FOREM Meeting – INRAE Grenoble

WaFfleS, a tree-level and distance-independant model to study multifunctionality and drought resilience of Belgian forests.

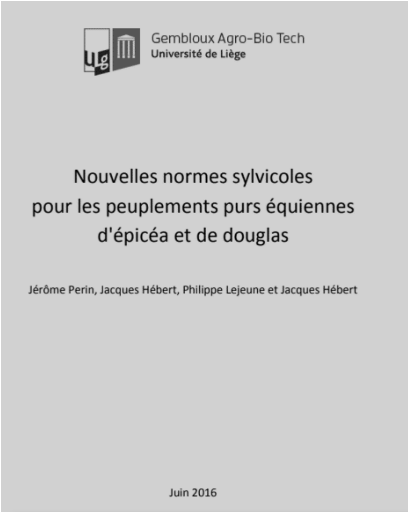
10.05.2023

Violette Van Keymeulen

Phd thesis director : Gauthier Ligot

Background informations

Spatial scale targeted	Stand	Region
Model name	Gymnos Heterofor	Simreg
Application	Sylvicultural recommandations	Regional policy


Gembloux Agro-Bio Tech
Université de Liège

Nouvelles normes sylvicoles
pour les peuplements purs équiennes
d'épicéa et de douglas

Jérôme Perin, Jacques Hébert, Philippe Lejeune et Jacques Hébert

Juin 2016


Forest Ecology and Management 327 (2014) 189–200

Contents lists available at ScienceDirect

Forest Ecology and Management

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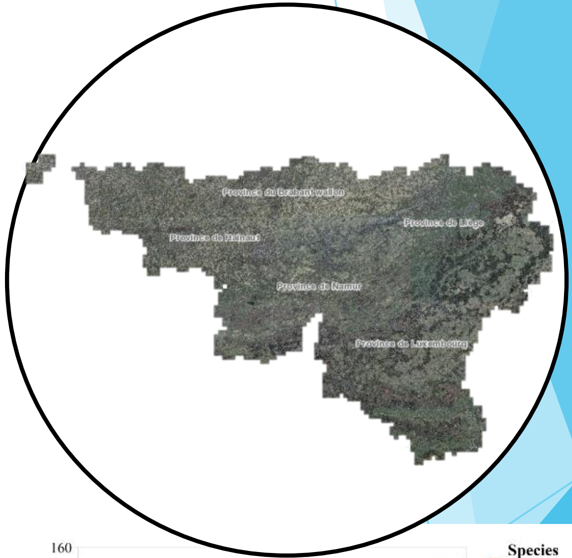
ELSEVIER

Managing understory light to maintain a mixture of species with different shade tolerance

Gauthier Ligot [a,*], Philippe Balandier [d], Benoît Courbaud [c], Mathieu Jonard [b], Daniel Kneeshaw [e], Hugues Claessens [a]



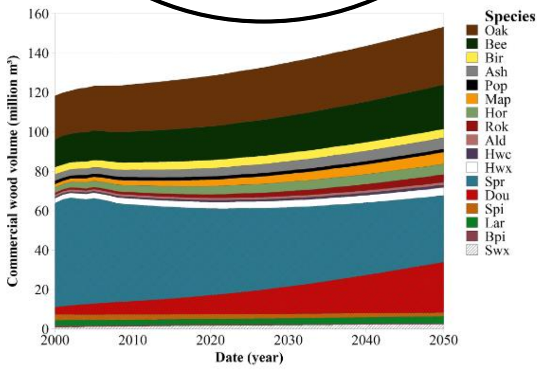
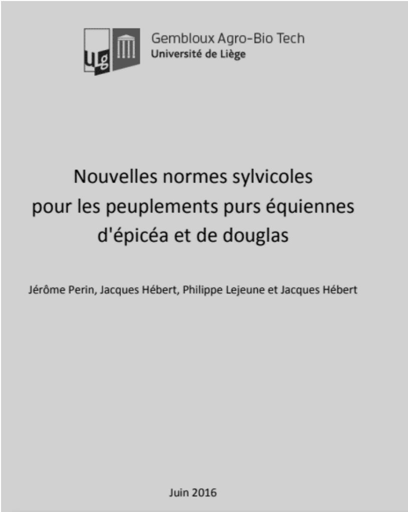


Fig. 3. Simulated development between 2000 and 2050 of the total growing solid wood stock (in millions m³) by species group.

Perin et al. 2020

Background informations

Spatial scale targeted	Stand	Multi-stand (forest)	Region
Model name	Gymnos	?	Simreg
Application	Sylvicultural recommandations	forest management plan	Regional policy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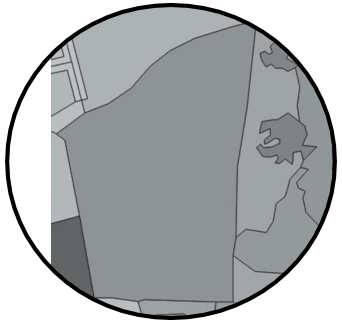
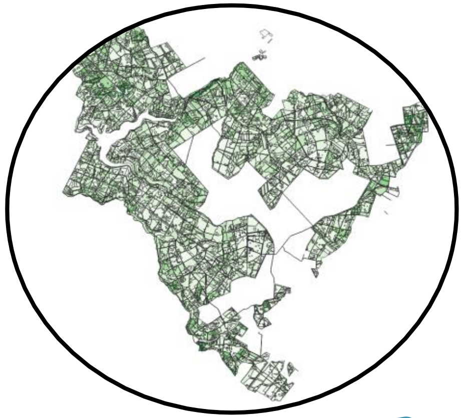
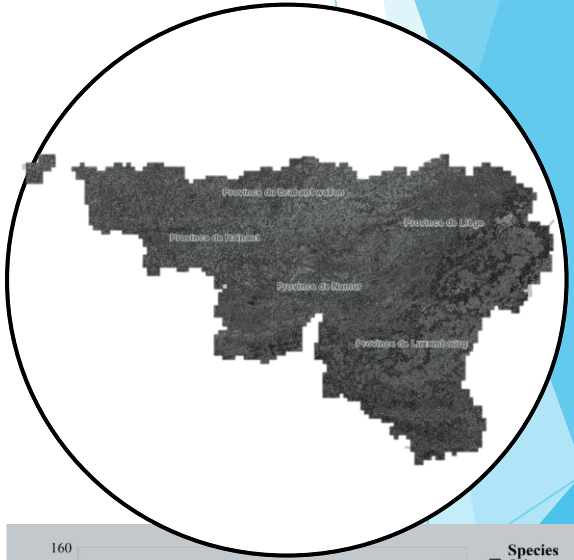






- Evolution of timber stocks
- Expected incomes
- Multifunctionnality management
- Climate change impact

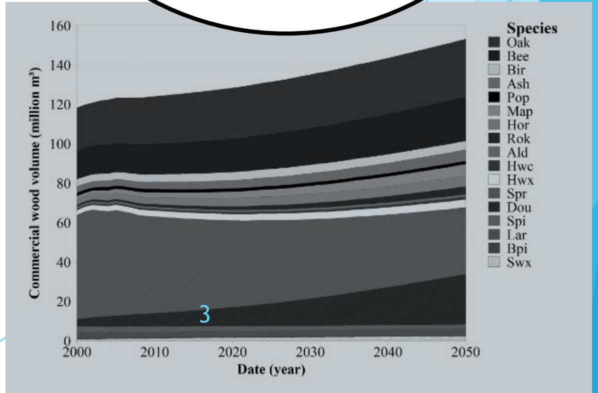
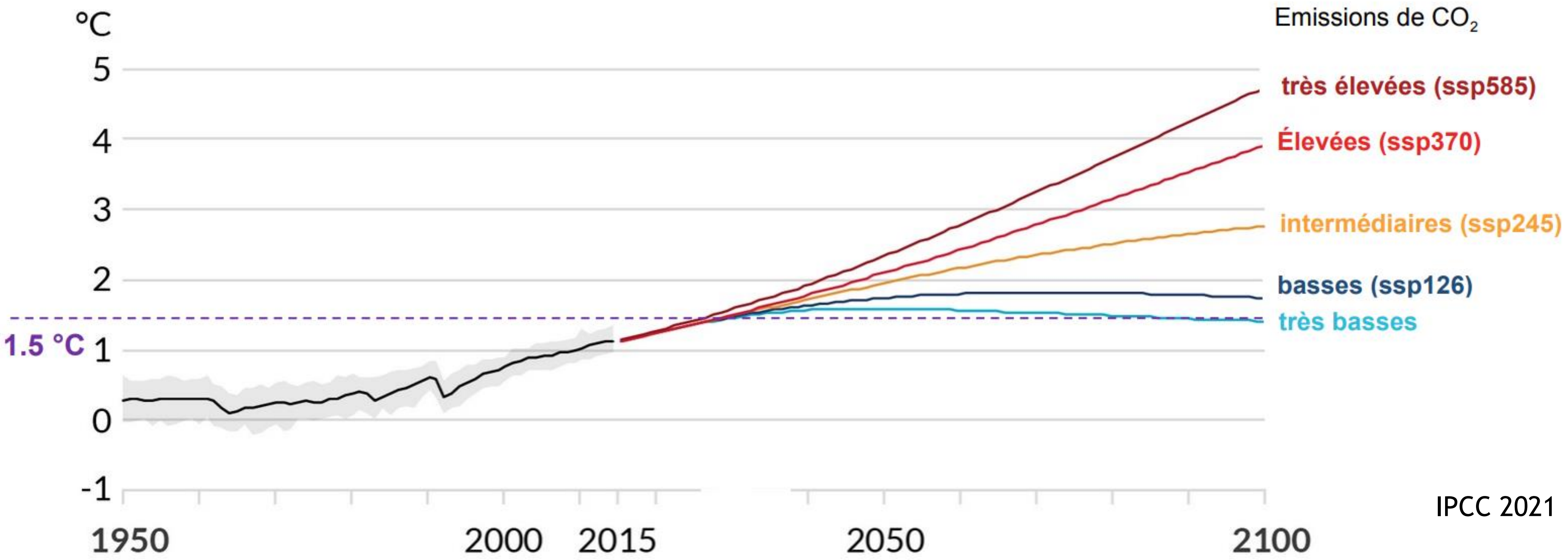


