A spatially explicit economic analysis of *Eucalyptus benthamii and Eucalyptus grandis* for short-rotation biomass in the Southern United States

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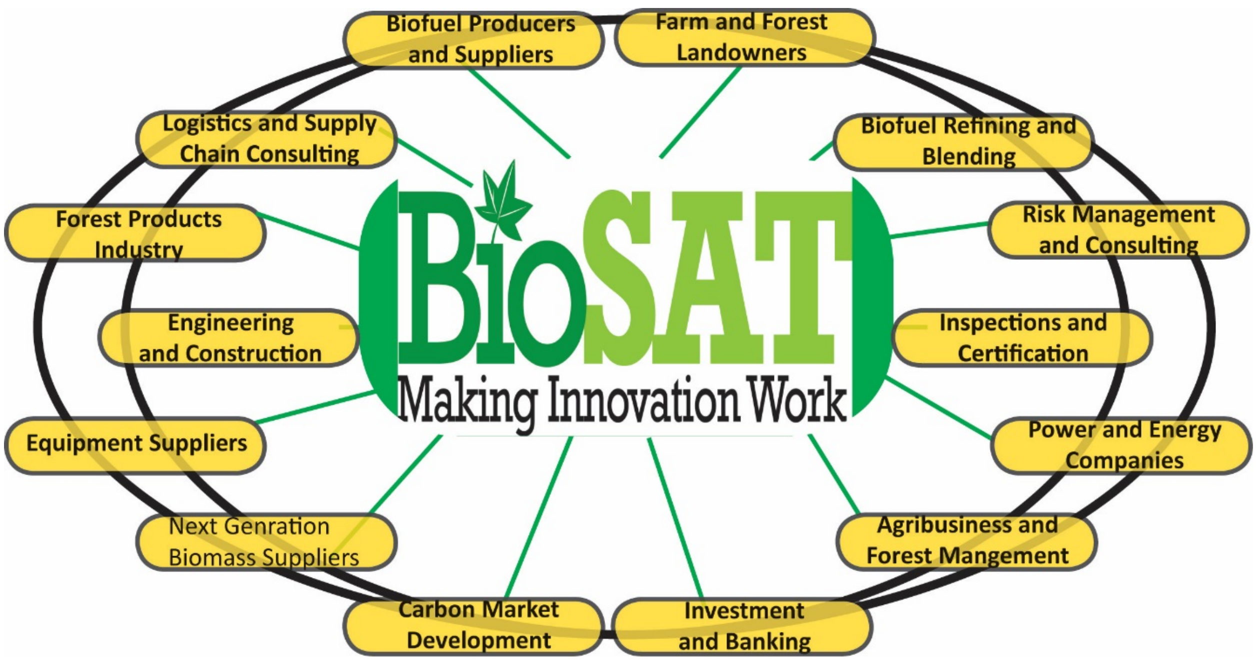
Motivation

- An extension of **BioSAT** (www.biosat.net) work began in **2011** to include SRWC



- Motivation: **Make biomass utilization economically feasible and sustainable** SRWCs are potential feedstocks that **may ensure long-term sustainable resources** for emerging biomass energy production facilities.

Project Goal

To assess the SRWC feasibility for the five subject species at **5-ZCTA spatial level** across 33 states of the Eastern US

Following steps for each species:

1) **Identify** the **geographic** and **economically feasible range**
2) **Acquire weather data** for each state in the operable range
3) **Produce a soil matrix for the sites**
4) **Complete a literature search** of **growth parameters** and the **growing regimes** for each species
5) **Define the model regimes (irrigation, fertilization, and thinning)**
6) Use the **individual species parameters, regional weather data**, and defined soil matrices to **generate 3-PG estimates of Mean Annual Increment (MAI)**

Five SRWC Species

- *Pinus taeda (loblolly pine)*

- ***Eucalyptus grandis****

- ***Eucalyptus benthammii****

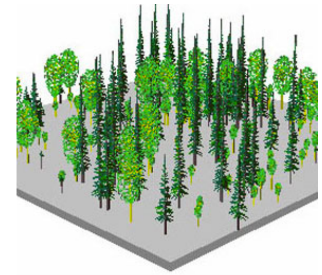
- *Salix spp.*

- *Populus spps.*

  (Eastern cottonwood regimes in the Southern US and hybrid poplar regimes in the Northern states)

3-PG Model

(A physiologically-based model)



- The computer 3-PG model (**Physiological Processes Predicting Growth**) was developed by Landsberg and Waring (1997).

- Includes **physical properties** of each species including the soil and climate data

- To **predict expected biomass production**

- **3-PG modeling structure** consists of equations:

  1) that ***estimate biomass monthly production values***

  2) that ***allocate the biomass into contributions of tree components*** (roots, shoots, branches, and leaves)

- **Previously:** Successfully model loblolly pine (Landsberg *et al.* 2001) in Scotland County, NC and in Waycross, GA (Bryars *et al.* 2013)

3-PG Model Inputs and Outputs

Initialization inputs (3-PG)

- Site name
- Latitude
- Fertility effect
- Soil texture class
- Establishment dates
- Stems per hectare
- Initial foliage
- Maximum and minimum available soil water

Silvicultural inputs (3-PG)

- Irrigation regime
- A fertilization regime
- A thinning regime
- A value that represents the genetics of the species
- Expected defoliation rates
- A ranking for competition from weeds

Outputs

- MAI: Mean Annual Increment in the unit of m^3/ha/yr
- Biomass production
- Stem density
- Stem mortality
- Water use

Base Assumptions

1. *Genotype*
   The yields reflect ***current average genetic technology***

2. *Weather*
   Monthly mean data from ***1995-2004*** at a **regional**, weather station basis

3. *Management regime*
   Aimed at advanced but ***economically feasible regimes***

4. *Fertilization*
   All stands are fertilized and regimes are comparable to ***current best practices*** for economically-viable biomass production

5. *Irrigation*
   Irrigation was considered to be ***cost-prohibitive*** and not included in the management regimes, other than perhaps at the time of establishment for eucalyptus species

6. *Soils*

Soil Matrices

Matrix of soil texture, fertility rating, available soil water and site position

Soil Texture	Site Position	Fertility Rating	Min ASW [mm/m]	Max ASW [mm/m]
Sand	*Upland*	0.15	50	100
Sand	*Lowland*	0.30	50	100
Sandy loam	*Upland*	0.30	100	150
Sandy loam	*Lowland*	0.50	100	150
Clay loam	*Upland*	0.55	150	200
Clay loam	*Lowland*	0.70	150	200
Clay	*Upland*	0.65	200	250
Clay	*Lowland*	0.75	200	250

A tabular component and a spatial component of soil data were collected from USDA Natural Resources Conservation Service (NRCS, 2012) SSURGO database at a county level.

