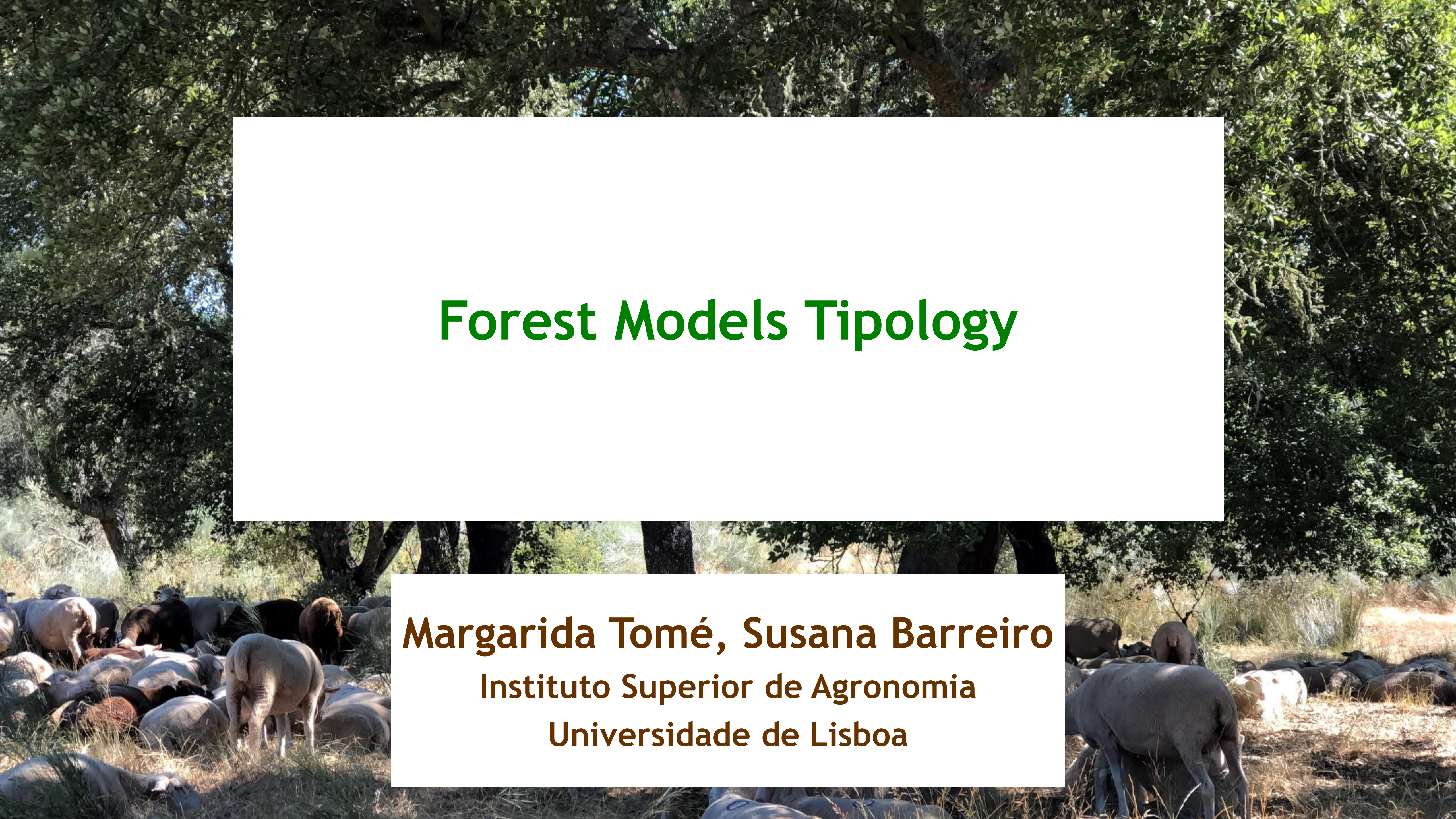

Forest Models Tipology

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▪Summary

- Forest growth models evolution
- Typology of forest growth models
  - ✓ Classification based on the **essence of the growth module** (empirical, process-based,…)
  - ✓ Classification based on the **unit of simulation** (individual tree, stand,…)
  - ✓ Classification based on the “**variability of outputs**” (deterministic, stochastic…)

