



## Growth, Yield and Carbon Balance Model

### For Planted Longleaf Pine

#### Model Version 1.31

This model allows the user to simulate stand dynamics of planted longleaf pine forests under different management scenarios. The model allows simulating the following:

- Growth and Yield (Survival; Dominant Height; Basal Area; Total Merchantable Volume outside and inside bark; Merchantable Volume inside bark partitioning in 3 wood products: sawtimber, chip-and-saw and pulpwood).
- Pinestraw production (pinestraw production from current year needlefall).
- *In Situ* Biomass stock (aboveground, coarse roots, forest floor, coarse woody debris, standing dead and understory biomass).
- *Ex Situ* C stock (dynamics of C sequestered in forest products: sawtimber, chip-and-saw and pulpwood)
- Stand C balance (*In Situ* + *Ex Situ* – Emissions due to Silviculture)
- Effects of prescribed burning on forest floor, coarse woody debris and understory biomass.



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For any publication produced from the use of this model, please use the following citation:

C.A. Gonzalez-Benecke, L.J. Samuelson, T.A. Martin, W.P. Cropper, Jr., T.A. Stokes, J. R. Butnor, K.H. Johnsen and P.H. Anderson. 2015. Modeling the effects of forest management on *in situ* and *ex situ* longleaf pine forest carbon stocks, *Forest Ecology and Management* 355: 24-36.

Thanks,

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## ACKNOWLEDGEMENT

This research was supported by the U.S. Department of Defense, through the Strategic Environmental Research and Development Program (SERDP). The authors acknowledge the U.S. Forest Service Southern Research Station for their assistance and for providing the long term datasets.

## 1. TAB: INPUTS

In this tab the user should enter the initial characteristics and the management activities of the stand to simulate, and the units (English or Metric) of the outputs calculated by the model. The model needs initial stand characteristics to start simulation. The Growth and Yield model is based on the functions reported by Gonzalez-Benecke et al. (2012a).

A summary of the stand parameters of plots used for model fitting is presented in Table 1. We suggest using initial values within the range of data used for model development.

Table 1. Summary statistics and stand characteristics for permanent longleaf pine plots used for model fitting.

Variable	Mean	SD	Minimum	Maximum
Age (yr.)	36	16	7	73
DBH (inch)	8.5	3.3	2.7	17.4
Height (ft)	61	17	17	99
N (trees / acre)	350	204	40	1,153
BA (ft <sup>2</sup> / acre)	118	49	29	274
Dq (inch)	8.9	3.3	2.8	17.4
SDI (trees / acre)	229	90	52	495
Hdom (ft)	68	18	22	105
SI (ft) (base age=50 yrs.)	85	6	64	101
VOL <sub>0B</sub> (ft <sup>3</sup> / acre)	3,924	2,018	667	9,841

### - Units (Outputs) (D1:D3)

Select units for **OUTPUT** by clicking the option button. If the user wants English units, then select “English” (D2). If the user wants Metric units, then select “Metric” (D3).

Note: all **INPUT** values should be entered in English units.

### - Type of Simulation (A2:B4)

Select simulation options by clicking the option button. The model can run from Establishment (B3) or from an inventory at any age post establishment (B4).

- **Rotation Age (A6:B6)**

Enter in cell **B6** the age when simulation ends (unit: years). We suggest not using the model beyond age 80 years.

- If the type of simulation selected was “**From Establishment**”:

- **Enter stand data at planting: (A9:B12)**

Enter planting density (**B10**), unit: trees / acre

Enter first year survival (**B11**), unit: % (default value =95%)

Enter site index (base age=50 years), (**B12**) unit: feet.

- If the type of simulation selected was “**From Inventory Post Establishment**” there are two options:

**a) Simulation from Inventory Tree List: Click the option button in cell E6.**

The user has to input **Inventory data list in TAB: INVENTORY**

**Important:** Do not input any data in tab “Inputs” cells **E11:E14**.

Go to tab “INVENTORY” by clicking button “Go To Inventory”.

