Assessing coupled process-based models' performance in predicting tree mortality under climate change

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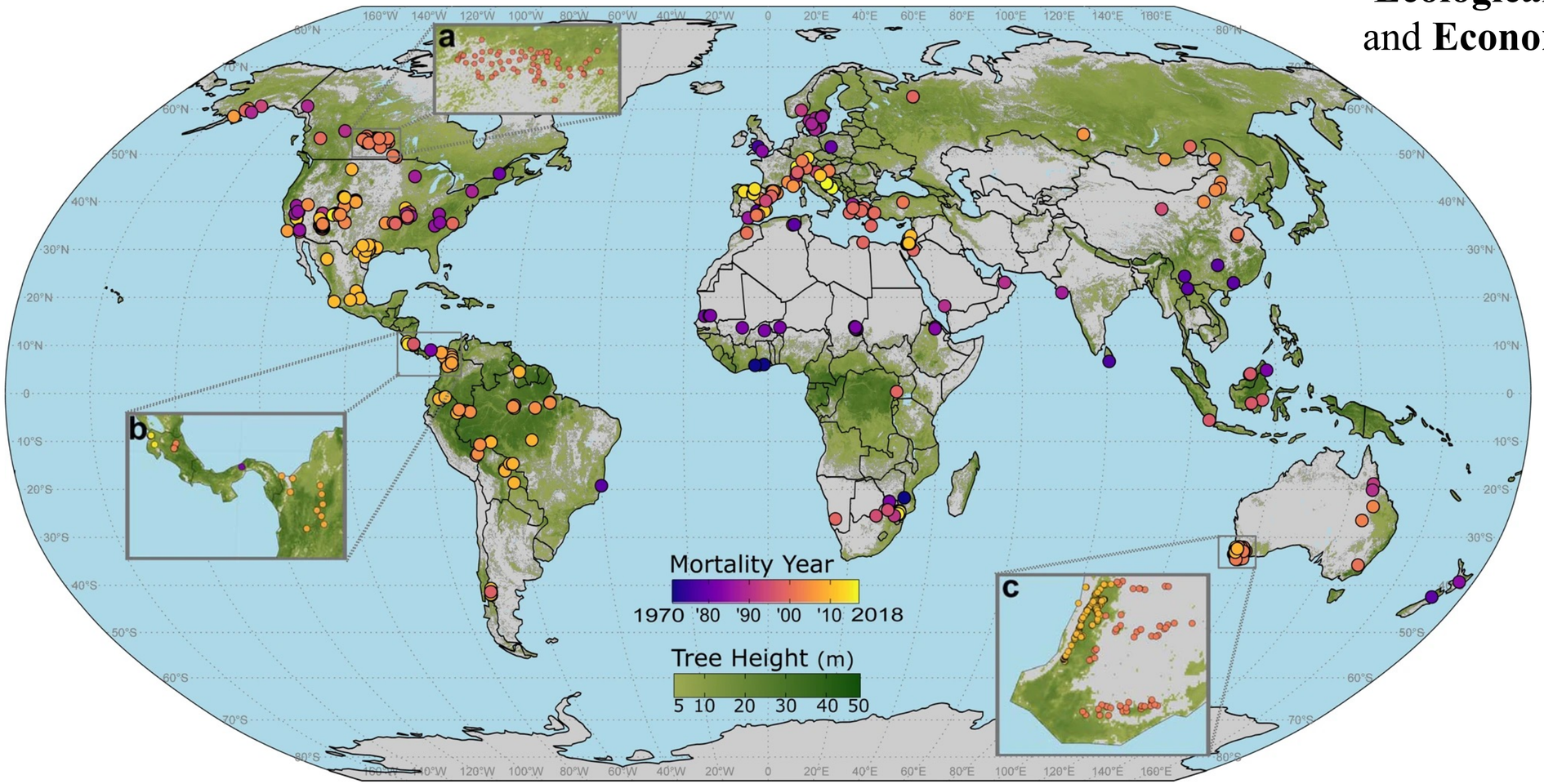
Introduction

Tree mortality under climate change

Loss of
Ecological benefits
and **Economic** value



Global distribution of hotter-drought tree mortality plots

Hammond et al., 2022

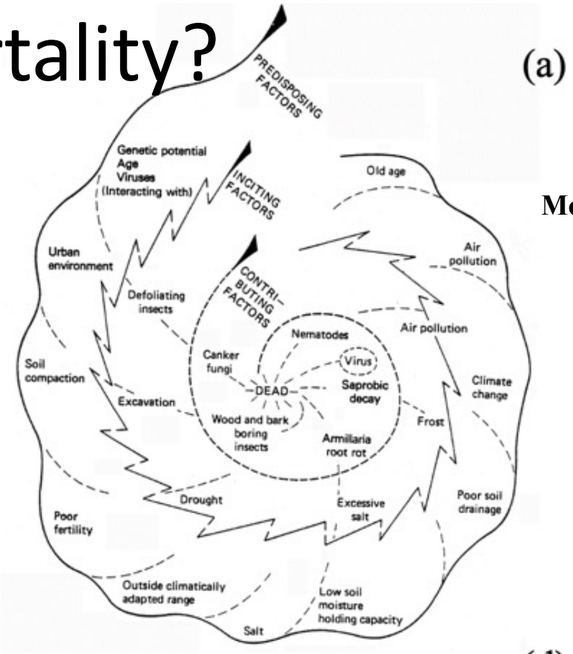
Introduction

How to predict tree mortality?

