The 3PG model
Applications to the Portuguese production forest

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Summary

- Overview of 3PG (brief)
- 3PG calibration (example with *E. globulus*)
- 3PG validation (examples at plot and stand level)
- Improving “information for managers” (hybridization)
- The 3PGpjs2.7.xls implementation
- Examples

Overview of 3PG

3PG is

- A tree growth model based on **P**hysiological **P**rinciples that **P**redict **G**rowth
- Bridges the gap between mensuration-based growth and yield models and process-based, carbon balance models
- Provides fully dynamic predictions of biomass pools and soil water use
- Includes process-based and empirical relationships
- Is based on a monthly time step

Comparison with empirical models

- Advantages
  - applicable under changing conditions
  - can be adapted for a range of species
  - parameterised using stand-level data
  - provides explanation, aids understanding
- Disadvantages
  - not as widely understood as empirical growth models
  - not necessarily as accurate, either
  - can require data not readily available
  - less detailed output
  - naïve treatment of soil nutrition, allocation based largely on size, poor predictor of canopy development and of mortality

Input data

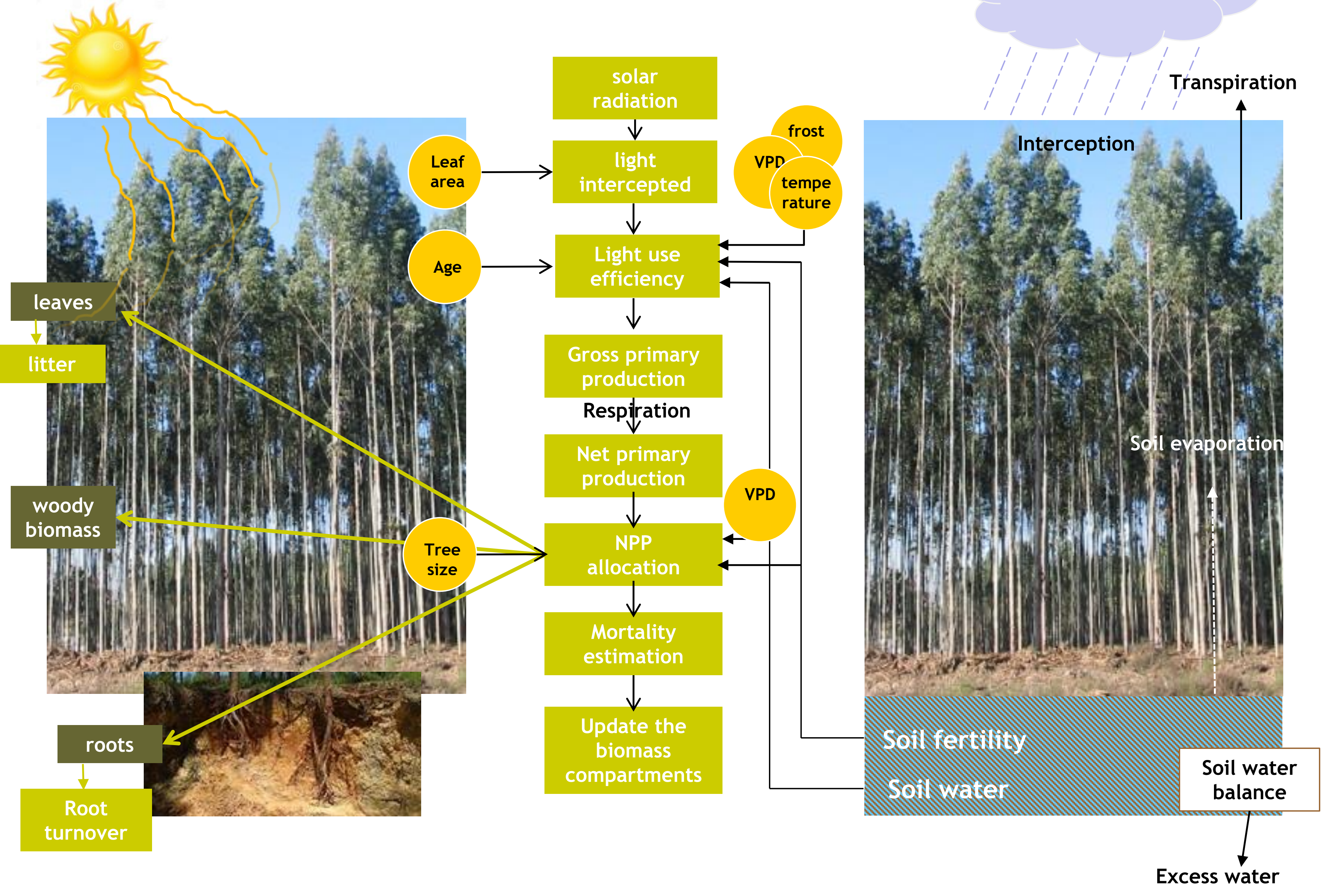
- Climate data
  - monthly mean temperature, radiation, rainfall, VPD
  - observed or long-term average data of the same variables
- Site and soil descriptors
  - latitude
  - soil texture and maximum soil water capacity
  - fertility rating (0-1)
- Also need stand initialisation data
  - foliage, stem+bark+branches and root biomass
  - stocking

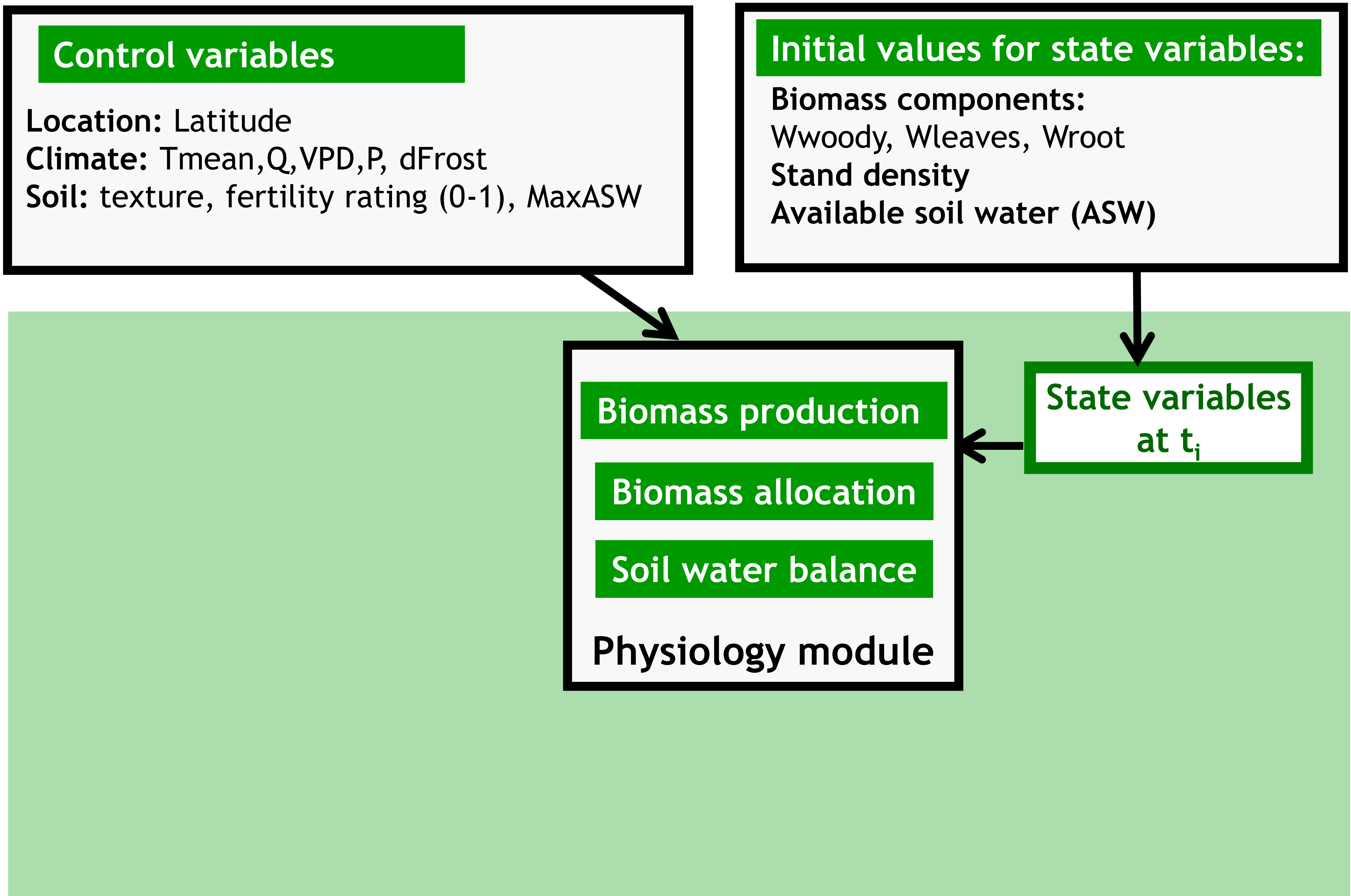
Outputs

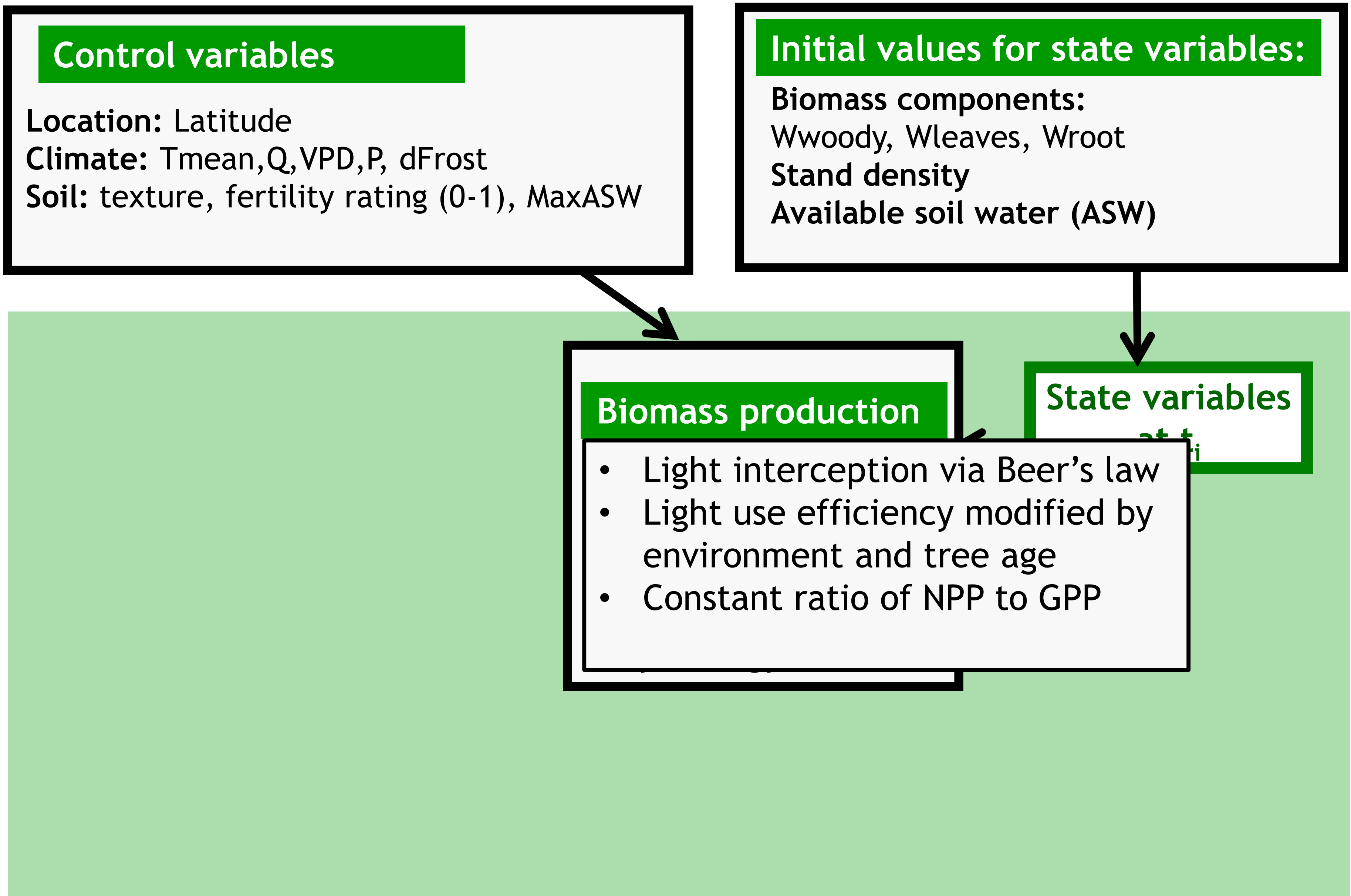
- Biomass pools (wood+bark+branches, leaves and roots)
- Stocking
- Available soil water
- NPP
- Evapotranspiration
- Average dbh
- Underbark volume
- Stand basal area

Main components of 3PG

- **Production of biomass** – environmental modification of light use efficiency; constant ratio of NPP to GPP
- **Biomass allocation** – affected by growing conditions +tree size
- **Stem mortality** – probability of death; self-thinning
- **Soil water balance** – single soil layer model; evapotranspiration determined from Penman-Monteith equation
- **Stand properties** – from biomass pools and assumptions about specific leaf area, branch+bark fraction, and wood density


solar radiation
light intercepted
Light use efficiency
Gross primary production
Respiration
Net primary production
NPP allocation
Mortality estimation
Update the biomass compartments
Leaf area
Age
Tree size
frost
VPD
tempe rature
VPD
leaves
litter
woody biomass
roots
Root turnover
Transpiration
Interception
Soil evaporation
Soil fertility
Soil water
Soil water balance
Excess water


Control variables
Location: Latitude
Climate: Tmean,Q,VPD,P, dFrost
Soil: texture, fertility rating (0-1), MaxASW
Initial values for state variables:
Biomass components:
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Biomass production
Biomass allocation
Soil water balance
Physiology module
State variables at t_i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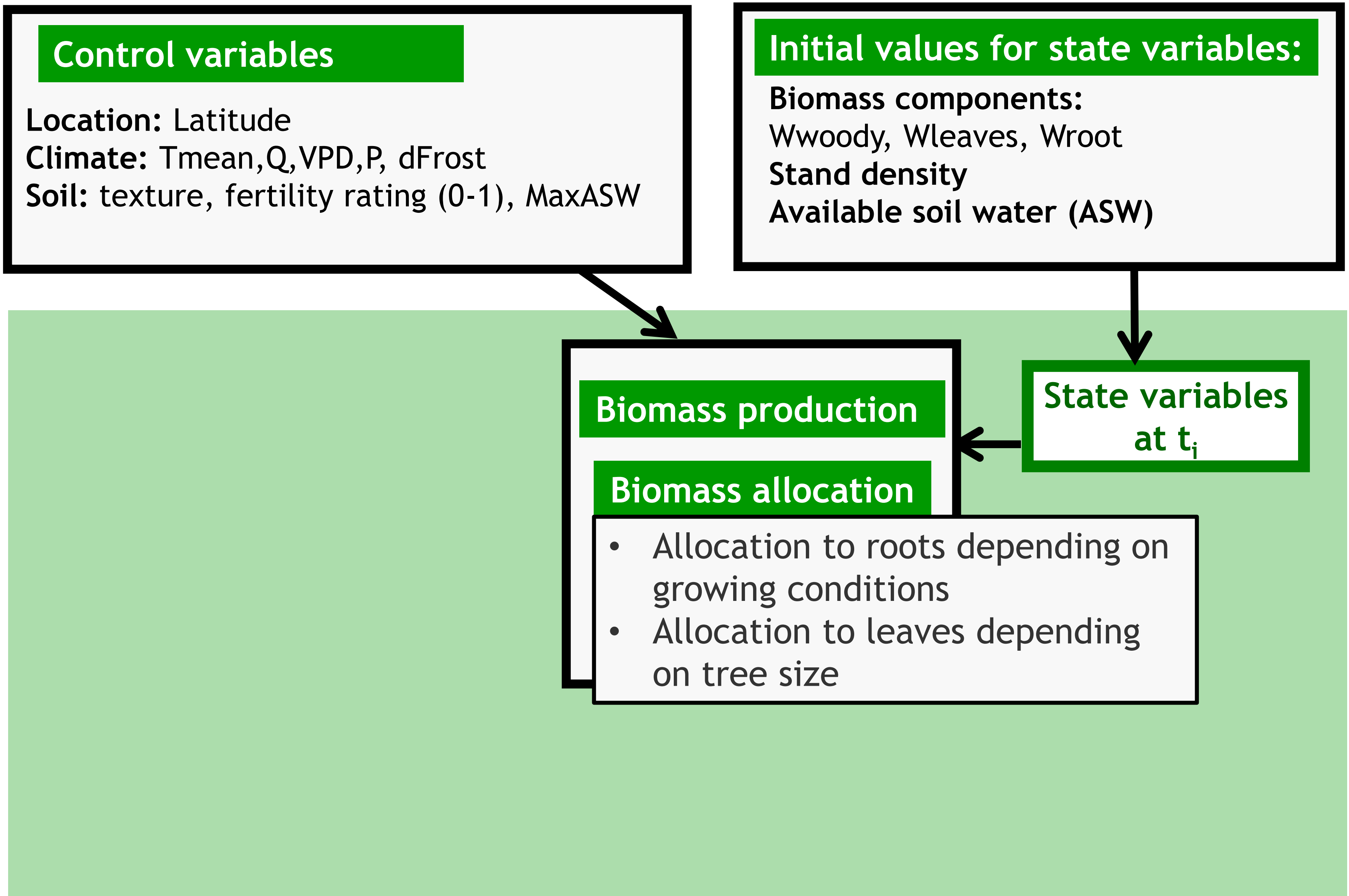
Soil: texture, fertility rating (0-1), MaxASW
Initial values for state variables:
Biomass components:
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Biomass production
State variables
• Light interception via Beer's law
• Light use efficiency modified by environment and tree age
• Constant ratio of NPP to GPP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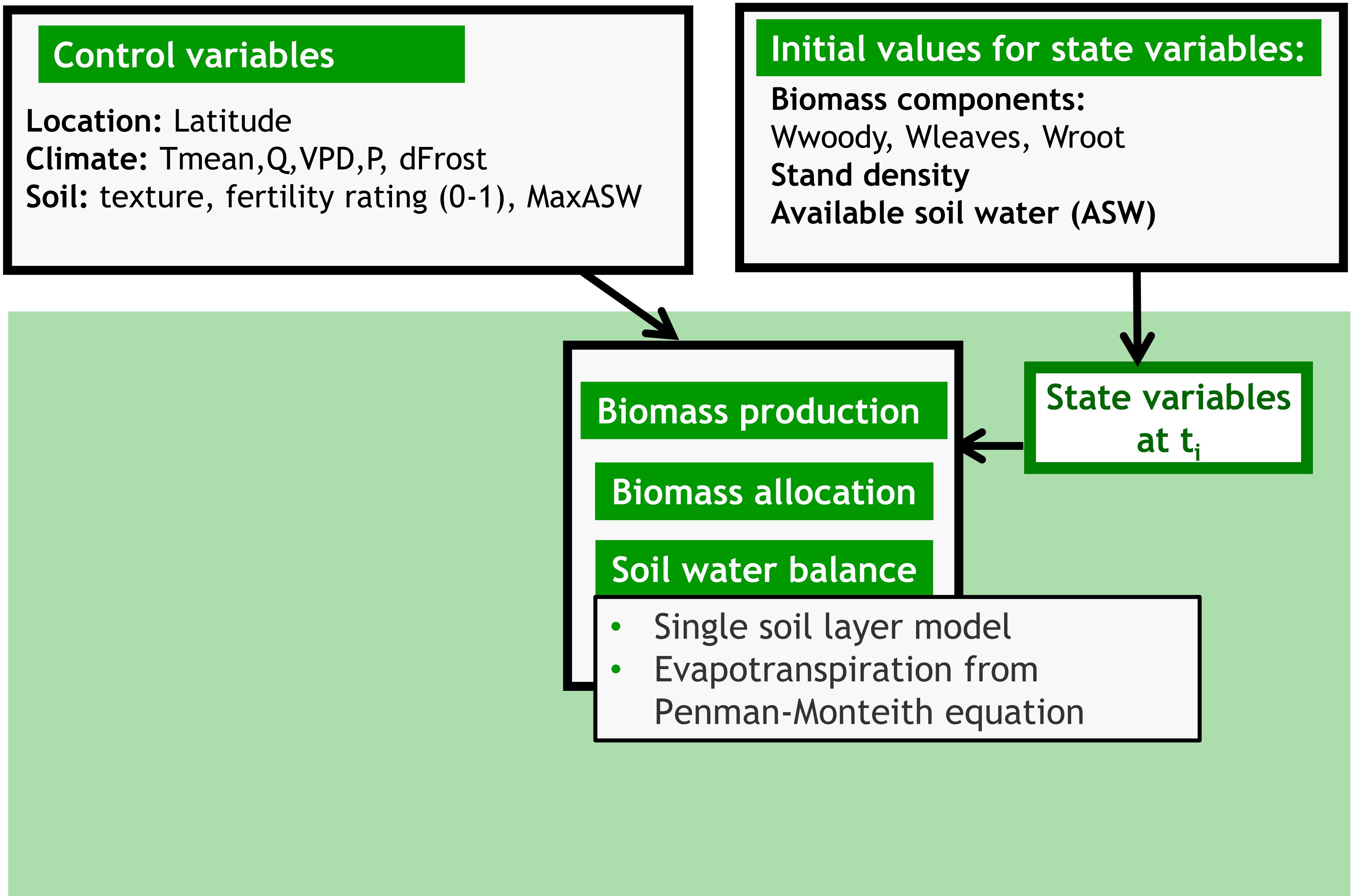
Climate: Tmean,Q,VPD,P, dFrost
Soil: texture, fertility rating (0-1), MaxASW
Initial values for state variables:
Biomass components:
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Biomass production
Biomass allocation
• Allocation to roots depending on growing conditions
• Allocation to leaves depending on tree size
State variables at t_i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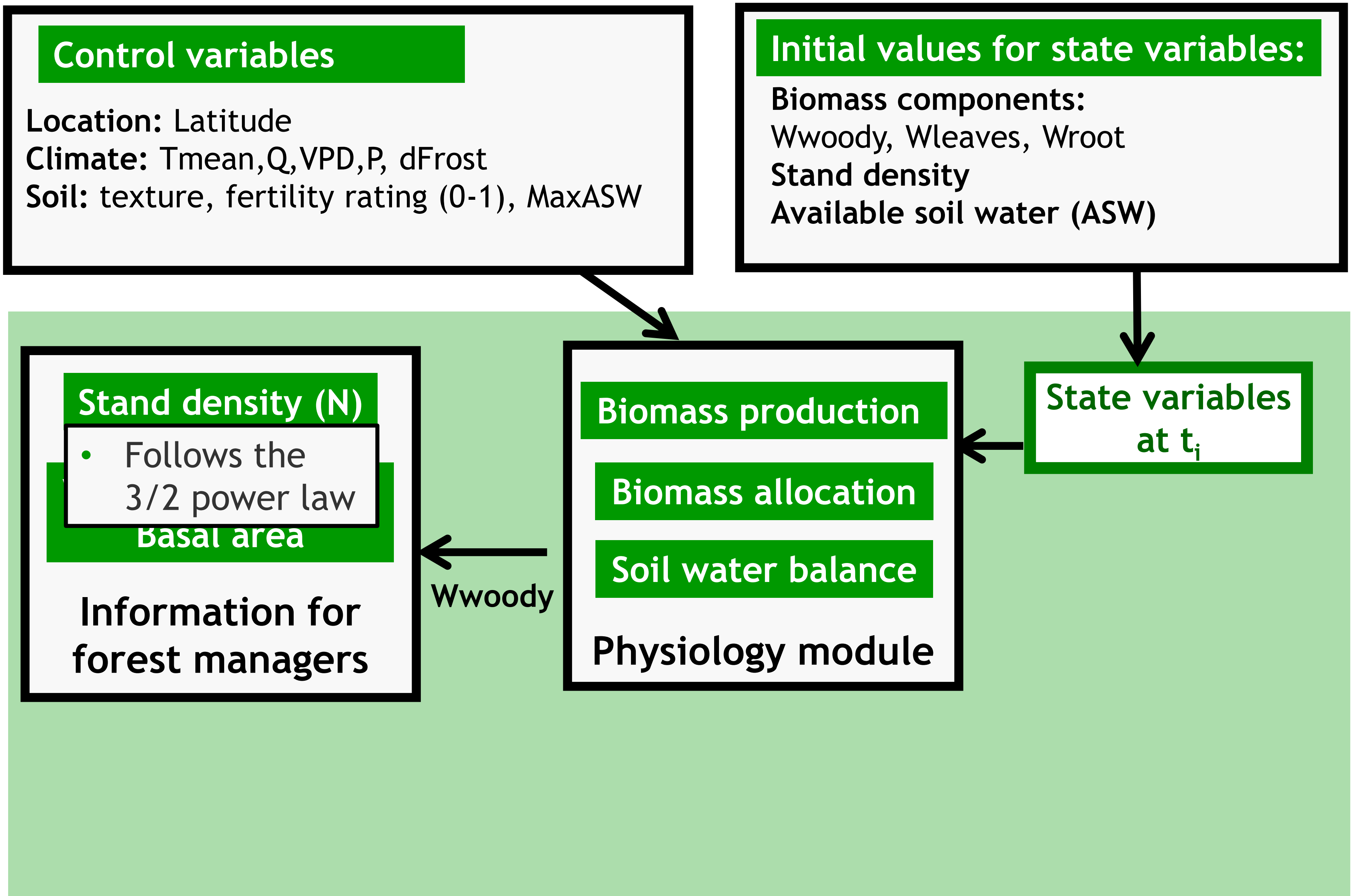
Stand density
Available soil water (ASW)
Biomass production
Biomass allocation
Soil water balance
State variables at t_i
• Single soil layer model
• Evapotranspiration from Penman-Monteith equation


