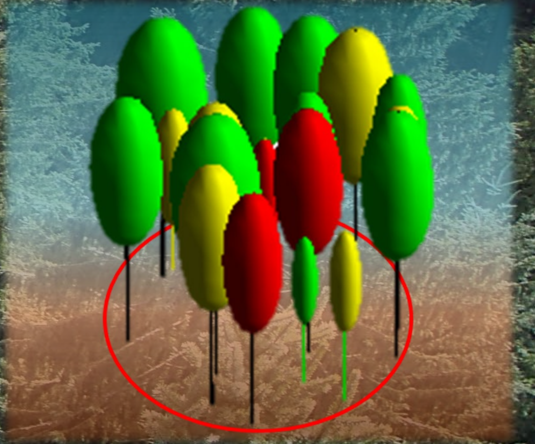
SIMREG

Large-scale forest simulation to synchronize and extrapolate the state of forest resources from NFI data.

JÉRÔME PERIN[1]



SIMREG PRESENTATION - MEETING DAY

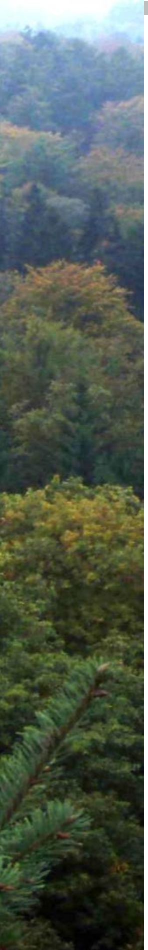
Gembloux, Belgique – 23 Septembre 2025

[1] Université de Liège
Gembloux Agro-Bio Tech
TERRA - ForestIsLife

LIÈGE université Forest is life
Wallonie environnement SPW

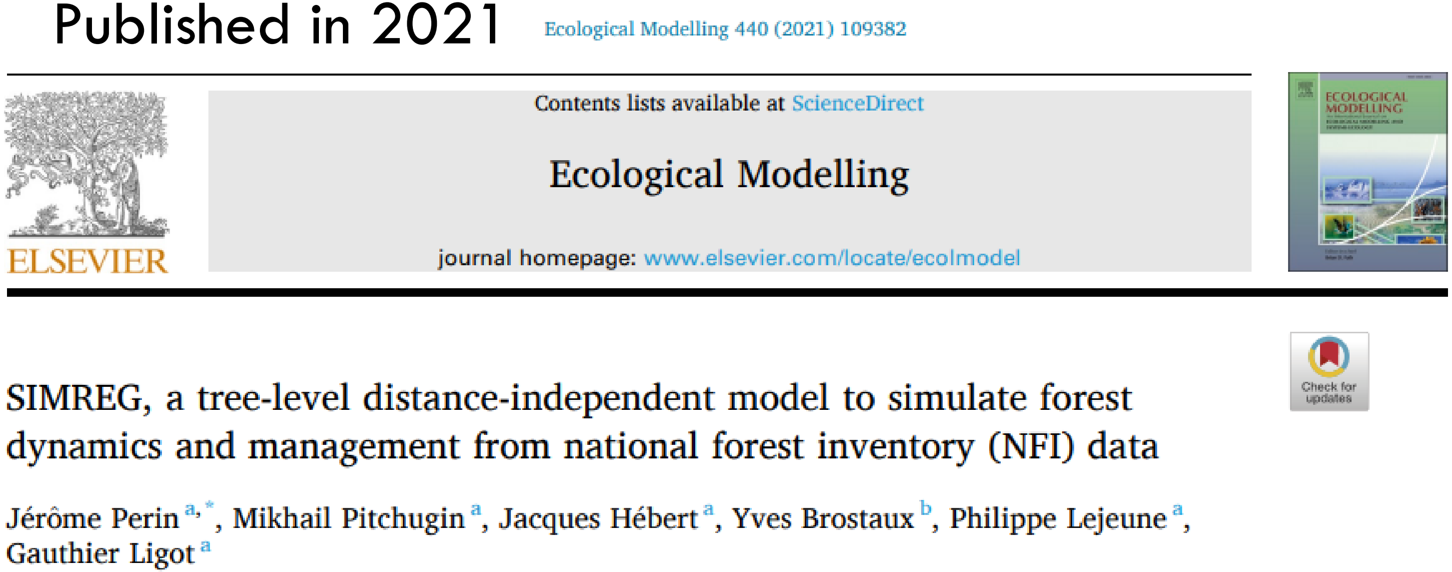
General overview of SIMREG

SIMREG : general overview



Large scale forest simulation model

- Integrated in the CAPSIS platform (java)
  - ➢ Computer-aided projection of strategies in silviculture (http://www7.inra.fr/capsis/)
- First version finalized in 2018 (to calibrate the first FRL)
- Published in 2021



Ecological Modelling 440 (2021) 109382

ELSEVIER

Contents lists available at ScienceDirect

Ecological Modelling

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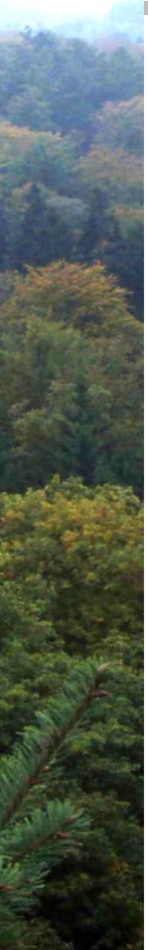
SIMREG, a tree-level distance-independent model to simulate forest dynamics and management from national forest inventory (NFI) data

Jérôme Perin[a,*], Mikhail Pitchugin[a], Jacques Hébert[a], Yves Brostaux[b], Philippe Lejeune[a], Gauthier Ligot[a]

SIMREG : general overview

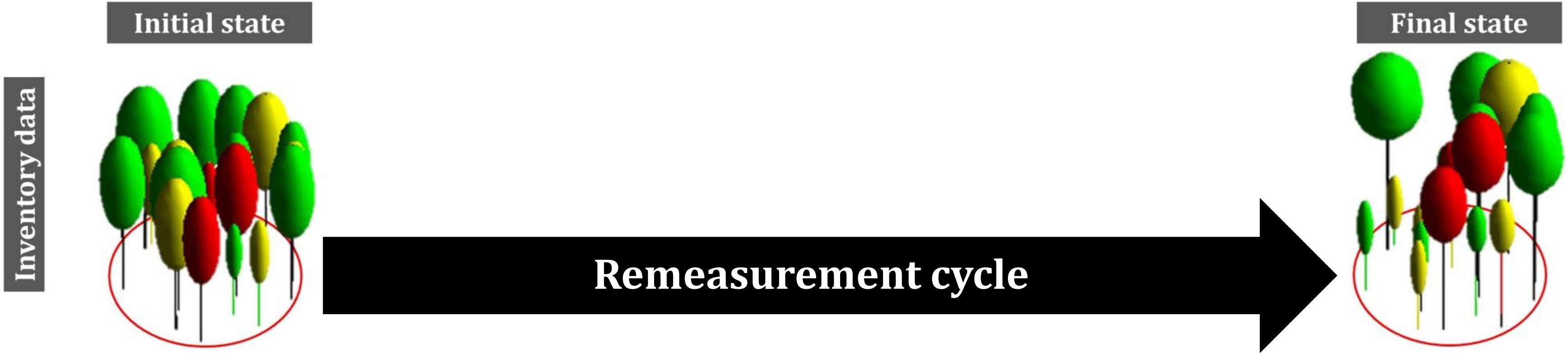


Built for optimal operation with NFI calibration data

- **Empirical model** based on measured data
- **Tree-level :** most useful level of detail for management support
- **Distance independent and non-deterministic :** stochastic emulation of omitted covariate to optimize processing time
- Compatible with **unsynchonized data**

