Whole stand models for even-aged stands

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Summary

- Whole stand models for even-aged stands
  - ➔ State variables
  - ➔ Control variables
    - Stand density and stocking
    - Stand density measures:
      - Stand density index (SDI)
      - Crown competition factor (CCF)
      - Relative spacing (Wilson factor)
      - Spacing factor (Sf)
      - Crown cover (CC)
  - ➔ Growth and calculus modules
    - Site productivity
    - Silvicultural treatments and thinning

Whole stand models
for
even-aged stands

Whole stand models - state variables

- In whole stand models the state variables are all defined at stand level:
  - → Dominant height (hdom)
  - → Number of trees per ha (N)
  - → Basal area (G)
  - → Volume (V) and merchantable volumes (Vdi or Vhi)
  - → Biomass (W) and biomass per tree component (Wr, Ww, Wb, Wbr, Wl)

Principal variables

Derived variables

- hdom, N and G are almost always principal variables, volume may be derived or not

Whole stand models - control variables

- The most important control variables are:

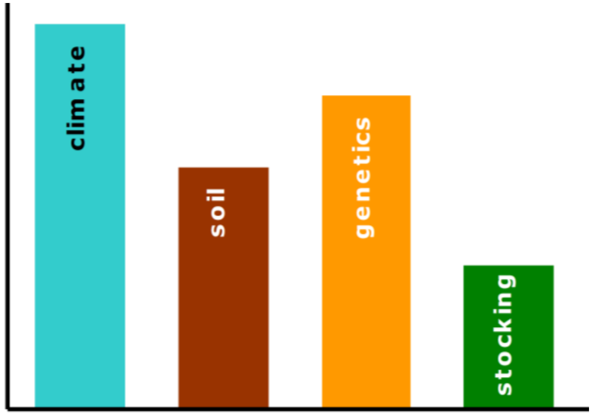
  → Site productivity (climate and soil), very often expressed as site index

  → Genetics

  → Application of fertilizers

  → Stocking control, either initial **stand density** and **thinnings**

  → **Other silvicultural techniques** (weeding, pruning, irrigation, etc)



- Selection of **quantitative measures of stand density** is therefore an important step in forest models development and/or application

Stocking and stand density

- Although stocking and stand density are terms that are often applied interchangeably in forestry use, the two terms are not synonymous
  - ➔ Stand density denotes a quantitative measurement of the stand (number of trees per hectare)
  - ➔ Stocking:
    - Stocking refers to the adequacy of a given stand density to meet some management objective (Bickford et al. 1957)
    - Stands may be referred to as "**understocked**", "**fully-stocked**", or overstocked
    - A stand that is "**overstocked**" for one management objective could be "understocked" for another

Quantifying stand density

- Stand density is a quantitative term describing the degree of stem crowding within a stocked area and it can be expressed in:

  ➔ **Absolute** measures of density are determined directly from a given stand without reference to any other stand:

  ➔ Basal area per ha

  ➔ Number of trees per ha

  ➔ **Relative** density is based on a selected standard density, usually the "fully-stocked" stand or the open-grown trees (the extremes):

  ➔ Stand density index (SDI)

  ➔ Crown competition factor (CCF)

  ➔ Other stand density measures:

  - Relative spacing (FW)
  - Spacing factor (SF)
  - Percent crown cover (CC)

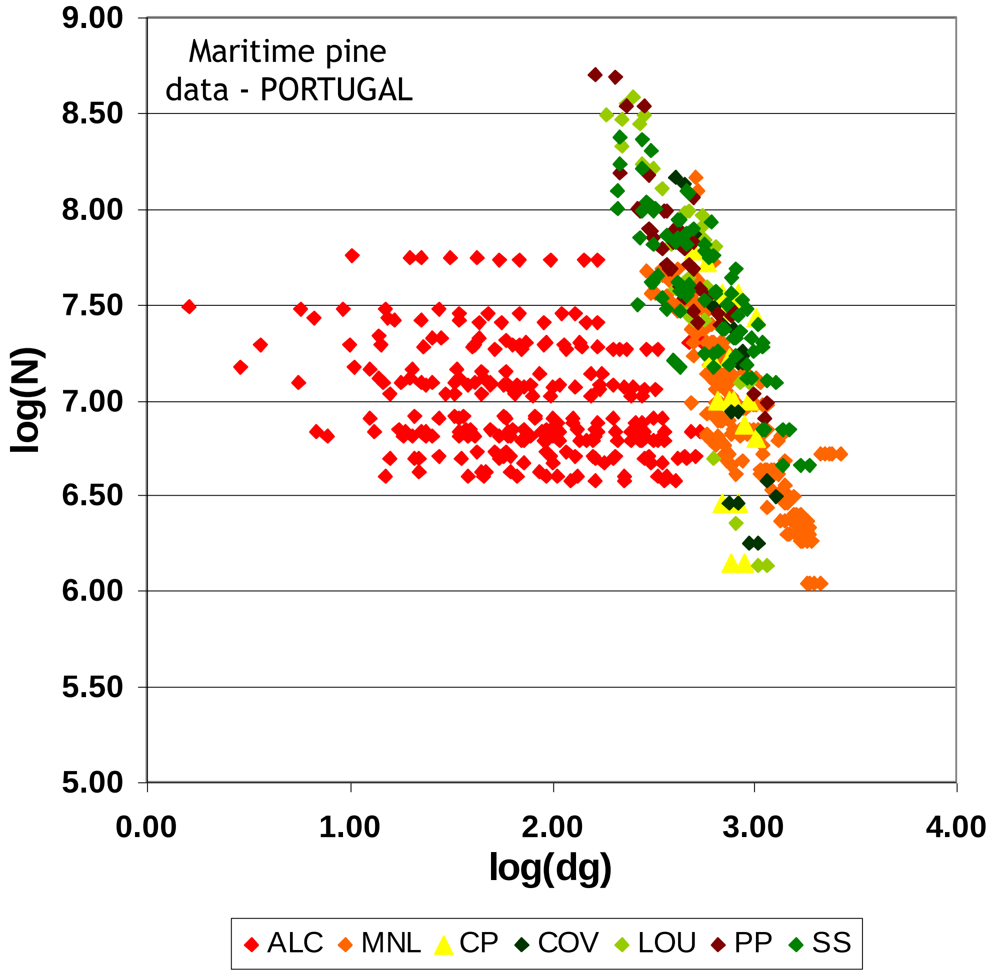
Quantifying stand density

- **Stand density index (SDI)** - Relative stand density measures

  - ➔SDI evaluates stand density by comparing it with the maximum density for a stand with the same quadratic mean dbh (*dg*) – limiting situation or <u>self-thinning line</u>

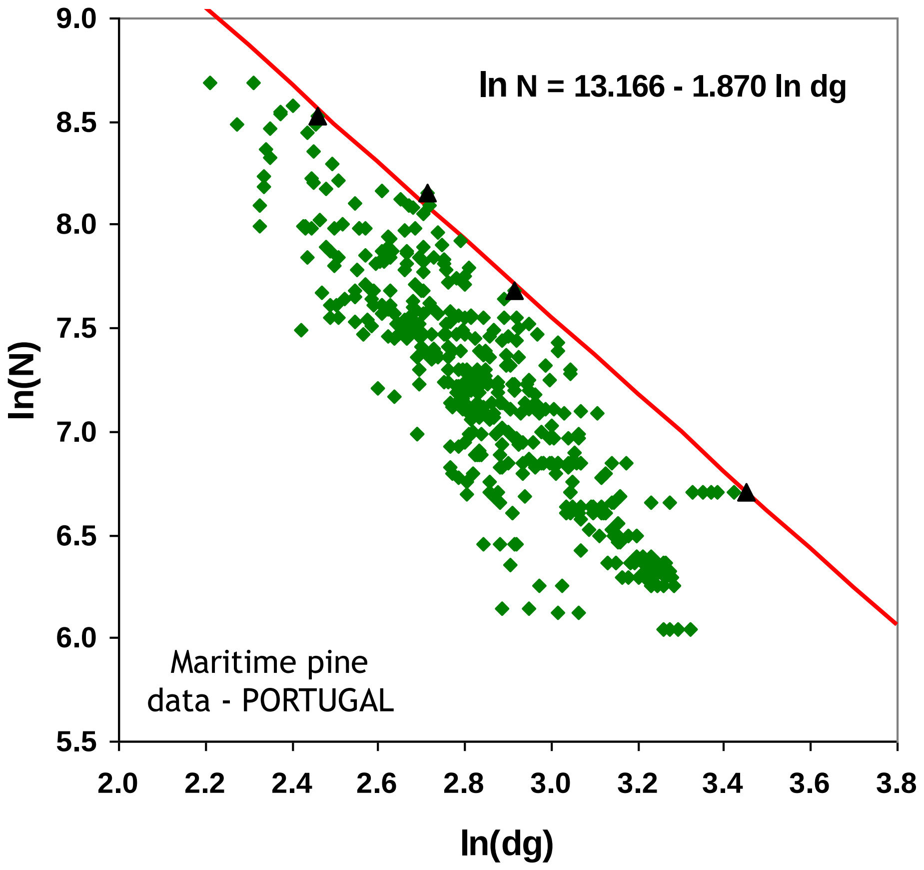
  - ➔For any given *dg* there is a limit to the number of trees per unit that can be carried