<u>*Fertilization Responses*</u>

Fertility Response by Soil Texture and Site Position

Soil Texture	Site Position	Fertility Rating	Fertility Response
Sand	*Upland*	0.15	0.60
Sand	*Lowland*	0.30	0.45
Sandy loam	*Upland*	0.30	0.50
Sandy loam	*Lowland*	0.50	0.30
Clay loam	*Upland*	0.55	0.25
Clay loam	*Lowland*	0.70	0.10
Clay	*Upland*	0.65	0.15
Clay	*Lowland*	0.75	0.05

Weather data methods

Weather data were collected from NOAA National Climatic Data Center (NOAA, 2012) and NASA Atmospheric Science Data Center (NASA, 2012) at a ***county*** weather station level.

Monthly mean data of a 10-year period from ***1995-2004***

Include:

- Precipitation
- Minimum temperature
- Maximum temperature
- Solar incoming radiation
- Frost days

Coppice Management

- The SRWC hardwood species evaluated in this project have the ability to stump sprout or coppice

- The productivity of a subsequent coppice rotation is dependent on ***coppice vigor*** and ***coppice survival***.

This project:

- To **estimate the mean of the productivity of the life** of a planted crop, i.e. the mean of the initial planting, plus coppice crop one, plus coppice crop two, and so on.

Validation

On an individual site basis

Validation of 3-PG was completed by:

- Full model parameterization of set of data

- Comparison of the **modeled site data to observed or measured data**

This project

Validation by:

- Comparison of the **modeled output to the observed yields at regional level**

- C**omparison to published or observed** data for a given range or region

Parameterization

42+ input parameters for one specific species

- ***The canopy structure*** and ***process suite of variables*** is particularly important as it defines the light use efficiency, light interception as and the canopy carbon capture

- ***The canopy quantum efficiency variable*** is an estimate of carbon production per unit of light captured. This parameter value is greatest for the ***Eucalyptus species***

GIS Visualization

Evaluation of soil texture at the level of 5-digit ZCTA

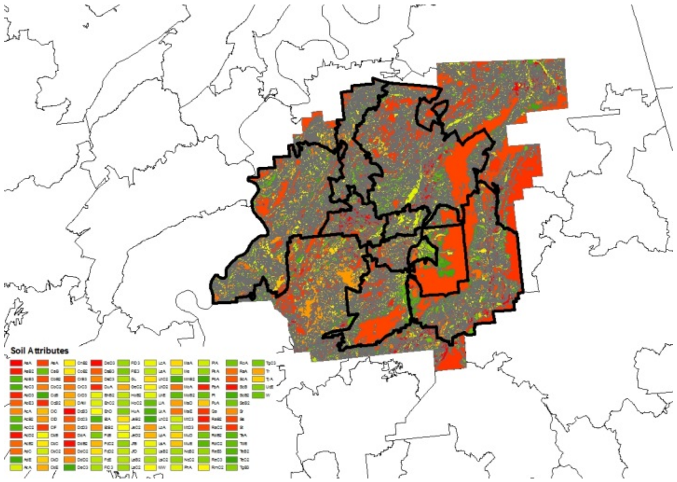
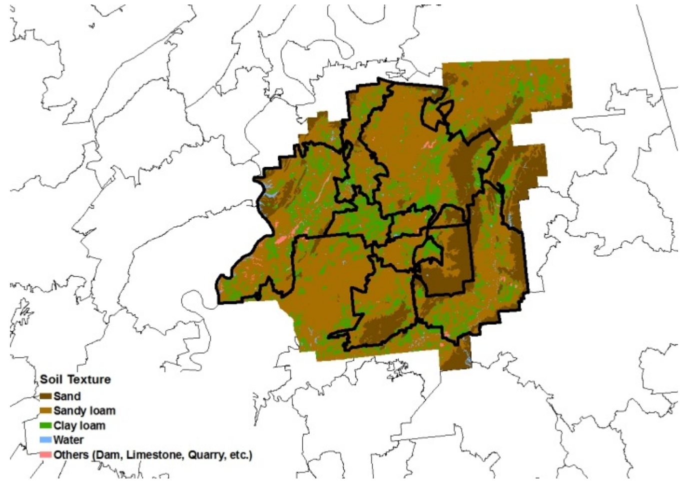
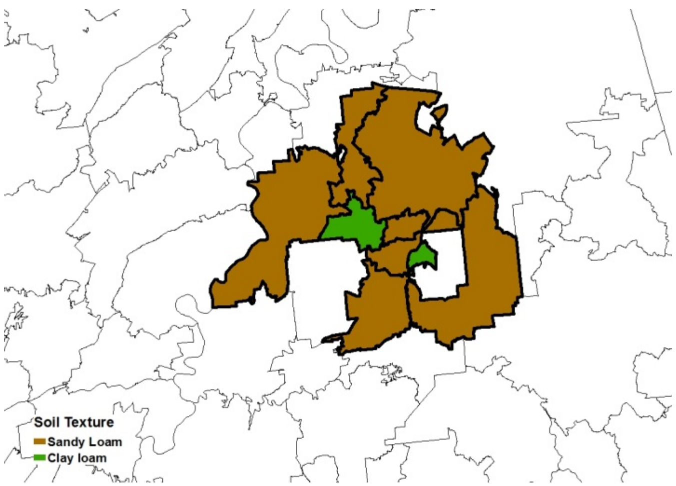