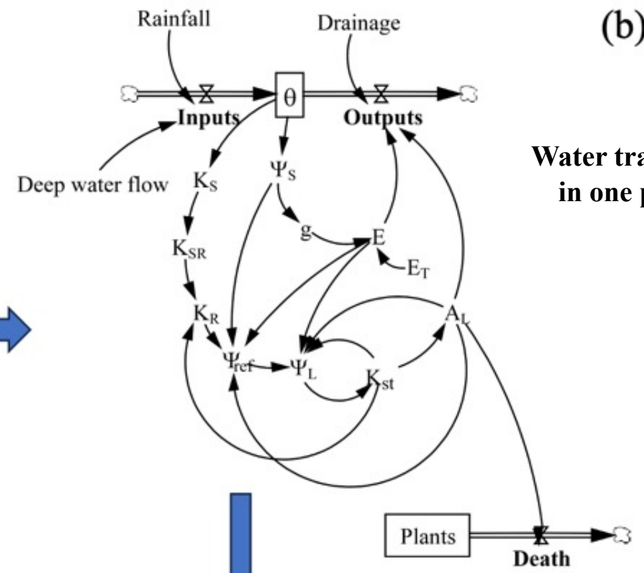
Forest plot

Empirical model

Process-based model



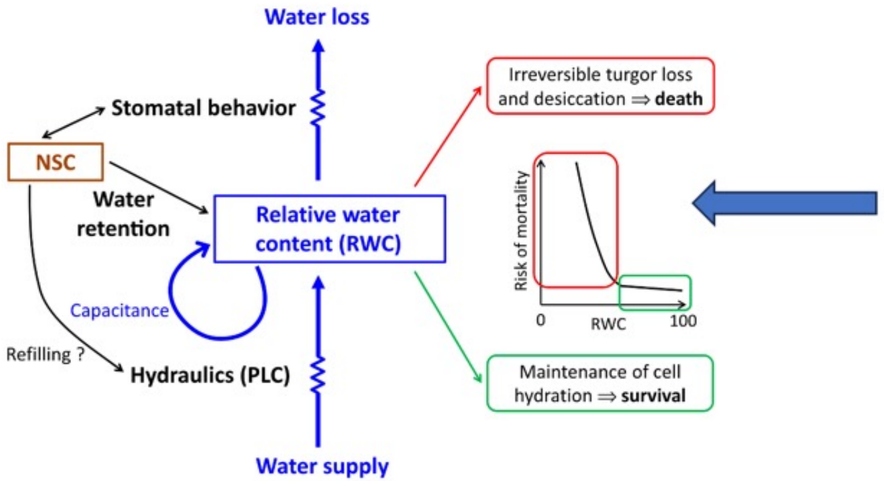
Mortality spiral framework

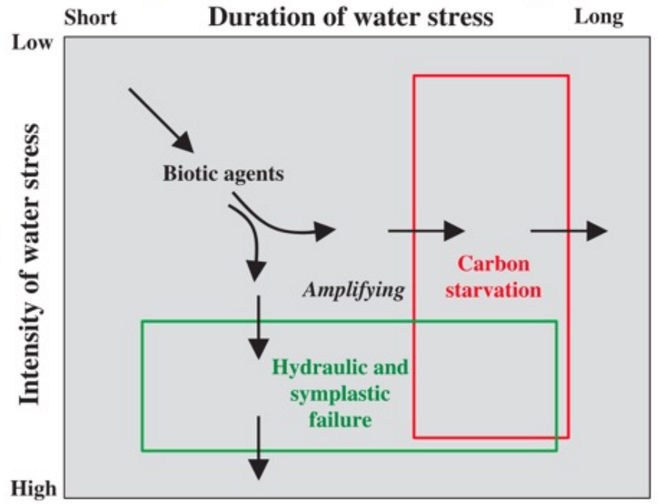


Water transport in one plant

Hypothesis between drought and mortality

Plant relative water content indicates mortality risk





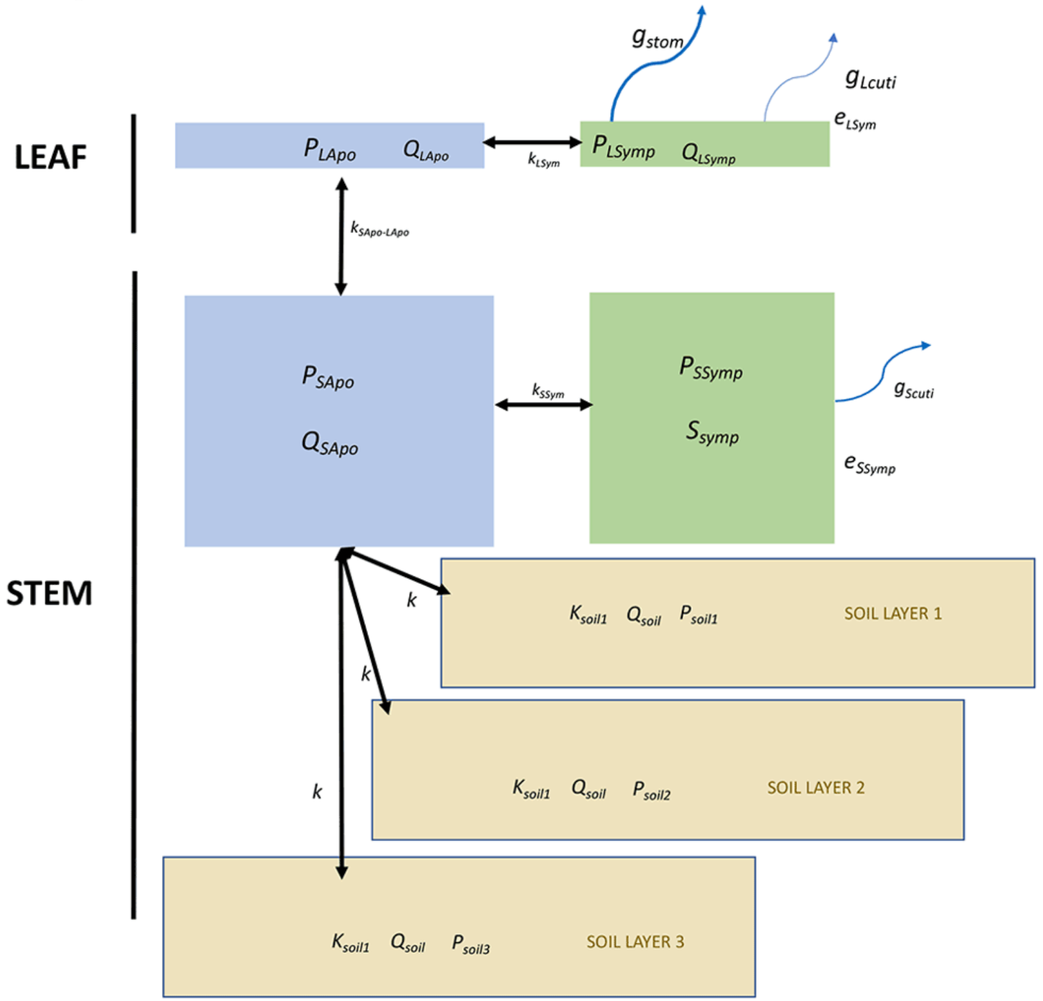
Plant hydraulic failure VS Carbon starvation

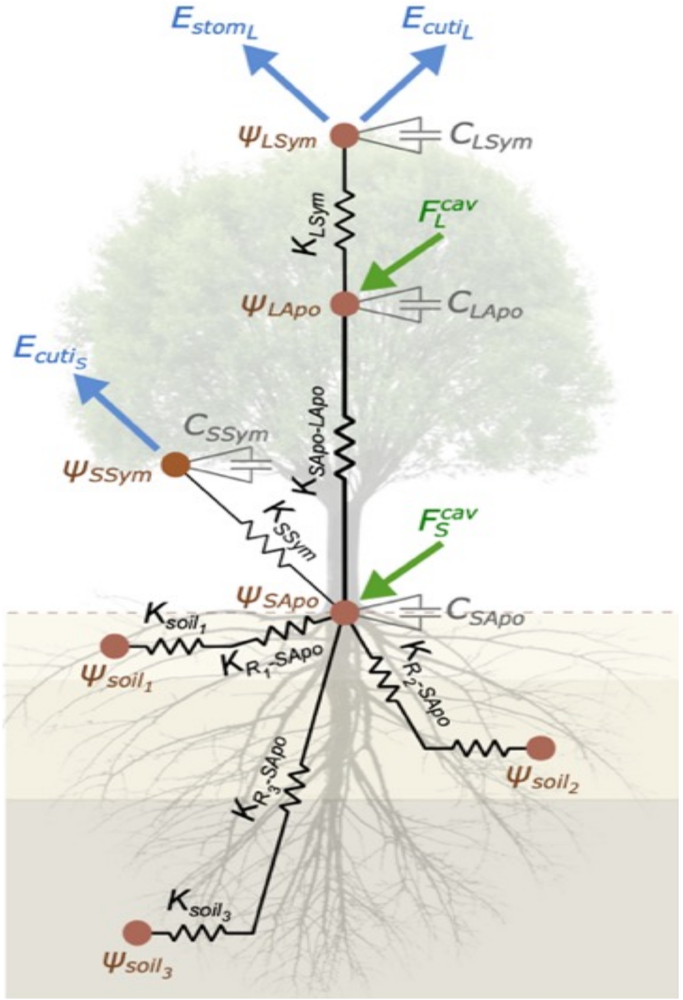
Manion, 1991; Martinez-Vilalta et al., 2019; Martínez-Vilalta et al., 2002; McDowell et al., 2008, 2011