SIMREG operation

SIMREG : Initialization with permanent NFI data



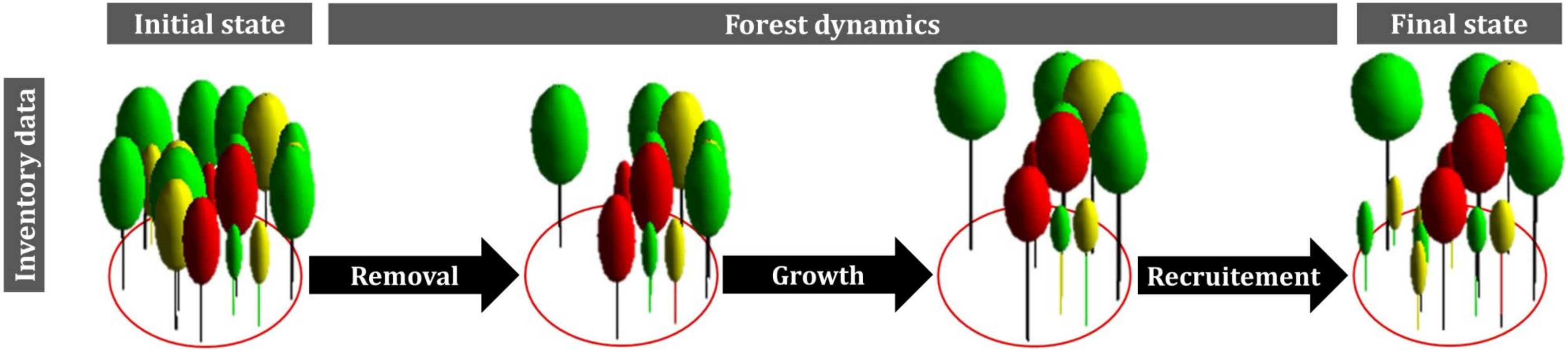
Initial state

Inventory data

Remeasurement cycle

Final state

SIMREG : NFI data formatting



Initial state

Forest dynamics

Final state

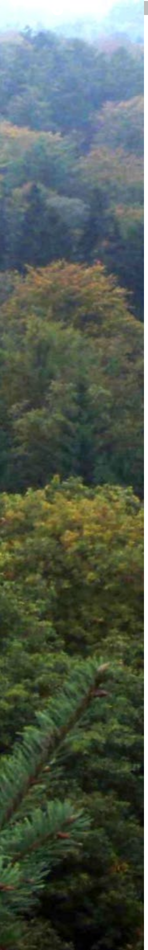
Inventory data

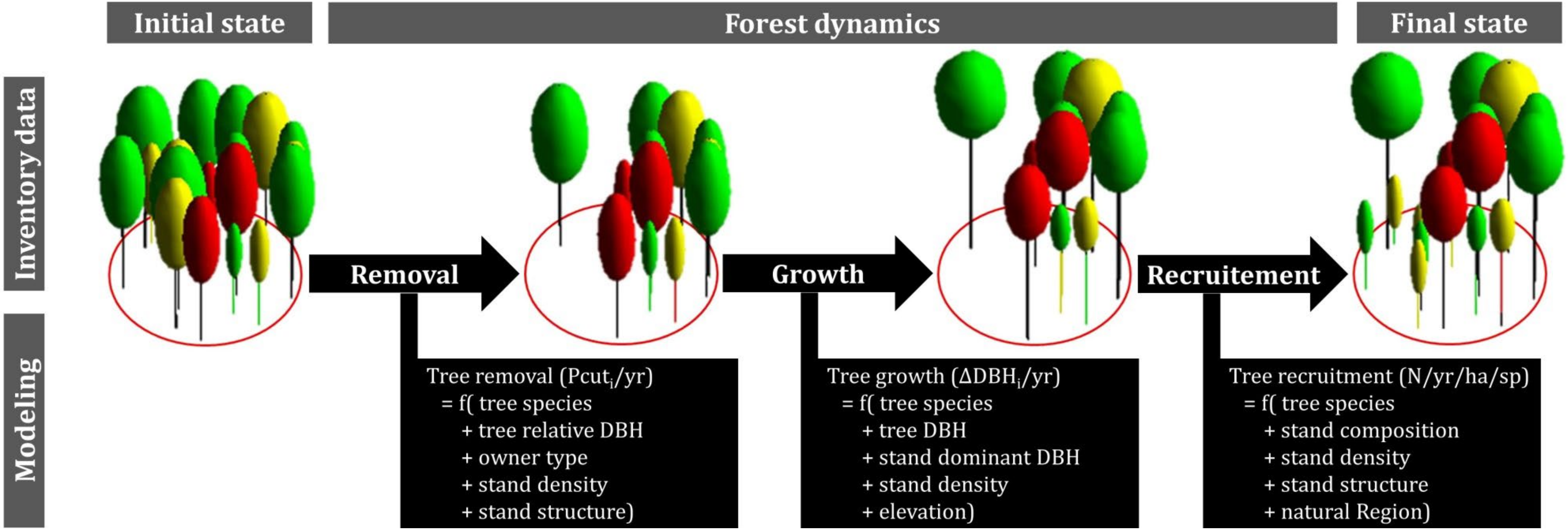
Removal

Growth

Recruitement

SIMREG : models calibration





Initial state

Forest dynamics

Final state

Inventory data

Modeling

Removal

Growth

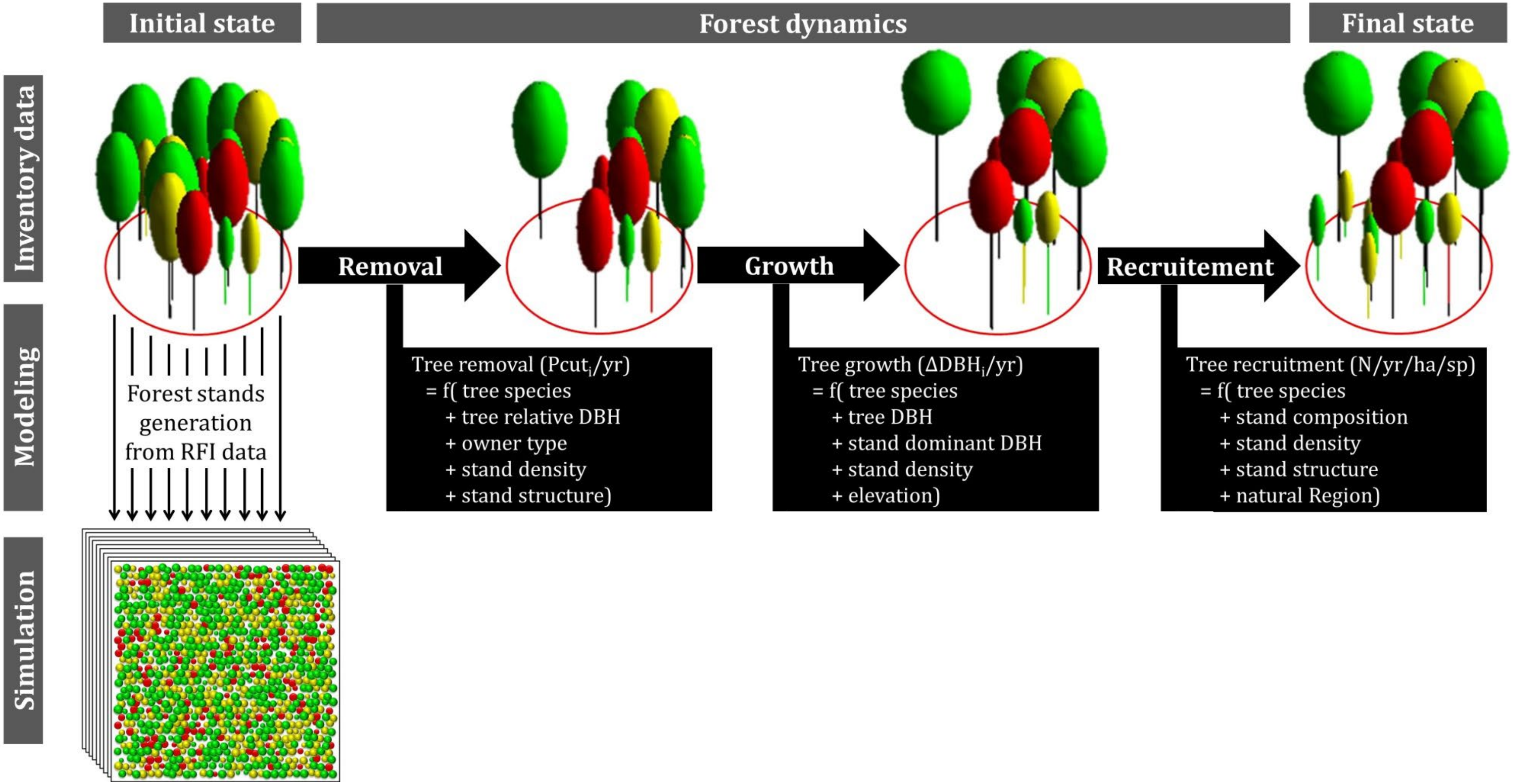
Recruitement

Tree removal ($Pcut_i$/yr)
= f(tree species
+ tree relative DBH
+ owner type
+ stand density
+ stand structure)

Tree growth (ΔDBH_i/yr)
= f(tree species
+ tree DBH
+ stand dominant DBH
+ stand density
+ elevation)

Tree recruitment (N/yr/ha/sp)
= f(tree species
+ stand composition
+ stand density
+ stand structure
+ natural Region)