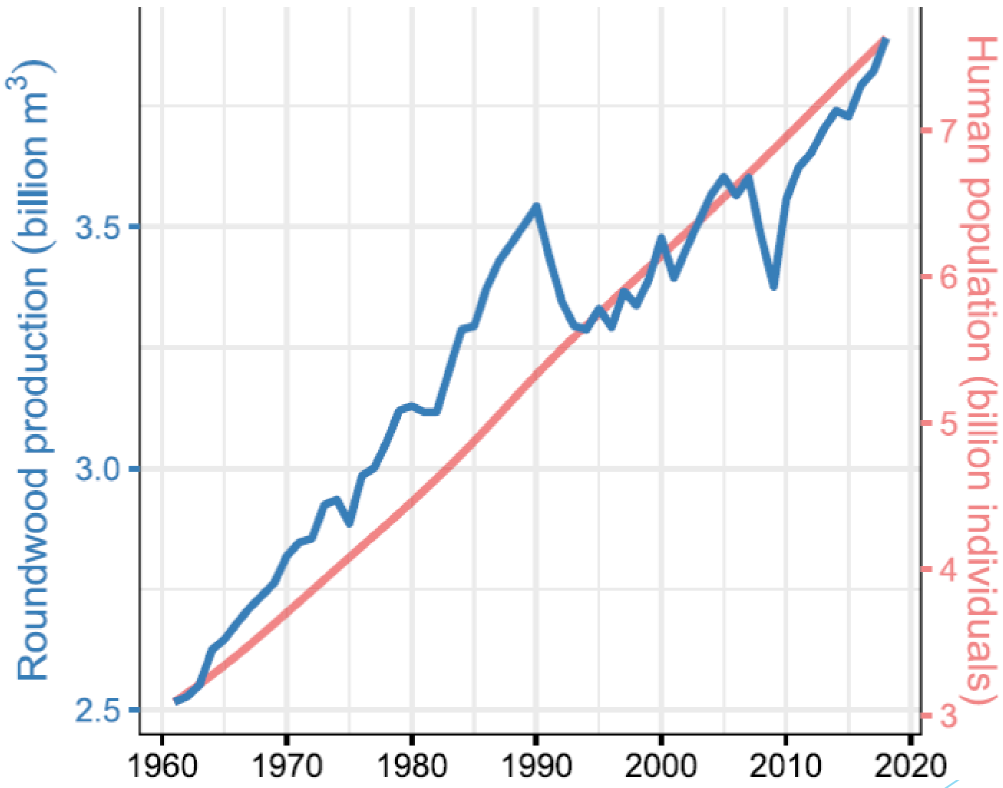
Fig. 3. Simulated development between 2000 and 2050 of the total growing solid wood stock (in millions m^3) by species group.

- Climate change will affect ecosystem services supply and we are facing uncertainty about frequency and severity of risks that are coming (IPCC 2021)



IPCC 2021

- Climate change will affect ecosystem services supply and we face uncertainty about frequency and severity of risks that are coming (IPCC 2021).
- forests resilience has globally decrease, also because of the homogenization of forests led by forest management and timber harvesting (Muller et al. 2022).
- The demand for other ecosystem services is also increasing.



Betts et al. 2021

Sustainability Science (2022) 17:2013–2029
https://doi.org/10.1007/s11625-022-01111-4

IR3S Integrated Research System for Sustainability Science

IGES Institute for Global Environmental Strategies

ORIGINAL ARTICLE

Check for updates

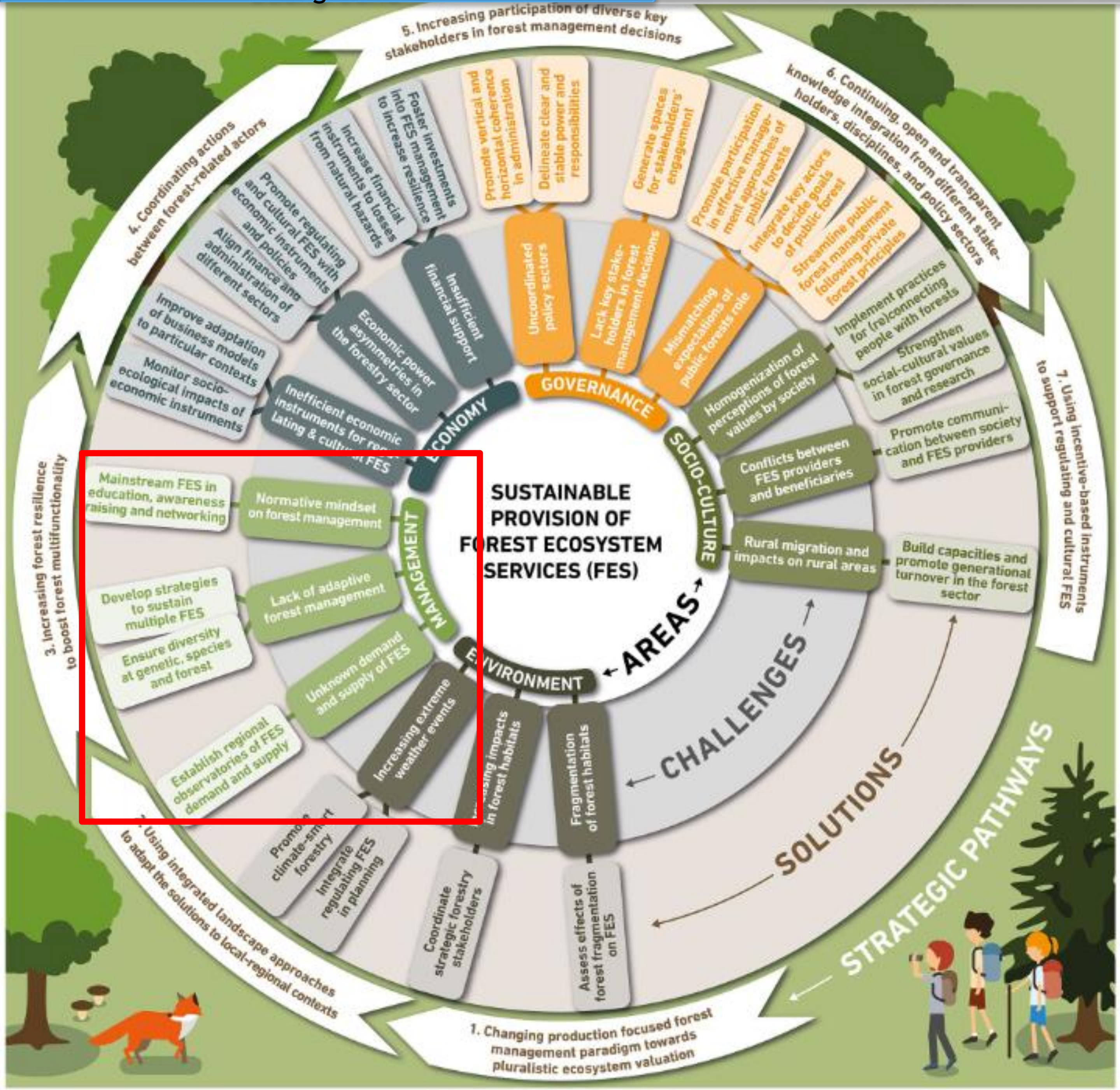
Scanning the solutions for the sustainable supply of forest ecosystem services in Europe

M. Hernández-Morcillo[1] · M. Torralba[2,3] · T. Baiges[4] · A. Bernasconi[5] · G. Bottaro[6] · S. Brogaard[7] · F. Bussola[8] · E. Díaz-Varela[9] · D. Geneletti[10] · C. M. Grossmann[11] · J. Kister[12] · M. Klingler[13] · L. Loft[14] · M. Lovric[15] · C. Mann[1] · N. Pipart[16] · J. V. Roces-Díaz[17] · S. Sorge[1] · M. Tiebel[18] · L. Tyrväinen[19] · E. Varela[20] · G. Winkel[21] · T. Plieninger[2,3]

Received: 20 August 2021 / Accepted: 8 February 2022 / Published online: 22 March 2022

Abstract

Forests are key components of European multifunctional landscapes and supply numerous forest ecosystem services (FES) fundamental to human well-being. The sustainable provision of FES has the potential to provide responses to major societal challenges, such as climate change, biodiversity loss, or rural development. To identify suitable strategies for the future sustenance of FES, we performed a solution scanning exercise with a group of transdisciplinary forest and FES experts from different European regions. We identified and prioritized fifteen major challenges hindering the balanced provision of multiple FES and identified a series of potential solutions to tackle each of them. The most prominent challenges referred to the increased frequency and impacts of extreme weather events and the normative mindset regarding forest management. The respective solutions pointed to the promotion of forest resilience via climate-smart forestry and mainstreaming FES-oriented



- We need solutions to increase forest resilience
- We need solutions to deal with tradesoff between ecosystem services and ensure forest multifunctionnality

1. A strategy to ensure forest resilience : increase forest complexity at multiple scales

Tree

Stand

Multi-stands (forest)

Landscapes

1. A strategy to ensure forest resilience : increase forest complexity at multiple scales

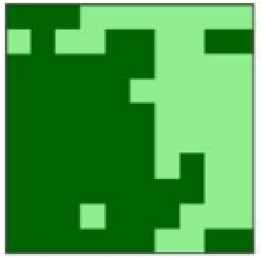
Tree

Stand

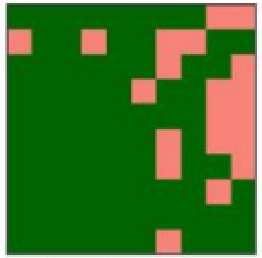
Multi-stands (forest)

Landscapes

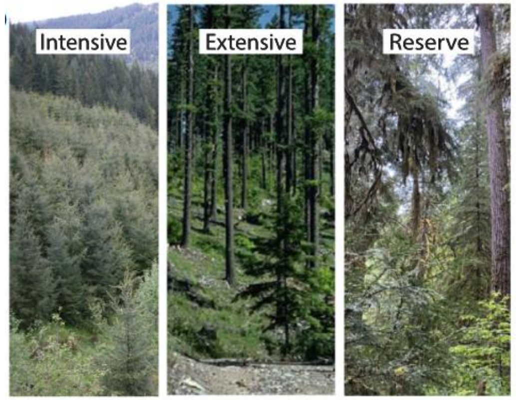
2. A strategy to reduce trades-off between ES : Consider multifunctionnality at forest scale



Land sharing



Land sparing



Diluated disturbances
Extensive management + reserves

Concentrated disturbances
Intensive management + reserves

Research plan

<u>A new simulator</u>
Adapted to belgian forests, forest scale and considering drought