Progression of mechanistic framework for predicting mortality

Method

Plant hydraulic model: SurEau-Ecos





Plant architecture in SurEau-Ecos

Cochard et al., 2021; Ruffault et al., 2022

Method

Coupling model

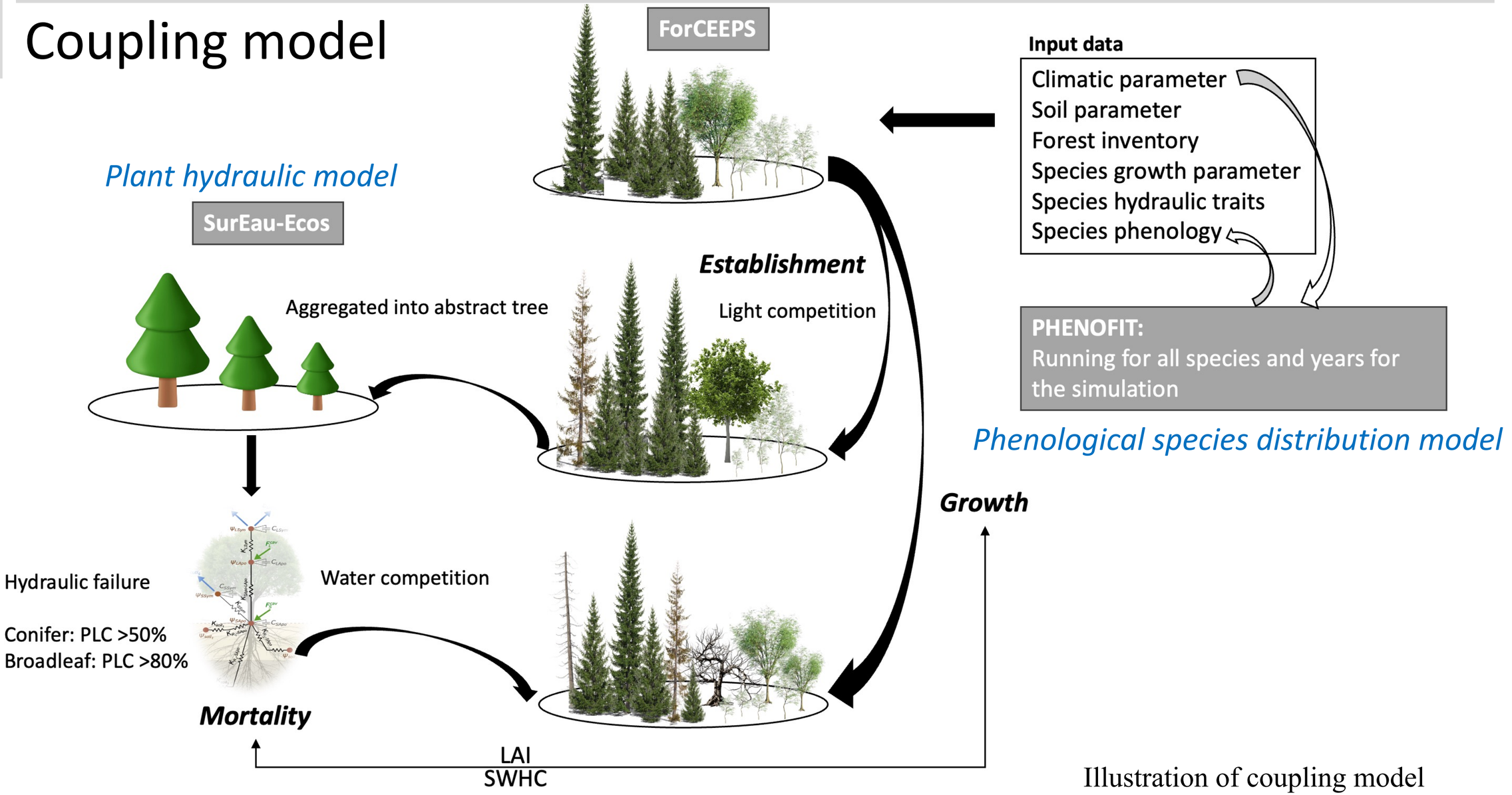


Illustration of coupling model

Chuine and Beaubien, 2001; Morin et al., 2021; Ruffault et al., 2022

Introduction

Research objectives

- Use **Vosges and NFI validation datasets** to assess whether this coupled model could **predict mortality** at both plot and tree scale.

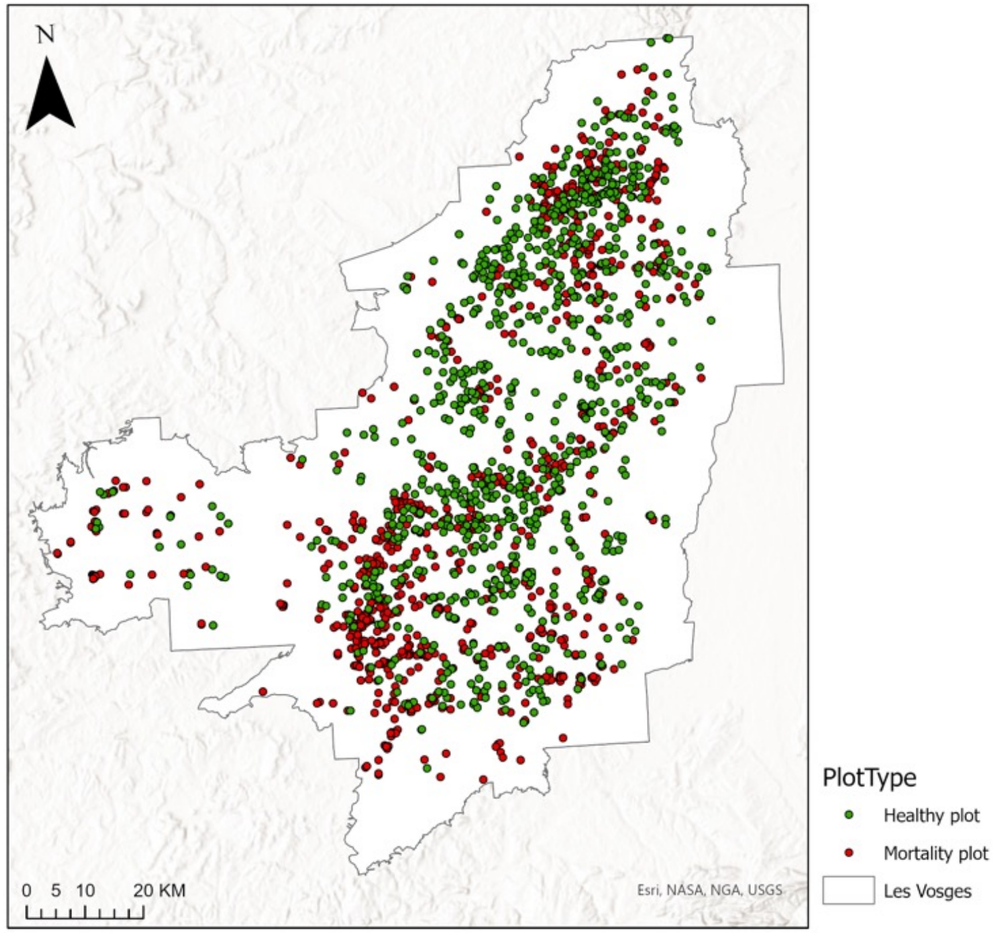
- To **distinguish** the mortality extent among **different species**, especially Spruce and Fir in Vosges dataset, and to reproduce **mortality spatial pattern** in this dataset.

- Study the **similarity** between LAI generated by model and LAI from two external sources, and evaluate the influence of **Soil Water Holding Capacity (SWHC)** on predictions.

