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Can we predict tree death based on its radial growth ?

M. Cailleret, C. Bigler, N. Bircher, H. Bugmann,
P. Brang, V. Dakos, F. Hartig, L. Hülsmann, S. Jansen,
J. Martinez-Vilalta, M. Vanoni, and many others…

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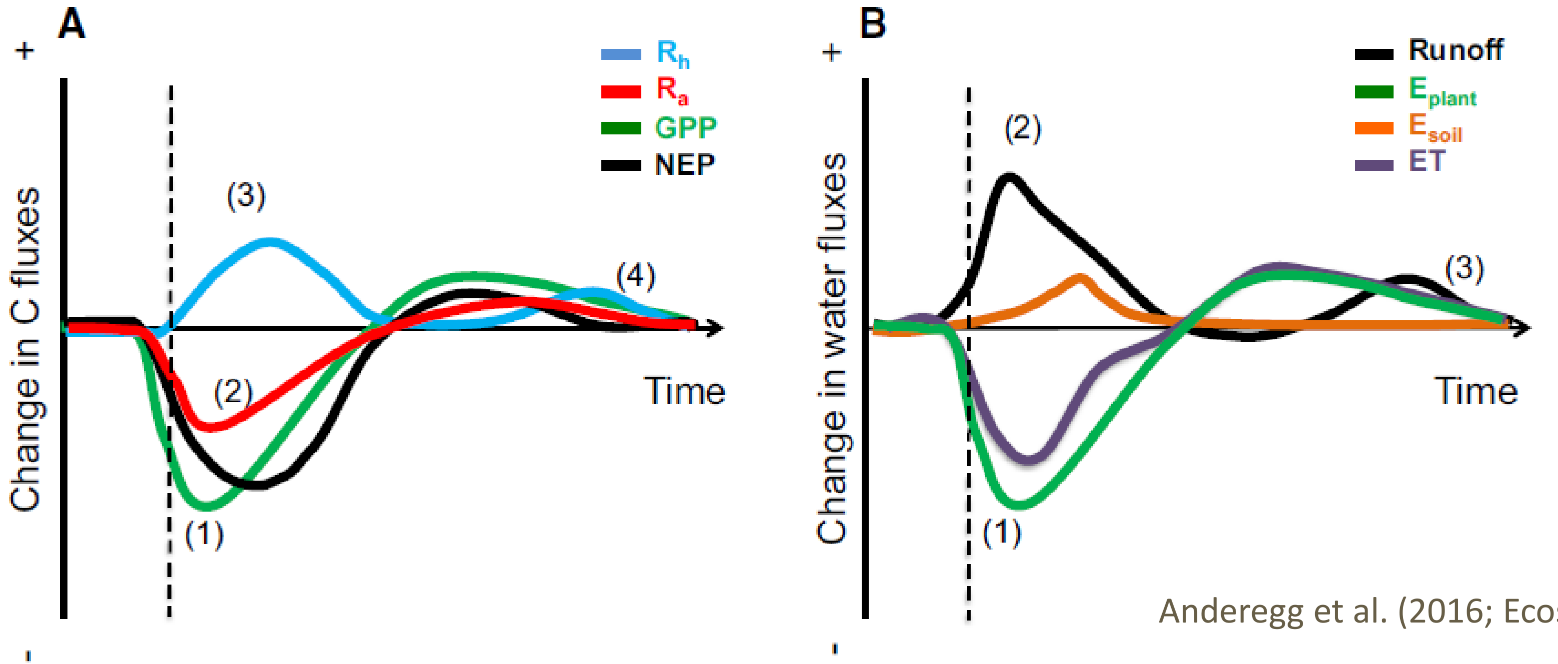
DE LA RECHERCHE SCIENTIFIQUE
cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY
STReESS
PROFOUND

Why should we study tree mortality ?

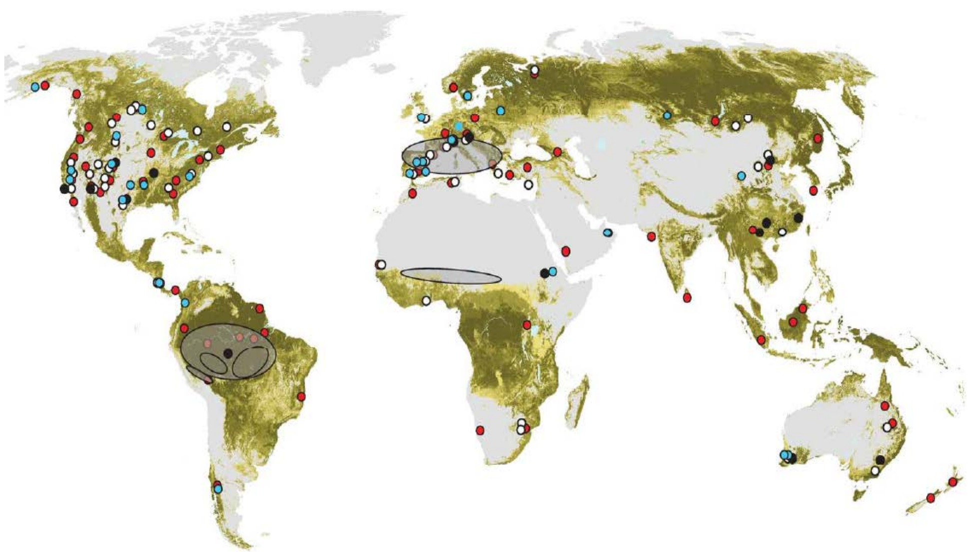
1. Tree mortality affects ecosystem functions, structure, and composition



Anderegg et al. (2016; Ecosystems)

Why should we study tree mortality ?

2. Increase in the number of drought-induced mortality events worldwide

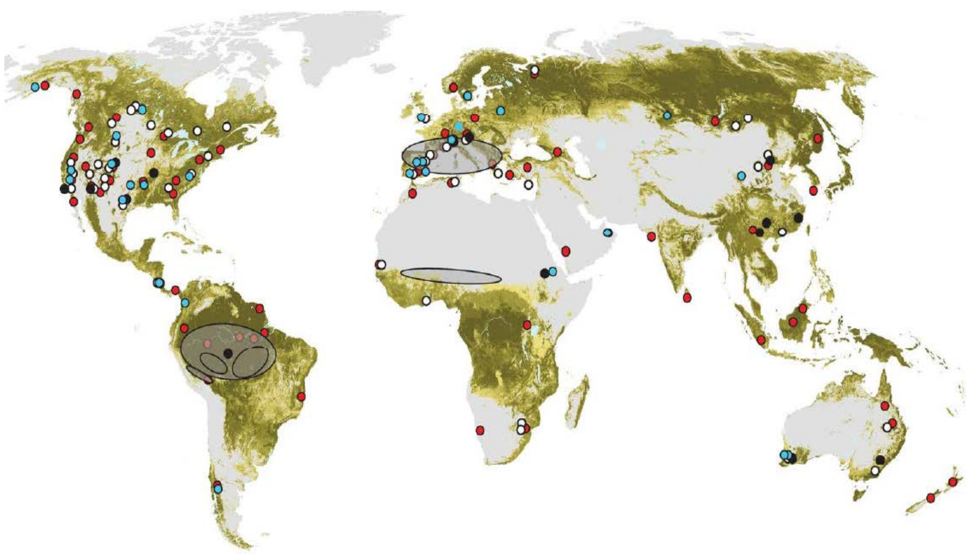


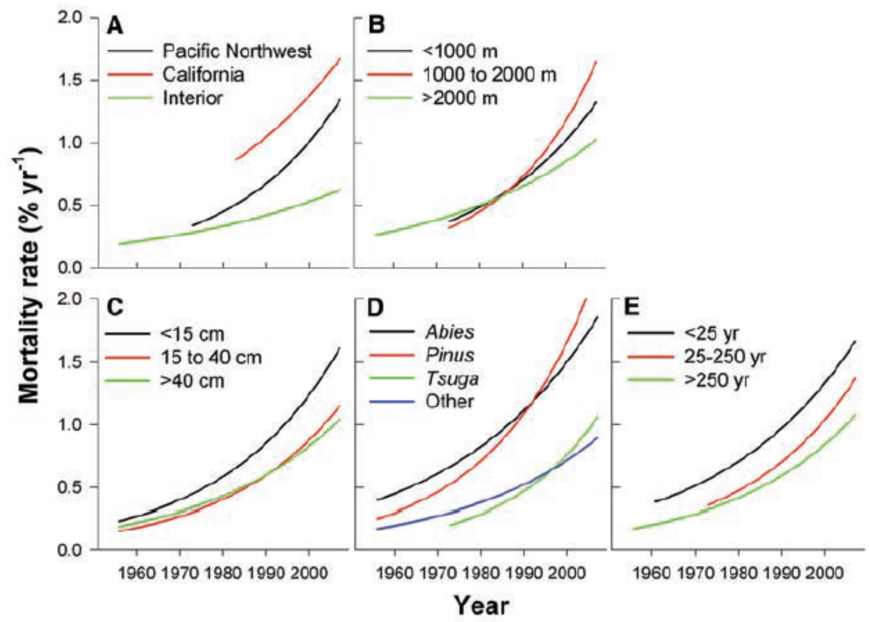
Allen et al. (2010; For. Ecol. Manage.)
Hartmann et al. (2018; New Phytol.)

Why should we study tree mortality ?

2. Increase in the number of drought-induced mortality events worldwide

Increase in «background mortality» rates



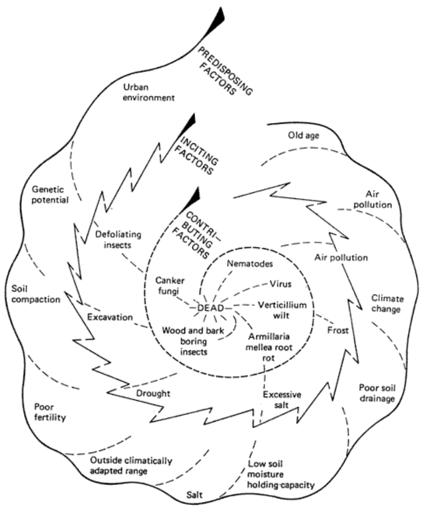


Allen et al. (2010; For. Ecol. Manage.)
Hartmann et al. (2018; New Phytol.)

Van Mantgem et al. (2009; Science)

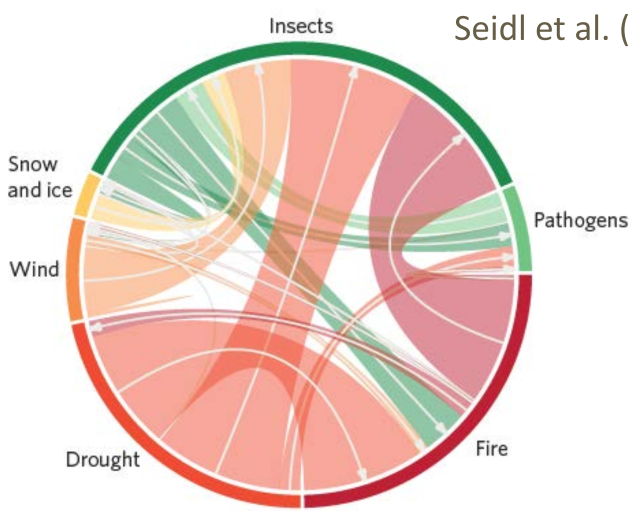
Why should we study tree mortality ?

3. Limited understanding: interactions among mortality factors



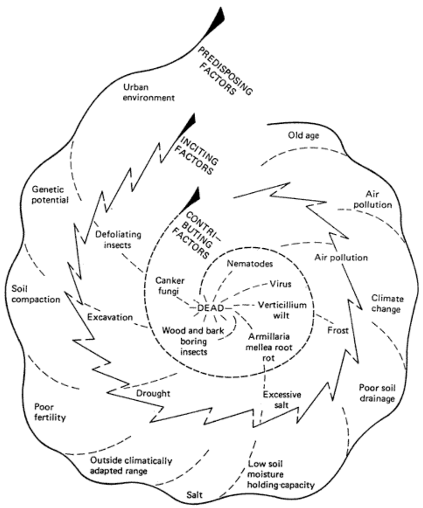
Manion (1991)

Seidl et al. (2017; NCC)



Why should we study tree mortality ?