Type or copy and paste a list (as column) of the diameter at breast height (DBH) of all trees in a single inventory plot (Column B, starting in cell **B4**), unit: inch.

If total HEIGHT of some or all inventory trees is available, also type or copy and paste in column C (starting in cell **C4**), unit: feet.

Enter stand age (**Q3**) at time of inventory, unit: years.

Enter inventory plot size (**Q4**), unit: acre.

If HEIGHT was measured in a subsample, the system calculates the missing heights in one of two ways:

- If HEIGHT was measured in more than 3 trees: missing HIEGHT is calculated using a local H-D function determined with the trees with HEIGHT and DBH measurements.
- If HEIGHT was measured in less than 4 trees: missing HIEGHT is calculated using a general H-D function published by Gonzalez-Benecke et al. (2013).

Note: For missing HEIGHT just leave blank cells. The system calculates stand density (**V4**), Basal Area (**V5**), Dominant Height (**V6**) and Site Index at base age=50 years (**V7**).

After checking that stand-level parameters in cells **V4:V7** were calculated, go back to INPUTS tab by clicking the button “Go To Inputs” in cell **Y4**.

**b) Simulation from Inventory Summary: Click the option button in cell E7**

If you already have summary data calculated from one or more measurement plots, you may enter Inventory Summary data (**F11:F14**)

- Enter stand age at time of inventory (**F11**), unit: years.
- Enter stand density (**F12**), unit: trees / acre.
- Input site index (base age=50 years) (**F14**), unit: feet.
- Optional: Input Basal Area (**F13**), unit ft<sup>2</sup> /acre.

Note: If BA is not available, the system calculates BA using stand Age, N/acre and SI (using the function reported in: Gonzalez-Benecke et al. 2012b).

**SITE INDEX CALCULATOR:**

If the user wants to estimate SI at base age=50 yrs. using known dominant height and age, click the button “**Site Index Calculator?**” in cell **N11**. The model use the function reported in: Gonzalez-Benecke et al. 2012b).

- Enter dominant height (**B3**), unit: ft.
- Enter stand age (**B4**), unit: years.

## SIMULATING THINNINGS:

If the user wants to simulate thinning, click the selection button “**Simulate Thinning?**” in cell **B15**.

The model can run up to 4 thinnings. The thinning method is random (same proportion of BA and N is removed at each thinning and there is no change in quadratic mean diameter after and before thinning).

Select thinning type by clicking one option button in cells **B22:B24**. The model can simulate thinning at fixed Age (**B22**), at Target BA (**B23**) or from Target Stand Density Index (**B24**).

- **Thinning at fixed age:** The user can simulate up to 4 thinnings. The user has to enter thinning age (years) and percentage of removal (%) in cells **B27** to **C30**. If less than 4 thinnings will be simulated, the corresponding input cells should be left in blank (no zeros or any number). As thinning is random, the same % of BA and trees/acre are removed each thinning.
- **Thinning at Target BA:** The user enters the Target BA (Upper Stocking Limit BA, cell **A34**) at which thinning is triggered, and the residual BA (**B34**) after the thinning. Unit: ft<sup>2</sup> / acre. Depending on stand characteristics (age, N per acre and SI), the model can simulate up to 4 thinnings.
- **Thinning at Target Stand Density Index:** The user has to enter the thinning threshold (**A35**) at which thinning is triggered and the lower limit for full site occupancy (**B35**). These values are set as a percentage of the maximum SDI observed for the species (Gonzalez-Benecke et al. 2012). This maximum value is shown in cell **D34**. This value can be changed by the user (recommended for experienced users only).

## SIMULATING STAND GROWTH AND YIELD:

If the user wants to simulate stand growth and yield, then click the button in cell **F2** (“**RUN Growth & Yield**”). The user will be directed to the TAB: “Report\_G&Yield” (if English units were selected in option button **D2**) or to the TAB: “Report\_G&Yield\_Metric” (if Metric units were selected in option button **D3**).