  - ➔Reineke (1933) noted that for a variety of species the slope of the limiting line was approximately -1.6 on the log-log scale



Quantifying stand density

- **Stand density index (SDI)** - Relative stand density measures

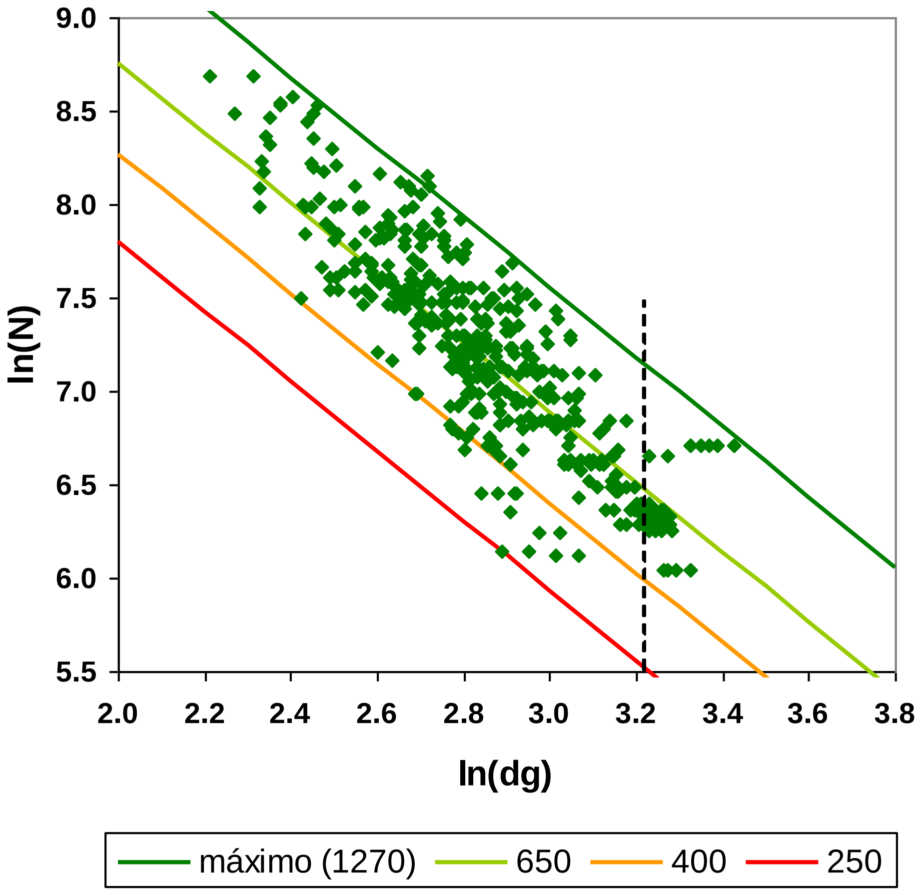


- SDI is based on the evaluation of the <u>difference between the number of trees in the stand and the maximum number of trees it could sustain</u> according to the self-thinning line

- SDI assumes that an understocked stand is located in a logN-logdg line parallel to the self-thinning line but with a smaller intercept

Quantifying stand density

- **Stand density index (SDI)** - Relative stand density measures



- The intercept for a stand can be obtained as

$$\ln N = k - 1.870 \ln dg$$

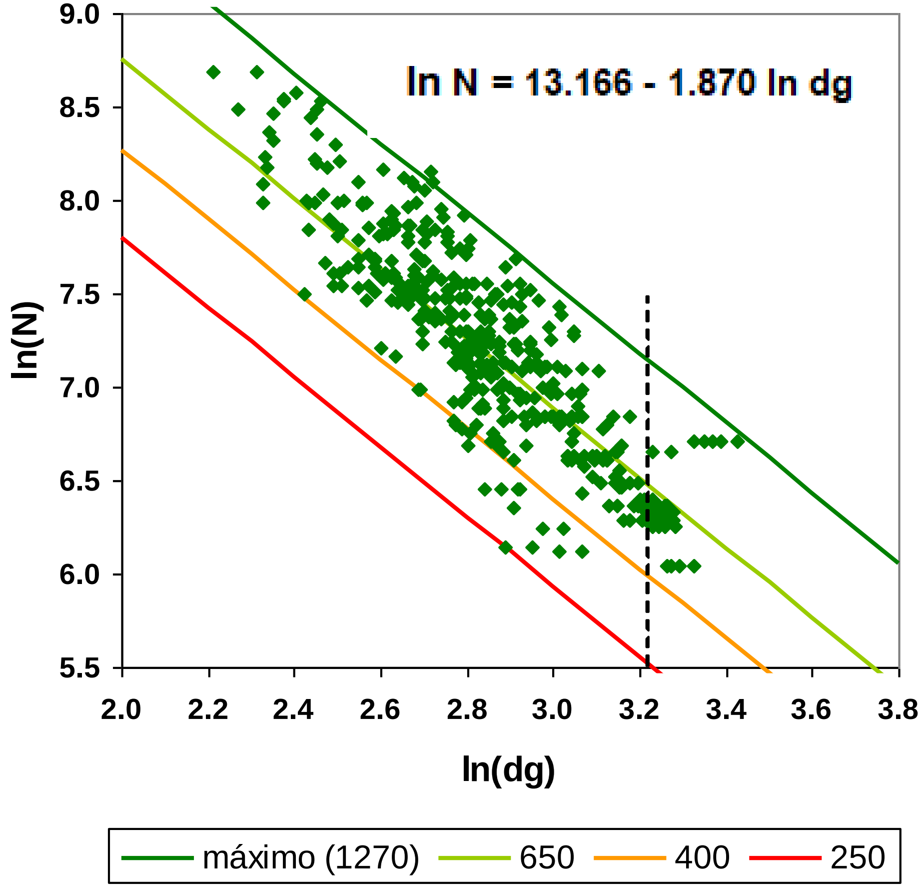
$$k = \ln N + 1.870 \ln dg$$

- The index is "normalized" by using the dg=25 as a basis for comparison

$$\ln SDI = k - 1.870 \ln 25$$

Quantifying stand density

- **Stand density index (SDI)** - Relative stand density measures



The expression for SDI in a particular stand is then obtained:

$$\ln SDI = -1.870 \ln 25 + k$$

&

$$k = \ln N + 1.870 \ln dg$$

$$\ln SDI = -1.870 \ln 25 + \ln N + 1.870 \ln dg$$

$$SDI = N \left(\frac{dg}{25} \right)^{1.870}$$

Quantifying stand density

- **Crown competition factor (CCF)** - Relative stand density measures

→CCF reflects the relationship between the area available for the average tree of the stand and the maximum area that the tree could use if it was growing in open space (open-grown tree)

