Alternative Parameterization and Regional Validation of the 3-PG Model for Loblolly Pine Stands

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PINEMAP

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Highlights

- The 3-PG model is an extensively applied tool for estimating forest growth
- We developed a new set of parameters and functions for loblolly pine
- We developed new functions for: NPP allocation, biomass, height, canopy cover, effects of frost, tree mortality and the fertility rating
- We developed new specific functions for stands in Uruguay: wood specific gravity, height and biomass partitioning
- We used the largest validation dataset ever used for 3-PG, including sites both within and beyond loblolly pine's native range
- We found strong agreement between measurements and model predictions both within and outside of the loblolly pine native range

Background

- Loblolly pine (*Pinus taeda* L.) is one of the fastest growing pine species and has been planted on more than 10 million ha in the southeastern U.S.
- Loblolly pine has also been introduced into many countries, and large-scale plantations for timber production are found in Argentina, Brazil, China, New Zealand, South Africa and Uruguay.
- The semi-process-based simulation model, 3-PG (Physiological Processes Predicting Growth; Landsberg and Waring, 1997), has been extensively used to estimate stand attributes such as volume growth or biomass dynamics.
- As we had access to the large datasets of **PINEMAP** (Pine Integrated Network: Education, Mitigation and Adaptation Project, http://www.pinemap.org/), we were able to revise some important parameters of 3-PG using the alternative methods suggested by Gonzalez-Benecke et al. (2014a) to estimate species-specific parameters for FR, monthly needlefall rate, canopy cover, density-independent and density-dependent tree mortality, bole volume bark fraction, mean tree height, stemwood specific gravity, and initial biomass pools at any starting age.

Methods

Model version:

We used the 3-PG version 3-PGpjs2.7 (Sands, 2010), implemented as a Microsoft Excel spreadsheet.
The user-interface was modified allowing the user to change FR using SI, and initial biomass using tree density, age, mean dbh and mean tree height.

Paramater Estimation:

We estimated the following parameters:
Using Eddy Covariance measurements:

- Canopy conductance (Fig. 2)

Using long-term permanent plots (Table 1, Fig. 1) and the general biomass functions reported by Gonzalez-Benecke et al. (2014b):

- NPP partitioning: pFS as a function of age and quadratic mean diameter (Dq)
- Density-independent and density-dependent tree mortality (Fig. 3)
- Allometric relationships (to estimate initial biomass (WS, WF, WR), Height, pBB, Dq, Vratio
- Canopy Cover (as a function of BA and age) (Fig. 4)
- Needlefall, Litterfall and Forest Floor Accumulation (Fig. 5)
- Wood Specific gravity (as a function of age) (Fig. 6)
- Specific Needle Area (SNA ,as a function of age) (Fig. 6)
- Effect of frost on production (data from Teskey et al. 1987)
- Fertility rating (as a function of site index, SI) (Fig. 7)
- To run the model starting from seedlings: Mean Height at end of first growing season (as a function of SI) (Fig. 8).

Model validation:

The independent validation dataset included data from 91 permanent plots distributed in 24 sites in 12 states in the southeastern U.S. (two sites per state). The model was also validated against data from 10 permanent plots growing in operational stands in Tacuarembó, Uruguay (properties of Cambium Forestal Uruguay S.A.) (Fig. 1)