Method

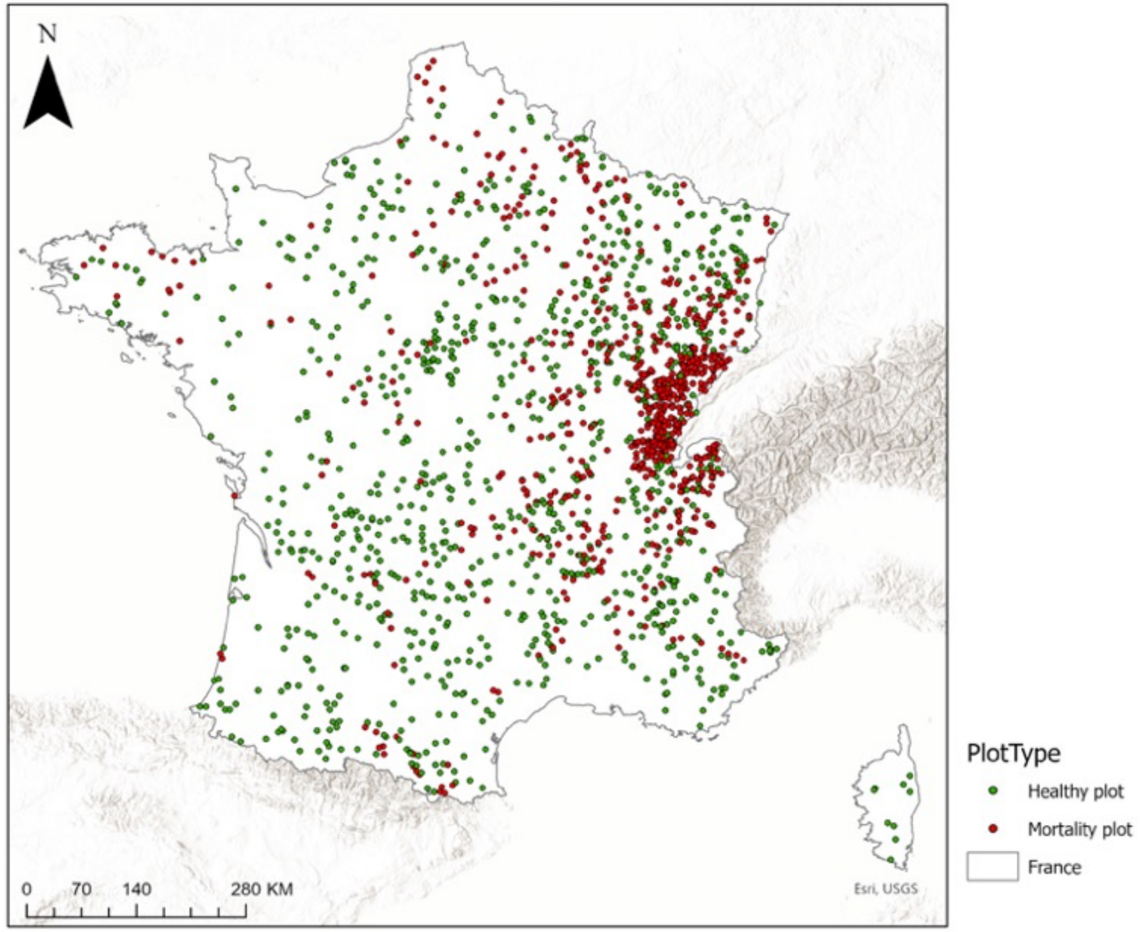
Validation dataset: Vosges and NFI with observed mortality

1866 plots **Norway spruce; Silver fir**



Simulation period: **2008-2019**

1694 plots **65 common species (Simulated 35)**



Simulation period: **Rolling 5y period from 2010-2020**

Distribution of Vosges (left) and NFI (right) plots

Method

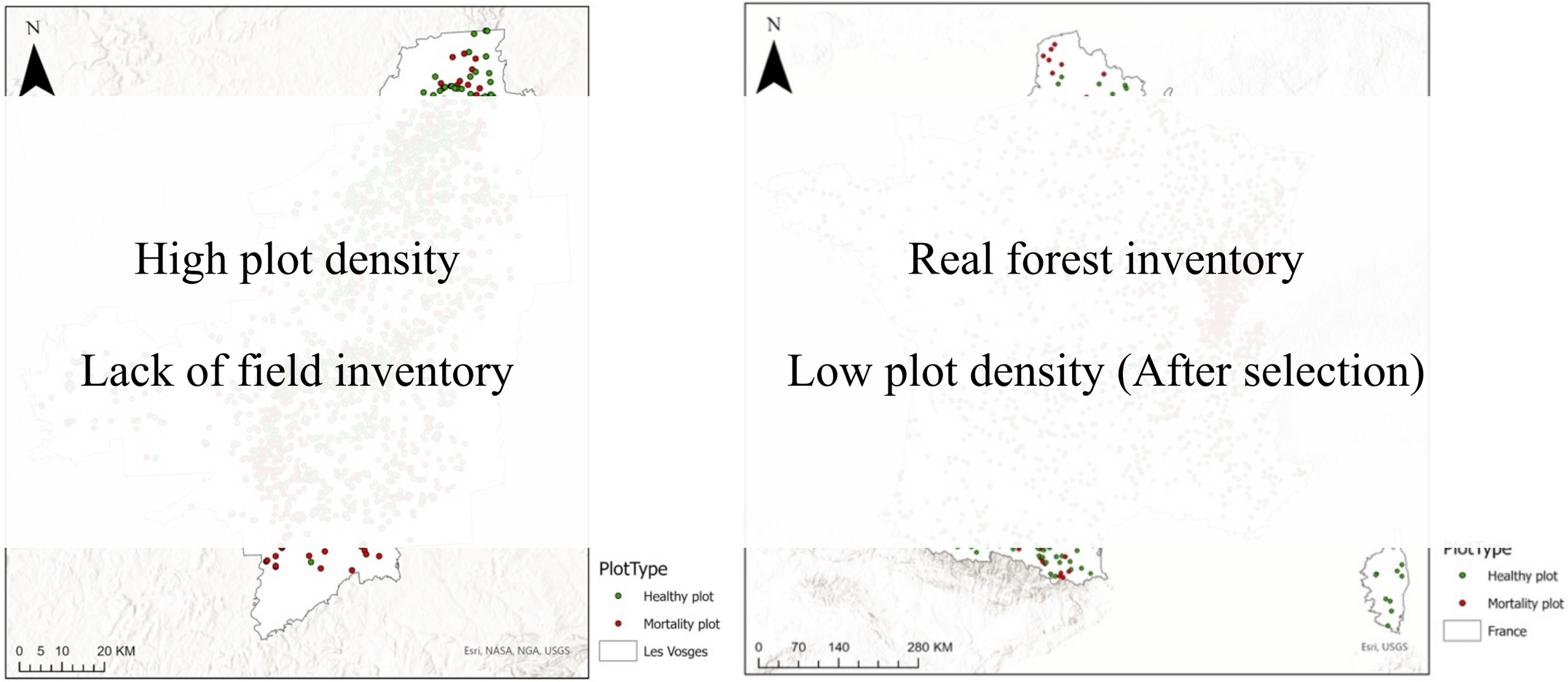
Validation dataset: Vosges and NFI with observed mortality

1866 plots **Norway spruce; Silver fir**

1694 plots **65 common species (Simulated 35)**

Pros: High plot density | Real forest inventory

Cons: Lack of field inventory | Low plot density (After selection)



Simulation period: **2008-2019**

Simulation period: **Rolling 5y period from 2010-2020**

Distribution of Vosges (left) and NFI (right) plots

Method

Model execution

Capsis

Computer-aided projection of strategies in silviculture

Each plot has two output files

#date	nTrees(/ha)	totalBiomass(t/ha)	totalBasalArea(m2/ha)	totalHeight(m/ha)	totalVolume(m3/ha)	LAI	droughtIndexAnnual	droughtIndexSeasonal	winterTMIN(deg)	GDDan
2008	810	180.56381	30.0175	14116.7793	212.32758	11.33557	0	0	0	
2009	810	180.23171	30.0175	14116.7793	212.32758	10.95691	0.4733	0.54092	-0.9	
2010	810	180.27413	30.0175	14116.7793	212.32758	11.00527	0.30568	0.30568	-2.58998	
2011	800	179.37987	29.81855	13988.04334	211.29217	11.03405	0.34428	0.44265	-1.1	
2012	800	179.43624	29.81855	13988.04334	211.29217	11.09833	0.32285	0.36897	-3.6	
2013	790	178.53846	29.61961	13859.30737	210.25676	11.12308	0.27505	0.27505	-2.01643	
2014	790	178.58476	29.61961	13859.30737	210.25676	11.17588	0.3153	0.40539	2.9	
2015	790	178.62443	29.61961	13859.30737	210.25676	11.22111	0.37072	0.47664	0.1	
2016	790	178.65797	29.61961	13859.30737	210.25676	11.25935	0.33781	0.33781	2.01314	
2017	790	178.68638	29.61961	13859.30737	210.25676	11.29174	0.38348	0.43826	-2.44752	
2018	780	176.84993	29.27297	13700.12893	208.10091	11.23912	0.48859	0.55838	-2	
2019	780	176.881	29.27297	13700.12893	208.10091	11.27456	0.48375	0.52574	-0.74708	