For further details on Growth and Yield Reports, please refer to TAB: “Report\_G&Yield”.

## SIMULATING NET C BALANCE:

If Carbon balance is to be simulated, the user should click the selection button in cell **B18** and select the number of rotations that should be included in Net C Balance estimations. The maximum simulation length is 500 years, so the number of rotations entered multiplied by the rotation age should not be larger than 500 yrs. Further description of biomass dynamics modelling can be found in Gonzalez-Benecke et al. 2015b.

After previous step, the user can click the button in cell **G2** (“**RUN C Balance**”). The user will be directed to the TAB: “**SUMMARY\_C**”, where a summary of In Situ, Ex Situ and Silviculture Emissions are shown as an average of yearly values for the simulation period. See TAB 6: **SUMMARY\_C** for further details.

Simulation options for Biomass and Carbon Dynamics:

- **Already Thinned?:** For simulations from Inventory Data, if the stand was thinned before inventory, the user has to click the selection button in cell **E16** in order to adjust standing dead tree biomass (when assessing C Balance).
- **Simulate Prescribed Burning:** The model can simulate the effects of prescribed burning on biomass dynamics of understory, forest floor, coarse woody debris and standing dead trees.
  - If site preparation includes Burning Residues, then click the selection button in cell **E20**.
  - If prescribed burning is to be included in stand biomass dynamics simulation, the stand Age at first burning (in years) should be enter in cell **E22** and the burning frequency (in years) should be entered in cell **E23**.
  - If the stand was previously burned, the user should click the selection button in cell **E24**.
  - The model also simulate the effects of prescribed burning on understory biomass dynamics using the functions reported by Gonzalez-Benecke et al. 2015a.

Note: If prescribed burning will not be included as a management alternative, please leave blank cells **E22** and **E23**. At this time the model assumes no effect of prescribed burning on longleaf pine stand mortality. A function to determine the proportion of dead trees after burning will be incorporated in a future version.

At this time, the model only includes one function for shrubs biomass, independent of site type. Separated functions for xeric, intermediate and mesic sites will be incorporated in a future version.

## 2. TAB: INVENTORY

This TAB is revealed when the Button “Go To Inventory” is clicked in Cell **M11** (needed to determine initial parameters when simulation From Inventory Post Establishment (**B4**) using Inventory Tree List (**E7**) option buttons were selected as simulation method).

- Type or copy and paste a list (as column) of all DBH in the inventory plot (Column B, starting in cell **B4**), unit: inch
- If HEIGHT is available, also type or copy and paste in column C (starting in cell **C4**), unit: feet
- Enter stand age at time of inventory (**Q3**), unit: years
- Enter inventory plot size (**Q4**), unit: acre
- If HEIGHT was measured in a subsample, the system calculates the missing heights in one of two ways:
  - If HEIGHT was measured in more than 3 trees: missing HEIGHT is calculated using a local H-D function determined with the trees with HEIGHT and DBH measurements.
  - If HEIGHT was measured in less than 4 trees: missing HEIGHT is calculated using a general H-D function published by Gonzalez-Benecke et al. (2013).

Note: The system calculate stand density (**V4**), Basal Area (**V5**), Dominant Height (**V6**) and Site Index at base age=50 years (**V7**).

After checking that stand-level parameters in cells **V4:V7** were calculated, go back to TAB: INPUTS by clicking the button “Go To Inputs” in cell **Y4**.

### 3. TAB: “REPORT\_G&Y” or “REPORT\_G&Y\_METRIC”

The tab shows a report of stand parameters at starting age and at rotation age after clicking the button “**RUN Growth & Yield**”. If thinning was carried out, details of stand characteristics after and before each thinning are shown.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **REPORT\_G&Y**. If the output unit selected was “Metric” (D3), the model will show the TAB: **REPORT\_G&Y\_METRIC**.