Control variables
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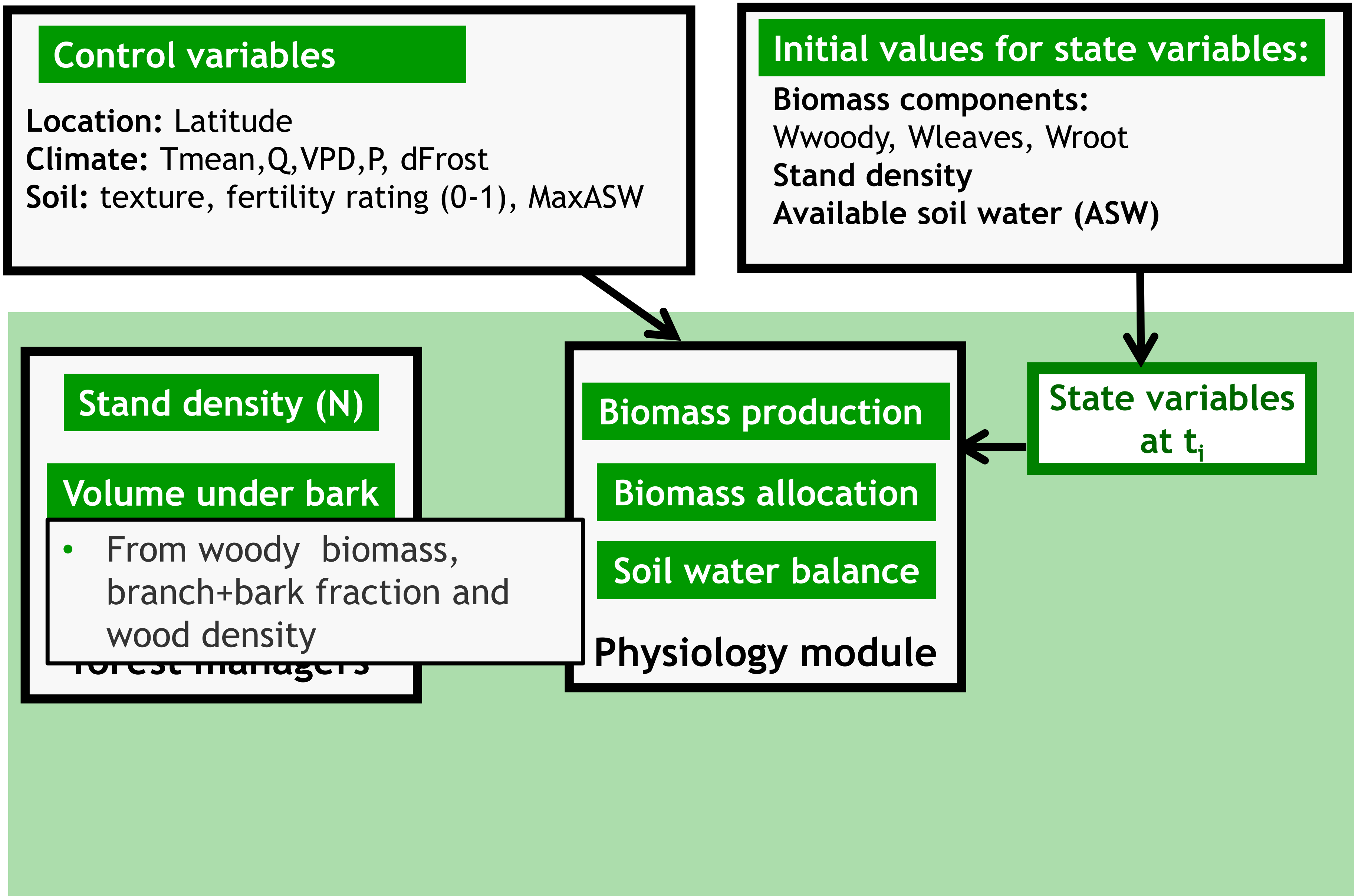
Climate: Tmean,Q,VPD,P, dFrost
Soil: texture, fertility rating (0-1), MaxASW
Initial values for state variables:
Biomass components:
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Stand density (N)
Follows the 3/2 power law
Basal area
Information for forest managers
Wwoody
Biomass production
Biomass allocation
Soil water balance
Physiology module
State variables at t_i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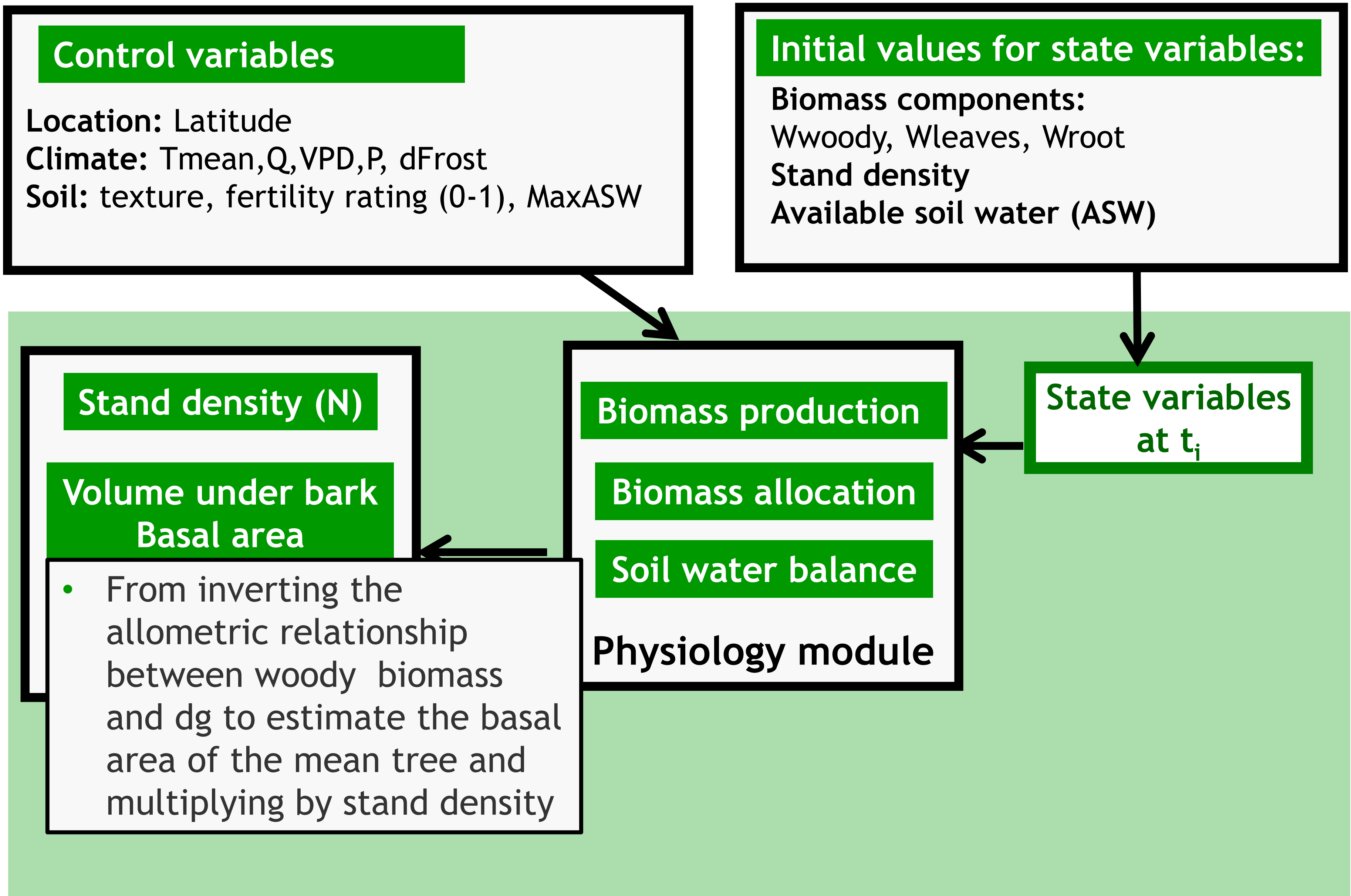
Soil: texture, fertility rating (0-1), MaxASW
Initial values for state variables:
Biomass components:
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Stand density (N)
Volume under bark
From woody biomass, branch+bark fraction and wood density
Biomass production
Biomass allocation
Soil water balance
Physiology module
State variables at t_i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Initial values for state variables:
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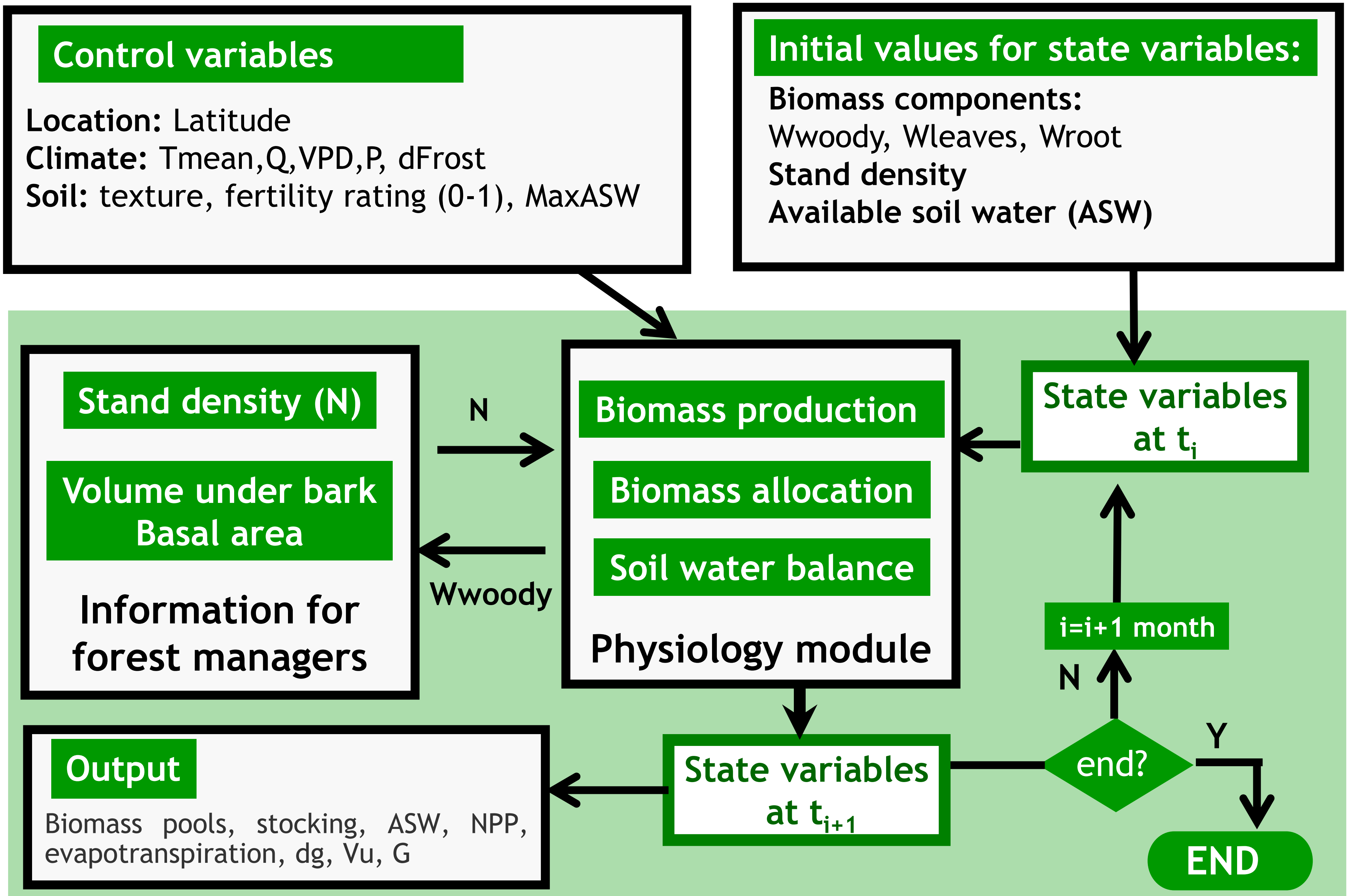
Wwoody, Wleaves, Wroot
Stand density
Available soil water (ASW)
Stand density (N)
Volume under bark
Basal area
Biomass production
Biomass allocation
Soil water balance
Physiology module
State variables
at t_i
• From inverting the allometric relationship between woody biomass and dg to estimate the basal area of the mean tree and multiplying by stand density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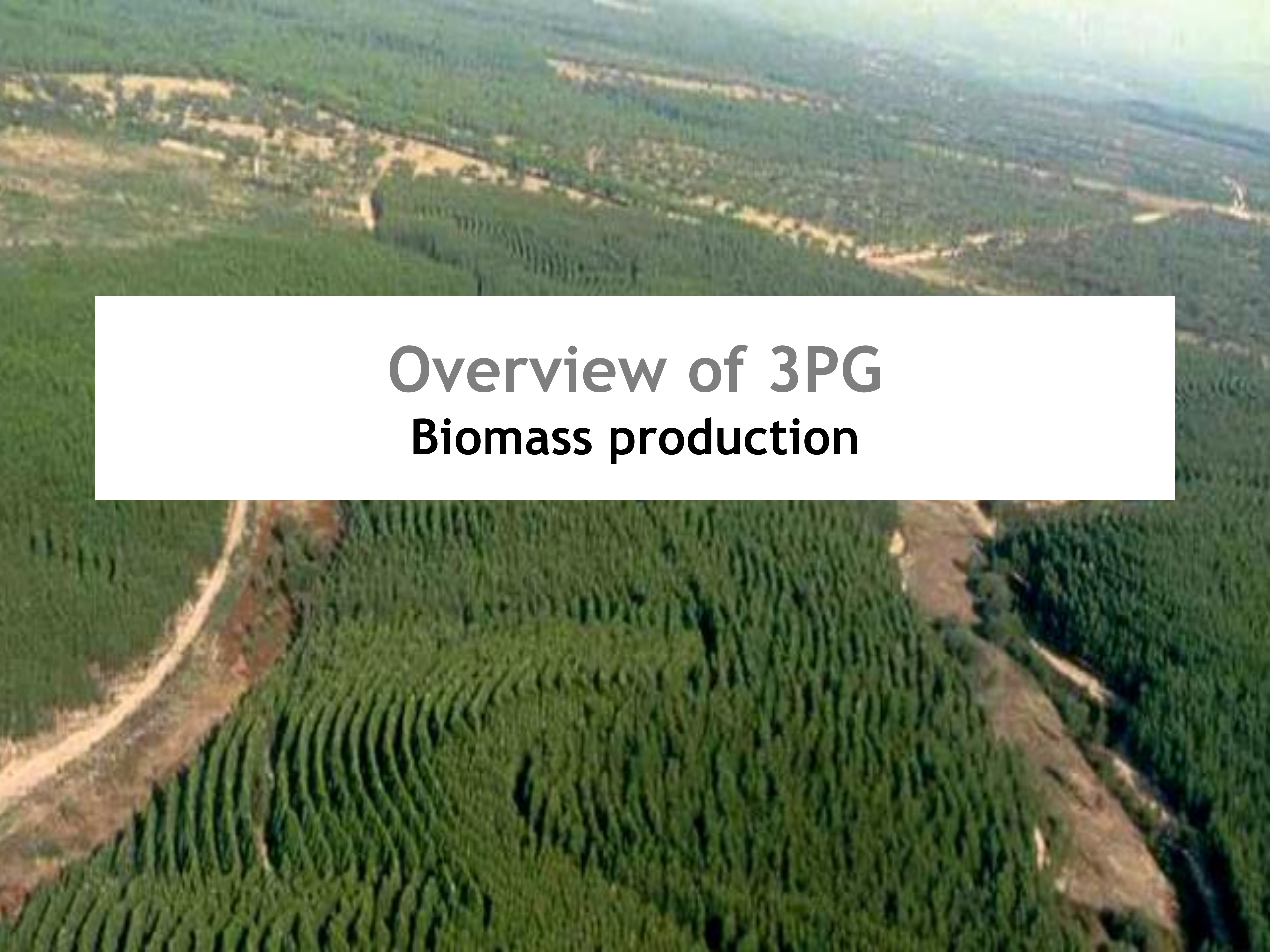
Stand density
Available soil water (ASW)
Stand density (N)
Volume under bark
Basal area
Information for forest managers
N
Wwoody
Biomass production
Biomass allocation
Soil water balance
Physiology module
State variables at t_i
i=i+1 month
N
end?
Y
END
State variables at t_{i+1}
Output
Biomass pools, stocking, ASW, NPP, evapotranspiration, dg, Vu, G

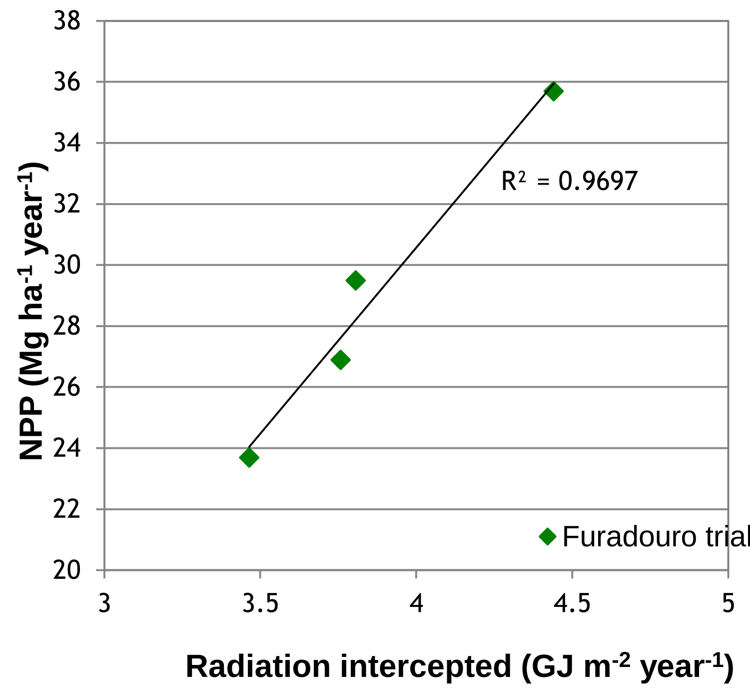
Overview of 3PG

Biomass production



Biomass production and intercepted radiation

- Observation shows that
  - Above-ground production is linearly related to intercepted radiation
  - Gross production is proportional to intercepted radiation
  - Slope of these relationships is light use efficiency ε (g_{DM} MJ^{-1}).



