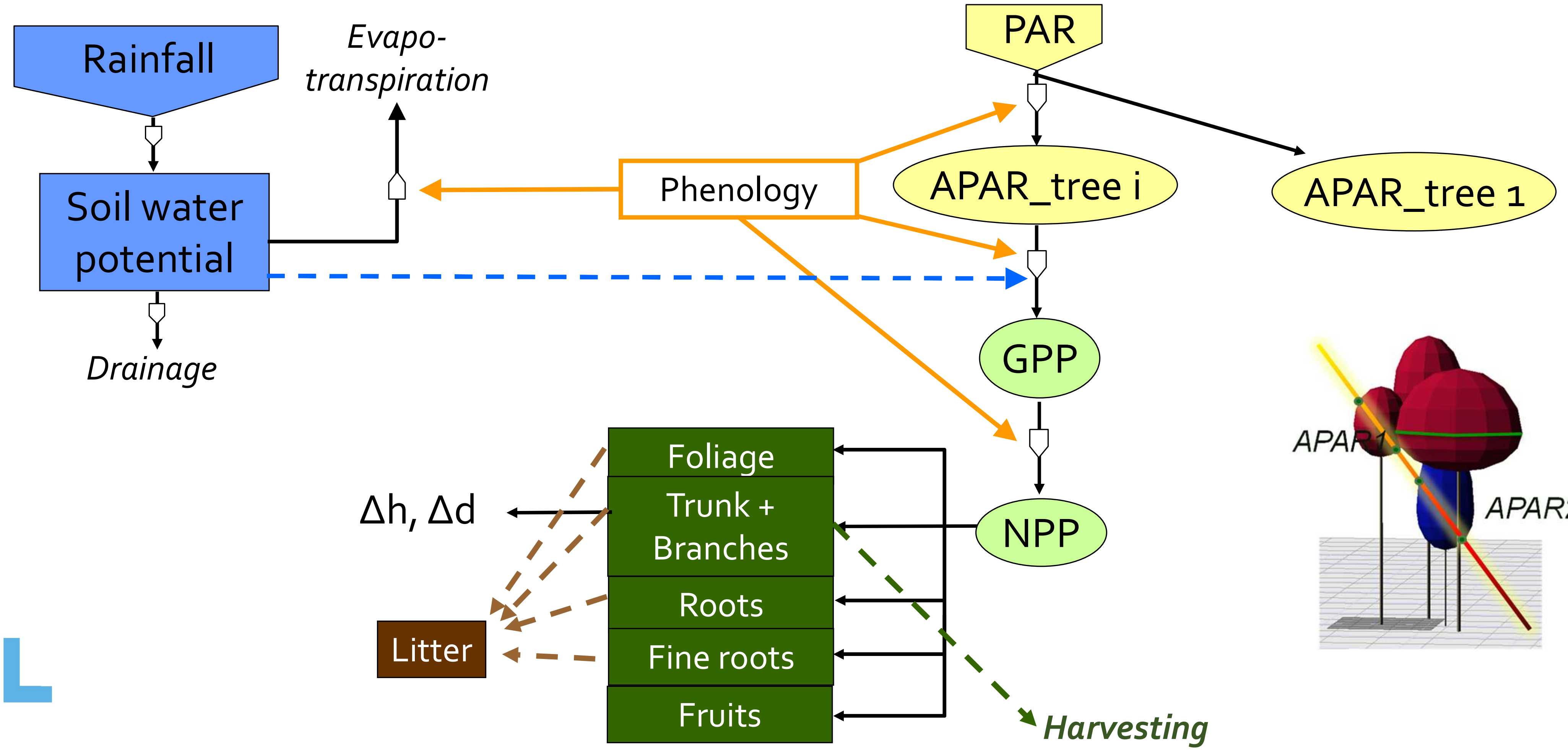


Radiative budget

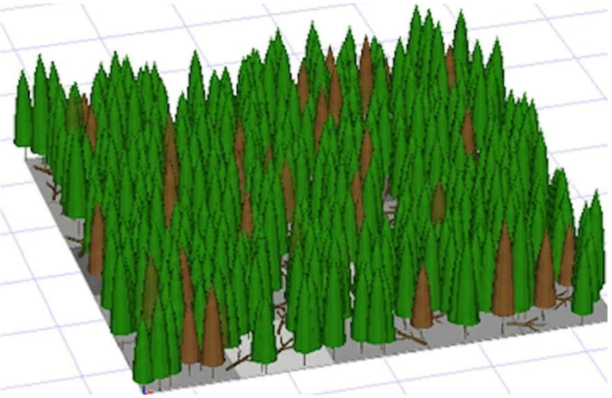


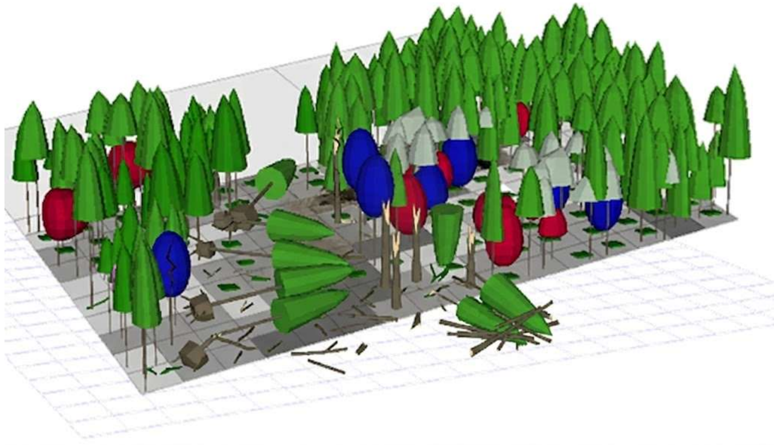


Tree growth of adult trees



Mortality: multiple possible mechanisms





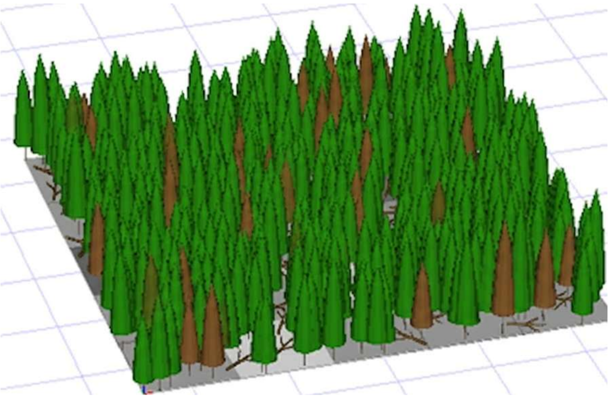
Carbon starvation
- light competition
=> self-thinning,
- reduced CUE with aging,
- water stress

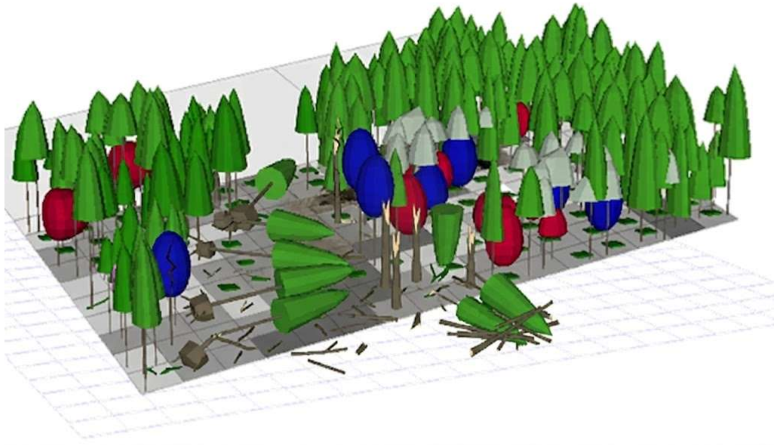
Hydraulic failure

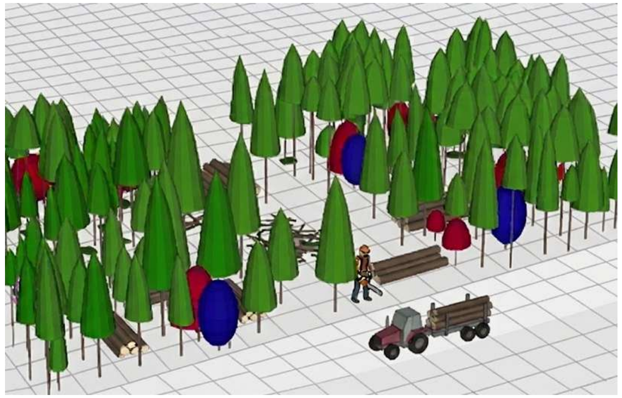
Wind damage
coupling with
an adapted version
of ForestGALES-TMC