→The computation of CCF requires the study of the relationship between **crown width of an open-grown tree** (cw_{og}) and its **dbh** (d_{og}), usually linear:

$$cw_{og} = b_0 + b_1 d_{og}$$

→The crown of an open-grown tree ocupies the area ca_{og}:

$$ca_{og} = \pi \frac{cw_{og}^2}{4} = \pi \frac{(b_0 + b_1 d_{og})^2}{4}$$

→CCF is then computed as the sum of the ca_{og} values for all the trees in the stand, expressed as a percentage of the plot area:

$$CCF = \frac{100}{A_p} \sum_{i=1}^{N} ca_{og_i}$$

Quantifying stand density

- **Relative spacing (Rs)**

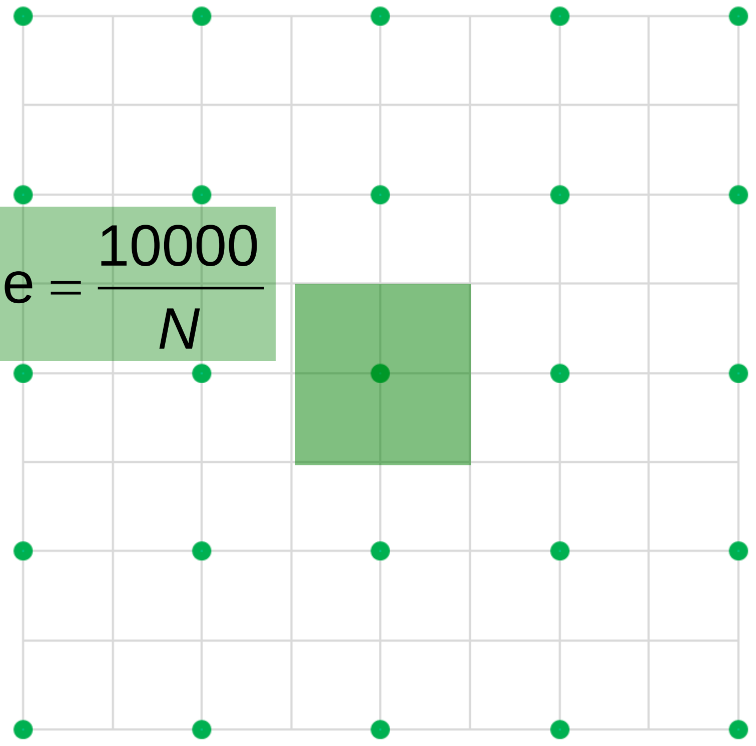
➔ RS is a stand density measure that relates the average distance between trees with the dominant height

➔ It is based on the assumption that the stand density must decrease as the stand develops (the dominant height increases)

$$Rs = \frac{\text{average distance between trees}}{hdom}$$

➔ Assuming that the trees are regularly spaced, the area available per tree is:

$$\text{Area per tree} = \frac{10000}{N}$$



Quantifying stand density

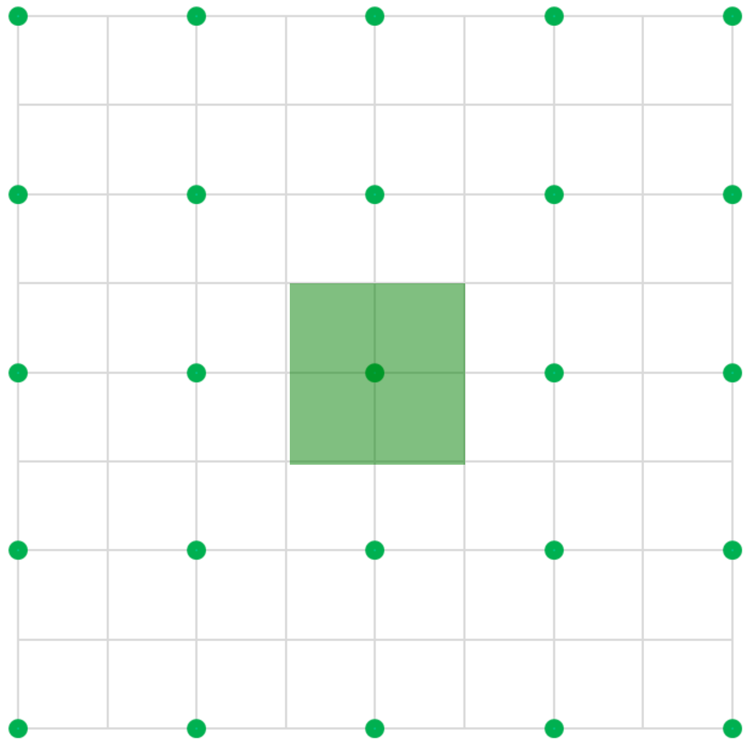
- **Relative spacing (Rs), Wilson factor (Fw)**

➔ Assuming that the trees are regularly spaced, the area available per tree is:

$$\text{Area per tree} = \frac{10000}{N} \Rightarrow dist_{mean} = \sqrt{\frac{10000}{N}}$$

➔ The relative spacing can be written in the form usually known as wilson factor

$$Fw = \frac{\sqrt{1000/N}}{hdom} = \frac{100}{hdom\ \sqrt{N}}$$



Quantifying stand density

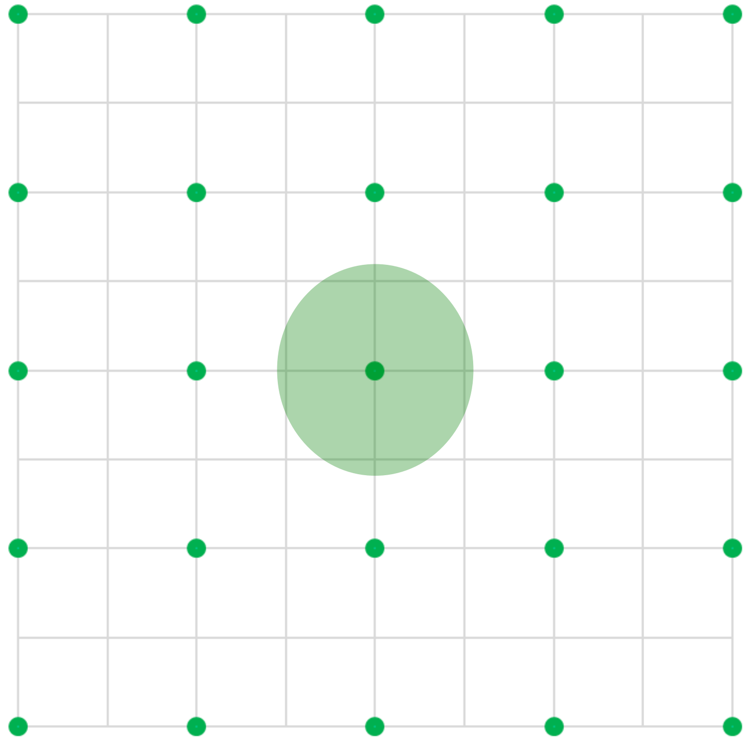
- **Spacing factor (Sf)**

  ➔ Sf is a stand density measure that relates the average distance between trees to the crown width of the average tree:

$$Sf = \frac{\text{average distance between trees}}{cw_{mean}}$$

  ➔ If a regularly spaced stand is assumed, Sf comes as:

$$Sf = \frac{100}{cw_{mean}\sqrt{N}}$$

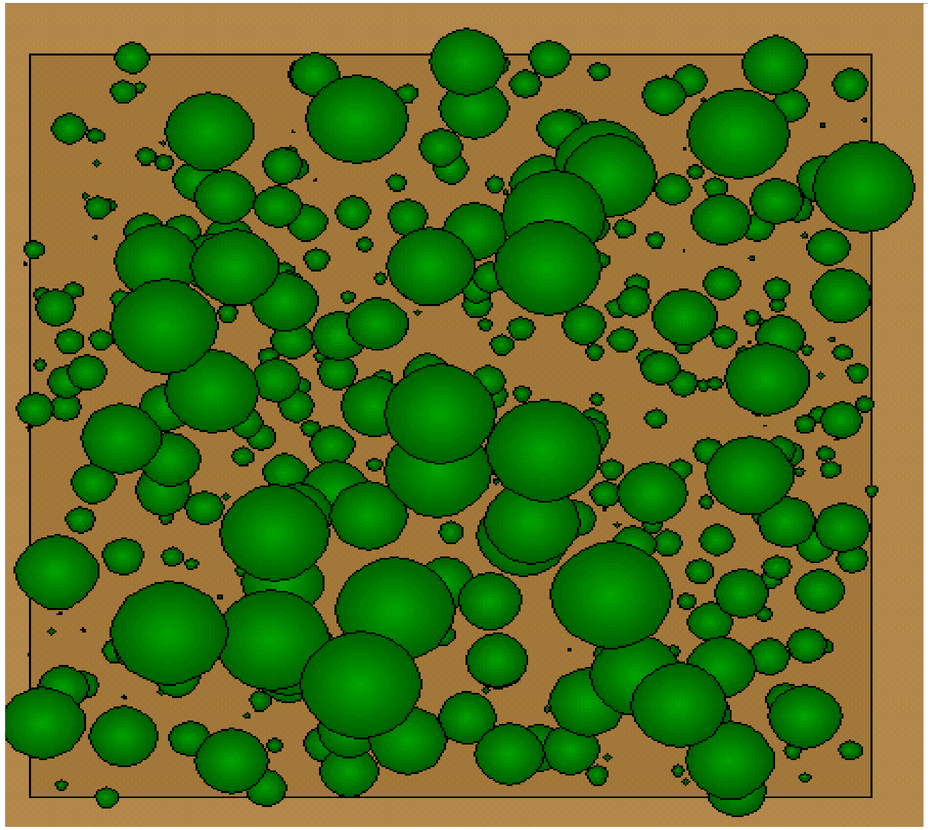


Quantifying stand density

- **Crown cover(*Cc*)**

  ➔ Crown cover (*Cc*) is a stand density measure that computes the percentage of area covered with crowns :

$$Cc = \frac{\sum_{\text{all trees}} \text{crown area}}{\text{Plot area}} \; 100$$