- **Forest growth models evolution**

Forestry and forest management evolution

+

Increased knowledge about ecosystems functioning

+

Technology development

+

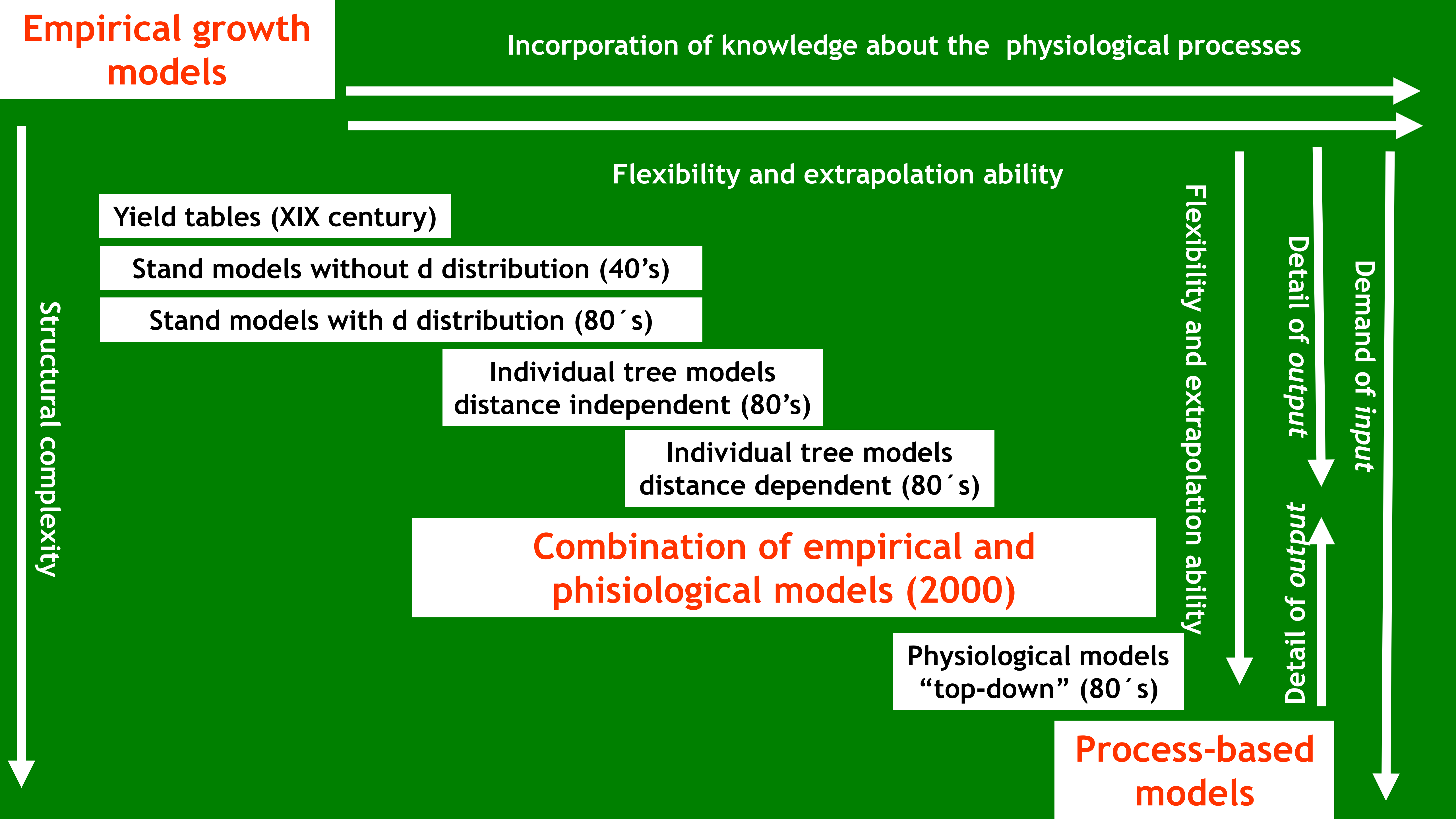
Climate change

+

Change in society requirements from forests

↓

EVOLUTION OF FOREST GROWTH MODELS



Empirical growth models
Incorporation of knowledge about the physiological processes
Flexibility and extrapolation ability
Yield tables (XIX century)
Stand models without d distribution (40’s)
Stand models with d distribution (80´s)
Individual tree models distance independent (80’s)
Individual tree models distance dependent (80´s)
Combination of empirical and phisiological models (2000)
Physiological models “top-down” (80´s)
Process-based models
Structural complexity
Flexibility and extrapolation ability
Detail of *output*
Detail of *output*
Demand of *input*

- **Typology of forest growth models**

Forest growth models

Classification according to the growth module
(to be used in practice all models need a static module)

- Empirical growth and yield models
- Semi-empirical models (LUE)
  - 3PG
  - YieldSAFE
  - ---
- Process based models

▪Statistical FGMs (empirical G&Y)

- ✓ Developed using statistical techniques and calibrated for large data-sets
- ✓ The site index (hdom at a given base-age) is often used as a proxy for environmental conditions
- ✓ Growth is usually modeled with the so-called growth functions
- ✓ Adequately describe growth for a range of silvicultural practices and site conditions
- ✓ Some are able to predict wood quality properties
- ✓ Exist for all of the most important forest types in Europe and most of them have been extensively validated
- ✓ Do not allow for the simulation of forest growth under a changing environment or subject to novel silvicultural practices

The G&Y model GLOBULUS (empirical)

Table 1. Site Index and dominant height projection functions.