Background mortality

Mortality: multiple possible mechanisms







Carbon starvation
- light competition
  => self-thinning,
- reduced CUE with aging,
- water stress

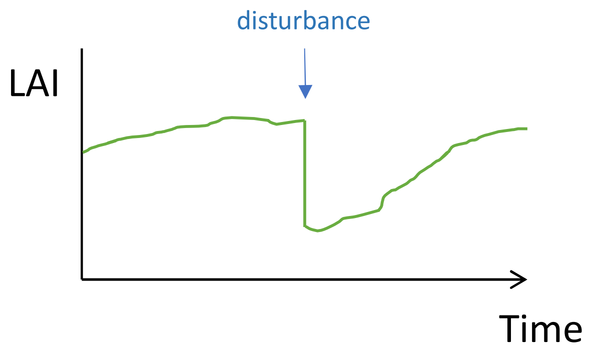
Hydraulic failure

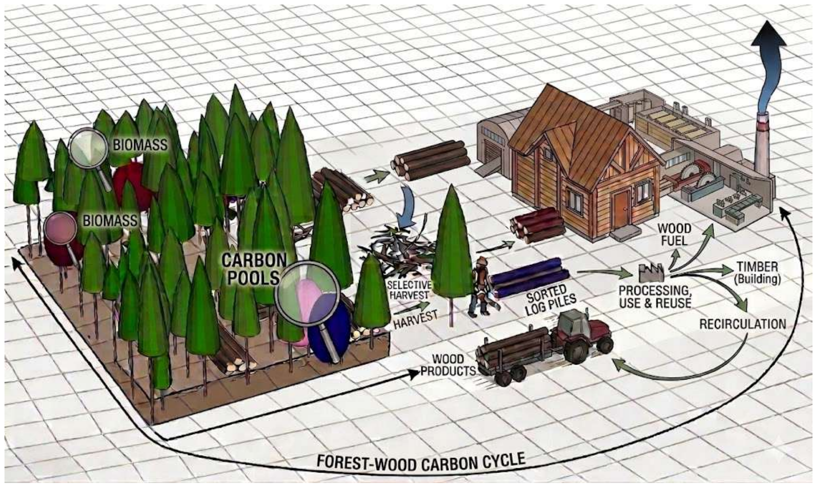
Wind damage
coupling with
an adapted version
of ForestGALES-TMC

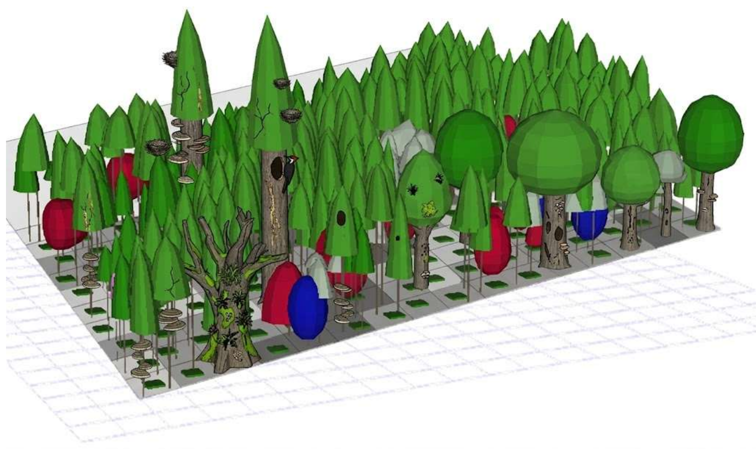
Background mortality

Silvicultural operations
- selective cutting in uneven-aged stands
- thinning in even-aged stands
- shelterwood cutting
- target tree silviculture
- gap creation
- Regeneration and vegetation clearing

Indicators of ecosystem functioning, services, and biodiversity







Resilience after disturbance

Forest-wood carbon cycle & Wood production profitability

Species diversity & tree microhabitats

4. Insights from simulation experiments

Improving forest resilience under multiple stressors: Which silvicultural strategies work best?

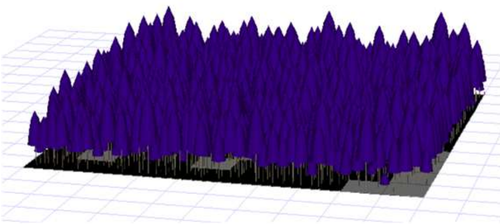
Strategy	Core principle
NM (No Management)	Reliance on natural ecosystem dyanmics without active intervention
BAU (Business As Usual)	Continuation of current forest management practices
CC (Climate Change adaptation)	Targeted adaptation to known risks through drought-adapted species enrichment
FD (Functional Diversification)	Increasing adaptive capacity through functionally diverse species mixtures

Guignabert *et al.* (2025)

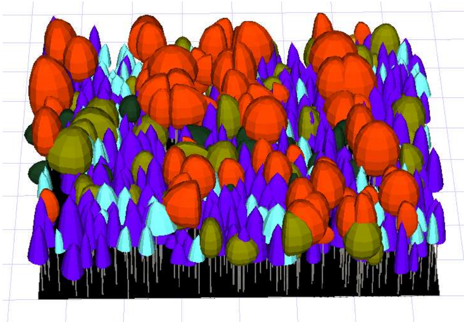
Selection of 8 sites (0.5 to 1.5ha) representative of the Quebec and Walloon forests

