Climate change altered the dynamics of stand dominant height in forests during the past century

Matthieu Combaud, Thomas Cordonnier, Sylvain Dupire, Patrick Vallet

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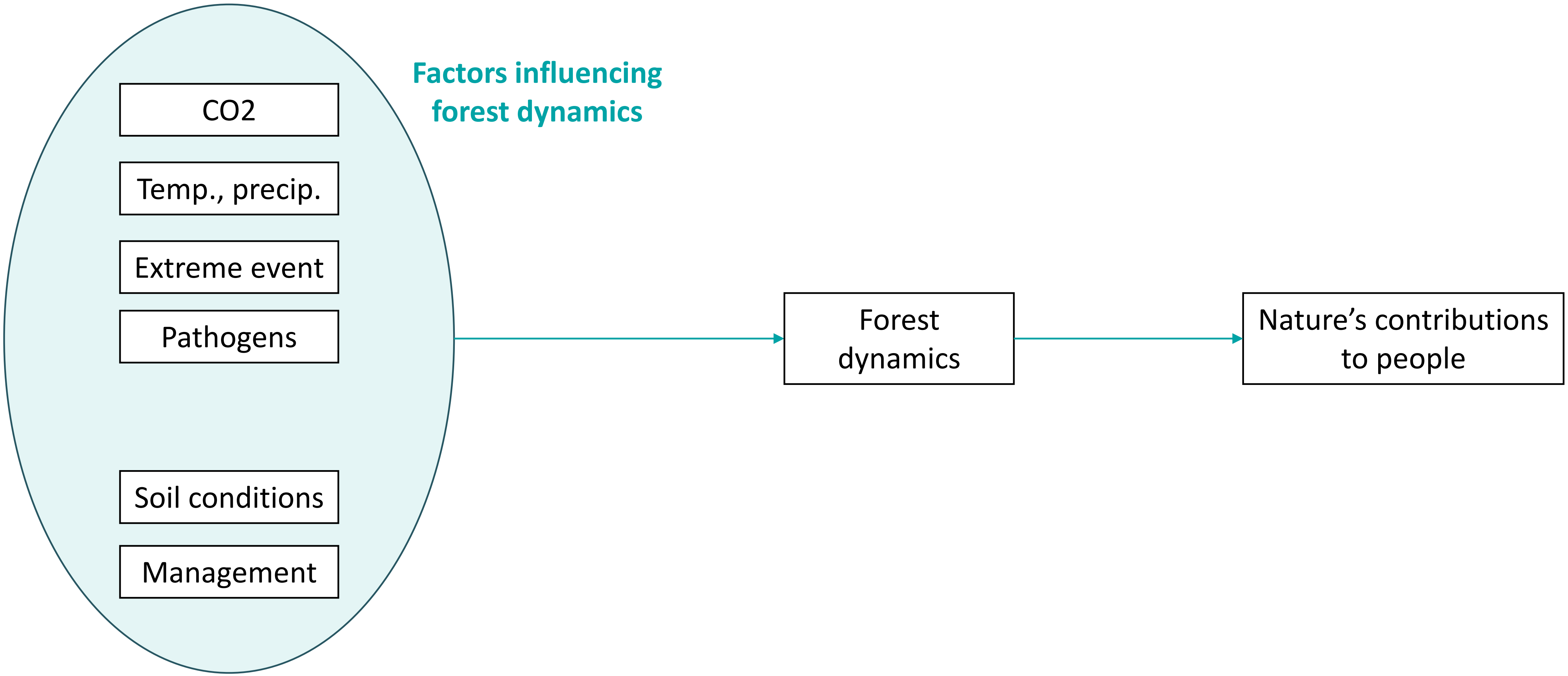
Analysis of 20 European tree species

Matthieu Combaud, Thomas Cordonnier, Sylvain Dupire, Patrick Vallet

BES Annual Meeting, Belfast, 13th December 2023

Need to anticipate forest dynamics response to climate change (CC)



Lindner et al., 2010

Need to anticipate forest dynamics response to climate change (CC)

Impact of CC

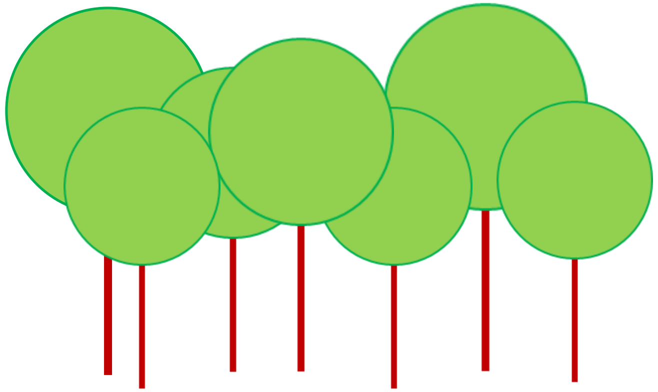
- CO_2
- Temp., precip.
- Extreme event
- Pathogens

- Soil conditions
- Management

→ Forest dynamics → Nature contributions to people

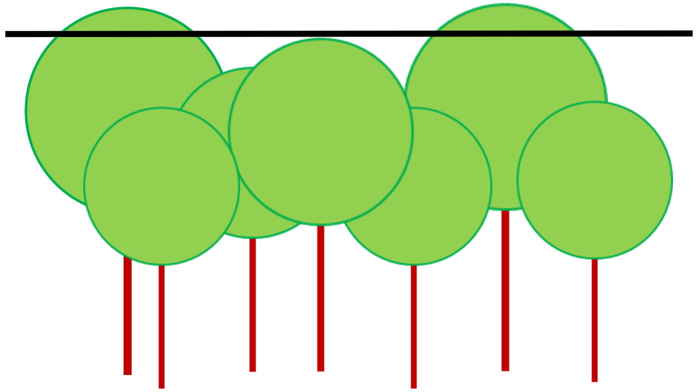
Lindner et al., 2010

Focus on even-aged pure stands



Stand = uniform group of trees
Pure stand = a single species
Even-aged = similar ages for all trees

Focus on even-aged pure stands



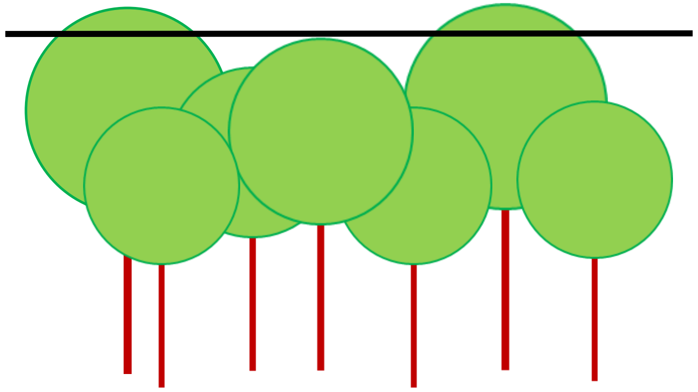
Two key indicators

- **Dominant height** = height of the biggest trees
- **Site index** = dominant height at 70 yrs

Stand = uniform group of trees
Pure stand = a single species
Even-aged = similar ages for all trees

Assmann & Davis, 1970
Skovsgaard & Vanclay, 2008

Focus on even-aged pure stands



Two key indicators

- **Dominant height** = height of the biggest trees
- **Site index** = dominant height at 70 yrs

Informs on productivity

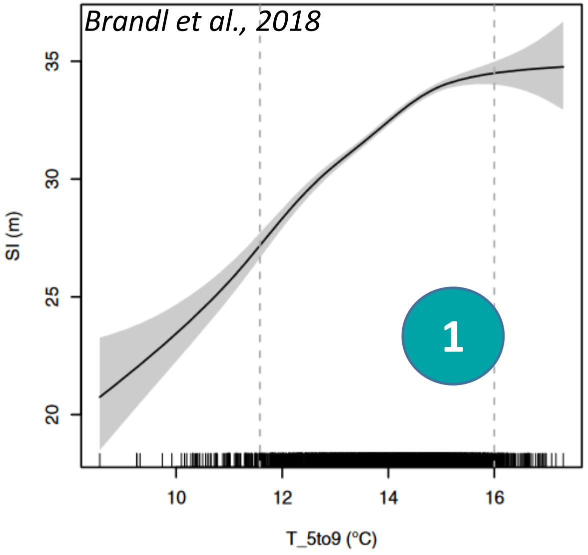
Little influenced by density

Influences response to disturbances

Stand = uniform group of trees
Pure stand = a single species
Even-aged = similar ages for all trees

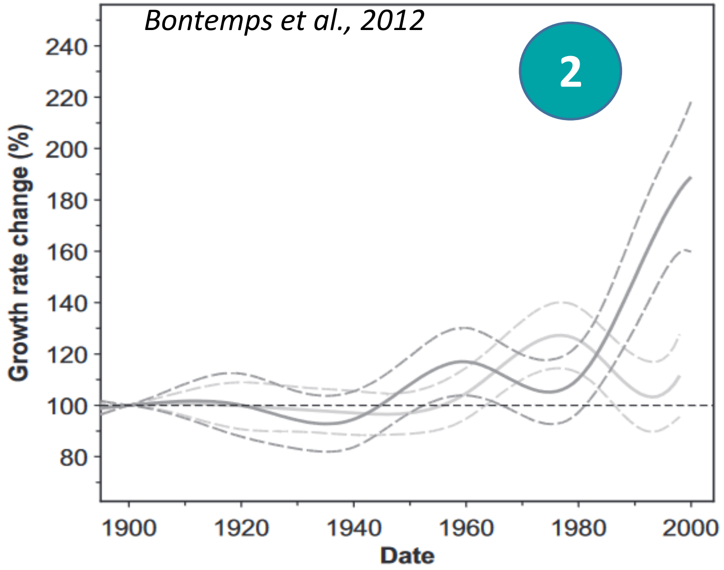
Assmann & Davis, 1970
Skovsgaard & Vanclay, 2008

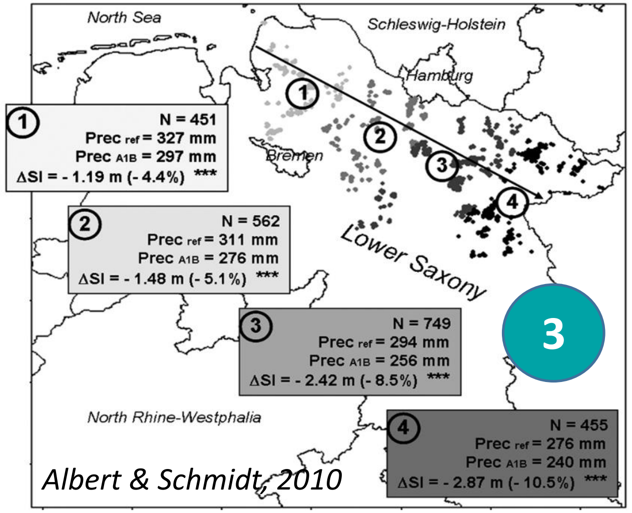
Literature on climate impacts on dominant height and site index