This finding is the basis for many simple models

Light use efficiency

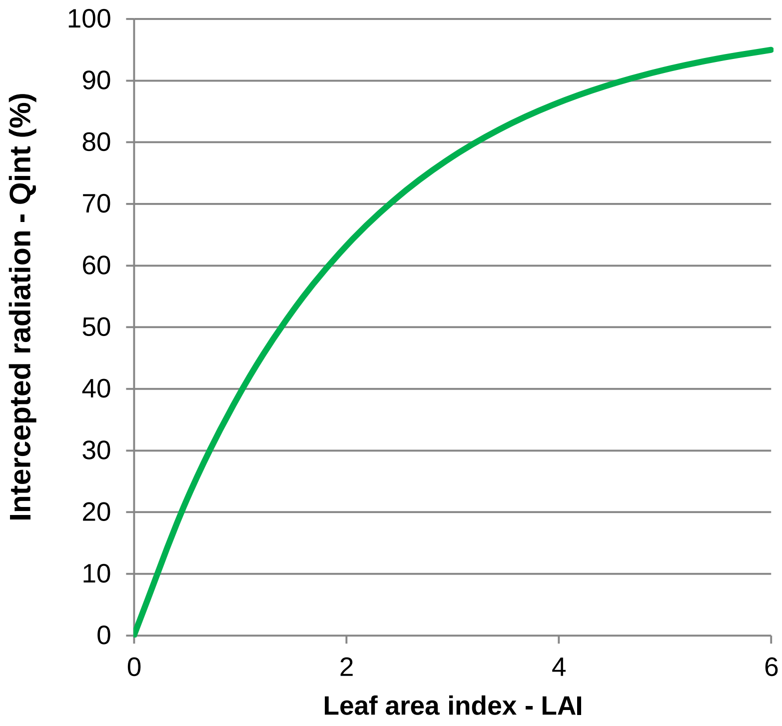
- Is affected by climatic factors (e.g. temperature) and site factors (e.g. soil-water status)
- Varies seasonally, but annual values more stable
- Gross production is affected by modifiers – functions that vary between 0 and 1 – related with climatic and site factors (multiplicative or according to the law of minimum)

Calculating intercepted radiation

- Beer's law determines light transmitted through canopy

$$Q_{int} = Q_0\left(1 - e^{-k\,LAI}\right)$$

Note diminishing returns from high leaf area indices



Gross canopy production (GPP)

- Intercepted radiation is converted into biomass

$$GPP = \varepsilon \underbrace{Q_0 \left(1 - e^{-k\,LAI}\right)}_{\text{Intercepted radiation}}$$

where ε (g_{DM} MJ^{-1}), light use efficiency:

- Measures the efficiency of conversion of solar radiation into biomass
- Depends on environmental and site factors

Gross canopy production (GPP)

- Light use efficiency is related to canopy quantum efficiency, α_C (mol mol^{-1})

$$\varepsilon\left(g_{DM}\ MJ^{-1}\right) = \text{gDM/mol mol/MJ}\ \alpha_c$$

Conversion factors

gDM/mol=24

mol/MJ=2.3

Net Canopy Production

- Respiration is assumed to be a constant fraction of gross canopy production:

$$NPP = Y\,GPP$$
$$= Y\,\varepsilon\,Q_0\,\left(1 - e^{-k\,LAI}\right)$$

where $Y \approx 0.47$

This is a contentious assumption, which greatly simplifies treatment of respiration

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}

Effects of *environment* on canopy production

- All modifiers affect canopy production:

$$\alpha_c = f_T\, f_F\, f_N\, min\{f_{VPD}, f_{SW}\} f_{age}\, \alpha_{cx}$$

where α_{cx} is maximum canopy quantum efficiency

- In 3-PG the combination of modifiers

$$\varphi = min\{f_{VPD}, f_{SW}\} f_{age}$$

also affects canopy conductance, and is called *PhysMod* in the program

Temperature growth modifier $f_T(T)$

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

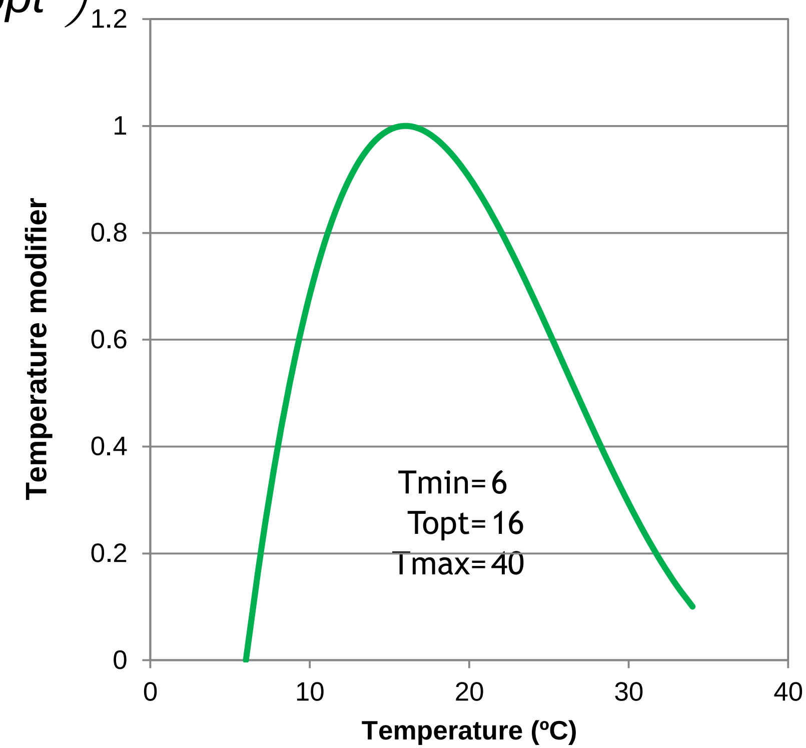
where

T = mean monthly daily temperature

T_{min} = minimum temperature for growth

T_{opt} = optimum temperature for growth

T_{max} = maximum temperature for growth



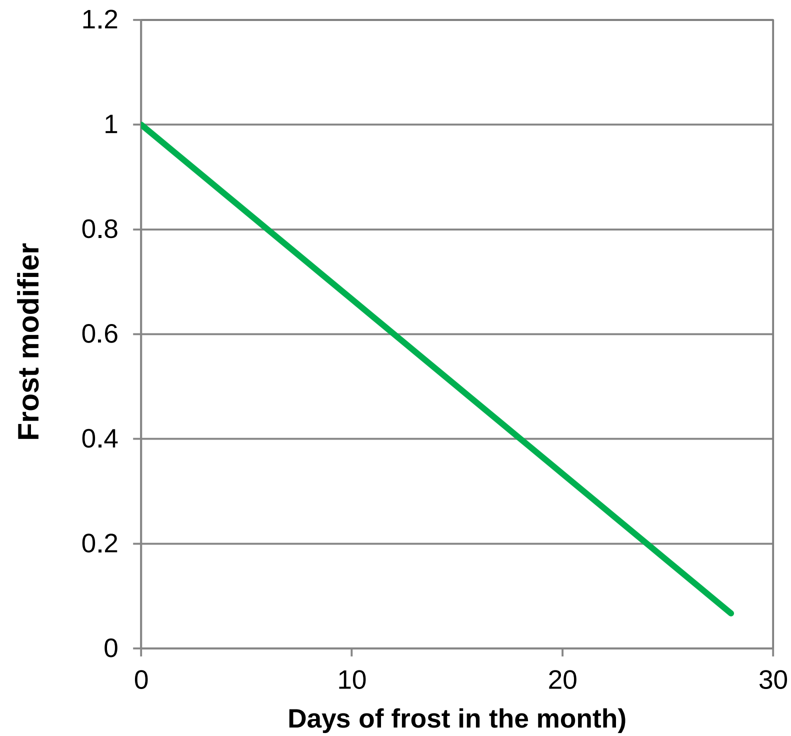
Frost growth modifier $f_F(dF)$

$$f_F(d_F) = 1 - k_F(d_F/30)$$

where

d_F = number of frost days in month

k_F = number of days of production lost for each day of frost



Soil-water growth modifier $f_{SW}(\theta)$

$$f_{SW}(\theta) = \frac{1}{1 + \left[\left(1 - \theta/\theta_x\right)/c_\theta\right]^{n_\theta}}$$

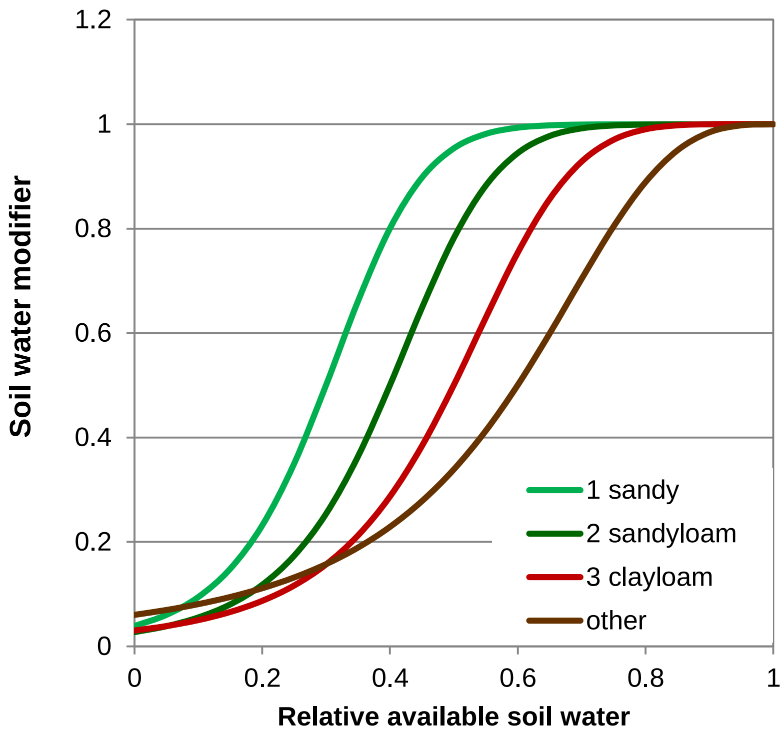
where

θ = current available soil water

θ_x = maximum available soil water

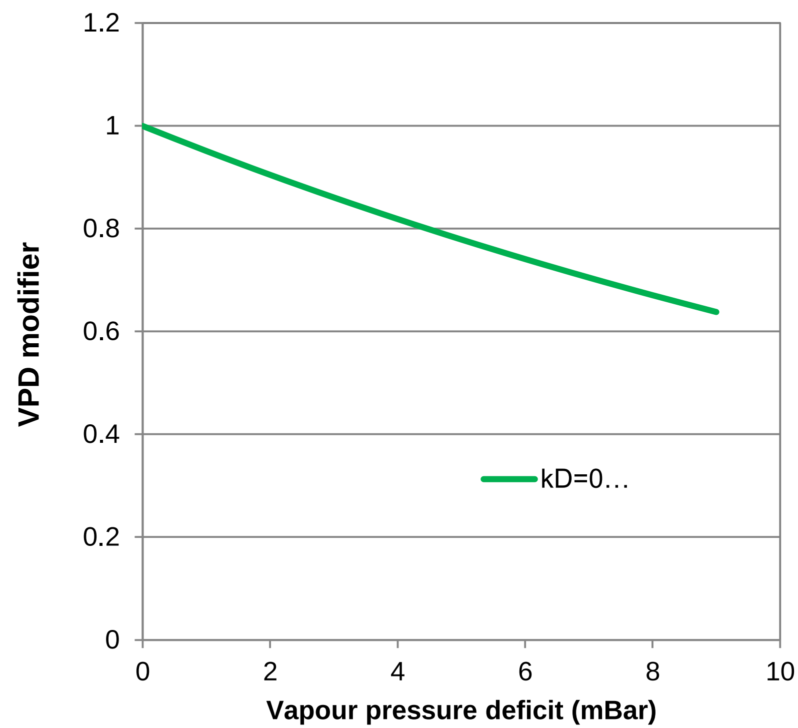
c_θ = relative water *deficit* for 50% reduction.

n_θ = power determining shape of soil water response



VPD growth modifier $f_{VPD}(d)$

$$f_{VPD}(D) = e^{-k_D D}$$



where

D = current vapor pressure deficit

k_D = strength of VPD response

Age-related growth modifier $f_{age}(t)$

$$f_{age}(t) = \frac{1}{1 + \left[\left(t/t_x \right)/r_{age} \right]^{n_{age}}}$$

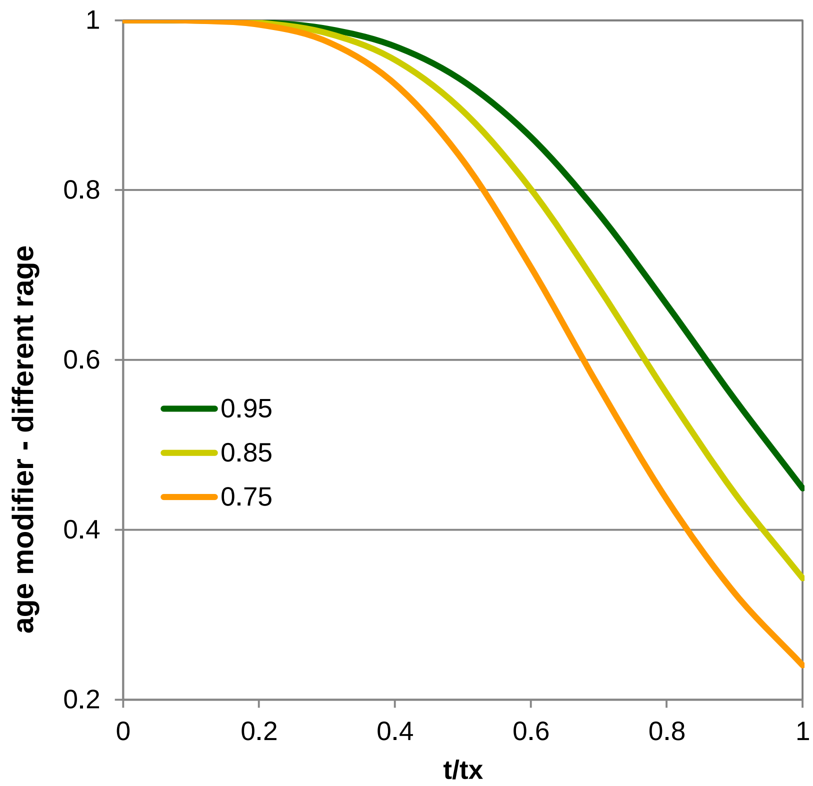
where

t = current stand age

t_x = likely maximum stand age

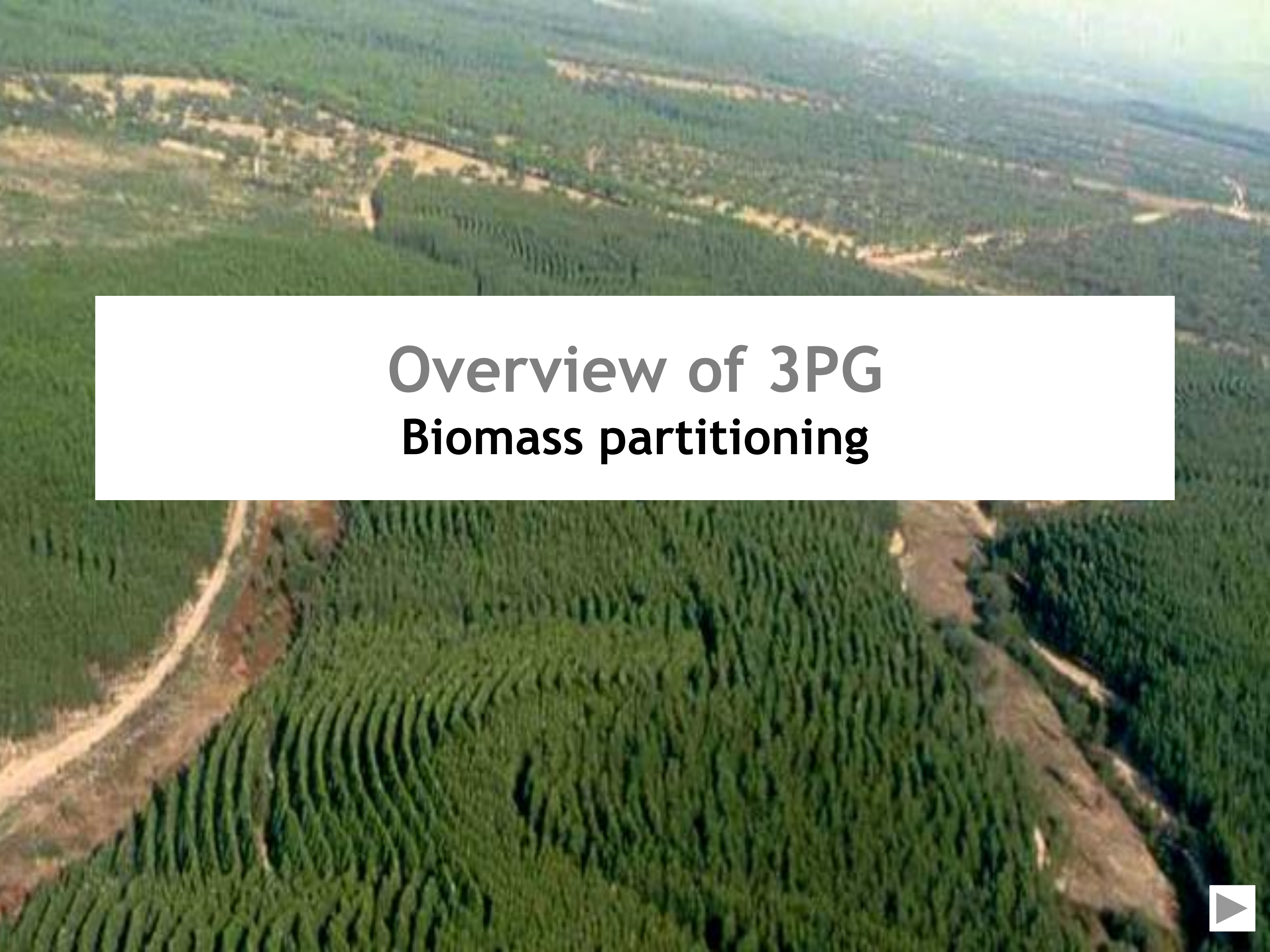
r_{age} = relative stand age for 50% growth reduction

n_{age} = power determining strength of growth reduction



Overview of 3PG

Biomass partitioning



Biomass partitioning

- NPP is partitioned into biomass pools (t_{DM} ha^{-1}):
  - roots (W_r), leaves (W_l), above-ground woody tissue (W_{wy})
- Partitioning rates (η_l, η_r and η_{wy}) depend on growth conditions and stand dbh (d)
- Litter-fall (γ_l), root-turnover (γ_r) and mortality (m_i is the fraction of the biomass per tree in the pool *i* that is lost when a tree dies) are also taken into account:

$$\Delta W_l = \eta_l NPP - \gamma_l W_l - m_l \left(W_l / N\right) \Delta N$$

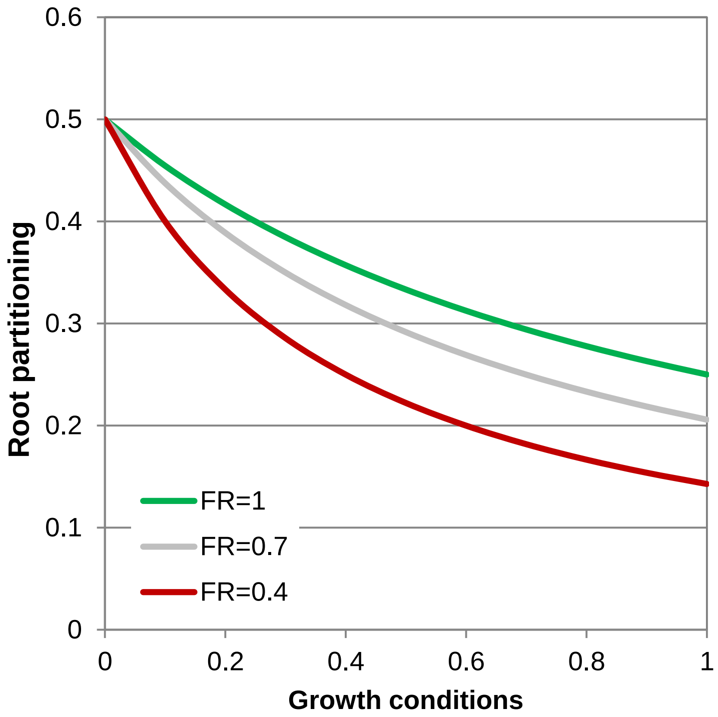
$$\Delta W_r = \eta_r NPP - \gamma_r W_r - m_r \left(W_r / N\right) \Delta N$$

$$\Delta W_{wy} = \eta_{wy} NPP - m_{wy} \left(W_{wy} / N\right) \Delta N$$

Root partitioning

- Partitioning to roots affected by growth conditions through φ (*PhysMod=min{f_{VPD},f_{SW}}f_{age}*) and by soil fertility (*m*):

$$\eta_r = \frac{\eta_{rx}\eta_{rn}}{\eta_{rn} + (\eta_{rx} - \eta_{rn}) m \varphi}$$



where

$m = m_0 + (1-m_0)FR$

η_{Rx} = root partitioning under very poor conditions

η_{Rn} = root partitioning under optimal conditions

m_0= value of m when FR=0

Foliage and stem partitioning

- Above-ground partitioning based on the following equations for allocation for stem and leaves:

$$\eta_l \approx (dW_l/dt)/(dW/dt) = dW_l/dW$$
$$\eta_{wy} \approx (dW_{wy}/dt)/(dW/dt) = dW_{wy}/dW$$