<u>A research question</u>
About management solutions to increase forest resilience and multifunctionnality

<u>A literature review</u>
About the link between forest heterogeneity at different scales and the resilience of forest ecosystem services

Step 1 : model generalities

Walsi and WaFfleS (Wallonia Forest Simulator) :

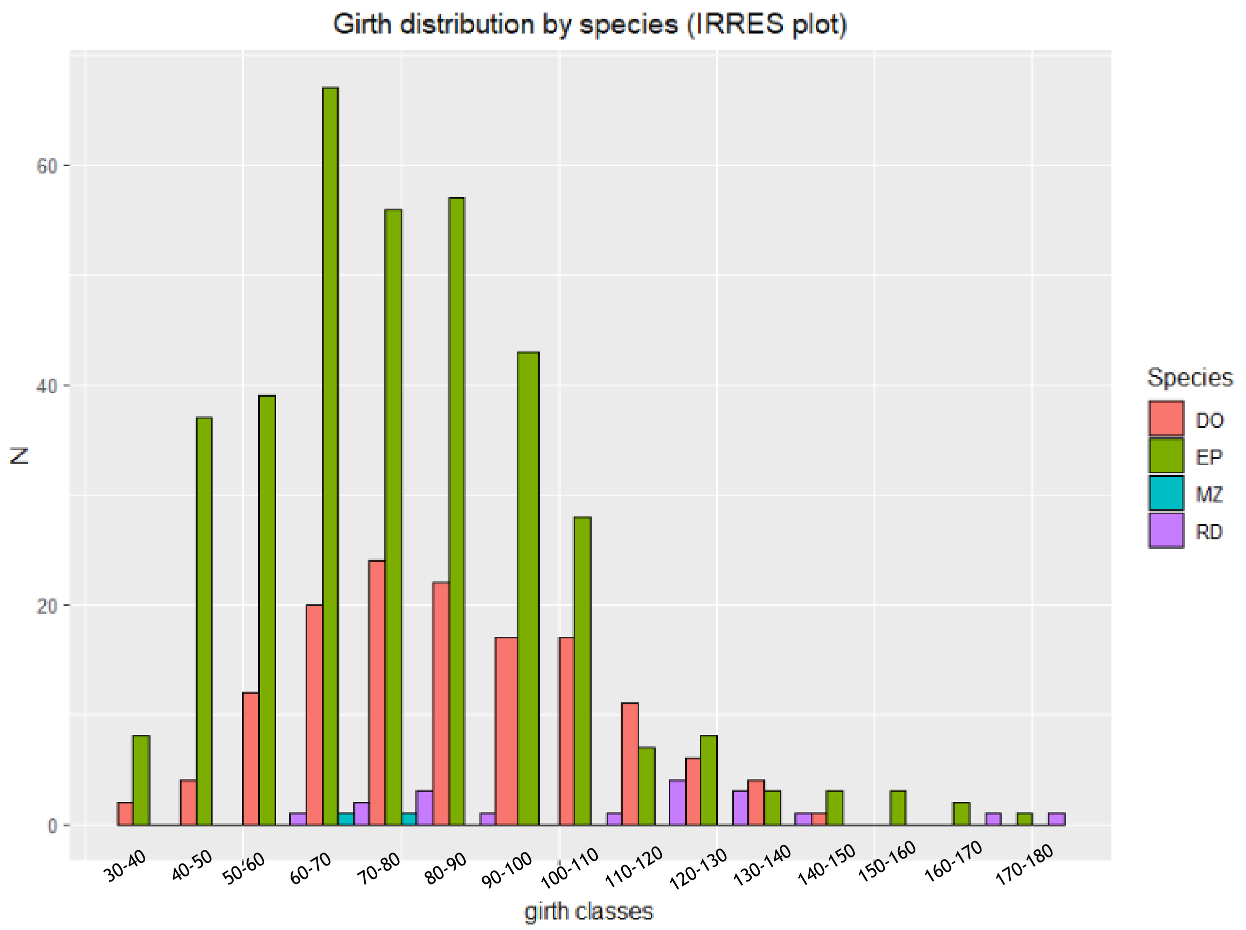
- A tree-individual and distance-independant model
- Designed for mixed, pure, even-aged and uneven-aged stand
- Drought sensitive
- Calibrated for 22 Belgian species

Quercus sp.	Picea abies	Carpinus betulus
Fagus sylvatica	Pseudotsuga menziesii	Alnus sp.
Betula sp.	Pinus sylvestris	Quercus rubra
Fraxinus excelsior	Sorbus aucuparia	Prunus avium
Populus x (hybridé)	Robinia pseudoacacia	Castanea sativa
Acer pseudoplatanus	Prunus serotina	Picea sitchensis
Larix sp	Pinus nigra	Other hardwood
Other softwood		

Step 2 : input files

Input files required :

- An inventory file



*C:\Users\vankey.v\Documents\1_DOCTORAT\4_Modélisation\input_data\Input_WALSI\inventory_figure2.inv - Notepad++

inventory_figure2.inv

```
# This is an inventory file for Walsi

# key records
standName = tenneville
inventoryDate = 2022
standArea_ha = 1
altitude = 500
classWidth = 10
naturalRegion = 4
soilWaterHoldingCapacity_mm = 60

polygon = MULTIPOLYGON (((0 0,100 0,100 100,0 100)))

#sp girth   N
CH  205 1
DO  35  2
DO  45  4
DO  55  12
DO  65  20
DO  75  24
DO  85  22
DO  95  17
DO  105 17
DO  115 11
DO  125 6
DO  135 4
DO  145 1
EP  35  8
EP  45  37
EP  55  39
EP  65  67
EP  75  56
EP  85  57
EP  95  43
```

Step 2 : input files

Input files required :

- ➢ An inventory file
- ➢ A species file

Species specific parameters

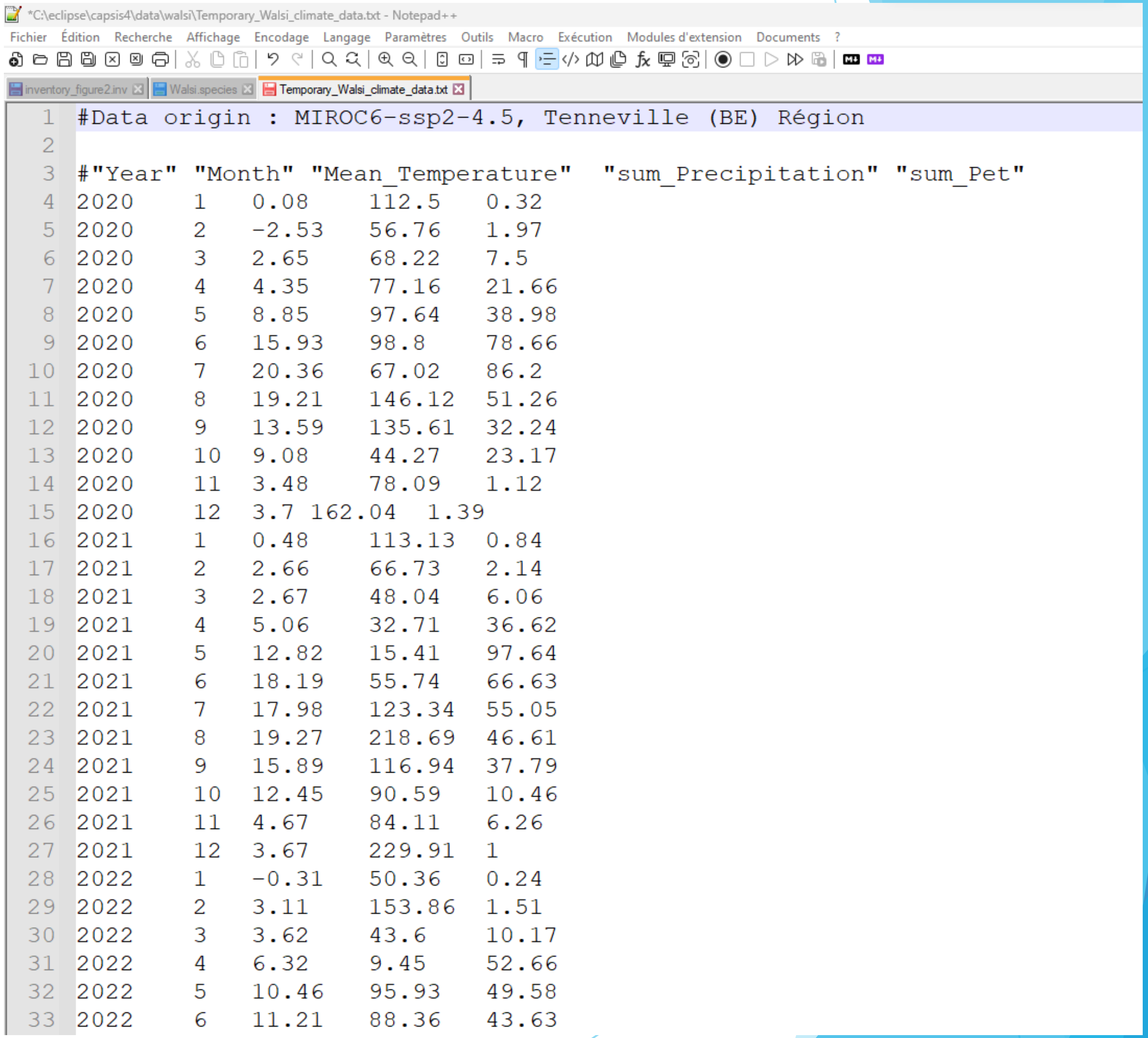
22 Species

```
C:\eclipse\capsis4\data\walsi\Walsi.species - Notepad++
inventory_figure2.inv   Walsi.species   Temporary_Walsi_climate_data.txt

# Walsi species file

# Color: r;g;b
# r, g and b in [0,255]

#spId   SimregName  latinName   Pa  Pb  Aa  Ab  ma  mb  v1  v2  v3  v4  c1  c2  mortality_c130_treshold survival_p_intercept    su
1   CH  Quercus sp. 0.1133068   0.0007591   0.2100735   1.1205395   1.847583    0.1587624   0.019546    -0.0029588  0.00011074  -3
2   HE  Fagus sylvatica 0.1344019   0.0007591   0.2100735   0.9444711   1.847583    0.1587624   0.01734 -0.003008   0.00011589  1.
3   BO, BP  Betula sp.  0.1117949   0.0007591   0.2100735   1.1298576   1.847583    0.1587624   0.0071727   -0.0022222  0.00010536
4   FR  Fraxinus excelsior  0.1419879   0.0007591   0.2100735   1.0638701   1.847583    0.1587624   -0.040364   0.00017945  7.6857
5   PE  Populus x   0.4086613   0.0007591   0.2100735   1.2267451   1.847583    0.1587624   0.0071727   -0.0022222  0.00010536  -1
6   ES  Acer pseudoplatanus 0.1185535   0.0007591   0.2100735   0.9493634   1.847583    0.1587624   -0.019508   0.00015072  5.7816
7   CA  Carpinus betulus    0.0954062   0.0007591   0.2100735   0.9491152   1.847583    0.1587624   0.01734 -0.003008   0.00011589
8   AL  Alnus sp.   0.2471932   0.0007591   0.2100735   1.1244754   1.847583    0.1587624   0.0071727   -0.0022222  0.00010536  -1
9   CR  Quercus rubra   0.1369393   0.0007591   0.2100735   1.1618045   1.847583    0.1587624   0.011189    -0.0023212  0.00010179
10  MR  Prunus avium    0.1057602   0.0007591   0.2100735   0.9911594   1.847583    0.1587624   0.048959    -0.002599   8.242001E-
11  CT  Castanea sativa 0.2471932   0.0007591   0.2100735   1.1244754   1.847583    0.1587624   0.01734 -0.003008   0.00011589  1.
12  SO  Sorbus aucuparia    0.1628127   0.0007591   0.2100735   1.0975823   1.847583    0.1587624   -0.019508   0.00015072  5.7816
13  RO  Robinia pseudoacacia    0.1628127   0.0007591   0.2100735   1.0975823   1.847583    0.1587624   0.019546    -0.0029588  0.
14  CS  Prunus serotina 0.1057602   0.0007591   0.2100735   0.9911594   1.847583    0.1587624   0.01734 -0.003008   0.00011589  1.
15  FD  Other hardwood  0.1628127   0.0007591   0.2100735   1.0975823   1.847583    0.1587624   0.01734 -0.003008   0.00011589  1.
16  EP  Picea abies 0.215601    0.0001898   0.3454868   1.0840982   -0.1987378  0.0666572   0.032253    -0.0040132  0.00013221  -1
17  DO  Pseudotsuga menziesii   0.3537123   0.0001898   0.3454868   1.0943286   -0.1987378  0.0666572   0.083862    -0.0064217  0.
18  PS  Pinus sylvestris    0.1270302   0.0001898   0.3454868   1.1328443   -0.1987378  0.0666572   -0.0052616  -0.001393   8.8771
19  MZ  Larix sp.   0.2297266   0.0001898   0.3454868   1.1295676   -0.1987378  0.0666572   0.019784    -0.0031514  0.00012589  -5
20  PI  Pinus nigra 0.1349973   0.0001898   0.3454868   1.0601591   -0.1987378  0.0666572   -0.0052616  -0.001393   8.8771E-05  1.
21  EK  Picea sitchensis    0.2572426   0.0001898   0.3454868   1.0258777   -0.1987378  0.0666572   0.032253    -0.0040132  0.0001
22  RD  Other softwood  0.2572426   0.0001898   0.3454868   1.0258777   -0.1987378  0.0666572   0.032253    -0.0040132  0.00013221
```

