Supplemental Material

Our analysis used a modified version of the 3-PG model (Landsberg and Waring, 1997). A detailed description of model modifications can be found in Gonzalez-Benecke et al. (2016). In this section, we describe the major assumptions of the model, highlighting our modifications.

At a monthly step, the model first calculates absorbed photosynthetically active radiation (APAR), using photosynthetically active radiation (PAR) computed from monthly mean solar radiation input, and light interception. Canopy light interception is computed from projected leaf area index (LAI, m^2 m^{-2}) using Beers Law. LAI was previously computed from foliage biomass (WF, Mg ha^{-1}) and projected specific needle area (SNA, m^2 kg^{-1}), corrected by foliage loss due to needlefall. For stands that have not reached canopy closure, a canopy closure index (CanCover, the proportion of ground area covered by the stand canopy) is computed to better calculate APAR. We developed new functions to estimate CanCover (as a function of stand age and basal area) and needlefall (as a function of phenological month and maximum monthly fractional rate of needlefall).

The canopy quantum efficiency (α_c, mol C mol^{-1} photon) is adjusted using the maximum quantum yield parameter observed under optimum conditions (α_{cx}) reduced by seven growth modifiers that account for air temperature, number of frost days, soil moisture, vapor pressure deficit, atmospheric [CO_2], stand age, and soil fertility. These modifiers can take a value between 0 and 1 (except for the CO_2 modifier which took values greater than 1 if atmospheric CO_2 was greater than 350 ppm).

$$\alpha_c = \alpha_{cx} \times f(\mathrm{Temp}) \times f(\mathrm{FrostDays}) \times f(\mathrm{VPD}) \times f(\mathrm{ASW}) \times f(\mathrm{CO_2}) \times f(\mathrm{Age}) \times f(\mathrm{Nutr})$$

In our modified model, the soil fertility rating (FR) - the factor that is included in f(Nutr) determination - was computed as a function of site index (SI), f(FrostDays) was computed as a function of the number of frost days and the frost intensity, and $f(CO_2)$ was determined using the approach described by Almeida et al. (2009) as follows:

$$f(\mathrm{CO_2}) = \frac{\mathrm{fCalpha_x} \cdot \mathrm{CO_2}}{350 \cdot (\mathrm{fCalpha_x} - 1) + \mathrm{CO_2}} \text{ , where } \mathrm{fCalpha_x} = \frac{\mathrm{fCalpha700}}{(2\text{-}\mathrm{fCalpha700})}$$

Using data from Ward et al. (2015), we estimated a value for fCalpha700 = 1.17.For CO_2= 350, 550 and 700 ppm, $f(CO_2)$ =1.0, 1.118 and 1.170, respectively.

Gross primary production (GPP, Mg ha^{-1} $month^{-1}$) is computed using the adjusted α_c and APAR and net primary production (NPP, Mg ha^{-1} $month^{-1}$) is calculated assuming a constant respiration proportion of 0.47. NPP is then allocated to the different biomass pools (foliage, WF; roots, WR and aboveground woody, WS) using partitioning coefficients (in 3-PG nomenclature, aboveground woody biomass is called stem biomass, WS). Root and foliage abscission are computed and discounted from the corresponding WR and WF pools. We modified the function that accounts for NPP allocation changes to WF and WS. We developed a new function that determines the fraction of NPP allocated to WF in relation to the fraction of NPP that is allocated to WS (pFS) as a function of stand age and quadratic mean diameter (qmd, cm) as the variables that account for such changes. We computed qmd, rather than mean diameter at breast height, using alternative stand-level functions that correlate qmd with WS, age, and number of trees per hectare.

In the water balance module, the model computes canopy conductance to water vapor, using the species-specific maximum canopy conductance (m s^{-1}), LAI, and adjusts the value depending on soil moisture, VPD, and stand age. Following Ward et al. (2015), the downregulating effect of atmospheric [CO_2] on canopy conductance was negligible so we used of fCg700 = 1 (no effect of CO_2 on canopy conductance) on the equation proposed by Almeida et al. (2009). After that, stand transpiration (mm $month^{-1}$) is calculated using the Penman-Monteith model, and canopy evaporation is determined using LAI, canopy interception, and the amount of rainfall. Stand evapotranspiration (ET) is computed as canopy transpiration + canopy evaporation. Changes in available soil water are then computed as the difference between rainfall and evapotranspiration losses.

In the tree mortality module, the model first calculates average single tree stem biomass (kg $tree^{-1}$). If that value is lower than the target single tree stem biomass at a stand density of 1000 trees ha^{-1}, then mortality is computed using a density-independent mortality function. If the average single tree stem biomass exceeds the biomass of the target stem biomass, then the number of trees is reduced using the self-thinning rule. If that average single tree stem biomass is smaller than the target stem biomass, then the number of trees is reduced using a mortality function from a published growth and yield model. After computing the number of dead trees, stocking and biomass pools are re-calculated. Then, stand basal area (BA, m^2 ha^{-1}) is computed from qmd and the updated tree density; bole volume inside bark (VIB, m^3 ha^{-1}) is computed from the updated WS (discounting the fraction of bark and branches, fracBB) and wood basic specific gravity (SG); and bole volume outside bark (VOB, m^3 ha^{-1}) is computed from VIB and the bark volume fraction. Mean tree height is computed using a new function that depends on stand age, qmd, and number of trees per hectare.

For the next time step (month), using the updated values of trees per ha, WS, WF and WR, the cycle is repeated, adjusting all the age-dependent functions. As we defined the starting age for our runs at the end of the first growing season, we determined initial biomass using the height-biomass functions reported in Gonzalez-Benecke et al. (2016) and a relationship between SI (m) and mean height of the stand at the end of first growing season (H1, m):

$$\mathrm{H1} = 0.10903 \cdot \mathrm{e}^{0.07337 \cdot \mathrm{SI}}$$

This model predicts, for stands with SI= 15, 23 and 30 m, a mean height at the end of the first growing season of 0.33, 0.59 and 0.99 m, respectively. To develop this equation, we used data from Jokela and Martin (2000) and Adegbidi et al (2002) from plots that had both, mean height at the end of the first growing season and mean dominant height at age 25 years (SI).

The 3-PG version used in this study was 3-PGpjs2.7 (Sands, 2010), which was implemented as a Microsoft Excel spreadsheet using Visual Basic for Applications. The model can be obtained from the corresponding author upon request.