Illustration of soil attributes in 5-digit ZCTAs



Soil texture allocation by 5-digit ZCTA

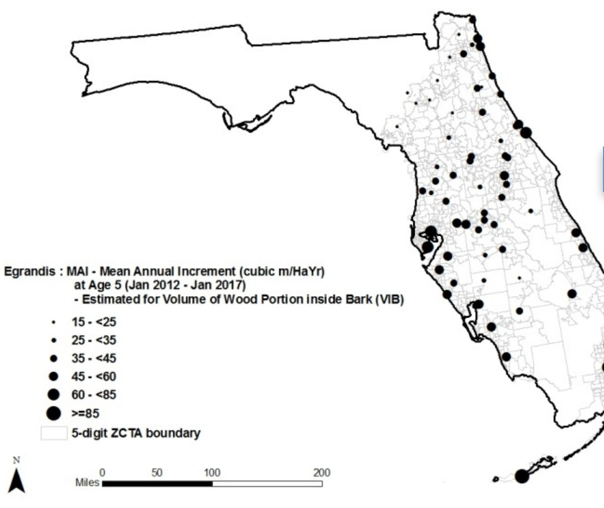


Representative soil texture for 5-digit ZCTAs

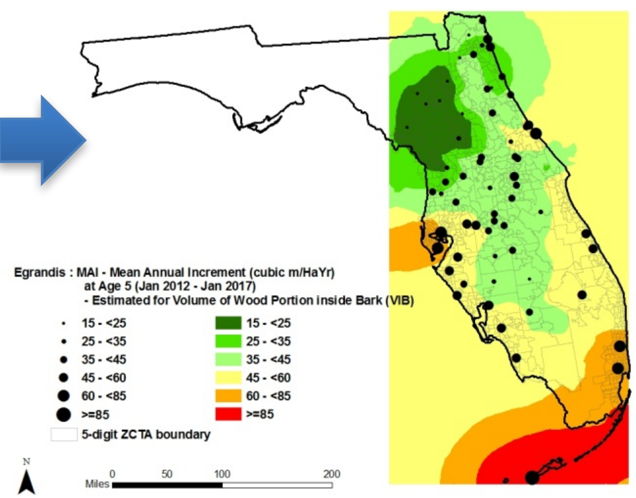
GIS Visualization

Simple Kriging Interpolation

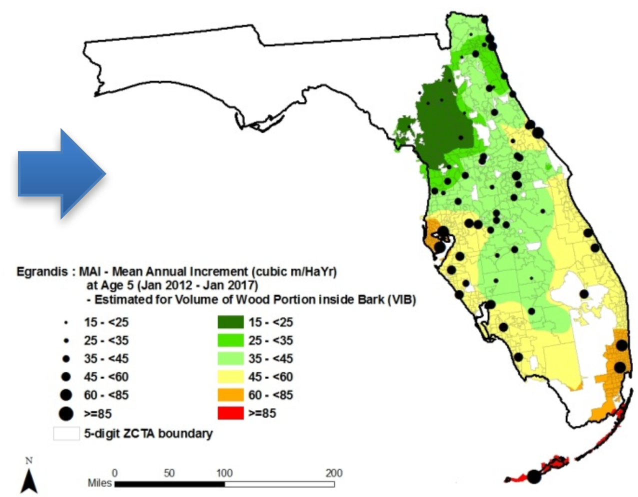
- To generate a smoother predictive output map from measured yield output data at known locations
- Supported by ArcGIS® Geostatistical Analyst



3-PG model yield MAI point output of Eucalyptus grandis



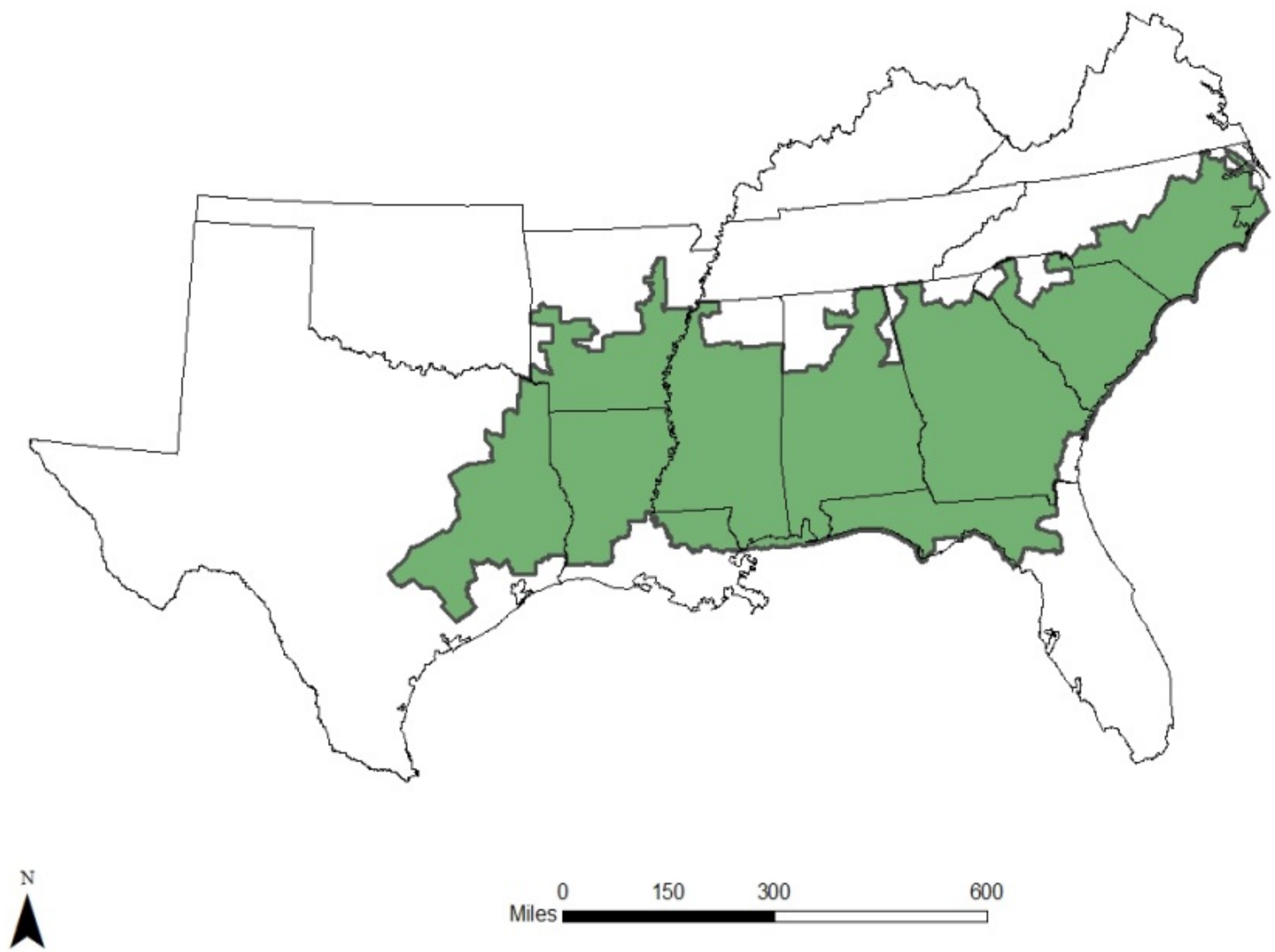
Simple Kriging predictive MAI output map of Eucalyptus grandis