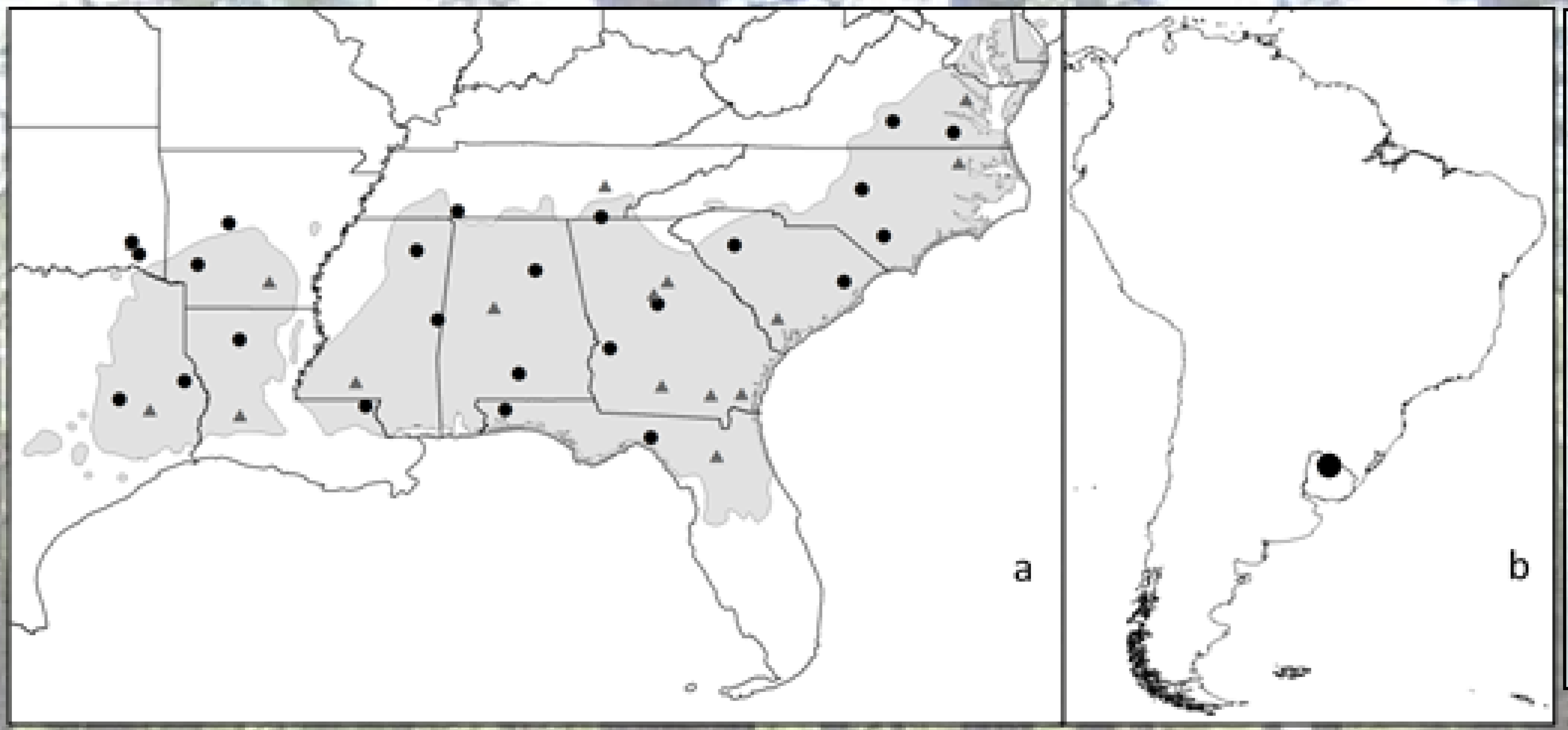

Figure 1. a) Location of sites used for validation (black circle, n=91 plots in 24 sites) or FR/SI analysis (grey triangle, n=63 plots in 16 sites) in the U. S.: the species natural distribution range is the shaded area; b) Location of sites used for validation in Uruguay (n=10 plots

Table 1. Summary of data used for parameter estimation.

Site	Institution	n	Lat	Long	AGE (yrs)	Dq (cm)	Nha (trees ha^{-1})	BA (m^2 ha^{-1})	SI (m)	Parameters Estimated
US-NC2	NCSU	4	35.80	-76.67	15 - 16	25.0 - 26.4	630 - 650	31.0 - 34.2	20.3 - 22.7	I
Gainesville	FBRC	12	29.76	-82.29	3 - 25	1.0 - 24.9	692 - 1538	0.1 - 50.1	13.9 - 27.2	II, IV, V, V VII, VIII
Sanderson	FBRC	96	30.24	-82.33	2 – 14	2.0 - 20.7	988 - 2964	0.4 - 45.5	17.1 - 30.7	III, IV
Waverly	FBRC	86	31.13	-81.75	2 - 14	2.2 - 21.5	988 - 2964	0.5 - 52.9	24.4 - 31.7	III, IV, VII
Various (18)*	PMRC	250			2 - 12	1.1 - 32.1	205 - 1810	0.1 - 54.8	14.0 - 29.2	III, VII
Various (14)*	PMRC	192			4 - 12	0.1 - 24.3	401 - 4485	0.1 - 46.3	16.8 - 33.2	II, III, VI
Various (25)*	WGFTIP	437			5 - 20	0.1 - 27.0	232 - 4483	0.1 - 55.0	18.3 - 30.4	III, VII
Various (11)*	FPC	141			4 - 23	0.2 - 30.9	156 - 2050	0.1 - 48.2	15.5 - 26.8	III
Various (8)*	FPC	196			11 - 31	14.1 - 30.3	225 - 2032	9.0 - 47.6	15.6 - 25.6	III
Various (26)*	FPC	96			9 - 33	7.5 - 30.7	252 - 2590	4.7 - 52.1	15.1 - 24.3	III
Tacuarembó	CAMBIUM	24			3 - 34	6.9 - 40.1	256 - 1381	5.1 - 55.3	20.9 - 29.8	V, VII
Total		1506			2 - 34	0.1 - 40.1	156 - 4485	0.1 - 55.3	13.9 - 33.2	

