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GLOBULUS 2.1 model

BRIEF DESCRIPTION & EQUATIONS

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Globulus 2.1 Model

Background Introduction

GLOBULUS 2.1 represents a perfected version of GLOBULUS 2.0 model. GLOBULUS is a whole stand model developed for even-aged eucalyptus plantations in Portugal. The 2.1 version was developed under the scope of a PRAXIS project reference PRAXIS/3/3.2/PAPEL/2323/95 (LCA – from eucalypt to paper). When compared to previous versions, the GLOBULUS 2.1 model has the following improvements:

- relies on a homogeneous classification of the country based on climatic regions (Ribeiro e Tomé, 2000)
- developed using a reasonable data coverage for all the considered homogenious regions except for 1sr rotation data in the North Litoral region.
- an analysis to assess the need for parameterizing the different regions and rotations was carries out.
- a methodology to obtain initialization and prediction compatible basal area models (dbh>5 cm) was developed.
- a methodology to obtain initialization and prediction compatible stand volume models (over- and under-bark) were developed, also compatible with the basal area and dominant height models.
- merchantable (over- and under-bark) volume models were also developed considering top diameters from 5 to 10 cm
- the productivity variability of eucalyptus stands for each particular region and for Portugal as a whole was analyzed according to 5 site index classes: very high, high, medium, low, very low.
- a methodology was developed that enables the number of trees at planting as well as the number of trees after shoots selection in the basal area prediction model to be replaced by the number of living trees at any given stand age. This will allow correcting the basal area predictions in stands with high mortality.
- an improved mortality model including site index, stand density and region as predictive variables was developed.
- a system of equations for total stand biomass and stand biomass by tree component was developed.
- based on the biomass estimates and on the chemical composition data published by Pereira et al. (1988), carbon and other macronutrients' estimates (N, P, K e Ca) estimates by biomass component are available.

Model Description

GLOBULUS 2.1 comprises a range of state and control variables (**Table 1**). One of the control variables is the climatic region that reflects different growth for different soil and climatic conditions. To enalble the model to take this into account, the country was ranked into eight homogeneous regions. **Figure 1** represents the regions resulting from the ranking of the municipalities into edapho-climatic homogeneous regions.