Step 2 : input files

Input files required :

- An inventory file
- A species file
- A climate file :
  - Data projection from SSP scenarios
  - Generated by M.A.R




```
#Data origin : MIROC6-ssp2-4.5, Tenneville (BE) Région

#"Year" "Month" "Mean_Temperature"  "sum_Precipitation" "sum_Pet"
2020	1	0.08	112.5	0.32
2020	2	-2.53	56.76	1.97
2020	3	2.65	68.22	7.5
2020	4	4.35	77.16	21.66
2020	5	8.85	97.64	38.98
2020	6	15.93	98.8	78.66
2020	7	20.36	67.02	86.2
2020	8	19.21	146.12	51.26
2020	9	13.59	135.61	32.24
2020	10	9.08	44.27	23.17
2020	11	3.48	78.09	1.12
2020	12	3.7 162.04	1.39
2021	1	0.48	113.13	0.84
2021	2	2.66	66.73	2.14
2021	3	2.67	48.04	6.06
2021	4	5.06	32.71	36.62
2021	5	12.82	15.41	97.64
2021	6	18.19	55.74	66.63
2021	7	17.98	123.34	55.05
2021	8	19.27	218.69	46.61
2021	9	15.89	116.94	37.79
2021	10	12.45	90.59	10.46
2021	11	4.67	84.11	6.26
2021	12	3.67	229.91	1
2022	1	-0.31	50.36	0.24
2022	2	3.11	153.86	1.51
2022	3	3.62	43.6	10.17
2022	4	6.32	9.45	52.66
2022	5	10.46	95.93	49.58
2022	6	11.21	88.36	43.63
```

Step 3 : Forest dynamic processes

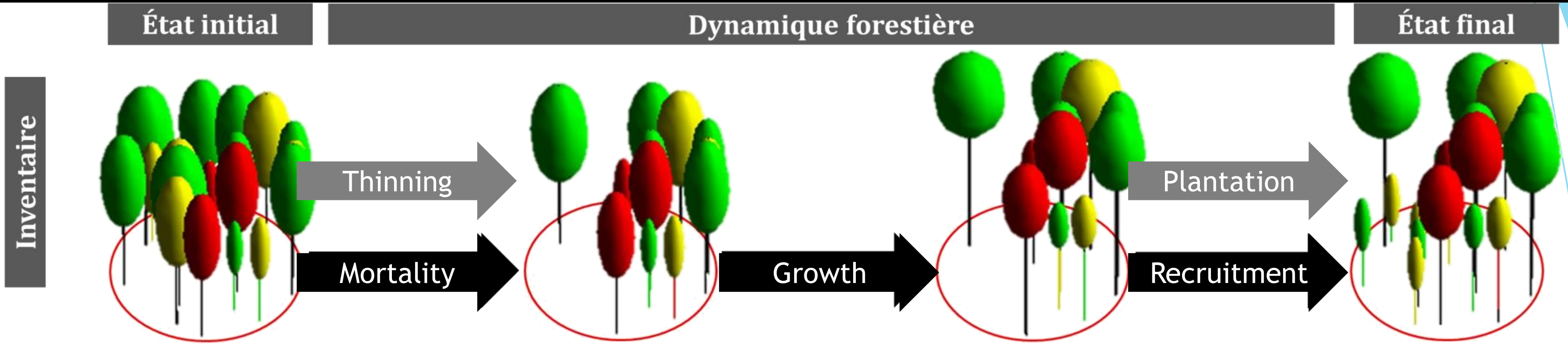
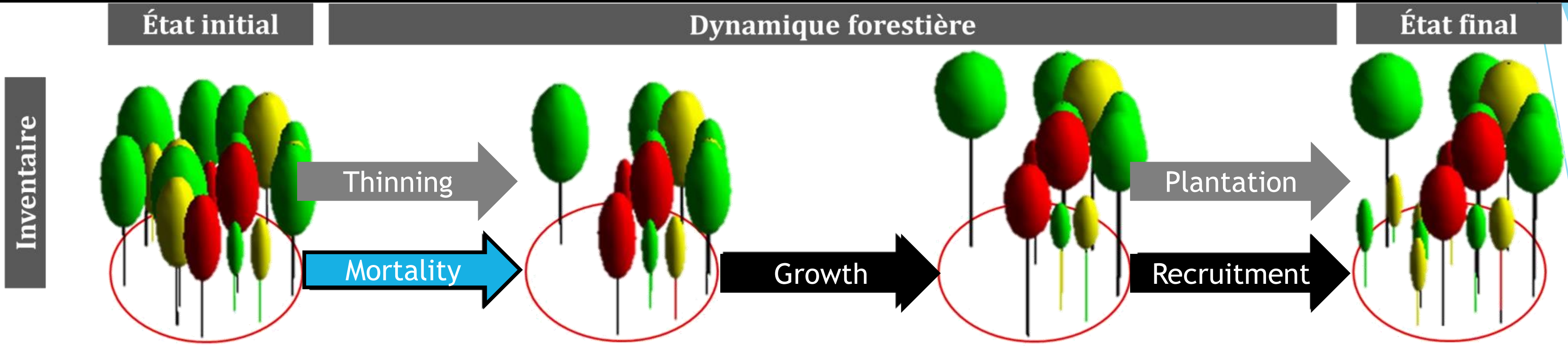