n: number of plots; AGE: range of age (yrs); Dq: range of quadratic mean diameter (cm); BA: range of basal area (m2 ha-1),SI: range of site index (m).
I: canopy conductance; II: NPP partitioning; III: density-dependent tree mortality; IV: canopy cover; V: needlefall; VI: dbh-Ht relationship; VII: Dq-STEM relationship; VIII: FR-SI relationship.
*: multiple sites were used.

Results

Model fitting

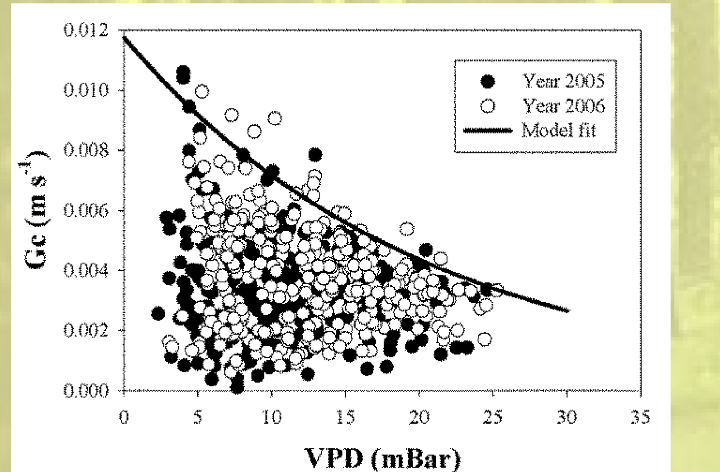

Fig 2. *Model fitting for canopy conductance sensitivity to VPD. Symbols are mean daily data from eddy covariance measurements in a 15-16 year-old stand located in the Lower Coastal Plain of North Carolina, U.S.*