- The following allometric relationships

$$w_l = k_l w^{b_l} \qquad w_{wy} = k_{wy} w^{b_{wy}} \qquad w = a_t d^{n_t}$$

are used to show that η_l and η_{wy} can be expressed as a function of quadratic mean diameter (*dg*)

Foliage and Stem Partitioning

- Allocation to leaves

$$\eta_l = (dW_l / dW) = k_l b_l W^{b_l - 1} = k_l b_l \left(a_t d^{n_t}\right)^{b_l - 1} = a_l d^{n_l}$$

$$\left(a_l = k_l b_l a_t^{b_l - 1} \text{ and } n_l = n_t (b_l - 1)\right)$$

- Allocation to stem (woody parts)

$$\eta_{wy} = (dW_{wy} / dW) = k_{wy} b_{wy} W^{b_{wy} - 1} = k_{wy} b_{wy} \left(a_t d^{n_t}\right)^{b_{wy} - 1} = a_{wy} d^{n_{wy}}$$

$$\left(a_{wy} = k_{wy} b_{wy} a_t^{b_{wy} - 1} \text{ and } n_{wy} = n_t (b_{wy} - 1)\right)$$

Foliage and Stem Partitioning

- Above-ground partitioning is then based on the foliage:stem partitioning ratio (p_{lw})

$$p_{lw} = \frac{\eta_l}{\eta_{wy}} = \frac{a_l d^{n_l}}{a_{wy} d^{n_{wy}}} = \frac{a_l}{a_{wy}} \; d^{n_l - n_{wy}} = a_p d^{n_p}$$

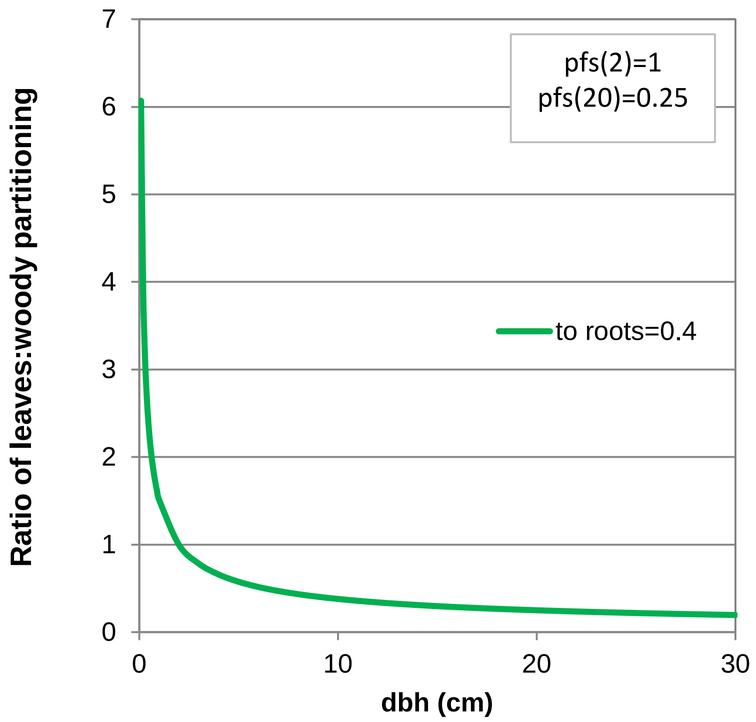
$$\left(a_p = pfsConst, \;\; n_p = pfsPower\right)$$

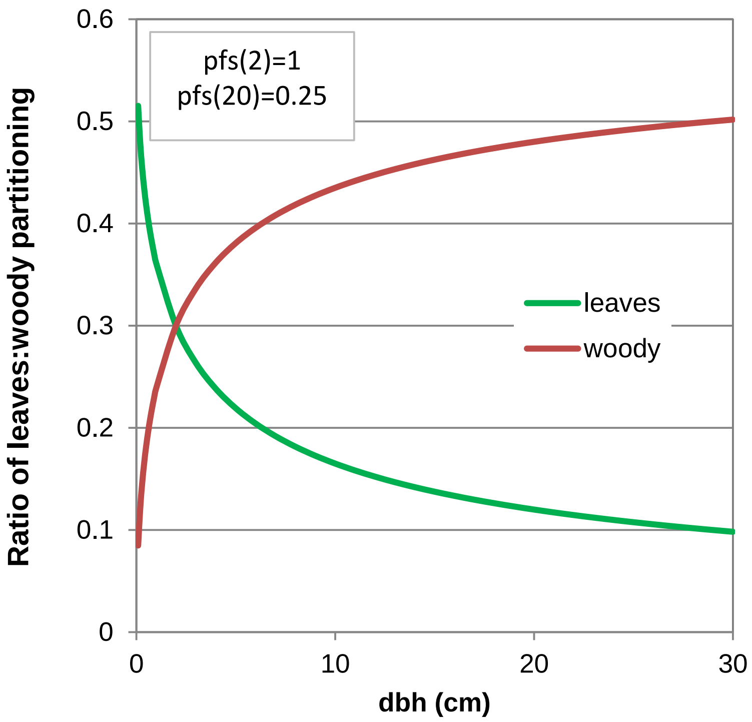
- Then

$$\eta_{wy} = \frac{1-\eta_r}{1+p_{lw}}, \qquad \eta_l = p_{lw}\eta_{wy}$$

Aboveground partitioning *versus* tree-size

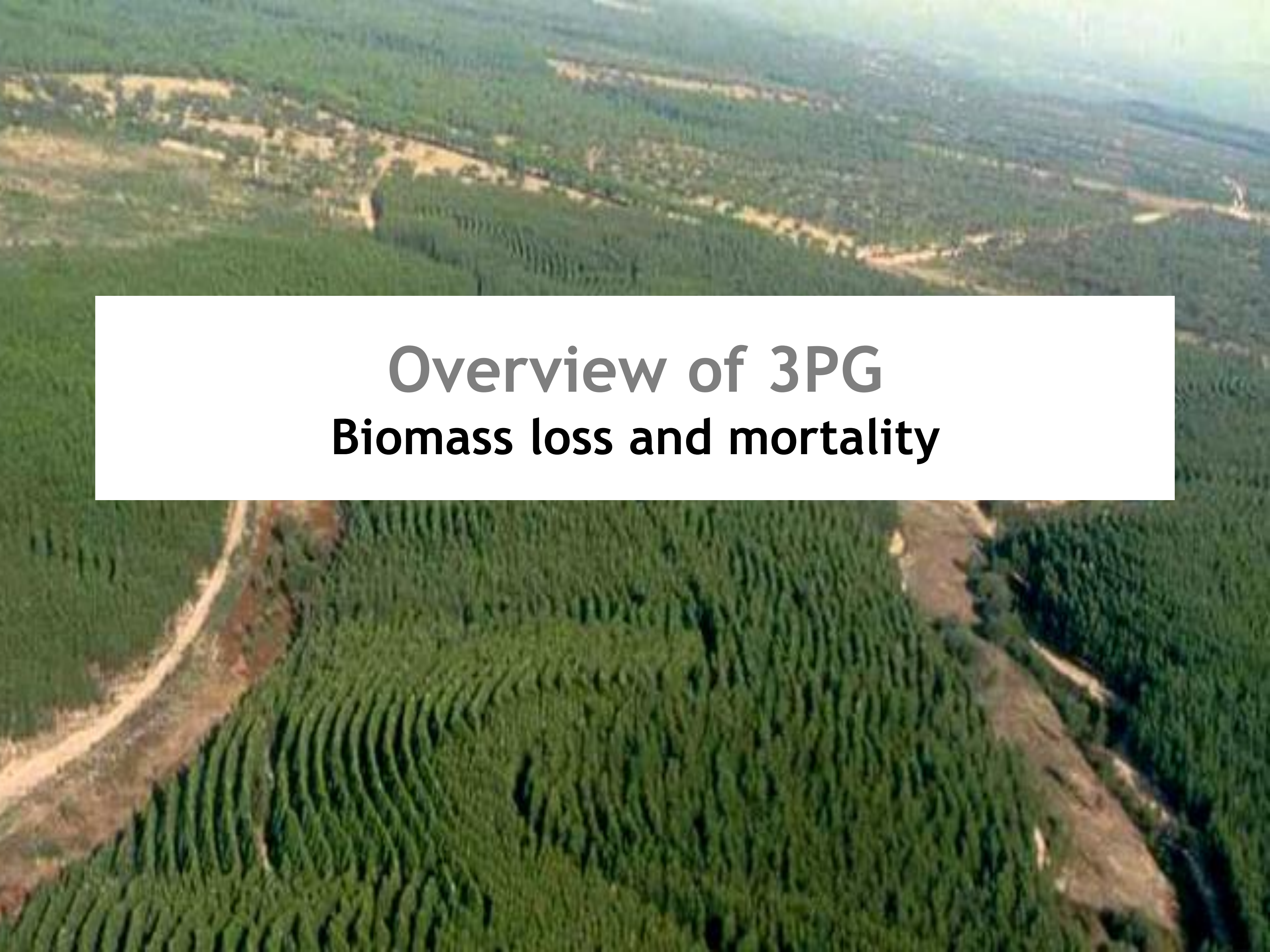
- Increasing dbh decreases foliage partitioning and increases stem partitioning





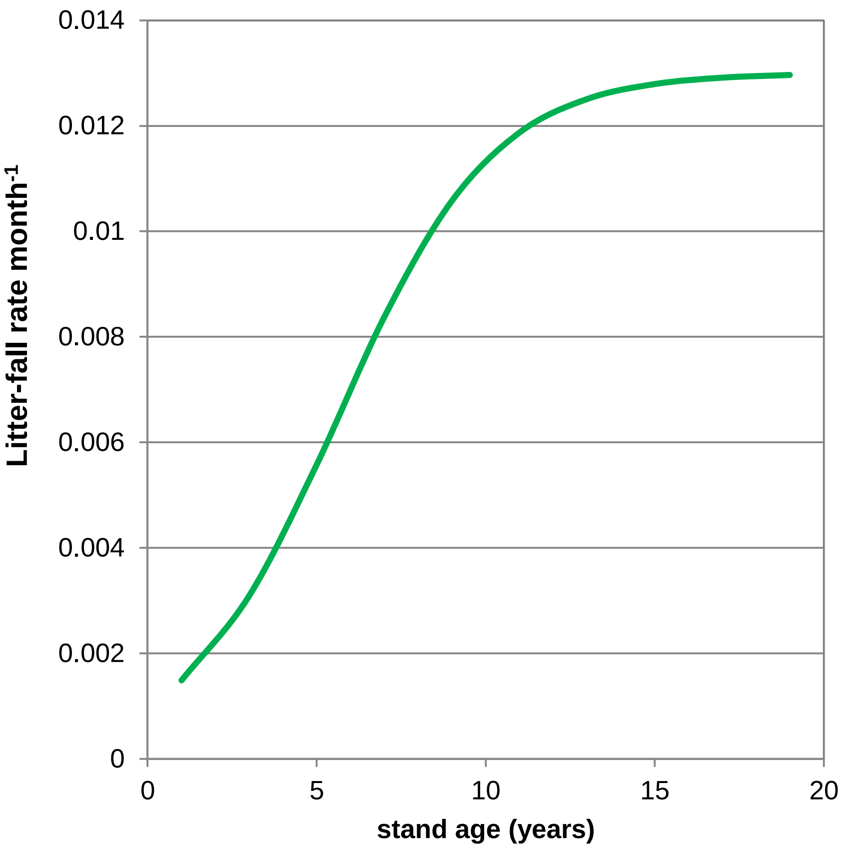
Overview of 3PG

Biomass loss and mortality



Root-turnover and litter-fall

- Root-turnover is a constant fraction of W_r (γ_r = 0.01 $month^{-1}$)
- Litter-fall is an age-dependent fraction of foliage biomass



Stem mortality (based on self-thinning)

$w_S(N)$ - average woody weight for current stocking

$w_S(N) \leq w_{Sx}(N)$ from the self-thinning line

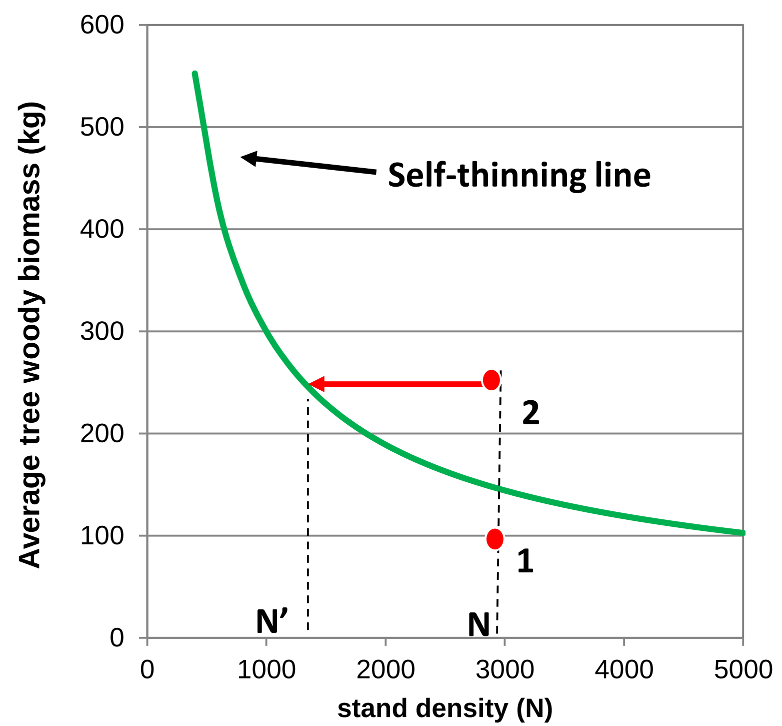
If $w_S \leq w_{Sx}(N) \Rightarrow$ no mortality (1)

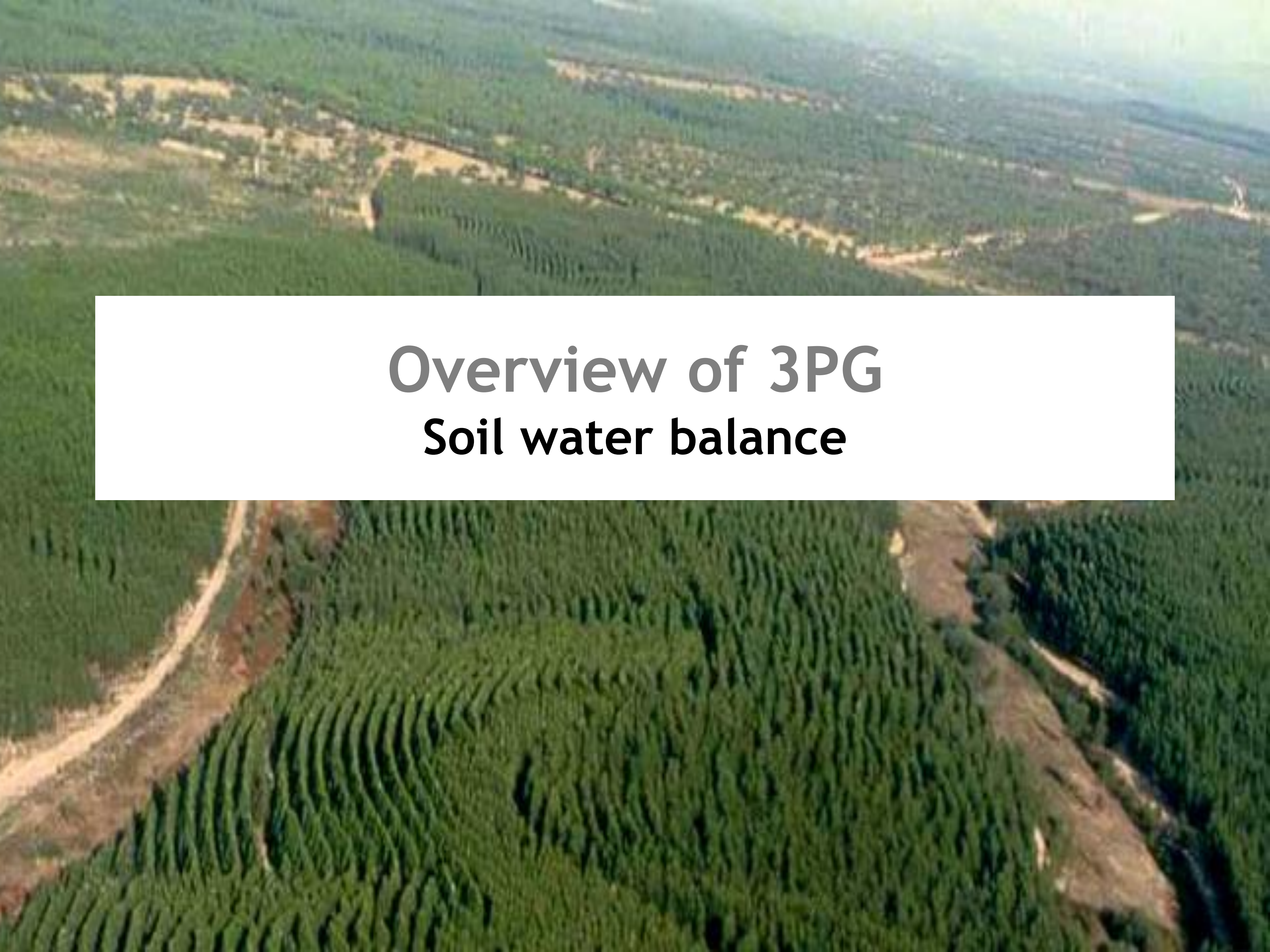
If $w_S > w_{Sx}(N) \Rightarrow$ self-thin to N´ (2)

$$N' = 1000\left(w_{wyx0} / w_{wy}\right)^{2/3}$$

$$\Delta W_i = -m_i \frac{W_i}{N}\left(N - N'\right)$$

where m_i is the fraction of biomass per tree in the pool *i* that is lost when a tree dies





Overview of 3PG

Soil water balance

Soil water balance

- Soil water balance based on single soil layer
- Uses monthly time steps

Inputs:

- rainfall and irrigation

Losses are:

- interception = fixed % of rainfall
- evapotranspiration – Penman-Monteith equation
- excess over field capacity lost as run off

Evapotranspiration

- Evapotranspiration is calculated using the *Penman-Monteith* equation
  - Directly affected by VPD and radiation
- Canopy conductance:
  - determined by LAI
  - affected by growth conditions – VPD, soil water and age
- Boundary layer conductance:
  - is assumed constant (0.2 m s^{-1})

Overview of 3PG

Management and information to managers

Fertilization and irrigation

- Fertilization can be considered by changing the fertility rating (FR) parameter
- Irrigation can be considered in several ways:
  1. By adding it to the precipitation days
  2. By indicating a value of minimum available soil water different from zero – it starts irrigation as soon as this threshold is attained
  3. By providing a list of ages and Ml ha^{-1} $year^{-1}$ – it will changes the amount of irrigation at every year indicated in the list

Thinning

- Thinning is simulated by indicating:
  1. The year of thinning
  2. Thinning intensity – number of trees that are thinned
  3. Thinning type – ratio of biomass of leaves, woody and roots of an average thinned tree and an average tree of the stand
- It is possible to simulate several thinnings along the rotation

Defoliation

- Defoliation can be considered by indicating
  1. The year
  2. The percentage of leaves that remain

Volume under bark prediction

- Woody biomass is converted into wood biomass through the ratio between branches+bark and the woody biomass (R_{Ww}) and then divided by wood density (ρ)
- Wwoody=Wwood+Wbark+Wbranches
- Both R_{Ww} and ρ are modeled as a function of age

$$Vu = \frac{W_{woody}\left(1 - R_{Ww}\right)}{\rho}$$

Basal area prediction

- Woody biomass of the mean tree is first predicted through division by stand density (N)

$$\overline{w_{woody}} = \frac{W_{woody}}{N}$$

- Quadratic mean diameter (dg) is then predicted through the inversion of the allometric equation for tree woody biomass prediction

$$\overline{w_{woody}} = k \; dg^{a} \quad \Rightarrow \quad dg = \left(\frac{\overline{w_{woody}}}{k} \right)^{\frac{1}{a}}$$