Schéma inspiré de Perin et al. 2018

Step 3 : Forest dynamic processes

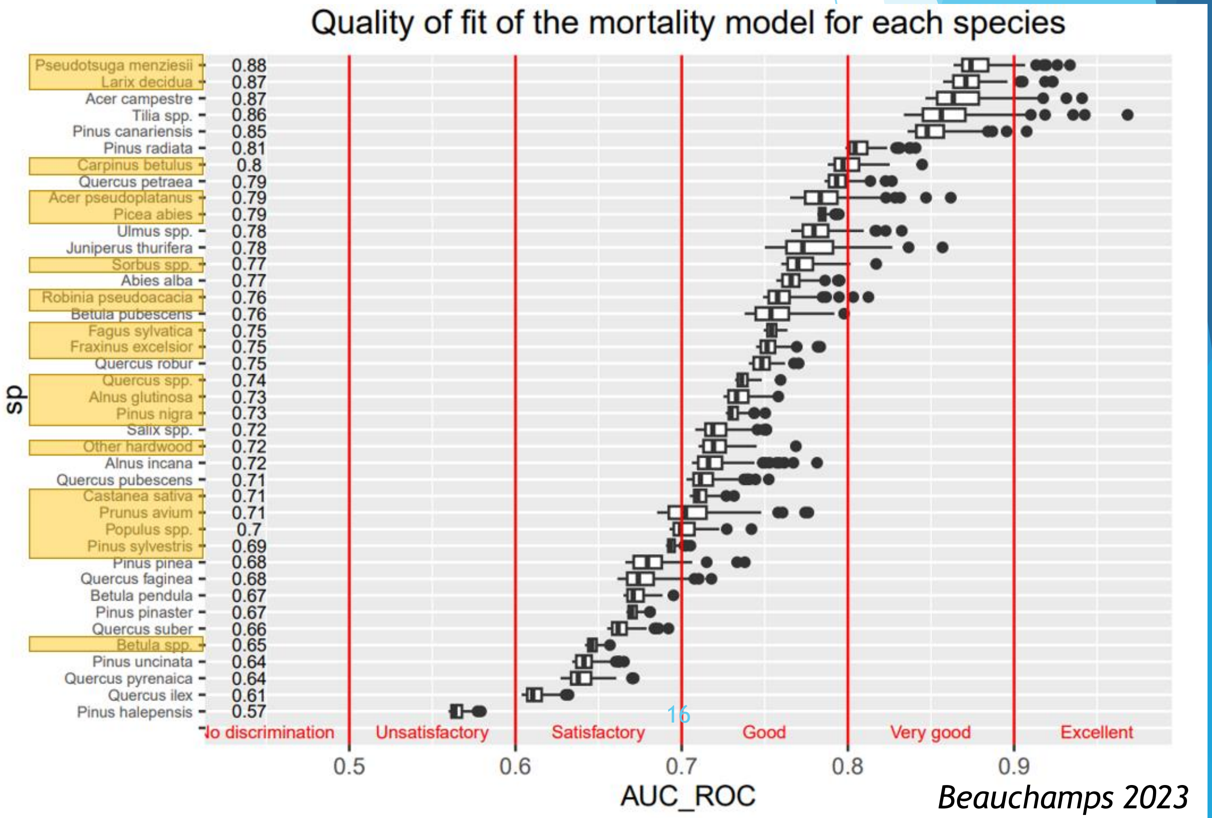


Mortality sub-model

- ➢ Also used in Samsara2
- ➢ From European NFI data

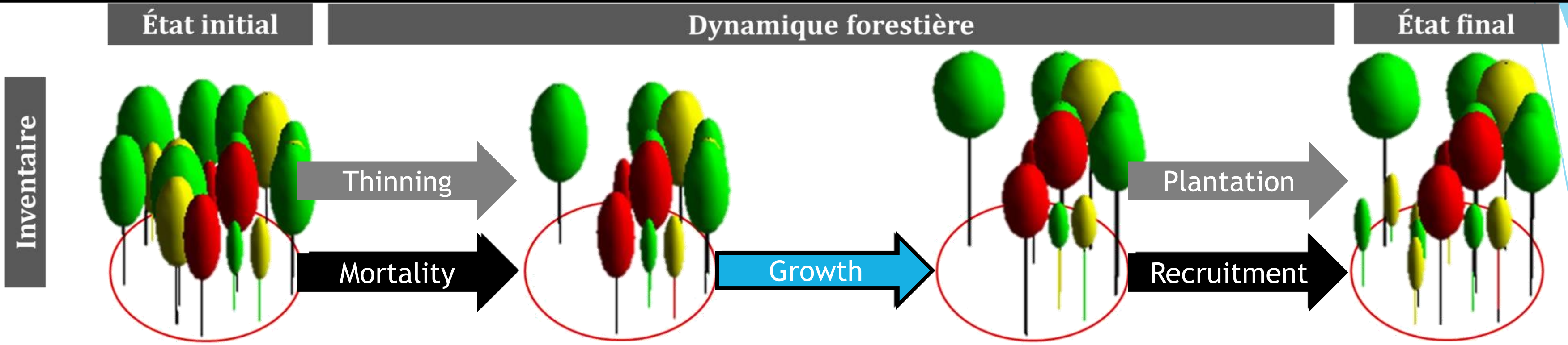
```
Predict_Survival <- function(dbh_mm, batot_m2, sgdd, aet2pet, dyears, params)
```

Deadwood decay sub-model



Beauchamps 2023

Step 3 : Forest dynamic processes



Growth sub-model

- From SIMREG model
- From Belgian NFI data

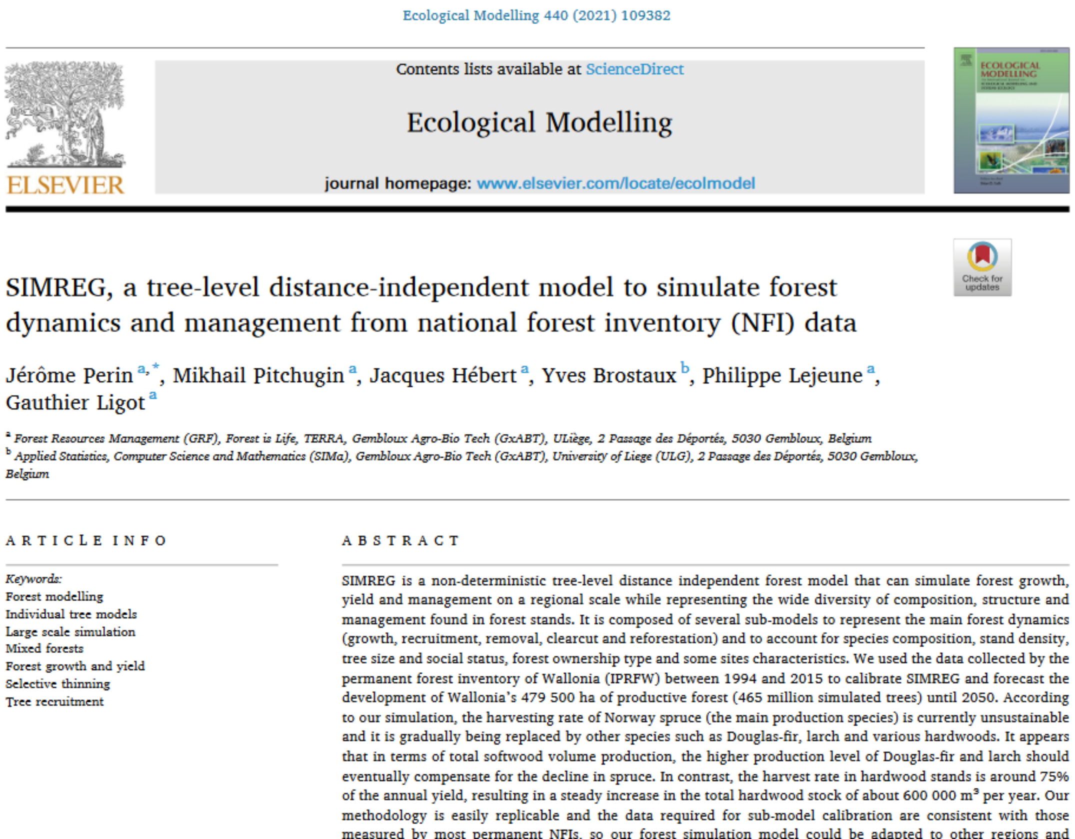
$$dG_i = 0.5 * P * \left(C_i - m * A + \sqrt{(m * A + C_i)^2 - 4 * A * C_i} \right)$$

Where:

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

$$P = Pa * exp(1 - Pb * Alt)$$

$$m = 1 + exp(ma - mb * Gha)$$


Ecological Modelling 440 (2021) 109382

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Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

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]

[a] Forest Resources Management (GRF), Forest is Life, TERRA, Gembloux Agro-Bio Tech (GxABT), ULiège, 2 Passage des Déportés, 5030 Gembloux, Belgium
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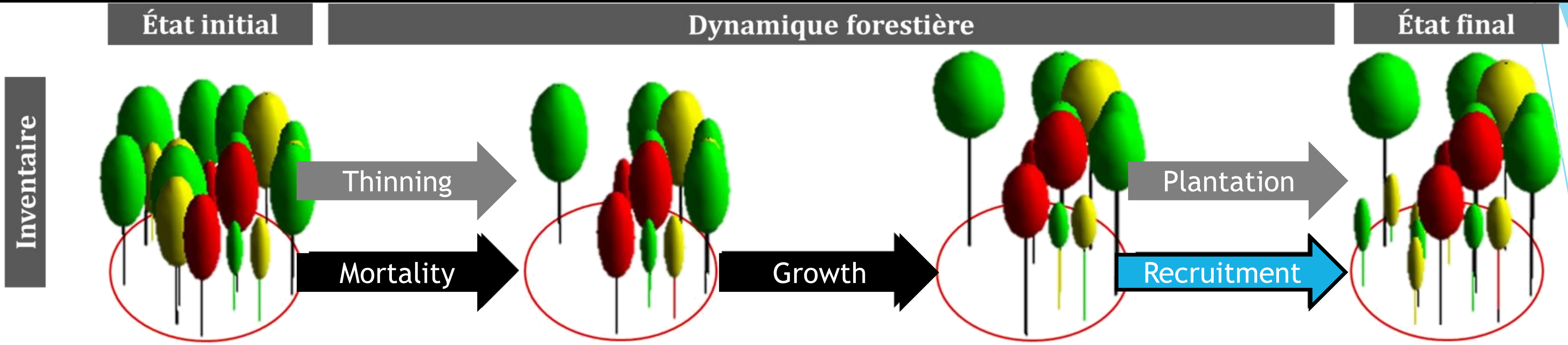
ARTICLE INFO

Keywords:
Forest modelling
Individual tree models
Large scale simulation
Mixed forests
Forest growth and yield
Selective thinning
Tree recruitment

ABSTRACT

SIMREG is a non-deterministic tree-level distance independent forest model that can simulate forest growth, yield and management on a regional scale while representing the wide diversity of composition, structure and management found in forest stands. It is composed of several sub-models to represent the main forest dynamics (growth, recruitment, removal, clearcut and reforestation) and to account for species composition, stand density, tree size and social status, forest ownership type and some sites characteristics. We used the data collected by the permanent forest inventory of Wallonia (IPRFW) between 1994 and 2015 to calibrate SIMREG and forecast the development of Wallonia's 479 500 ha of productive forest (465 million simulated trees) until 2050. According to our simulation, the harvesting rate of Norway spruce (the main production species) is currently unsustainable and it is gradually being replaced by other species such as Douglas-fir, larch and various hardwoods. It appears that in terms of total softwood volume production, the higher production level of Douglas-fir and larch should eventually compensate for the decline in spruce. In contrast, the harvest rate in hardwood stands is around 75% of the annual yield, resulting in a steady increase in the total hardwood stock of about 600 000 m^3 per year. Our methodology is easily replicable and the data required for sub-model calibration are consistent with those measured by most permanent NFIs, so our forest simulation model could be adapted to other regions and