3. Limited understanding: interactions among mortality factors and among physiological processes



Manion (1991)

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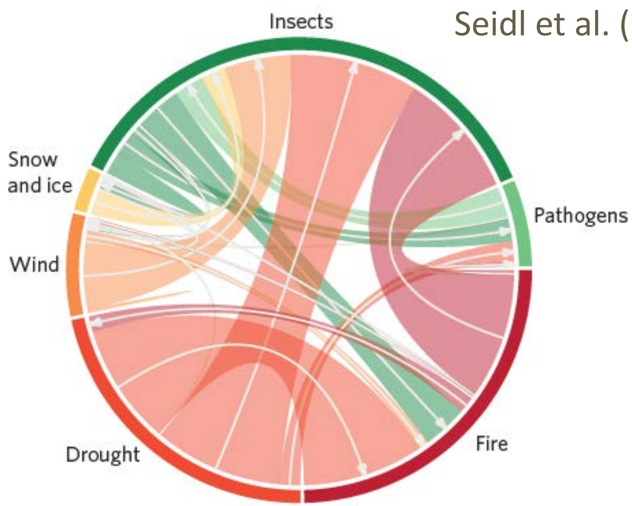
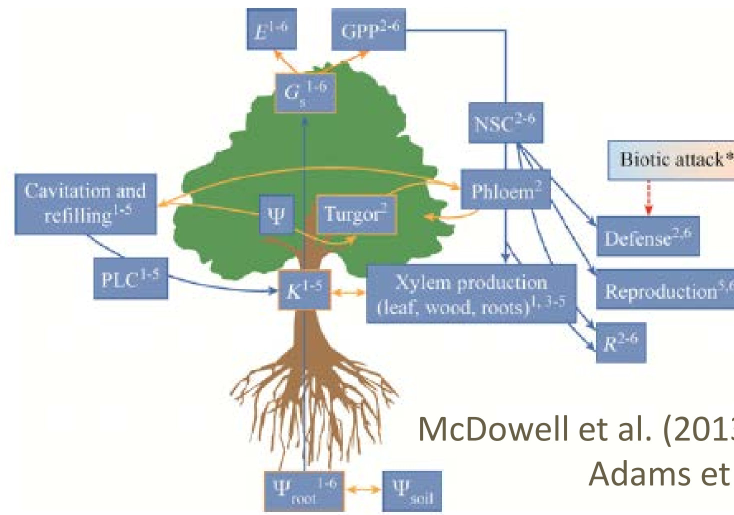
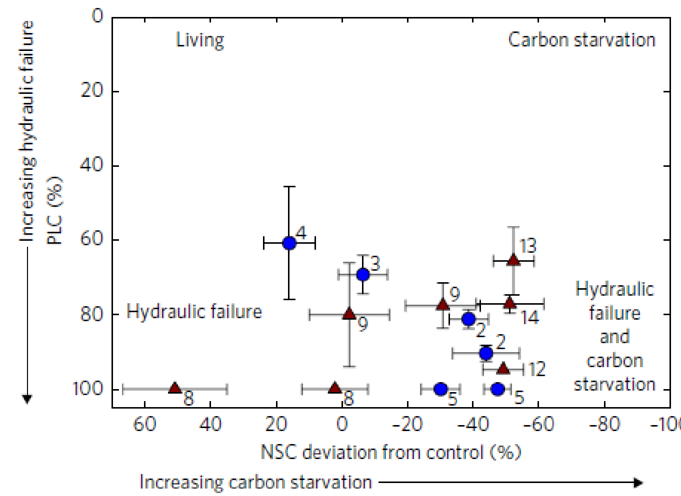




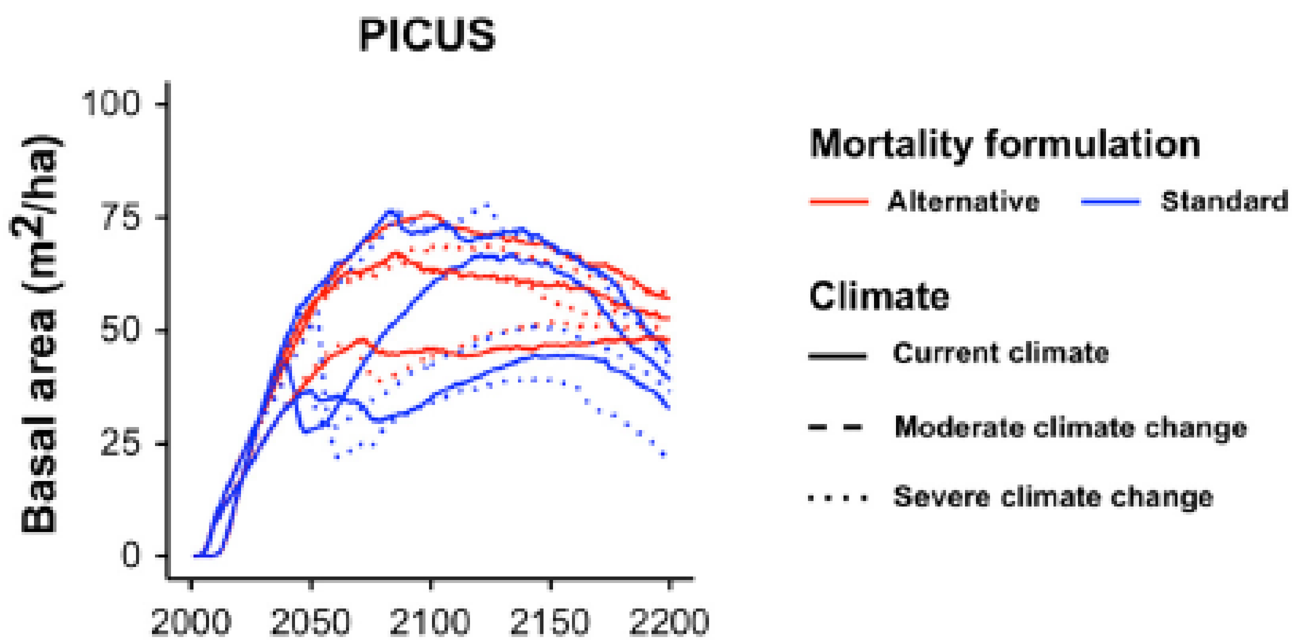
McDowell et al. (2013; New Phytol.)

Adams et al. (2017; NEE)



Why should we study tree mortality ?

4. Dynamic vegetation models poorly simulate tree mortality (e.g., constant % of the biomass in some biome models), but are highly sensitive to mortality functions

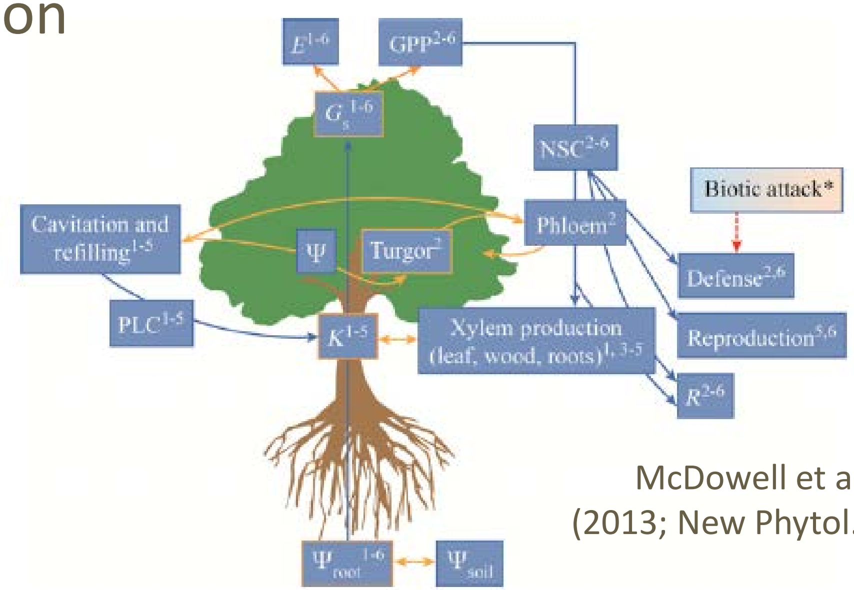


Bugmann et al. (2019; Ecosphere)

Approaches to predict stress-induced tree mortality

Empirical approach: only dependent on environmental conditions

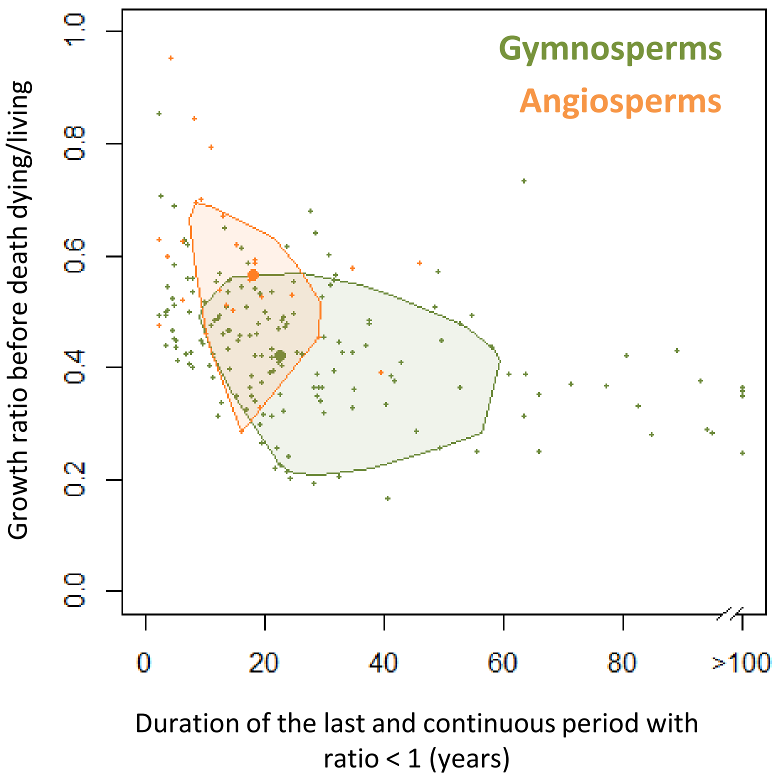
Mechanistic approach: based on physiological processes



McDowell et al. (2013; New Phytol.)

Semi-empirical approach based on tree growth

Global synthesis of the ring-width patterns before death



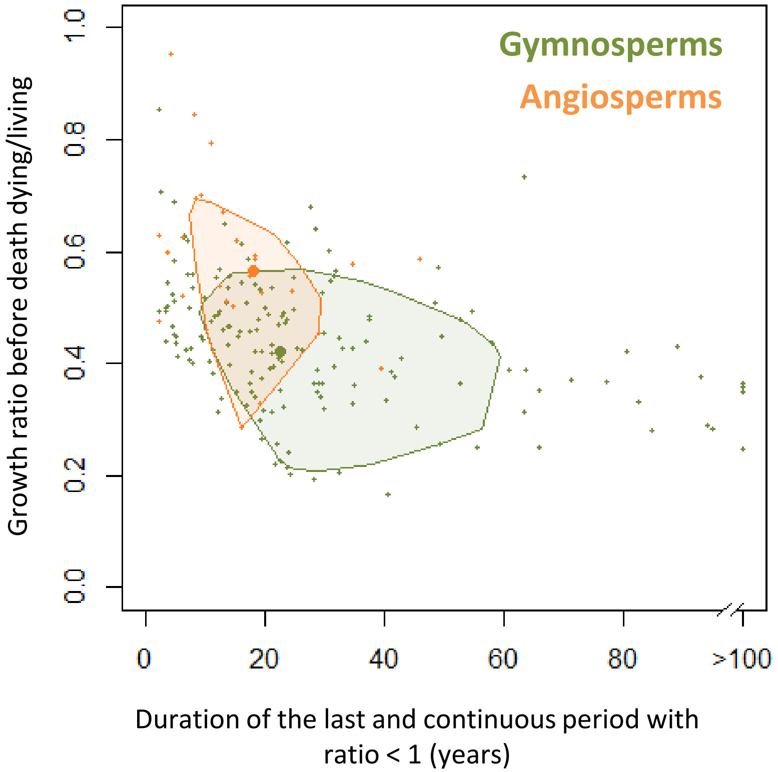
Decrease in growth before tree death in 85% of the mortality events (190 sites)

Effective for gymnosperms

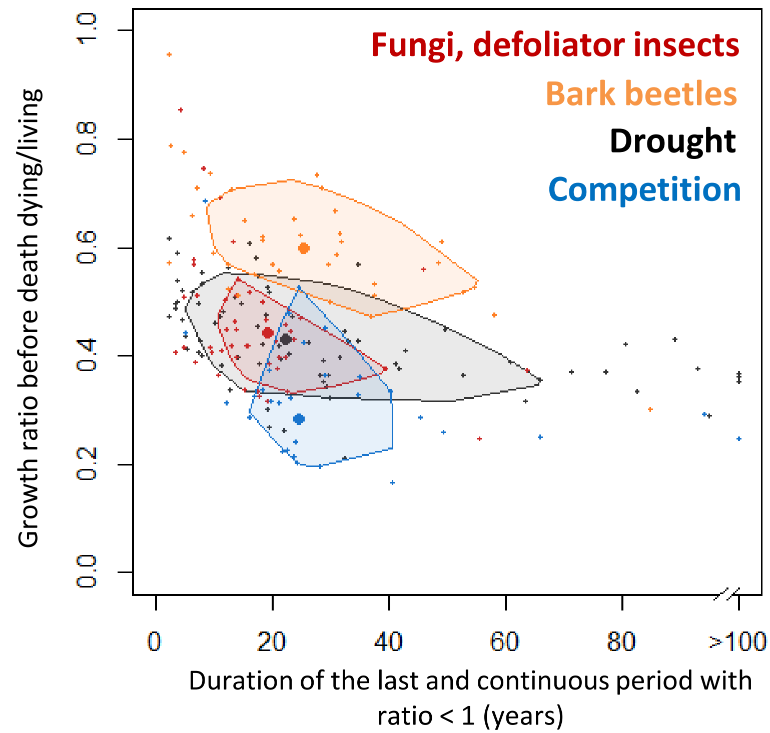
Cailleret et al. (2017; GCB)

Can we predict mortality based on growth ? **YES !**

Global synthesis of the ring-width patterns before death



Decrease in growth before tree death in 85% of the mortality events (190 sites)

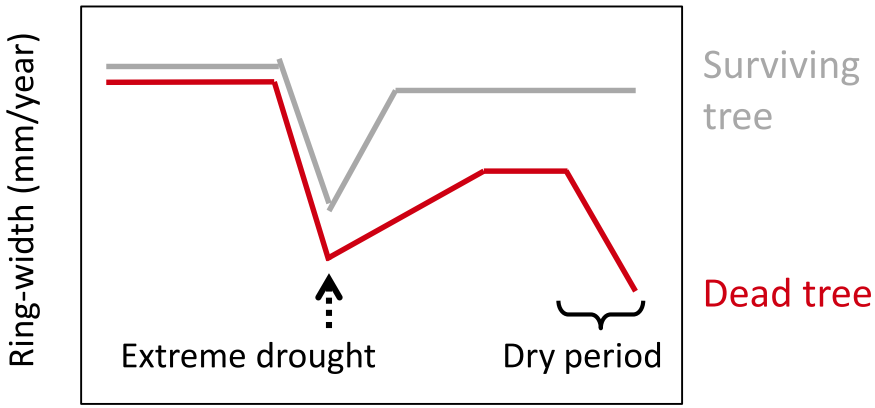


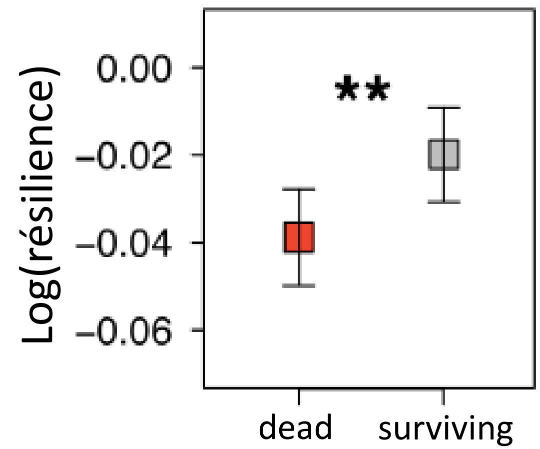
Effective for gymnosperms, but less so for angiosperms and in case of bark beetle attack

YES ! BUT…

Cailleret et al. (2017; GCB)

Global synthesis of the ring-width patterns before death





Trees that died during a dry period were less resilient to previous extreme drought events than surviving ones.