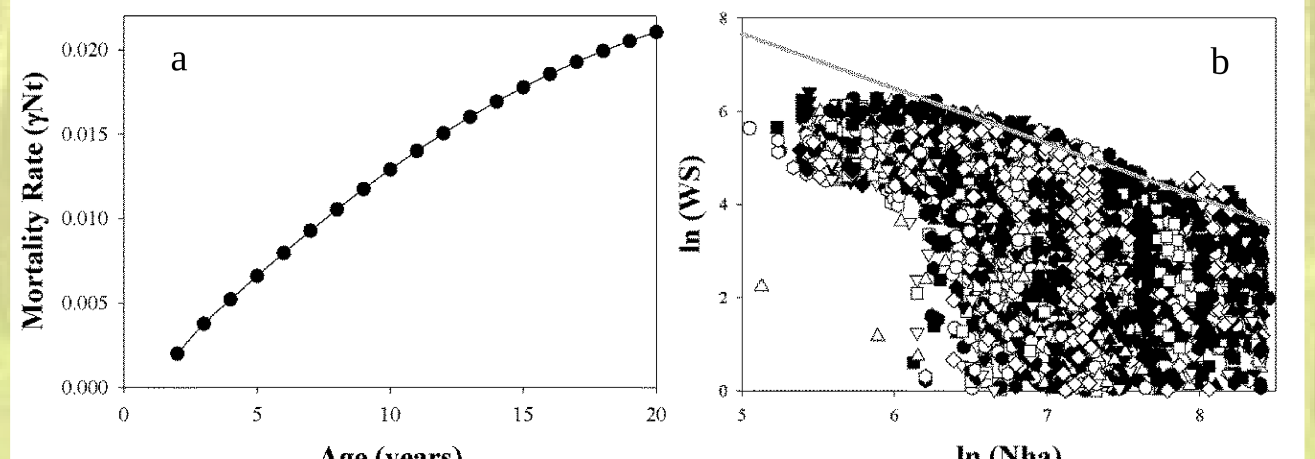

Fig 3. *Tree mortality relationships. a) Relationship between age density-independent tree mortality (γNt) using the model of Harrison and Borders (1996); b) Density-dependent tree mortality, based on the relationship between stem biomass (WS, kg tree-1) and stand density (both in natural logarithm scale). The self-thinning line is the theoretical upper limit.*

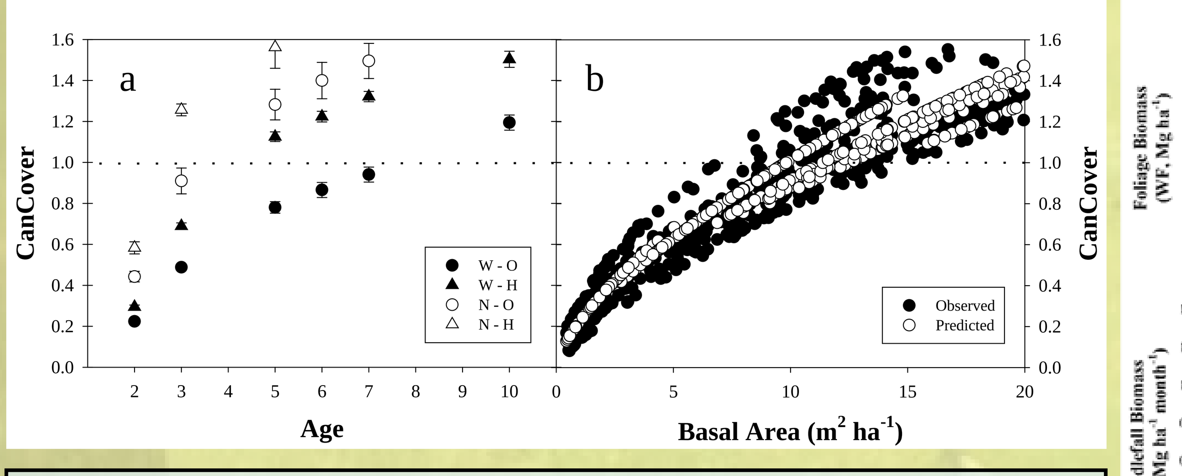

Fig 4. *Relationship between canopy development (expressed as fractional canopy cover, CanCover) and a) age and b) basal area for loblolly pine stands of PPINES study. Plots that received combinations of two contrasting silvicultural treatments (operational, O, and high intensity, H) and two contrasting planting densities (1,334 trees ha-1, W, and 2,990 trees ha-1, N). Panel a) show mean values for stands growing in GA. Panel b) show observed and predicted values for all plots growing on sites in FL and GA. Dashed line represents the point when the stand reach canopy closure (CanCover=1).*

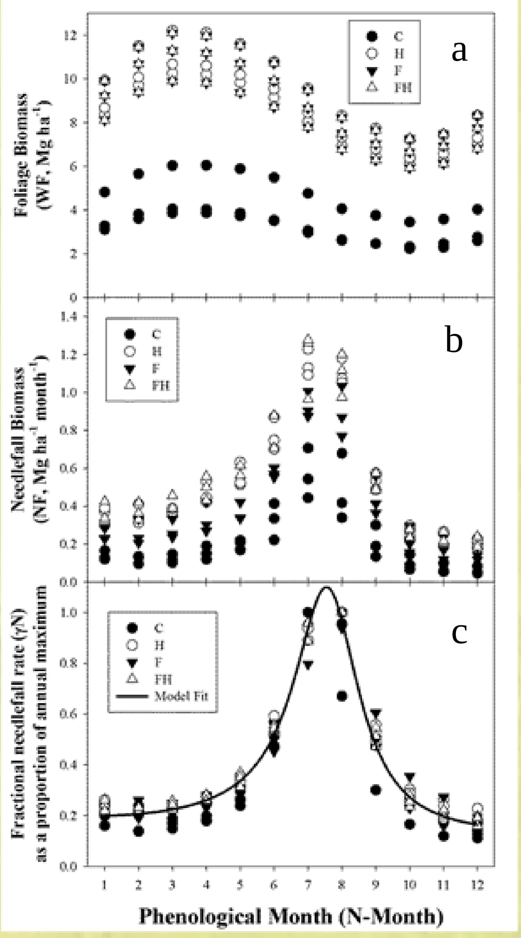

Fig 5. *Seasonal dynamics of foliage biomass and needlefall for the IMPAC study, showing average monthly a) foliage dry mass (WF, Mg ha-1), b) needlefall (NF, Mg ha-1 month-1) and c) fractional needlefall (γN as a proportion of annual maximum).*