QUEBEC

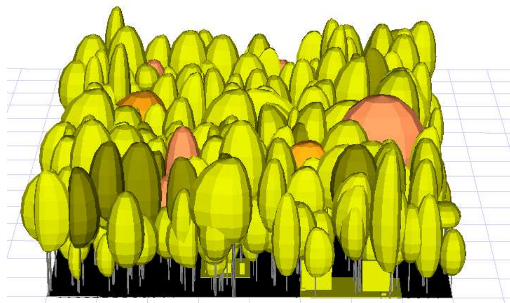
Even-aged white spruce



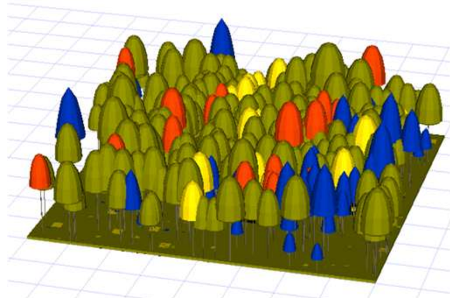
Even-aged balsam fir



Uneven-aged sugar maple

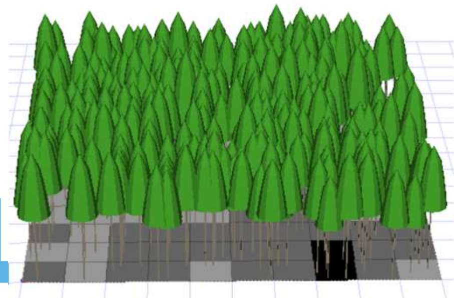


Uneven-aged red maple

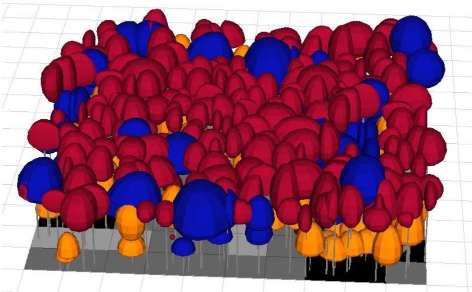


WALLONIA

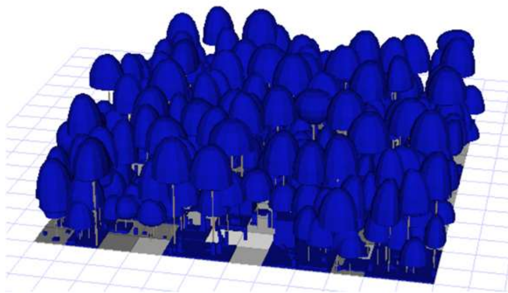
Even-aged douglas fir



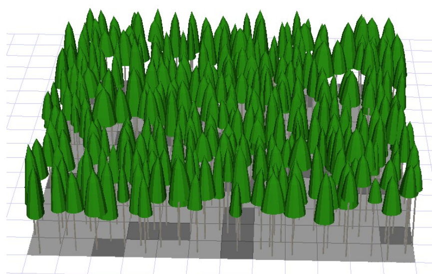
Even-aged oak



Uneven-aged beech

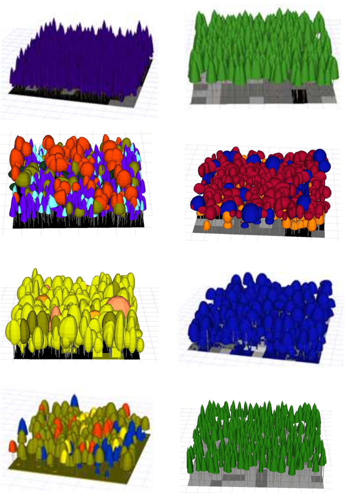


Even-aged Norway spruce



Simulation design

Case studies



Management

BUSINESS-AS-USUAL

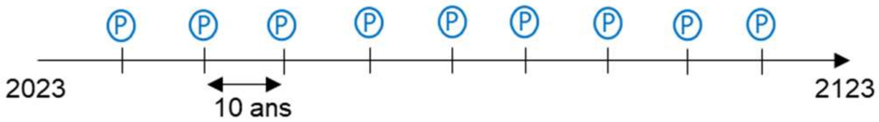
CLIMATE CHANGE ADAPTATION

FUNCTIONAL DIVERSITY

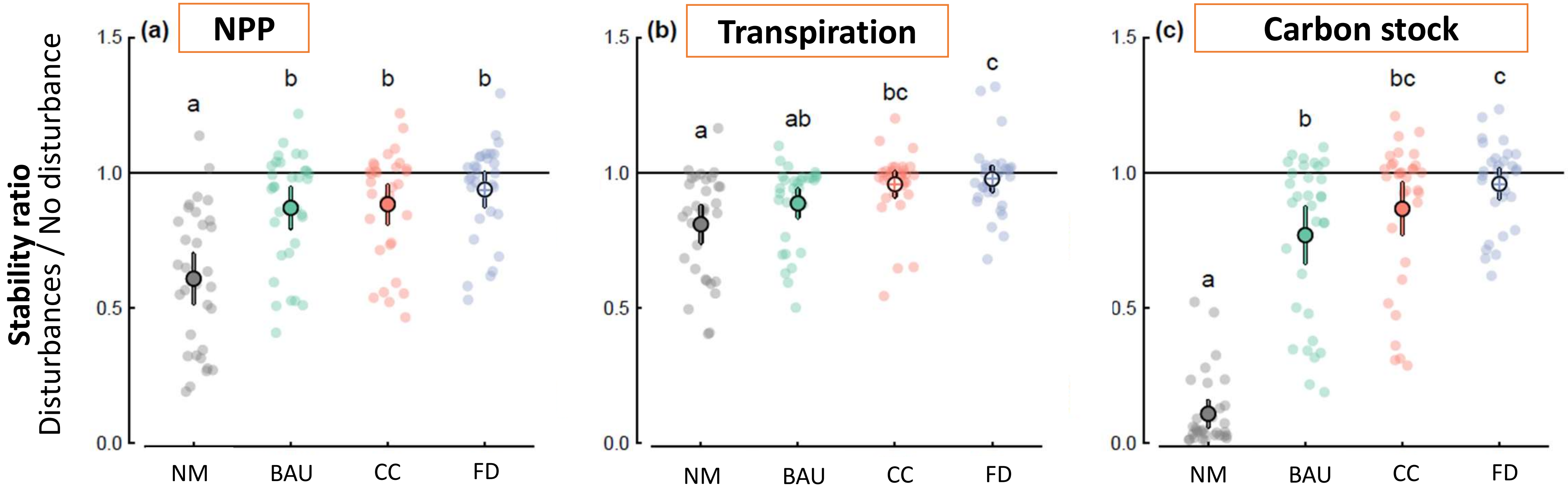
NO MANAGEMENT

Disturbances

4 disturbance regimes
+ no disturbance