SIMREG : virtual stands generation



Initial state | **Forest dynamics** | **Final state**

Inventory data

Modeling

Simulation

Removal → **Growth** → **Recruitement**

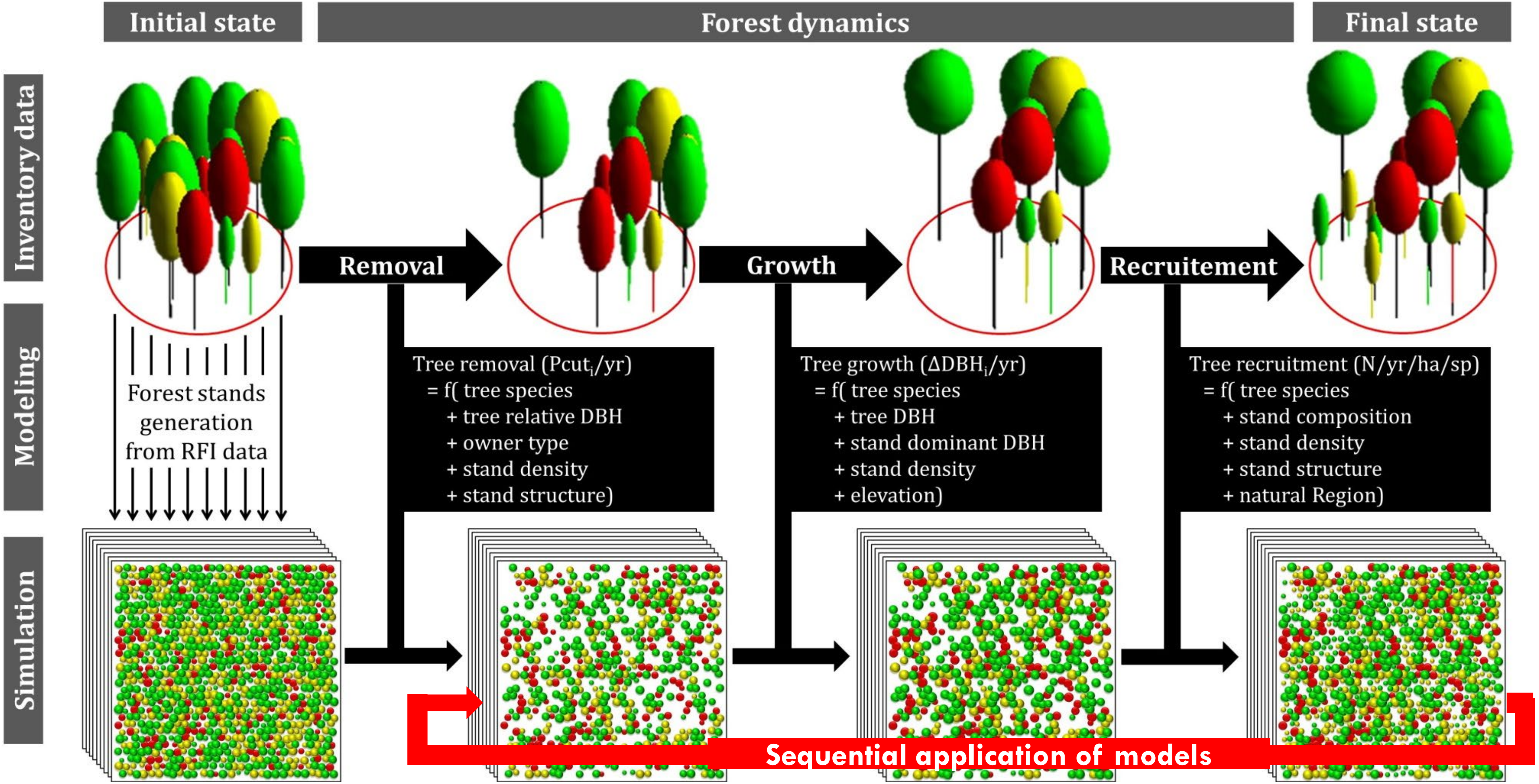
Forest stands generation from RFI data

Tree removal (Pcut$_i$/yr)
= f(tree species
+ tree relative DBH
+ owner type
+ stand density
+ stand structure)

Tree growth (ΔDBH$_i$/yr)
= f(tree species
+ tree DBH
+ stand dominant DBH
+ stand density
+ elevation)

Tree recruitment (N/yr/ha/sp)
= f(tree species
+ stand composition
+ stand density
+ stand structure
+ natural Region)

SIMREG : forest simulation



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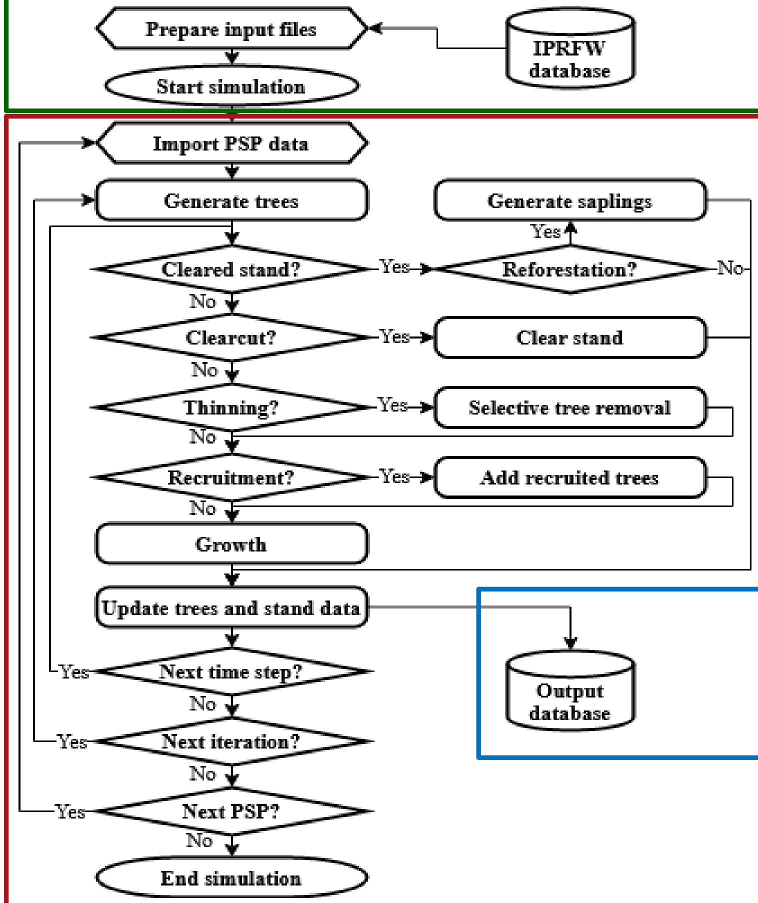
Tree growth (ΔDBH$_i$/yr)
= f(tree species
+ tree DBH
+ stand dominant DBH
+ stand density
+ elevation)

Tree recruitment (N/yr/ha/sp)
= f(tree species
+ stand composition
+ stand density
+ stand structure
+ natural Region)

SIMREG : functional shart



NFI data processing (calibration)

Forest simulation

Virtual stands generation

(= collection of trees)

Sequential application of models (annual)

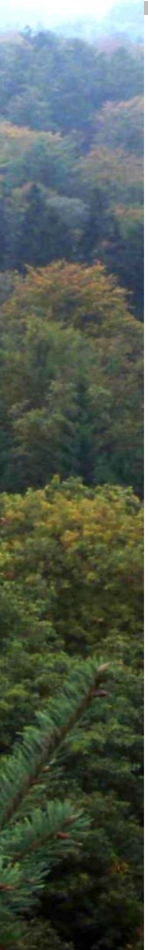
Removals => Recruitment => Growth

Configurable output database

1 record = 1 simulated stands /year

Calibration of SIMREG

SIMREG calibration



2 mandatory initialization files

1) Stands.inv ➔ simulated stands parameters
2) Trees.inv ➔ simulated tree parameters

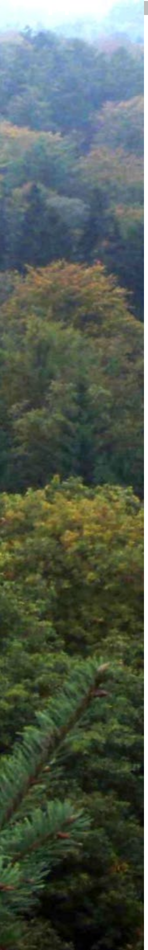
➔ *Direct NFI data processing*

Optional parameters files for every submodel

- Clearcut, thinning and mortality
- Recruitement and reforestation,
- Primary and secondary tree growth

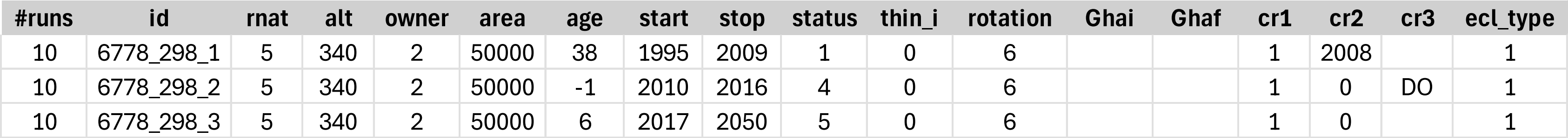
➔ *Statistical modelling from permanent NFI data*

SIMREG calibration : initialization files



2 mandatory initialization files

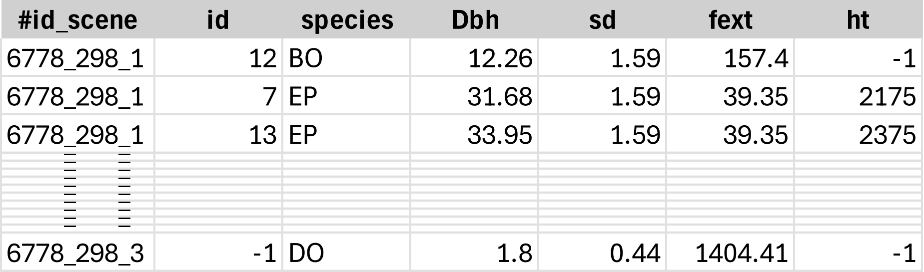
1) Stands.inv ➔ simulated stands parameters