The user can decide if yield output is presented as merchantable volume (inside or outside bark) or as green tons, inside or outside bark) by clicking one option button in cell **B32** (volume outside bark), **B33** (volume inside bark), **C32** (green tons outside bark) or **C33** (green tons inside bark). A volume to weight factor of 37.75 was used to transform ft<sup>3</sup> to green ton.

The units will be English if TAB: **REPORT\_G&Y** was displayed, or Metric if TAB: **REPORT\_G&Y\_METRIC** was displayed.

From this TAB the user also can:

- Run Carbon Balance Modeling, by clicking button “**RUN C Balance**” in cell **E31**.
- Start a new simulation, by clicking button “**New Simulation?**” in cell **G31**.
- Print a Report, by clicking button “**PRINT**” in cell **H31**.

### 4. TAB: “REPORT\_STAND\_TABLE” or “REPORT\_STAND\_TABLE\_METRIC”

The tab is shown as complimentary information when the TAB: **REPORT\_G&Y** was shown after clicking the button “**RUN Growth & Yield**”. This report shows a stand table at rotation age using the equations reported by Leduc et al. (2014; unpublished) that used neural network modelling.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **REPORT\_STAND\_TABLE**. If the output unit selected was “Metric” (D3), the model will show the TAB: **REPORT\_STAND\_TABLE\_METRIC**.

The stand table uses 1 inch DBH classes. For each DBH class, the table shows stem density, mean height, basal area, merchantable volume and merchantable green weight. The user can decide if merchantable volume and

merchantable green weight are presented as outside bark (by clicking one option button in cell **B31**) or inside bark (by clicking one option button in cell **B32**).

The units will be English if TAB: **REPORT\_STAND\_TABLE** was displayed, or Metric if TAB: **REPORT\_STAND\_TABLE\_METRIC** was displayed.

From this TAB the user also can:

- Run Carbon Balance Modeling, by clicking button “**RUN C Balance**” in cell **E31**.
- Start a new simulation, by clicking button “**New Simulation?**” in cell **G31**.
- Print a Report, by clicking button “**PRINT**” in cell **H31**.

## 5. TAB: “**SUMMARY\_G&Y**” or “**SUMMARY\_G&Y\_METRIC**”

The tab is shown as complimentary information when the TAB: **REPORT\_G&Y** was shown after clicking the button “**RUN Growth & Yield**”.

The tab shows a summary of stand parameters from the growth and yield model (from simulation starting age to rotation age).

If in “INPUT” TAB, the output unit selected was “English” (**D2**), the model will show the TAB: **SUMMARY\_G&Y**. If the output unit selected was “Metric” (**D3**), the model will show the TAB: **SUMMARY\_G&Y\_METRIC**.

At each age, details of N (stand density), Hdom (dominant height), BA (basal area), Dq (quadratic mean diameter), SDI (stand density index), VOB (Merchantable stem volume outside bark), VIB (Merchantable stem volume inside bark), VIB-ST (sawtimber volume inside bark), VIB-CNS (chip-and-saw volume inside bark) and VIB-PW (pulpwood volume inside bark). Also Current Annual Increment in stem volume outside Bark (CAI-VOB) and Mean Annual Increment in stem volume outside bark (MAI-VOB) are displayed.

The units will be English if TAB: **SUMMARY\_G&Y** was displayed, or Metric if TAB: **SUMMARY\_G&Y\_METRIC** was displayed.

The user should go to TAB: **REPORT\_G&Y** for further actions as Run Carbon Balance or Run a New Simulation.

## 6. TAB: “PINESTRAW” or “PINESTRAW\_METRIC”

The tab is shown as complimentary information when the TAB: **REPORT\_G&Y** was shown after clicking the button “**RUN Growth & Yield**”.