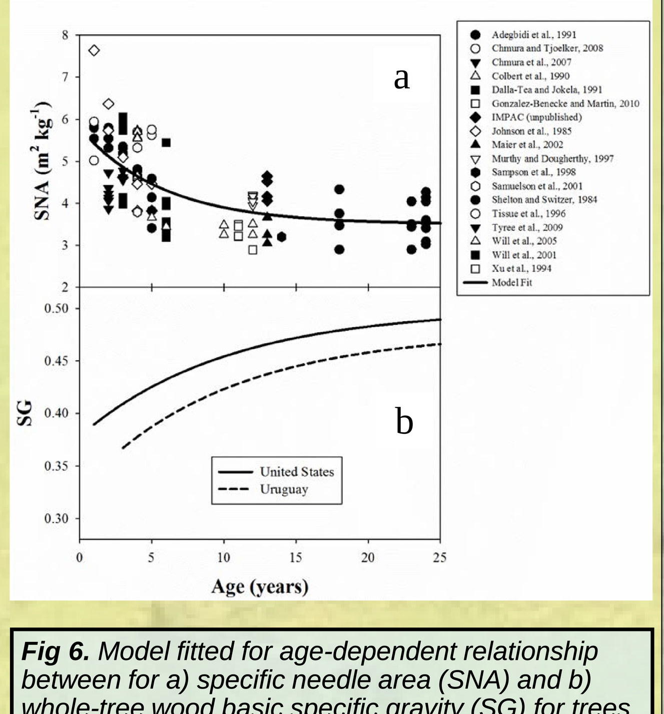

Fig 6. *Model fitted for age-dependent relationship between for a) specific needle area (SNA) and b) whole-tree wood basic specific gravity (SG) for trees growing in southeast U.S. (solid line; adapted from Harrison and Borders, 1996) and Uruguay (dashed line).*

Fertility Rating –Site Index

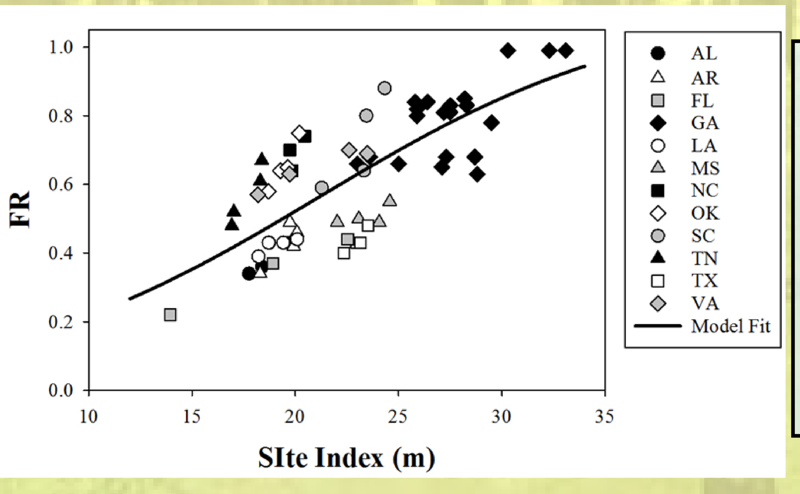

Fig 7. *Relationship between site index (SI, m) and FR after iterative calibration for 63 plots in 12 states in southeastern U.S.*