Cailleret et al. (2019; Front. Plant Sci.)
DeSoto et al. (submitted; Nat. Comm.)

YES !

A dynamic vegetation modeling perspective with ForClim

1. Based in expert knowledge (Solomon 1986; Oecologia)

P_{mort} = fn ($age_{tree}/age_{max,species}$, RW of the last 3 years)

In ForClim v3

Model development for 18 tree species in Europe

2. Empirical model based on forest inventory data

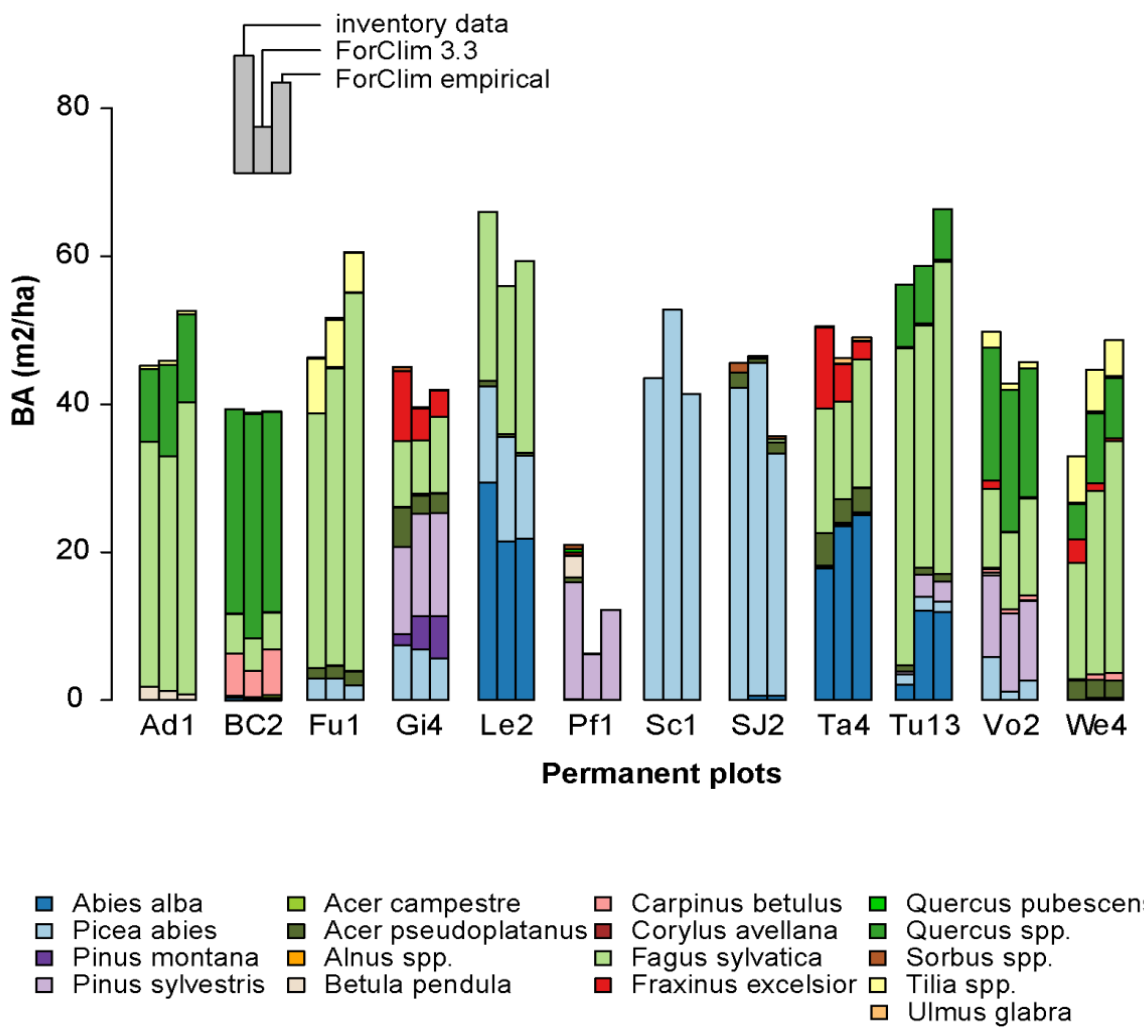
P_{mort} = fn (DBH, relative growth over the last 7-10 years, stand density, climate)

Calibration: 54 forest reserves in Switzerland and Germany

Bircher et al. (2015; Ecol. Appl.); Hülsmann et al. (2018; Ecol. Appl.)

Empirical model based on forest inventory data

Validation 1: Historical short-term (30-50 ys) simulations



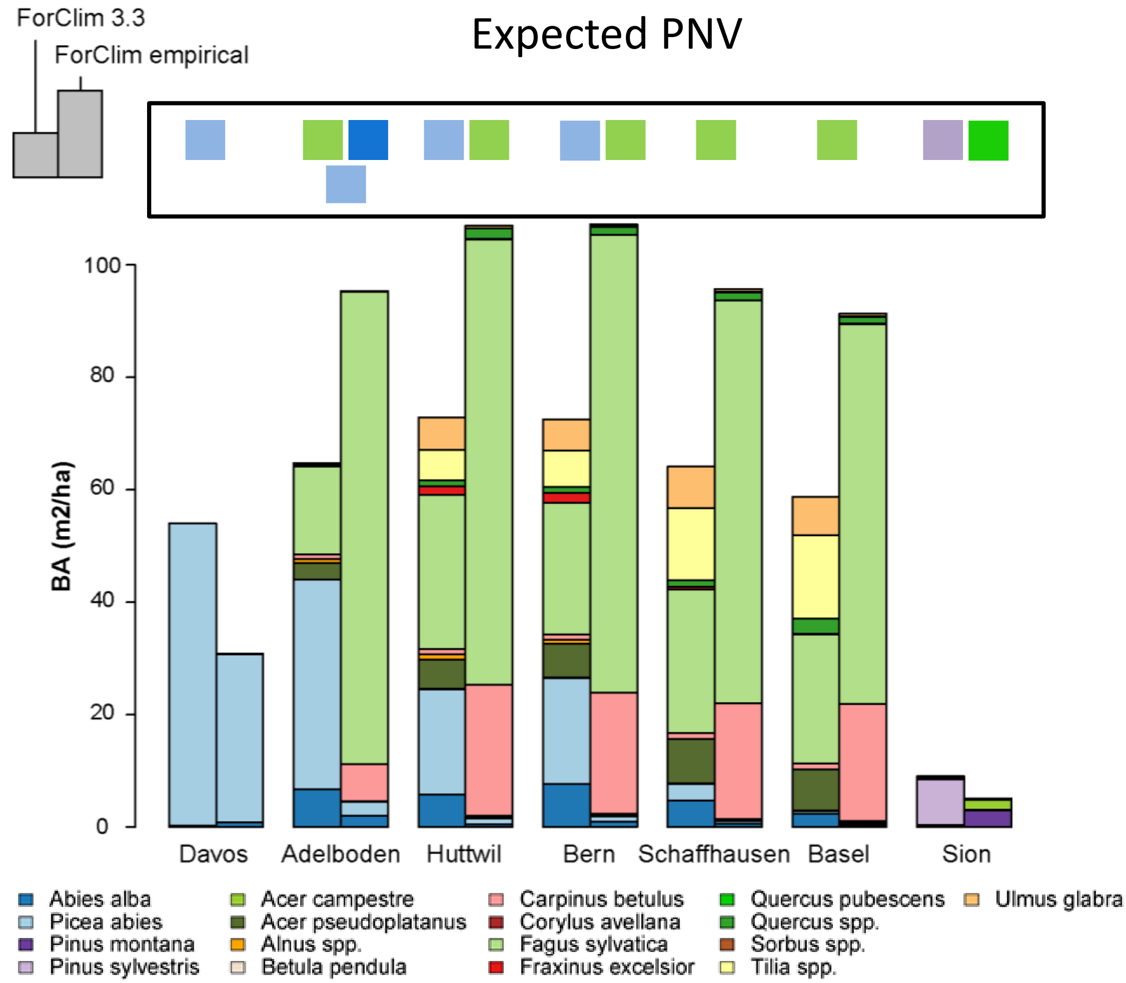
Hülsmann et al. (2018; Ecol. Appl.)

YES !

Empirical model based on forest inventory data

Validation 2: Long-term (1500 ys) simulations: Potential Natural Vegetation along a „Swiss Environ. Gradient“

The inventory-based mortality model does not kill enough beech trees -> annual resolution?



Hülsmann et al. (2018; Ecol. Appl.)