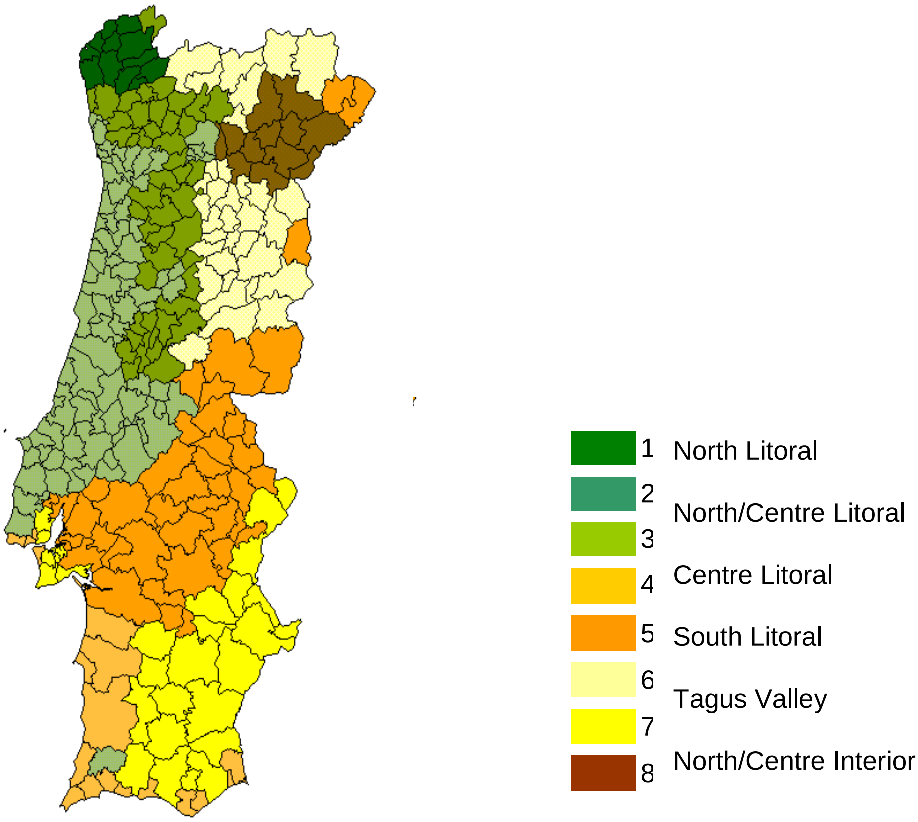

Figure 1. Map containing the distribution of the 8 edapho-climatic homogeneous regions.

The model has an initialization and a prediction module. The prediction module is built by a set of growth functions (e.g. dominant height, basal area) formulated as difference equations that predict the value of a particular state variable in instant t_2 (principal variables) as a function of the values of state variables in instant t_1 as well as of control variables. Additionally, the model integrates a range of other equations that allow estimating the values of derived variables based on the values of other variables in the same instant in time (e.g. merchantable volume, biomass).
The prediction of growth for a stand that has forest inventory data available only requires the prediction module to be used. On the other hand, growth simulation of stands that have been harvested or of new plantations require que use of the initialization module to set the initial conditions based on the control variables. The models can be found in **Tables 2** to **10**.