- Finally G is predicted by multiplying the basal area of the mean tree by stand density

$$G = N \; \frac{\pi}{4} \; dg^{2}$$

Overview of 3PG

Summary of 3PG parameters

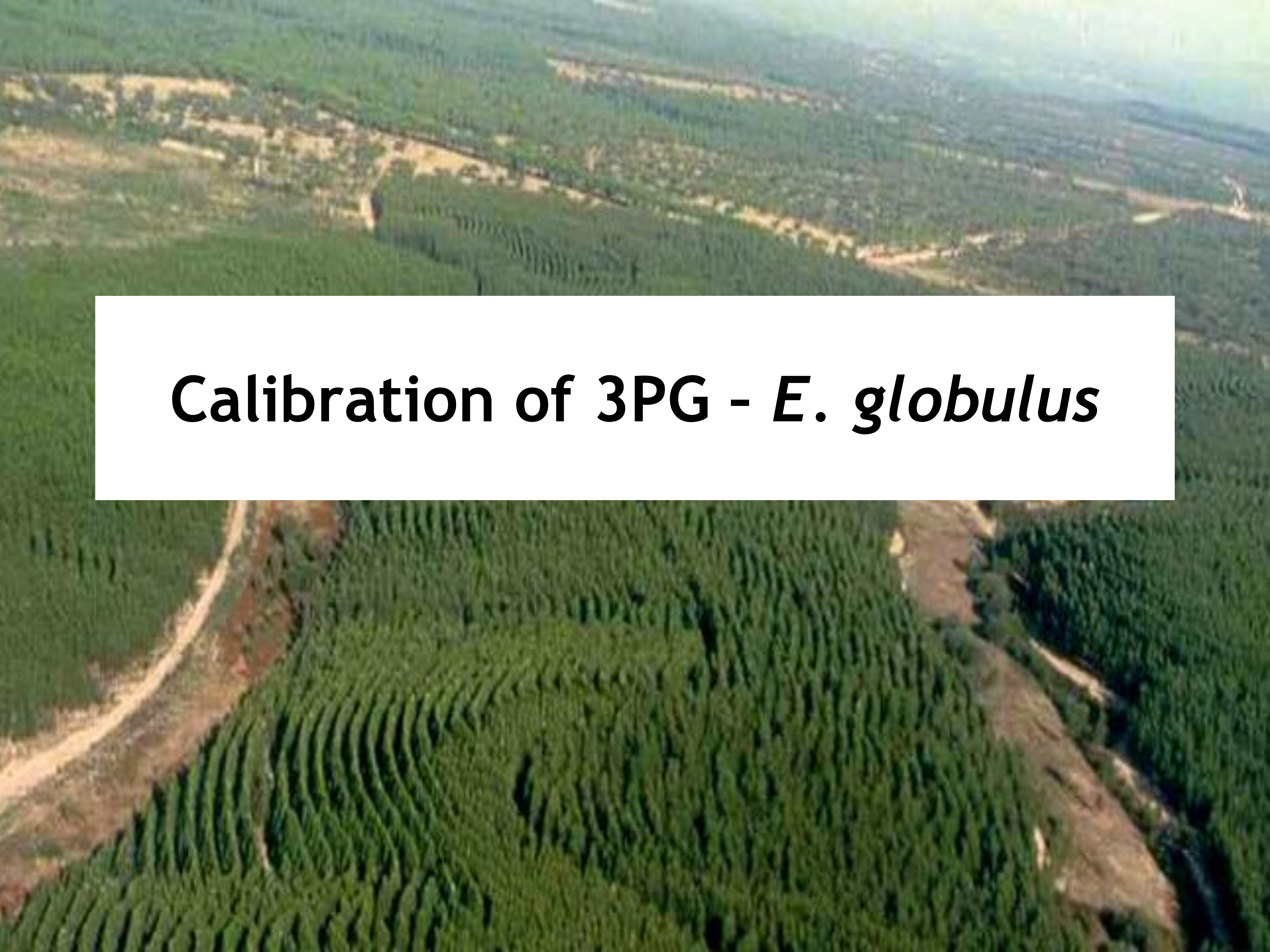
Summary of 3PG parameters (1/2):

- Biomass partitioning and turnover
  - Allometric relationships & partitioning
  - Litterfall & root turnover
- NPP & conductance modifiers
  - Temperature modifier (fT)
  - Frost modifier (fFRost)
  - Soil water modifier (fSW)
  - Fertitlity effects
  - Age modifier (fAge)
- Stem mortality & self-thinning

Summary of 3PG parameters (2/2):

- Canopy structure and processes
  - Specific leaf area
  - Light interception
  - Production and respiration
  - Conductance
- Wood and stand properties
  - Branch and bark fraction (fracBB)
  - Basic Density
- Conversion factors

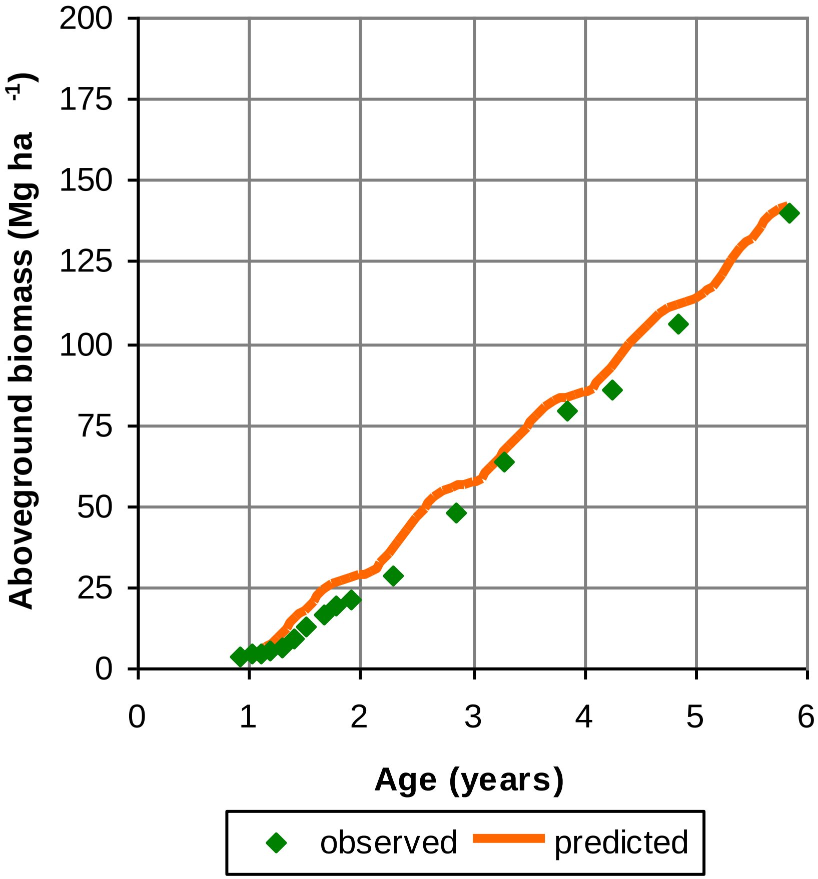
Calibration of 3PG – *E. globulus*

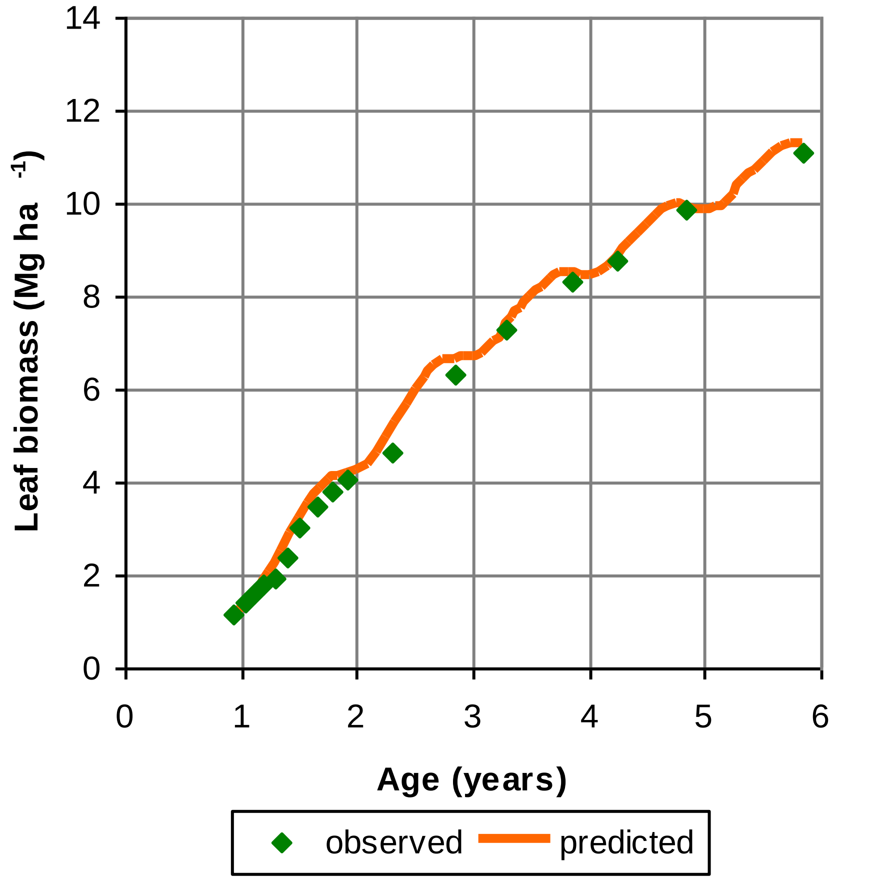


- 3PG has three types of parameters (adapted from Sands,2004):
  - **Default** - can be assigned some generic value, e.g. based on work with other species, or from a priori knowledge
  - **Observed** - can be directly measured, e.g. via gas-exchange analysis
  - **Empirically estimated** (statistics) – estimated using experimental data, e.g. by regression analysis
  - **Estimated (tuned)** - can only be estimated indirectly, e.g. by adjusting its value to optimize the fit of some output to observed data

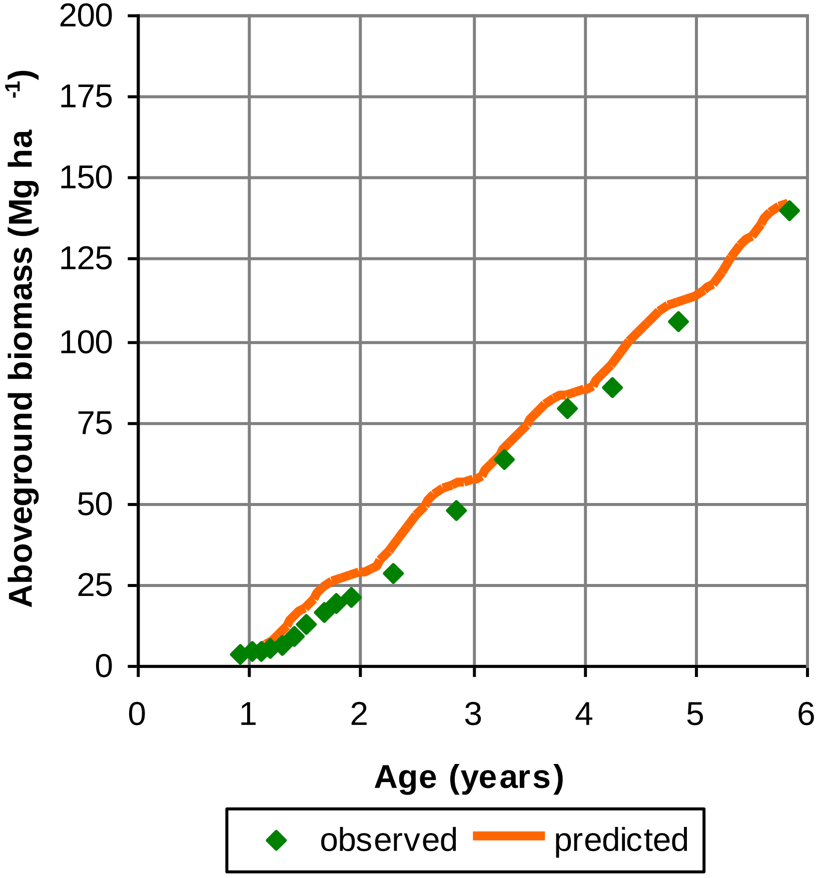
- Calibration was made for the four types of parameters
  - Default and observed parameters were first fixed
  - Empirically estimated parameters were then estimated using available data, namely
    - Trees destructively sampled for biomass determination
    - Litterfall data or literature references for the species
  - Remaining parameters were “tuned” with data from permanent plots:
    - Plots with no or low restrictions to growth (e.g. Trials with irrigation and fertilization)
    - Plots with serious restrictions to growth (nutrients and/or water)

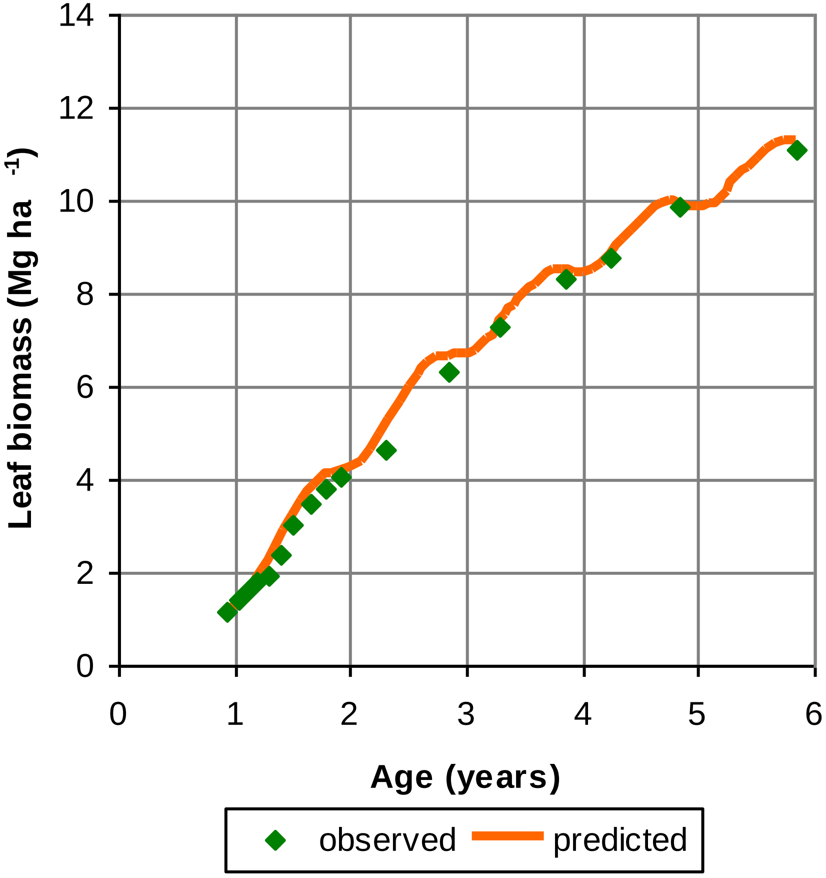
Ferilization and irrigation trial for eucalyptus	
Soil texture	Sandy
Fertility rating	1
MaxASW	150
Irrigation	YES



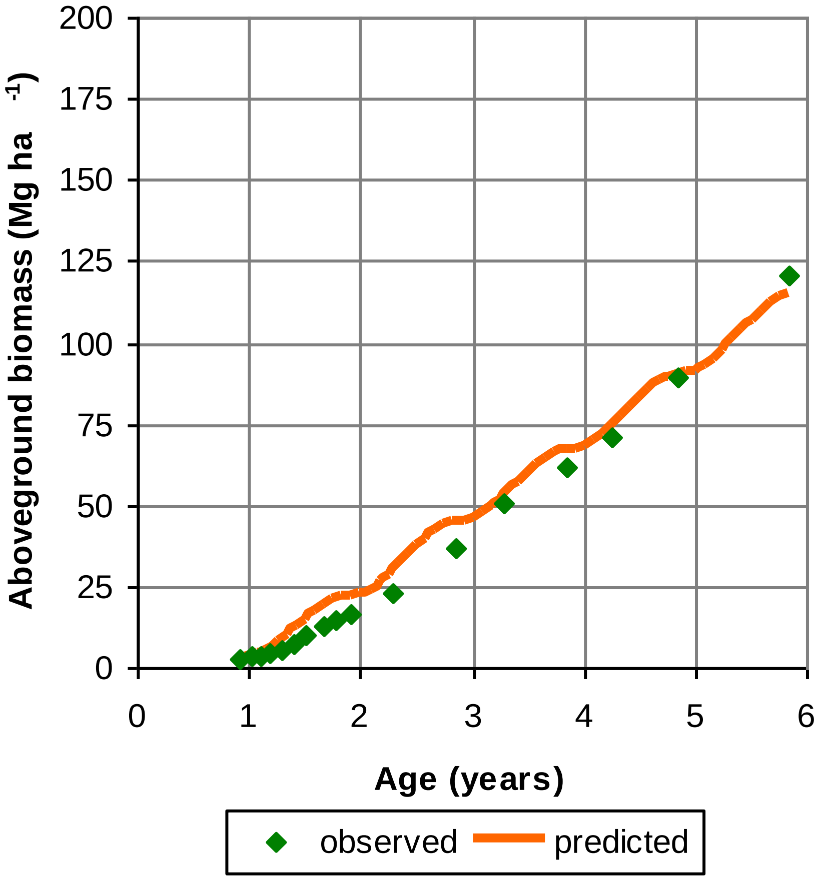


Ferilization and irrigation trial for eucalyptus	
Soil texture	Sandy
Fertility rating	1
MaxASW	150
Irrigation	YES

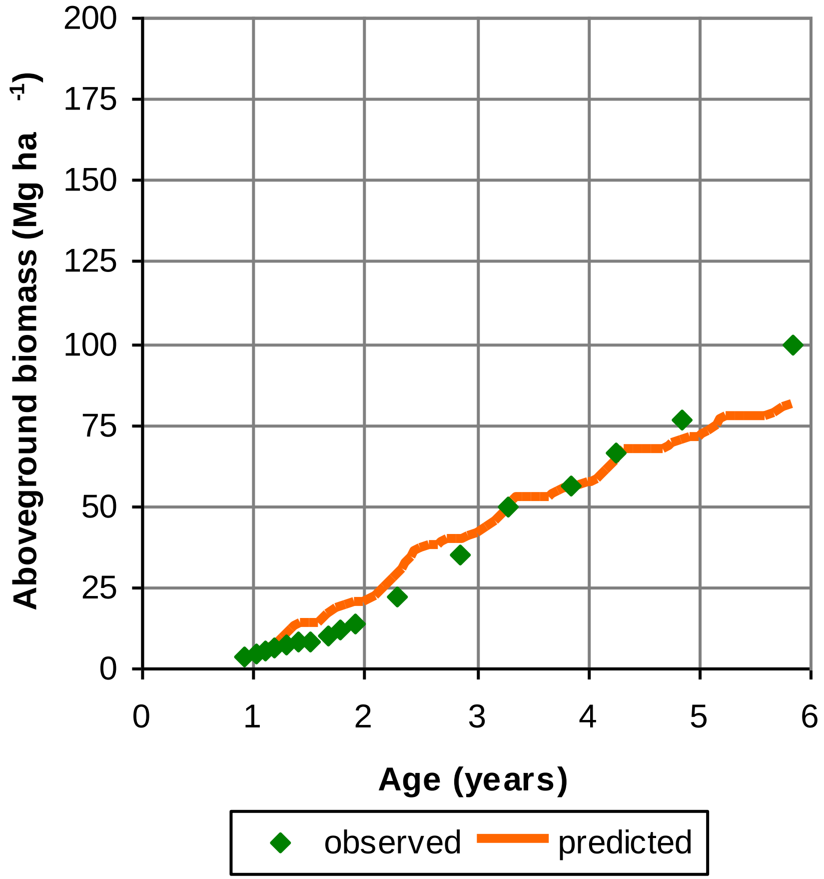


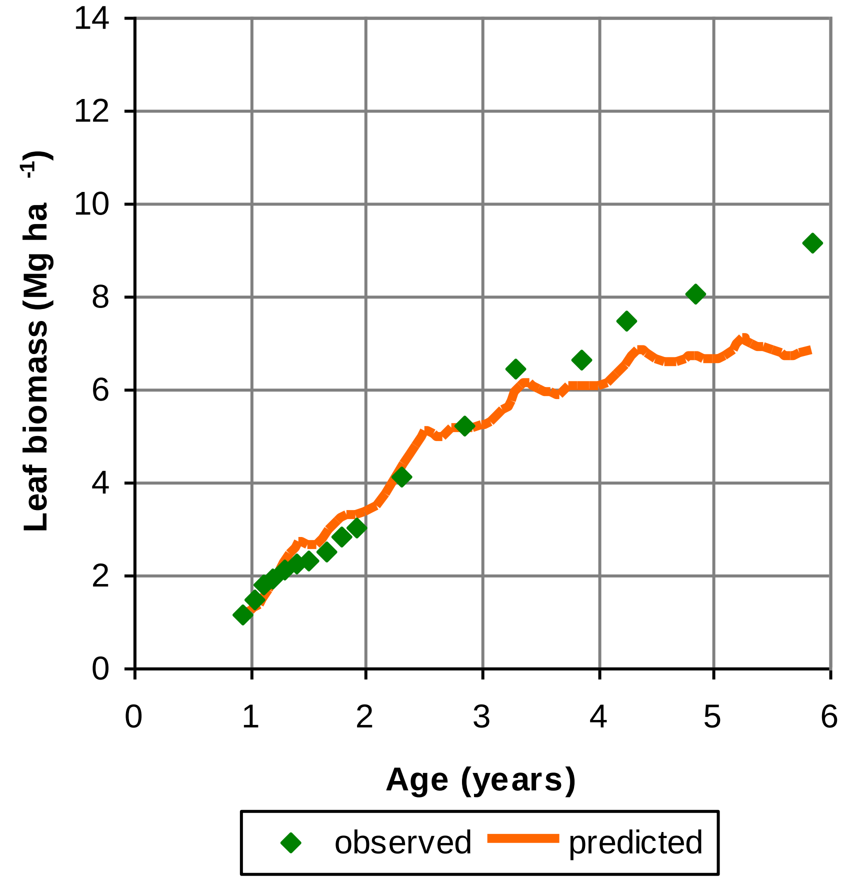


Ferilization and irrigation trial for eucalyptus	
Soil texture	Sandy
Fertility rating	0.4
MaxASW	150
Irrigation	YES