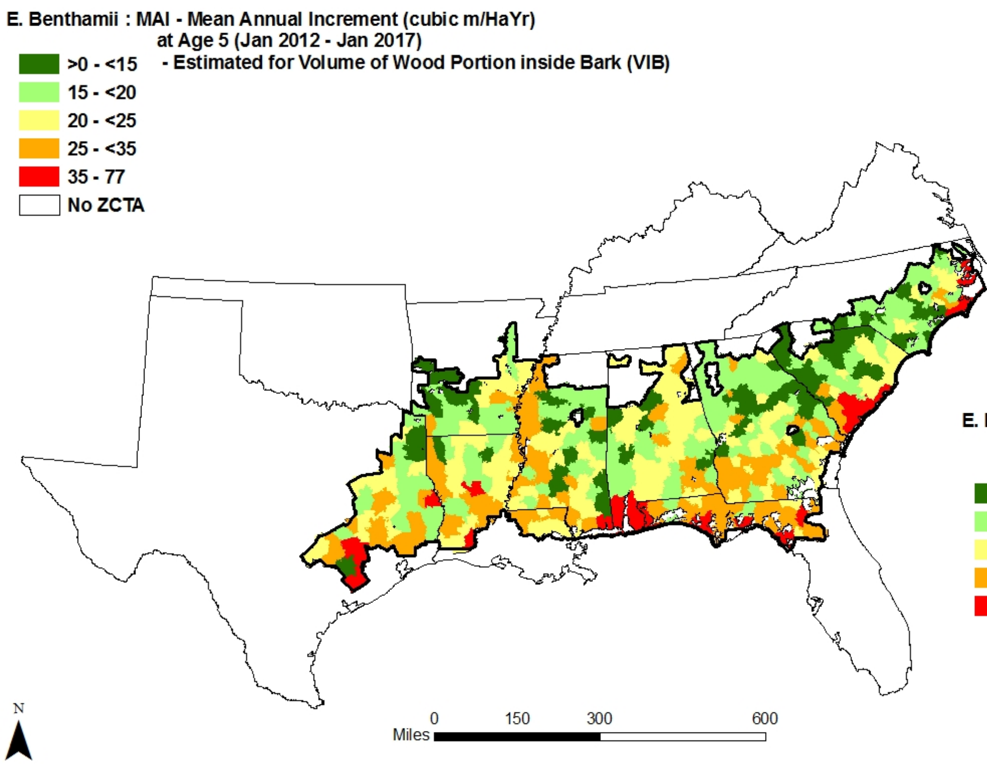
Simple Kriging predictive MAI output map in Eucalyptus grandis range