Initial Height - Site Index

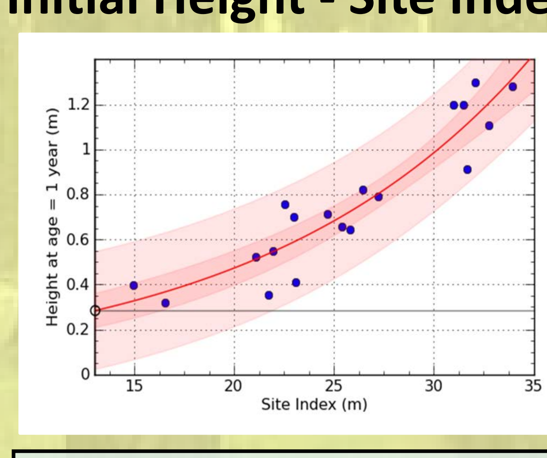

Fig 8. *Relationship between site index (SI, m) and Mean Height (m) at the end of first growing season.*
This relationship is used to determine initial biomass using H-Biomass functions if user need to run the model starting from seedlings

Conclusions

The model was tested against data from replicated experimental measurement plots covering a wide range of stand characteristics, distributed across the southeastern U.S. and also beyond the natural range of the species, using stands in Uruguay, South America. We used the largest validation dataset for 3-PG, and the most geographically extensive within and beyond a species' native range. We found that 3-PG predicted growth well.

The 3-PG model has broad potential for application e.g., for regional analysis of loblolly pine stand dynamics or assessing the impact of future climate scenarios on stand productivity across a wide range of ages and stand characteristics.

Model validation

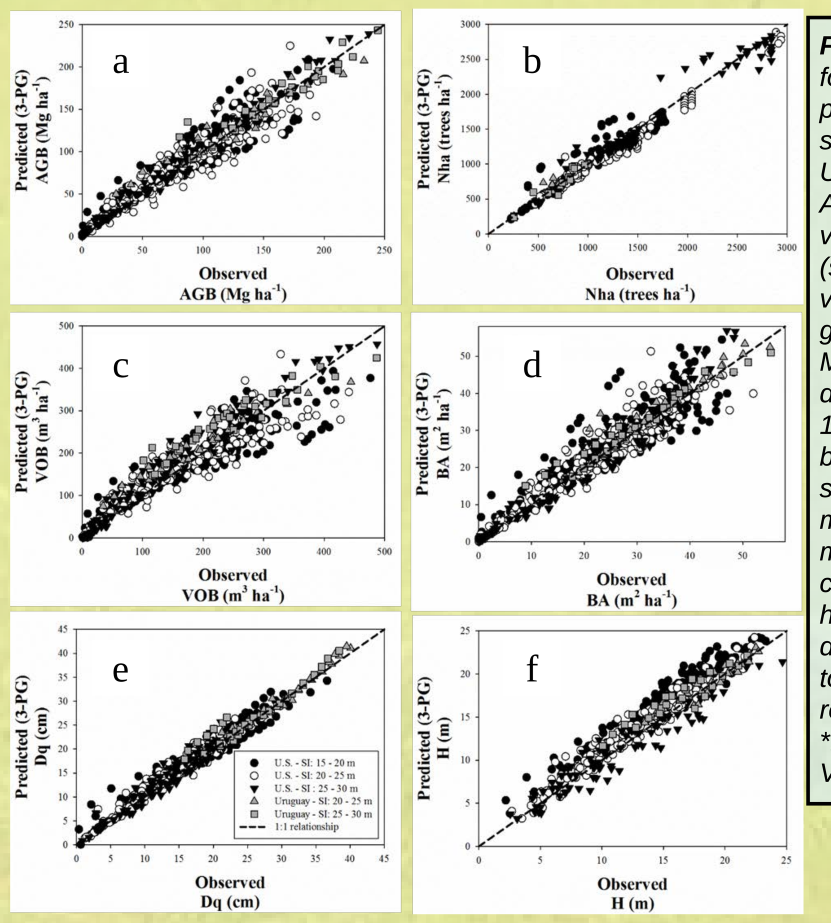

Fig 9. *Model validation for 34 tested sites (101 plots total; 91 in the southeastern U.S.; 10 in Uruguay, South America). Observed versus predicted (simulated with 3-PG) values of a) total above ground biomass (AGB, Mg ha^{-1}), b) stand density (Nha, trees ha-1); c) bole volume over-bark (VOL, m3 ha^{-1}); d) stand basal area (BA, m2 ha^{-1}); e) quadratic mean diameter (Dq, cm), and f) mean tree height (H, m). The dotted line corresponds to the 1-to-1 relationship.*
**: For sites in Uruguay: VIB.*