Step 3 : Forest dynamic processes



Recruitment sub-model

- From SIMREG model
- From belgian NFI data

1. Recruitment density computation

$$Nha_{recrut} = 400 * exp(Yrecrut)/(1 + exp(Yrecrut))$$

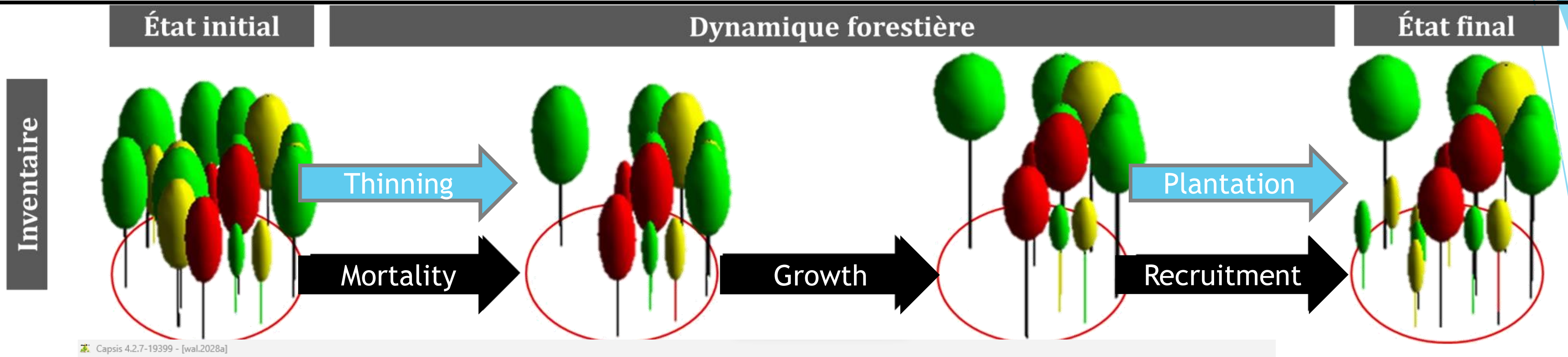
Where:

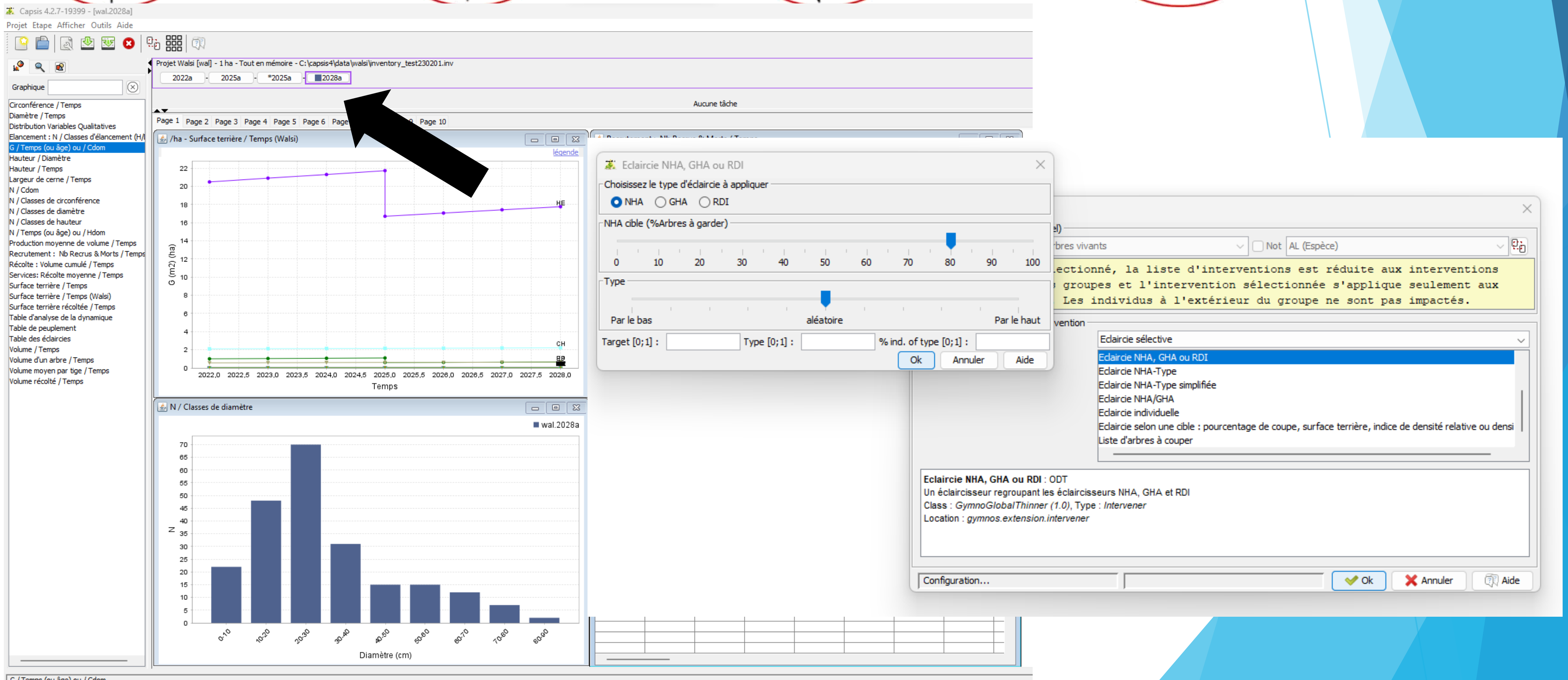
$$Yrecrut = f(RN * Gha + Cg + Cg^2 + CV)$$

2. Recruitment composition computation

	%	Recruitment composition Oak	Bee	Bir	Ash	Pop	Map	Hor	Ald	Rok	Hwc	Hwx	Spr	Dou	Spi	Lar	Bpi	Swx
Stand composition	Oak	7	28	11	5	0	9	22	0	1	2	8	7	0	0	0	0	0
	Bee	1	74	1	1	0	5	7	1	0	1	3	6	0	0	0	0	0
	Bir	9	12	28	5	0	6	6	4	1	2	16	9	0	0	2	0	0
	Ash	3	5	6	25	3	31	11	4	0	2	6	2	2	0	0	0	0
	Pop	7	4	1	28	0	19	0	20	0	7	11	4	0	0	0	0	0
	Map	2	12	2	15	0	44	7	2	1	4	7	2	1	1	0	0	0
	Hor	0	9	0	15	0	15	57	0	2	0	2	0	0	0	0	0	0
	Ald	0	10	3	28	0	23	0	21	0	0	3	12	0	0	0	0	0
	Rok	0	12	16	0	0	34	0	0	26	2	10	0	0	0	0	0	0
	Hwc	1	9	0	18	0	31	6	0	1	7	19	0	7	0	0	0	0
	Hwx	4	12	13	14	0	13	9	1	4	1	28	2	0	0	0	0	0
	Spr	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
	Spi	23	8	20	6	0	0	2	0	2	3	16	11	0	11	0	0	0
	Lar	8	5	11	1	0	6	4	0	0	5	7	24	13	0	15	0	0
	Bpi	12	0	0	7	0	0	0	0	0	0	81	0	0	0	0	0	0
	Swx	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60