Mean output file for Vosges dataset: **Plot average information for each year**

#Trees													
#date	patchId	id	speciesId	speciesShortName	genotypeName	age	dbh(cm)	basalArea(m2)	height(m)	volume(m3)	crownA1	crownLength	dbhI
2008	1	10149821	2	PAbi	2-Genotype-1	30	33.4225	0.087734	22.2784	0.7317	0.4116	9.1692	
2009	1	10149821	2	PAbi	2-Genotype-1	31	33.4225	0.087734	22.2784	0.7317	0.4116	9.1687	
2010	1	10149821	2	PAbi	2-Genotype-1	32	33.4225	0.087734	22.2784	0.7317	0.4085	9.1004	
2011	1	10149821	2	PAbi	2-Genotype-1	33	33.4225	0.087734	22.2784	0.7317	0.4077	9.0834	
2012	1	10149821	2	PAbi	2-Genotype-1	34	33.4225	0.087734	22.2784	0.7317	0.4079	9.0869	
2013	1	10149821	2	PAbi	2-Genotype-1	35	33.4225	0.087734	22.2784	0.7317	0.408	9.0902	
2014	1	10149821	2	PAbi	2-Genotype-1	36	33.4225	0.087734	22.2784	0.7317	0.4083	9.0973	
2015	1	10149821	2	PAbi	2-Genotype-1	37	33.4225	0.087734	22.2784	0.7317	0.4087	9.1047	
2016	1	10149821	2	PAbi	2-Genotype-1	38	33.4225	0.087734	22.2784	0.7317	0.409	9.1118	
2017	1	10149821	2	PAbi	2-Genotype-1	39	33.4225	0.087734	22.2784	0.7317	0.4093	9.1186	
2018	1	10149821	2	PAbi	2-Genotype-1	40	33.4225	0.087734	22.2784	0.7317	0.4096	9.1248	
2019	1	10149821	2	PAbi	2-Genotype-1	41	33.4225	0.087734	22.2784	0.7317	0.41	9.1352	

Complete output file for Vosges dataset: **Detail information for each tree**

Method

Mortality definition

At plot scale

LAI loss

Number of dead trees

BA loss ✓

+ : Healthy plot
– : Mortality plot

Prediction \ Observation	Mortality plot	Healthy plot
Mortality plot	True positive (TP)	False positive (FP)
Healthy plot	False negative (FN)	True negative (TN)

$$Success\ of\ model\ (SOM) = \frac{TP+TN}{TP+FP+FN+TN} \quad (Eq.\ 2)$$

$$Sensitivity\ (Sn) = \frac{TP}{TP+FN} \quad (Eq.\ 3)$$

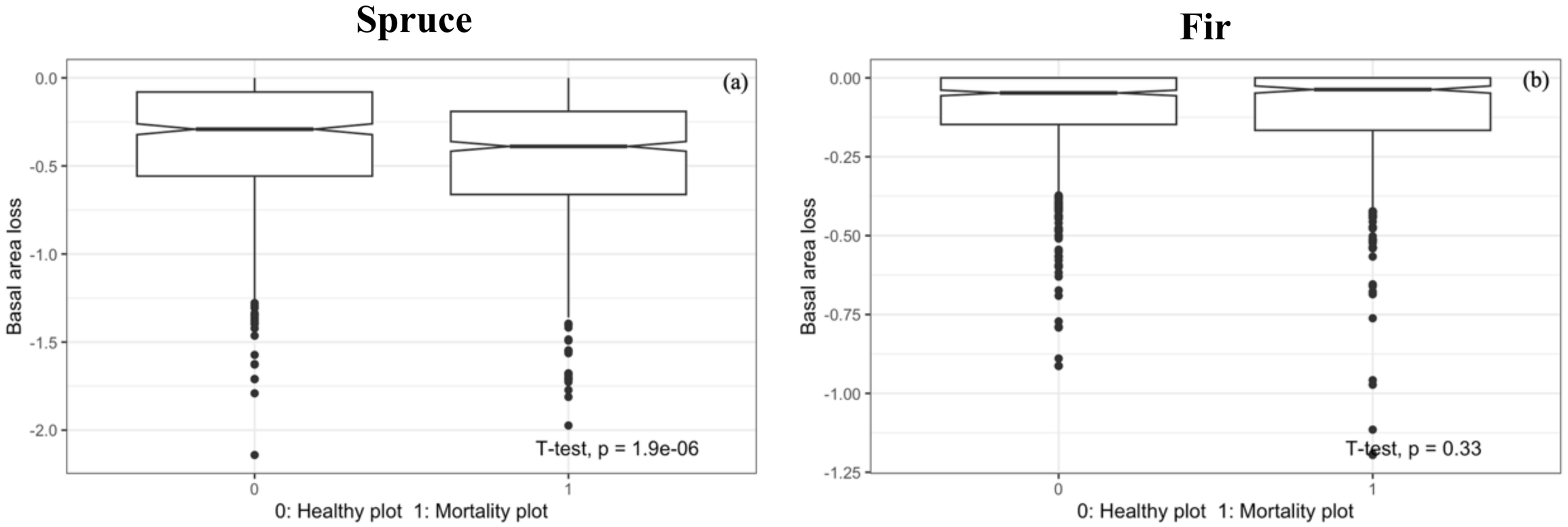
$$Specificity\ (Sp) = \frac{TN}{TN+FP} \quad (Eq.\ 4)$$

At tree scale 

Monitor and log **unique tree ID**, noting their disappearance as an indication of death.