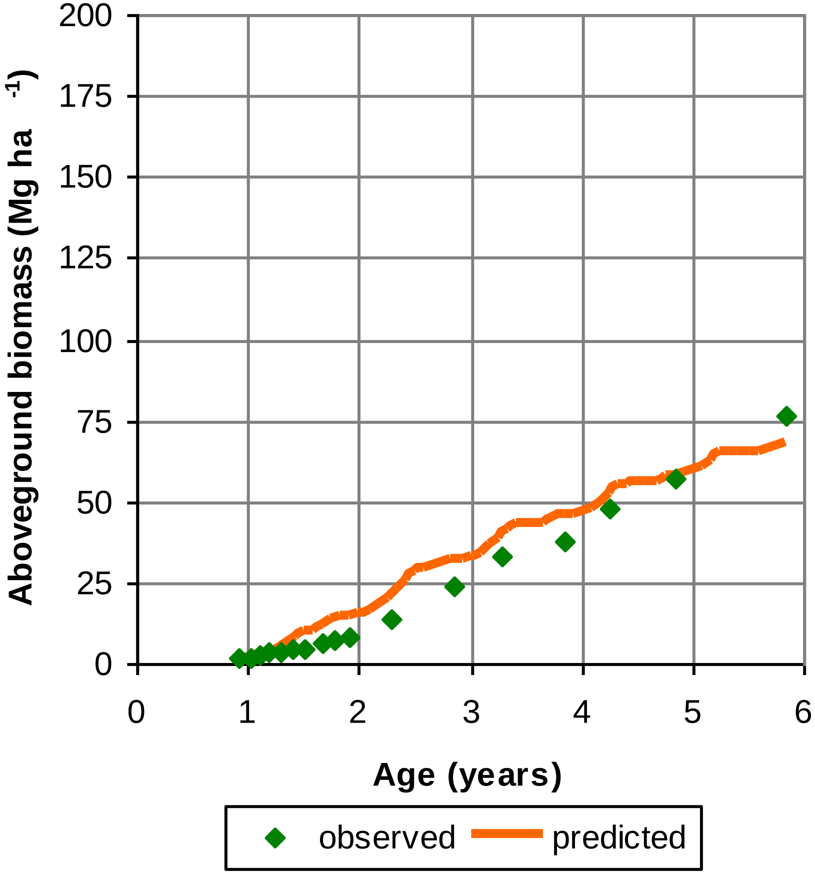


Ferilization and irrigation trial for eucalyptus	
Soil texture	Sandy
Fertility rating	1
MaxASW	150
Irrigation	NO





Ferilization and irrigation trial for eucalyptus	
Soil texture	Sandy
Fertility rating	0.4
MaxASW	150
Irrigation	NO



Improving “information for managers” (hybridization)

Volume under bark prediction

- Woody biomass is converted into wood biomass through the ratio between branches+bark and the woody biomass (R_{Ww}) and then multiplied by wood density (ρ)
- Wwoody=Wwood+Wbark+Wbranches
- Both R_{Ww} and ρ are modeled as a function of age

$$Vu = \frac{W_{woody}\left(1 - R_{Ww}\right)}{\rho}$$

Basal area prediction

- Woody biomass of the mean tree is first predicted through division by stand density (N)

$$\overline{w_{woody}} = \frac{W_{woody}}{N}$$

- Quadratic mean diameter (dg) is then predicted through the inversion of the allometric equation for tree woody biomass prediction

$$\overline{w_{woody}} = k\ dg^{a} \quad \Rightarrow \quad dg = \left(\frac{\overline{w_{woody}}}{k}\right)^{\frac{1}{a}}$$

- Finally G is predicted by multiplying the basal area of the mean tree by stand density

$$G = N\ \frac{\pi}{4}\ dg^{2}$$

Hibridization

- The hibridization is a tentative of combining different types of models
  - A process-based model that:
    - is not excessively input demanding
    - but still 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 an empirical growth and yield model that gives a more detailed output

- Objective of the “hibridization” procedure
  - To improve basal area (G) and underbark volume (Vu) prediction by developing allometric equations based on existing empirical data
  - To develop an equation for dominant height (hdom) prediction
- The “hybrid” model is named GLOB-3PG

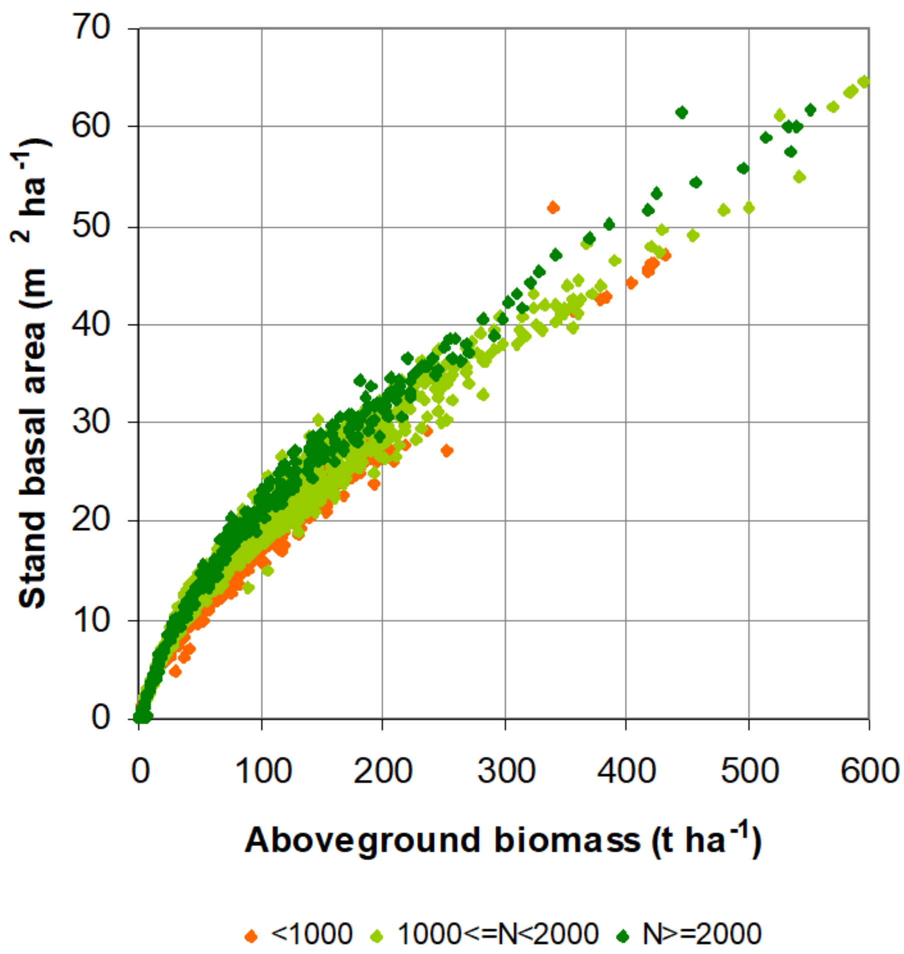
Allometric relationship for G

$$G = G_0 + kg\ W^{ag}$$

$$G_0 = \alpha \frac{N}{1000}$$

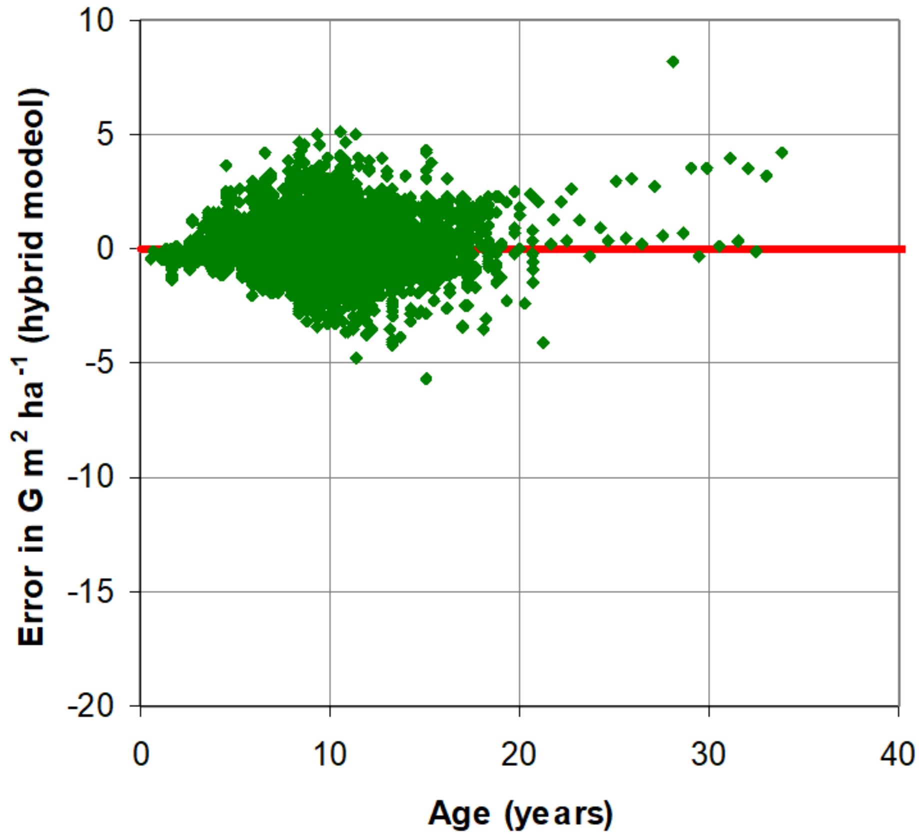
$$kg = \beta 0 + \beta 1 \frac{N}{1000}$$

$$ag = \gamma 0 + \gamma 1 \frac{N}{1000}$$



- Error in G prediction (3PG)

Error in G prediction (hybrid model)

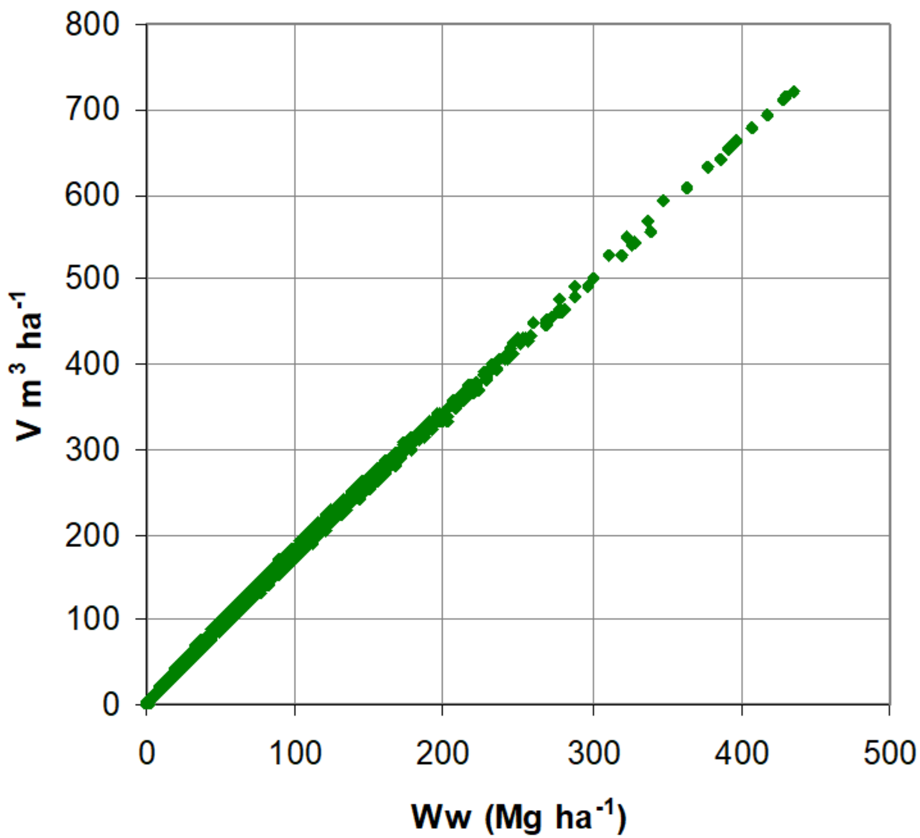


Allometric relationship for Vu

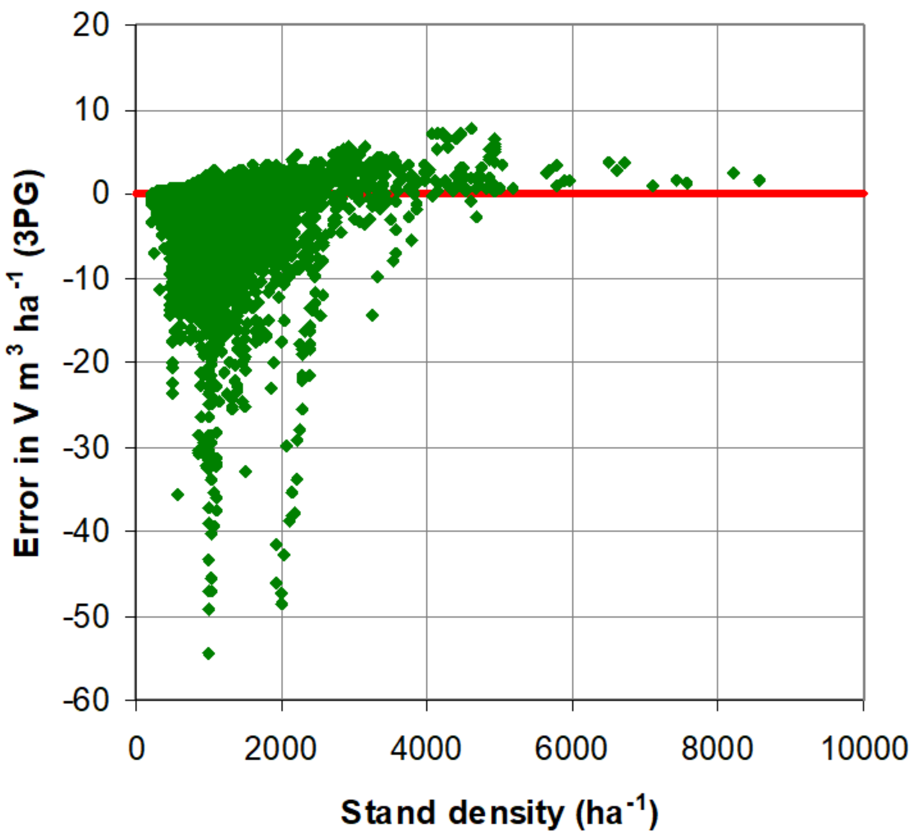
$$Vu = kh \; Ww^{ah}$$

$$kh = \beta 0 + \beta 1 \frac{N}{1000}$$

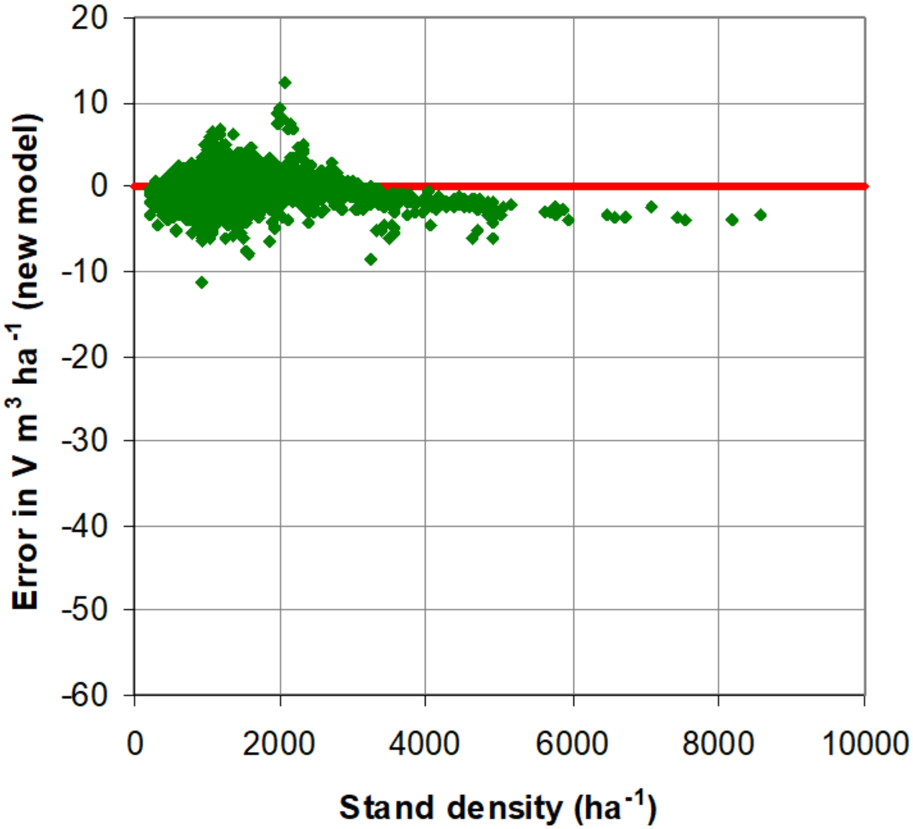
$$ah = \gamma 0 + \gamma 1 \frac{N}{1000}$$



- Error in Vu prediction (3PG)