Impact of mean climate on site index and dominant height

Temporal trends in height growth dynamics





CC impact depends on stand climatic conditions

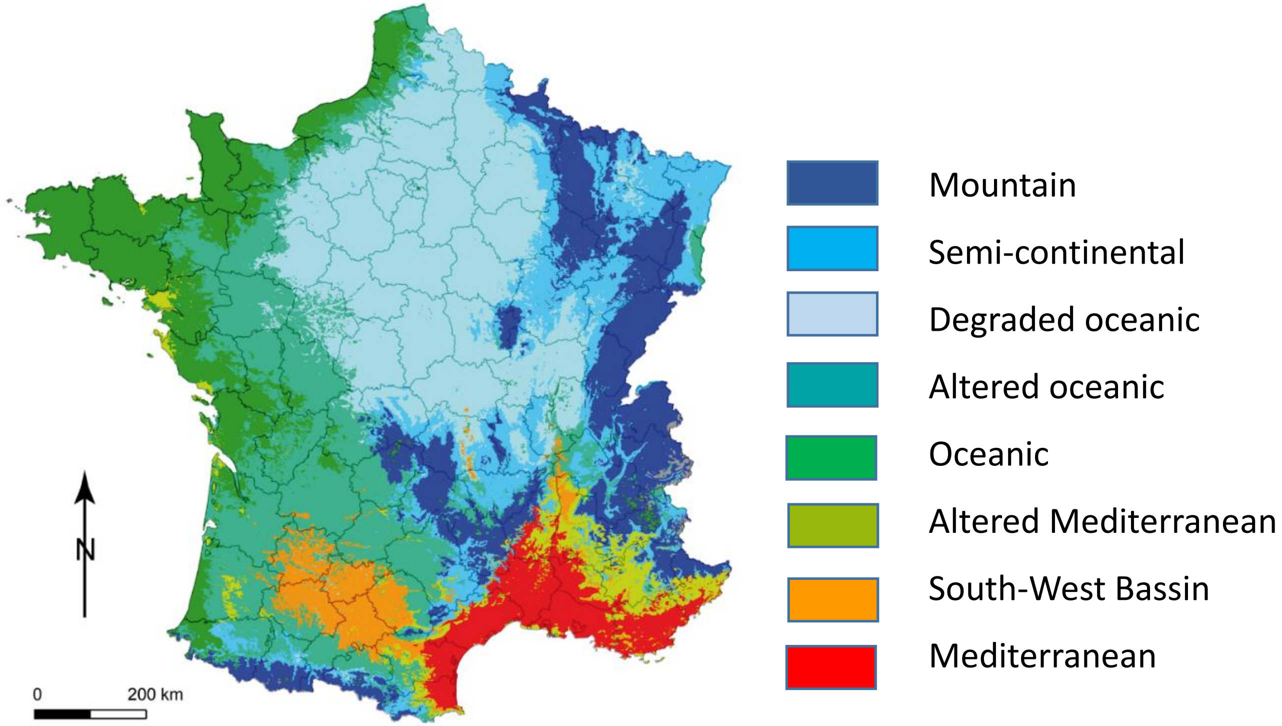
How has climate change over the past century modified dominant height dynamics and site index for 20 common European tree species ?

Focus on

- Temperature and precipitation changes
- Height growth process
- Even-aged pure stand

Modeling dominant height as a function of annual climate, per species

- Large climatic gradient, large species number, large set of control variables



From Joly et al., 2010

→ French National Forest Inventory (NFI)

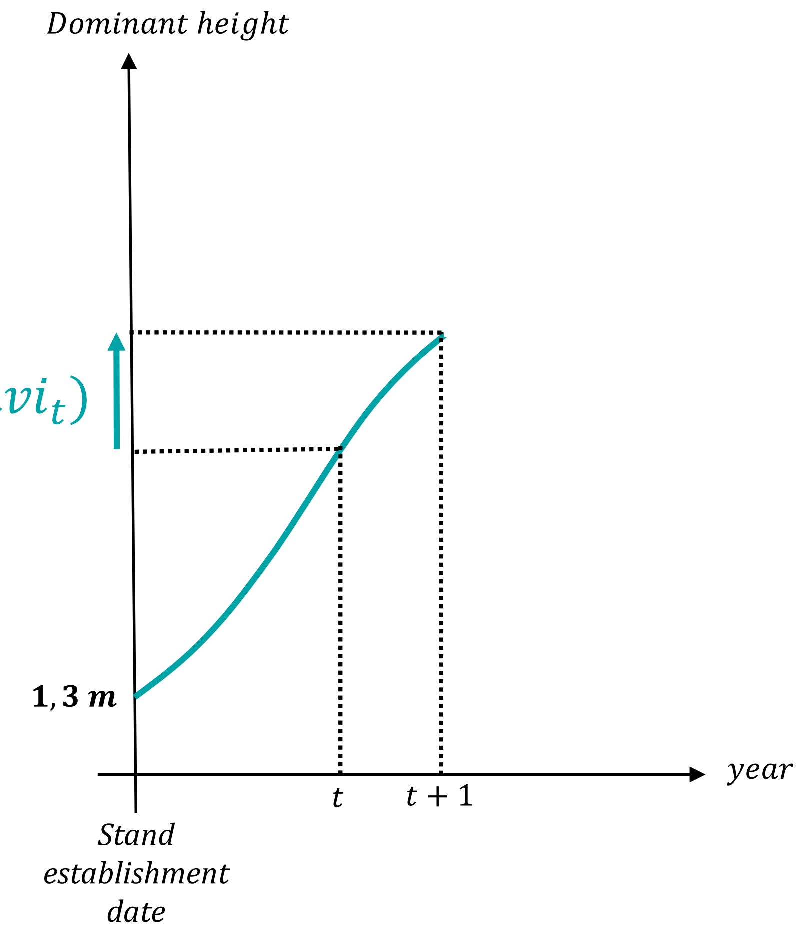
Modeling dominant height as a function of annual climate, per species

- Large climatic gradient, large species number, large set of control variables

- Integration of an annual increment equation

$$Dominant\ height\ increment_t = f(dominant\ height_t, envi_t)$$

Not observed



Zeide, 1993
Bontemps et al., 2009

Modeling dominant height as a function of annual climate, per species

- Large climatic gradient, large species number, large set of control variables
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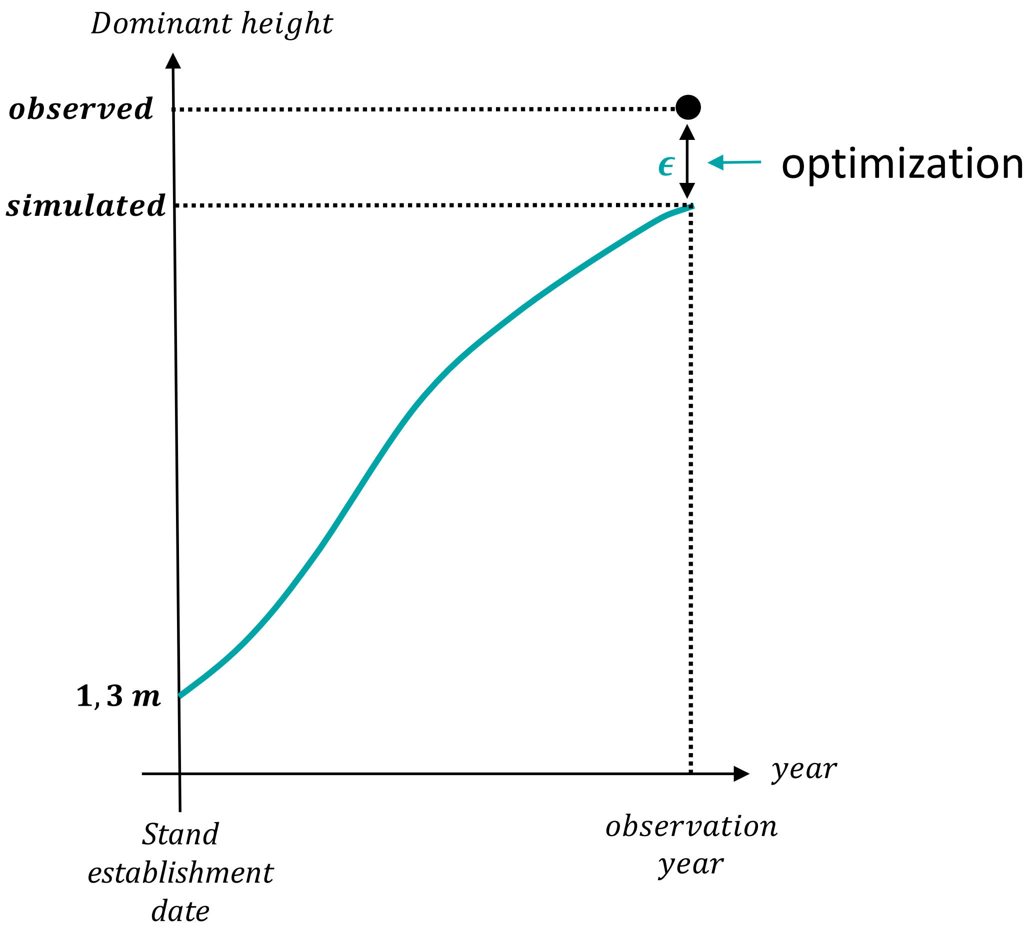