If in “INPUT” TAB, the output unit selected was “English” (**D2**), the model will show the TAB: **Pinestraw**. If the output unit selected was “Metric” (**D3**), the model will show the TAB: **Pinestraw \_METRIC**.

This tab shows the pinestraw production (from simulation starting age to rotation age). If bale weight is entered in cell **G2** and pinestraw harvest efficiency (%) is entered in cell **H2**, the model will estimate bale production each year. The system assumes no effect of prescribed burning.

The units will be English if TAB: **Pinestraw** was displayed, or Metric if TAB: **Pinestraw \_METRIC** was displayed.

The user should go to TAB: **REPORT\_G&Y** for further actions as Run Carbon Balance or Run a New Simulation.

## 7. TAB: “SUMMARY\_C” or “SUMMARY\_C\_METRIC”

The tab shows a report of Carbon Stock Modeling after clicking the button “**RUN C Balance**”.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **SUMMARY\_C**. If the output unit selected was “Metric” (D3), the model will show the TAB: **SUMMARY\_C\_METRIC**.

In this tab a summary of *In Situ*, *Ex Situ* and Silviculture Emissions are shown as an average of yearly values for the simulation period.

This tab also shows the dynamics of the *In Situ* (Living longleaf pine, Forest floor, Dead Pool – standing dead, harvest residues and CWD – and Understory) and *Ex Situ* (forest products sawtimber, chip-and-saw and pulpwood) Carbon Pools. Three figures are displayed in this report: A bar graph showing the average values of *In Situ* C stock (Living Longleaf Pine, Forest Floor, Dead Longleaf Pine and Understory), *Ex Situ* C stock (sawtimber, chip-and-saw, and pulpwood) and Silviculture Emissions. Also two line graphs show the time series of *In Situ* and *Ex Situ* C Stock, from simulation starting age to rotation age at last rotation selected.

The units will be English (ton C /acre) if TAB: **SUMMARY\_C** was displayed, or Metric (tonne C / ha) if TAB: **SUMMARY\_C\_METRIC** was displayed.

Note: The model does not include soil C dynamics. The model assumes that soil C is in steady state condition.

From this TAB the user also can:

- Run Growth and Yield Modeling, by clicking button “**RUN Growth and Yield**” in cell V2.
- Start a new simulation, by clicking button “**New Simulation?**” in cell V6.
- Print a Report, by clicking button “**PRINT**” in cell V10.

## 8. TAB: “IN\_SITU” or “IN\_SITU\_METRIC”

The tab is shown as complimentary information when the TAB: **SUMMARY\_C** was shown after clicking the button “**RUN C Balance**”.

This tab shows the *In Situ* biomass of the stand. Details of Living Longleaf Pine (stemwood, bark, foliage, branch and coarse roots), Dead Longleaf Pine (standing dead, forest floor, thinning and harvest residues) and Understory Biomass at each simulation age are shown. Also Longleaf Pine projected leaf area index (LAI, m<sup>2</sup> / m<sup>2</sup>) is presented.

Above-ground biomass functions from Samuelson et al. (2016). Below-ground biomass functions from Gonzalez-Benecke et al. (2015 ) using data collected by Center for Longleaf Pine Ecosystems (<http://clpe.auburn.edu/>). Needlefall estimated from foliage biomass, assuming 2 years needle retention.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **IN\_SITU**. If the output unit selected was “Metric” (D3), the model will show the TAB: **IN\_SITU\_METRIC**.

The units will be English if TAB: **IN\_SITU** was displayed, or Metric if TAB: **IN\_SITU\_METRIC** was displayed.

The user should go to TAB: **SUMMARY\_C** for further actions as Run Growth and Yield or Run a New Simulation.

## 9. TAB: “EX\_SITU” or “EX\_SITU\_METRIC”

The tab is shown as complimentary information when the TAB: **SUMMARY\_C** was shown after clicking the button “**RUN C Balance**”.