Step 4 : Interveners for management at stand scale

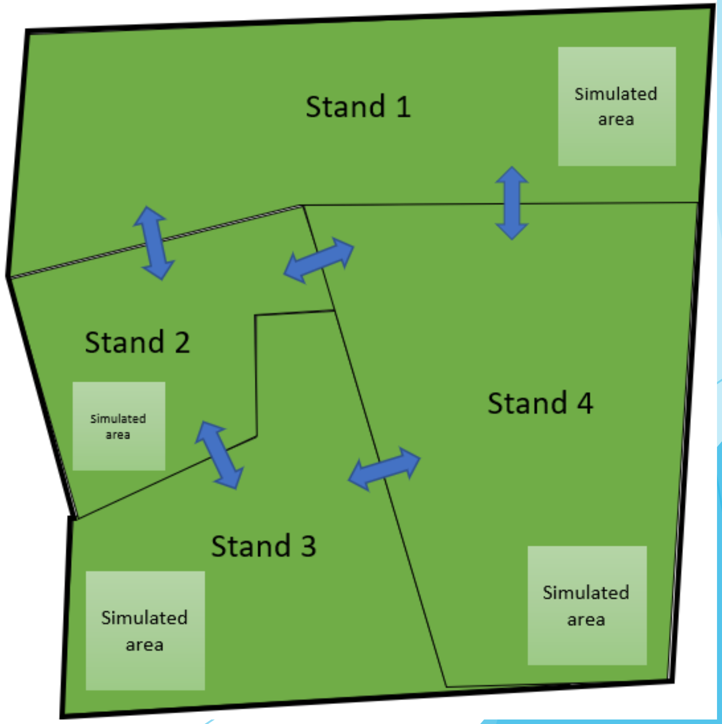




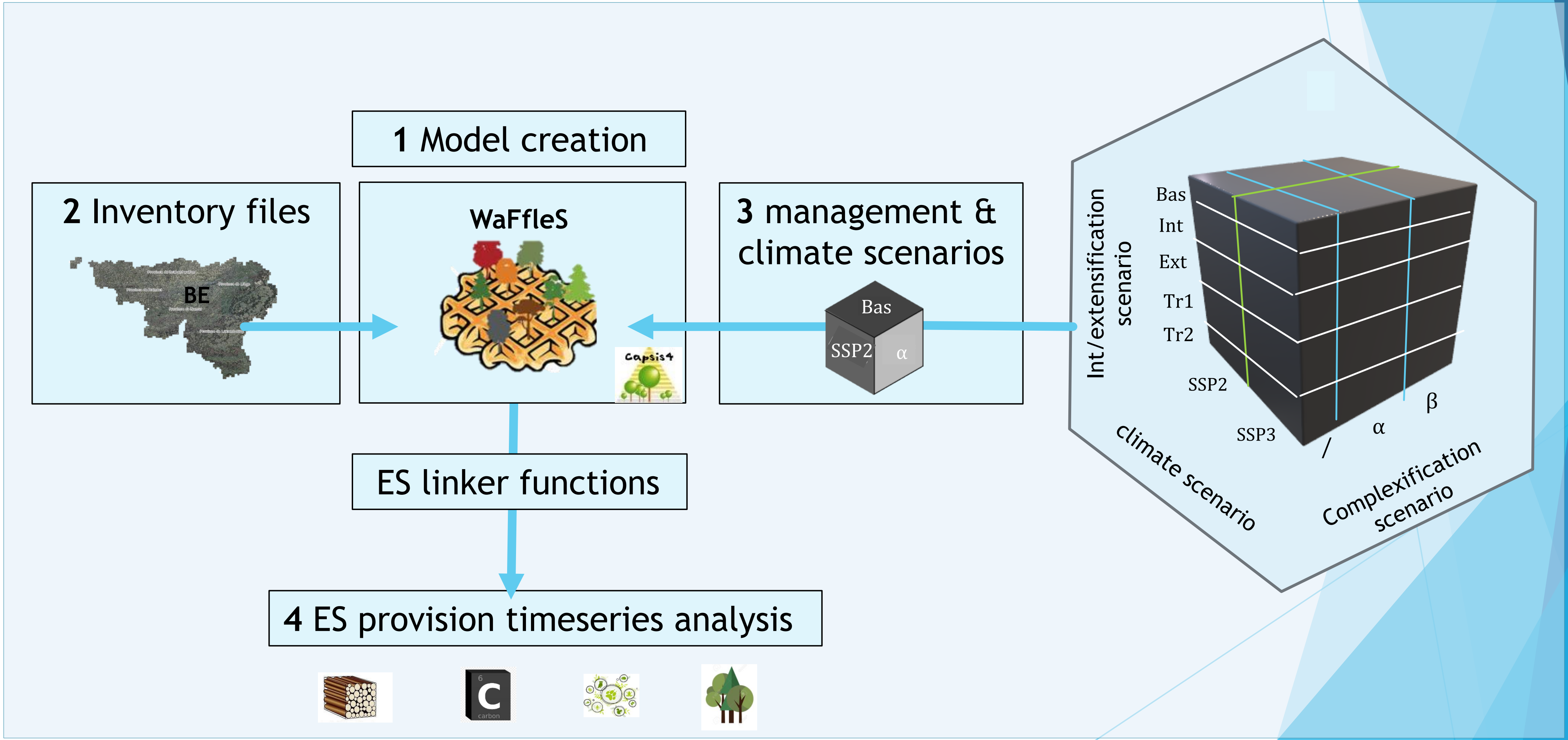
WaFfleS and Walsi : two different model

WaFfleS

- In WaFfleS :
  - Stands are spatialized
  - Stands interacts (recruitment process)
  - A simulated area is used
  - We need to find solution for large scale management



Managing the forest at multiple scales as a way to enhance forest resilience to drought and multifunctionnality : Are intensification, extensification and complexification strategies relevant ?

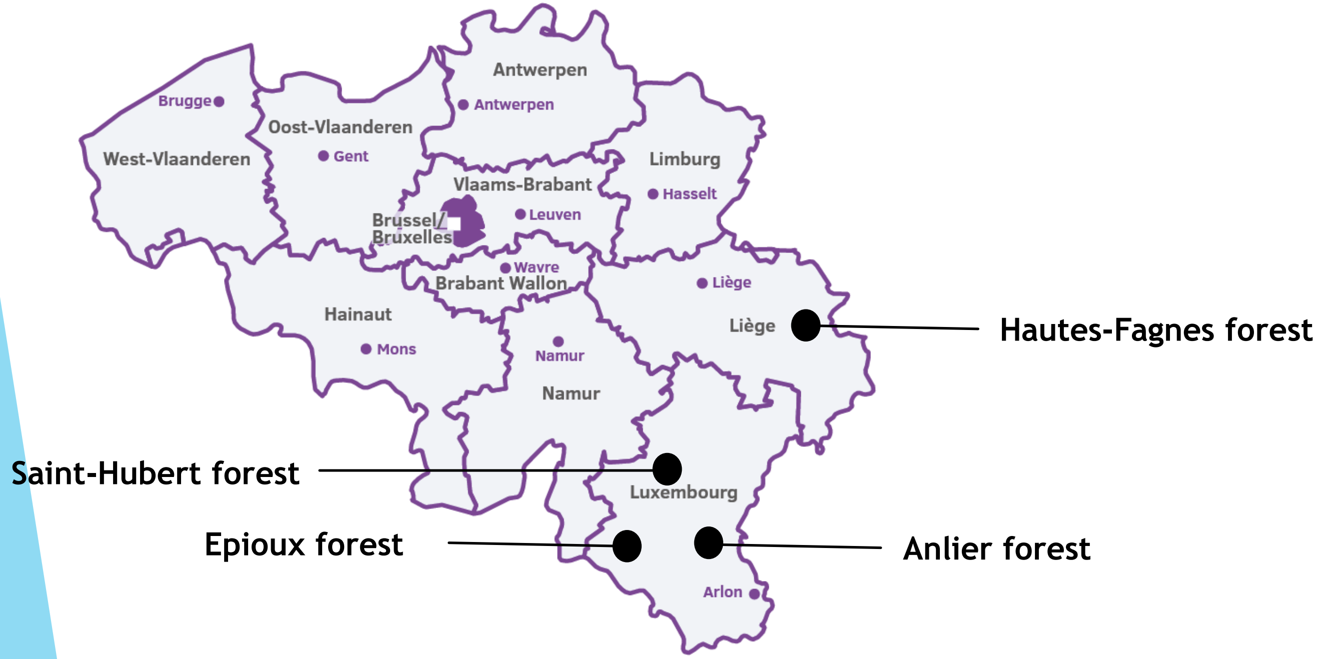


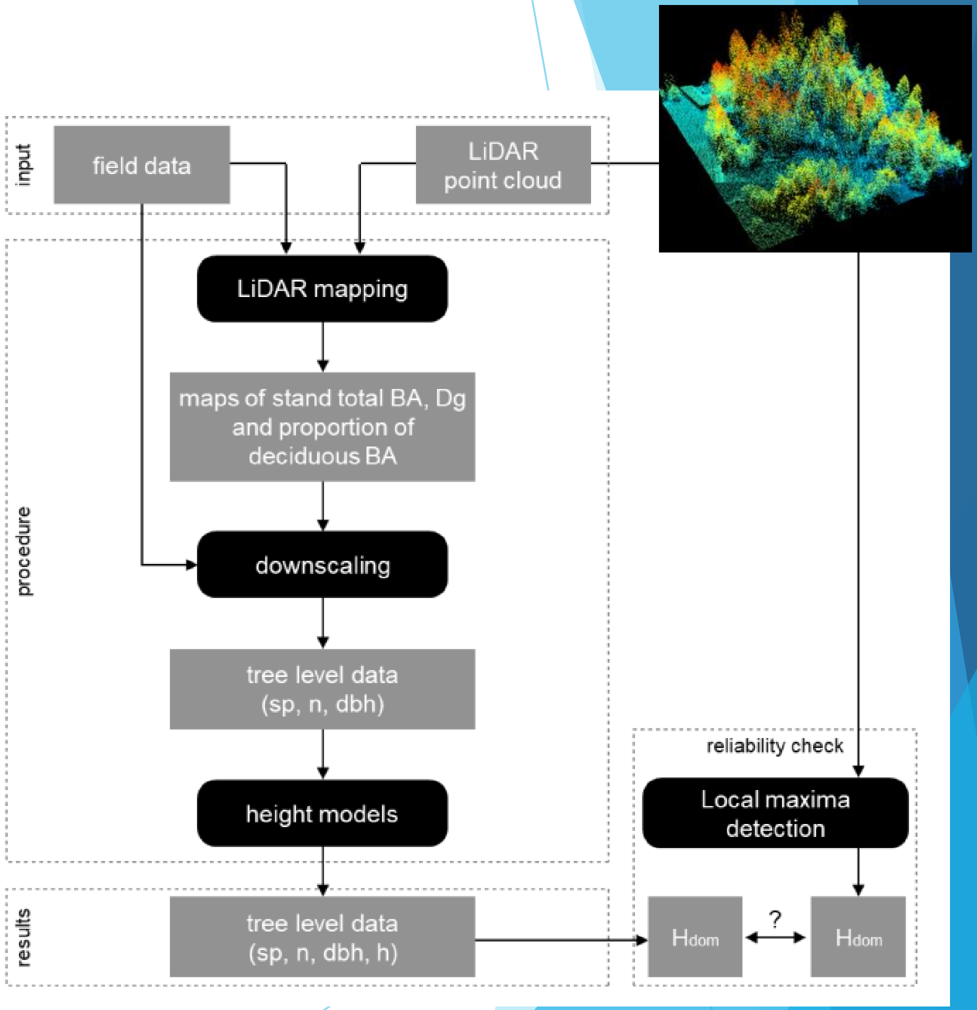
2 Inventory files

The methodology to gather data at large scale still need to be define.

- Full inventory
- Samples methodology
- Airborne laser scanning (ALS)

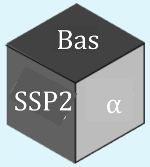
Public forests only





Processing chain to reconstitute tree characteristics for large areas (Vallet et al. 2023)

3 management & climate scenarios



We will investigate intensification / extensification and complexification strategies at stand and forest scales

Intensification	Reduce minimum cutting diameter Increase thinning intensity	Increase proportion of managed area
Extensification	Increase minimum cutting diameter Decrease thinning intensity	Decrease the proportion of managed area
Complexification	Increase alpha diversity	Increase beta diversity

- We will test 5 mixed intensification /extensification scenarios

Scenario type	Stand scale	Forest scale
Baseline	S-Baseline	F-Baseline
Intensification	SI	FI
Extensification	SE	FE
Trade-off 1	SE	FI
Trade-off 2	SI	FE

Legend
S : “stand”
F : “forest”

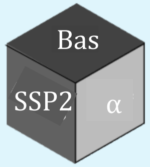
I : “intensification”
E : “extensification”