Zeide, 1993
Bontemps et al., 2009

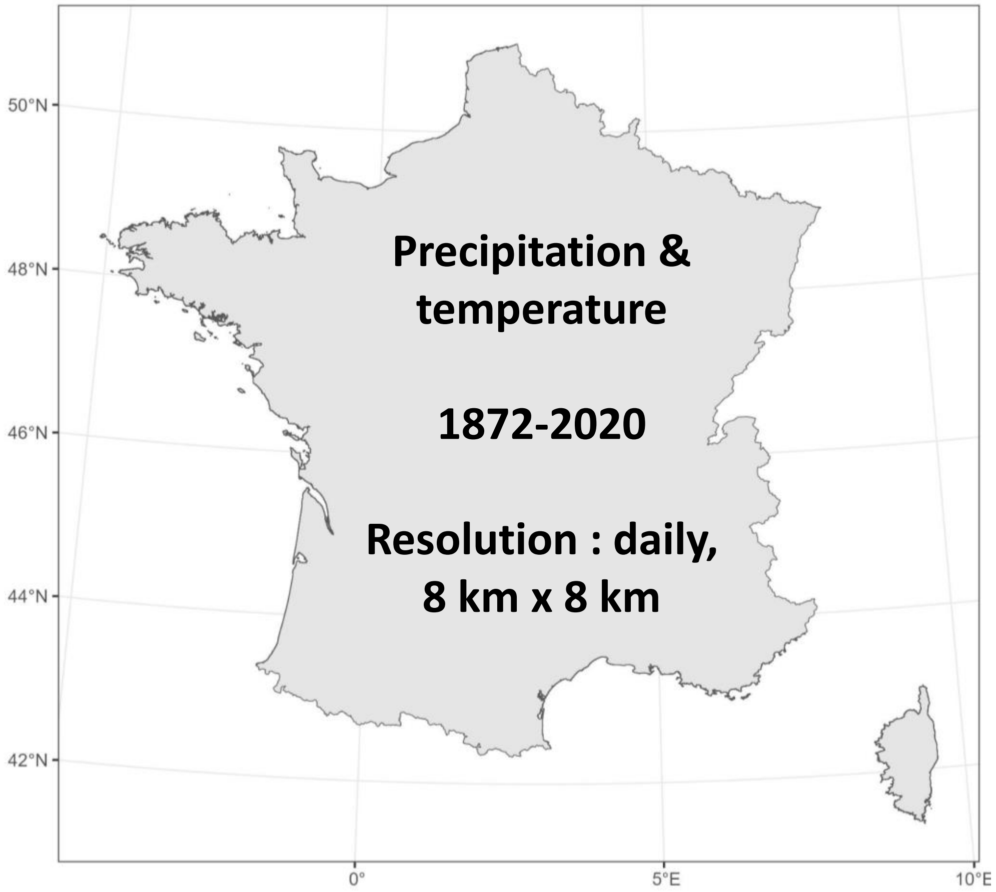
Modeling dominant height as a function of annual climate, per species

- Large climatic gradient, large species number, large set of control variables

- Integration of an annual increment equation

- Climatic data with high temporal depth and precise spatial resolution

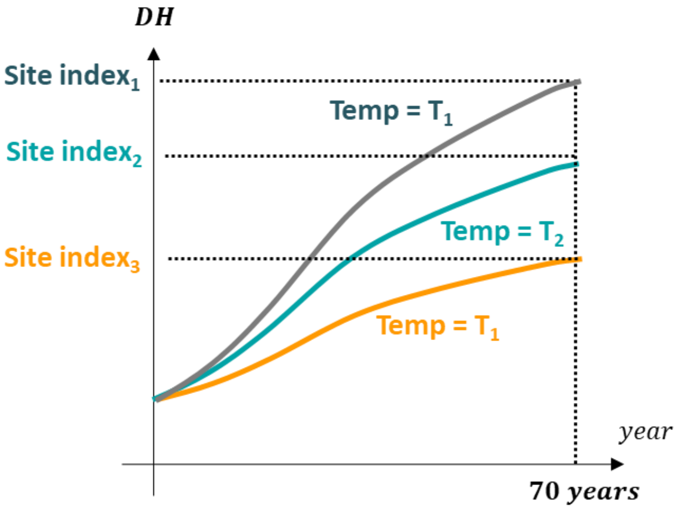
→ FYRE database (and Safran)



Devers et al., 2021

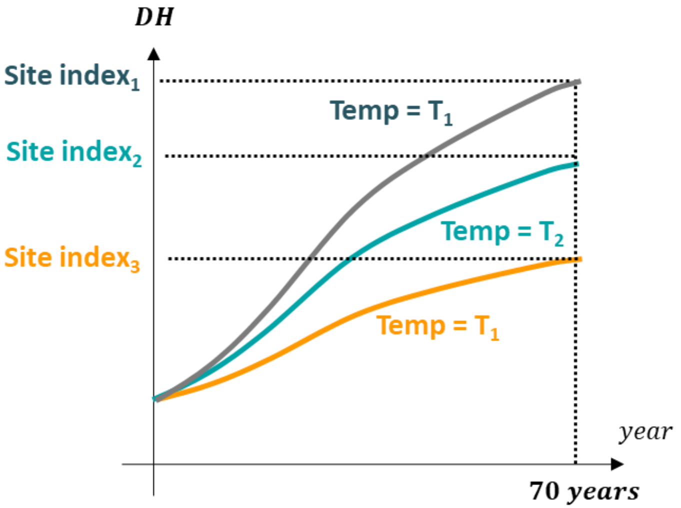
Simulations for all stands

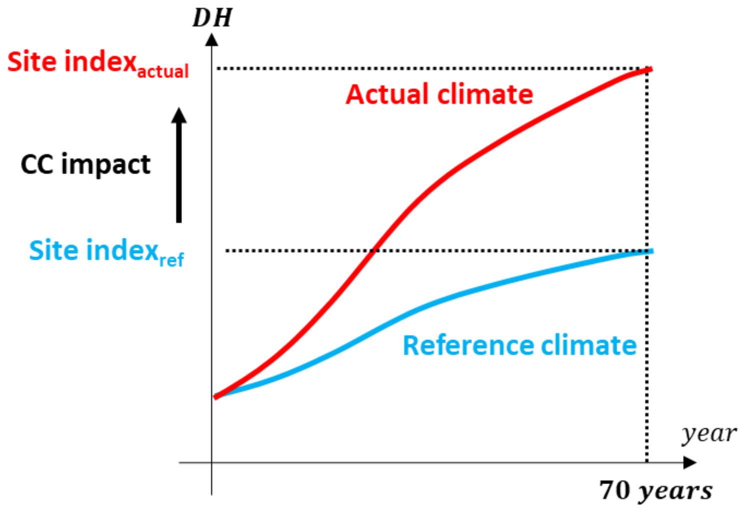
- Impact of each climate variable:
  simulations of site index for different values of the variable

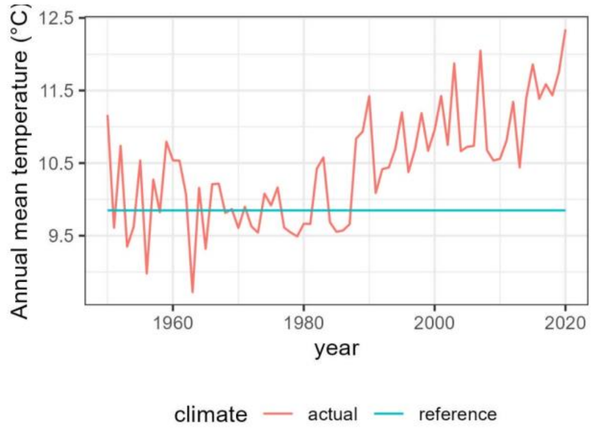


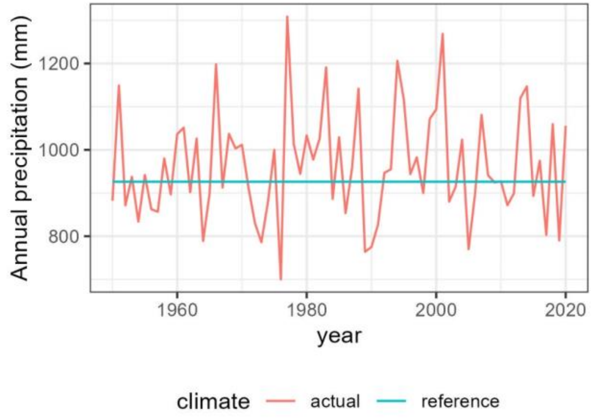
Simulations for all stands

- Impact of each climate variable: simulations of site index for different values of the variable
- Impact of CC: comparison of site index simulated under a reference climate (average 1891-1920) and actual climate (1950-2020)