Whole stand models for even-aged stands (WSM-eas)

- Site productivity

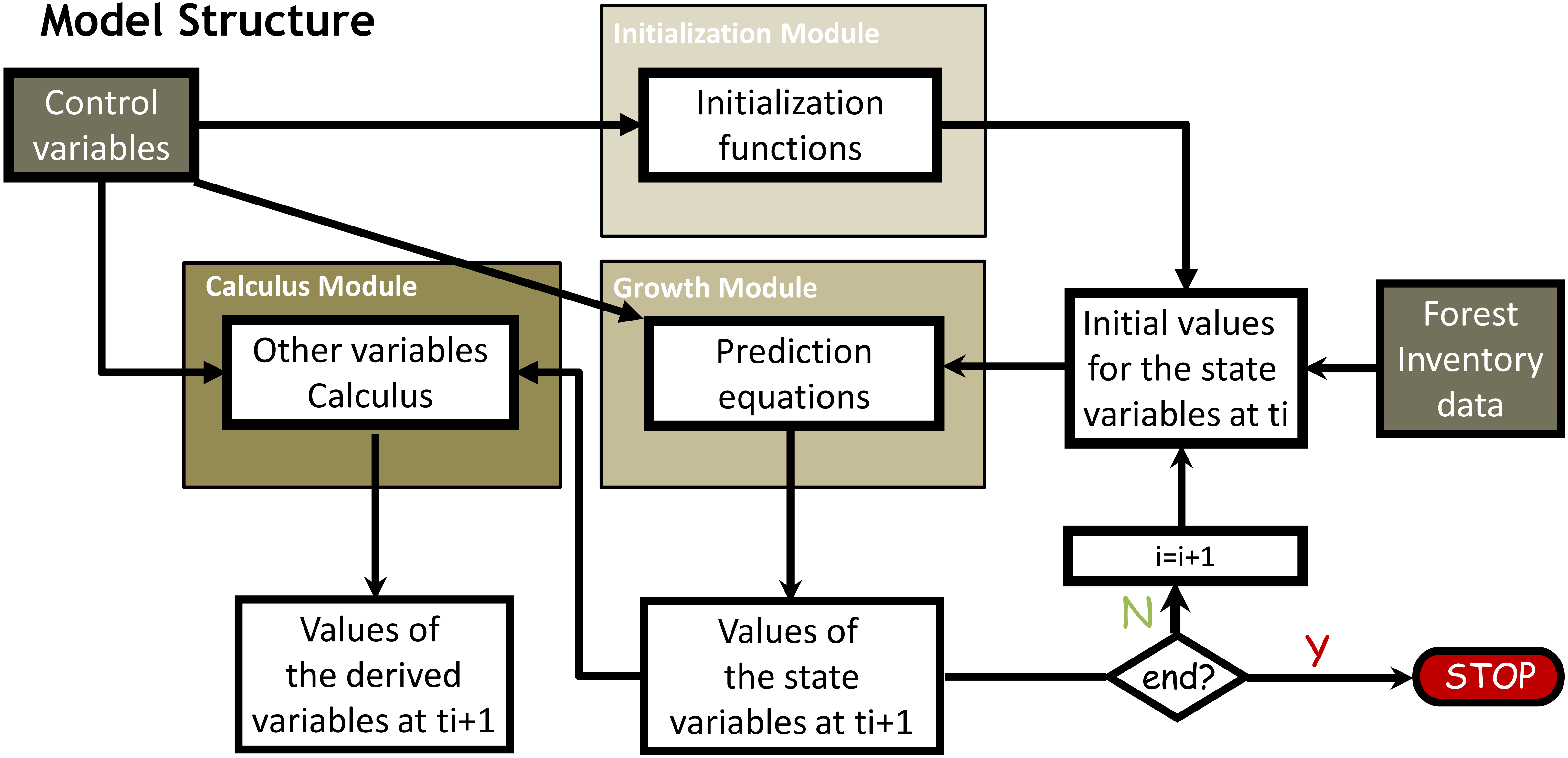
  ➔ A system of **site index curves** is the most common way to express site productivity in WSM-eas

  ➔ In species in which age is difficult to determine:

  - Site index may be assessed with a **site prediction equation**
  - Site productivity may be included in the several **sub-models through climatic and soil variables**

Whole stand models for even-aged stands (GLOBULUS 3.0)

Model Structure



Whole stand models for even-aged stands (WSM-eas)

Growth modules

- Growth modules refer to principal variables, the ones whose growth is predicted from one instante in time to the next by the model:
  - Direct prediction of growth

    $i_{X1\text{-}2} = f(S, t_1, t_2, SD_1)$

    $X_2 = X_1 + i_{X1\text{-}2}$

  - Direct prediction of future value

    $SD2 = f(S, t_1, t_2, SD_1)$

    $X_2 = f(S, t_1, t_2, X_1, SD_1, SD_2,$ *other stand variables*$)$

- Notation
  - S = site index or site variables (climate and soil)
  - t_i = stand age at time t_i
  - X_i = principal stand variable X at time t_i
  - SD_i = stand density measure at time t_i
  - $i_{X1\text{-}2}$ = growth of variable X in the period between t_1 and t_2
  - Y_i = derived stand variable Y at time t_i

Whole stand models for even-aged stands (GLOBULUS 3.0)

- **Module Growth:** $hdom_2 = f\ (t_1, t_2, hdom_1, Rain)$

SUM | =($B$4+$B$5*$A$48)*(B54/($B$4+$B$5*$A$48))^((A54/A55)^($B$6))

Planted Stand

Number of Days with Rain	Altitude	Number of Days with Frost	Rain	Mean Temperature
114	550	7.00	650.00	15.50

Site Index	Number of Trees at Planting	Rotation	Top Diameter
21.8	1250	0	6.20

Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	=($B$4+$	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
5	14.3	1170	1170	9.2	46.2	10.7	1.2	10.0	40.6	22.6	4.4	3.1	3.9	34.0	8.5
6	16.2	1154	1154	11.2	63.3	14.3	1.4	11.1	57.4	31.9	5.1	4.3	4.7	46.1	11.5
7	17.9	1139	1139	13.1	80.7	17.8	1.7	12.1	74.5	41.7	5.7	5.5	5.5	58.5	14.6
8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7
9	20.6	1109	1109	16.3	115.3	24.6	2.2	13.7	108.8	61.9	6.6	8.1	6.9	83.5	20.8

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module Growth: $Nst_2 = f\,(t_1, t_2, Nst_1, NPL, rotation)$

SUM | fx | =C54*EXP(-($B$9+$B$10*$J$48+$B$11*$I$48/1000)*(A55-A54))

Planted Stand

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Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	=C54*EXP	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
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Whole stand models for even-aged stands (GLOBULUS 3.0)

Module Growth: $G_2 = f\,(t_1, t_2, Nst_1, Nst_2, G_1, rotation, Rain, altitude)$

SUM

```
=($B$15+$B$16*$A$48)*(E54/($B$15+$B$16*$A$48))^((A54^($E$18*C54/1000))/(A55^($E$18*C55/1000))*((A54/A55)^($E$15+($E$16/(1-($B$48/2000)))+$E$17*$J$48)))
```

Planted Stand

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Inicialization | Prediction / Growth | Calculus

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1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	\$48)*(E54/($E	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
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11	22.9	1080	1080	19.1	148.5	30.9	2.6	15.0	141.7	81.7	7.3	10.6	8.1	107.7	26.8
12	23.8	1066	1066	20.4	164.3	33.9	2.8	15.6	157.4	91.3	7.5	11.9	8.6	119.3	29.7

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module Growth: $Vu_2 = f\,(t_1, t_2, hdom_1, hdom_2, G_1, G_2, Vu_1)$

SUM

=F54*((A55/A54)^$B$21)*((B55/B54)^$B$22)*((E55/E54)^$B$23)