Eucalyptus Species

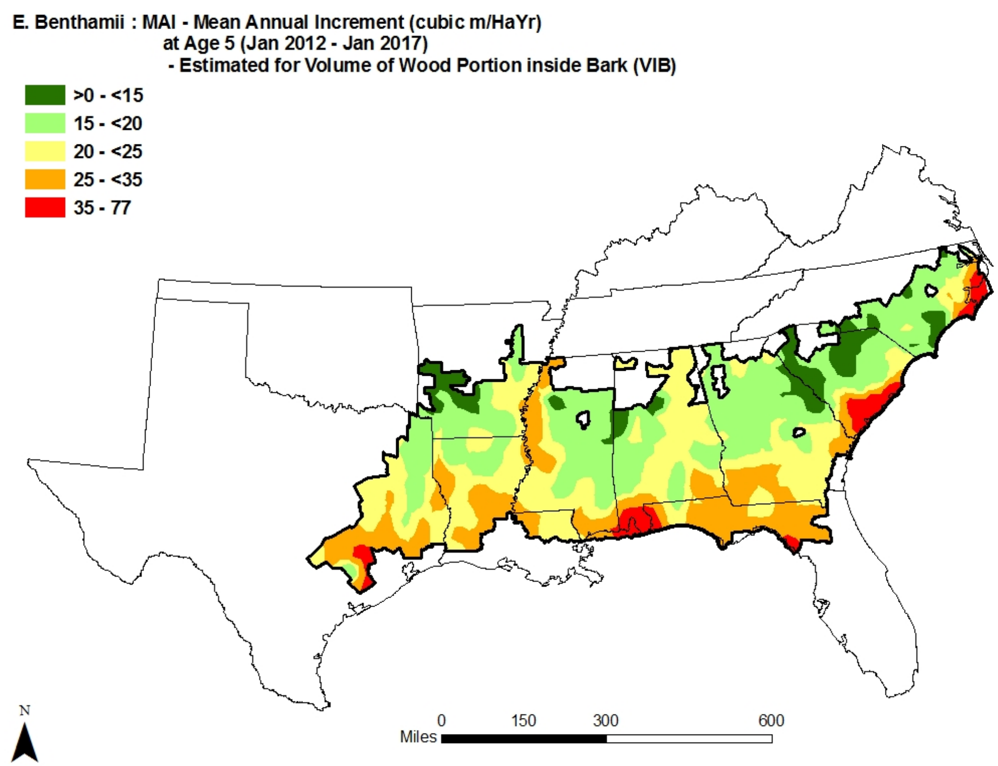
Eucalyptus benthamii Range



Eucalyptus benthamii Output Maps-MAI



Simple Kriging



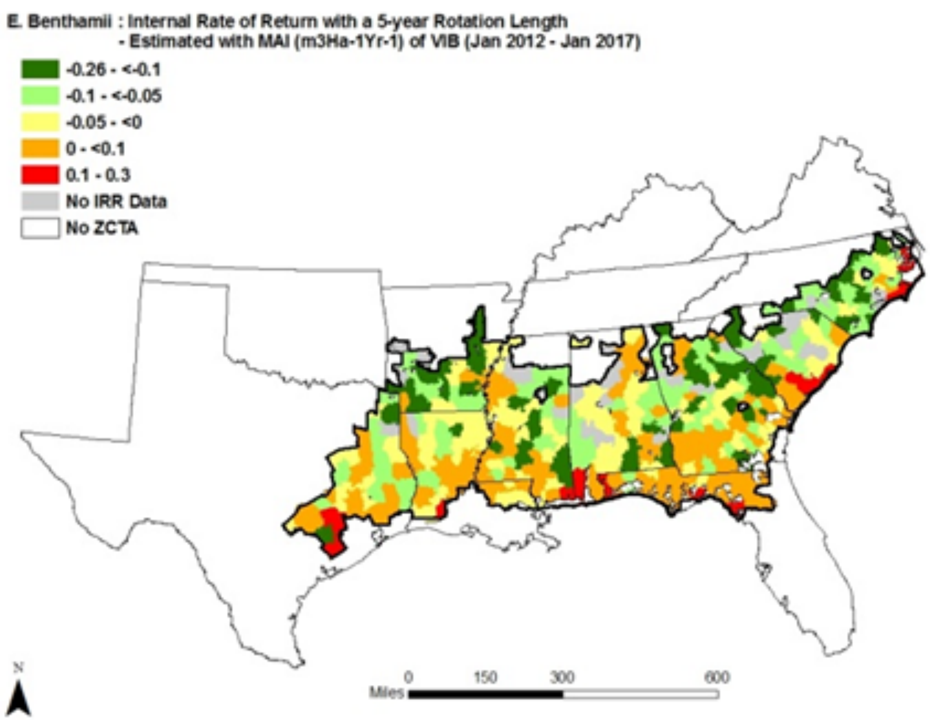
Eucalyptus benthamii

Management practices and related costs

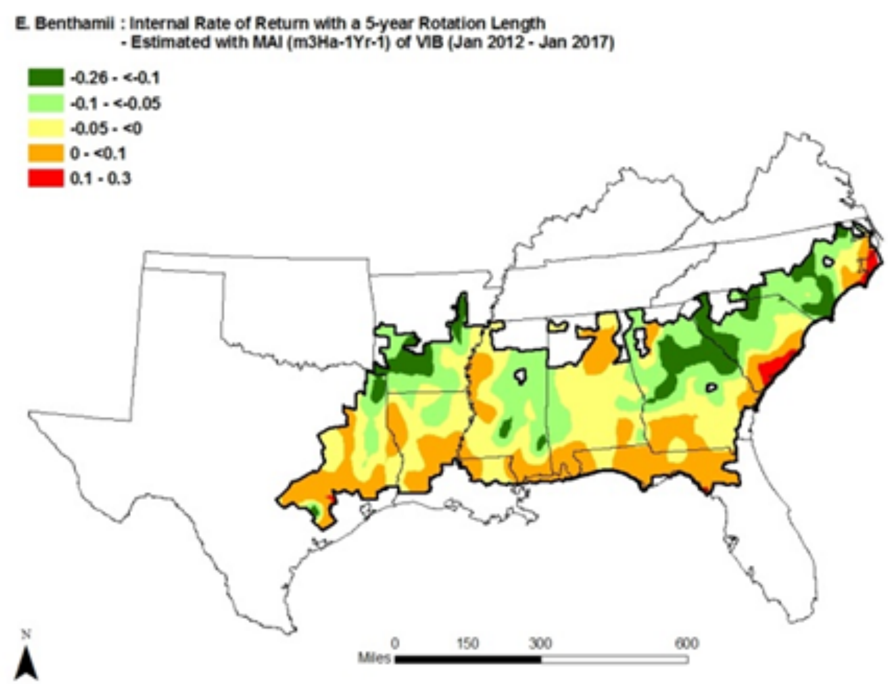
Year[a]	Activity	Cost/Acre	Sum/Acre
0	Spot raking	$40	
0	Chemical Site Prep /Vegatation removal	$65	
0	Single pass bed	$85	
0	Weeding	$35	
0	Planting (700 cutting/ac)	$245	$470
1	Weeding	$50	
1	Nitrogen Fertilizer (40 lbs/acre)	$39	$89
2	Nitrogen Fertilizer (160 lbs/acre)	$157	$157
4	Nitrogen Fertilizer (200 lbs/acre)	$196	$196
5	Harvest[b]		
0	Shearing (after each harvest)	$90	$90
	Total		$1,002

[a]Indicates the year of each rotation; [b]Harvesting incurs at ages 5, 10, and 15.