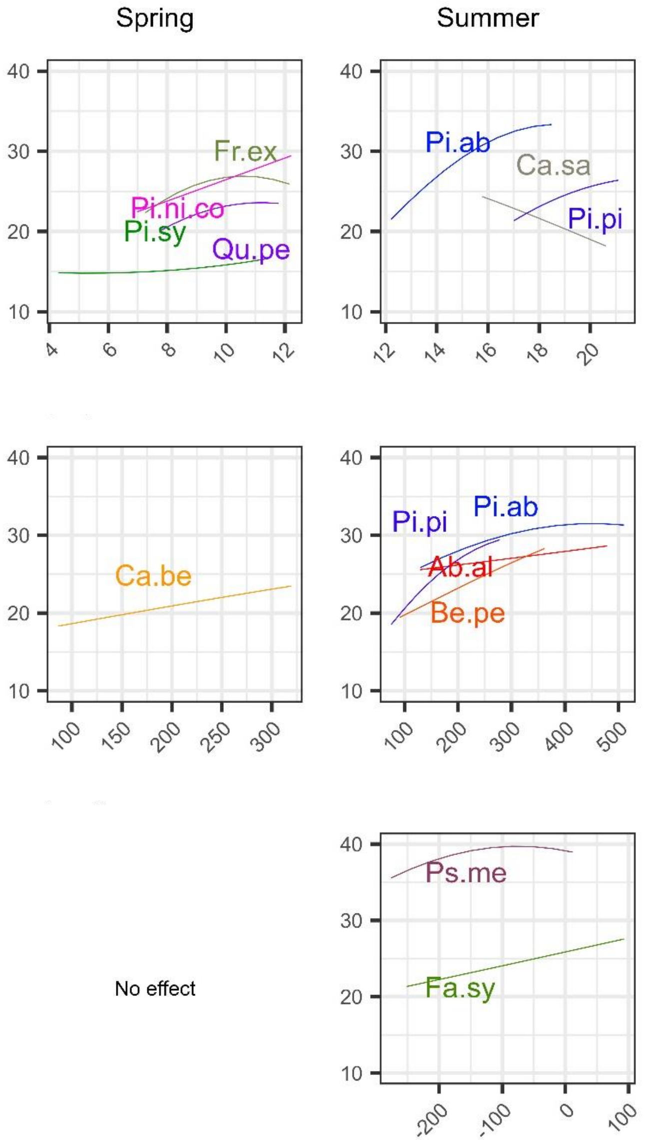


Response to each climate variables

Temperature

Precipitation

Water balance



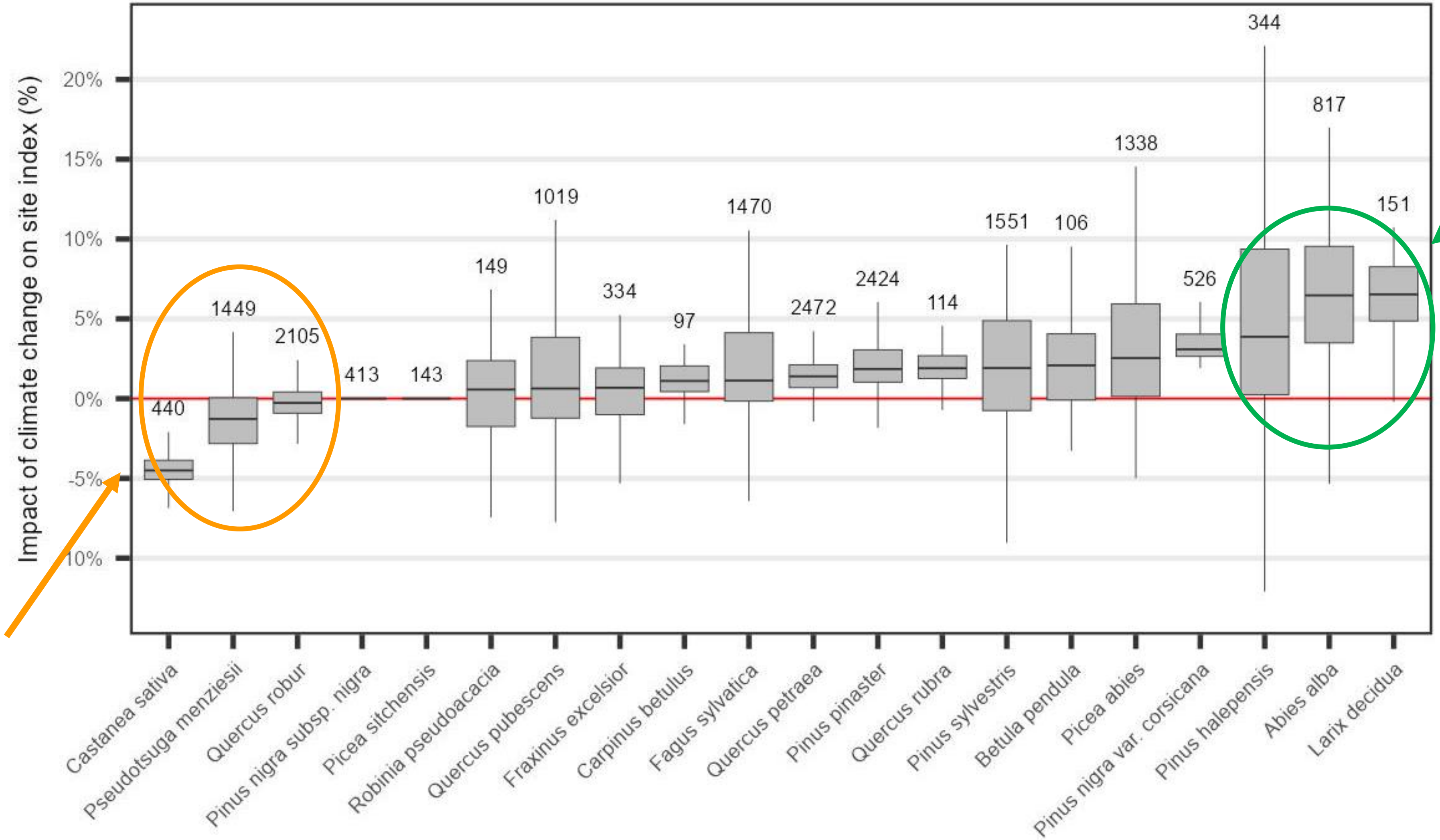
→ Positive impact until saturation

→ Positive impact until saturation

→ Positive impact until saturation

Combaud et al., 2024, FEM

Impact of CC on site index

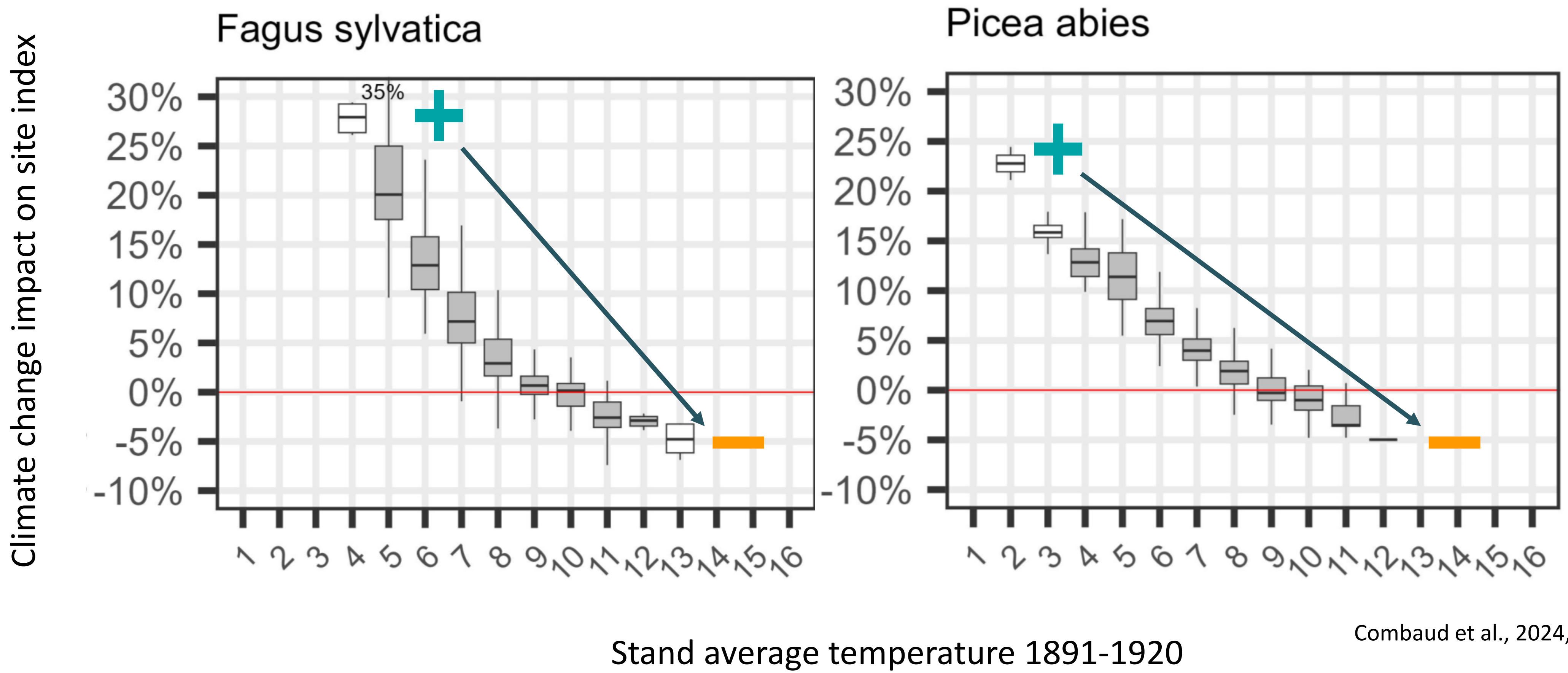


3 species show negative impact

3 species show strong positive impact

Combaud et al., 2024, FEM

Within-species variations



+ Positive impact on cold stands

– Negative impact on warm stands

Combaud et al., 2024, FEM

- Method able to study CC long term impact on height increment …

  … even without height increment data !