Result

Vosges: Mortality prediction vs observation at plot scale

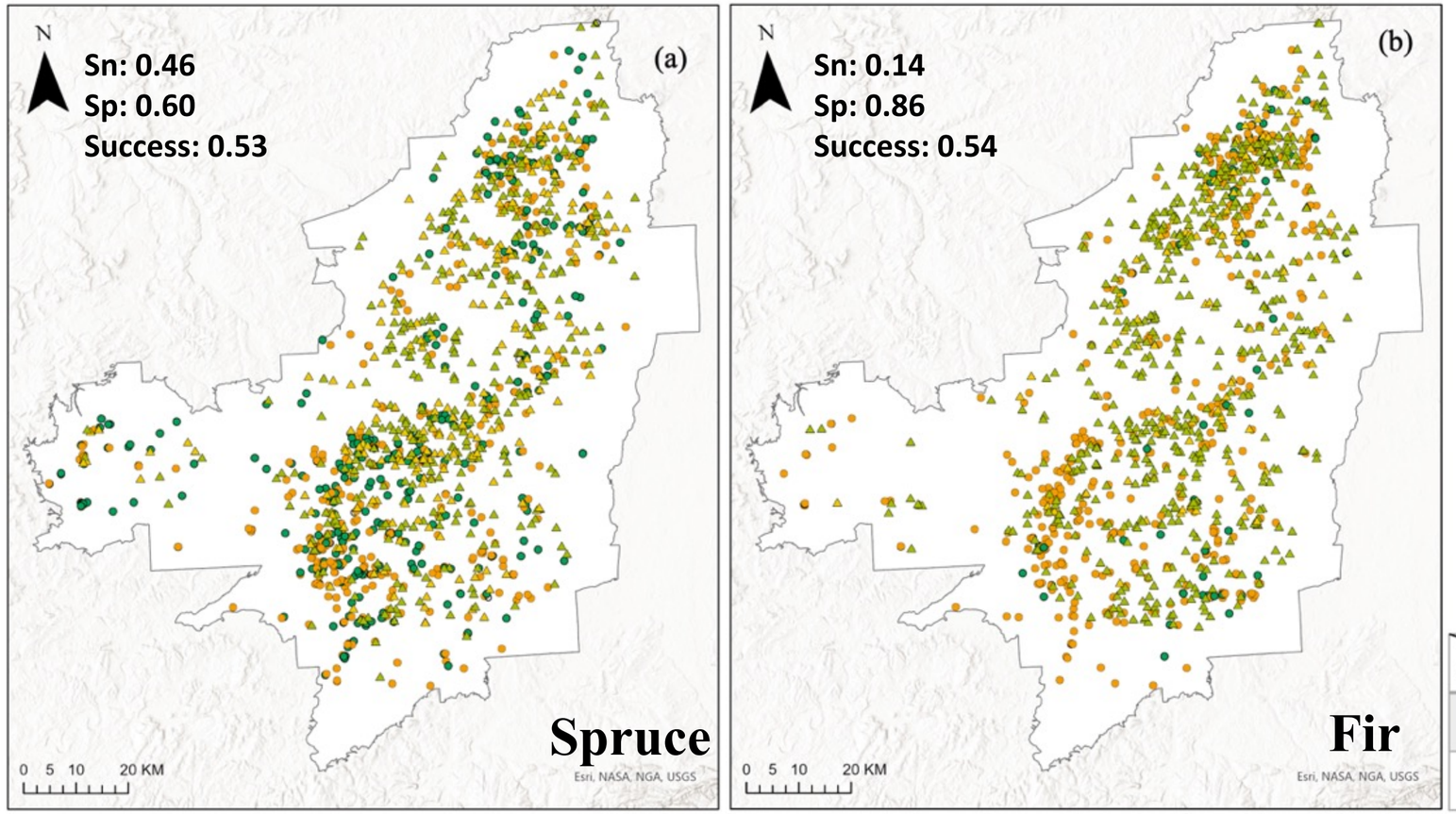


Predicted basal area loss against observed plot status for Spruce (a) and Fir (b).

- No significant difference between healthy and mortality plot.
- Difference of Spruce is slight obvious than Fir.

Result

Vosges: Mortality prediction at plot scale



Ratio comparison

Item	Spruce	Fir
Observed mortality frequency	0.55	0.44
Predicted mortality frequency	0.43	0.14

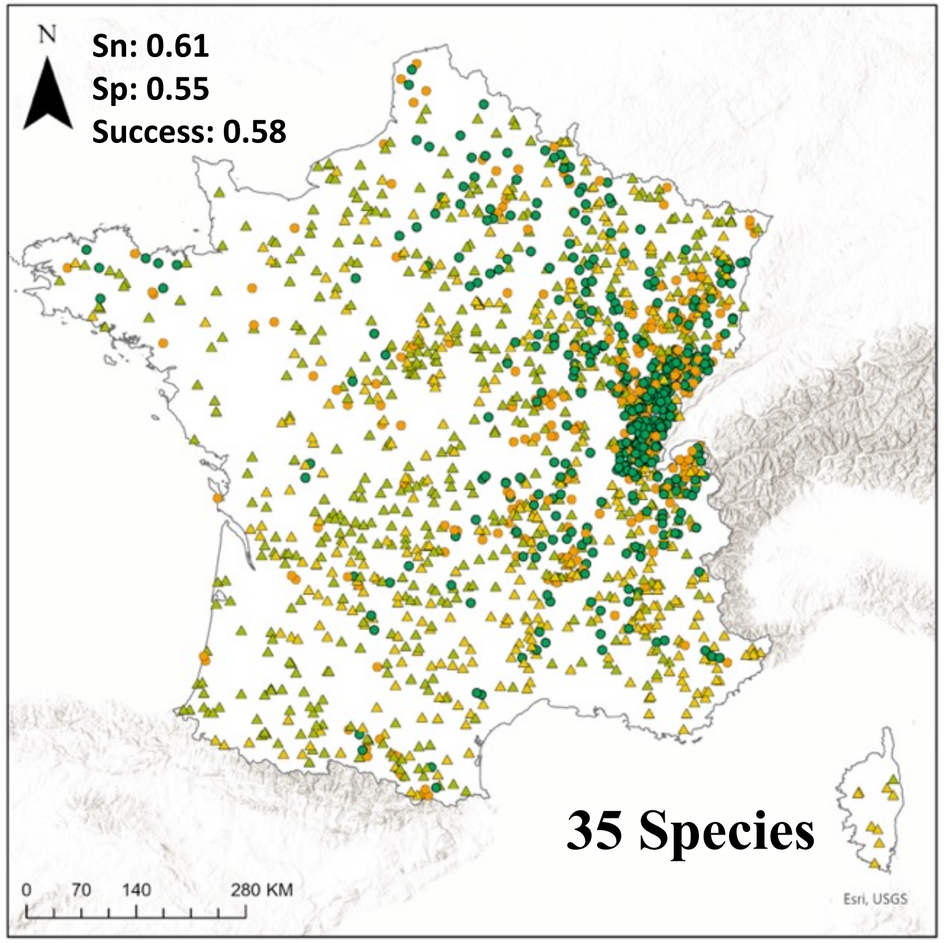
Prediction \ Observation	Mortality plot	Healthy plot
Mortality plot	True Positive	False Positive
Healthy plot	False Negative	True Negative

Quality of prediction distribution for Spruce (a) and Fir (b) in Vosges

- Model has better mortality prediction for Spruce.
- Mortality is underestimated for both species, especially Fir.
- Model could partly reproduce mortality spatial pattern.

Result

NFI: Mortality prediction at plot scale



Quality of prediction distribution for all species for NFI dataset

Ratio comparison

Item	NFI
Observed mortality frequency	0.71
Predicted mortality frequency	1.07

Prediction \ Observation	Mortality plot	Healthy plot
Mortality plot	True Positive	False Positive
Healthy plot	False Negative	True Negative

- Accurate mortality predictions are concentrated in the Jura mountains.
- Mortality is overestimated for NFI dataset, especially in south of France.

Result

NFI: Mortality prediction at tree scale

Comparison of mortality frequency

Species	Observed frequency	Predicted frequency
Castanea sativa	0.51	0.63
Picea abies	0.49	0.55
Fraxinus excelsior	0.49	0.51
Corylus avellana	**0.37**	**0.28**
Pinus sylvestris	0.34	0.55
Populus tremula	0.32	0.38
Abies alba	0.32	0.45
Betula pendula	0.27	0.37
Carpinus betulus	**0.27**	**0.69**

- Model predicted similar or slightly higher mortality frequency for almost all the listed species except *Corylus avellana*, and *Carpinus betulus* has a much higher predicted frequency.

Method

3 LAI datasets and 2 SWHC datasets

LAI
Vosges

- Generated by ForCEEPS: To be compared.
- PROBAV: 300 m resolution from remote sensing.
- Sentinel 2: 10 m resolution from remote sensing.