#runs	id	rnat	alt	owner	area	age	start	stop	status	thin_i	rotation	Ghai	Ghaf	cr1	cr2	cr3	ecl_type
10	6778_298_1	5	340	2	50000	38	1995	2009	1	0	6			1	2008		1
10	6778_298_2	5	340	2	50000	-1	2010	2016	4	0	6			1	0	DO	1
10	6778_298_3	5	340	2	50000	6	2017	2050	5	0	6			1	0		1

- Each row = parameters of one PSP measurement cycle

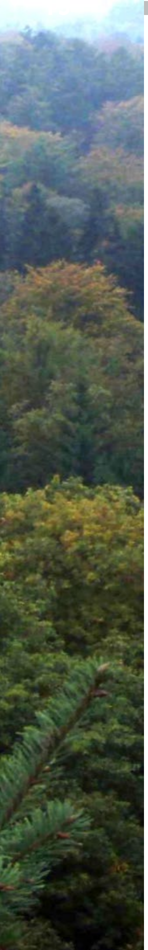
2) Trees.inv ➔ simulated tree parameters



#id_scene	id	species	Dbh	sd	fext	ht
6778_298_1	12	BO	12.26	1.59	157.4	-1
6778_298_1	7	EP	31.68	1.59	39.35	2175
6778_298_1	13	EP	33.95	1.59	39.35	2375
⋮	⋮					
6778_298_3	-1	DO	1.8	0.44	1404.41	-1

- Each row = parameters of one measured/estimated tree

SIMREG calibration : initialization files



2 mandatory initialization files

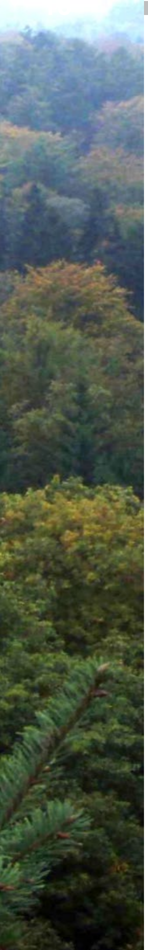
1) Stands.inv ➔ simulated stands parameters

#runs	id	rnat	alt	owner	area	age	start	stop	status	thin_i	rotation	Ghai	Ghaf	cr1	cr2	cr3	ecl_type
10	6778_298_1	5	340	2	50000	38	1995	2009	1	0	6			1	2008		1
10	6778_298_2	5	340	2	50000	-1	2010	2016	4	0	6			1	0	DO	1
10	6778_298_3	5	340	2	50000	6	2017	2050	5	0	6			1	0		1

General stands parameters :

- Identifier
- Natural region
- Elevation
- Public or private ownership
- Age of the forest stand
- Status (1 = forest stands, 4 = clearcut, 5 = young regeneration)

SIMREG calibration : initialization files



2 mandatory initialization files

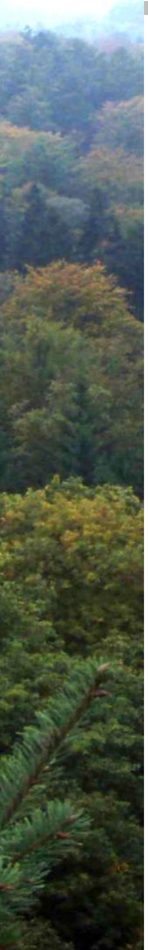
1) Stands.inv ➔ simulated stands parameters

#runs	id	rnat	alt	owner	area	age	start	stop	status	thin_i	rotation	Ghai	Ghaf	cr1	cr2	cr3	ecl_type
10	6778_298_1	5	340	2	50000	38	1995	2009	1	0	6			1	2008		1
10	6778_298_2	5	340	2	50000	-1	2010	2016	4	0	6			1	0	DO	1
10	6778_298_3	5	340	2	50000	6	2017	2050	5	0	6			1	0		1

Initialization parameters :

- Number of simulation runs
- Area (in m^2) represented by each run
- Starting and ending dates of the simulation

SIMREG calibration : initialization files



2 mandatory initialization files

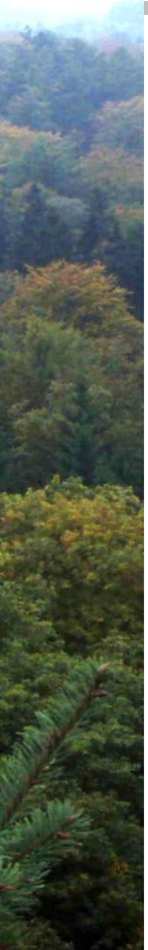
1) Stands.inv ➔ simulated stands parameters

#runs	id	rnat	alt	owner	area	age	start	stop	status	thin_i	rotation	Ghai	Ghaf	cr1	cr2	cr3	ecl_type
10	6778_298_1	5	340	2	50000	38	1995	2009	1	0	6			1	2008		1
10	6778_298_2	5	340	2	50000	-1	2010	2016	4	0	6			1	0	DO	1
10	6778_298_3	5	340	2	50000	6	2017	2050	5	0	6			1	0		1

Thinning parameters :

- Date of the First simulated thinning
- Thinning rotation
- *(legacy) Ghai and Ghaf : target thinning parameters*
- *(legacy) Ecl_type : thinning algorythm selection*

SIMREG calibration : initialization files



2 mandatory initialization files

1) Stands.inv ➔ simulated stands parameters

#runs	id	rnat	alt	owner	area	age	start	stop	status	thin_i	rotation	Ghai	Ghaf	cr1	cr2	cr3	ecl_type
10	6778_298_1	5	340	2	50000	38	1995	2009	1	0	6			1	2008		1
10	6778_298_2	5	340	2	50000	-1	2010	2016	4	0	6			1	0	DO	1
10	6778_298_3	5	340	2	50000	6	2017	2050	5	0	6			1	0		1

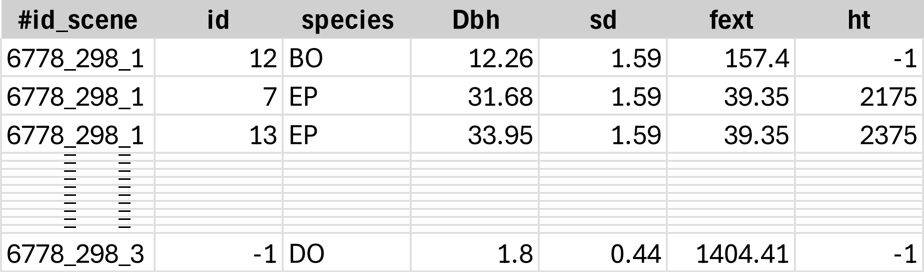
Observed clearcut and regeneration (optional) :

- When CR1 = 1, clearcut in CR2
- When CR1 = 2, no clearcut until CR2
- CR3 : type of reforestation after clearcut

SIMREG calibration : initialization files

2 mandatory initialization files

2) Trees.inv → simulated tree parameters

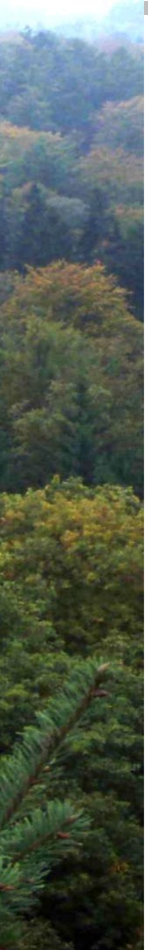


#id_scene	id	species	Dbh	sd	fext	ht
6778_298_1	12	BO	12.26	1.59	157.4	-1
6778_298_1	7	EP	31.68	1.59	39.35	2175
6778_298_1	13	EP	33.95	1.59	39.35	2375
⋮						
6778_298_3	-1	DO	1.8	0.44	1404.41	-1

Inventory data used to recreate virtual stands :

- id_scene = corresponding record in stands.inv
- id and species of the tree
- Dbh and sd = Mean and StDev of the tree diameter
- Fext = number of trees/ha that will be generated
- Htot is the total height (optional)

SIMREG calibration : statistical modelling



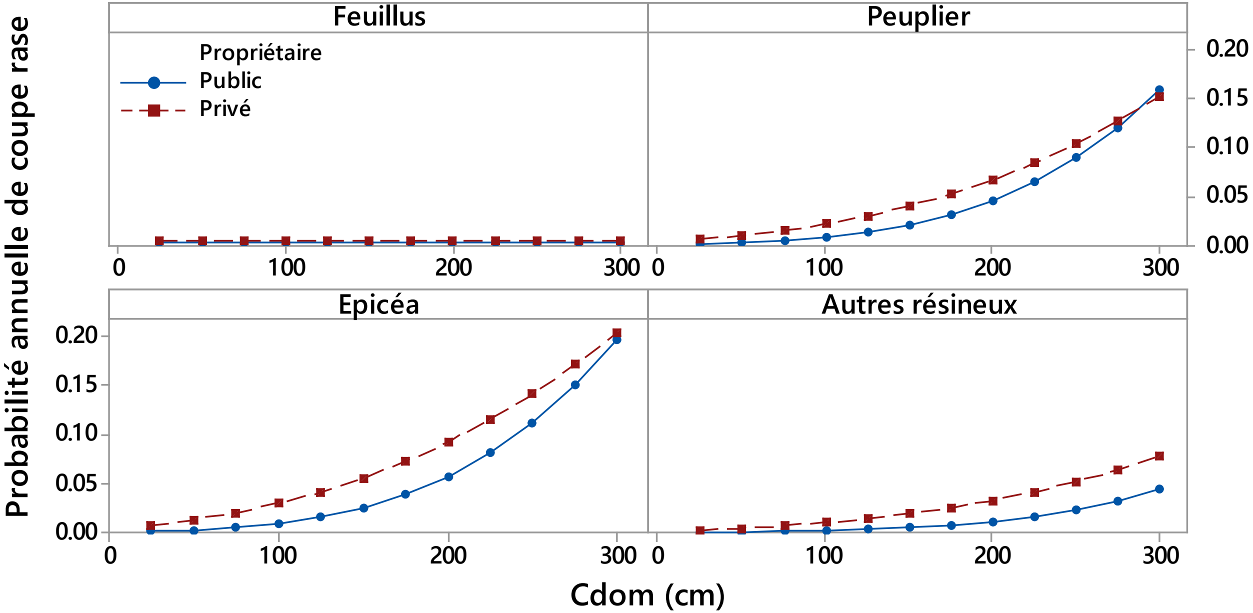
Main covariates :