- Positive impact of CC so far …

  … that could turn into negative in the future

- Strong variabilities in the between and within species response to CC…

  … that should be taken into account to design adaptation strategies

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Thanks to

ONF

CLIMAE Metaprogram

IGN-IFN

Jean-Claude Gégout

Antoine Devers & Jean-Philippe Vidal

Björn Reineking

Jordan Bello

Mathieu Jonard

Xavier Morin

François Morneau

Nathéo Beauchamp

Anne Baranger

Maxime Jaunâtre

Carine Babusiaux

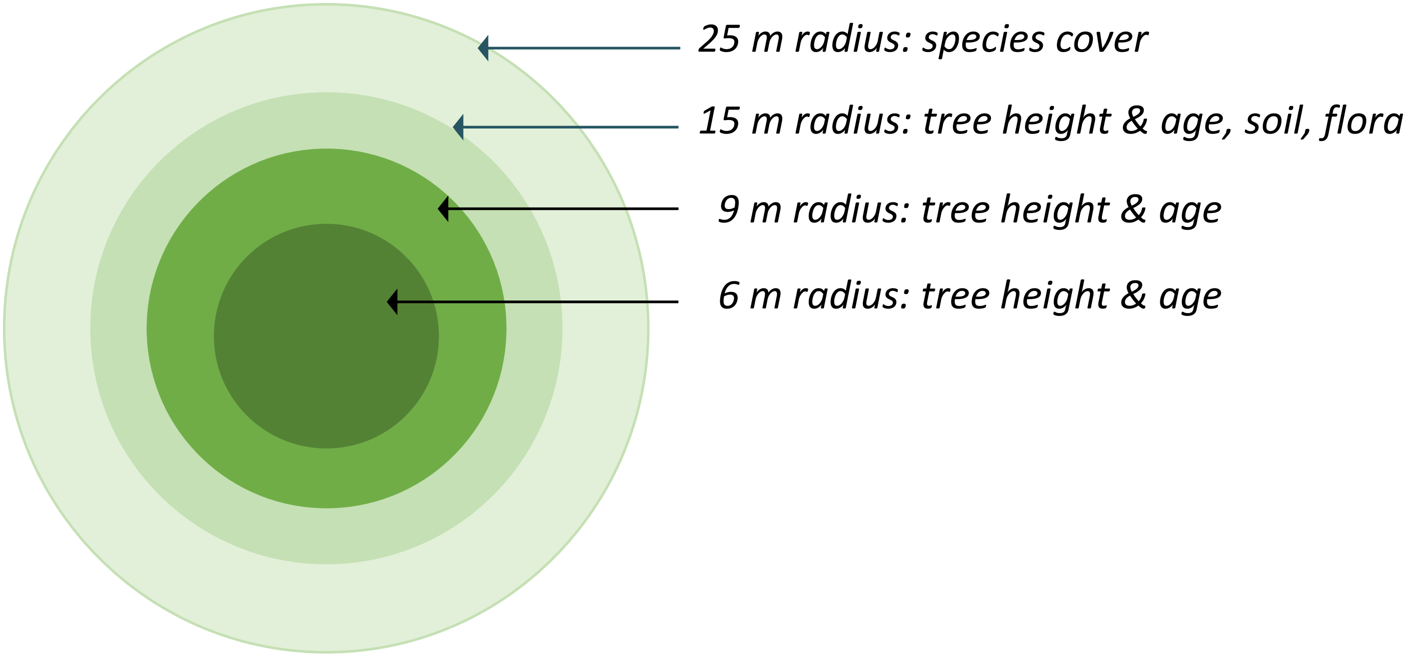
Compléments

Hypotheses

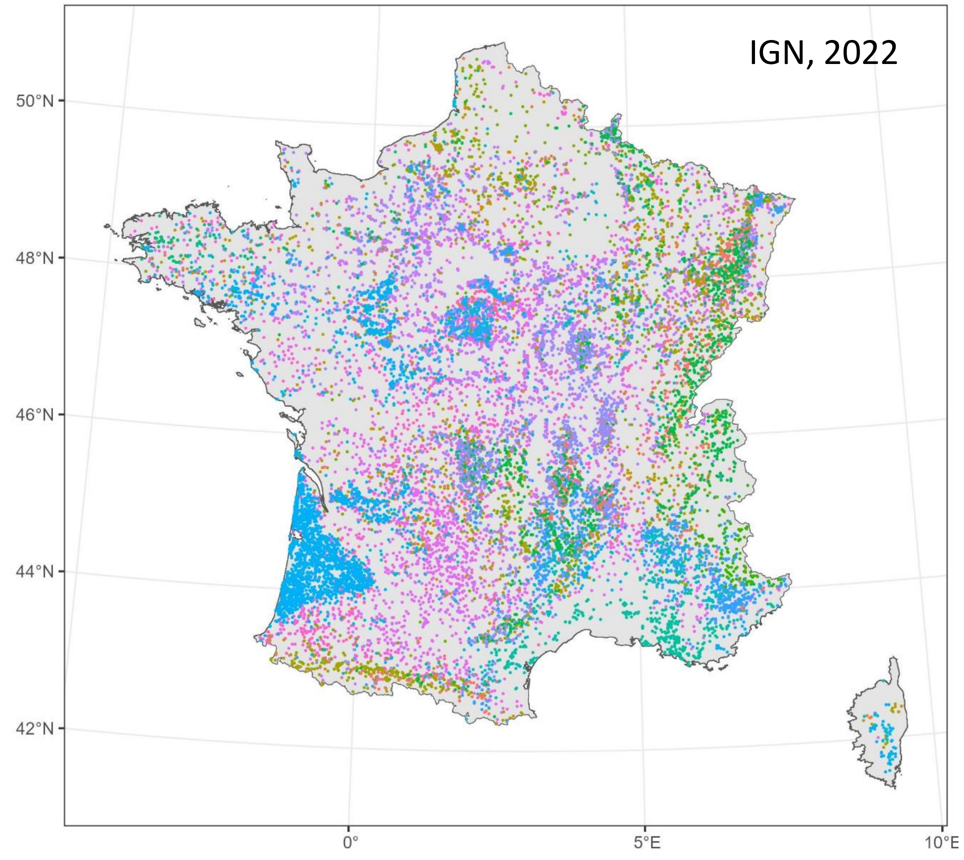
- Higher temperature, precipitation and water balance during spring and summer favor site index, but these positive effects saturate

- Climate change has had a different effect depending on the species and, for a given species, depending on the stand context

IFN measurement strategy



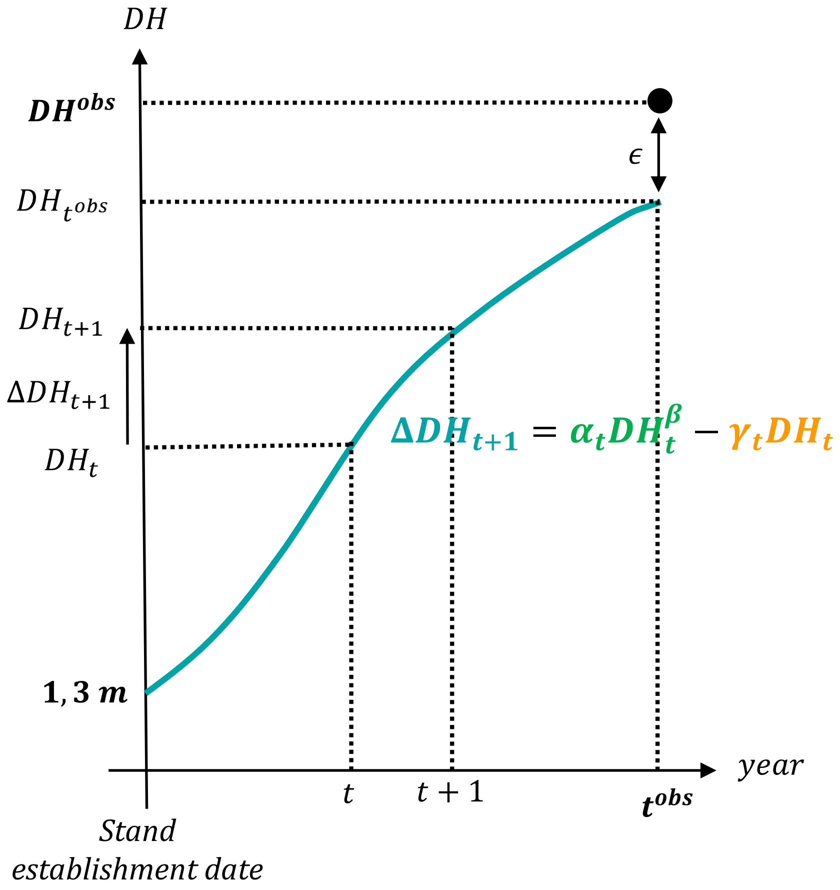
IFN measurement strategy



Dendrometric data

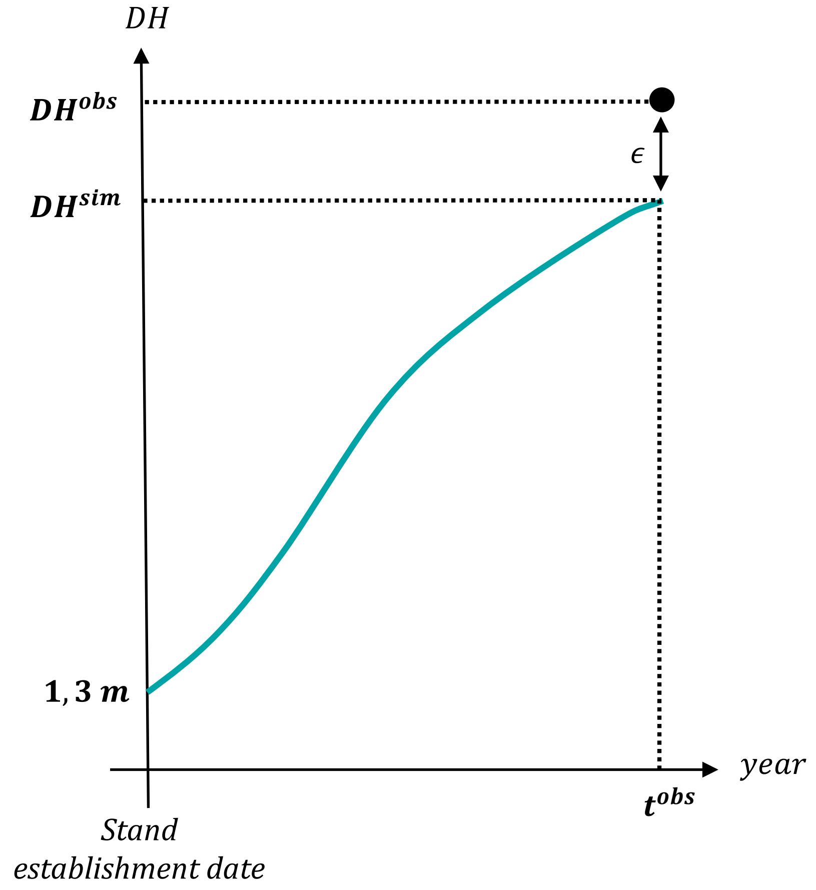
		SDH (m)		Age (year)				Stand establishment date	
Species	Number of stands	Mean	s.d	Mean	s.d.	Min	Max	Min	Max
Abies alba Mill., 1768	817	25.5	6.2	72.7	33.6	9	147	1871	2002
Betula pendula Roth, 1788	106	16.0	4.5	31.2	16.5	4	83	1932	2009
Carpinus betulus L., 1753	97	19.5	4.9	63.4	25.5	11	125	1885	2003
Castanea sativa Mill., 1768	440	17.7	4.8	43.9	26.1	5	141	1871	2013
Fagus sylvatica L., 1753	1,470	23.4	7.2	83.1	35.0	8	147	1871	2006
Fraxinus excelsior L., 1753	334	21.6	6.9	50.9	28.2	6	131	1875	2011
Larix decidua subsp. decidua Mill., 1768	151	19.0	6.1	67.5	36.0	7	137	1873	2009
Picea abies subsp. abies (L.) H.Karst., 1881	1,338	22.9	6.6	42.7	22.5	7	145	1871	2011
Picea sitchensis (Bong.) Carrière, 1855	143	22.3	6.9	31.0	10.3	5	63	1944	2013
Pinus halepensis Mill., 1768	344	12.5	3.9	50.1	23.6	6	137	1875	2010
Pinus nigra subsp. nigra J.F.Arnold, 1785	413	15.0	5.3	53.2	29.3	6	135	1881	2012
Pinus nigra var. corsicana (Loudon) Hyl., 1913	526	16.0	5.9	30.6	20.3	4	146	1871	2015
Pinus pinaster subsp. pinaster Aiton, 1789	2,424	16.8	6.5	30.3	20.8	2	132	1876	2018
Pinus sylvestris L., 1753	1,551	15.8	5.9	59.3	27.6	5	144	1873	2011
Pseudotsuga menziesii (Mirb.) Franco, 1950	1,449	24.1	8.6	30.6	13.0	4	110	1910	2015
Quercus petraea subsp. petraea (Matt.) Liebl., 1784	2,472	22.2	6.1	80.6	33.4	7	149	1871	2010
Quercus pubescens Willd., 1805	1,019	13.9	4.3	67.6	25.0	7	145	1871	2006
Quercus robur var. robur L., 1753	2,105	20.7	5.4	70.3	30.9	8	149	1871	2006
Quercus rubra L., 1753	114	18.5	6.2	26.4	16.3	4	81	1930	2006
Robinia pseudoacacia L., 1753	149	18.0	5.1	32.3	18.0	5	94	1916	2014

Modeling strategy



Model selection and parameter estimation

$$DH^{obs} = 1,3 + \sum \Delta \mathrm{DH_t} + \epsilon$$



$$f_{exp}\left(X_t^{exp}\right) = A_0 . \frac{exp\left(\alpha . X_t^{exp}\right)}{1 + exp\left(\alpha . X_t^{exp}\right)} (eq. 1)$$