Error in Vu prediction

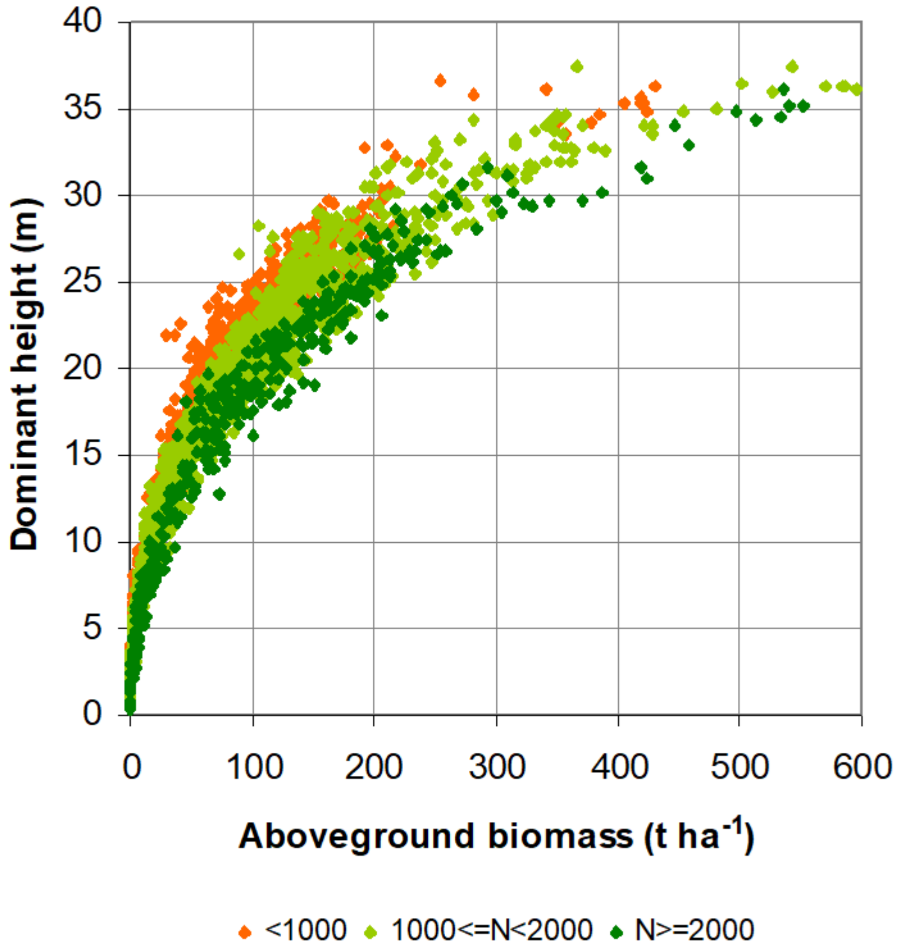


Allometric relationship for hdom

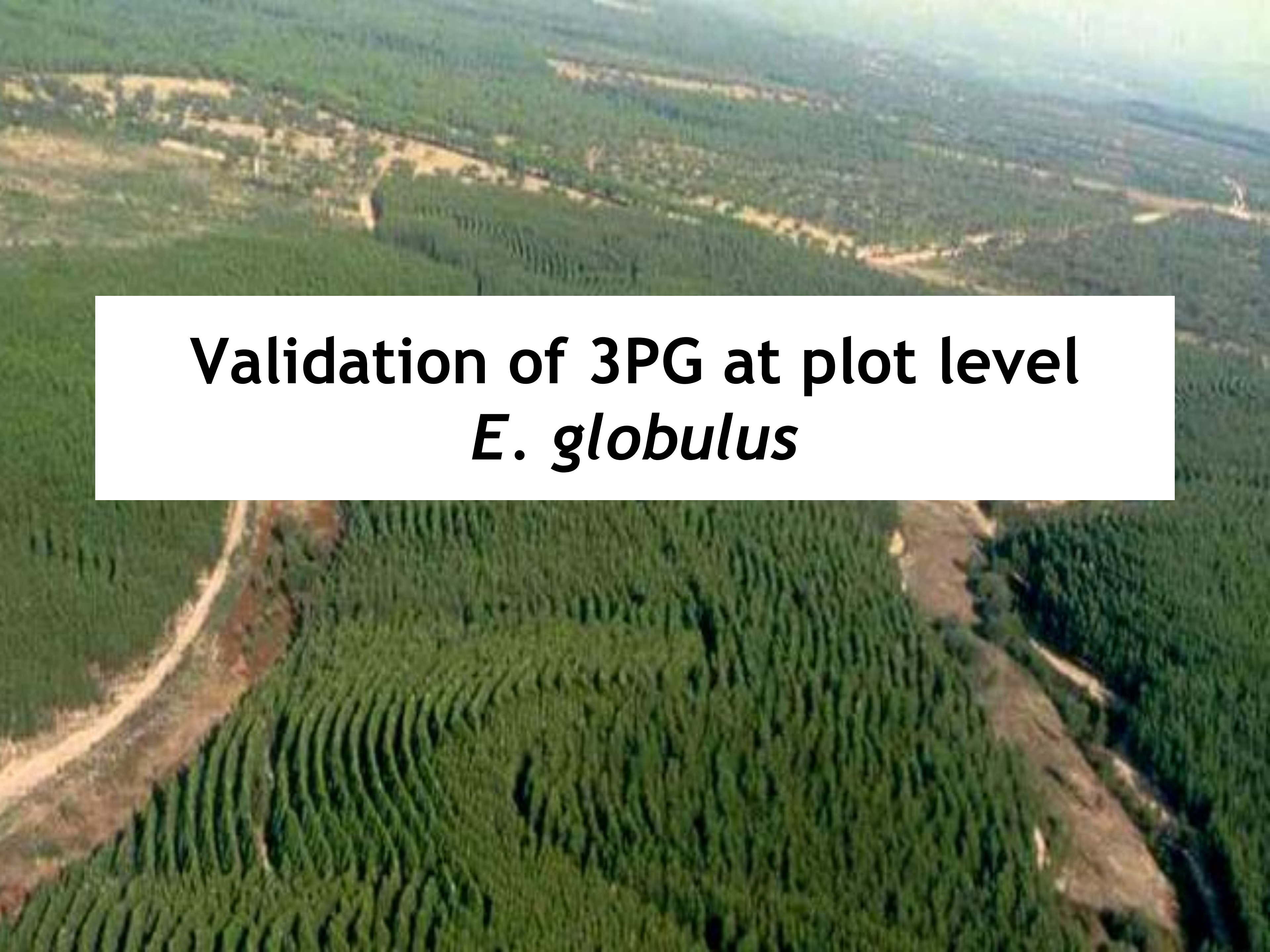
$$hdom = kh \; W^{ah}$$

$$kh = \beta 0 + \beta 1 \; \frac{N}{1000}$$

$$ah = \gamma 0 + \gamma 1 \; \frac{N}{1000}$$



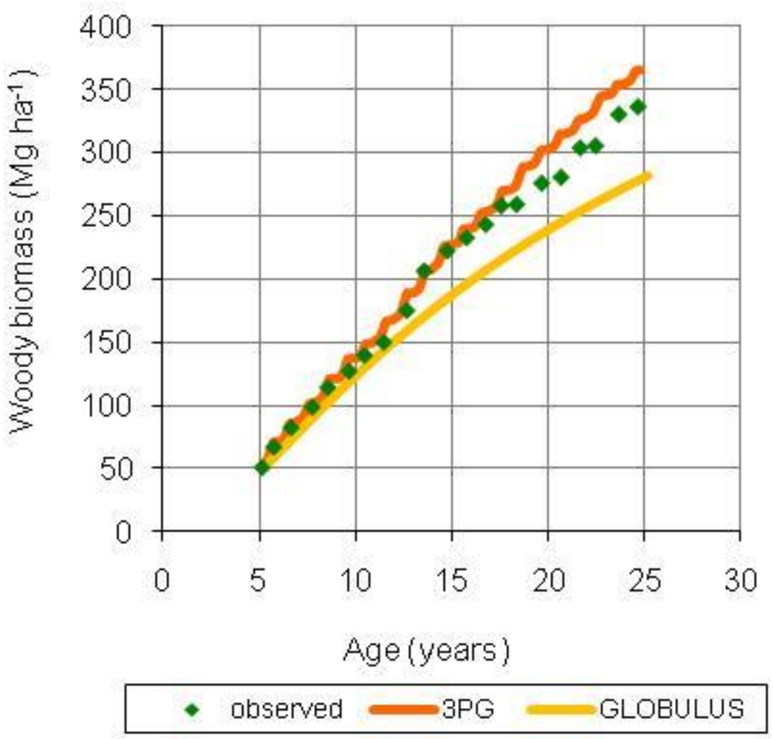
Validation of 3PG at plot level
E. globulus

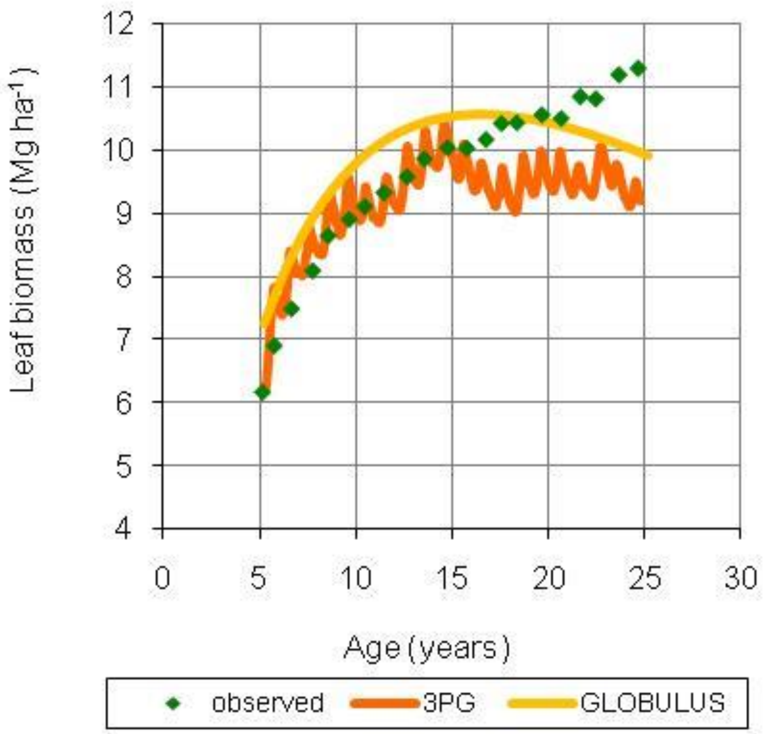


Validation at plot level - *Eucalyptus globulus*

- Validation was carried out by comparing observed versus simulated values of stand variables
  - Woody biomass
  - Stem wood biomass
  - Leaf biomass
  - Basal area
  - Stand volume
- Site characterization (FR, MaxASW) was obtained with the help of a expert on soils by opening a soil profile close to each plot

Example for one permanent plot	
Site index	21.5 m at 10 years
Initial stand density	1111 trees ha^{-1}





Example for one permanent plot	
Site index	21.5 m at 10 years
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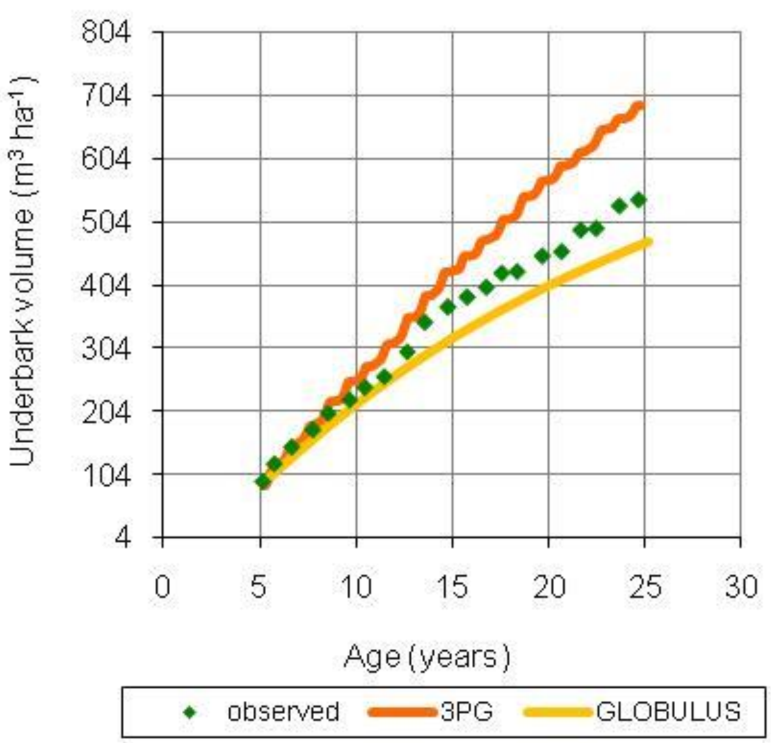
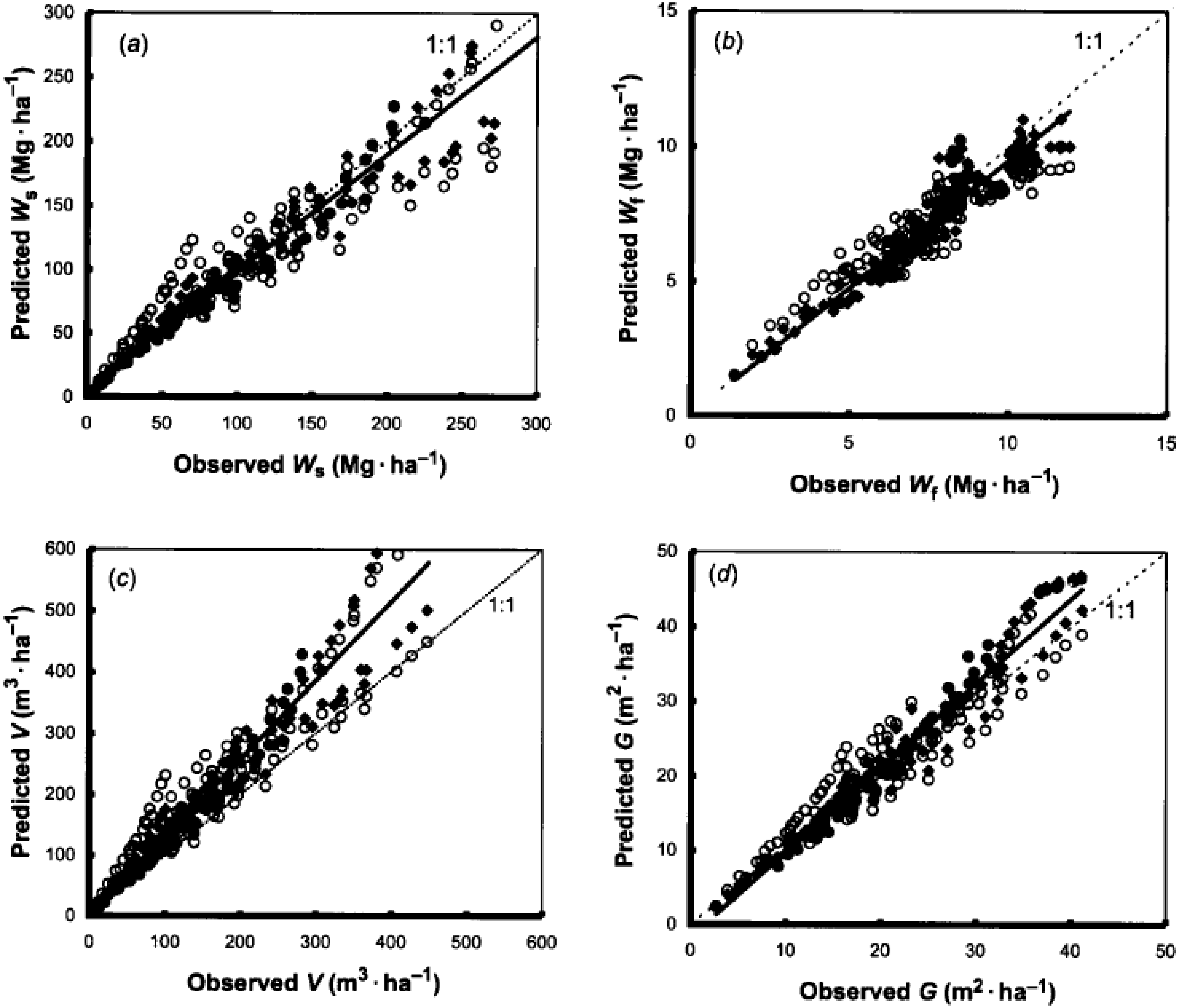
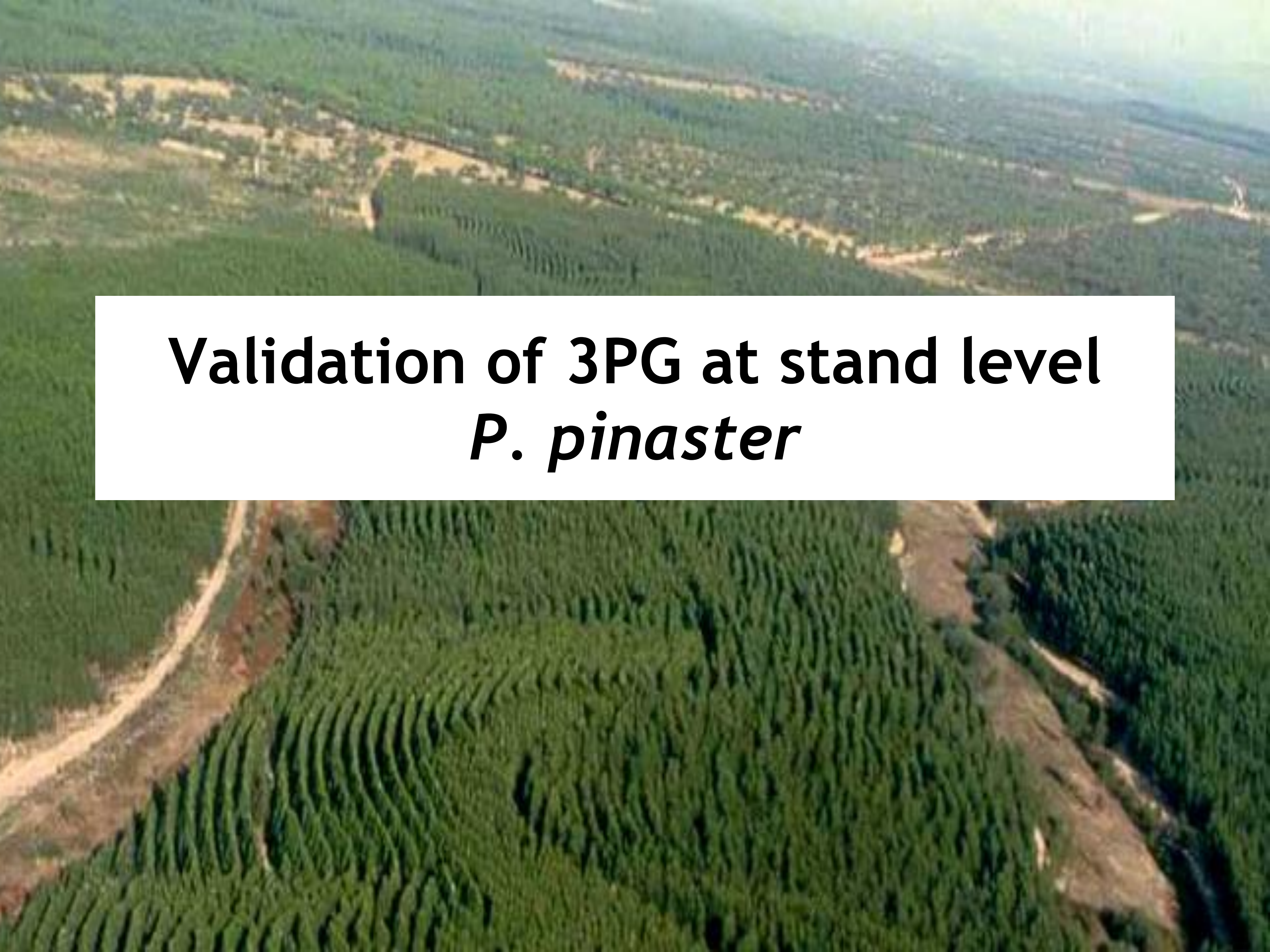



(a)
1:1
Predicted W_s (Mg · ha^{-1})
Observed W_s (Mg · ha^{-1})
(b)
1:1
Predicted W_f (Mg · ha^{-1})
Observed W_f (Mg · ha^{-1})
(c)
1:1
Predicted V (m^3 · ha^{-1})
Observed V (m^3 · ha^{-1})
(d)
1:1
Predicted G (m^2 · ha^{-1})
Observed G (m^2 · ha^{-1})

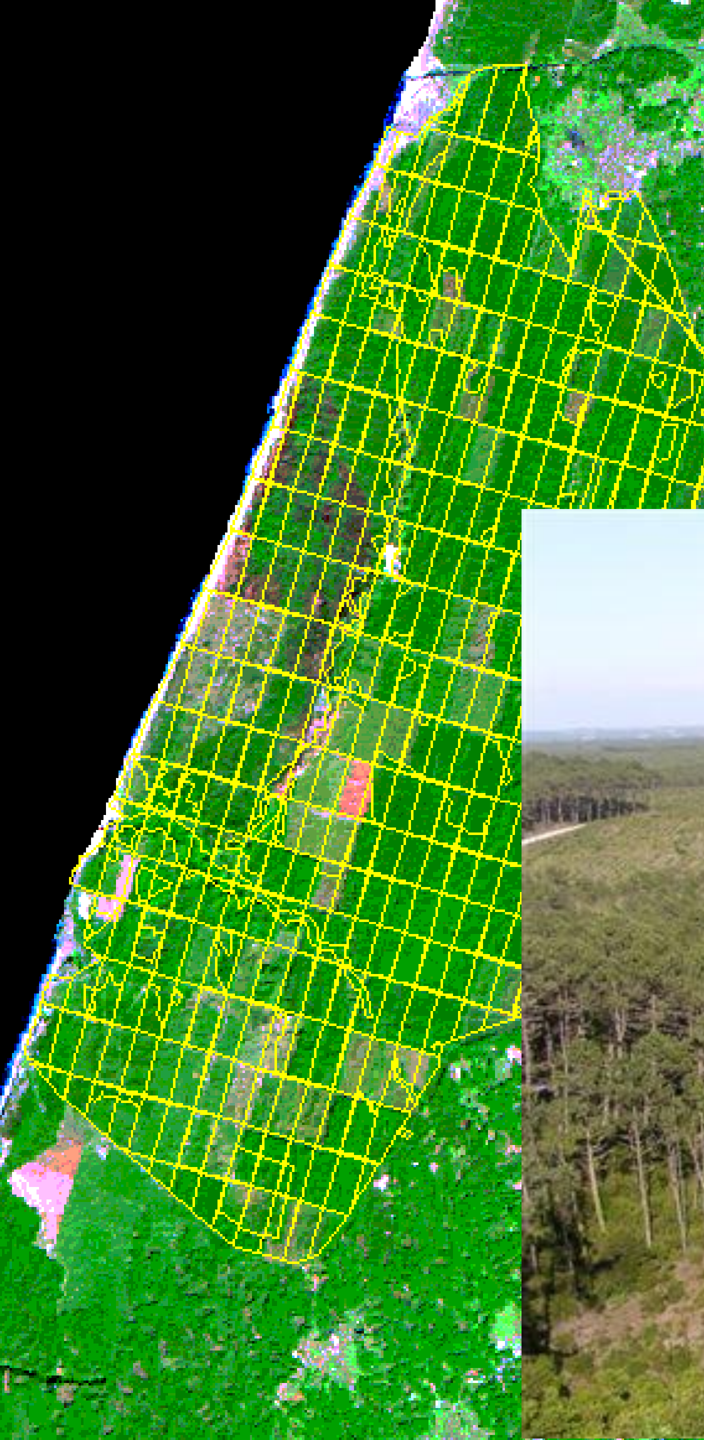
- With the prediction residuals we can compute several evaluation statistics:
  - Average (measures model bias)
  - Average of absolute values, sum of squares, etc (measure model precision)
  - 5% and 95% percentiles (measure prediction)
  - Modelling efficiency (computed as R-square in linear regression models)
  - ....
- The above statistics can be computed by classes of stand and/or environmental variables in order to detect bias or low-precision in relation to any of them