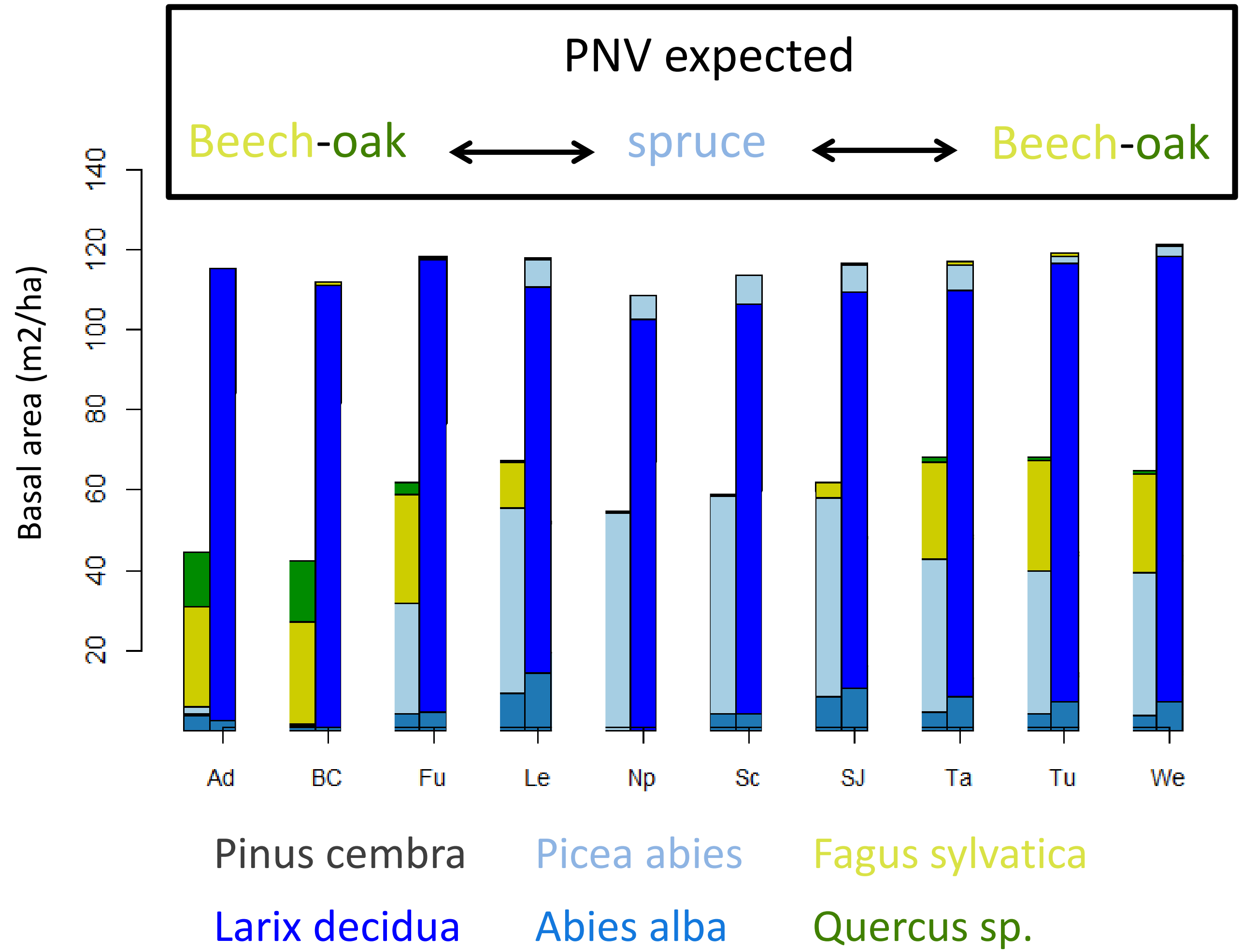
YES ! BUT…

Empirical model based on inventory and ring-width data

Calibration data:
12 forest reserves in Switzerland
6 species

Validation 1: Historical short-term (30-50 ys) simulations **OK!**

Validation 2: Long-term (1500 ys) simulations: Potential Natural Vegetation

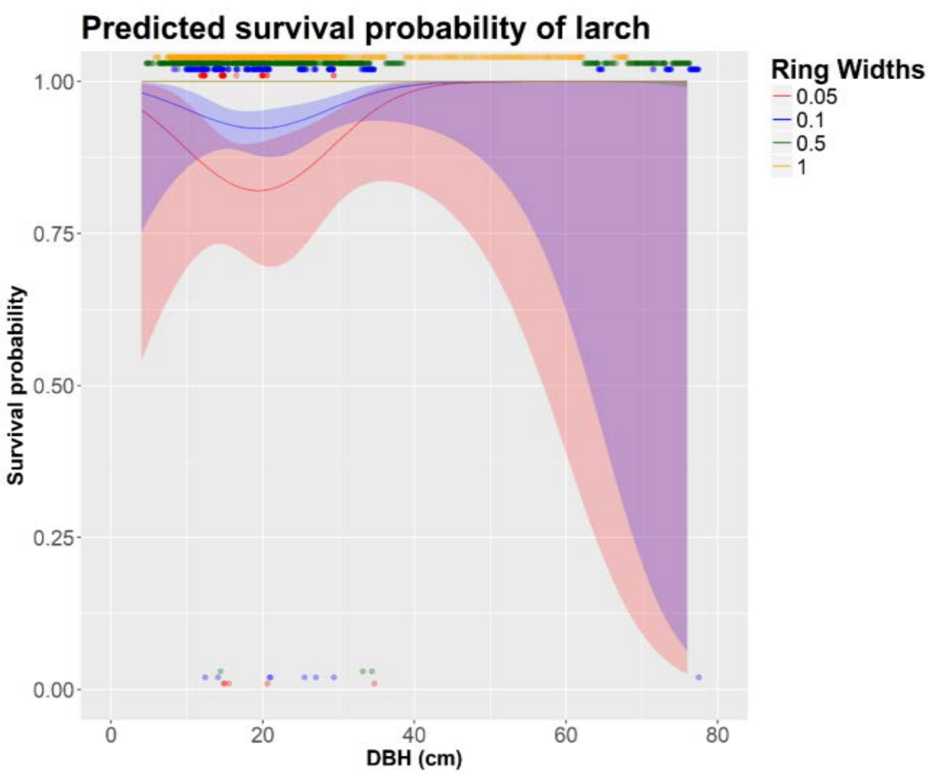


Vanoni et al. (2019; For. Ecol. Manage.)

YES ! BUT...

Empirical model based on inventory and ring-width data

Overestimation of larch because of the scarce information for large trees (only one dead tree at DBH >40cm)



- Larch trees become almost immortal
- Version considering variability/uncertainty in the parameters of the mortality models

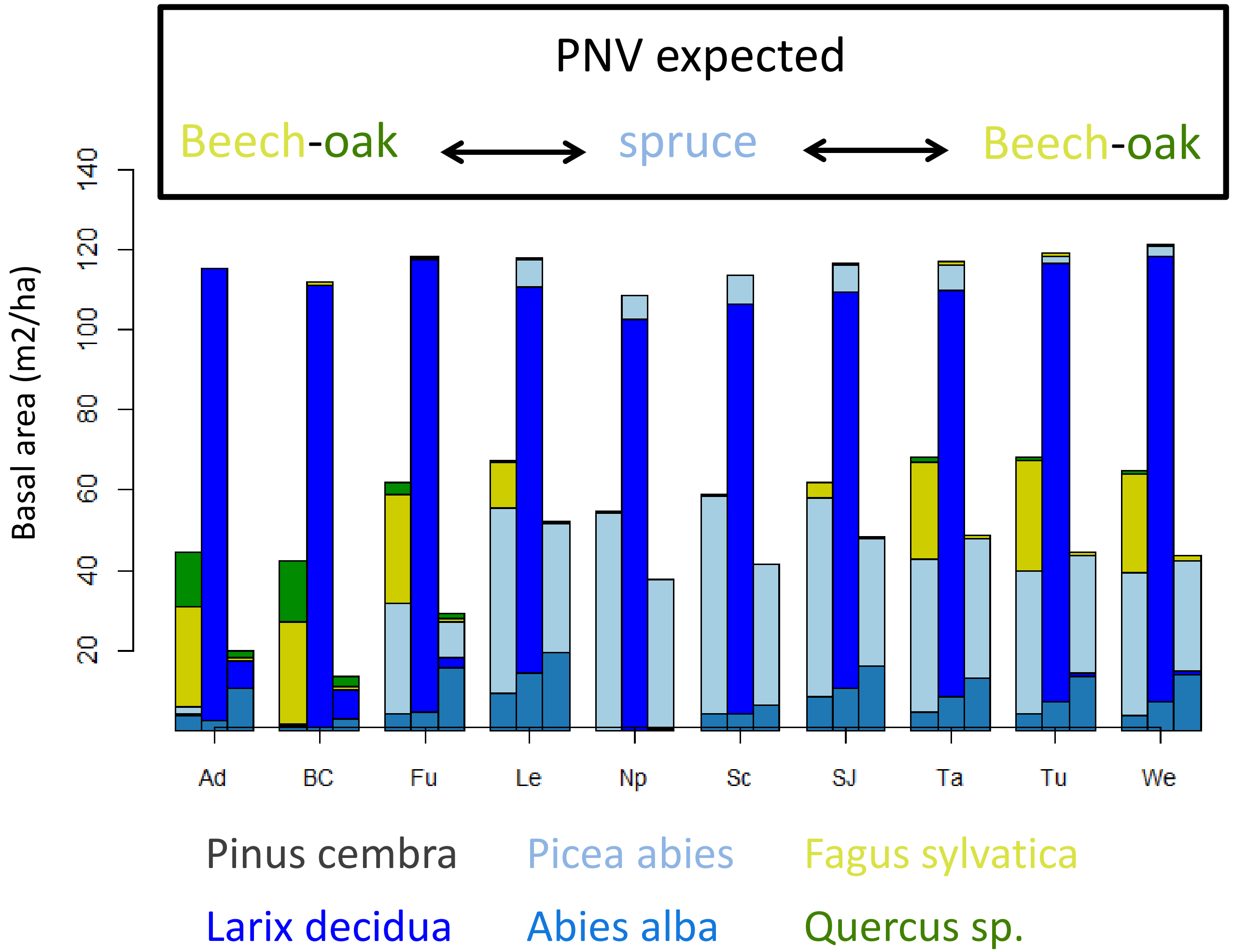
Vanoni et al. (2019; For. Ecol. Manage.)

Empirical model based on inventory and ring-width data

Calibration data:
12 forest reserves in Switzerland
6 species - 528 trees

Validation 1: Historical short-term (30-50 ys) simulations **OK!**

Validation 2: Long-term (1500 ys) simulations: Potential Natural Vegetation



Vanoni et al. (2019; For. Ecol. Manage.)

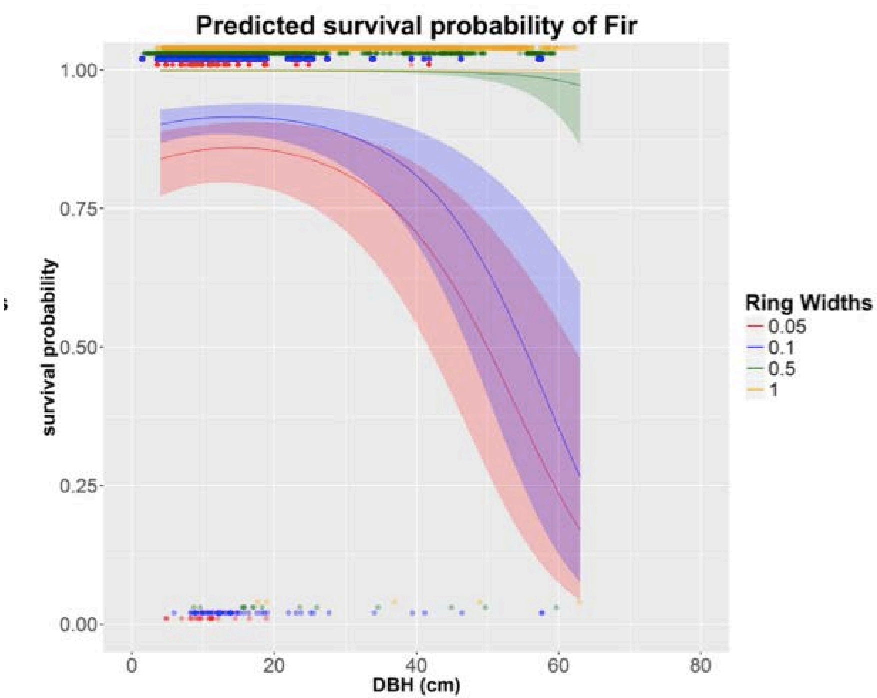
YES ! BUT…

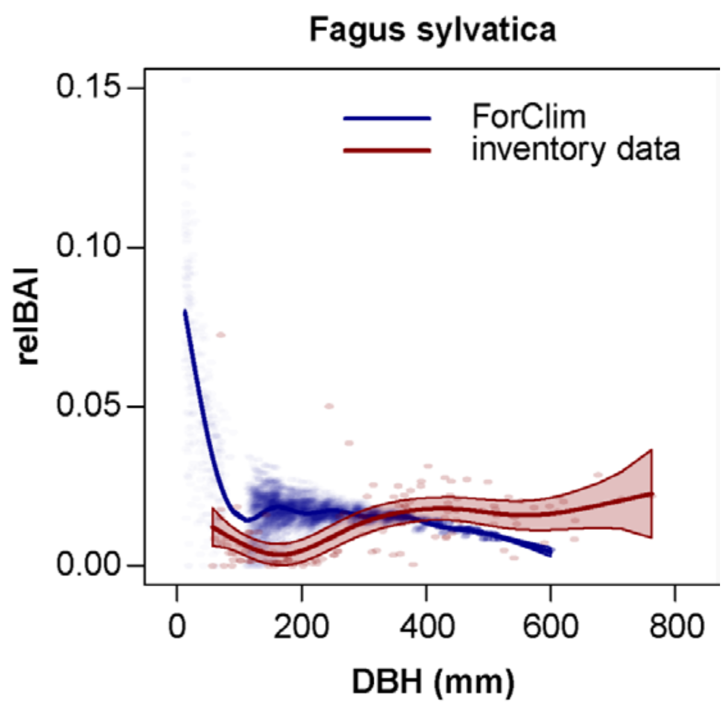
Insights from these modelling exercices

Problems in the calibration dataset: no data for small trees (callipering limit) and for very big trees (reserves ≠ primary forests) -> extrapolation issue

Parameters may not be adequate for an implementation into ForClim because growth may not be accurately simulated