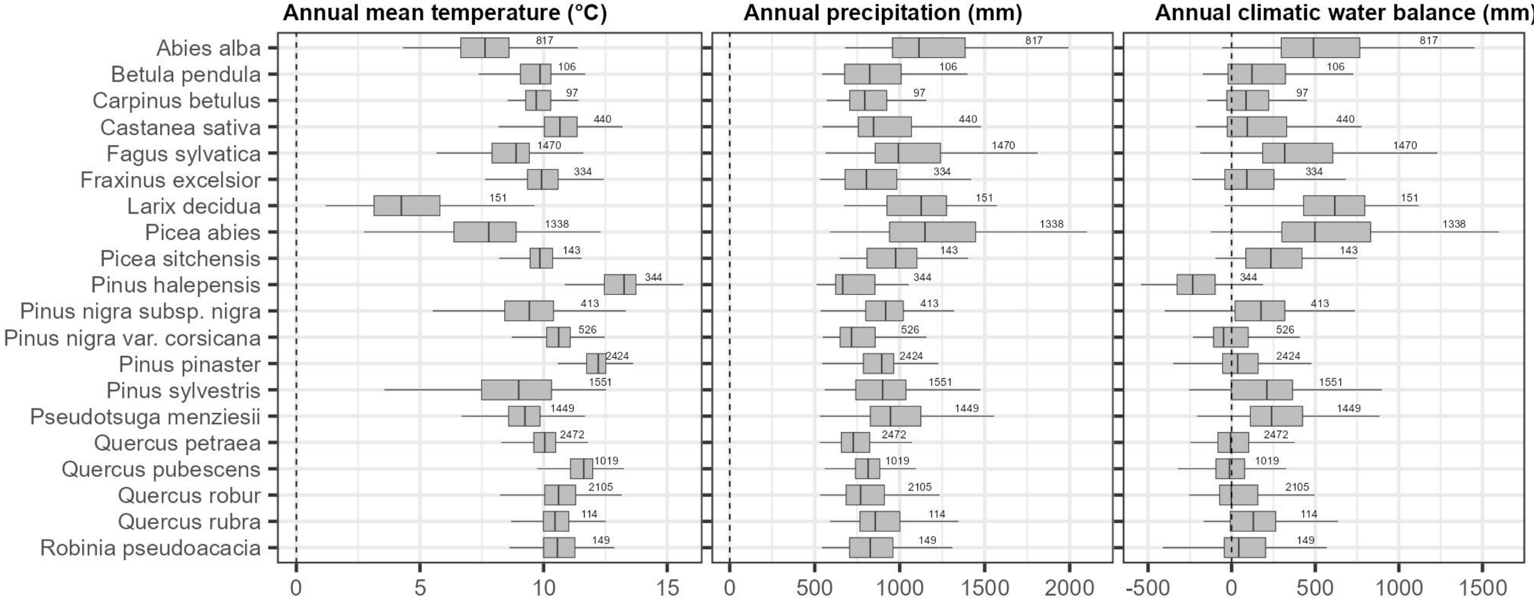
$$f_{decline}\left(X_t^{decl}\right) = C_0 . \frac{exp\left(\gamma . X_t^{decl}\right)}{1 + exp\left(\gamma . X_t^{decl}\right)} (eq. 2)$$

The final increment equation is equation (3). In this equation, SDH_t is SDH at the beginning of year t and ΔSDH_t is the SDH variation between the beginning of years t and $t + 1$.

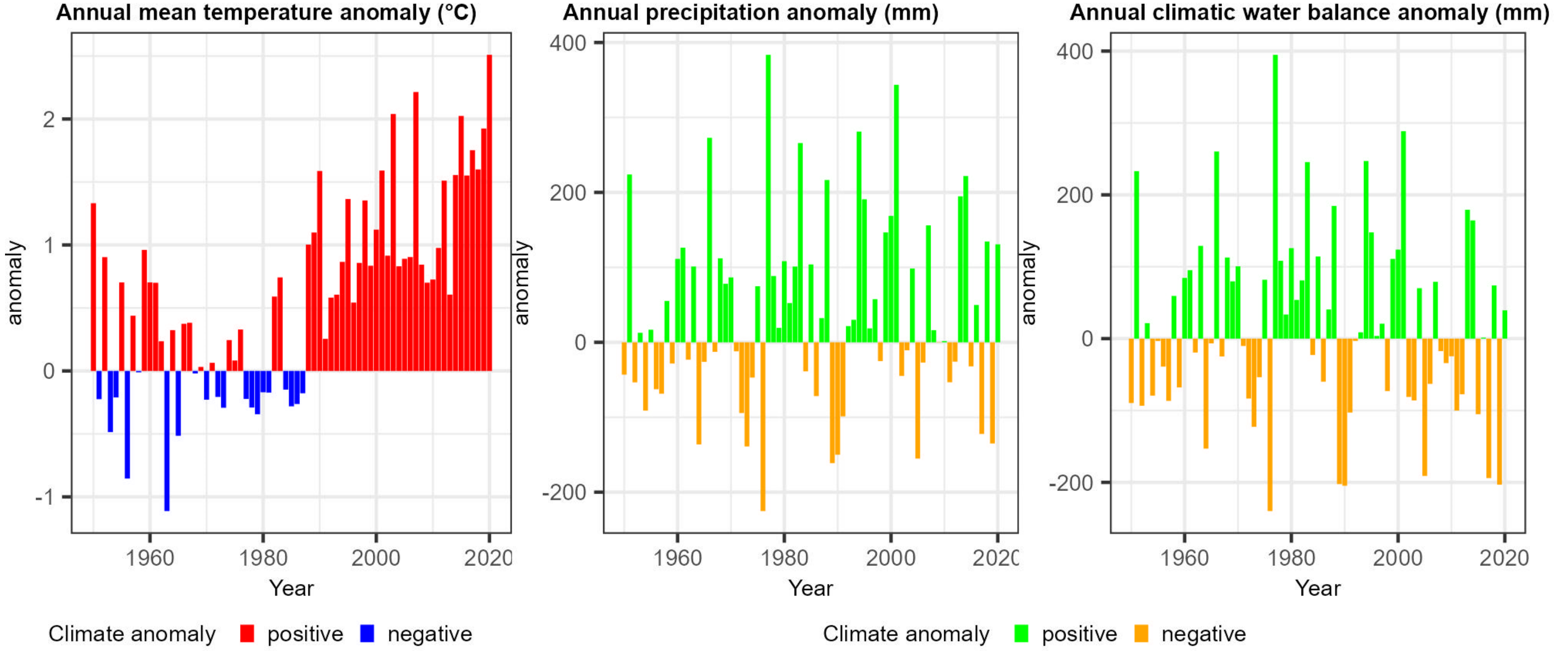
$$\Delta SDH_t = max\left[0, f_{exp}\left(X_t^{exp}\right) . SDH_t{}^{\beta_0} - f_{decl}\left(X_t^{decl}\right) . SDH_t\right] (eq. 3)$$

$$SDH_i^{obs} = 1.3 + \sum_{t=t_i^{ori}}^{t_i^{obs}-1} \Delta\, SDH_{t,i} + \epsilon_i (eq. 4)$$

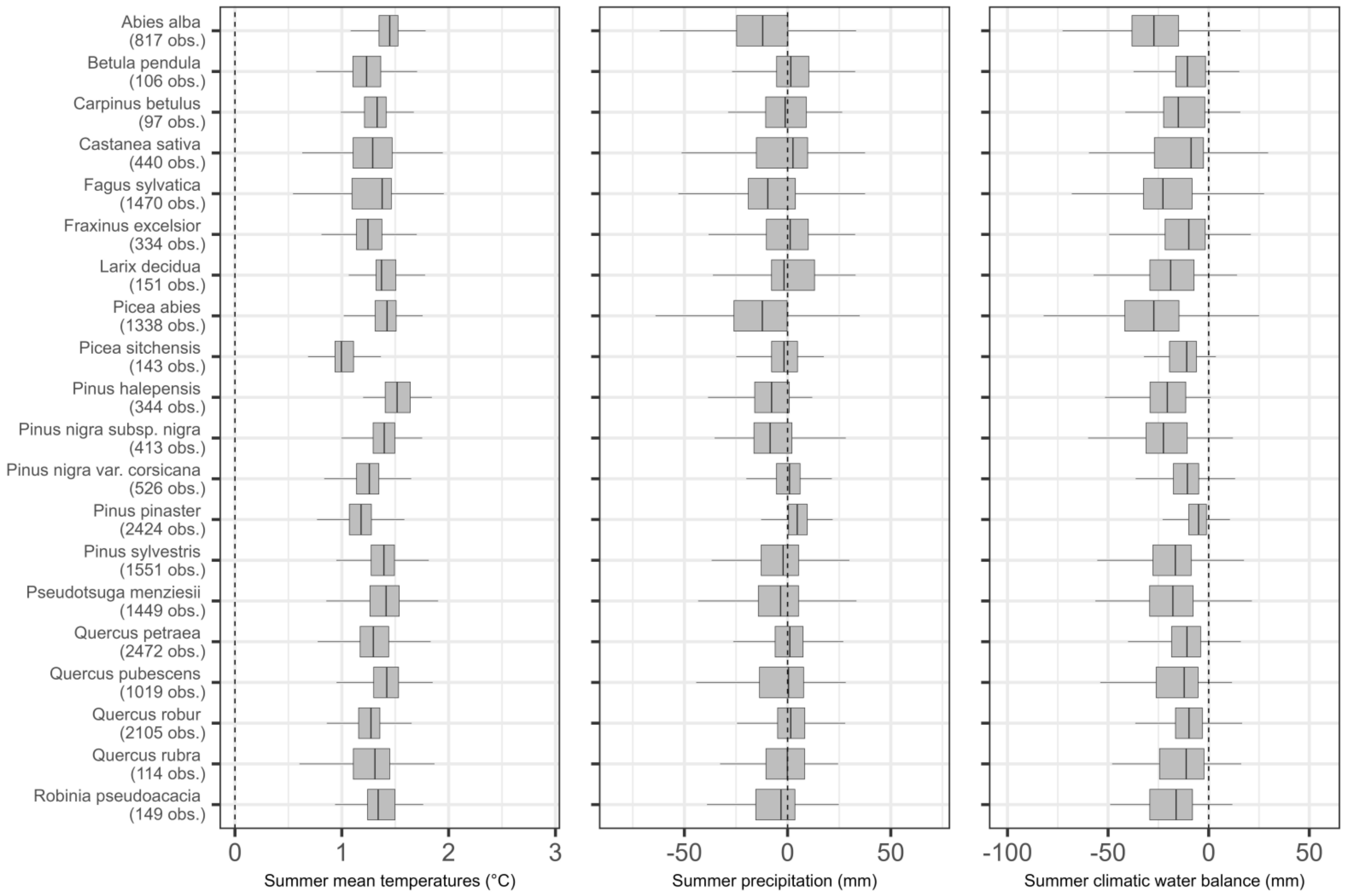
Reference climate (average 1891- 1920)