Validation of 3PG at stand level
P. pinaster



Validation at stand level - maritime pine

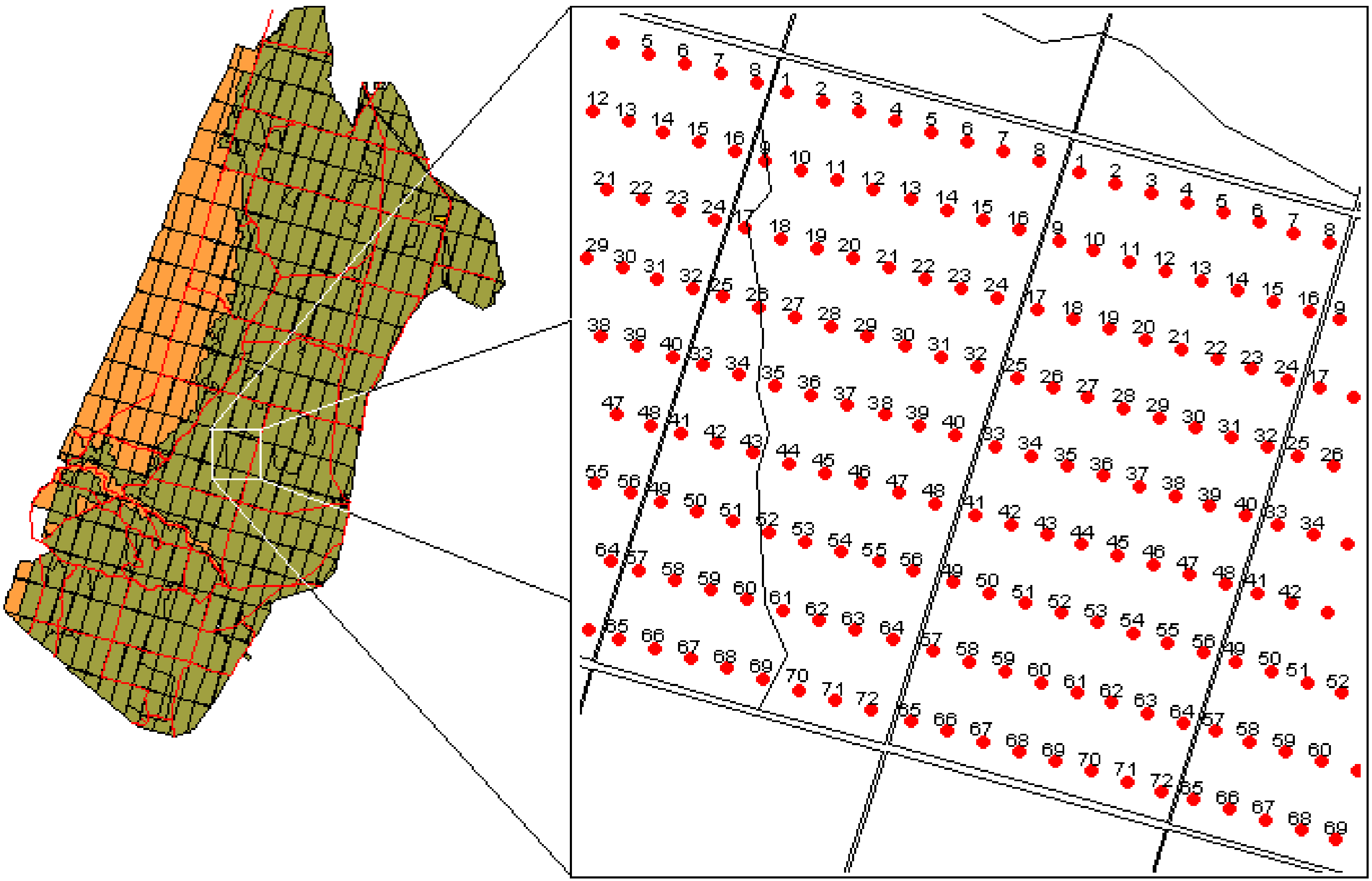
- Validation was carried out in Mata Nacional de Leiria, a state owned forest (total area: 11,000 ha) with different types of land uses:
  - Protection forest along the coast
  - Mixed forests along water courses
  - 8,700 ha of pure maritime pine stands managed for high quality timber
  - other minor uses
- For management purposes, the forest is divided into 343 management units with an approximate area of 30 ha each, which creates heterogeneity in the forest



The National Forest of Leiria

- For management purposes, a continuous forest inventory covers the forest since 1970
- Inventory covers 1/5 of the forest every year
- Sampling intensity:
  - 2 plots (500-2000 m^2) per ha till 1980
  - 1 plot (500-2000 m^2) per ha 1980-2000
  - 1 plot (500-2000 m^2) per 2 ha since 2000
- dbh is measured in every tree, tree height is measured in a sub-sample of trees (1 out of each 5 trees per dbh class)

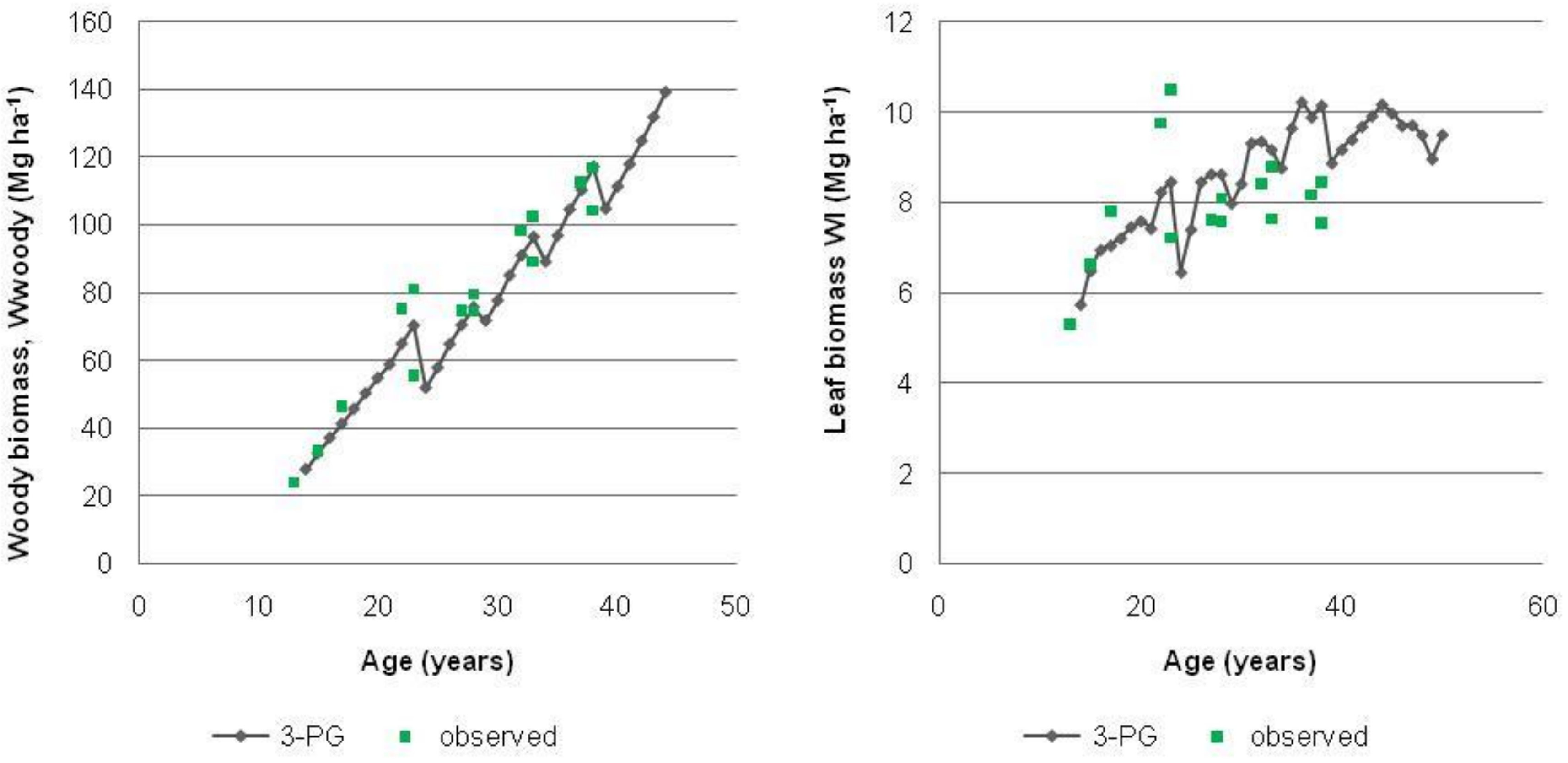
NFL – continuous forest inventory



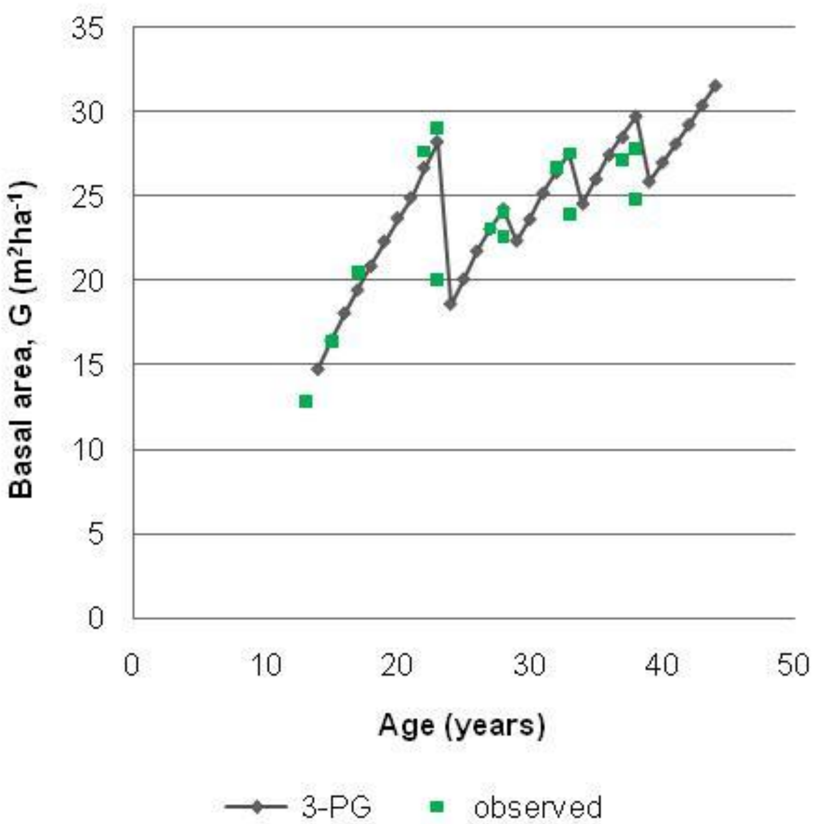
- Data from the NFL forest inventory were analyzed and a series of 72 stands (area of ~ 30 ha) were selected
- Selection criteria:
  - The length of the growth series
  - Cover the range of site index, stand density
  - Consider different ages to start the simulation
  - Include thinnings during the simulation period
- Site characterization (FR, MaxASW) was made with the help of site index and local visits

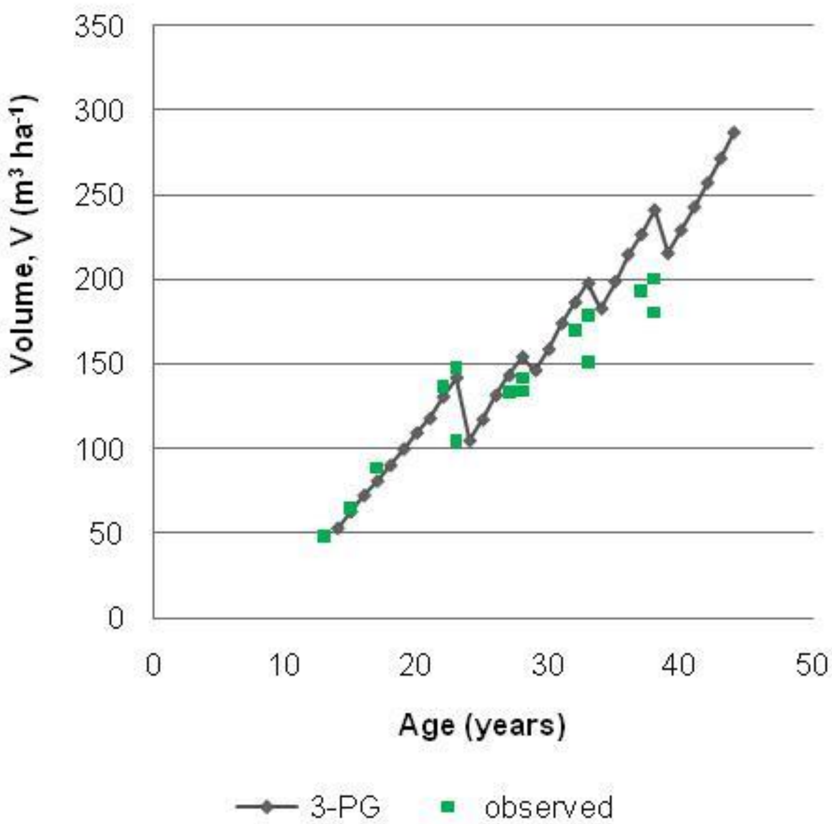
- Observed values were obtained by averaging the several plots measured in each stand
- Validation was carried out by comparing observed versus simulated values of stand variables
  - Woody biomass
  - Stem wood biomass
  - Leaf biomass
  - Basal area
  - Stand volume

Example for one stand

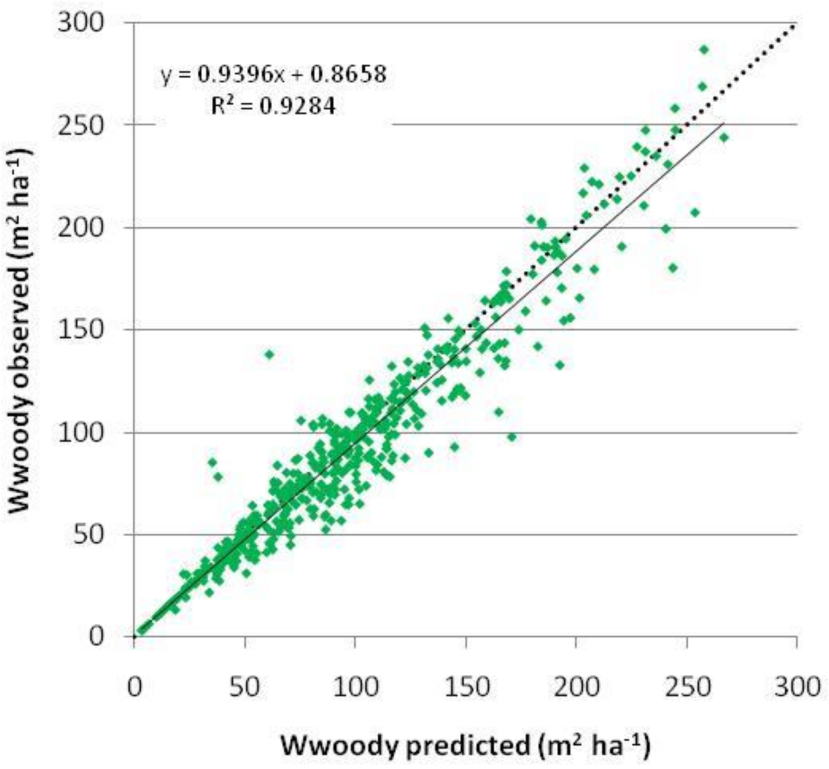


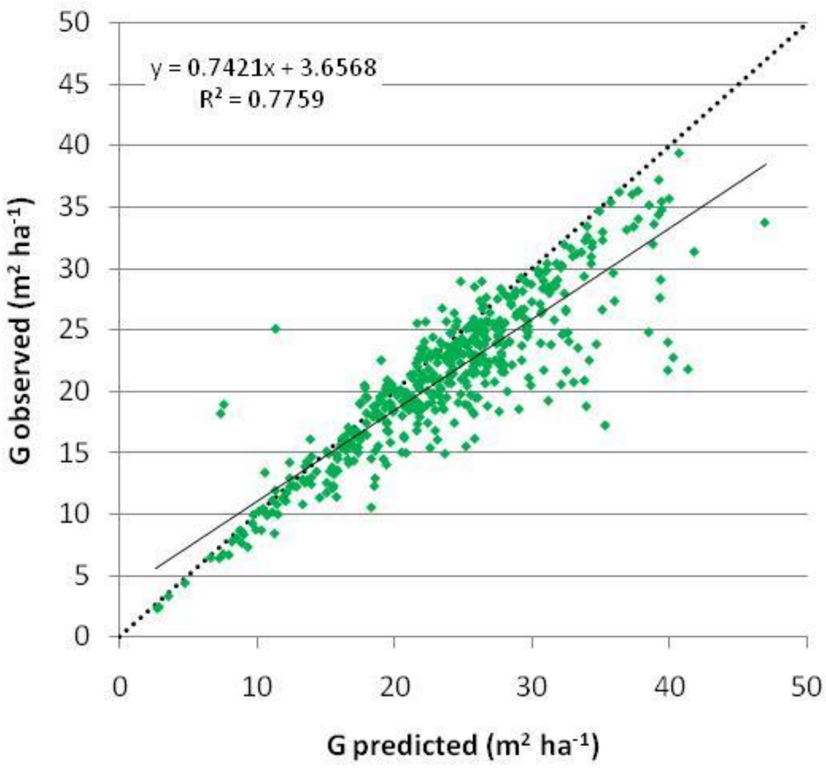
Example for one stand



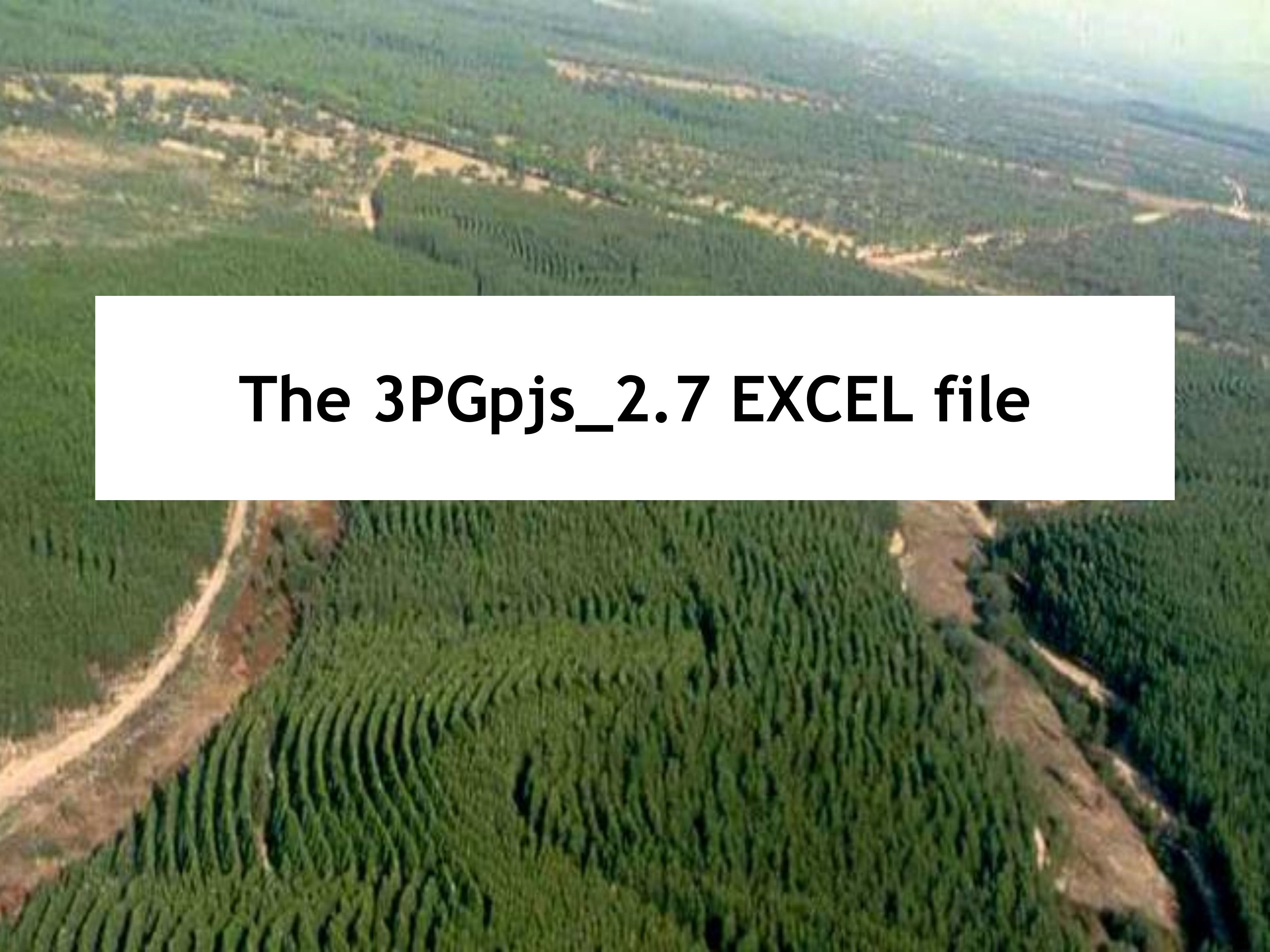


Summary for the 72 stands





The 3PGpjs_2.7 EXCEL file



- 3PG is implemented in Visual Basic for applications as an Add-ins for EXCEL, available in the site

  3pg.forestry.ubc.ca

  - To install 3PGpjs proceed as follows:

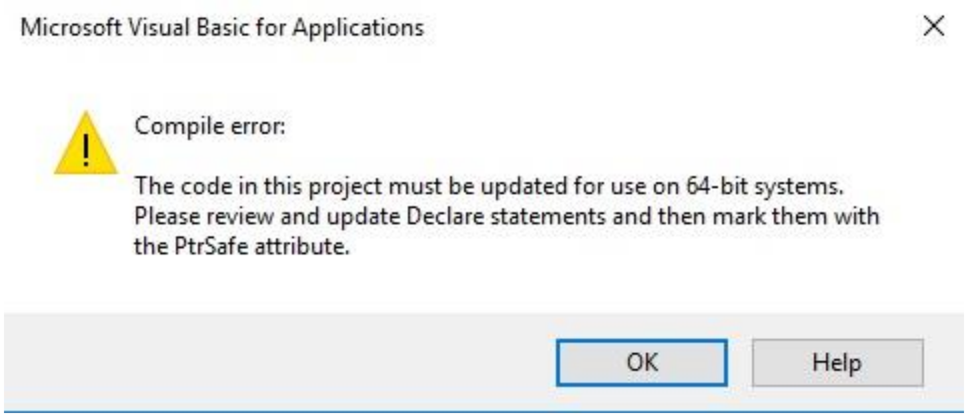
    a) Download the **3PGpjs27.zip** and extract all files and folders in **3PGpjs27.zip** to a folder of your choice

    b) Open 3PGPJS27.xls and save it as 3PGpjs27.xla (Excel Add-in)

    c) To load the 3PGpjs add-in go to Excel's TOOLS|ADD-INS menu and place a tick against the '3PGpjs27' add-in name. If you do not see this listed, use the BROWSE button to locate it. You can also unload the add-in by repeating this process and removing the tick mark

    d) The EXCEL file 3PGpjs27.Data is prepared to run 3PG in 32-bits computers

- How to solve the error that appears when running 3PGpjs27 if you are using a 64-bits computer
  - When trying to run 3PGpjs you will get an error message:



  - You have to modify the code that is shown to:

Private Declare **PtrSafe** Function ShellExecute Lib …..