Potential solution -> inverse calibration of the mortality model





Bayesian calibration of an inventory-based model in ForClim

Inventory-based mortality model

8 parameters

→ ForClim →

Likelihood BA and stem number (simulated ~ measured) at 9 calibration sites

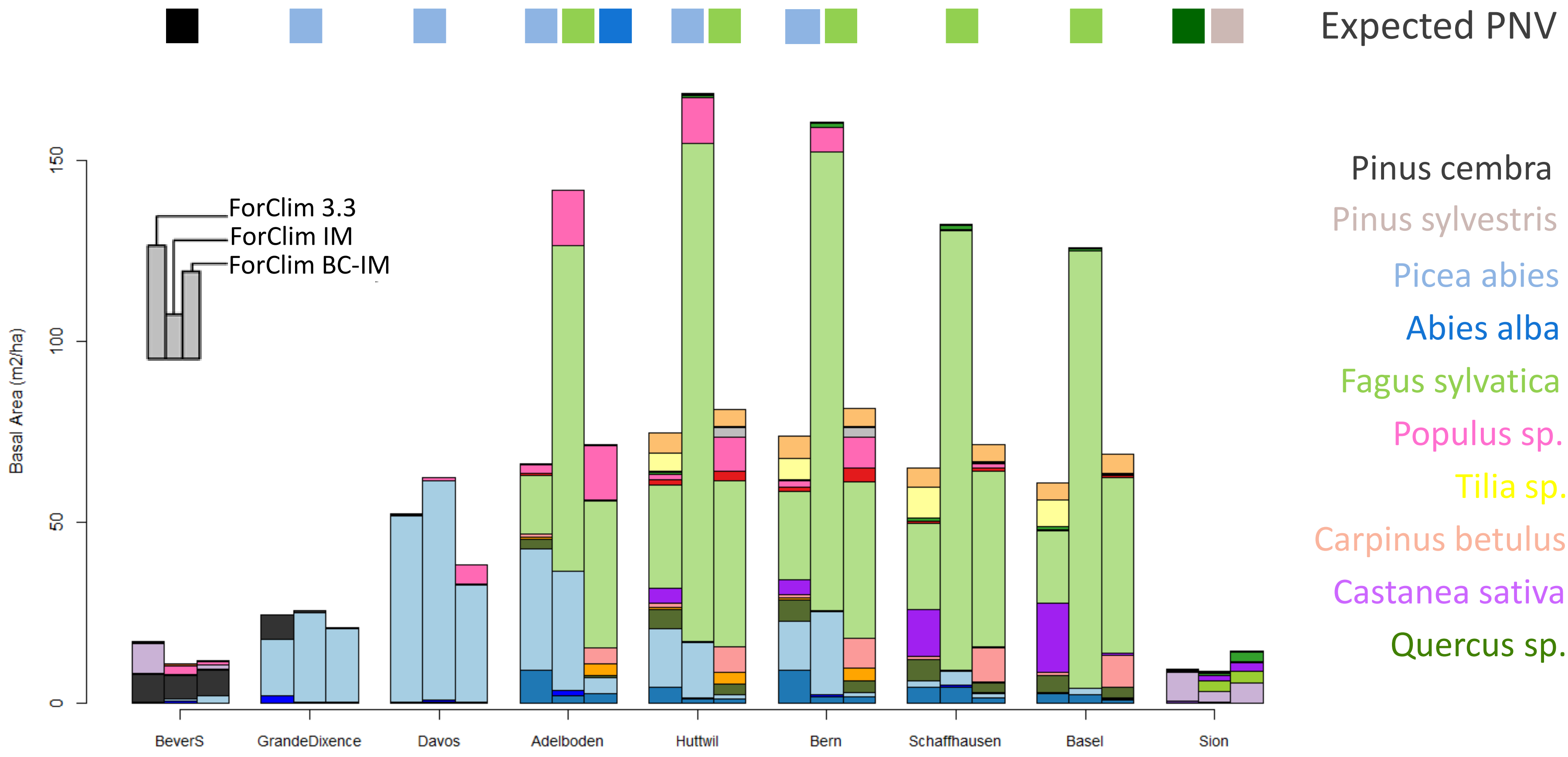
←

Validation 1: Historical short-term (30-50 ys) simulations		Stem numbers			Basal area increment		
		3.3	**IM**	**BC-IM**	**3.3**	**IM**	**BC-IM**
Number of sites with best performance	Calibration	0	1	8	2	4	3
	Validation	2	8	11	9	4	8

Hartig et al. (2012; J. Biogeo); Cailleret et al. (in revision; Ecol. Appl.)

Bayesian calibration of a multi-species IM into ForClim

Validation 2: Plausibility of the long-term projections (PNV)



Beech is not overestimated anymore, but pb with spruce and poplar

Cailleret et al. (in revision; Ecol. Appl.)

Conclusions – Perspectives

- Change in growth patterns is a good – but not perfect – indicator of mortality probability, especially for gymnosperms and in case of long-term stress
- The ‚old‘ theoretical model is not so bad :-) :-(
- Making mortality models more empirical doesn‘t do the job, mainly because of the lack of data for small and big trees
- Bayesian approach can be a solution but can be problematic for model development: if the parameter values do not make sense, we can get good results for the wrong reasons

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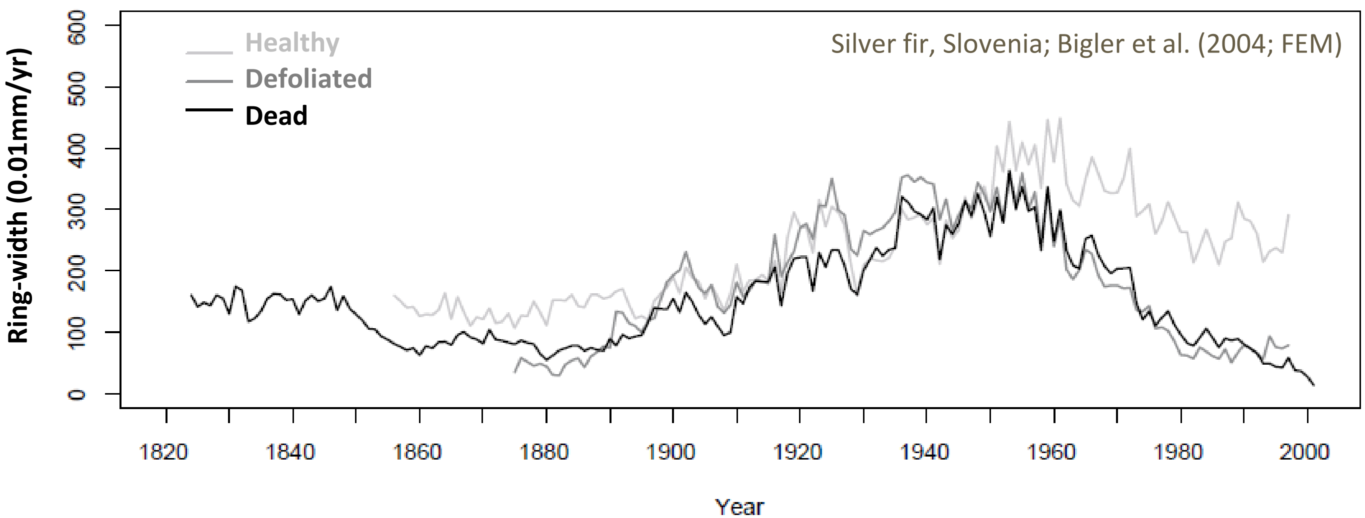
Fonds national suisse de la recherche scientifique
European Cooperation in Science and Technology

Interests of the growth-based approach



(+) Radial growth is related to tree productivity and crown defoliation

Individual resolution; multi-annual to annual resolution

Long-term (last 20 years -> tree lifespan)

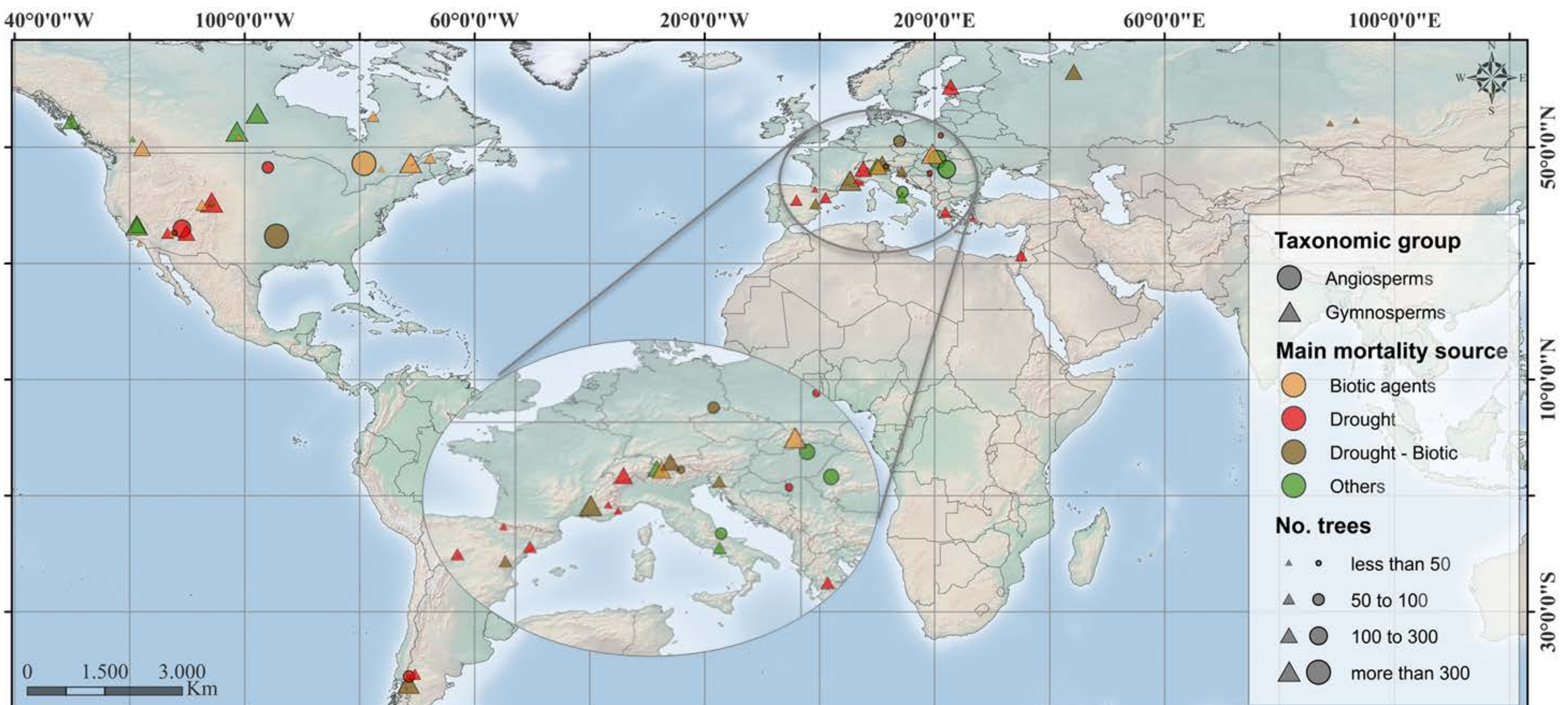
Sampling substantial (although limited for tree-rings)

Biased estimation of the year of death?

(-) Wood growth is also sink-driven

Compilation of a new tree ring-width database

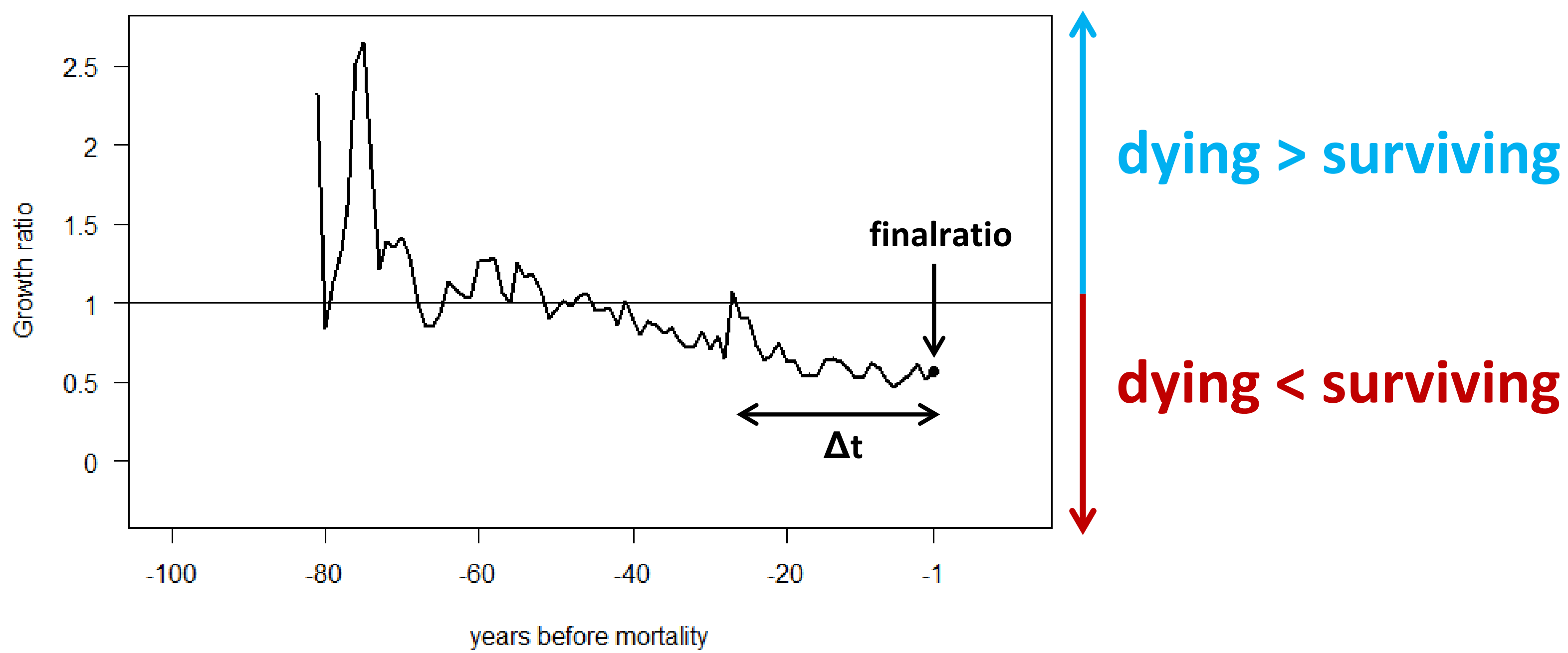
36 species | 196 sites | >8000 trees | >800’000 rings



Cailleret et al. (2017; GCB)