Site Index and Dominant height

(1) SI =

model
(1) and (2)

Where SI is the si
(tp=10 for eucalypt
2 represent the ins

Table 2. Basal area: initialization function (1) and growth projection function (2).

Basal Area

$$(1)\ G = A_G\ e^{-k_G \left(\frac{1}{t}\right)\left(n_{Gp} +\right.}$$

$$A_G = (a_{G0} + a_{G1}\ DR)$$

$$n_{Gp} = n_{G0} + \frac{n_{G1}}{\left(1 - \left(\frac{cota}{2000}\right.\right.}$$

model	a_{G0}	a_{G1}	k_{G0}
(1)	80.1683	0.2354	8.8294
(2)	80.1683	0.2354	-

Where G is the stand basal area; t
Symbols); SI is the site index; Cota
stand rotation (0 for planted and 1 f
time.

Table 3. Functions to predict the evolution of the number of trees, stumps and shoots

Density and/or Mortality

Planted Stands:

$$(1)\ N = Npl\ e^{-am\ t}$$

$$(2)\ N_2 = N_1\ e^{-am\ (t_2 - t_1)}$$

Coppice Stands:

$$(3)\ N_{stools} = N_{harv}\ (1 - dea$$

$$(4)\ N_{stools\ 2} = N_{stools\ 1}\ e^{-a}$$

$$(5)\ N_{sprouts\ t \le 2} = N_{stools}$$

$$(6)\ N_{sprouts\ t=3} = \frac{}{1 - e^{-\left(am\right.}}$$

If there is any kind of sprouts selecti
=1.6

Table 4. Volume initialization function (1) and Volume projection function (2),

Volume Total

$$(1)\ V_i = Kv\ \ t^{a}\ hdo$$

$$(2)\ V_{i2} = V_{i1} \left(\frac{t_2}{t_1}\right)^{a} \left(\frac{h}{h}\right.$$

model	a
(1) Vu	-0.0510
(2) Vu	-0.0511
(1) Vb	-0.0548
(2) Vb	-0.0548
(1) V_st	-0.0821
(2) V_st	-0.0821

Where Vi represents the

Table 6. Biomass prediction functions

Biomass

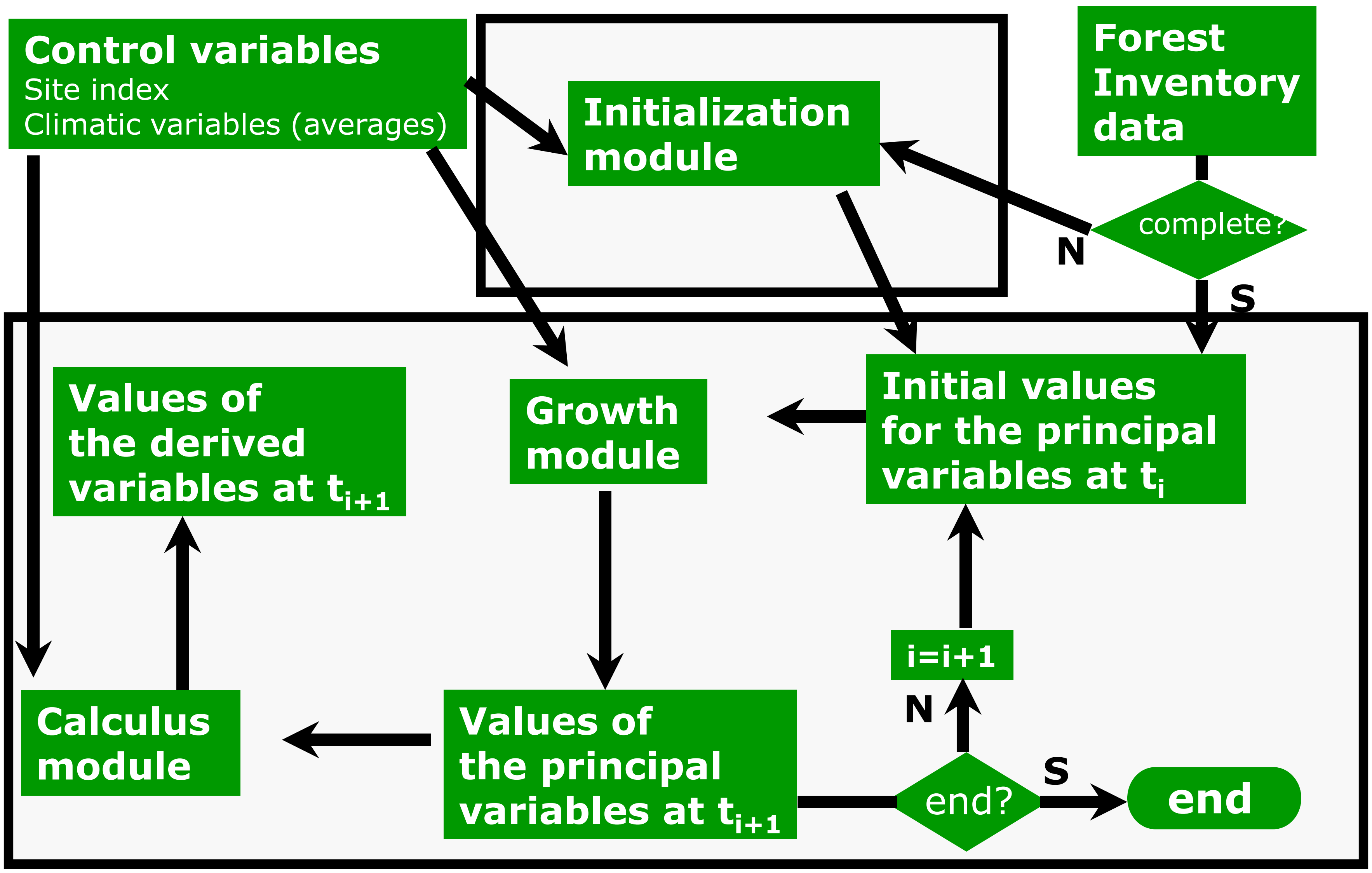
$$W_i = a\ G^{b}\ hdom^{c} \qquad b = b_0 + b_1\ rot + b_2 \left(\frac{N}{1000}\right) + b_3 \left(\frac{SI}{1000}\right) + b_4 \left(\frac{t}{1000}\right)$$