Effect of four silvicultural strategies on ecosystem stability

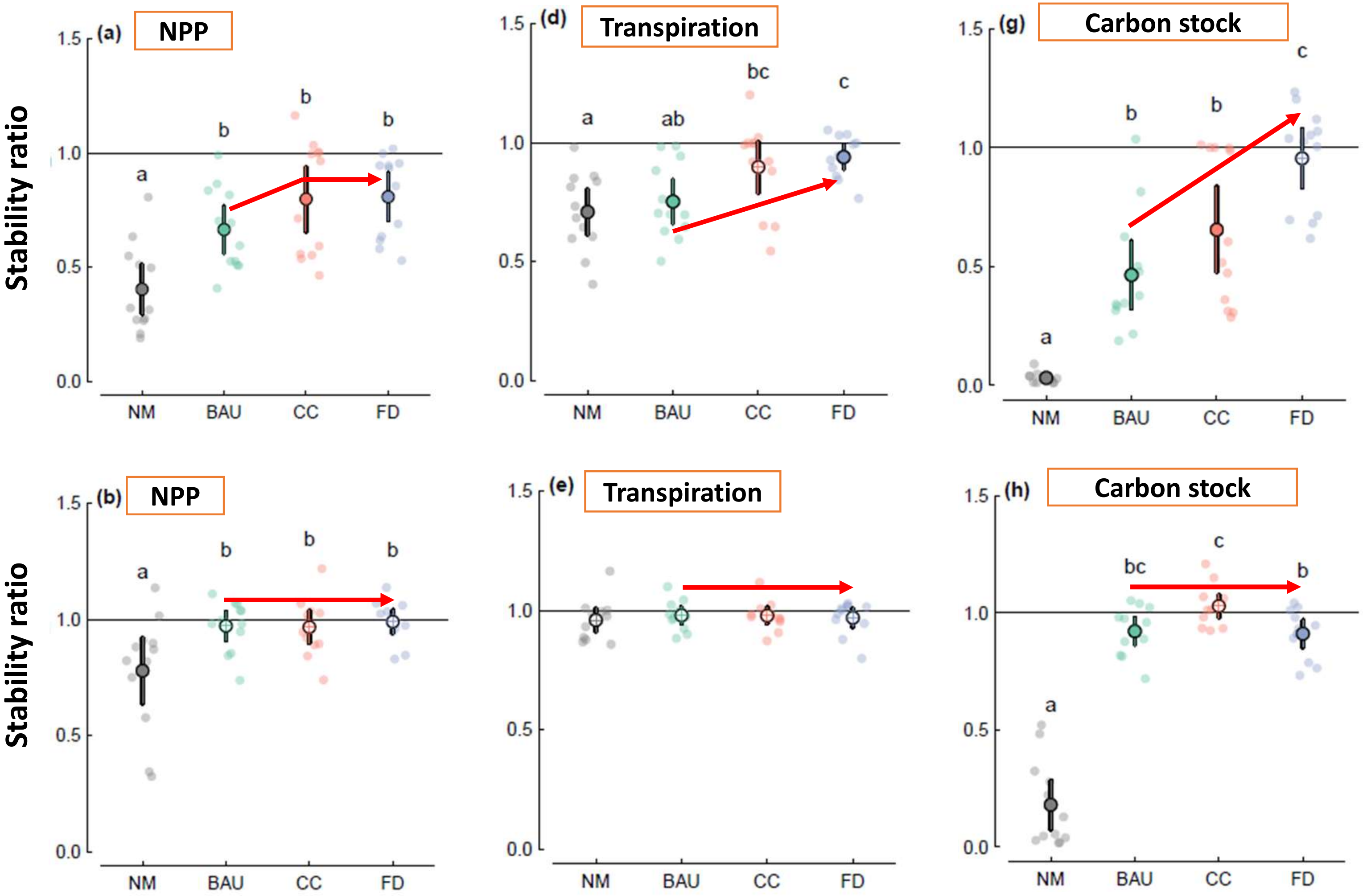


Effect of four silvicultural strategies on ecosystem stability

- **By stand type**

- coniferous stands

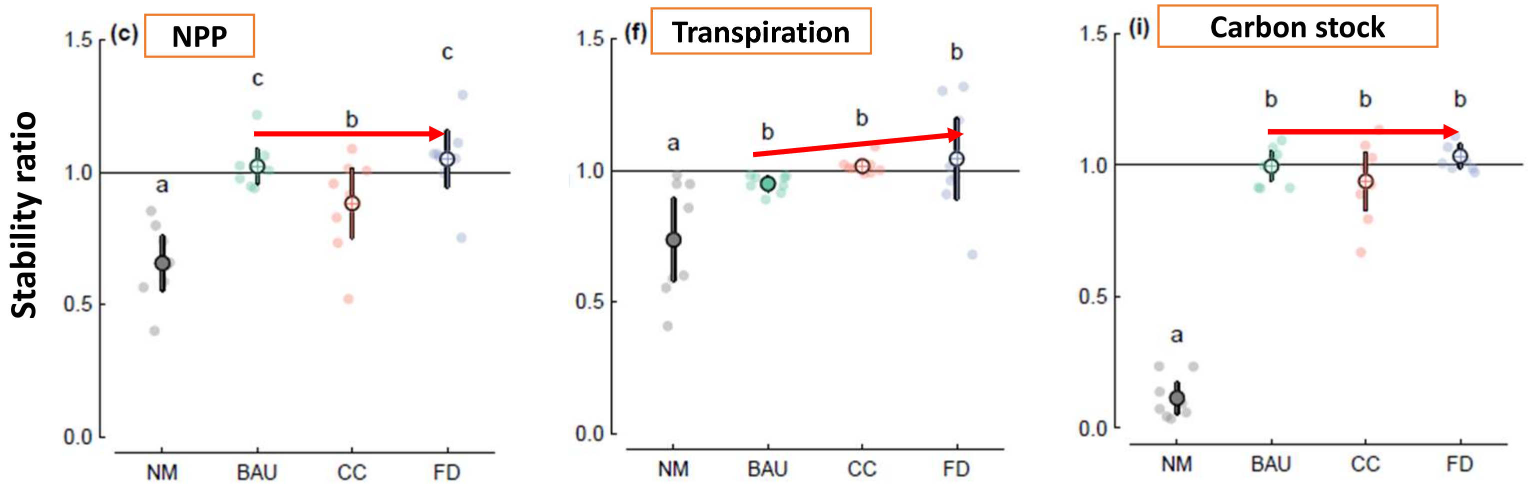
- broadleaved stands



Effect of four silvicultural strategies on ecosystem stability

- **By stand type**

- Mixed stands

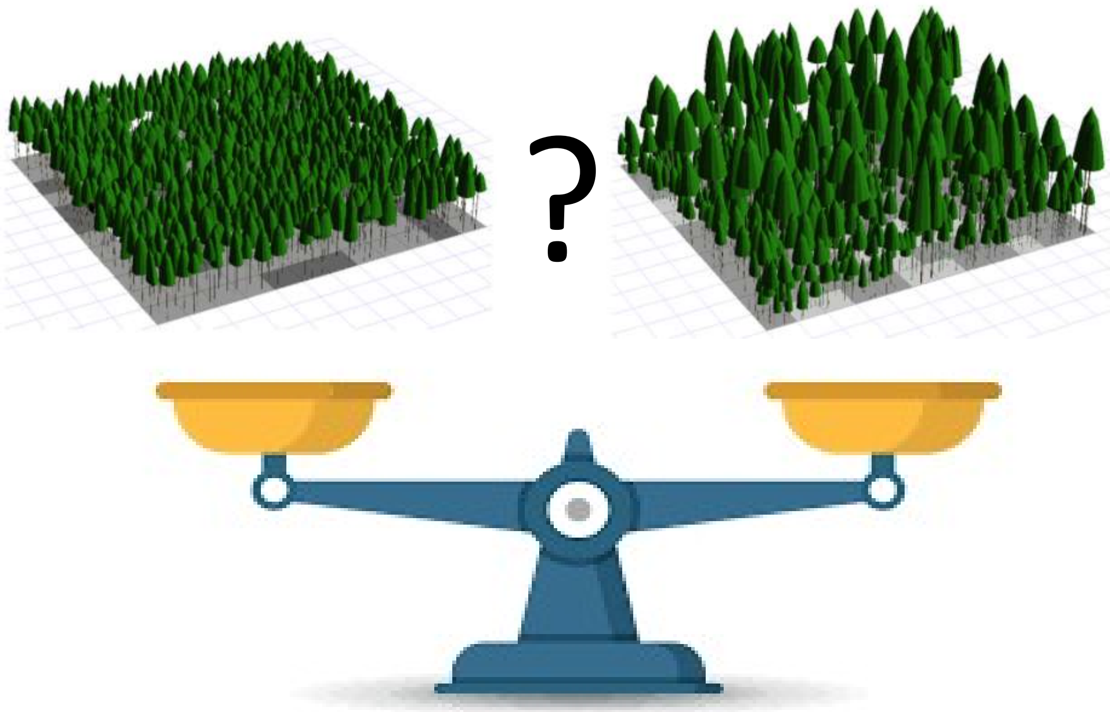


Key messages from the first simulation experiment

Functional diversification delivered the greatest gains in ecosystem stability.

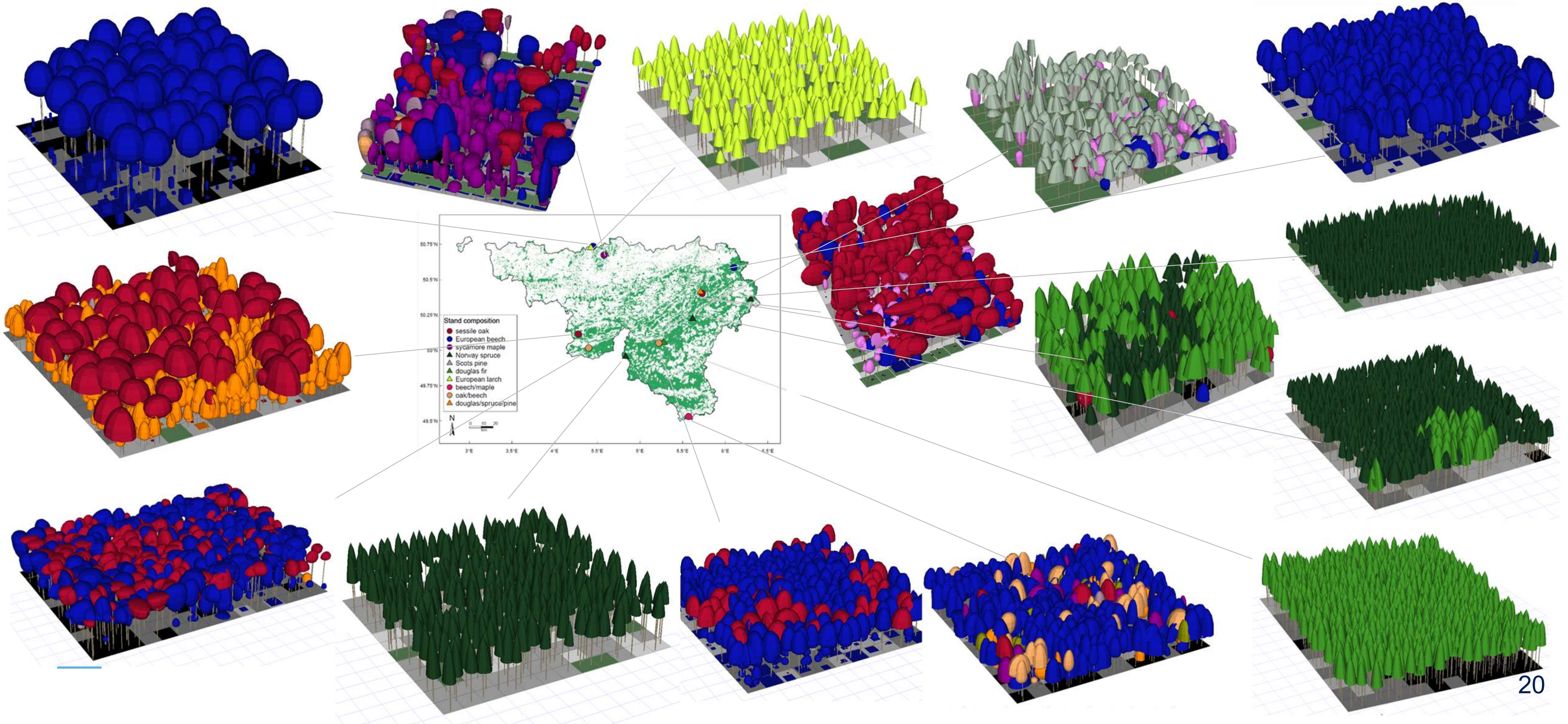
- Stability increased along the gradient: NM << BAU < CC < FD.
- Responses were strongest for carbon stocks, followed by NPP and transpiration.
- Effects were particularly pronounced in coniferous stands.