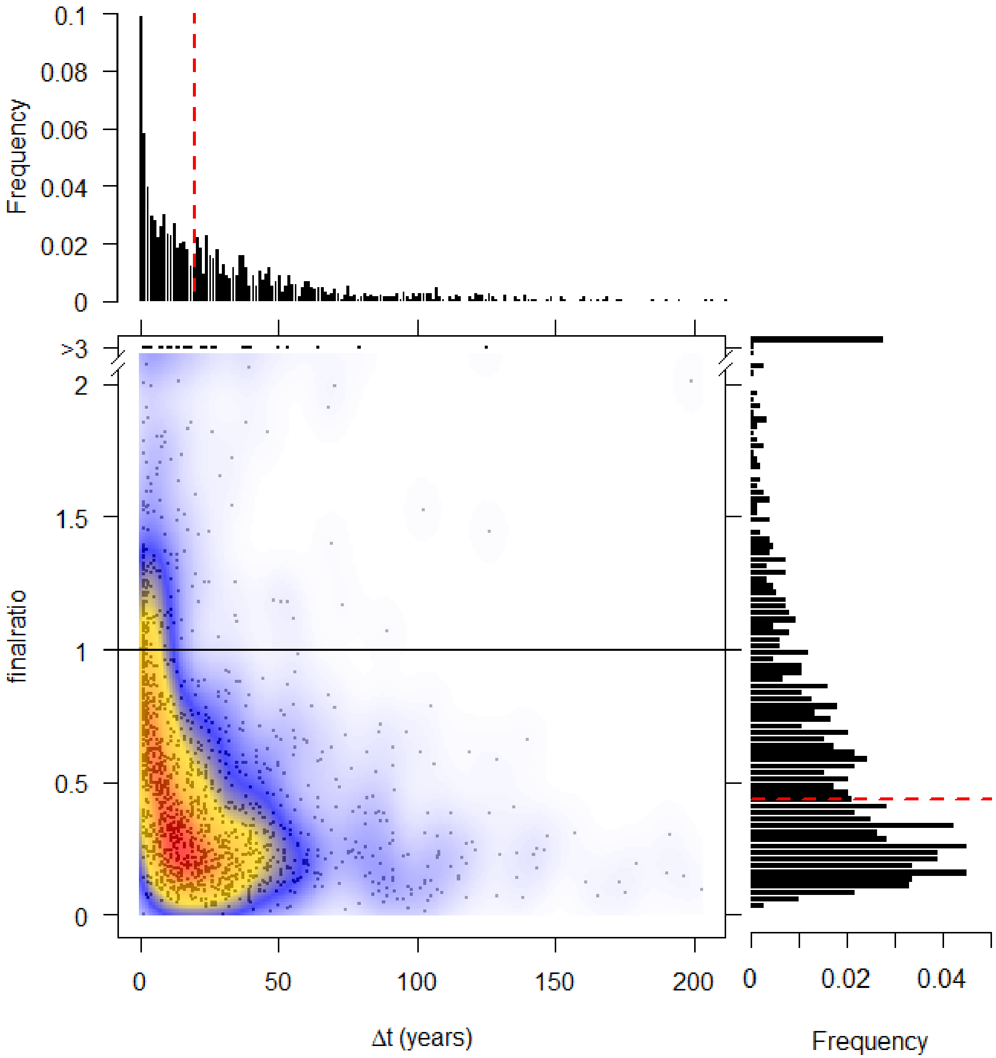
Analysis of the growth patterns before mortality

For each of the mortality events, we calculated the growth ratio between trees that died and trees that survived (with similar size)



- finalratio: growth ratio the year before mortality
- Δt: duration of the last and continuous period with ratio < 1 (or >1)

Large variability in the growth patterns before mortality



Period with reduced growth (Δt) from 1 to 200 years

Median in Δt = 19 years

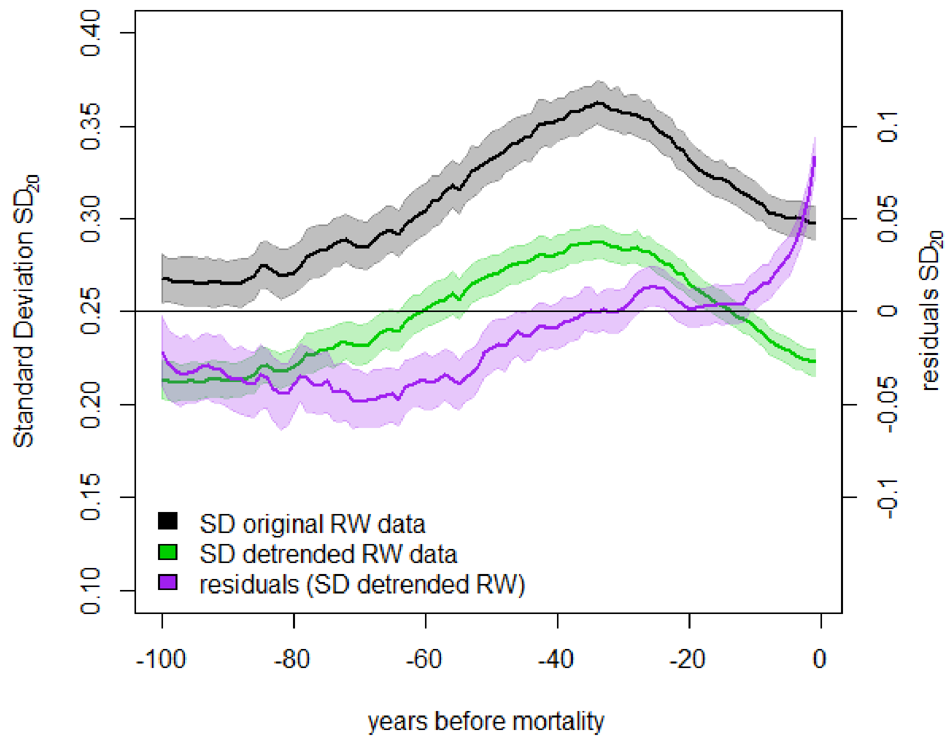
Dying trees had lower growth than living ones for 85% of the mortality events

Median in finalratio = 40%

Cailleret et al. (2017; GCB)

Other changes in growth patterns before mortality

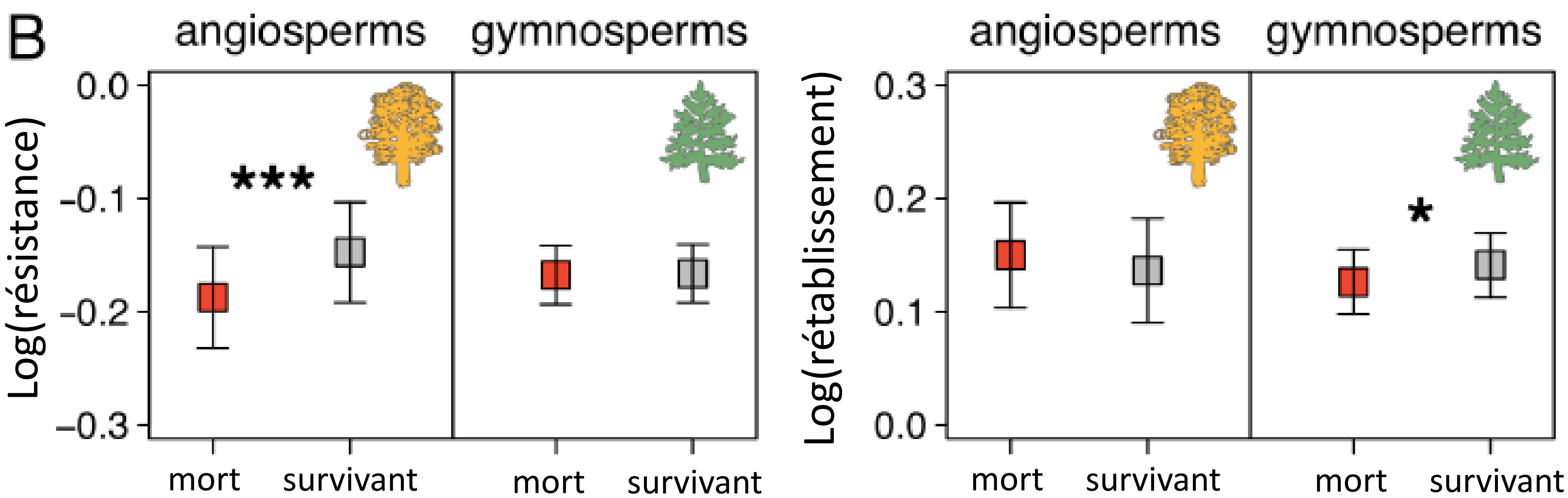
Change in SD in ring-width of dying trees (moving 20-y window) before their death



Increase in SD before tree mortality, no change for AR1

Cailleret, Dakos, Martinez-Vilalta et al. (in prep)

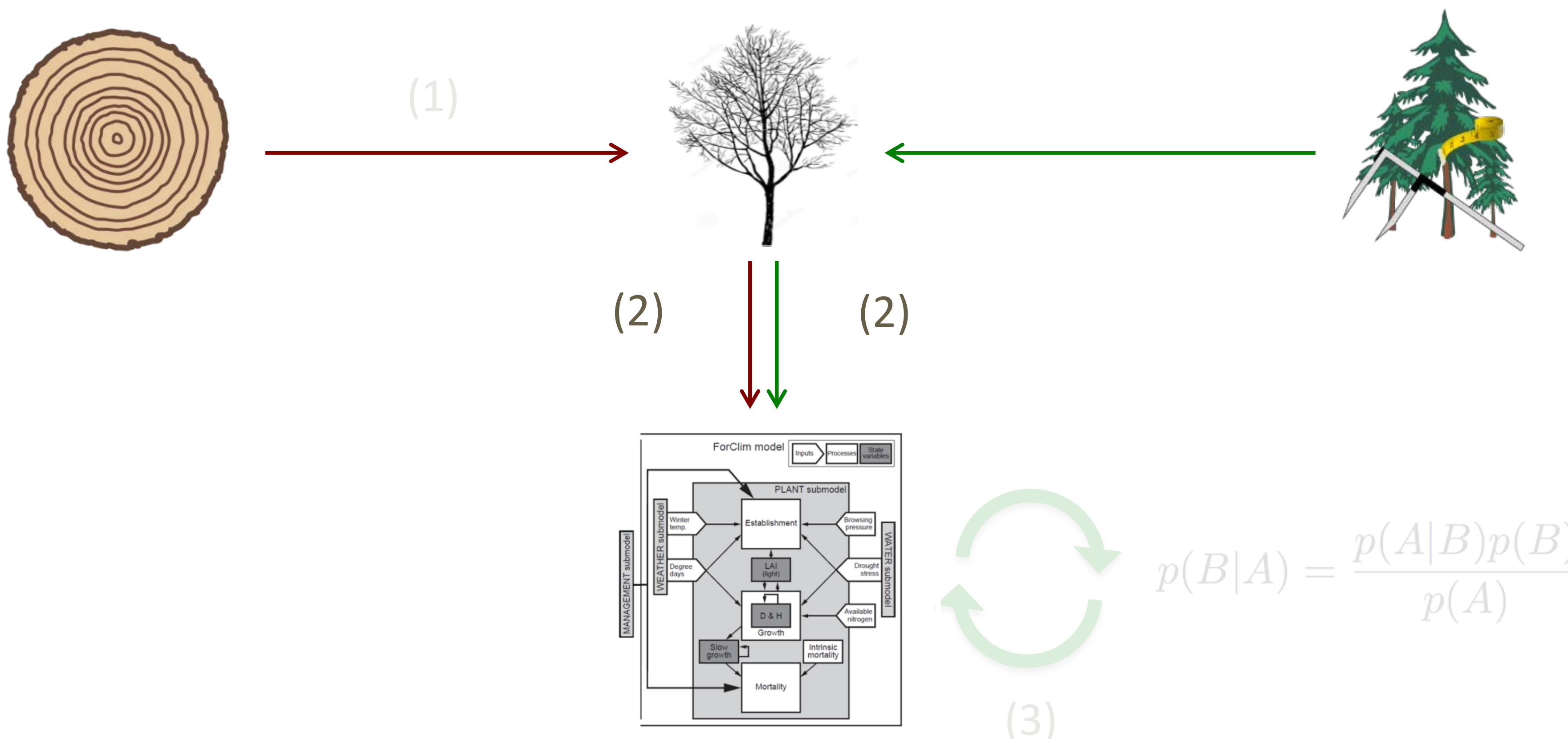
Comparaison de la résilience d'arbres morts et survivants



La résistance à la sécheresse et le rétablissement après sécheresse peuvent respectivement être utilisés comme indicateurs du risque de mortalité pour les angiospermes et les gymnospermes

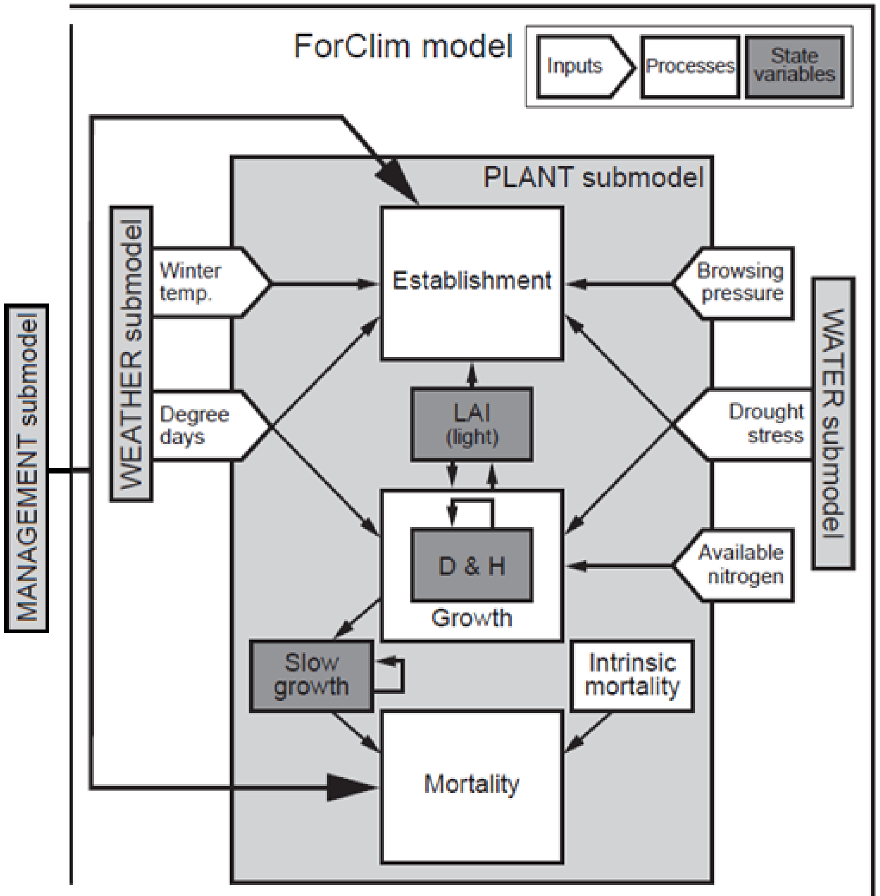
DeSoto et al. (soumis; Nat. Clim. Change)