$$W_a = W_w + W_b + W_l + W_{br} \qquad W_r = a\ W_a \qquad W_t = W_a + W_r$$

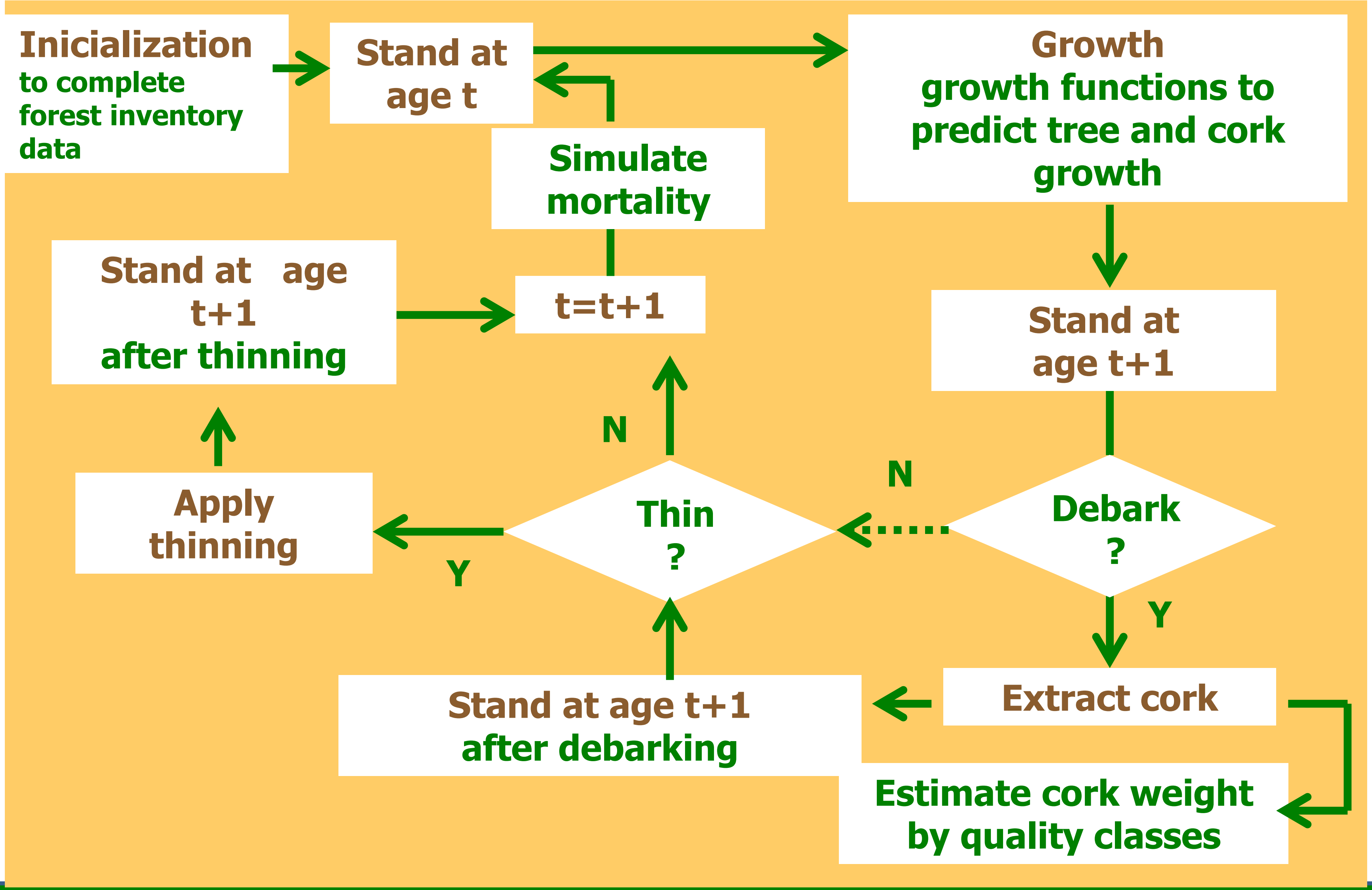
model	a	b_0	b_1	b_2	b_3	b_4	c
W_w	0.0967	1.0547	-0.0018	-0.0065	-0.5198	-1.2105	1.1886
W_b	0.03636	1.1691	-0.0083	-0.0459	3.2289	2.0880	0.6710
W_l	1.0440	1.0971	-	-0.0112	-1.2207	-6.2807	-0.3129
W_{br}	0.3972	1.0005	-	-0.0192	3.3170	-1.2747	-0.0160
W_r	0.2487	-	-	-	-	-	-