I-MAESTRO

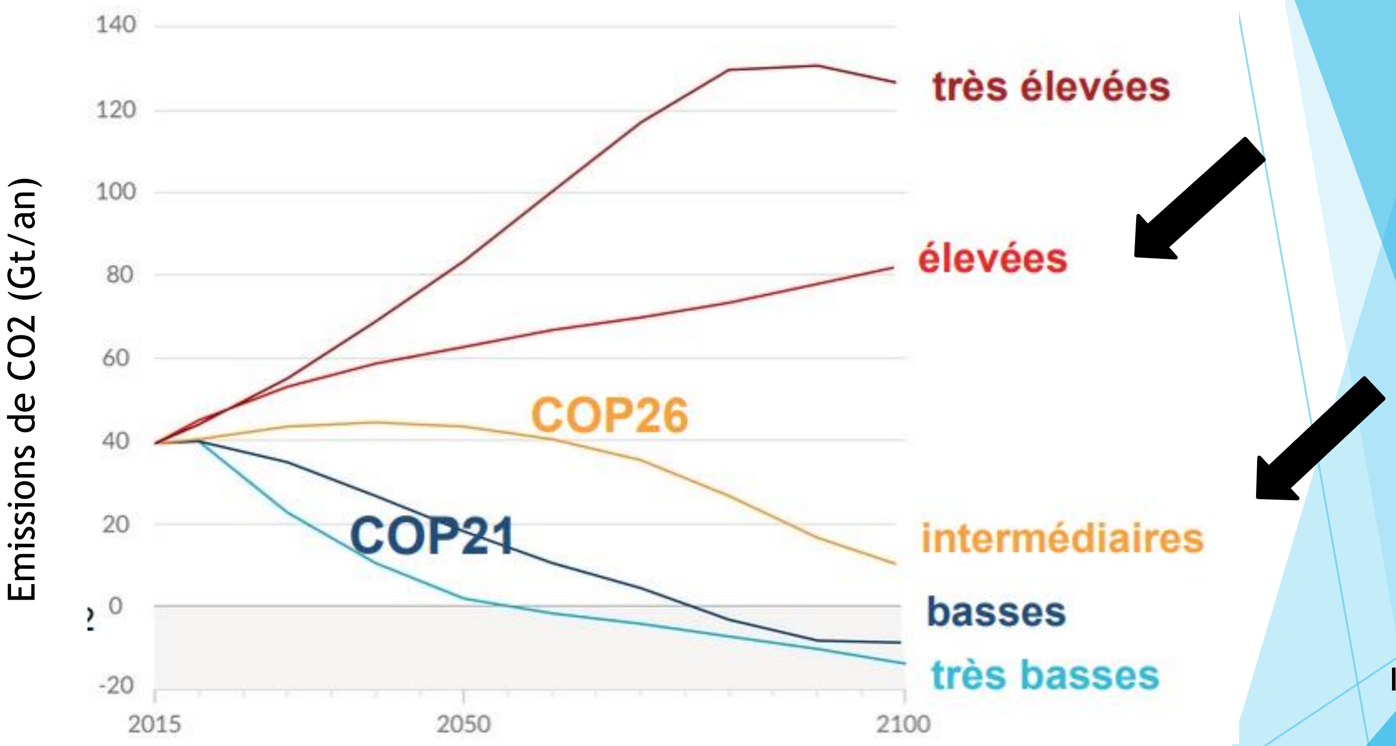
- We will test 5 mixed intensification /extensification scenarios x 3 complexification scenarios

Scenario type	Stand scale	Forest scale	Enhance Complexity 1	2	3
Baseline	S-Baseline	F-Baseline	No	α	β
Intensification	SI	FI	No	α	β
Extensification	SE	FE	No	α	β
Trade-off 1	SE	FI	No	α	β
Trade-off 2	SI	FE	No	α	β

3 management & climate scenarios



- Two climate scenario will be explore
- Focus on drought issue



IPCC 2021

4 ES linker functions

WaFfleS

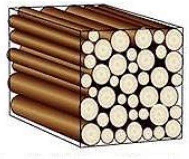
IN/OUTput WaFfleS :

- Espèce
- Classes de circonférence
- Nombre de tiges

→

- Calcul volume
- Calcul surface terrière
- Calcul hauteur
- Taux de conversion carbone

→



Volume récolté [m^3/ha/an]
Volume récolté par essence [m^3/ha/an]
Volume récolté par essence et par classe de circonférence [m^3/ha/an]

Augmentation de la surface terrière [m^2/ha/an]
Augmentation de la surface terrière par essence [m^2/ha/an]
Augmentation de la surface terrière par essence et par classe de circonférence [m^2/ha/an]

Stock de carbone sur pied : biomasse aérienne et souterraine [T/ha]
Stock de carbone exporté [T/ha] -> C.A.T

Volume de bois mort [m^2/ha]
Diversité de bois morts
Nombre de très gros bois vivants [n/Ha]

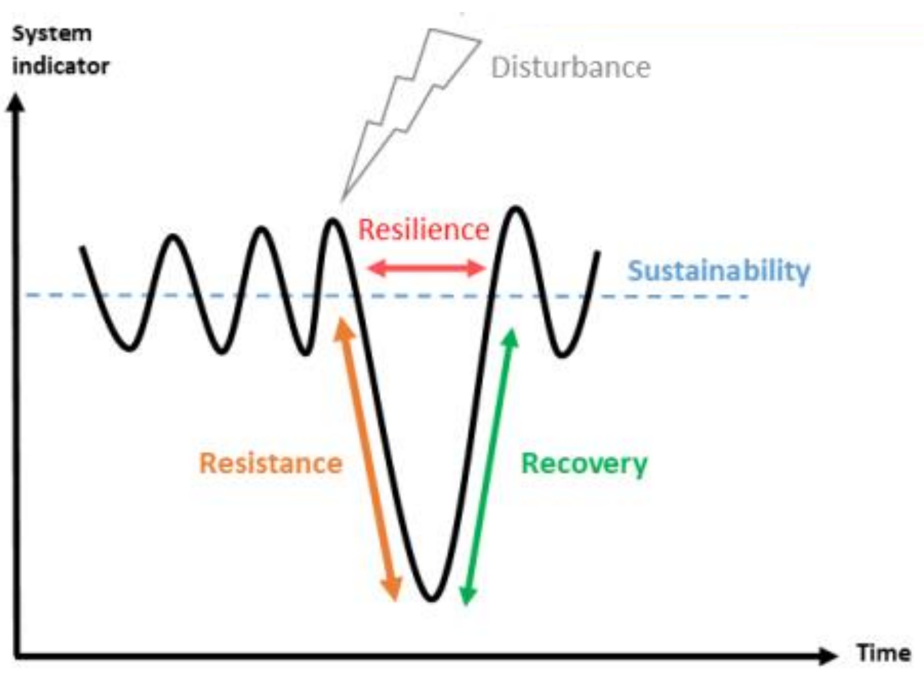
Indices de diversité spécifique :
- Richesse en espèce
- Indice de Shannon
- Indice de dominance de Simpson

Diversité structurelle :
- Indice de Shannon
- Indice de Gini

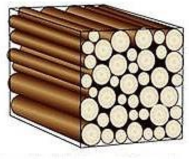
Indice de diversité du paysage

4 ES linker functions

WaFfleS



Niimmo et al. 2017



Volume récolté [m^3/ha/an]
Volume récolté par essence [m^3/ha/an]
Volume récolté par essence et par classe de circonférence [m^3/ha/an]

Augmentation de la surface terrière [m^2/ha/an]
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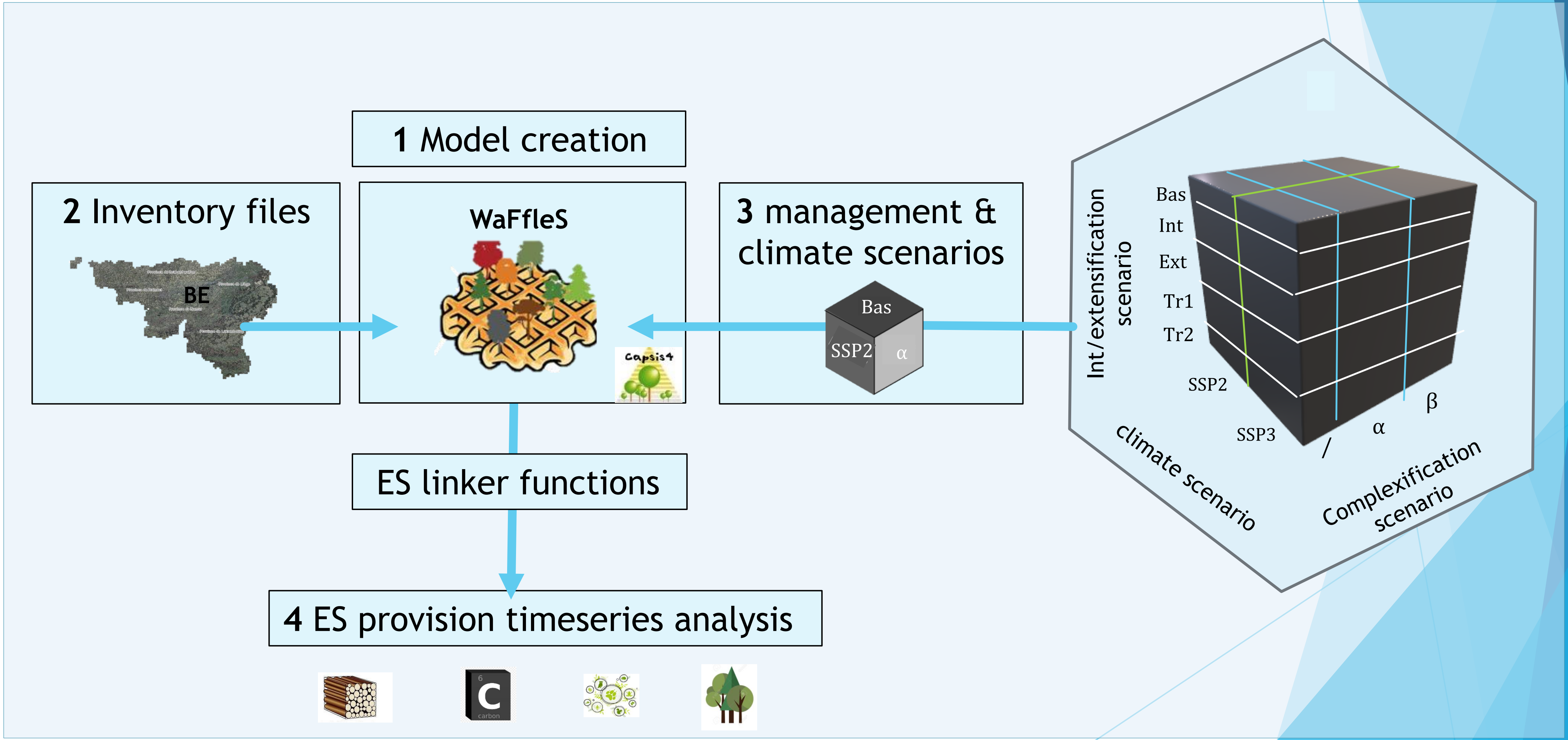


Thank you for your attention
Contact : v.vankeymeulen@uliege.be

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