- 17 species explicitly considered in RW *(23 for BE)*
  - 11 hardwood *(14)*
  - 6 softwood *(9)*
- Type of manager/owner : public/private * Region
- Stand structure (Cg, Cdom, CV) and density (Gha)
- Tree size (C130) and social status (Crel = C130/Cdom)

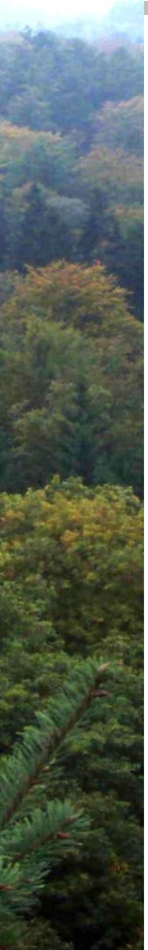
SIMREG calibration : clearcuts

Logistic regression of CR probability (%/yr)

$$P_{CR} = \text{logit}(\text{OwnerType} * \text{Species} * \text{Cdom})$$



SIMREG calibration : thinning



Logistic regression of thinning probability (%/yr)

$$P_{ecl} = \text{logit}(\underbrace{Div*Gha}_{A} + \underbrace{\%Sp}_{B} + \underbrace{Prop*Crel + Sp*Crel + Div*CV*Crel}_{C})$$

A) **$P_{ecl/an}$** increase with **Gha**

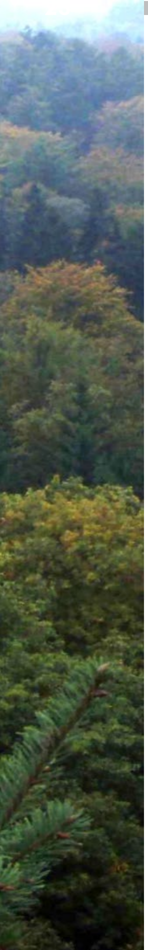
B) **$P_{ecl/an}$** increase with **%Sp**

- ➢ focus on the dominant species

C) **$P_{ecl/an}$** decrease with **Crel** and increase with **CV*Crel**

- ➢ Thinning from below except in irregular structure

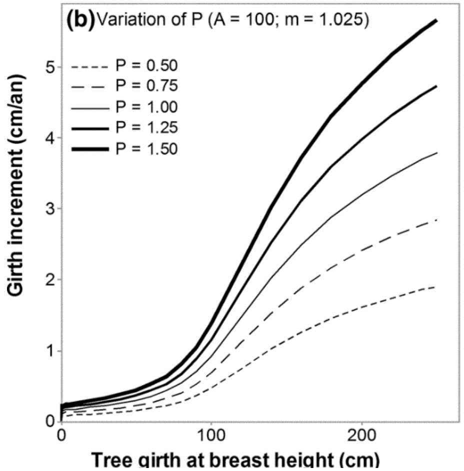
SIMREG calibration : secondary growth



Nonlinear modelling of girth growth (cm²/yr)

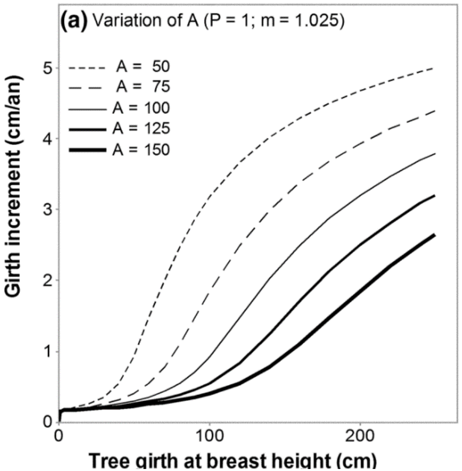
$$dGi = \mathbf{P} * (Ci - \mathbf{m} * \mathbf{A} + ((\mathbf{m} * \mathbf{A} + Ci)^{2} - 4 * \mathbf{A} * Ci)^{0.5}) \;/\; 2$$

$\mathbf{P} = Pa * exp(1 - Pb * Alt)$



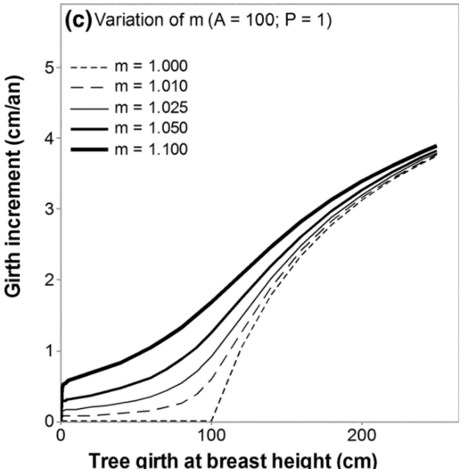
Productivity = f(elevation)

$\mathbf{A} = Aa * Cdom^{Ab}$



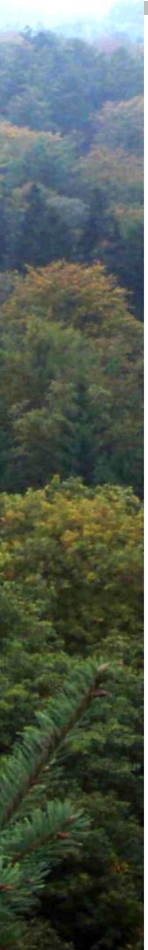
Social threshold = f(Cdom)

$\mathbf{m} = 1 + exp(ma - mb * Gha)$



Competitive stress = f(Gha)

SIMREG calibration : secondary growth



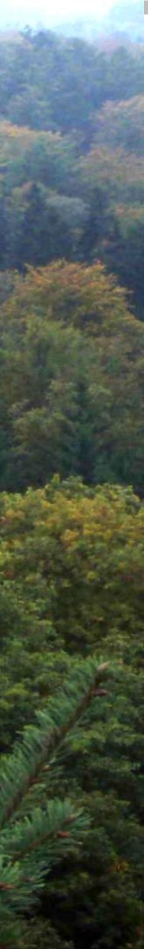
Essence	Acc moyen	R² ajusté	Validation RMSE	Validation ME
Chênes ind.	1.00 (23.64)	0.12 (0.39)	0.51 (12.65)	0.00 (0.03)
Hêtre	1.36 (29.73)	0.15 (0.50)	0.69 (16.12)	0.00 (0.58)
Bouleau	0.78 (9.33)	0.12 (0.40)	0.59 (7.60)	-0.02 (-0.09)
Frêne	1.34 (26.97)	0.19 (0.54)	0.68 (14.22)	-0.01 (-0.39)
Peuplier	2.78 (58.54)	0.33 (0.32)	1.56 (33.86)	-0.04 (-0.17)
Erable	1.23 (18.98)	0.14 (0.50)	0.70 (11.16)	0.00 (0.24)
Charme	0.89 (10.93)	0.10 (0.44)	0.55 (7.68)	-0.02 (-0.10)
Aulne	0.89 (11.53)	0.24 (0.38)	0.60 (7.62)	0.01 (0.41)
Chêne R	2.19 (49.39)	0.20 (0.58)	0.92 (21.78)	-0.01 (-0.94)
F. prod	1.08 (18.27)	0.09 (0.30)	0.85 (16.26)	0.00 (0.44)
F. divers	1.04 (13.38)	0.29 (0.57)	0.84 (12.42)	0.02 (-0.46)
Epicéa	1.44 (24.65)	0.31 (0.59)	0.54 (9.99)	0.00 (0.15)
Douglas	2.36 (47.45)	0.41 (0.72)	0.77 (15.94)	0.01 (-0.63)
Pin sylv.	0.83 (16.25)	0.16 (0.29)	0.47 (9.62)	0.00 (0.16)
Mélèze	1.52 (30.58)	0.21 (0.40)	0.61 (13.26)	-0.01 (0.00)
Pin A	1.08 (21.04)	0.15 (0.36)	0.65 (13.67)	-0.08 (-0.89)
R. divers	2.09 (40.10)	0.37 (0.64)	0.85 (19.29)	0.01 (-0.08)
Total	**1.31 (25.83)**	**0.41 (0.58)**	**0.63 (13.43)**	**0.00 (0.09)**