Where Wi represents the following biomass components: Ww is the biomass of wood, Wb is the biomass of bark, Wbr is the biomass of branches and Wl is the biomass of leaves; Wa is the ttotal aboveground biomass; Wr is the biomass of roots;hdom is the stand dominant height; G is the stand basal area; SI is the site index; rot is the stand rotation (0 for planted and 1 for coppice stands); N is the stand density and

GLOBULUS - structure



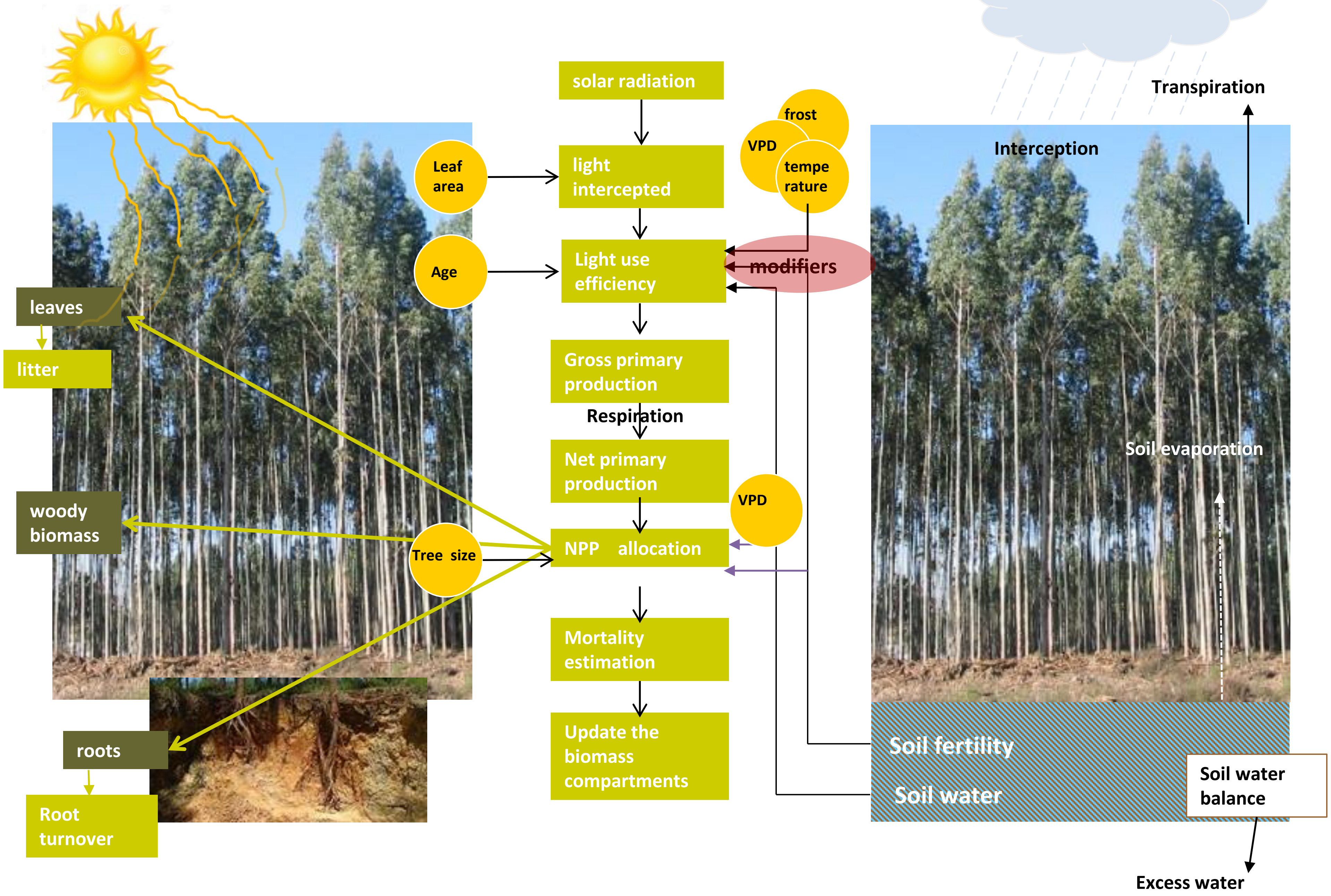
SUBER model - structure



Process-based ecophysiological models

- Developed to understand forest behavior from a description of plant-soil and carbon-nutrient-water interactions
- Allow the simulation of forest growth under a changing environment or subject to novel silvicultural practices
- The principal variables are biomass pools per tree component (leaves, branches, roots, wood)
- A specific problem with this type of model is the need for detailed input, demanding data which are rarely available at regional or lower levels
- Do not give all the output needed for forest management (but it can be easily added)

3PG model structure



Growth modifiers in 3PG

- Each environmental factor is represented by a growth modifier or function of the factor that varies between 0 (total limitation) and 1 (no limitation)

Factor	Modifier	Parameters
Vapor pressure deficit	$f_{VPD}(D)$	k_D
Soil water	$f_{SW}(\theta)$	θ_{max}, c_θ, n_θ
Temperature	$f_T(T_{av})$	T_{min}, T_{opt}, T_{max}
Frost	$f_F(d_f)$	k_F
Site nutrition	$f_N(FR)$	f_{N0}
Stand age	$f_{age}(t)$	n_{age}, r_{age}

An example: temperature growth modifier $f_T(T)$

$$f_T(T) = \left(\frac{T - T_{min}}{T_{opt} - T_{min}}\right)\left(\frac{T_{max} - T}{T_{max} - T_{opt}}\right)^{(T_{max} - T_{opt})/(T_{opt} - T_{min})}$$