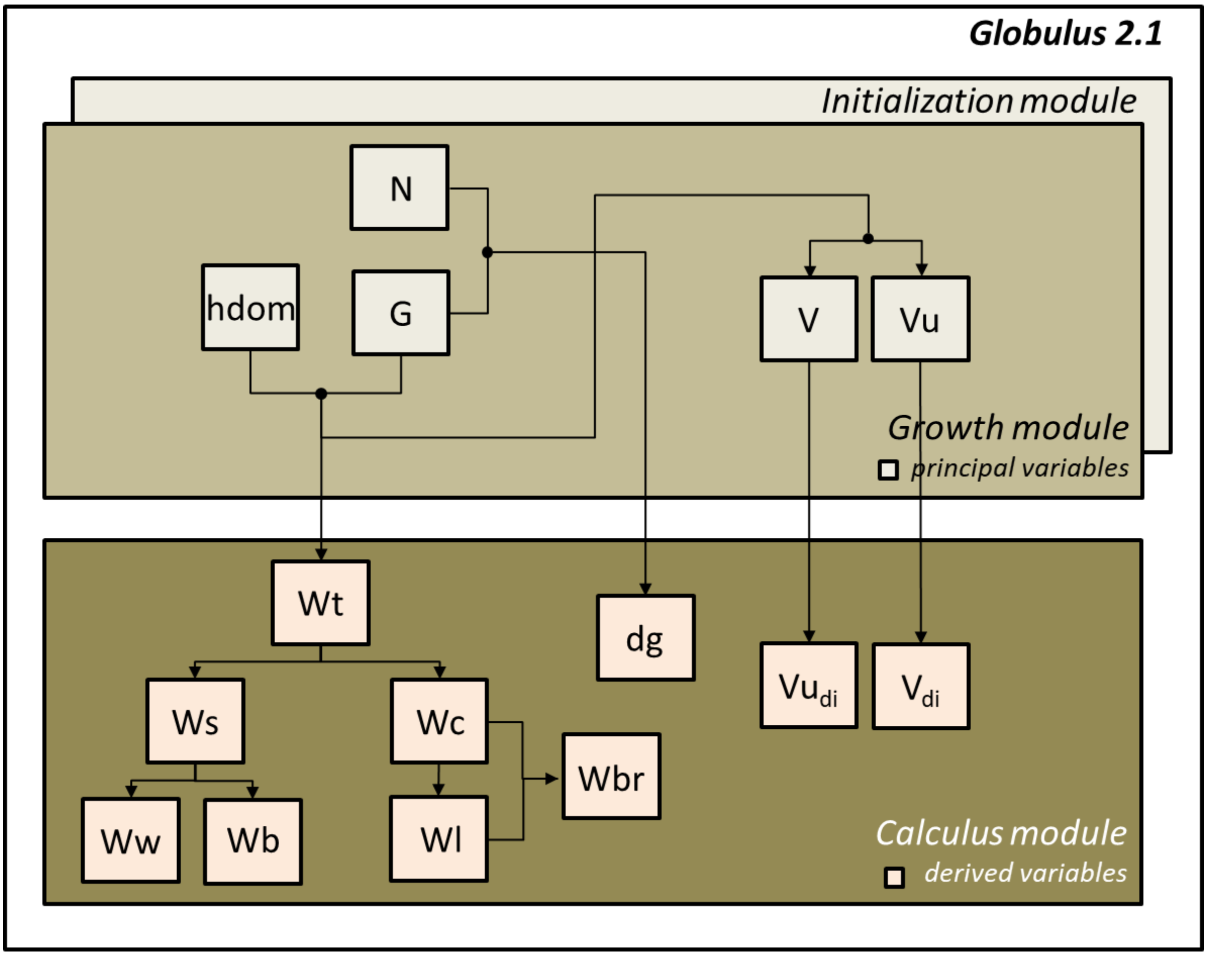

Table 1. GLOBULUS 2.1 model variables.

Control Variables	State variables	
	Principal variables	Derived variables
Environmental: - Site index (standard age=10) Climatic region Cultural: - Number of trees at planting (1st rotation) - Number of sprouts after shoots selection (coppice rotations) - Stand age Stand: - Stand rotation (0-planted, 1-coppice) - Stand age	Dominant height Stand density (ha^{-1}) Stand basal area Stand total volume (with and without bark)	Merchantable volumes (with and without bark, top diameters from 5 - 10 cm) Total aboveground biomass Root biomass Biomass by tree component: wood, bark, branches and leaves Carbon stock by tree component: wood, bark, branches, leaves and roots Nutrients (N, P, K, Ca) by tree component: wood, bark, branches, leaves and roots

Table 2. Site Index and dominant height functions.

$$hdom_2 = A_h \left(\frac{hdom_1}{A_h} \right)^{\left(\frac{t_1}{t_2} \right)^{n_h}}$$

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
A_h	Planted	61.1372							
	Coppice								
n_h	Planted	0.5225		0.4805	0.4407	0.4780	0.4805	0.3955	
	Coppice	0.4384		0.3964	0.2826	0.3199	0.3964	0.2374	

Table 3. Stand density functions.

Inicialization: $N = Npl \; e^{-a_m(t)}$ (planted stands) $N = N_0 \; e^{-a_m(t\text{-}3)}$ (coppice stands)

$$a_m = a_{m0} + a_{mnp} \frac{N_{pl}}{1000} + a_{mQ} \frac{SI}{10}$$

Prediction: $N_2 = N_1 \; e^{-a_m(t_2 - t_1)}$

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{m0}	Planted	0.0211				0.0242	0.0211	0.0401	0.0242
	Coppice	0.0052				0.0083	0.0052	0.0090	0.0083
a_{mnp}	Planted	0.0013							
	Coppice								
a_{mQ}	Planted	-0.0064							
	Coppice	-0.0014							

Table 4. Stand basal area initialization and prediction functions.

Inicialization: $G = A_g \; e^{-k_g \left(\frac{1}{t}\right)^{n_g}}$ $\qquad k_g = k_{g0} + k_{gQ} \frac{1}{SI} + k_{gnp} \frac{N_{pl}}{1000} + k_{gf} \; Fe$

Prediction: $G_2 = A_g \left(\frac{G_1}{A_g}\right)^{\frac{t_1^{n_{g1}}}{t_2^{n_{g2}}}}$ $\qquad A_g = A_{gQ} \; Iqe^2$ $\qquad n_{gi} = n_{g0} + n_{gQ} \; ln(SI) + n_{gn} \frac{N_i}{1000}$