Climate anomaly compared to reference climate (average 1891-1920)

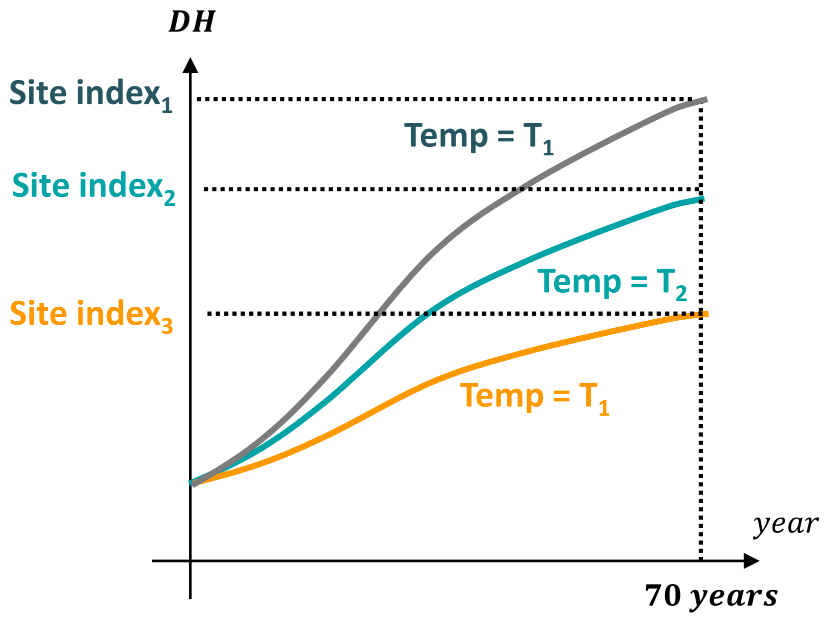


Climate evolution (1891-1920 vs 1991-2020)

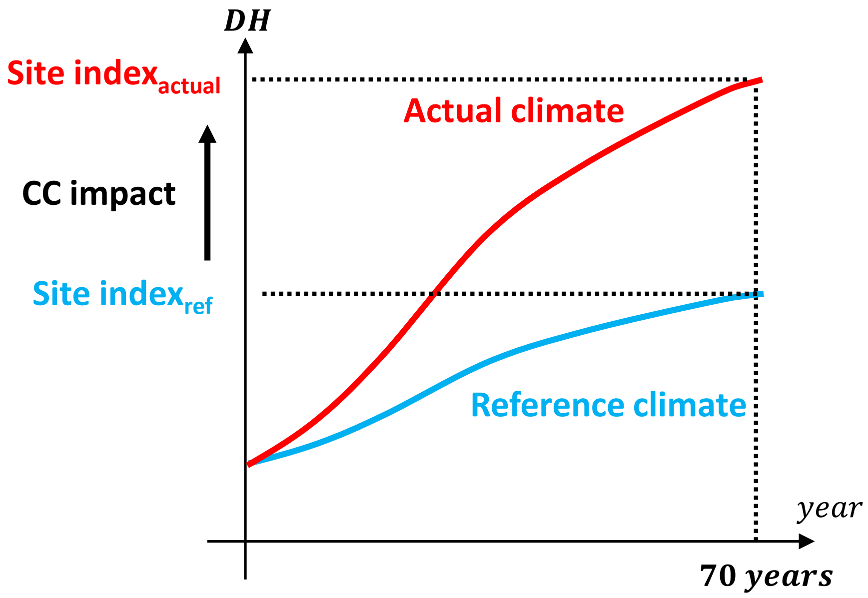


Simulations for all stands

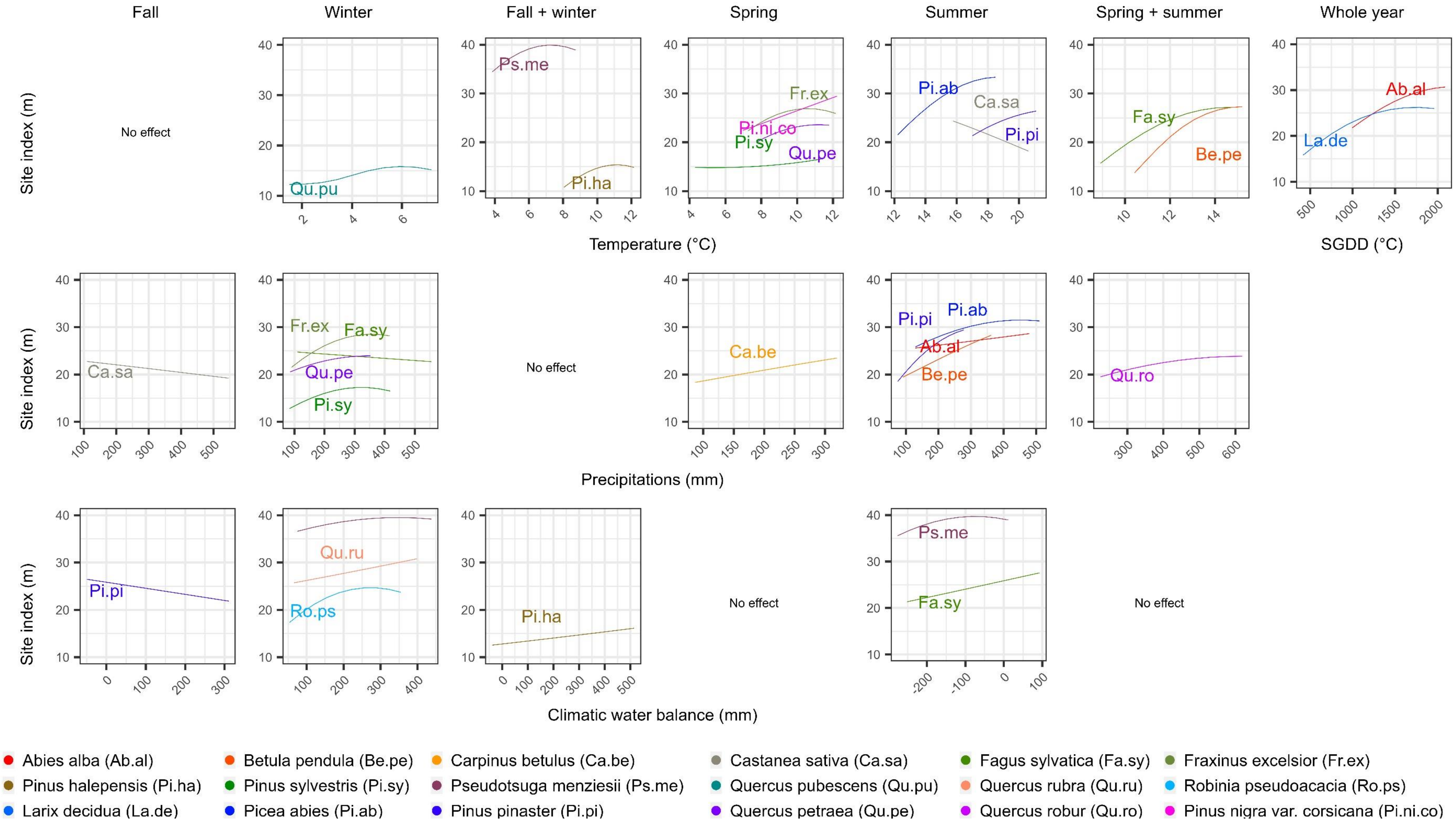
- Impact of each climate variable: simulations of site index for different values of the variable



- Impact of CC: comparison of site index simulated under a reference climate (average 1891-1920) and actual climate (1950-2020)