This tab shows the dynamics of the *Ex Situ* Carbon Pool. Details of C sequestered in forest products sawtimber (ST), chip-and-saw (CNS) and pulpwood (PW) is presented, assuming industrial conversion efficiencies and product proportion in 4 half-life classes defined in TAB: EQUATION – PARAMETERS, CELLS **A127** to **F133**.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **EX\_SITU**. If the output unit selected was “Metric” (D3), the model will show the TAB: **EX\_SITU\_METRIC**.

The units will be English if TAB: **EX\_SITU** was displayed, or Metric if TAB: **EX\_SITU\_METRIC** was displayed.

The user should go to TAB: **SUMMARY\_C** for further actions as Run Growth and Yield or Run a New Simulation.

## 10.TAB: “C\_STOCK” or “C\_STOCK\_METRIC”

The tab is shown as complimentary information when the TAB: **SUMMARY\_C** was shown after clicking the button “**RUN C Balance**”.



This tab shows the dynamics of the *In Situ* (Living longleaf pine, Forest floor, Dead Pool – standing dead, harvest residues and CWD – and Understory), *Ex Situ* (forest products sawtimber, chip-and-saw and pulpwood) and Emissions due to Silviculture Carbon Pools.

If in “INPUT” TAB, the output unit selected was “English” (D2), the model will show the TAB: **C\_STOCK**. If the output unit selected was “Metric” (D3), the model will show the TAB: **C\_STOCK\_METRIC**.

The units will be English if TAB: **C\_STOCK** was displayed, or Metric if TAB: **C\_STOCK\_METRIC** was displayed.

The user should go to TAB: **SUMMARY\_C** for further actions as Run Growth and Yield or Run A New Simulation.

There are other hidden tabs:

## 11.TAB: EQUATIONS - PARAMETERS

This tab is hidden and protected and the user should not change it.

If the user wants to view the equations and parameters used in this model system, then click the button “**Edit Equations / Parameters**” in TAB: INPUTS, cell **N2**.

If the user wants to make changes to some of the parameters the spread sheet can be unprotected by using a password that may be provided on request from the model administrator at [www.carboncenter.ifas.ufl.edu/models/](http://www.carboncenter.ifas.ufl.edu/models/)

This TAB shows details of function parameters for growth and yield (cells **A4** to **J69**), longleaf pine biomass (cells **A75** to **J97**; Baldwin and Saucier 1983; Santantonio et al. 1977), needlefall/litterfall ratio (cells **A98** to **J101**; Gonzalez-Benecke et al. 2012a), understory biomass (cells **A102** to **J104**; Gonzalez-Benecke et al. 2010), forest floor accumulation (cells **A105** to **J109**) and standing dead longleaf pine biomass (cells **A110** to **J112**).

Other parameters such as Carbon Concentration in biomass, decay rate, specific needle area, specific gravity (as a function of age), product (sawtimber, chip-and-saw, pulpwood) diameter threshold and half-life(**A127** to **H133**; Gonzalez-Benecke et al. 2010) , percentage of commercial volume in residues after harvest (**A138** to **B140**; Gonzalez-Benecke et al. 2010), percentage of consumption by fire (for needles, branches, coarse woody debris, standing dead trees and understory; Reinhardt 2003), and function parameters for fuel consumption recovery for understory are shown in rows **153** to **157** (models fitted from: Digital Photo Series <http://depts.washington.edu/nwfire/dps/>; Kirkman et al 2001; Lavoie et al 2010).

Silviculture cost for different management activities such as site preparation, machine planting, weed control, fertilization, prescribed burning, thinning, harvest and transport are shown in cells **A159** to **B167** (Markewitz 2005; Chapagain 2012).

To go back to TAB: INPUTS, click the button “Go To Inputs” in cell **L2**.

## 12.TAB: GROWTH\_&\_YIELD

This tab shows details of all computations for the growth and yield model.

This tab is hidden and protected and the user should not change it.

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