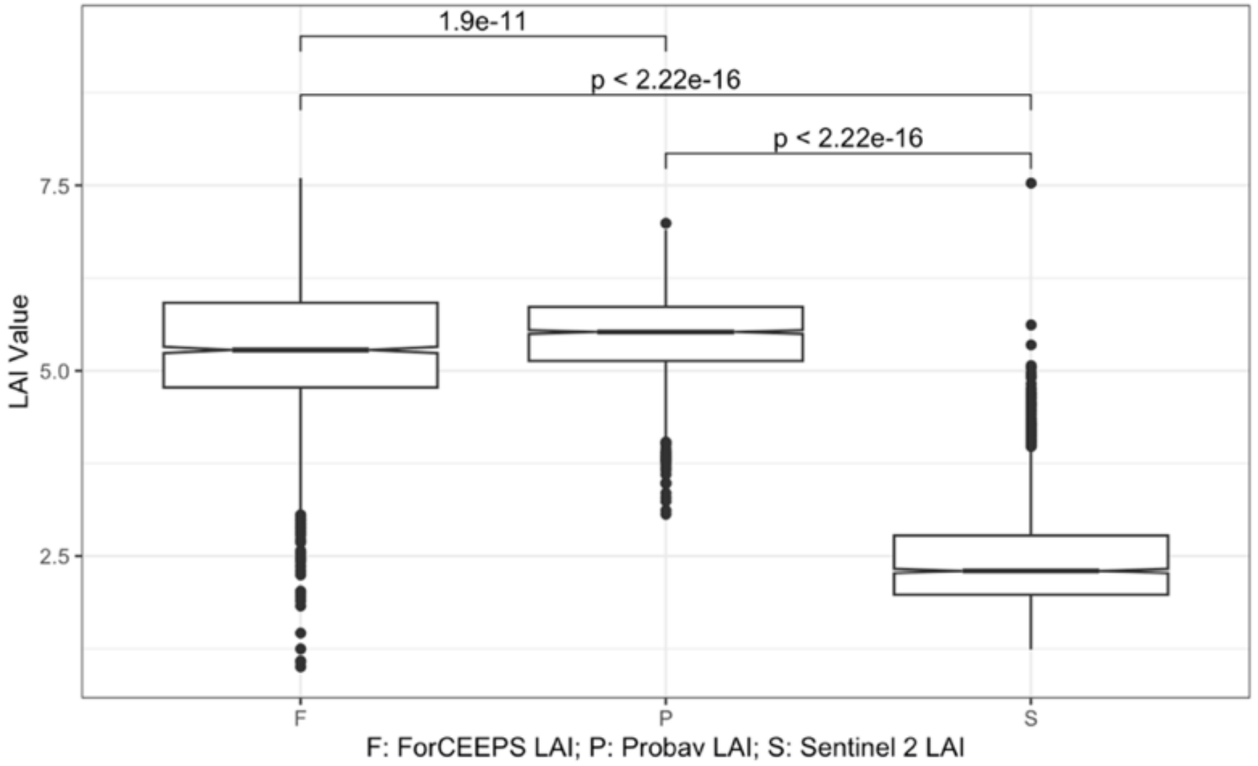
SWHC
Vosges / NFI

- Original soil data: Soil water holding capacity for the uppermost **1-meter** soil layer.
- Modified soil data: Applied a coefficient derived from the Max rooting depth provided by the ESDAC to the Original Soil Dataset. Soil water holding capacity for the uppermost **5-meter** soil layer.

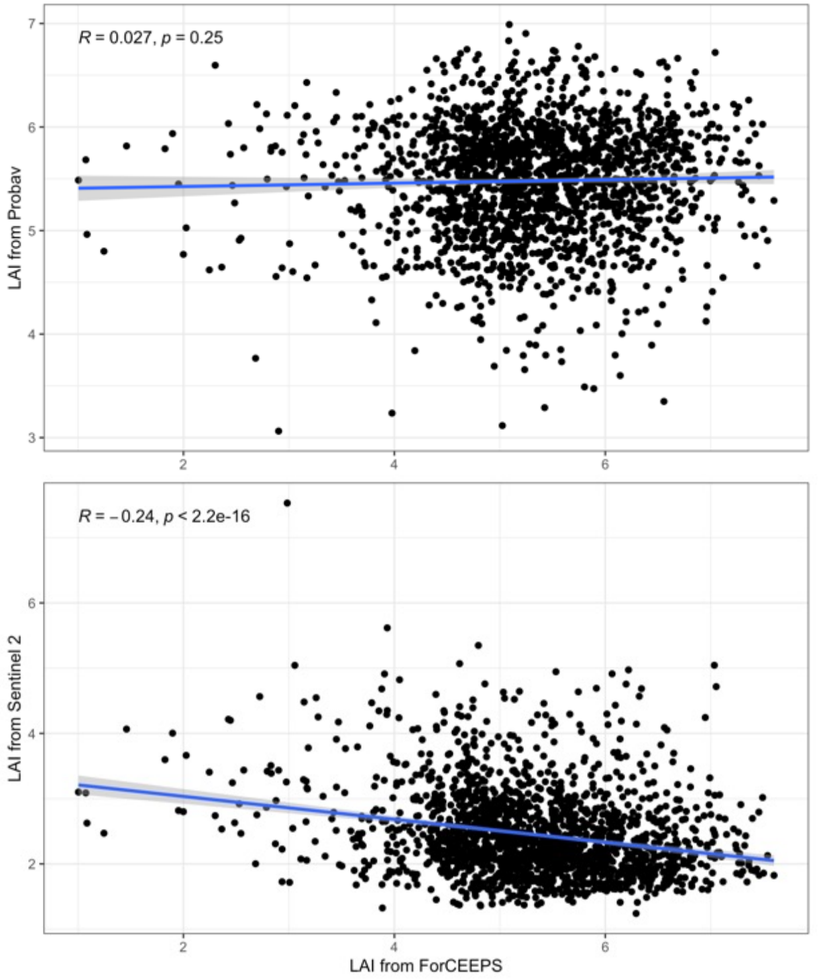
Panagos et al., 2012; Piedallu et al., 2013

Result

LAI comparison



LAI values from ForCEEPS, Probav and Sentinel 2

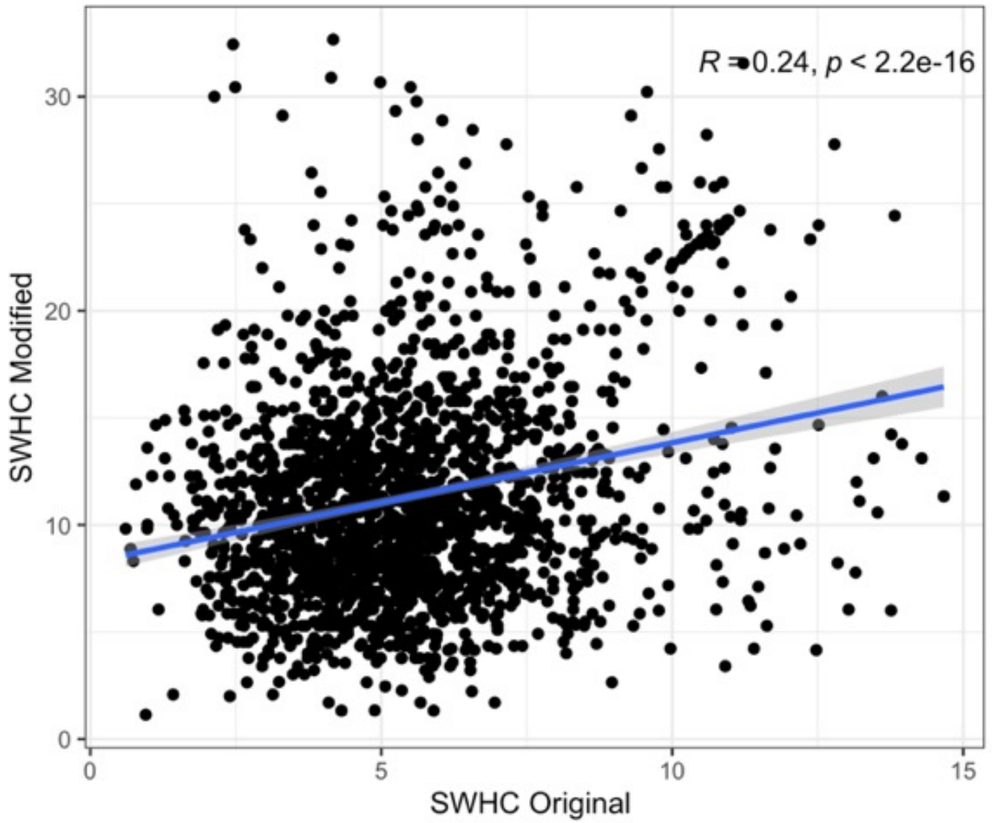


LAI ForCEEPS against Probav and Sentinel 2

- ForCEEPS LAI has a week positive correlation with Probav and a strange negative correlation with Sentinel 2.
- Three different LAI has small similarity and with a large uncertainty.