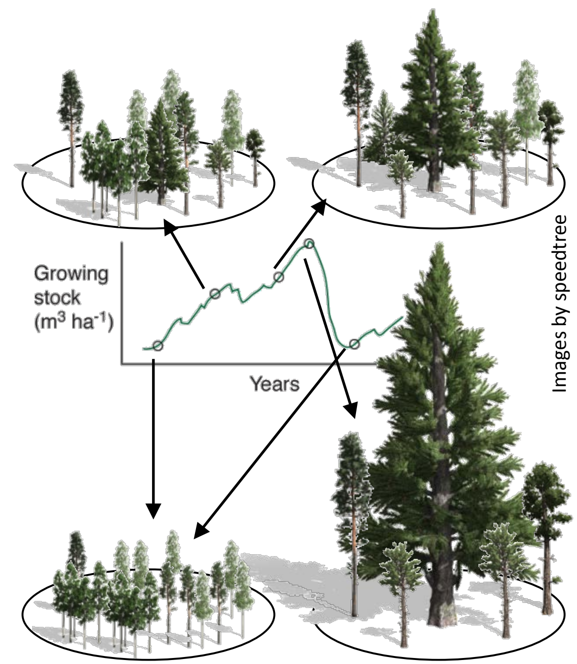
General empirical and modeling framework



(2) Implementation of tree-ring-based and inventory-based mortality models into ForClim

The ForClim forest succession model





Bugmann (1996; Ecology)
Rasche et al. (2012; Ecol. Model.)
Mina et al. (2017; Reg. Env. Change)

Output: Stem number, basal area, biomass… for 30 tree species (in Europe)

Comparison of different mortality models on spruce

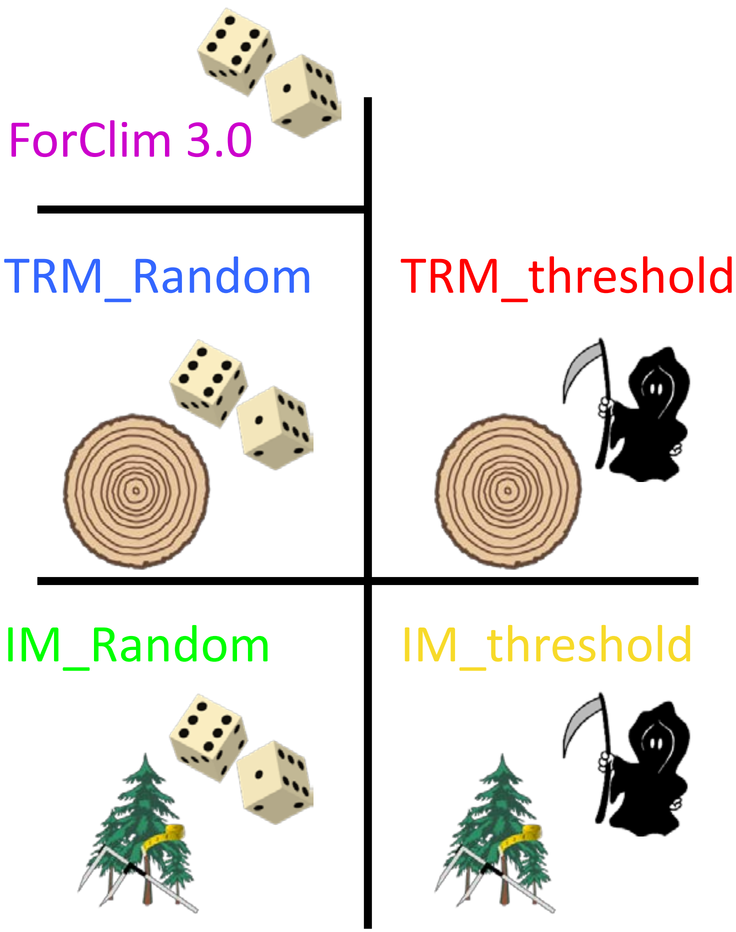
Theoretical | tree-ring based (TRM) | inventory-based (IM)

ForClim 3.0

$P_{mort} = fn(age_{max}, RW_{t,t-1,t-2})$

Comparison of different mortality models on spruce

Theoretical | tree-ring based (TRM) | inventory-based (IM)



$P_{mort} = fn(age_{max}, RW_{t,t-1,t-2})$

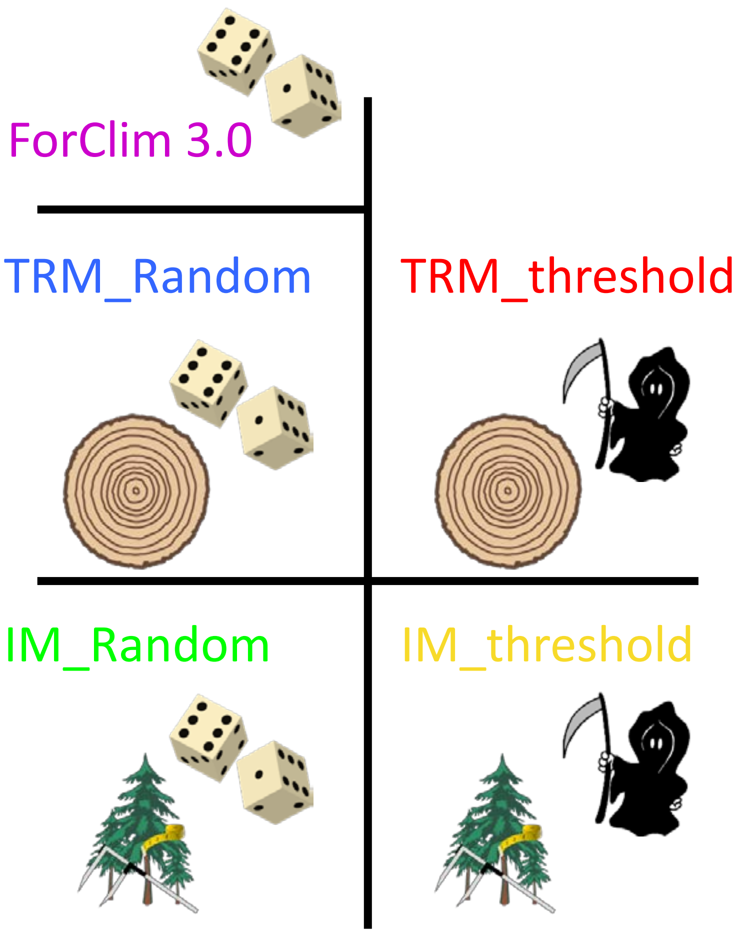
$P_{mort} = fn(BAI_3, relBAI, locreg_5)$

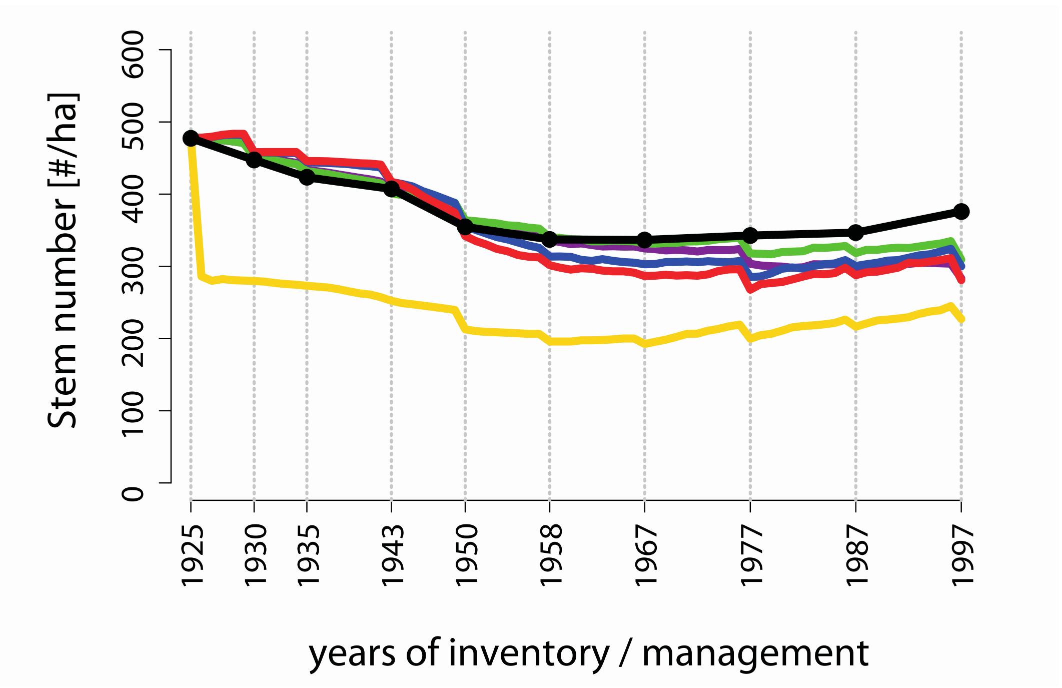
$P_{mort} = fn(DBH, relBAI, DD)$

Bircher et al. (2015; Ecol. Appl.)

Comparison of different mortality models on spruce

Historical simulation in Sigriswil (managed forest)

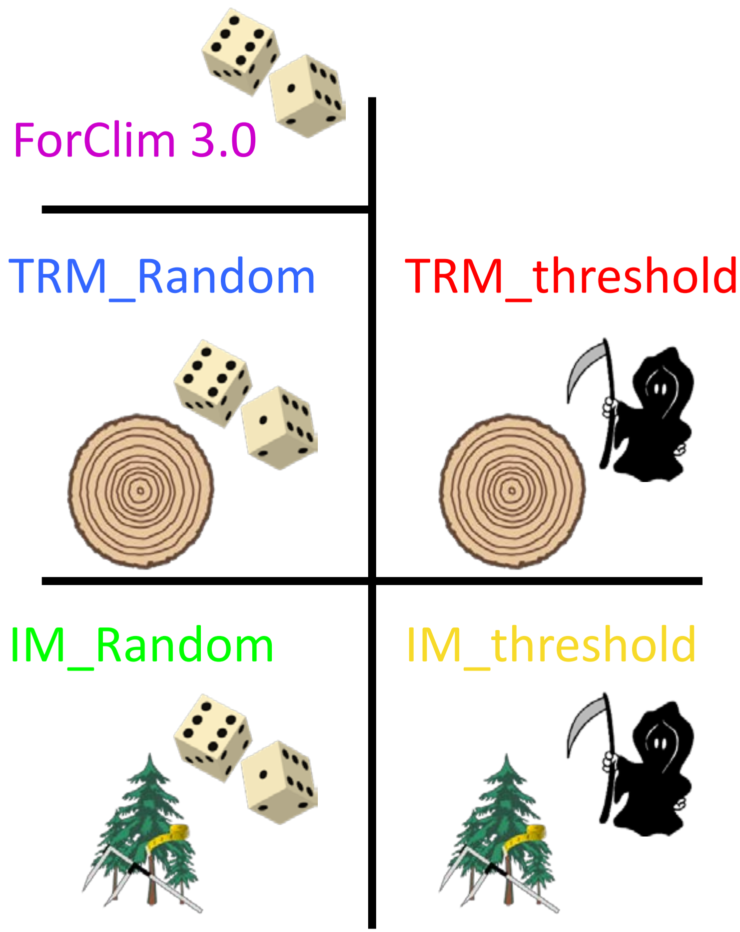


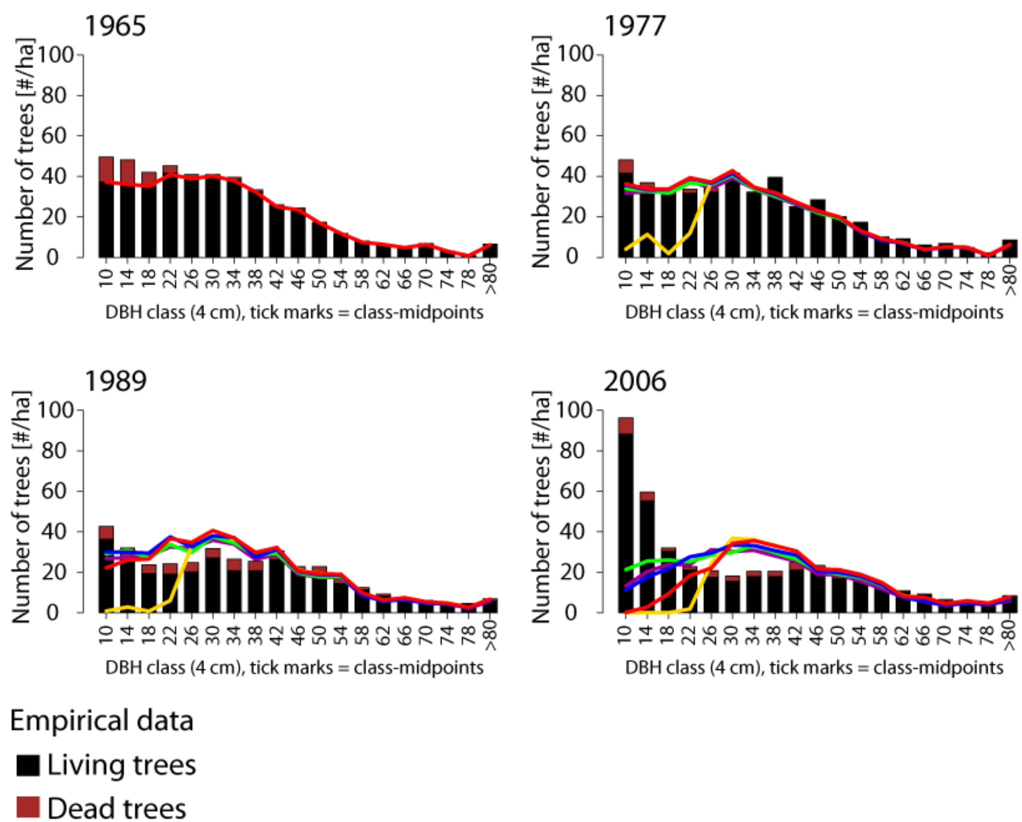


Bircher et al. (2015; Ecol. Appl.)