Performances :

- 58% R² on the dGi
- Varies by species
  - ➢ *29 - 72% R²*
  - ➢ *↗ with fast growing sp.*
- Valid for ≠ stands structure

Type	Structure	Acc moyen	RMSE	Erreur moyenne	Erreur médiane	R² dCi	R² dGi
Feuillus	Taillis	1.17	0.69	0.02	0.08	0.37	0.53
Feuillus	Irrégulier	1.24	0.72	-0.09	0.02	0.30	0.54
Feuillus	Régulier	1.21	0.62	0.01	0.06	0.41	0.54
Résineux	Taillis	1.34	0.72	-0.04	-0.02	0.39	0.54
Résineux	Irrégulier	1.33	0.70	-0.09	0.01	0.48	0.67
Résineux	Régulier	1.49	0.55	0.01	0.04	0.44	0.66

SIMREG calibration : recruitment



Logistic regression of recruitment density (N/ha/yr)

$$Nha_{recrut} = 400*logit(\underbrace{RNAT * Gha}_{A} + \underbrace{Cg + Cg^2}_{B} + \underbrace{CV}_{C})$$

A) **Nha$_{recrut}$** decrease with **Gha**

- ➢ stronger effect in Ardenne

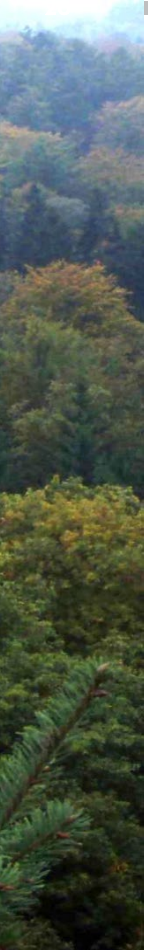
B) **Nha$_{recrut}$** peaks when Cg is below 75 cm or over 200 cm

- ➢ transition to high forest of younger stands
- ➢ regeneration in older forests

C) **Nha$_{recrut}$** increase with **CV**

- ➢ more regeneration in irregular forest structure

SIMREG calibration : recruitment



Matrix model of recruitement composition

$$Nha_{recrut/Sp} = Nha_{recrut} * Vector_{forest\_sp} * Matrice_{recrut}$$

Composition du recrutement (%)

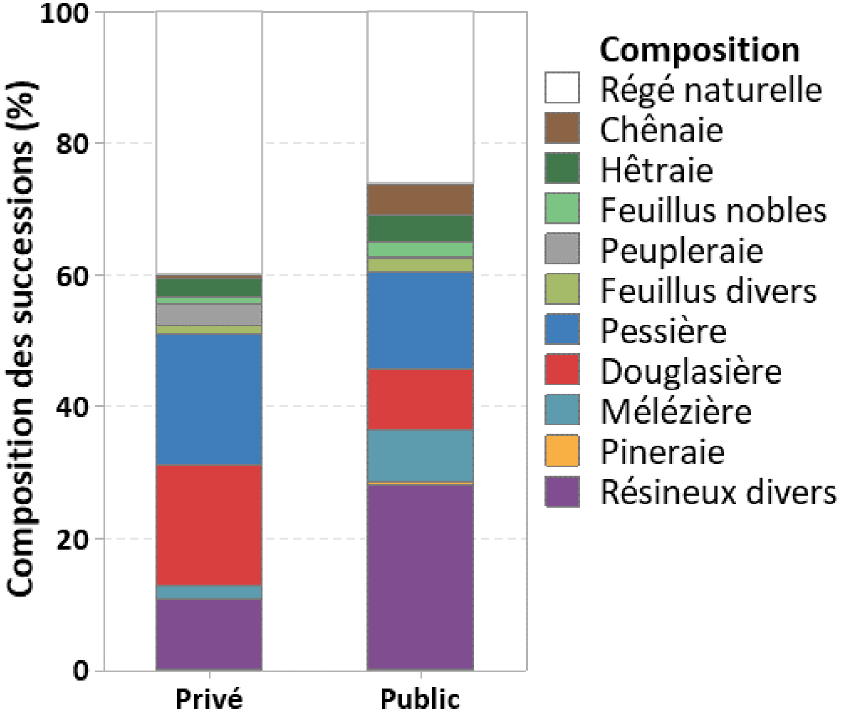
Composition du peuplement

%	CHI	HET	BOU	FRE	PEU	ERS	CHA	AUL	CHR	FN	FD	EPC	DOU	PIS	MLZ	PIA	RD
CHI	**7**	28	11	5	0	9	22	0	1	2	8	7	0	0	0	0	0
HET	1	**74**	1	1	0	5	7	1	0	1	3	6	0	0	0	0	0
BOU	9	12	**28**	5	0	6	6	4	1	2	16	9	0	0	2	0	0
FRE	3	5	6	**25**	3	31	11	4	0	2	6	2	2	0	0	0	0
PEU	7	4	1	28	**0**	19	0	20	0	7	11	4	0	0	0	0	0
ERS	2	12	2	15	0	**44**	7	2	1	4	7	2	1	1	0	0	0
CHA	0	9	0	15	0	15	**57**	0	2	0	2	0	0	0	0	0	0
AUL	0	10	3	28	0	23	0	**21**	0	0	3	12	0	0	0	0	0
CHR	0	12	16	0	0	34	0	0	**26**	2	10	0	0	0	0	0	0
FN	1	9	0	18	0	31	6	0	1	**7**	19	0	7	0	0	0	0
FD	4	12	13	14	0	13	9	1	4	1	**28**	2	0	0	0	0	0
EPC	5	10	10	0	0	3	3	0	0	0	6	**59**	4	0	0	0	0
DOU	0	20	35	0	0	2	2	0	0	0	0	25	**17**	0	0	0	0
PIS	23	8	20	6	0	0	2	0	2	3	16	11	0	**11**	0	0	0
MLZ	8	5	11	1	0	6	4	0	0	5	7	24	13	0	**15**	0	0
PIA	12	0	0	7	0	0	0	0	0	0	81	0	0	0	0	**0**	0
RD	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**60**

SIMREG calibration : reforestation

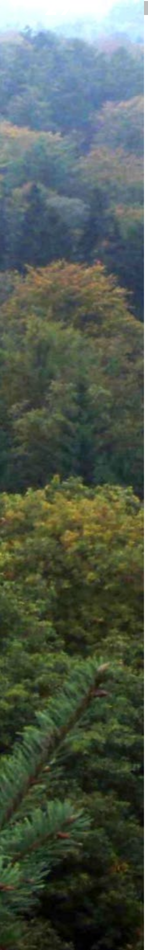
Probability for each composition = f(OwnerType)

Reforestation type	Prob PB	Prob PR	Composition per ha
Natural regeneration	26.24	40.09	2000 * recruit
Spruce	14.83	19.81	2250 * Spr
Spruce + douglas	22.43	9.91	1500 * Spr + 750 * Dou
Douglas	9.13	18.4	2000 * Dou
Larch	7.98	1.89	2000 * Lar
Beech	3.04	2.83	2250 * Bee
Native oak	4.18	0	2000 * Oak
Hybrid poplar	0.38	3.3	120 * Pop
Douglas + larch	2.28	0.5	1500 * Dou + 750 * Lar
Red oak	1.14	0.94	2000 * Rok
Misc. hardwood	0.76	0.94	1100 * Hwc
Spruce + larch	1.52	0	1500 * Spr + 750 * Lar
Maple	0.76	0.47	2000 * Map
Misc. softwood	0.76	0.47	2000 * Swx
Birch	1.14	0	2000 * Bir
Beech + oak	1.14	0	1000 * Bee + 1000 * Oak
Ash	0.76	0	2000 * Ash
Beech + douglas	0.76	0	1500 * Bee + 750 * Dou
Black alder	0	0.47	2000 * Ald
Beech + larch	0.38	0	1500 * Bee + 750 * Lar
Scot pine	0.38	0	2000 * Spi



SIMREG simulation output

Simulation output



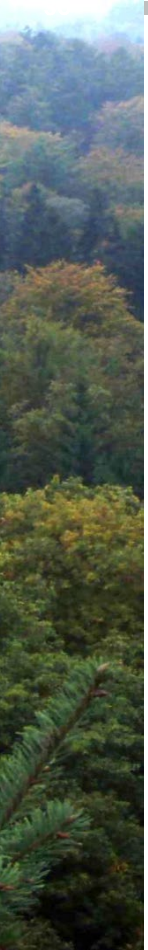
Tree allometries are computed using relevant models

- VBFT and VBFB with Dagnelie taper models
  - Choice between 1 and 2-input model (second recommended)
  - Alternative modern calibration can also be used
- VEF of Longuetaud et al. (2013)
- WD from H2020 project diabolo

Output data aggregated at the stand level

- Each row = characteristics of one run/yr
- Configurable content : Cmean, Nha, Gha, Vha, AGBha,…
  - standing/thinned, /sp, /Dbh class,…