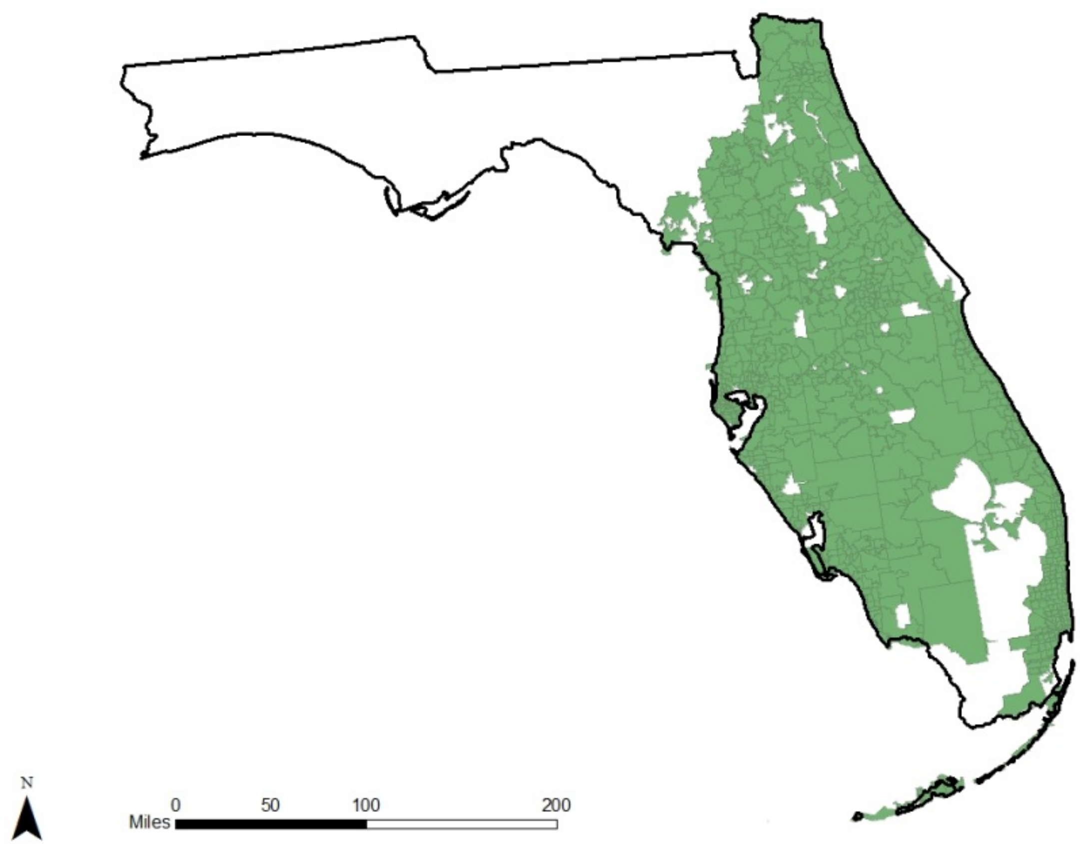
Eucalyptus benthamii Output Maps - IRR



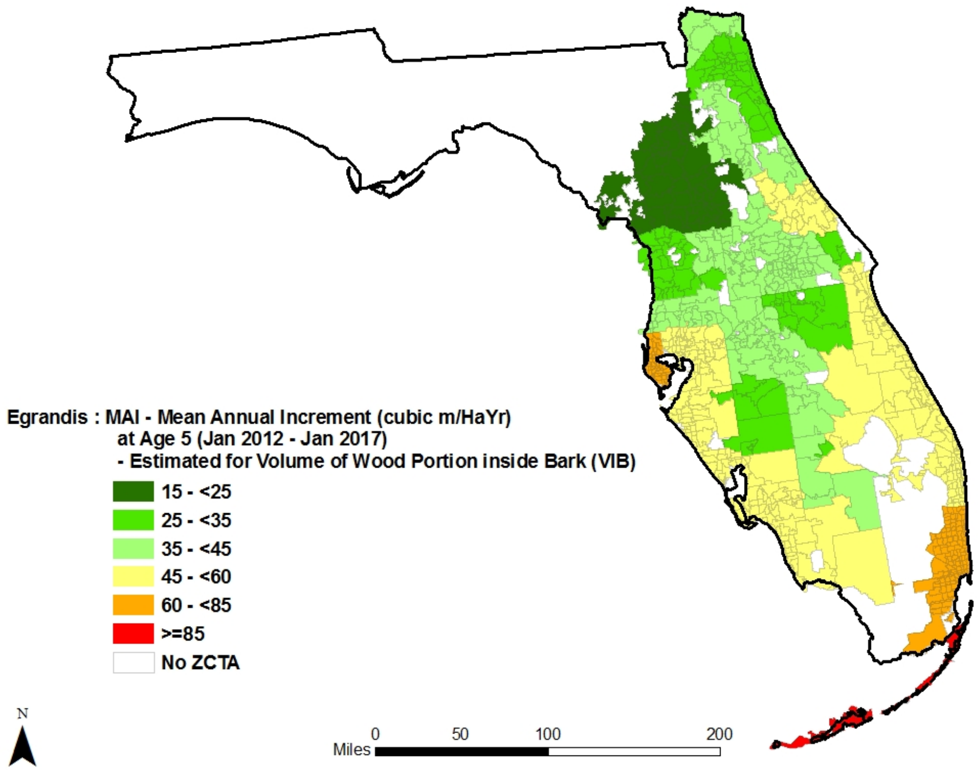
Simple Kriging



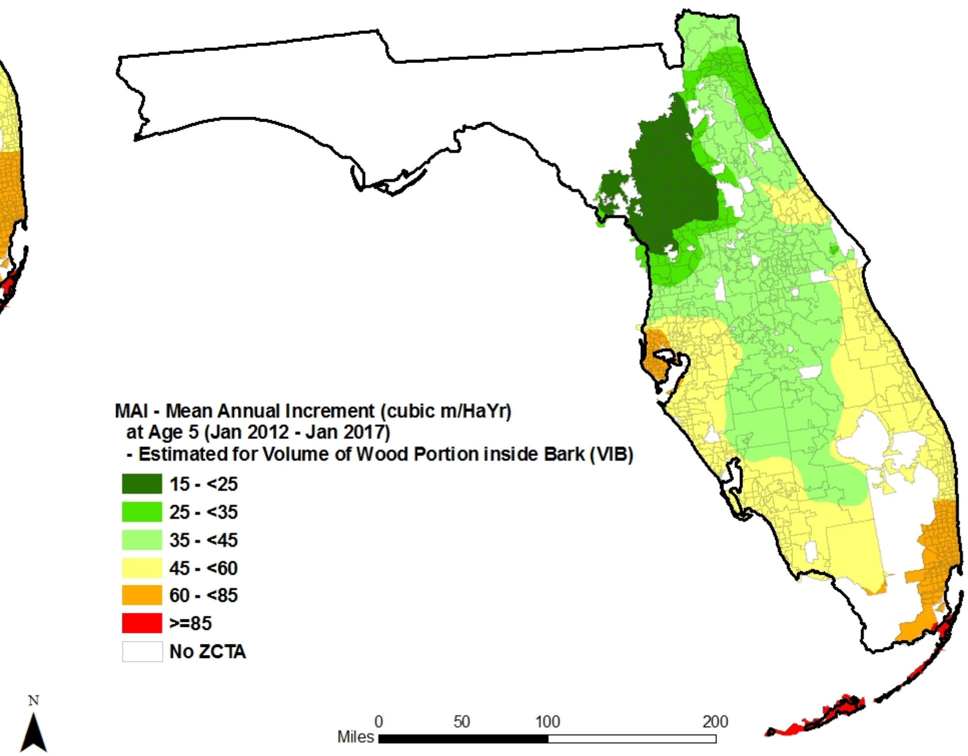
Eucalyptus grandis Range



Eucalyptus grandis Output Maps-MAI



Simple Kriging



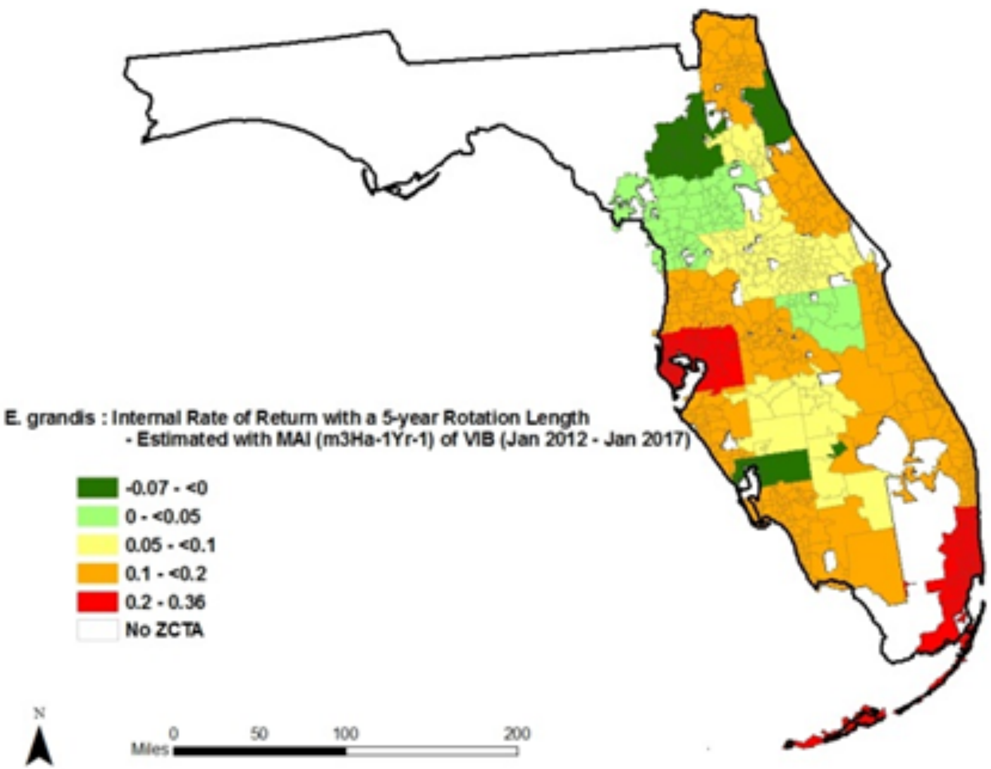
Eucalyptus grandis

Management practices and related costs

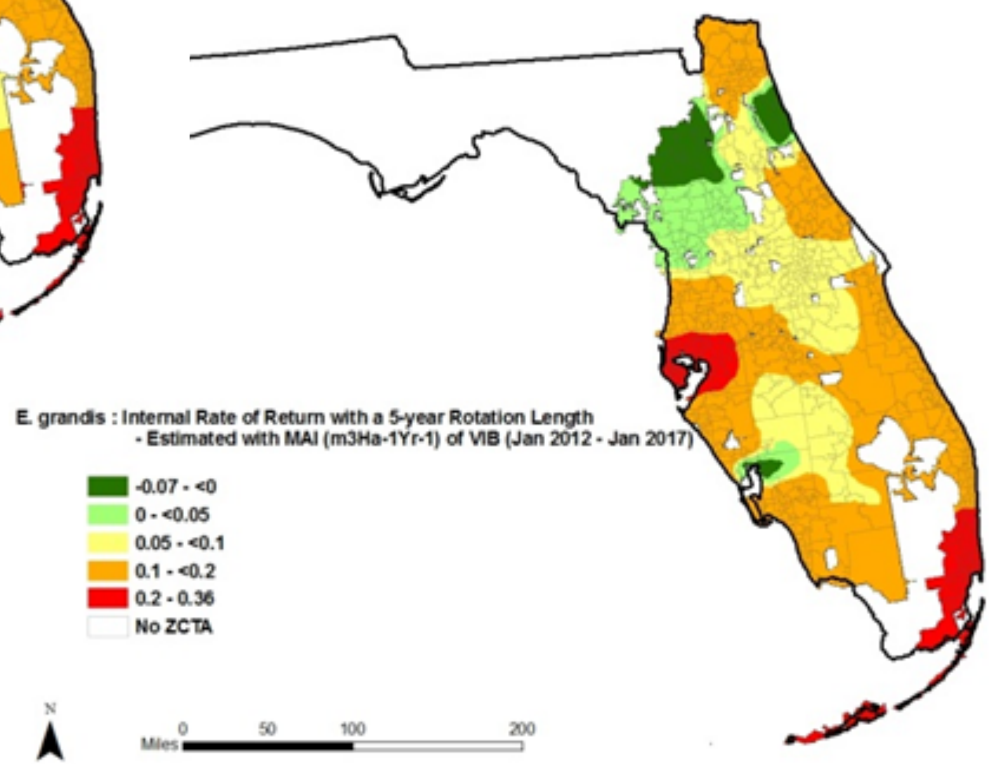
Year[a]	Activity	Cost/Acre	Sum/Acre
0	Spot raking	$40	
0	Chemical Site Prep /Vegatation removal	$65	
0	Single pass bed	$85	
0	Weeding	$35	
0	Planting (700 cutting/ac)	$245	$470
1	Weeding	$50	
1	Nitrogen Fertilizer (40 lbs/acre)	$39	$89
2	Nitrogen Fertilizer (160 lbs/acre)	$157	$157
4	Nitrogen Fertilizer (200 lbs/acre)	$196	$196
5	Harvest[b]		
0	Shearing (after each harvest)	$90	$90
	Total		$1,002

[a]indicates the year of each rotation; [b]Harvesting incurs at ages 5, 10, and 15.