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
A_{gQ}	Planted	0.1586							
	Coppice								
n_{g0}	Planted	3.7350		3.6354	3.6091	3.5676	3.6893	3.4571	3.5676
	Coppice	2.8638		2.7642	2.6990	2.6575	2.8181	2.5470	2.6575
n_{gQ}	Planted	-1.0288							
	Coppice	-0.7316							
n_{gn}	Planted	0.1024							
	Coppice	0.0216							
k_{g0}	Planted	-4.4826		-5.5311	-6.1201	-6.2433	-4.7560	-7.7941	-6.9326
	Coppice	0.7582		-0.2903	-0.8793	-1.0025	0.4848	-2.5533	-1.6918
k_{gQ}	Planted	177.9							
	Coppice	72.3							
k_{gnp}	Planted	0.5408							
	Coppice	0.0134							
k_{gf}	Planted	16.015							
	Coppice	14.1898							

Table 5. Total volume with stump with and without bark initialization and prediction functions.

Inicialization: $V = k_v \; t^{a_v} hdom^{b_v} \; G^{c_v}$ $\qquad k_v = k_{v0} + k_{vf} \; Fe$

Prediction: $V_2 = V_1 \left(\frac{t_2}{t_1}\right)^{a_v} \left(\frac{hdom_2}{hdom_1}\right)^{b_v} \left(\frac{G_2}{G_1}\right)^{c_v}$

Total volume with stump and bark

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{vc}	Planted	0.0655							
	Coppice								
b_{vc}	Planted	0.8830							
	Coppice								
c_{vc}	Planted	1.0263							
	Coppice								
k_{v0c}	Planted	0.5007			0.4886		0.5007	0.4886	
	Coppice	0.5355			0.5272		0.5355	0.5272	
k_{vfc}	Planted	-0.1348			-		-0.1348	-	

	Coppice	-0.3828			-0.2480		-0.3828	-0.2480	

Total volume with stump without bark

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{vs}	Planted	0.0592							
	Coppice								
b_{vs}	Planted	0.9349							
	Coppice								
c_{vs}	Planted	1.0077							
	Coppice								
k_{v0s}	Planted	0.3886			0.3724		0.3886	0.3724	
	Coppice	0.4218			0.4108		0.4218	0.4108	
k_{vfs}	Planted	-0.1497			-		-0.1497	-	
	Coppice	-0.3616			-0.2119		-0.3616	-0.2119	

Table 6. Merchantable volume with and without bark equations.

$$V_d = V\, e^{a_{vm}\left(\frac{d_d}{d_g}\right)^{b_{vm}}} \qquad a_{vm} = a_{vm0} + a_{vmnp}\frac{N_{pl}}{1000} + a_{vmf}\, Fe$$

Merchantable volume with bark

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{vm0c}	Planted	-1.0904							
	Coppice	-1.2881							
a_{vmnpc}	Planted	0.0729							
	Coppice	0.09267			0.0729		0.0927	0.0729	
a_{vmfc}	Planted	0.3851							
	Coppice	1.0378							
b_{vmc}	Planted	3.3716							
	Coppice	3.3716							

Merchantable volume without bark

	Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{vm0s}	Planted	-1.0625							
	Coppice	-1.2531							
a_{vmnps}	Planted	0.0654							
	Coppice	0.0850			0.0654		0.0850	0.0654	
a_{vmfs}	Planted	0.3841							
	Coppice	1.0247							
b_{vms}	Planted	3.3288							
	Coppice	3.3288							

Table 7. Total aboveground biomass equations.

$$W_t = \alpha_w \, G^{\beta_w} hdom^{\gamma_w} \qquad \alpha_w = \alpha_{w0} + \alpha_{wQ} \frac{Iqe}{10} \qquad \beta_w = \beta_{w0} + \beta_{wn} \frac{N}{1000} + \beta_{wt} \, t$$

Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
α_{w0}	0.0095							
α_{wQ}	-0.0025							
β_{w0}	1.1392							
β_{wn}	-0.0424							
β_{wt}	-0.0115							
γ_w	2.4043							

Table 8. Stem and canopy biomass equations.