Planted Stand

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Inicialization		Prediction / Growth		Calculus	

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	=F54*((A5	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
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8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7

Whole stand models for even-aged stands (WSM-eas)

Calculus module

→ Calculus modules refer to derived variables, the ones that are computed from other variables at the same point in time:

Computed variable:

$Y_2 = f(S, t_2, SD_2, \text{other stand variables})$

→ Notation

- S = site index or site variables (climate and soil)
- t_i = stand age at time t_i
- X_i = principal stand variable X at time t_i
- SD_i = stand density measure at time t_i
- $i_{X1\text{-}2}$ = growth of variable X in the period between t_1 and t_2
- Y_i = derived stand variable Y at time t_i

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module calculus: Vdi = (Vu, Vs, dg, Altitude, S, NPL, top_diameter)

SUM

```
=(F59-H59)*EXP((($K$48/I59)^($D$27+$D$28*$J$48))*($B$27+$B$28*$J$48+$B$29*$I$48/1000+$B$30*(100/($H$48*SQRT($I$48)))+$B$31*(1/(1-($B$48/2000)))))
```

Planted Stand

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1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
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11	22.9	1080	1080	19.1	148.5	30.9	2.6	15.0	141.7	81.7	7.3	10.6	8.1	107.7	26.8
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Whole stand models for even-aged stands (GLOBULUS 3.0)

Module calculus: Vdi = (Vu, Vs, dg, Altitude, S, NPL, top_diameter)

SUM

```
=(F59-H59)*EXP((($K$48/I59)^($D$27+$D$28*$J$48))*($B$27+$B$28*$J$48+$B$29*$I$48/1000+$B$30*(100/($H$48*SQRT($I$48)))+$B$31*(1/(1-($B$48/2000))))
```

Planted Stand

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21.8	1250	0	6.20

Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
5	14.3	1170	1170	9.2	46.2	10.7	1.2	10.0	40.6	22.6	4.4	3.1	3.9	34.0	8.5
6	16.2	1154	1154	11.2	63.3	14.3	1.4	11.1	=(F59-H5	31.9	5.1	4.3	4.7	46.1	11.5
7	17.9	1139	1139	13.1	80.7	17.8	1.7	12.1	74.5	41.7	5.7	5.5	5.5	58.5	14.6
8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7
9	20.6	1109	1109	16.3	115.3	24.6	2.2	13.7	108.8	61.9	6.6	8.1	6.9	83.5	20.8
10	21.8	1095	1095	17.8	132.1	27.8	2.4	14.4	125.5	71.9	7.0	9.4	7.5	95.7	23.8
11	22.9	1080	1080	19.1	148.5	30.9	2.6	15.0	141.7	81.7	7.3	10.6	8.1	107.7	26.8
12	23.8	1066	1066	20.4	164.3	33.9	2.8	15.6	157.4	91.3	7.5	11.9	8.6	119.3	29.7

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module calculus: Ww = (t, hdom, G, Nst, S, rotation)

SUM | fx | =B$34*$E59^(B$35+B$36*$J$48+B$37*($C59/1000)+B$38*($H$48/1000)+B$39*($A59/1000))*$B59^B$40

Planted Stand

Number of Days with Rain	Altitude	Number of Days with Frost	Rain	Mean Temperature
114	550	7.00	650.00	15.50

Site Index	Number of Trees at Planting	Rotation	Top Diameter
21.8	1250	0	6.20

Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
5	14.3	1170	1170	9.2	46.2	10.7	1.2	10.0	40.6	22.6	4.4	3.1	3.9	34.0	8.5
6	16.2	1154	1154	11.2	63.3	14.3	1.4	11.1	57.4	=B$34*$E	5.1	4.3	4.7	46.1	11.5
7	17.9	1139	1139	13.1	80.7	17.8	1.7	12.1	74.5	41.7	5.7	5.5	5.5	58.5	14.6
8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module inicialization: hdom = f(t, Rain, S)

SUM =($B$4+$B$5*$A$48)*($H$48/($B$4+$B$5*$A$48))^((10/A54)^$B$6)

Planted Stand

Number of Days with Rain	Altitude	Number of Days with Frost	Rain	Mean Temperature			Site Index	Number of Trees at Planting	Rotation	Top Diameter
114	550	7.00	650.00	15.50			21.8	1250	0	6.20

Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	=($B$4+$	1234	1234	0.6	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
5	14.3	1170	1170	9.2	46.2	10.7	1.2	10.0	40.6	22.6	4.4	3.1	3.9	34.0	8.5
6	16.2	1154	1154	11.2	63.3	14.3	1.4	11.1	57.4	31.9	5.1	4.3	4.7	46.1	11.5
7	17.9	1139	1139	13.1	80.7	17.8	1.7	12.1	74.5	41.7	5.7	5.5	5.5	58.5	14.6
8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7
9	20.6	1109	1109	16.3	115.3	24.6	2.2	13.7	108.8	61.9	6.6	8.1	6.9	83.5	20.8

Whole stand models for even-aged stands (GLOBULUS 3.0)

Module initialization: G = f(t, Nst, Rain, Altitude, S, NPL, rotation)

SUM

=($B$15+$B$16*$A$48)*EXP(-($H$15+$H$16*$H$48+$H$17*100/($H$48*SQRT($I$48))+$H$18*$J$48)*(1/A54)^($E$15+$E$16/(1-($B$48/2000))+$E$17*$J$48+E
C54/1000))

Planted Stand

Number of Days with Rain	Altitude	Number of Days with Frost	Rain	Mean Temperature
114	550	7.00	650.00	15.50

Site Index	Number of Trees at Planting	Rotation	Top Diameter
21.8	1250	0	6.20

Inicialization | Prediction / Growth | Calculus

t	hdom	Nst	N	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	1234	1234	=($B$15+B	0.5	0.2	0.0	2.5	0.0	0.2	0.5	0.0	0.2	0.9	0.2
2	6.3	1217	1217	2.5	5.7	1.6	0.3	5.1	2.3	2.2	1.6	0.4	1.0	5.2	1.3
3	9.4	1201	1201	4.8	16.2	4.1	0.5	7.2	11.5	7.1	2.6	1.1	2.0	12.8	3.2
4	12.1	1185	1185	7.1	30.2	7.3	0.9	8.7	25.0	14.1	3.6	2.0	3.0	22.7	5.6
5	14.3	1170	1170	9.2	46.2	10.7	1.2	10.0	40.6	22.6	4.4	3.1	3.9	34.0	8.5
6	16.2	1154	1154	11.2	63.3	14.3	1.4	11.1	57.4	31.9	5.1	4.3	4.7	46.1	11.5
7	17.9	1139	1139	13.1	80.7	17.8	1.7	12.1	74.5	41.7	5.7	5.5	5.5	58.5	14.6
8	19.3	1124	1124	14.8	98.1	21.3	2.0	12.9	91.8	51.8	6.2	6.8	6.2	71.1	17.7
9	20.6	1109	1109	16.3	115.3	24.6	2.2	13.7	108.8	61.9	6.6	8.1	6.9	83.5	20.8
10	21.8	1095	1095	17.8	132.1	27.8	2.4	14.4	125.5	71.9	7.0	9.4	7.5	95.7	23.8
11	22.9	1080	1080	19.1	148.5	30.9	2.6	15.0	141.7	81.7	7.3	10.6	8.1	107.7	26.8
12	23.8	1066	1066	20.4	164.3	33.9	2.8	15.6	157.4	91.3	7.5	11.9	8.6	119.3	29.7

Whole stand models for even-aged stands (GLOBULUS 3.0)

Coppice - 2nd cycle

H81

Coppice 1

Number of Days with Rain	Altitude	Number of Days with Frost	Rain	Mean Temperature
114	550	7	650	15.5

Site Index	Number of Trees at harvest time	Rotation	Top Diameter	Proportion of Mortality in the Transition between Rotations	Number of Sprouts per Stool after Shoots Selection
21.8	1066	1	6.20	0.2	1.2