Simulation output

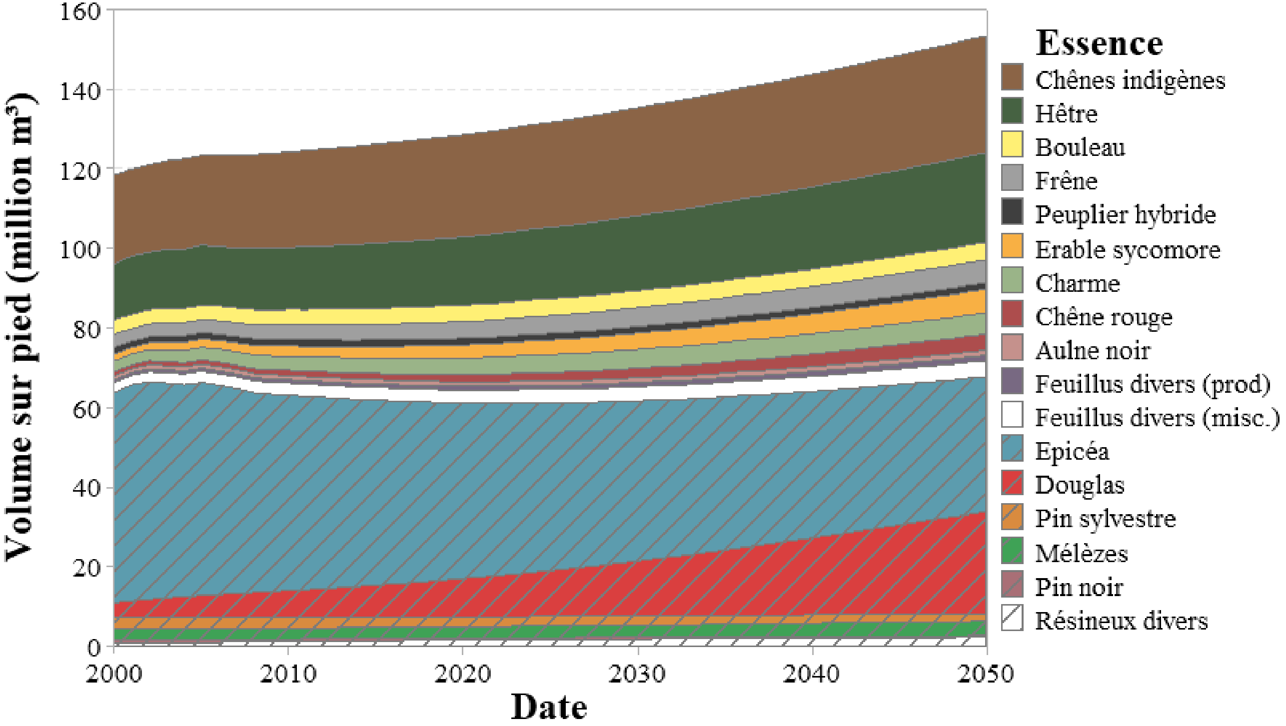


Performance test with 1994-2015 IPRFW data

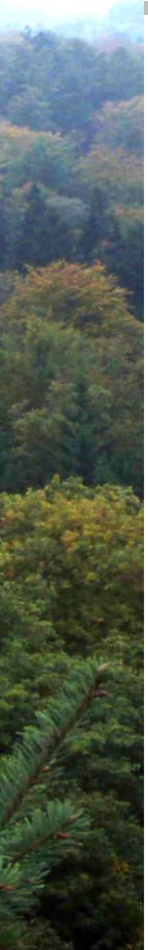
- UE integrated from their first inventory cycle (1994-2008)
- Full-scale simulation :
  - Each UE ➔ 10 simulated stands of 5 ha
    - ➢ 95 900 simulated stands (479 500 ha)
  - Each measured tree ➔ 500 to 8000 simulated trees
    - ➢ 465 million simulated trees
- Synchronisation to 2012 to compare with historical data
  - ➢ Results within a one year variation
  - ➢ A bit too optimistic for softwood plantations
- About one hour to simulate until 2050
  - ➢ 5 millions rows (runs*yr)

Simulation output

Performance test with 1994-2015 IPRFW data



Simulation output



Performance test with 1994-2015 IPRFW data

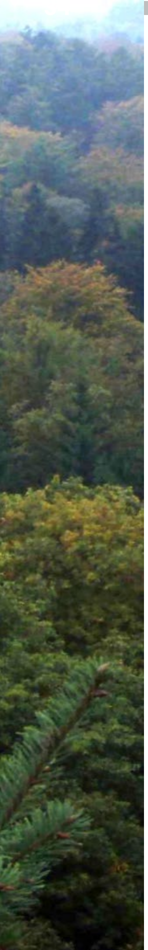
Species	Volume total (10^3 m^3) IPRFW	SIMREG	Différence (10^3 m^3)
Chênes	24 656	24 292	-364
Hêtre	15 876	15 870	-6
Frêne	3 857	3 666	-191
Bouleau	3 991	3 959	-32
Peuplier	1 759	1 712	-47
Feuillus divers	12 395	12 755	360
Total Feuillus	**62 534**	**62 254**	**-280**
Epicéa	47 858	47 935	77
Douglas	6 589	7 253	664
Mélèzes	2 683	2 747	64
Pins	3 366	3 223	-143
Résineux divers	1 116	1 442	326
Total Résineux	**61 612**	**62 599**	**987**
Total	**124 145**	**124 853**	**708**

Softwood plantation success was overestimated

Total difference is within a one year variation

Recent developments

Recent developments



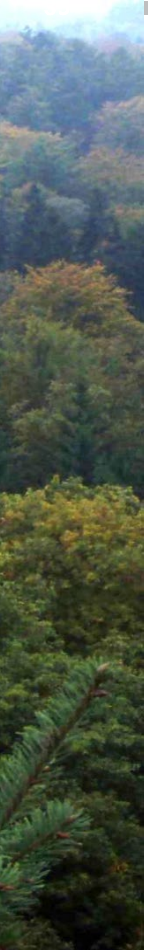
Several significant forest health crises

- Spruce bark beetle outbreak
- Ash dieback
- Douglas-fir needle cast
- Severe drought

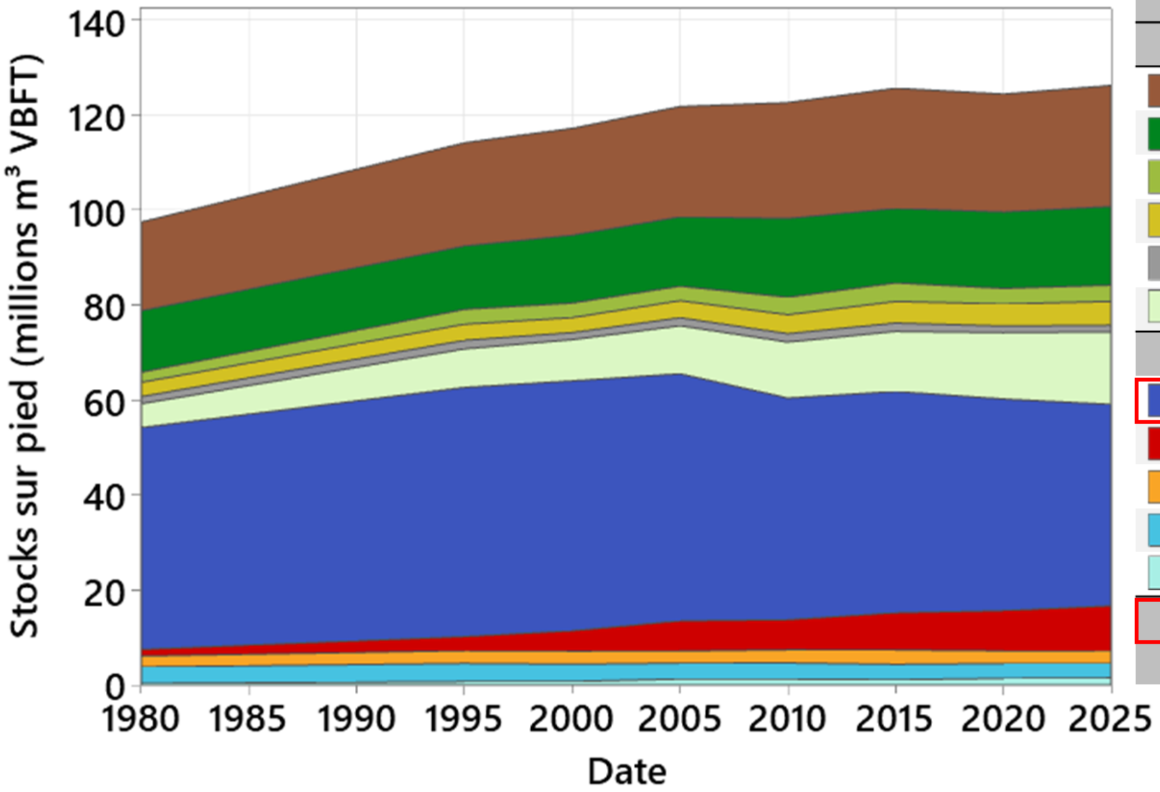
About 100% new IPRFW remeasurement data

- Recent data indicate a clear shift in trend

Recent developments : new IPRFW data

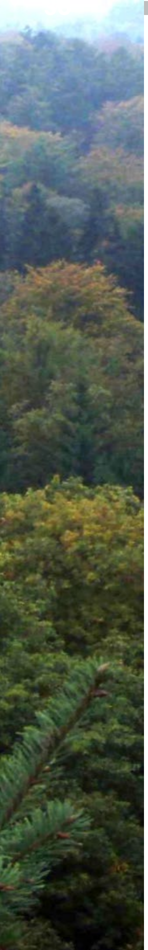


Stock change from 1980 to 2025



1000 m^3/an	1980-2005	2005-2025
Essences	ACC net	ACC net
🟫 Chêne	+181	+112
🟩 Hêtre	+66	+99
🟩 Frêne	+37	+18
🟨 Bouleau	+24	+71
⬜ Peuplier	+7	-14
⬜ Feu div.	+203	+258
Total feuillus	**+519**	**+543**
🟦 Epicéa	+213	-480
🟥 Douglas	+197	+154
🟧 Mélèzes	+11	+7
🟦 Pins	-6	-15
⬜ Res div.	+37	+12
Total résineux	**+453**	**-322**
TOTAL	**+971**	**+221**