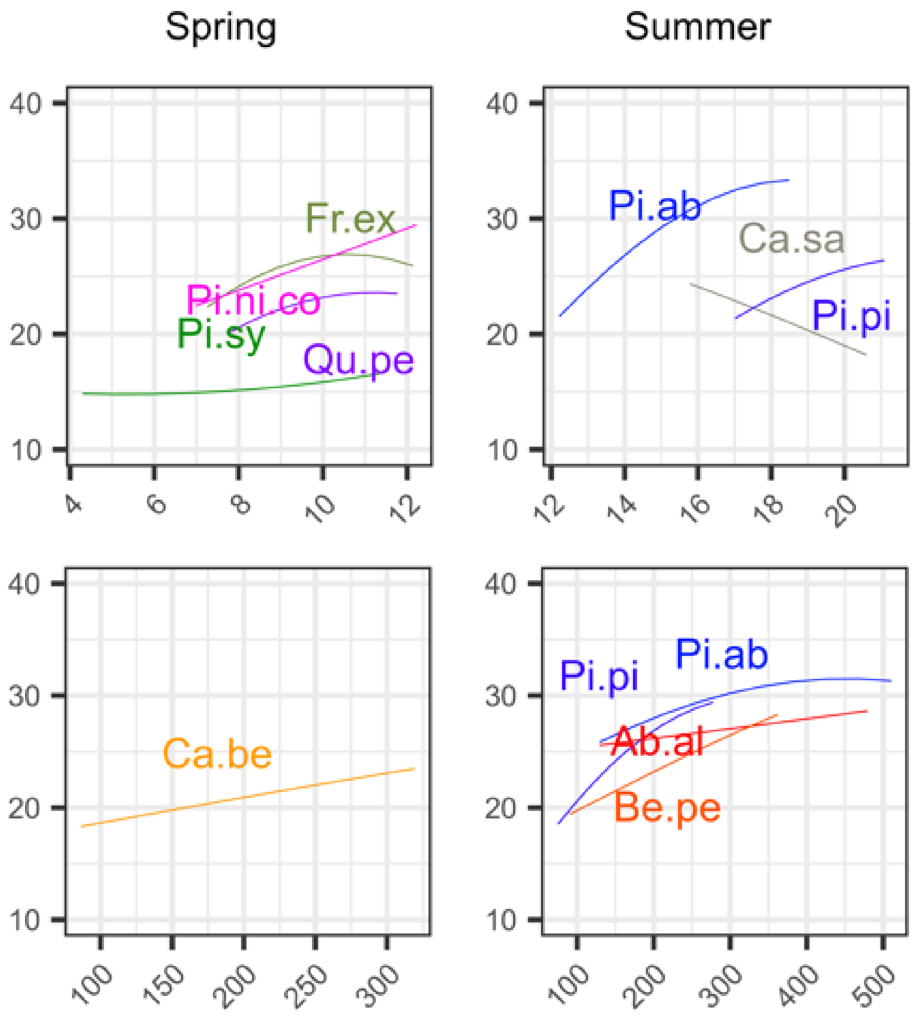
Partial impact



Response to temperature and to precipitation

Temperature

Precipitation



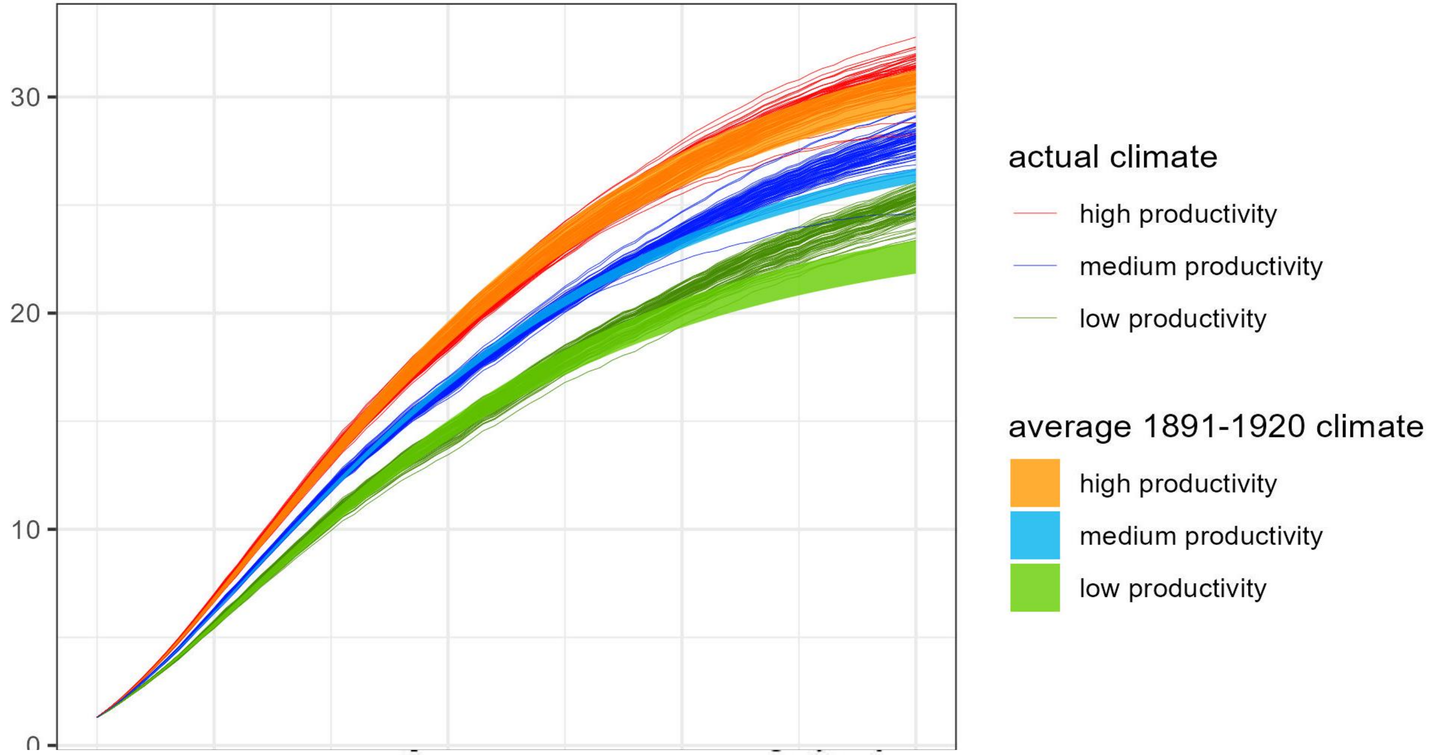
→ Positive impact until saturation

→ Positive impact until saturation

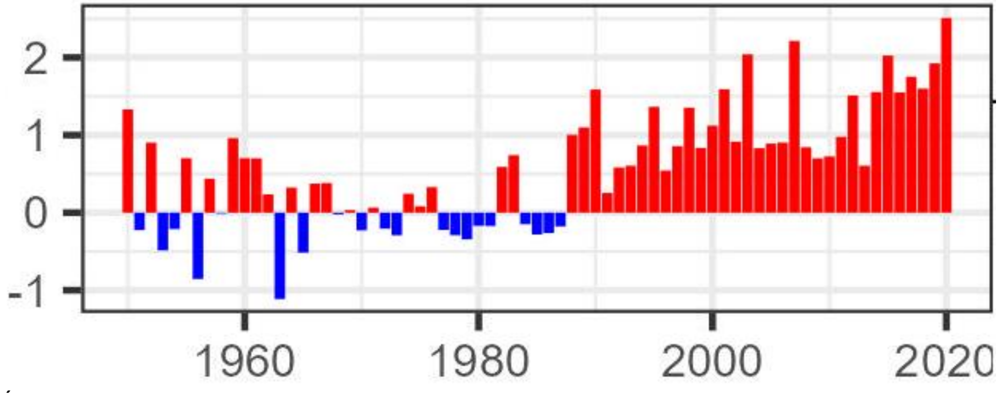
Combaud et al., 2024, FEM

Impact of CC on dominant height dynamics

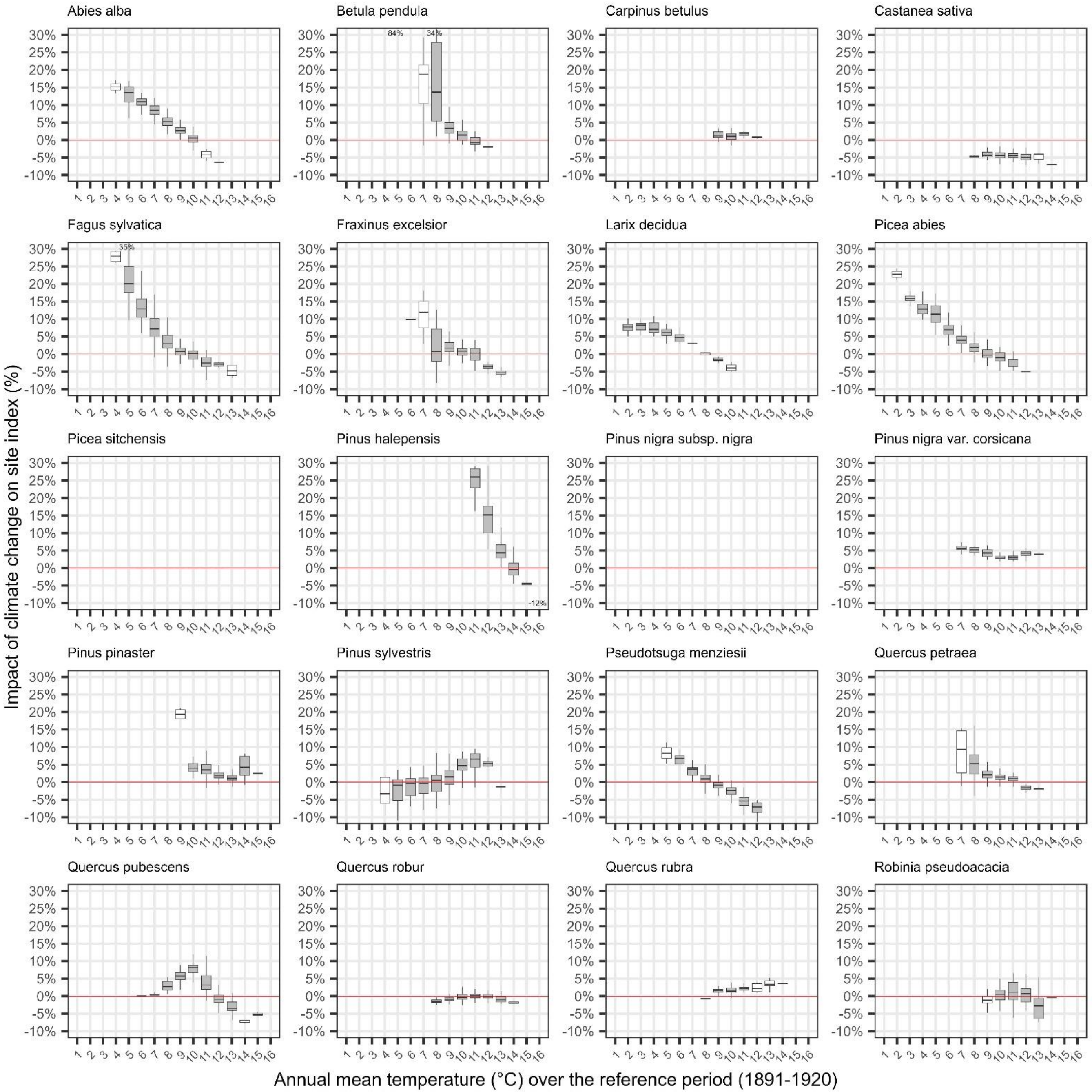
Dominant height
Abies alba (m)



French temperature anomalies (°C)



Within-species impact



Quality metrics

species	RMSE (m)	RMSPE (%)	bias (m)	optimism (%)
Abies alba	3.6	22.0	0.0	3.8
Betula pendula	2.5	21.0	0.0	34.7
Carpinus betulus	2.9	18.9	0.0	18.7
Castanea sativa	3.1	20.0	0.0	7.0
Fagus sylvatica	3.8	21.2	0.0	2.9
Fraxinus excelsior	3.7	21.3	0.0	6.5
Larix decidua	3.1	21.0	0.0	25.6
Picea abies	2.9	15.0	0.0	5.9
Picea sitchensis	3.5	23.5	0.0	9.3
Pinus halepensis	2.6	24.5	0.0	6.8
Pinus nigra subsp. nigra	3.2	28.5	0.0	9.6
Pinus nigra var. corsicana	2.4	17.4	0.0	7.1
Pinus pinaster	2.5	17.8	0.0	3.8
Pinus sylvestris	3.2	29.9	0.0	3.1
Pseudotsuga menziesii	2.9	14.3	0.0	3.6
Quercus petraea	3.2	17.6	0.0	2.1
Quercus pubescens	2.9	26.7	0.0	3.1
Quercus robur	3.4	19.8	0.0	2.9
Quercus rubra	3.0	18.3	-0.1	22.6
Robinia pseudoacacia	3.4	21.7	0.0	13.5