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Inicialization	Projection	Prediction

t	hdom	Nst	Nsp	G	Vu	Vb	Vs	dg	Vdi	Ww	Wl	Wb	Wbr	Wa	Wr
1	2.5	853	3926	0.6	0.6	0.2	0.1	1.5	0.0	0.2	0.5	0.0	0.3	1.0	0.2
2	6.3	842	4168	4.1	9.2	2.5	0.4	3.5	0.0	3.6	2.4	0.5	1.6	8.1	2.0
3	9.4	832	4410	9.1	30.4	7.7	1.0	5.1	7.0	12.9	4.7	1.6	3.4	22.5	5.6
4	12.1	822	987	5.8	24.2	5.6	0.7	8.6	19.2	11.4	2.9	1.6	2.4	18.3	4.5
5	14.3	812	977	7.5	37.2	8.3	0.9	9.9	32.1	18.3	3.6	2.4	3.2	27.5	6.8
6	16.2	802	967	9.2	51.2	11.1	1.2	11.0	46.1	26.0	4.2	3.4	3.9	37.5	9.3
7	17.9	793	957	10.8	65.6	13.9	1.4	12.0	60.4	34.2	4.7	4.4	4.6	47.8	11.9
8	19.3	783	947	12.2	80.1	16.6	1.6	12.8	74.9	42.6	5.2	5.4	5.2	58.4	14.5
9	20.6	773	938	13.6	94.5	19.4	1.8	13.6	89.3	51.1	5.5	6.5	5.8	68.9	17.1
10	21.8	764	928	14.8	108.8	22.0	2.0	14.3	103.5	59.6	5.9	7.5	6.3	79.3	19.7
11	22.9	755	919	16.0	122.8	24.5	2.2	14.9	117.5	68.1	6.1	8.6	6.8	89.6	22.3

Whole stand models for even-aged stands (WSM-eas)

- Stand response to silvicultural treatments

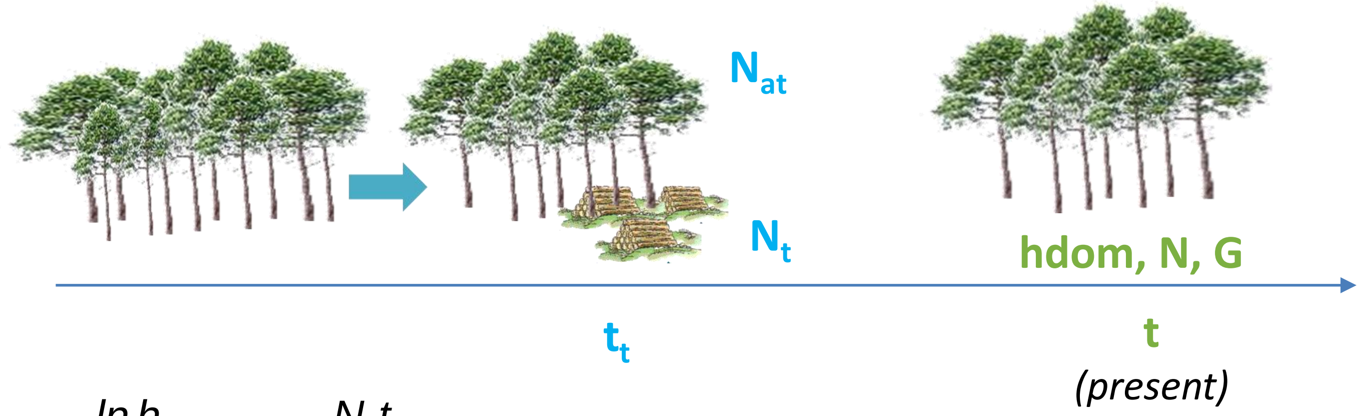
  ➔ Including stand response to silvicultural treatments into forest models is crucial for the selection of the most efficient management

  ➔ In spite of this importance, there is no established theory and the study of such models is usually made through examples

  ➔ Some examples from Burkhart and Tomé (2012) are presented here as an illustration

Whole stand models for even-aged stands (WSM-eas)

- **Stand response to thinning**
  - ➔ Pienaar and Shiver (1986)



$$\ln G = b_0 + b_1 \frac{1}{t} + b_2 \ln N + b_3 \ln h_{dom} + b_4 \frac{\ln N}{t} + b_5 \frac{\ln h_{dom}}{t} + b_6 \frac{N_t t_t}{N_{at} t}$$

- t_t = plantation age at last thinning
- N = present number of trees per unit area
- N_t = number of trees removed in last thinning
- N_{at} = number of trees remaining after last thinning
- G = basal area per unit area
- t = plantation age
- hdom = dominant height

Whole stand models for even-aged stands (WSM-eas)

Stand response to thinning

→ Pienaar and Shiver (1986)

- The term $(N_t t_t / N_{at} t)$ modifies the basal area of unthinned plantations of given age, stems per unit area, and average dominant height to predict the basal area for comparable thinned plantations
- In the non-logarithmic form of the prediction equation, it is a multiplicative modifier theoretically between 0 and 1
- For any given age, t, the earlier a thinning of given intensity (N_t / N_{at}) occurs, the larger (closer to 1) the modifier will be
- If thinnings of different intensities occur the same time ago, so that (t_t / t) and N_{at} are the same, then the modifier will be larger for the less intensive thinning.

Whole stand models for even-aged stands (WSM-eas)

- **Stand response to thinning**

  ➔ Pienaar and Shiver (1986)

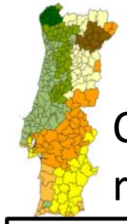
  - A basal area growth equation was derived from the previous equation

$$\ln G_2 = \ln G_1 + b_1\left(\frac{1}{t_2} - \frac{1}{t_1}\right) + b_2(t_2 - t_1) + b_3\left(1 - \frac{t_1}{t_2}\right) + b_4\left(\frac{1}{t_2^2} - \frac{1}{t_1 t_2}\right)$$

$$+ b_5 \ln N_1\left(\frac{1}{t_2} - \frac{1}{t_1}\right) + b_6 \ln h_{dom1}\left(\frac{1}{t_2} - \frac{1}{t_1}\right) + b_7\left(\frac{N_t t_t}{N_{at} t_2} - \frac{N_t t_t}{N_{at} t_1}\right)$$