$$W_{tronco} = W_t \; P_{tronco} = W_t \; (\alpha_{wt} \; G^{\beta_{wt}} hdom^{\gamma_{wt}}) \qquad \beta_{wt} = \beta_{wt0} + \beta_{wtn} \frac{N}{1000} + \beta_{wtt} \; t + \beta_{wtQ} \frac{Iqe}{10}$$

$$W_{copa} = W_t - W_{tronco}$$

Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
α_{wt}	0.2019							
β_{wt0}	0.1613							
β_{wtn}	0.0046							
β_{wtt}	-0.0037							
β_{wtQ}	-0.0355							
γ_{wt}	0.4301							

Table 9. Biomass equations by tree component.

$$W_{casca} = W_{tronco}\left(a_{c0} + a_{ct}\,t + a_{ct2}\,\frac{t^2}{10}\right) \qquad W_{lenho} = W_{tronco}(1 - P_{casca})$$

$$W_{folhas} = W_{copa}\left(a_{f0} + a_{ft}\,t + a_{ft2}\,\frac{t^2}{10}\right) \qquad W_{ramos} = W_{copa} - W_{folhas}$$

Region	1NL	2NC	3CL	4SL	5VT	6NI	7SI	8VD
a_{c0}	0.1946							
a_{ct}	-0.0094							
a_{ct2}	0.0026							
a_{fo}	0.7304							
a_{ft}	-0.0154							
a_{ft2}	0.0021							

The biomass and nutrient estimates' module is in GLOBULUS 2.1 is still quite simple. The conversion factors for roots are the same applied for wood.

Table 10. Conversion factors used in the GLOBULUS 2.1 model for converting the biomass by tree component into carbon and macronutrients.

Components	Carbon	Nutrients (% kg/kg)			
	%	N	P	K	Ca
Wood	49.0	0.0753	0.0221	0.0682	0.1086
Bark	46.8	0.1862	0.0137	0.1271	0.6651
Leaves	49.2	1.1363	0.0548	0.5285	0.5280
Branches	47.4	0.2763	0.0117	0.3593	0.6896
Roots	49.0	0.0753	0.0221	0.0683	0.1086

List of Symbols

SI or IQE – Site Index, which is the stand's dominant height at the age of 10 years (m);
t – Stand age (years);

t_1 – Stand age at instant 1 (years);
t_2 – Stand age at instant 2 (years);
t_p – Standard age, which for eucalyptus corresponds to 10 years (years);
hdom – Stand dominant height (m);
$hdom_1$ – Stand dominant height at instant 1 (m);
$hdom_2$ – Stand dominant height at instant t_2 (m);
N – Stand density (ha^{-1});
N_1 – Stand density at instant 1 (ha^{-1});
N_2 – Stand density at instant 2 (ha^{-1});
Npl – Stand density at plantation (ha^{-1});
rot – dummy variable with 0 representing planted stands and 1 representing coppice stands;
G – Stand basal area (m^2 ha^{-1});
G_1 – Stand basal area at instant t_1 (m^2 ha^{-1});
G_2 – Stand basal area at instant t_2 (m^2 ha^{-1});
V – Stand volume with stump (m^3 ha^{-1});
V_1 – Stand volume with stump at instant t_1 (m^3 ha^{-1});
V_2 – Stand volume with stump at instant t_2 (m^3 ha^{-1});
V_d – Stand mercantile volume without stump and bark up to a top diameter of di (m^3 ha^{-1});
d_d – top diameter with bark (cm);
dg – Stand quadratic mean d.b.h (cm^2 ha^{-1});
W_{lenho} – Stand wood biomass (Mg ha^{-1});
W_{casca} - Stand bark biomass (Mg ha^{-1});
W_{folhas} – Stand leaves biomass (Mg ha^{-1});
W_{ramos} - Stand branches biomass (Mg ha^{-1});
W_r - Stand roots biomass (Mg ha^{-1});
W_t – Stand aboveground biomass (Mg ha^{-1});
W_{tronco} - Stand stem biomass (Mg ha^{-1});
W_{copa} - Stand canopy biomass (Mg ha^{-1});