Comparison of different mortality models on spruce

Historical simulation in Scatlè (forest reserve)

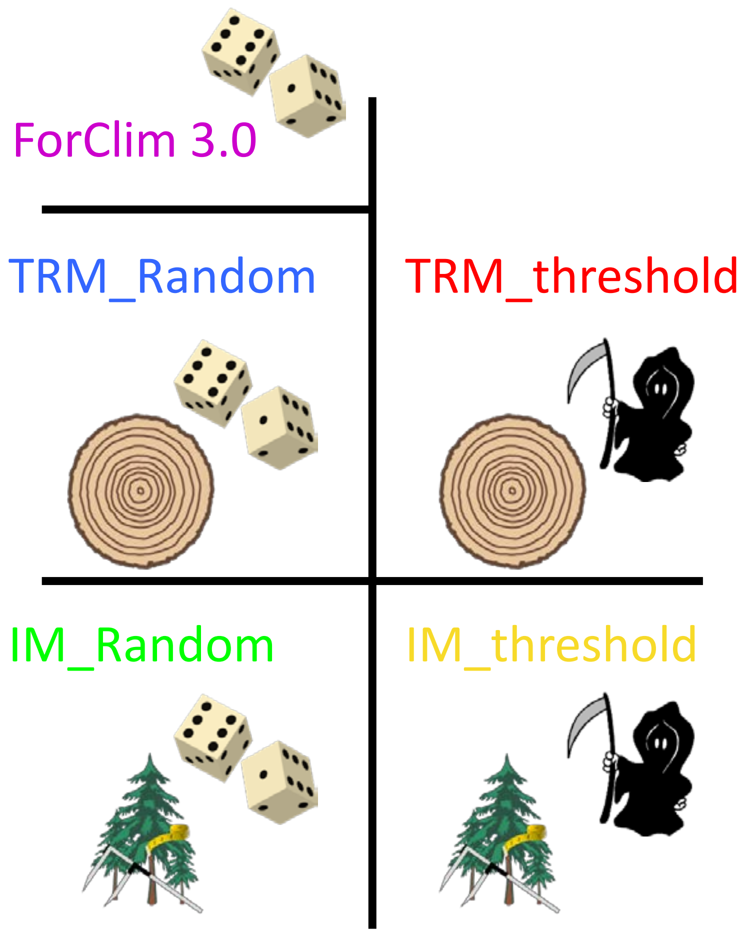


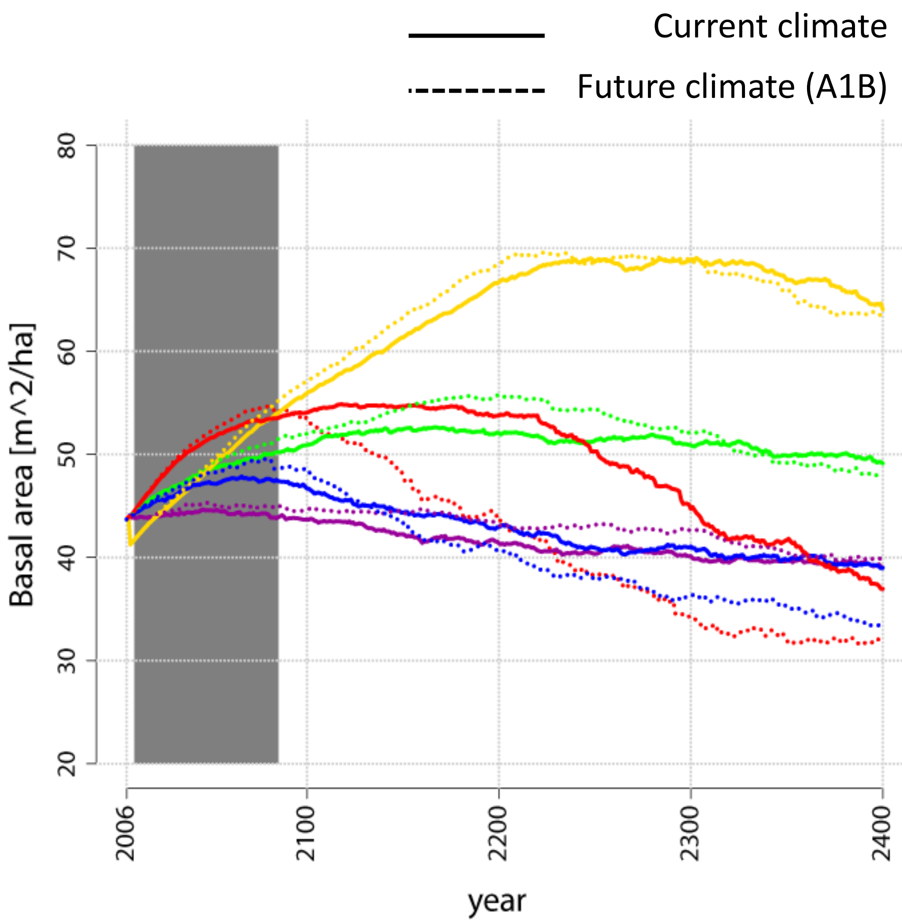


Bircher et al. (2015; Ecol. Appl.)

Comparison of different mortality models on spruce

Long-term simulation in Scatlè



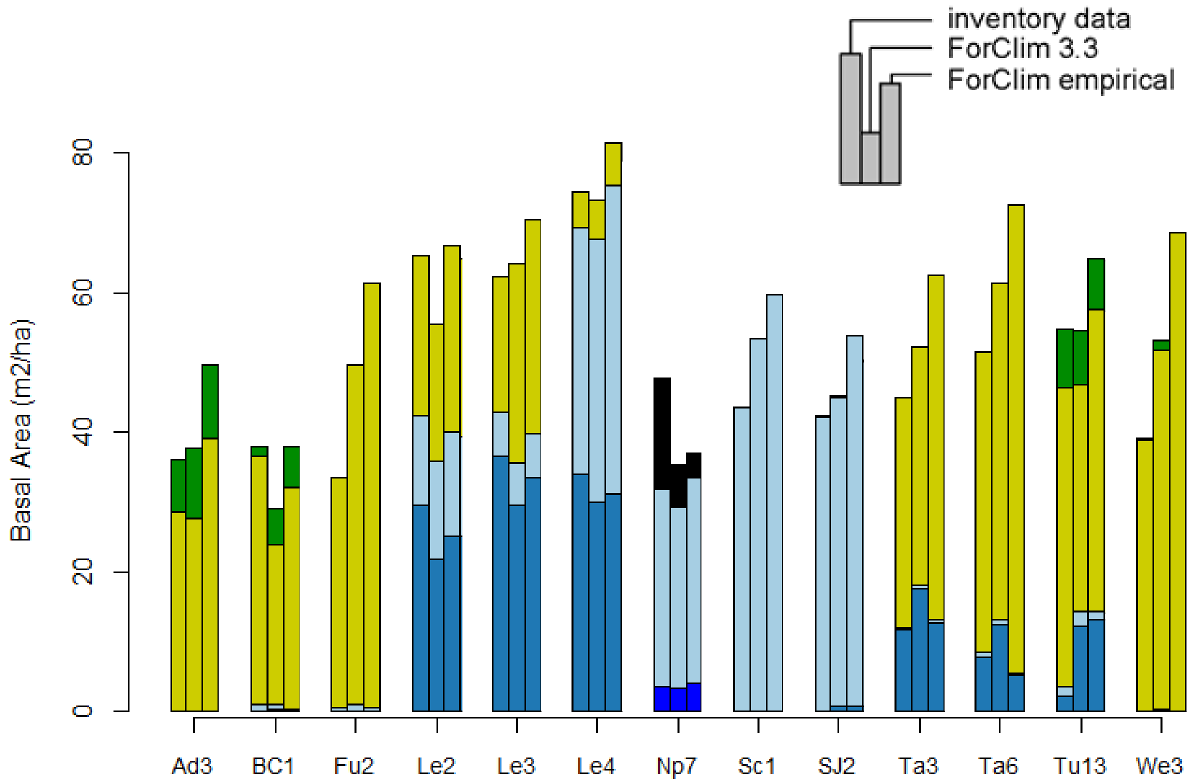


Bircher et al. (2015; Ecol. Appl.)

Empirical model based on inventory and ring-width data

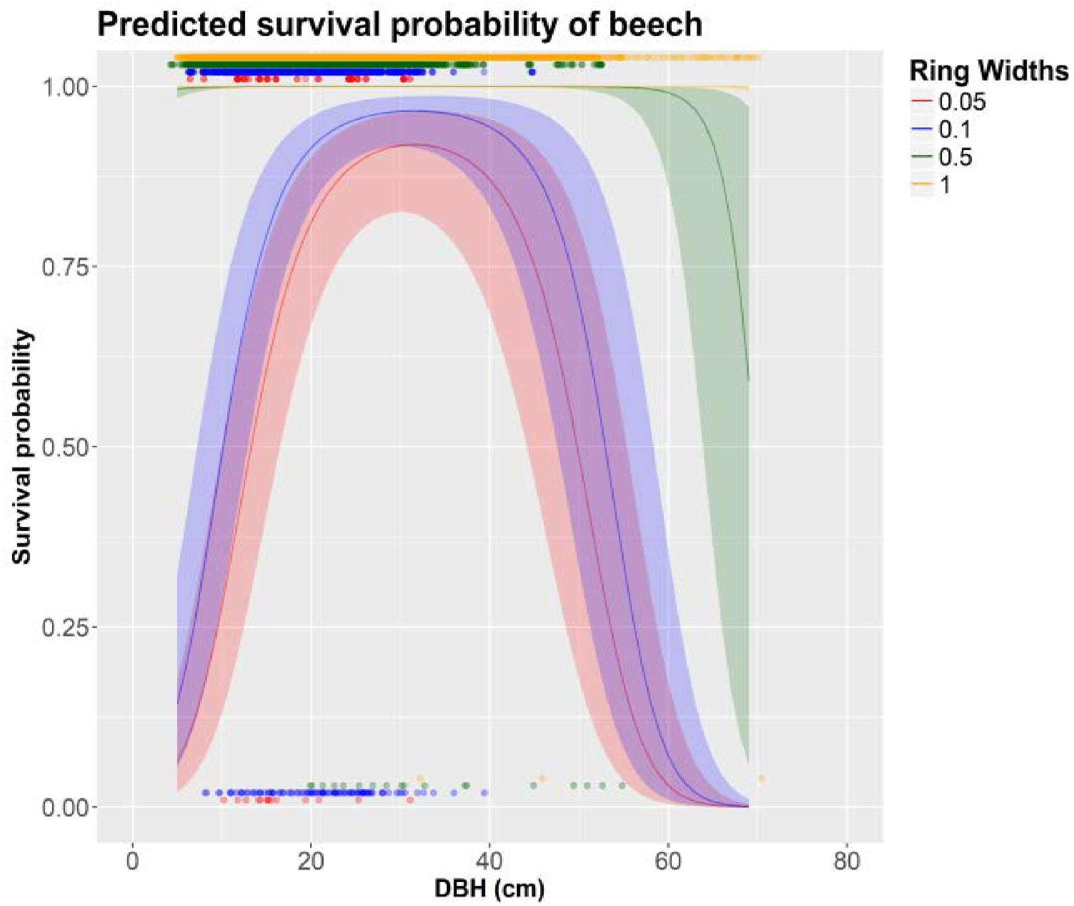
Calibration data:
12 forest reserves in Switzerland
6 species - 528 trees

Validation 1: Historical short-term (30-50 ys) simulations



Pinus cembra | Picea abies | Fagus sylvatica
Larix decidua | Abies alba | Quercus sp.

Vanoni et al. (2019; For. Ecol. Manage.)



Predicted survival probability of beech
Survival probability
1.00
0.75
0.50
0.25
0.00
0
20
40
60
80
DBH (cm)
Ring Widths
0.05
0.1
0.5
1