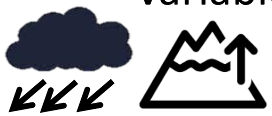
Whole stand models for even-aged stands

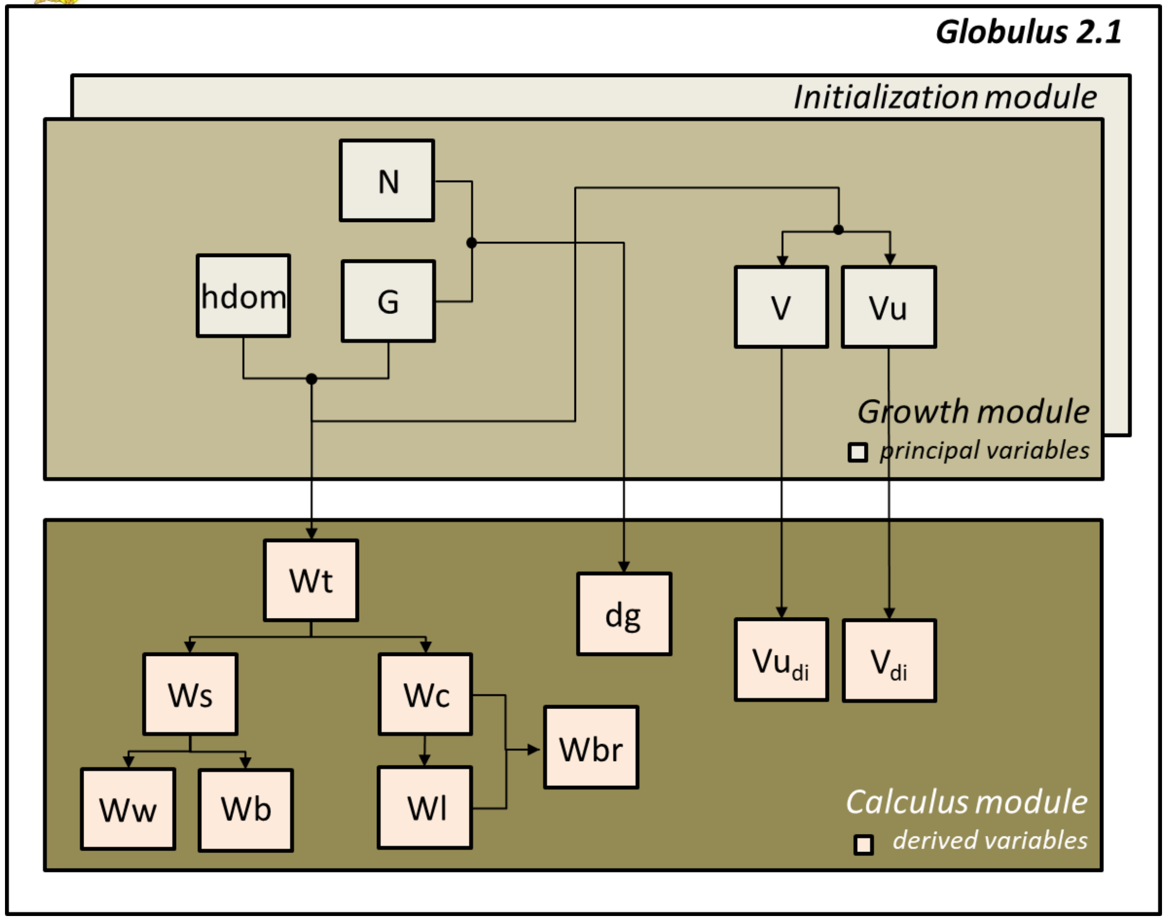
Globulus 2.1 & GLOBULUS 3.0

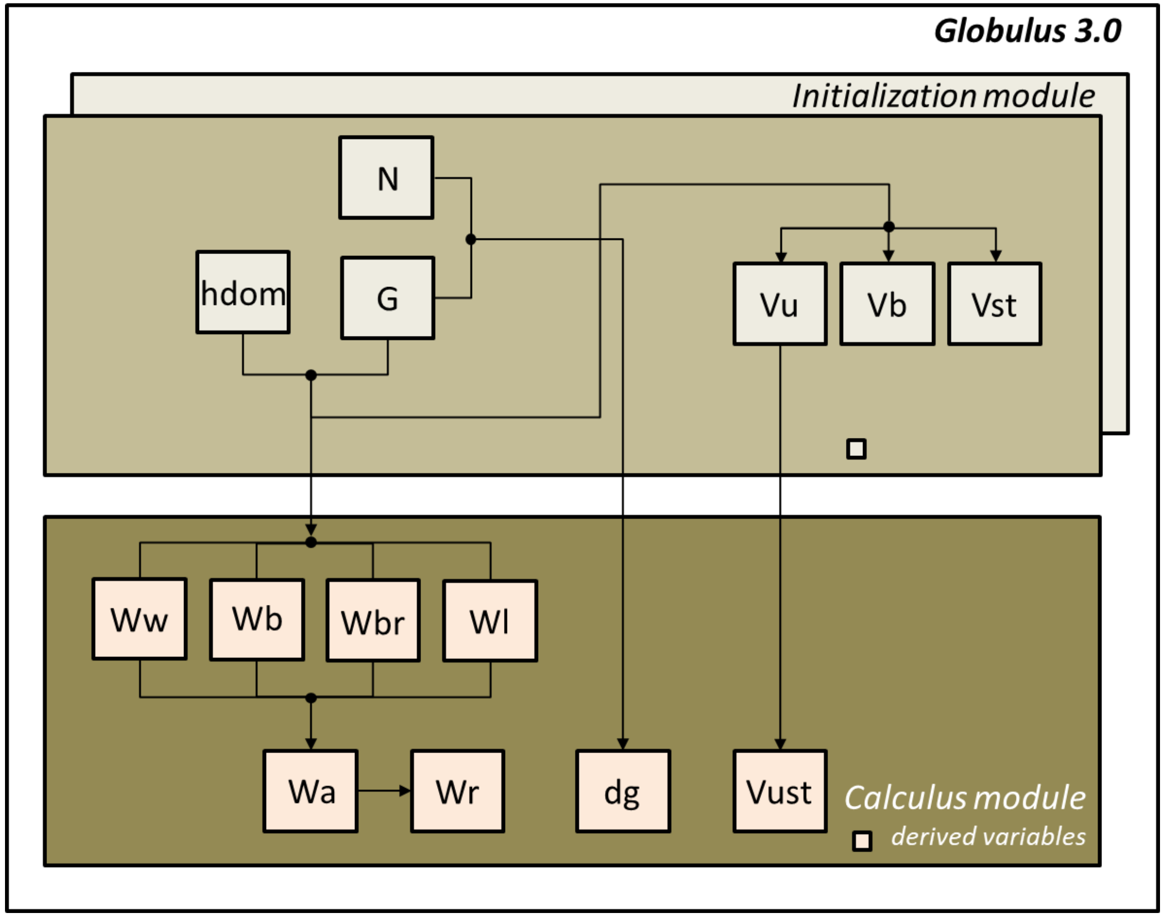


Climatic regions

Climatic topographic variables





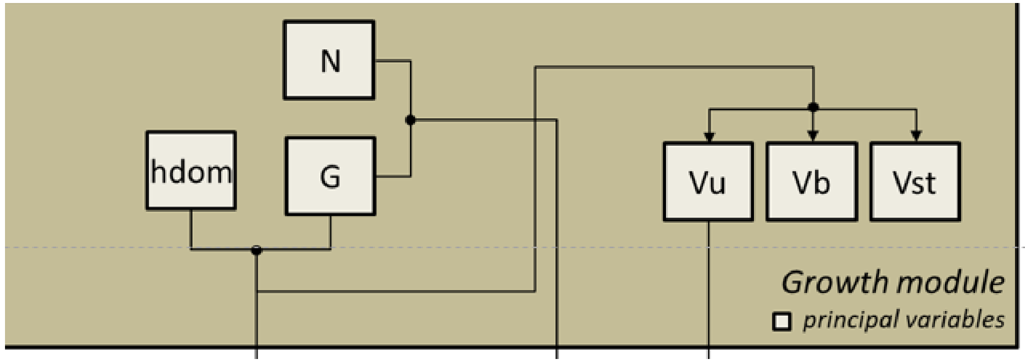


The Initialization module contains equations for the variables present in the growth module but estimates values based on control variables and/or variables previously initialized

Whole stand models for even-aged stands

GLOBULUS 3.0 – initialization vs growth

Plantation



Initialization functions

$$SI = A \left(\frac{hdom}{A}\right)^{\left(\frac{t}{tp}\right)^{n}}$$

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

$$N = Npl \; e^{-am \; t}$$

Nst	N
1234	1234
1217	1217
1201	1201
1185	1185
1170	1170

Growth functions

$$hdom_2 = A \left(\frac{hdom_1}{A}\right)^{\left(\frac{t_1}{t_2}\right)^{n}}$$

$$G_2 = A_G \left(\frac{G_1}{A_G}\right)^{\left(\frac{t_1^{\,n_{GN1}}}{t_2^{\,n_{GN2}}}\right)\left(\frac{t_1}{t_2}\right)^{\left(n_{Gp}\right)}}$$

$$N_2 = N_1 \; e^{-am \; \left(t_2 - t_1\right)}$$

No difference between stool and sprout/tree

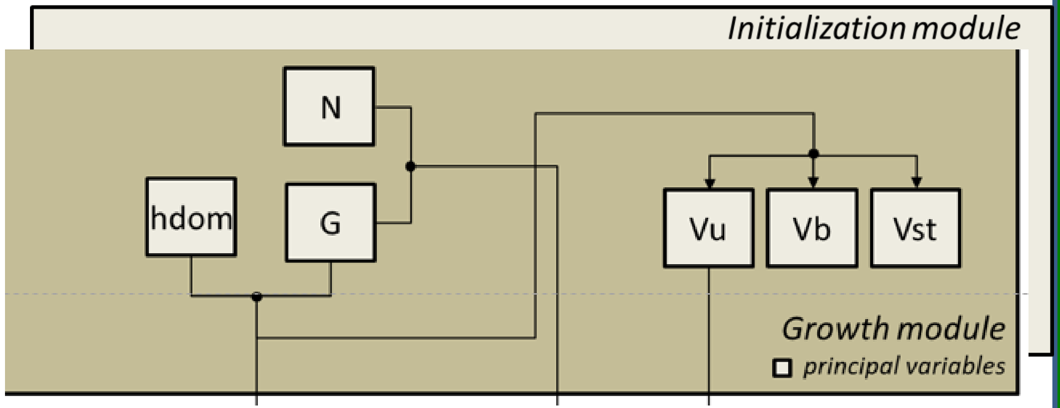
$$V_i = Kv \;\; t^{a} \; hdom^{b} \; G^{c}$$

$$V_{i2} = V_{i1} \left(\frac{t_2}{t_1}\right)^{a} \left(\frac{hdom_2}{hdom_1}\right)^{b} \left(\frac{G_2}{G_1}\right)^{c}$$

Whole stand models for even-aged stands

GLOBULUS 3.0 – initialization vs growth

Coppice



Initialization functions

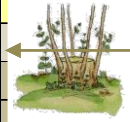
$$SI = A\left(\frac{hdom}{A}\right)^{\left(\frac{t}{tp}\right)^{n}}$$

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

$$N_{stools} = N_{harv}\left(1-death\%\right)$$

$$V_i = Kv\ t^{a}\ hdom^{b}\ G^{c}$$

Nst	Nsp
853	3926
842	4168
832	4410
822	987
812	977
802	967
793	957



Stools may have more than 1 sprout/tree

If the manager does not know how many sprouts per stool to keep, he can estimate it.