Result

Sensitivity of SWHC



Soil water holding capacity comparison for Vosges

Model performance for two different soil input for Vosges dataset

Soil input	Spruce			Fir		
	Sn	Sp	Success	Sn	Sp	Success
Modified soil data	0.46	0.60	**0.53**	0.14	0.86	**0.54**
Original soil data	0.11	0.90	0.43	0.10	0.88	0.51

Model performance for two different soil input for NFI dataset

Soil input	Sn	Sp	Success
Modified soil data	0.61	0.55	**0.58**
Original soil data	0.85	0.27	0.51

- A weak positive correlation has been observed in two soil data.
- Modified soil data has better model performance compared to Original soil data for both datasets.

Discussion

Answer to research objective

- This coupled model could give the consistent results but the performance is low (0.53-0.58) at plot scale. And it can differentiate species and partly reproduce mortality spatial pattern.
- LAI generated by this model is not similar with external LAI which still needs to be enhanced. And the model is sensitive to SWHC calculation method.

Ways to improve

- Test new mortality dataset with detailed stand characteristics and mortality variation.
- Based on ecological resource balance theory, a new method to collect soil water holding capacity data is going on.
- Achieving equilibrium within each plot before drought simulation is pivotal.

Druel et al., 2023; Hülsmann, 2021; Ruiz-Benito et al., 2020; Stewart, 1986

Conclusion

Future perspective

The first time to couple three different process-based model together to simulate forest dynamics and predict drought-induced mortality on regional and national scale.

Answer theoretical questions regarding tree mortality

Drought tolerance of each species?

Tree size effects mortality?

Growth with mortality?

PLC threshold?

Answer practical questions in forest sector

Species choice?

Optimize ecosystem services?

The effect of mixed forest?

Assistant migration?


Thank you for listening
Q&A

Result

LAI Sentinel 2 and mortality

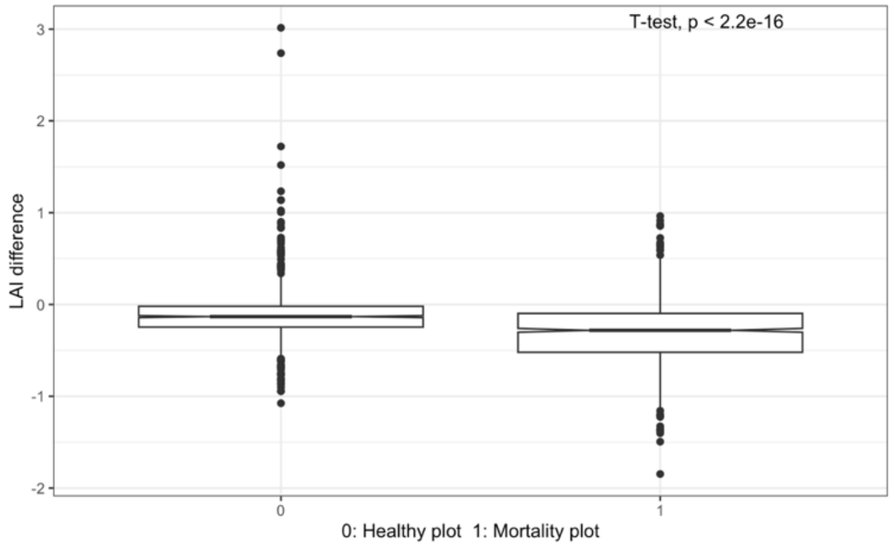


Fig 12. LAI sentinel 2 difference and plot status.

Table 5. Statistical comparison of LAI Sentinel 2 for four years.

Index	2017	2018	2019	2020
Min	0.46	0.67	0.72	0.23
Max	6.41	6.30	6.69	5.92
Median	2.00	1.93	1.84	1.74
Mean	**2.12**	**2.07**	**1.94**	**1.81**
Std	0.59	0.59	0.64	0.66

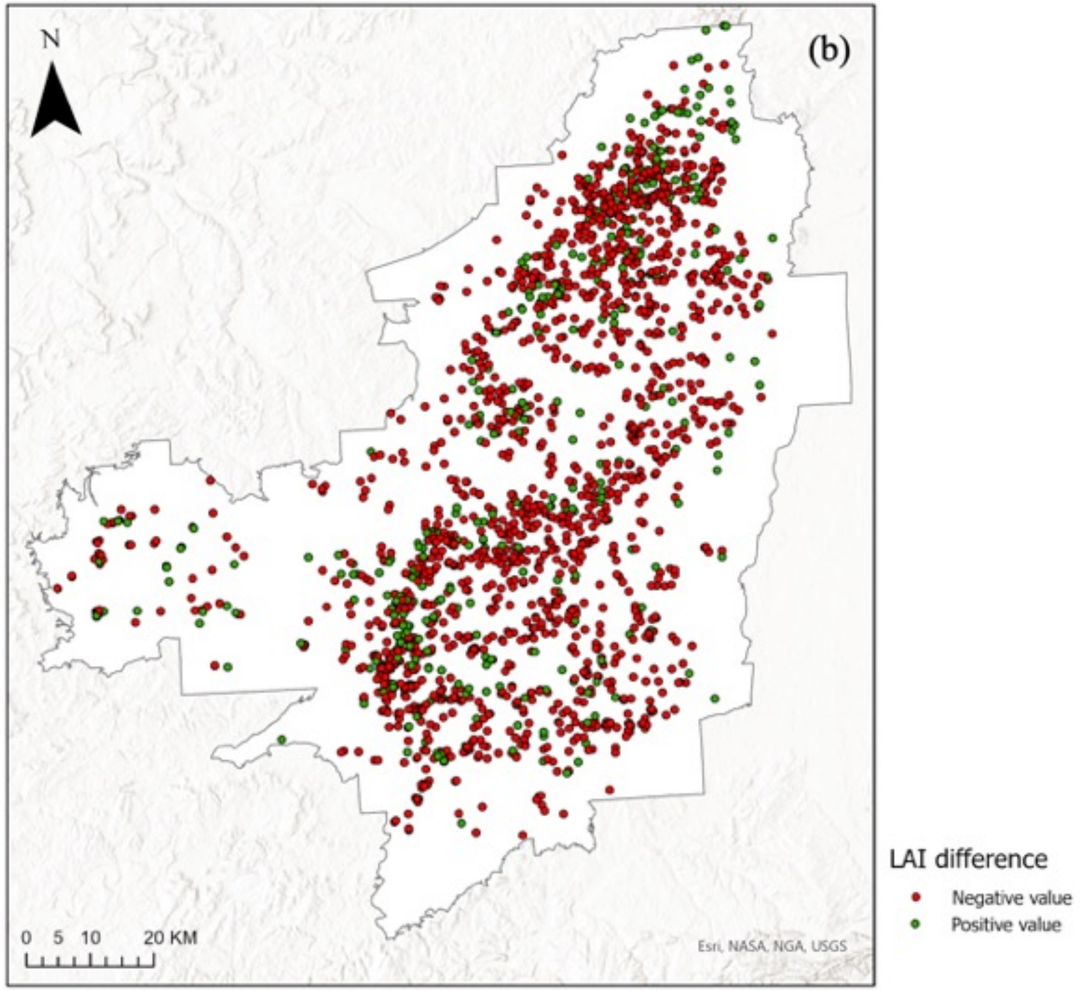


Fig 13. LAI difference between 2017-2018 and 2019-2020.

- Mean value of LAI decreased from 2017 to 2020.
- LAI decrease pattern is consistent as the distribution of observed mortality.