Is uneven-aged silviculture best for maximizing ecosystem functioning, services, biodiversity and resilience?



André *et al.* (2026)

Selection of 15 sites (0.5 to 1.5ha) representative of the Walloon forest



Climate and silvicultural scenarios

One climate scenario:

- SSP 3.70
- Projections from 5 GCMs
- constant atmospheric CO_2 concentration

Climate and silvicultural scenarios

One climate scenario:

- SSP 3.70
- Projections from 5 GCMs
- constant atmospheric CO_2 concentration

Two silvicultural scenarios:

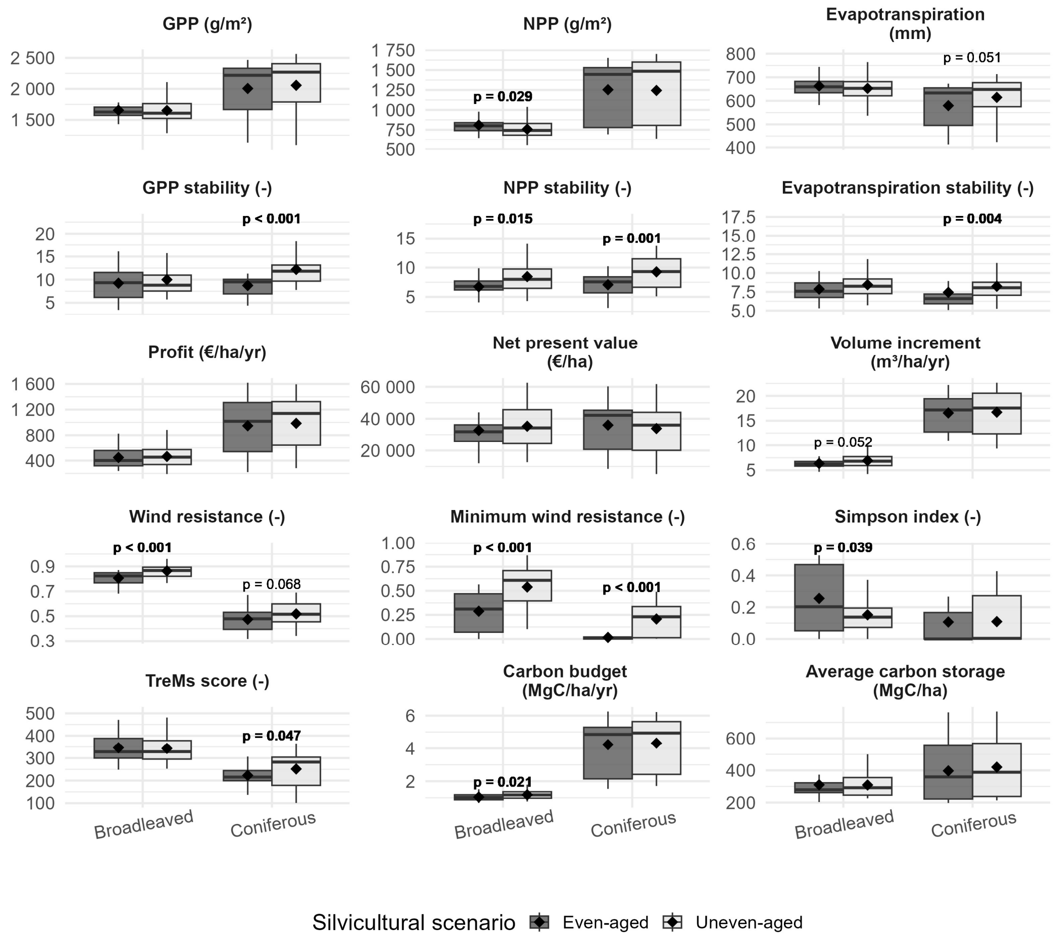
- *Continuation of the even-aged silviculture*

  shelterwood cuts and natural regeneration, target basal area from yield tables
- *Transformation to an uneven-aged structure*

  selective harvesting (< 20-25% in BA), continuous natural regeneration,

  target basal area from continuous cover forestry guidelines

Detailed effects of the silvicultural scenario on various indicators



Relative effect of the uneven-aged silviculture

Relative uneven-aged effect

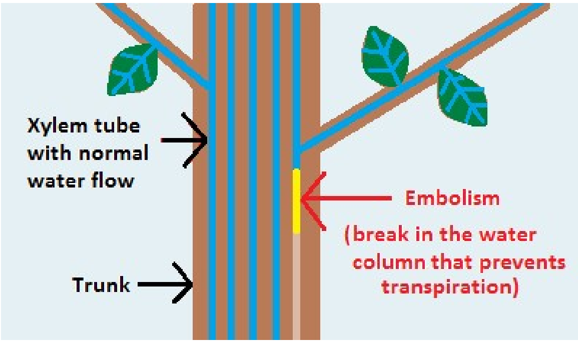
$$= \frac{Unevenaged - Evenaged}{Evenaged} \cdot 100$$

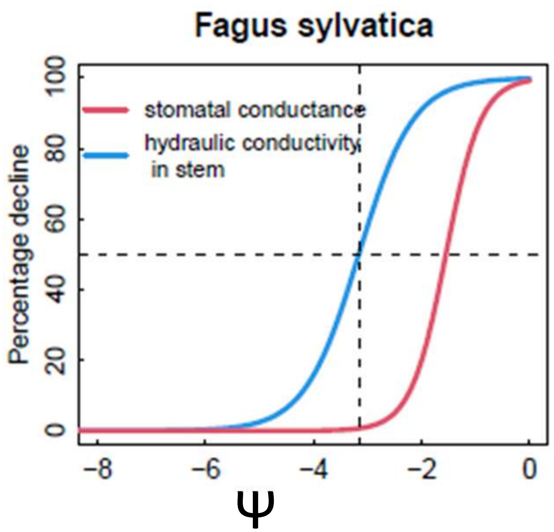
Criterion	Indicator	Broadleaved	Coniferous
Ecosystem functioning	GPP		
	NPP	**-6.4 %**	
	Evapotranspiration		+5.9 %
Wood production	Volume production	+8.9 %	
	Profit		
	Net present value		
Biodiversity	Simpson index	**-40.4 %**	
	Tree micro-habitat		**+12.0 %**
Resilience	GPP stability		**+33.1 %**
	NPP stability	**+25.7 %**	**+26.8 %**
	Evapotranspiration stability		**+10.3 %**
	Wind resistance	**+7.1 %**	+8.9 %
	Wind resistance min	**+87.1 %**	**+1163.3 %**
Carbon	C budget	**+13.4 %**	
	C storage		

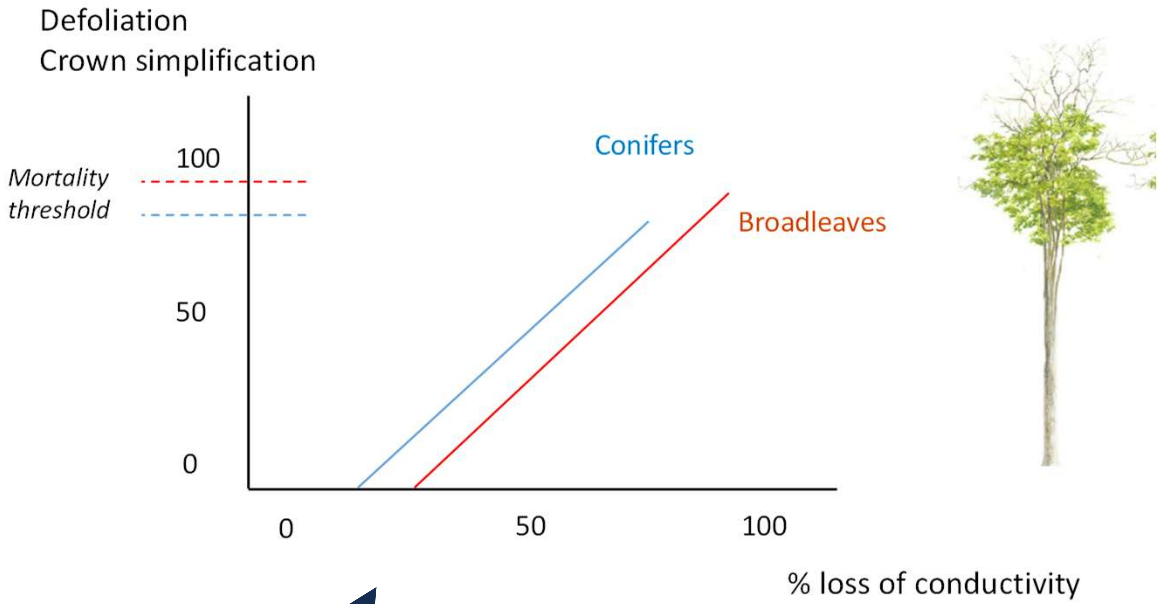
5. Future challenges for forest modelling:

integrating mechanical, hydraulic and nutritional constraints

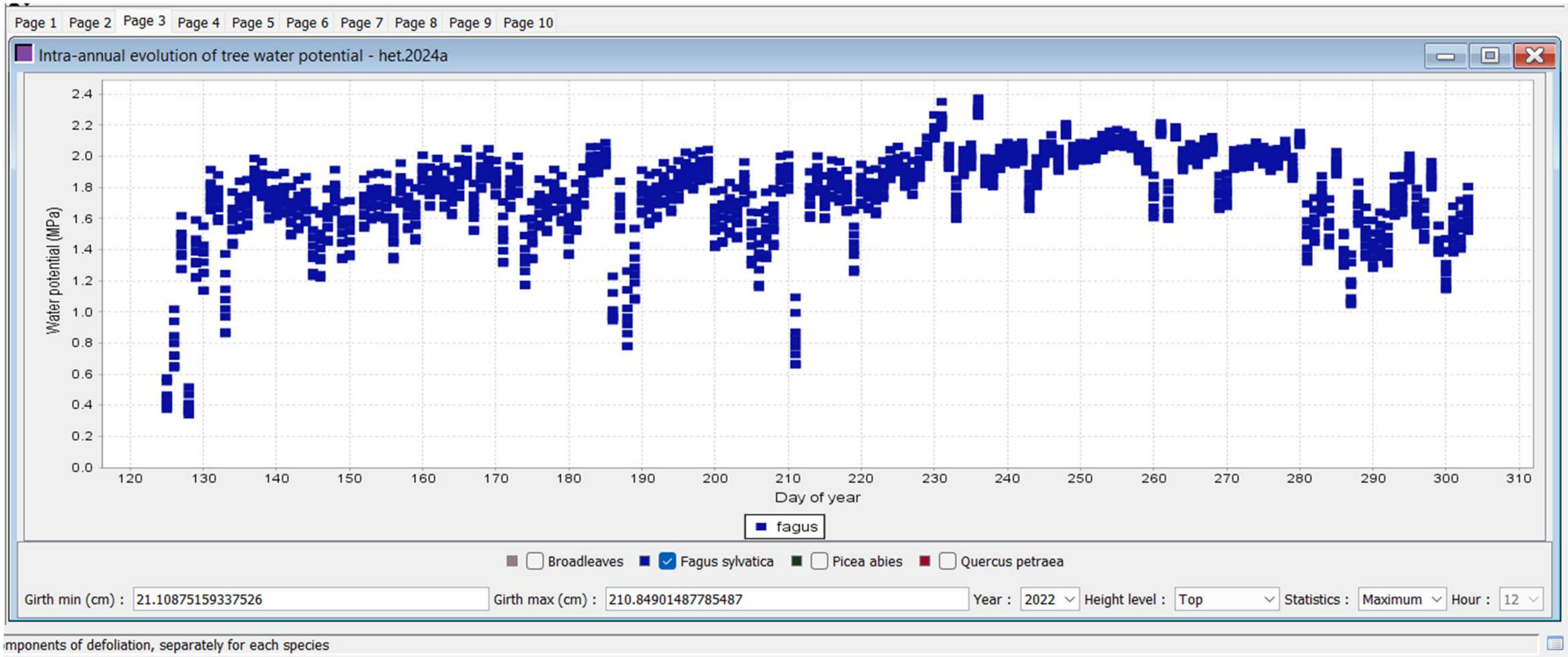
Integrating tree hydraulics to account for stress memory



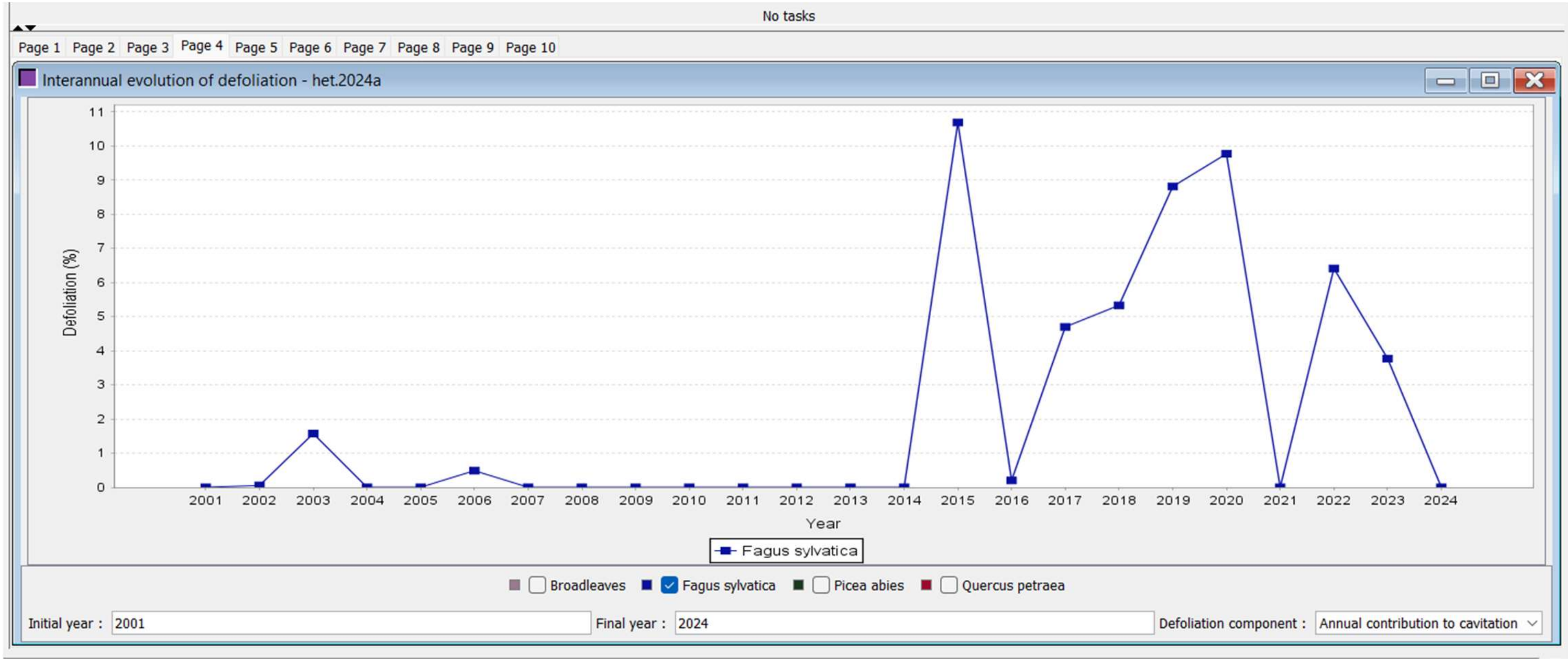




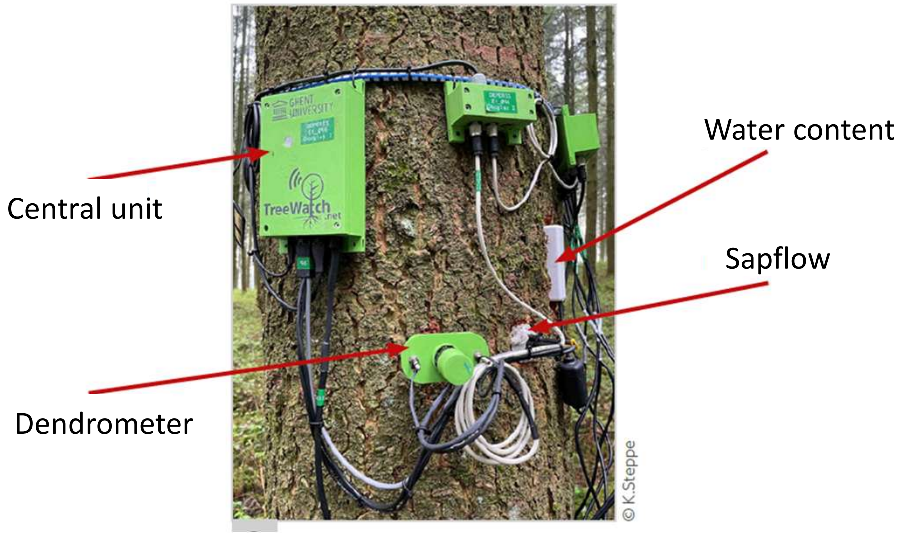
Example of HETEROFOR output: temporal dynamics of tree water potential in 2022