However, if he does, he just has the multiply that number by the number of living stools at the age of shoots selection

Growth functions

$$hdom_2 = A\left(\frac{hdom_1}{A}\right)^{\left(\frac{t_1}{t_2}\right)^{n}}$$

$$G_2 = A_G\left(\frac{G_1}{A_G}\right)^{\left(\frac{t_1^{\,n_{GN1}}}{t_2^{\,n_{GN2}}}\right)\left(\frac{t_1}{t_2}\right)^{\left(n_{Gp}\right)}}$$

$$N_2 = N_1\, e^{-am\left(t_2-t_1\right)}$$

$$N_{sprouts\ t\le 2} = N_{stools}\left(b_0 + b_1 t\right)$$

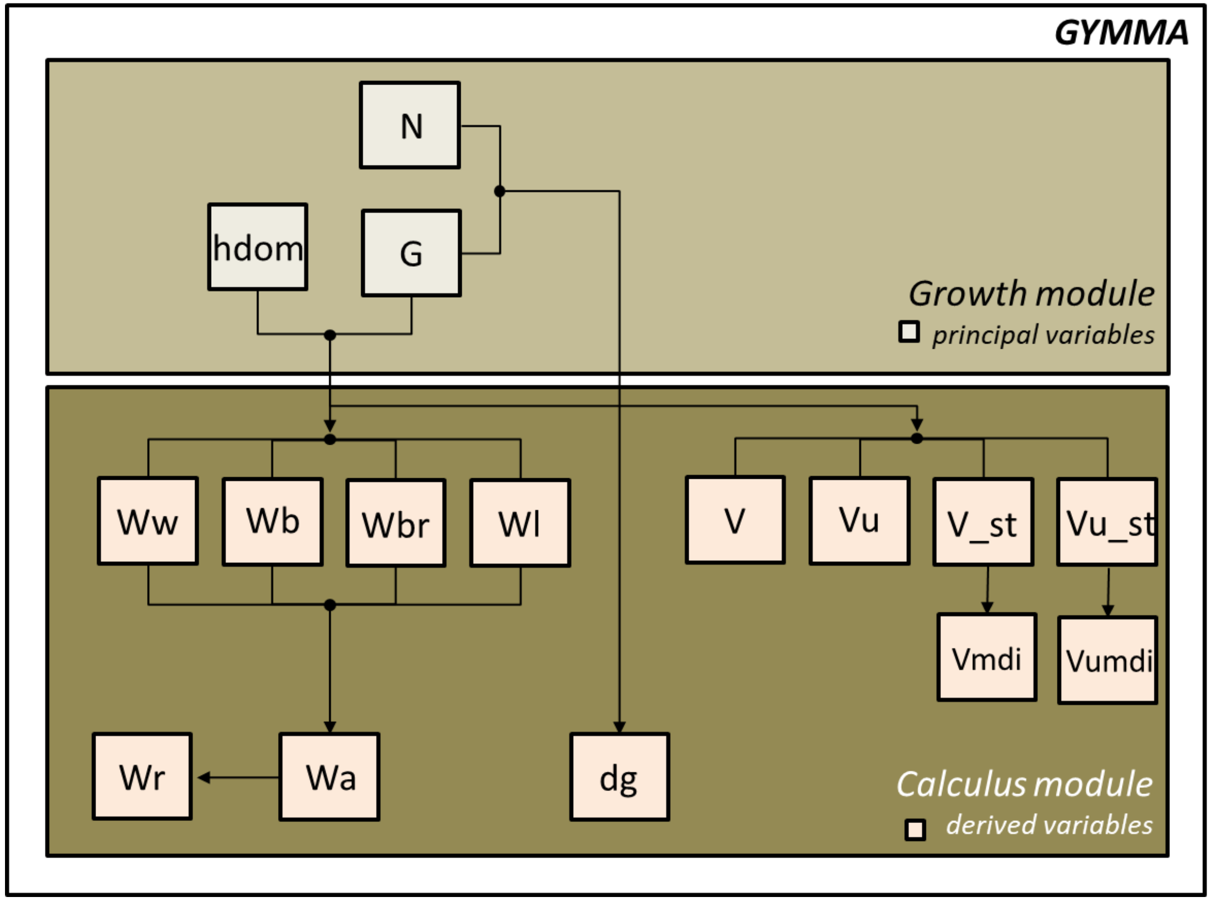
$$N_{sprouts\ t=3} = \frac{N_{stools}}{1-e^{-\left(am_2 \frac{N_{stools}}{1000} + am_3 \frac{1}{SI}\right)}}$$

$$N_{stools\,2} = N_{stools\,1}\, e^{-am\left(t_2-t_1\right)}$$

$$V_{i2} = V_{i1}\left(\frac{t_2}{t_1}\right)^{a}\left(\frac{hdom_2}{hdom_1}\right)^{b}\left(\frac{G_2}{G_1}\right)^{c}$$

Whole stand models for (un)even-aged stands

GYMMA



$$hdom_2 = A\ e^{\frac{-k}{\left(\left(\frac{-k}{\ln(hdom_1/A)}\right)^{\frac{1}{n}}+1\right)^n}}$$

$$k = k_0 + k_1\ G + k_2\ hdom$$

model	a	K_0	K_1	K_2	n
(1)	84.2463	3.0839	-0.1142	0.1202	0.4057

- GYMMA and Globulus 2.1 were compared for dominant height, basal area and volume(s) and graphical analyses showed GYMMA **performed reasonably well**.
- **However**, GYMMA will neither allow to determine the **exploitable age** nor to estimate a **site index** value for a given stand

Whole stand models for even-aged stands

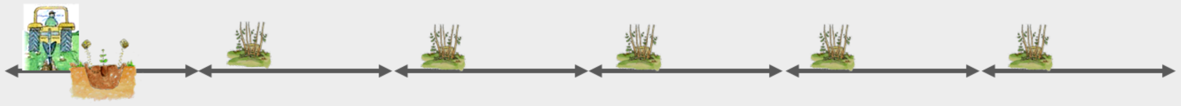
Usability

Suppose you want to simulate the growth for a period of 60 yrs testing different management schedules. How would you do it in EXCEL?

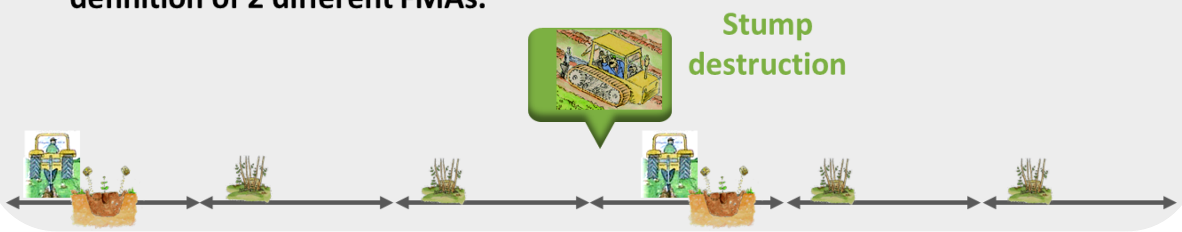
Discuss how to do it in EXCEL and solve it using with simflor.online / **StandsSIM.md**.

For a planning horizon of 60 years compare the following prescriptions:

a) **6 cycles for each the plantation is harvested at age 10, followed by 5 coppices always harvested at age 10**



b) **6 cycles all harvested at age 10, but considering a replantation in the 4th cycle. Please note that soil preparation when replanting is different which implies the definition of 2 different FMAs.**



How much standing volume of eucalyptus could be obtained over the next 30 years if a plantation with the following characteristics is made:

Location: Coruche municipality
Altitude: 14 m (if you don't know the altitude you can use the webGLOBULUS stand simulator to obtain it)
Site index: 15 m (base age 10 years)
Plantation spacing: 4 x 2.5 (the interface requires the number of trees per hectare)

a) **Consider 3 cycles with 10 years each (one plantation followed by two coppices).**

a) **Consider 3 cycles with 12 years for the plantation followed by two coppices harvested at age 9.**

The end!!