Recent developments : new IPRFW data



Net growth (growth – mortality) before and after 2010

Yield (10^3 m^3/yr)	2000-2010		2010-2020		Lost (%)
Species	**PROD**	**%ECL**	**PROD**	**%ECL**	
Indigenous oaks	472	70	344	77	-27
Beech	485	78	408	67	-16
Ash	123	58	73	171	-41
Birch	93	72	104	47	+12
Poplar	71	135	54	233	-25
Hardwood misc	343	31	286	38	-17
Total hardwood	**1 588**	**66**	**1 269**	**75**	**-20**
Spruce	2 267	118	2 023	124	-11
Douglas	326	42	385	47	+18
Larch	107	93	101	84	-6
Pines	101	111	31	312	-70
Softwood misc	46	66	45	82	-3
Total softwood	**2 847**	**107**	**2 584**	**112**	**-9**
TOTAL	**4 435**	**92**	**3 852**	**100**	**-13**

Net VBFT yield

Widespread loss

Except BO and DO

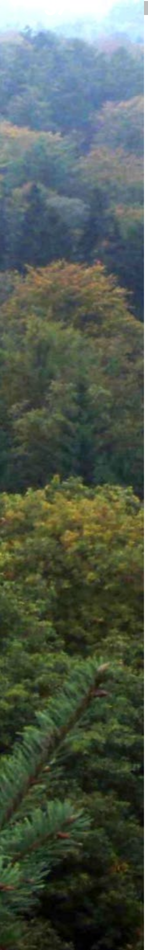
➔ area ↗ ↗

Species change

or

Other causes ??

Recent developments : new IPRFW data



Net yield per ha before and after 2010

Species	Yield m³/ha/yr		Lost (%)
	2000-2010	2010-2020	
Indigenous oaks	4.8	3.6	-25
Beech	8.2	6.5	-21
Ash	7.6	4.2	-44
Birch	4.7	4.2	-9
Poplar	9.5	9.1	-4
Hardwood misc	6.6	4.5	-32
Spruce	15.0	15.3	+2
Douglas	16.8	14.5	-14
Larch	11.0	9.8	-11
Pines	7.7	2.8	-64
Softwood misc	18.7	18.4	-1
Total	**9.9**	**8.5**	**-14**

Net VBFT yield/ha

Widespread loss confirmed

Lower growth

+

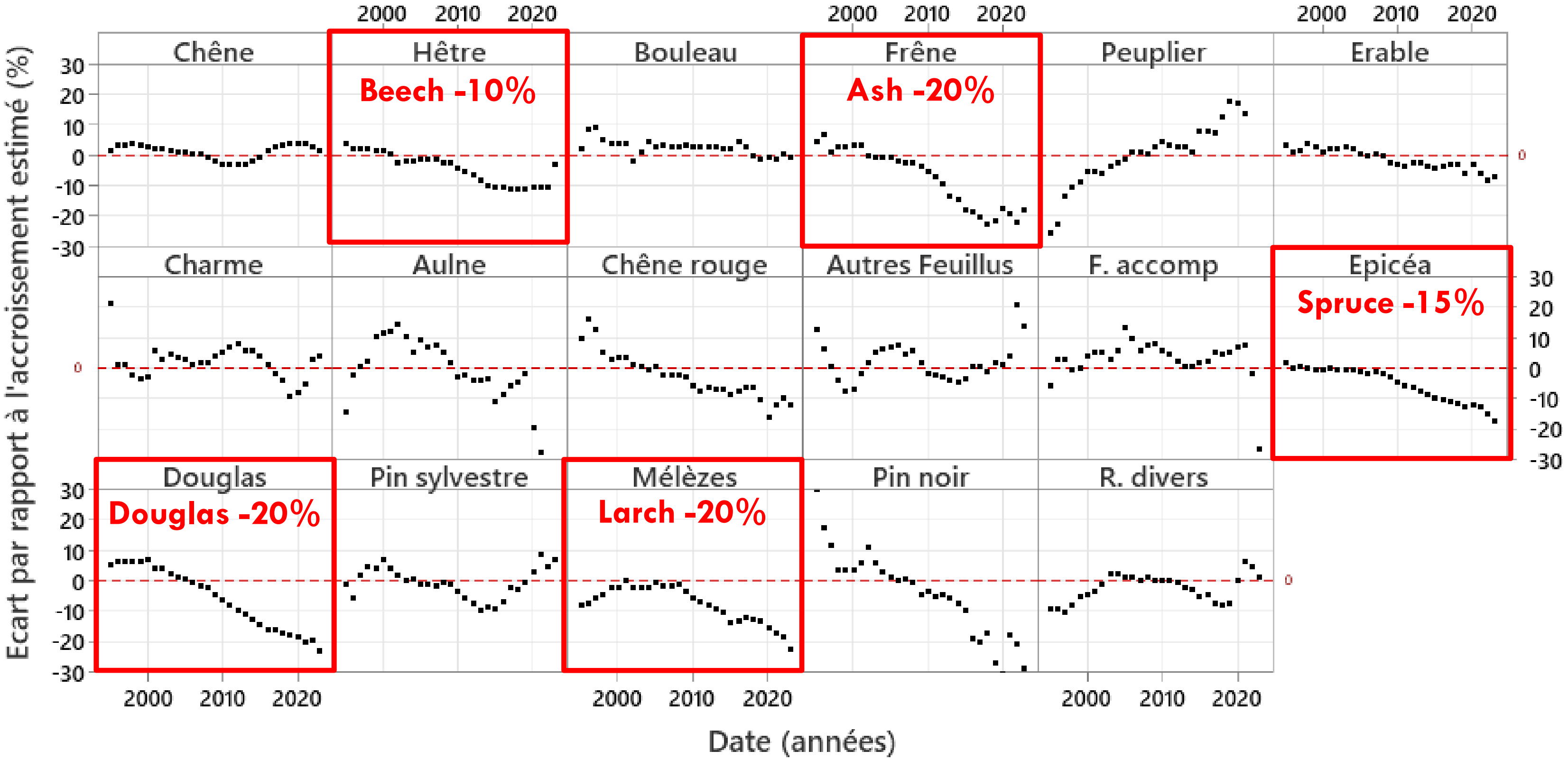
Higher mortality

=

Lower carbon sink

Recent developments : new IPRFW data

Mean deviation from the estimated growth



Beech -10%

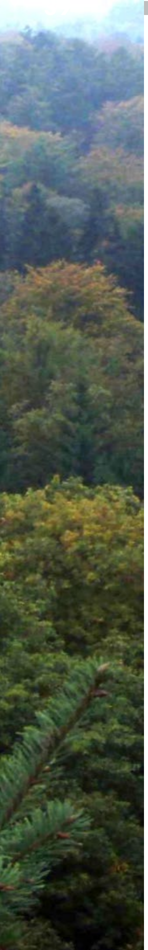
Ash -20%

Spruce -15%

Douglas -20%

Larch -20%

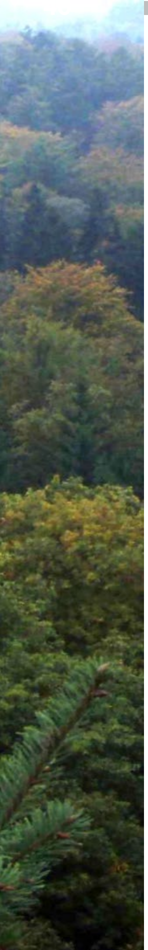
Recent developments



Conclusions

- RW forest carbon sink may have decreased by 50%
  - Not related to a management change
- Significant drop in forest productivity
  - Global climate changes likely responsible
  - A recovery seems unlikely
  - New calibration of growth models required
- Tree mortality increase
  - Now represents a significant part of gross production
  - Need to be modelled and integrated in SIMREG
- A new calibration of the FRL is required

Perspectives



Next in SIMREG

- Mortality model = f(species, site, competition)
    - ➢ Probably based on the current thinning model
- Improved model for total height and Ht growth estimation
    - Significant ≠ between 1-input and 2-input taper models
        - ➢ *H/D allometry changes ≈ 20% of net stock growth*
    - Current model too simple to fully account for these
- Model for species site adequation
    - Site productivity/sp = trophic * hydric disponibility
        - ➢ *Climate sensitive with relative extractable water ?*
- Log grading model (cascading use)

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LIÈGE université
Forest is life

Wallonie
environnement
SPW

Merci de votre attention !