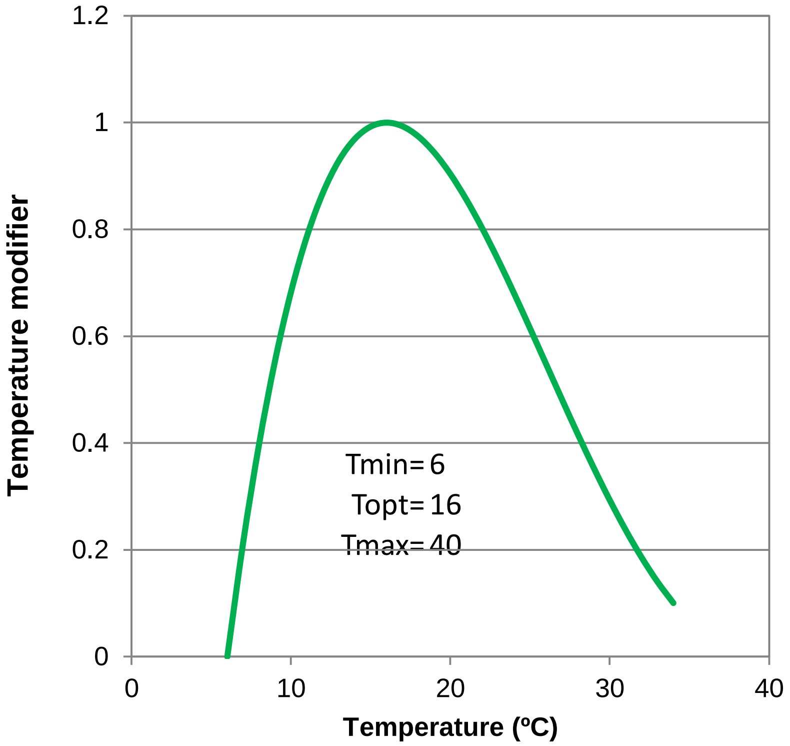
where

T = mean monthly daily temperature

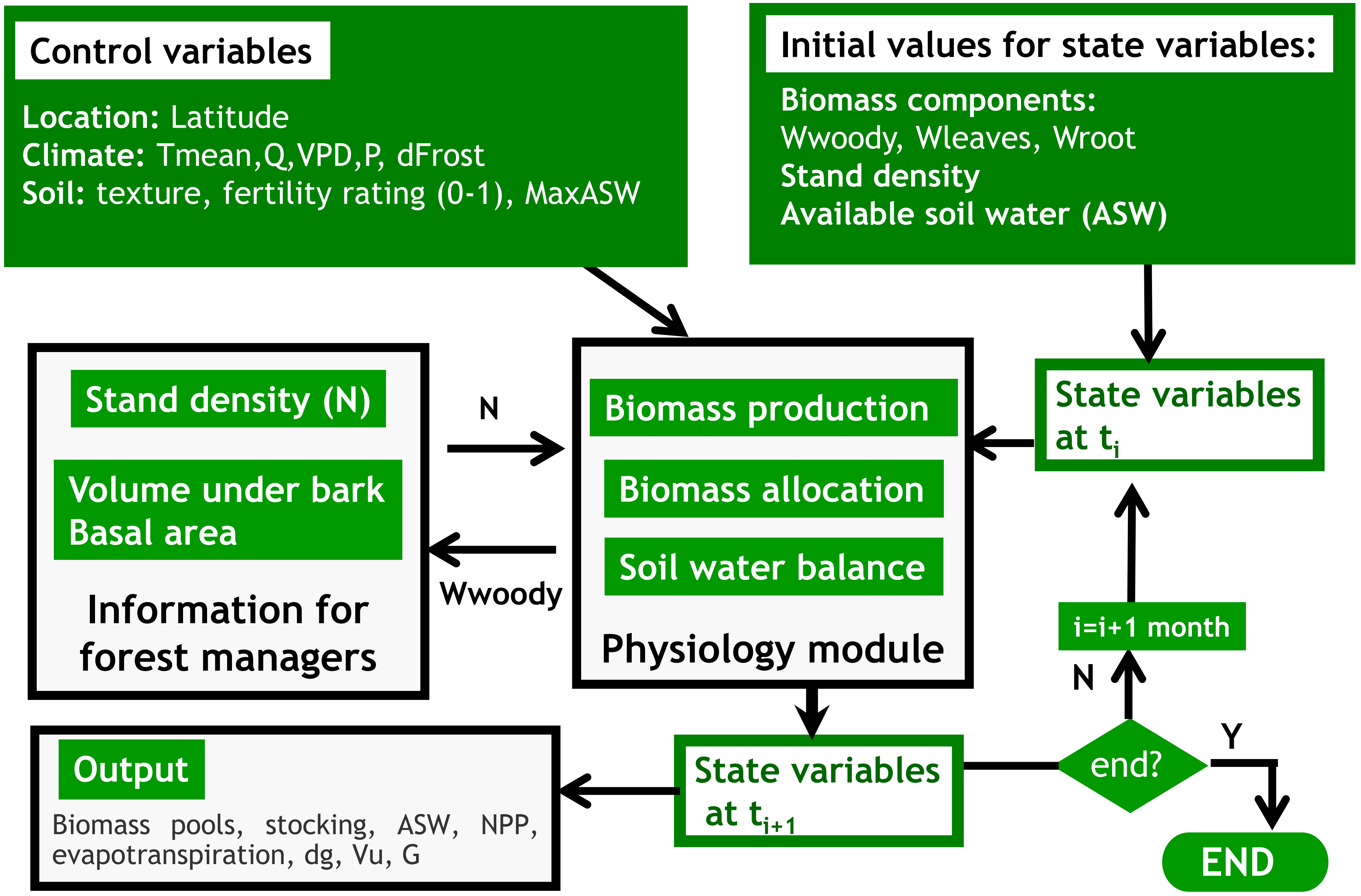
T_{min} = minimum temperature for growth

T_{opt} = optimum temperature for growth

T_{max} = maximum temperature for growth



3PG structure



Hybridization

- Combination of different types of models/modelling methodologies, usually:
  - ➔ A process-based model (preferably not excessively input demanding) that:
    - is able to reflect the effect of climate changes
    - as well as the effect of management practices such as fertilization, irrigation, weeding ...
    - or the impact of pests and diseases
  - ➔ With empirical functions in order to obtain the same output as traditional growth and yield models (usually more detailed in what concerns stand and tree variables)