Eucalyptus grandis Output Maps - IRR



Simple Kriging



Preliminary (Non Peer Reviewed) Estimates

Higher yields in the southern portion of the operable ranges of the species resulted in corresponding higher estimates of the land expectation value (LEV) and the internal rate of return (IRR).

Eucalyptus benthamii

- Estimated mean annual increment (MAI) ranged from 0.8 to 18.6 ODT acre^{-1} year^{-1}, with a mean of 5.4 ODT acre^{-1} year^{-1}
- Estimated **land expectation value** (LEV) up to $1,532 per acre
- Estimated **internal rate of return** (IRR) nearing 16% in the coastal regions of the southern U.S.

Eucalyptus grandis

- Estimated mean annual increment (MAI) ranged from 4.0-26.5 ODT acre^{-1} year^{-1} with a mean of 9.3 ODT acre^{-1} year^{-1}.
- Estimated **land expectation value** (LEV) up to $1709.9 per acre
- Estimated internal rate of return (IRR) exceeding 20% in coastal regions of south Florida.

Conclusion

- ***3-PG*** method can be used as a **powerful planning tool** for yield estimates by species and by region.

- ***Builds Foundation*** for economic evaluation, wood basket feasibility evaluations, and even carbon sequestration or ecosystem level sustainability work

However,

- Biomass production occurs in a ***dynamic*** and ***continually changing*** system

- ***Continued research*** should be completed to further frame the parameters for 3-PG for species of interest

Note: Multiple peer reviewed journal articles are in progress

References

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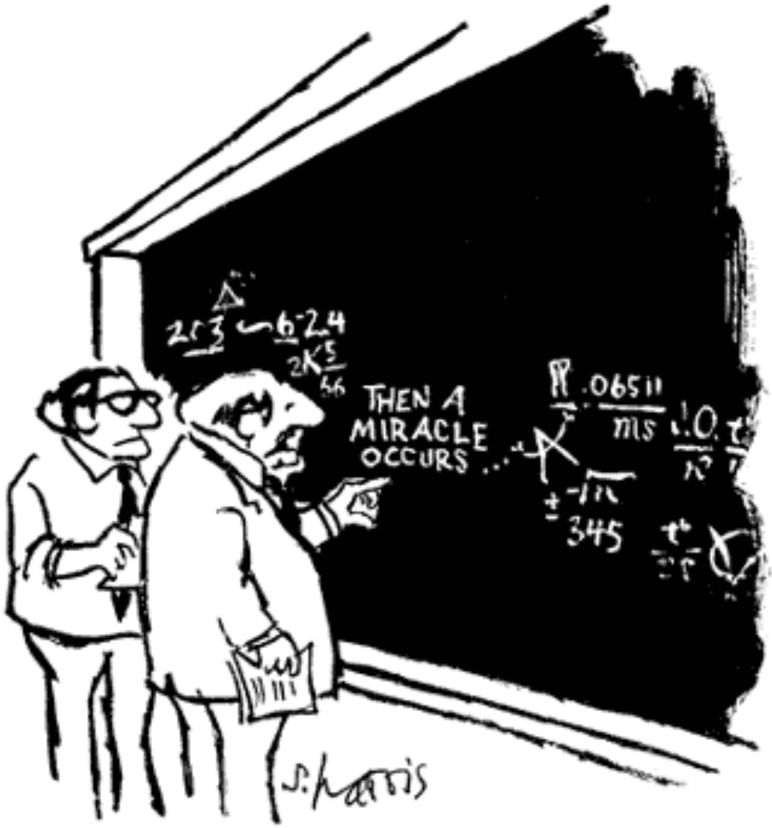
Questions?



"I think you should be more explicit here in step two."

"All Models are Wrong, Some are Useful"

George Box (U of Wisconsin)

Thank You