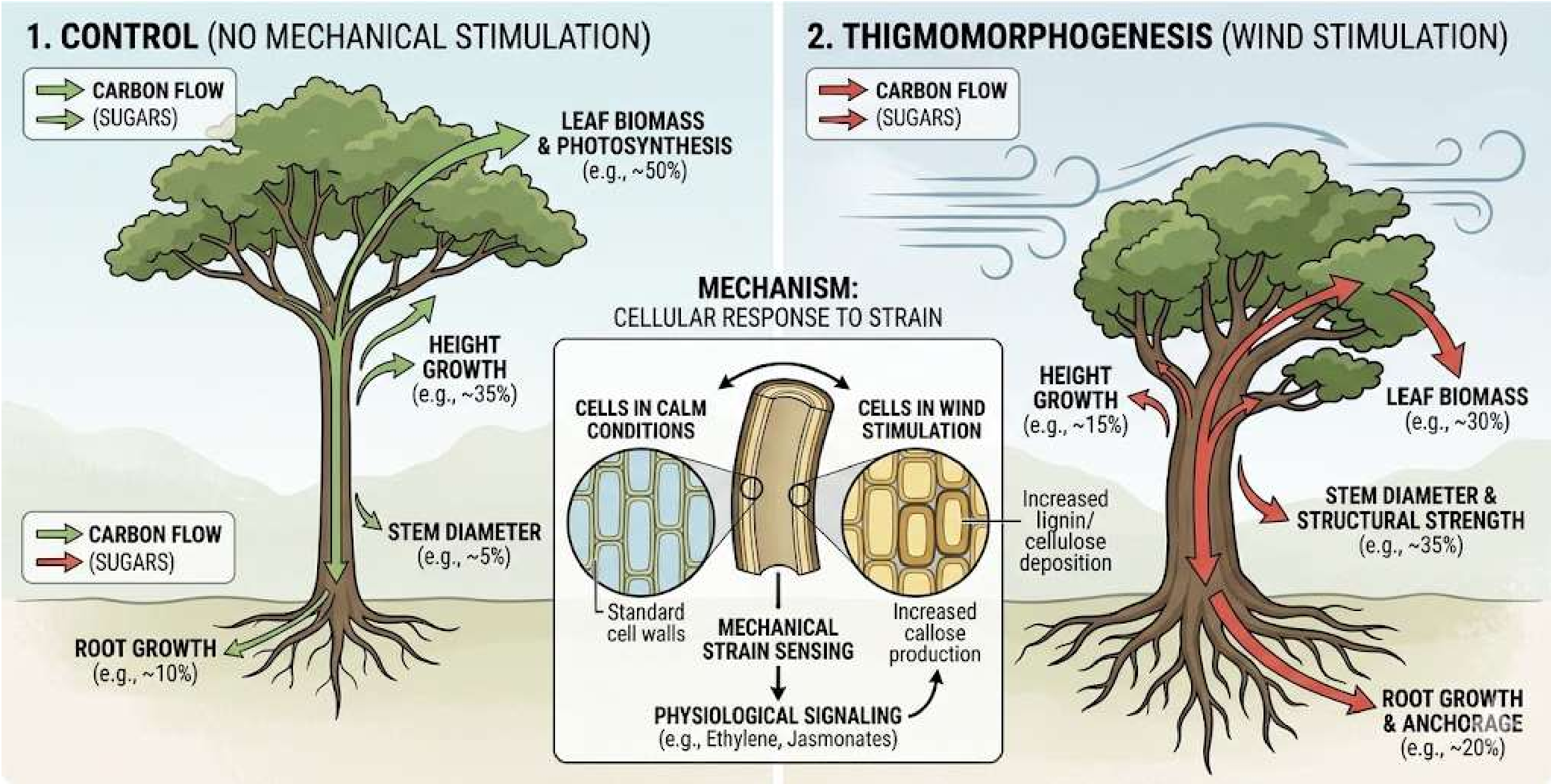
Example of HETEROFOR output: temporal dynamics of defoliation due to cavitation (2001-2024)



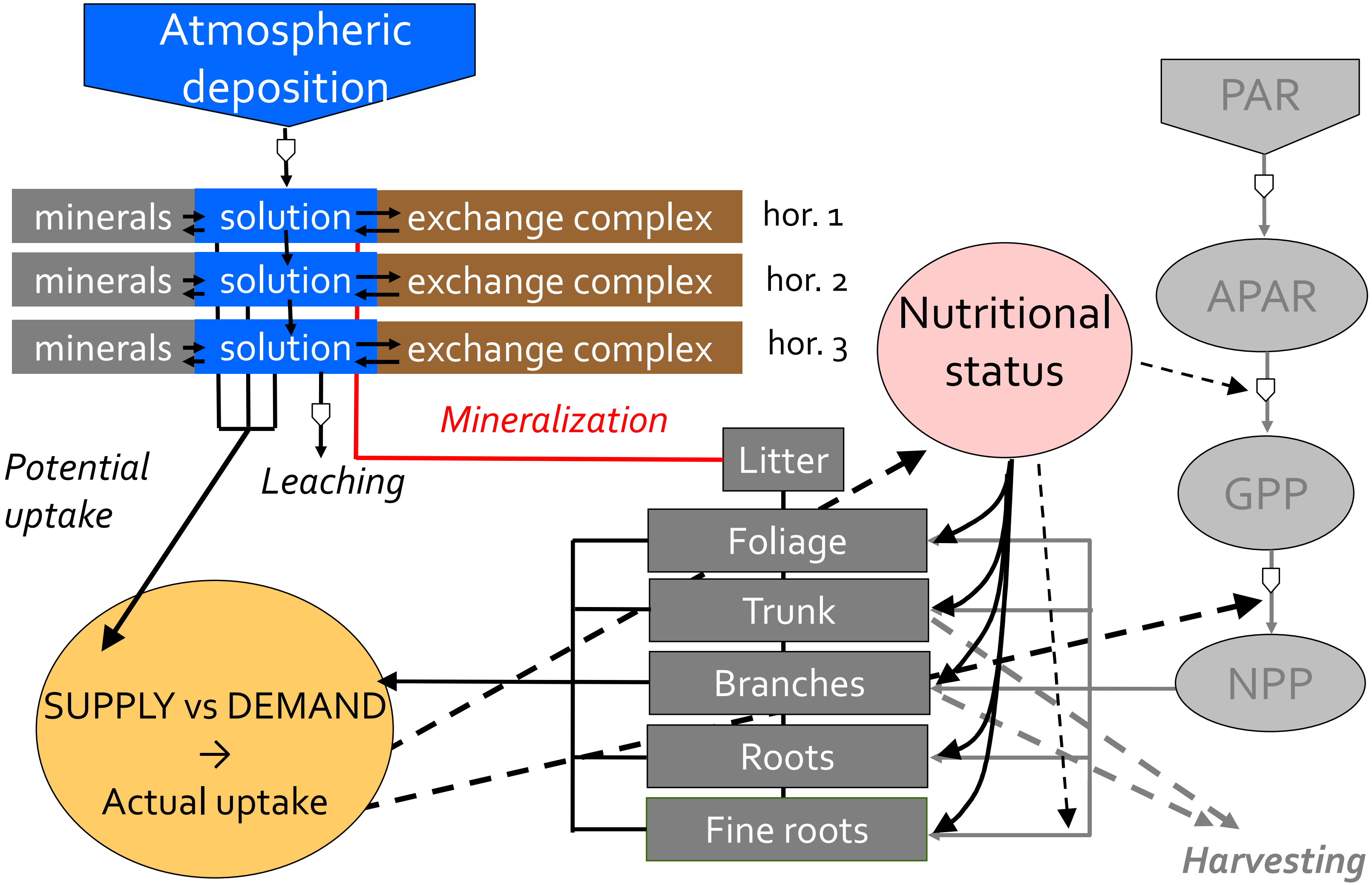
Reliable predictions require careful calibration and evaluation against observations