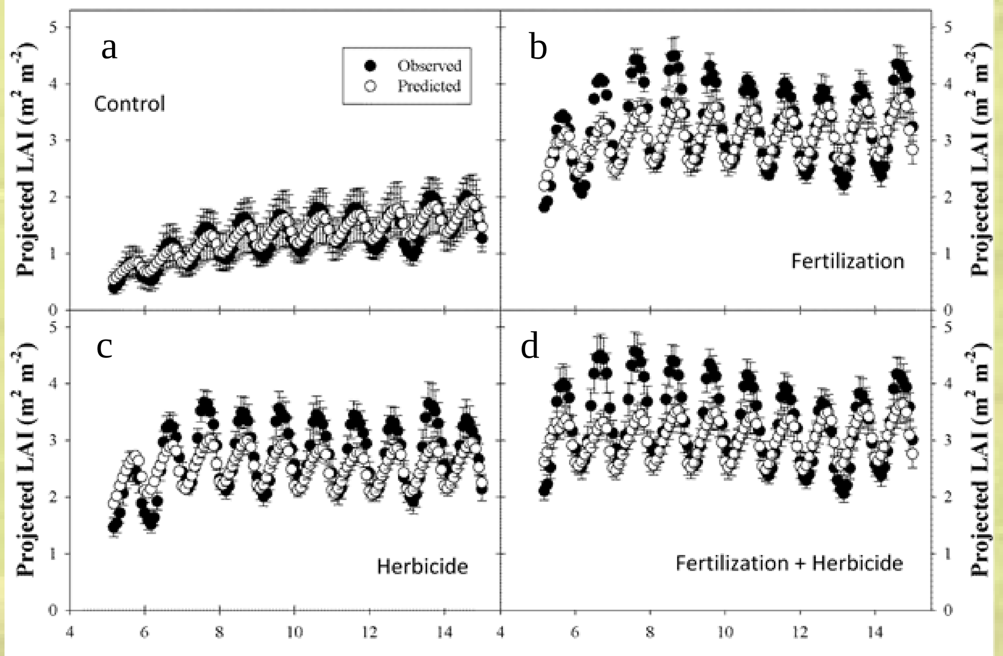

Fig 10. *Validation of monthly projected leaf area index (LAI, m2 m-2). Observed (filled circle) and predicted (open circle) values for loblolly pine stands grown at the IMPAC study under the following silvicultural treatments a) Control, b) Fertilization, c) Herbicide, and d) Fertilization + Herbicide (Jokela and Martin, 2000).*

Acknowledgements
This research was supported by the U.S. Department of Defense, through the Strategic Environmental Research and Development Program (SERDP), the Pine Integrated Network: Education, Mitigation and Adaptation project (PINEMAP), a Coordinated Agricultural Project funded by the USDA National Institute of Food and Agriculture, Award #2011-68002-30185, the University of Florida's Carbon Resources Science Center and the Forest Biology Research Cooperative. Special thanks goes to Dr. Harold Burkhart at Virginia Tech University, Dr. Thomas Byram at Texas A&M University and to Mr. Daniel Ramirez and Mr. Juan P. Burgos at Cambium Forestal Uruguay S.A., for providing valuable data for parameter estimation and model validation.

References:

Jokela, E.J., Martin, T.A., 2000. Effects of ontogeny and soil nutrient supply on production, allocation and leaf area efficiency in loblolly and slash pine stands. Can. J. Forest Res. 30, 1511-1524.

Landsberg, J.J., Waring, R.H., 1997. A generalized model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. Forest Ecol. Manage. 95, 209-228.

Gonzalez-Benecke, C.A., Jokela, E.J., Cropper Jr., W.P., Bracho, R., Leduc, D.J., 2014a. Parameterization of model 3-PG for *Pinus elliottii* stands using alternative methods to estimate fertility rating, biomass partitioning and canopy closure. Forest Ecol. Manage. 327:55-75.

Gonzalez-Benecke, C.A., Gezan, S.A., Albaugh, T.J., Burkhart, H.E., Jokela, E.J., Maier, C.A., Martin, T.A., Rubilar, R.A., Samuelson, L.J., 2014b. Local and general above-stump biomass functions for loblolly and slash pine trees. Forest Ecol. Manage. 334, 254-276.

Sands, P.J., 2010. 3PGPJS user manual, 27 p.