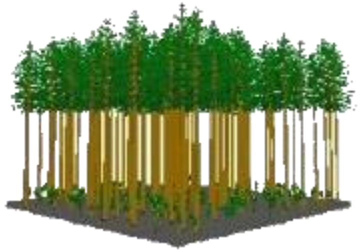
Forest growth models

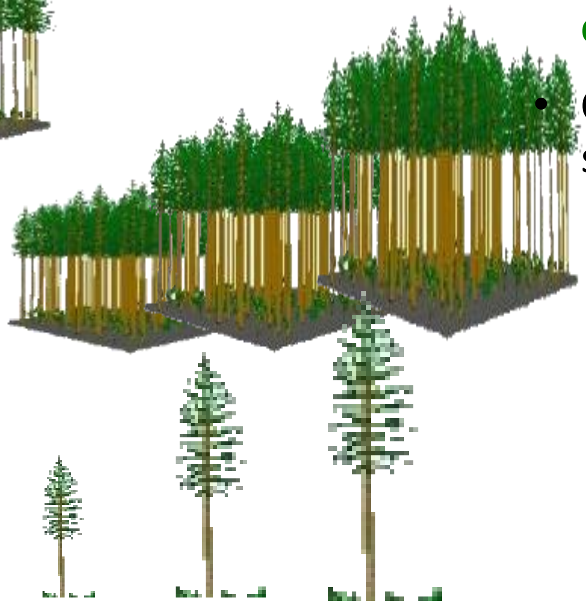
Classification according to the unit of simulation (growth module)

- Stand models
- Stand models with simulation of the diameter distribution
- Individual tree models

Stand Model

- **Principal variables**:
  stand variables (all)
- **Competition**:
  stand density measures



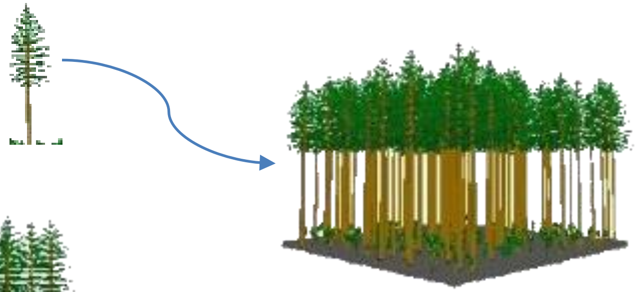


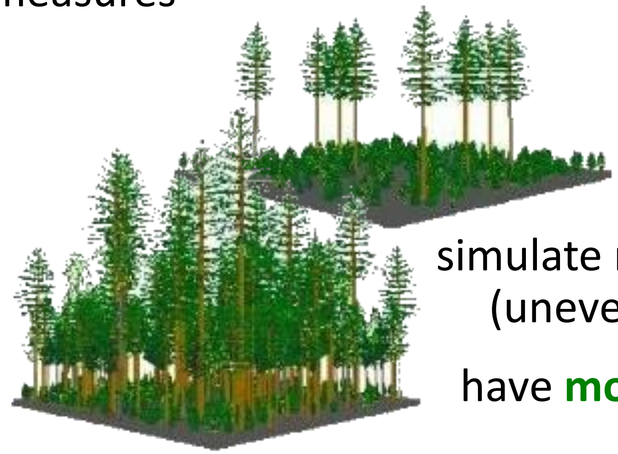
Stand Model *with* Diameter Distribution

- **Principal variables**:
  stand variables
  (including the variables
  needed to simulate
  diameter distribution)
- **Volume and biomass computed from the dd**
- **Competition**:
  stand density measures

Individual Tree Model

- **Principal variables**:
  tree variables (except hdom)
- **Competition (inter-tree)**:
  - competition indices
  - light interception modules





simulate more **complex structures**
(uneven-aged, mixed-stands)

have **more extrapolation ability**

▪Requirements from forest models - moving

FROM	TO
✓ Stand models	✓ Individual tree models
✓ Empirical models	✓ Process based models
✓ Stand simulators	✓ Management unit simulators
✓ Simple structure forests	✓ Complex forests (uneven and mixed)
✓ Focusing just trees	✓ Focusing other ecosystem components (e.g shrubs, soils)
✓ Simple output, mainly traditional stand variables and volume harvested	✓ Diversified outpus, including social, economic and ecological indicators

Life is not easy for growth modelers!!

▪Deterministic *versus* stochastic models

- ✓ Provide an estimation of the expected growth in a stand, for certain initial conditions
- ✓ For the same initial conditions, the models always provides the same prediction

- ✓ Try to simulate the variation from the real world
- ✓ For the same initial conditions provides different predictions (as a function of its probability of occurence)
- ✓ Gives additional information on the variability observed in growth

The two types of models can be combined in the same simulator