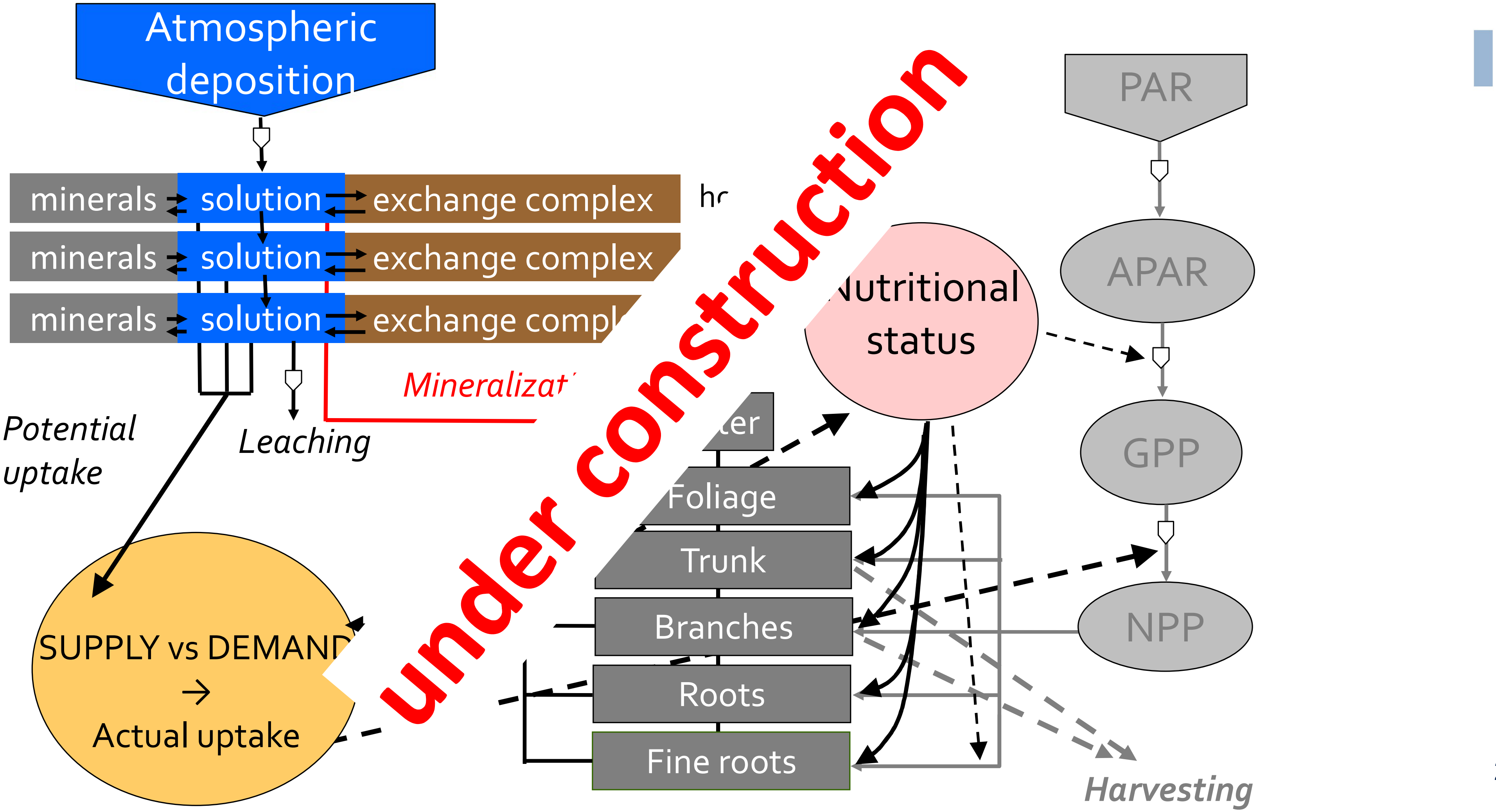
Wind-induced mechanical strains shape trees & reduce wind risk

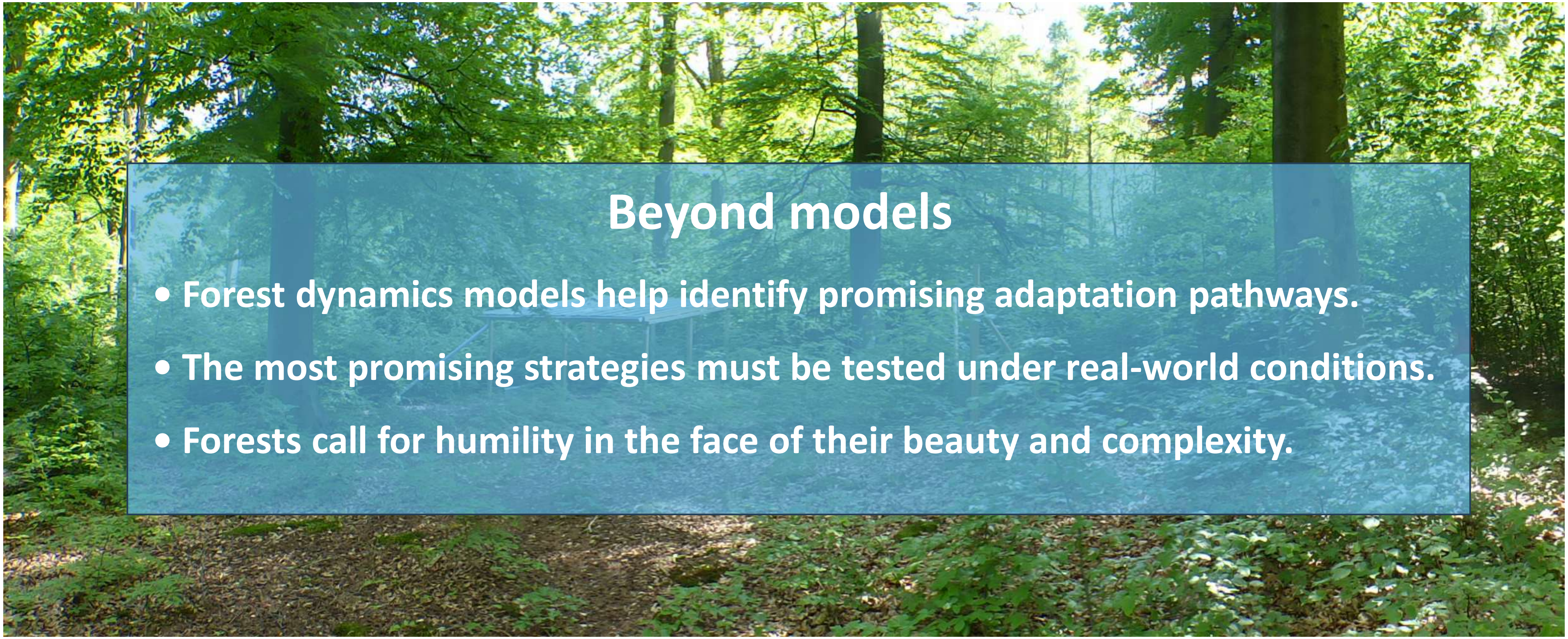


Integrating nutritional constraints



Integrating nutritional constraints

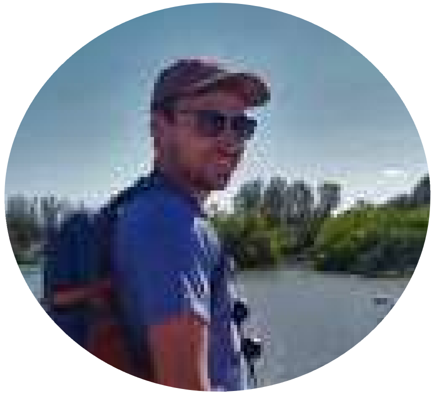




Beyond models

- Forest dynamics models help identify promising adaptation pathways.
- The most promising strategies must be tested under real-world conditions.
- Forests call for humility in the face of their beauty and complexity.

***F. André**, senior researcher*
HETEROFOR developer
Forest monitoring



***A. Guignabert**, Post-doc*

***L. de Wergifosse**, PhD*

F. de Coligny
CAPSIS developer

Thank you
for your invaluable contributions!

E. *Neimry*, *PhD student*

H. Goosse

C. Vincke

Q. Ponette

Colleagues, close collaboration, co-supervision

Many other colleagues from Europe and North America

THANK YOU