A modeling approach for determining the actual productivity for *E. benthamii* in the southeastern United States

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Dr. JL Stape, North Carolina State University
Dr. Bronson Bullock, North Carolina State University
Dr. Jeff Wright, ArborGen

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Frost-Hardy Eucalyptus Grow Well in the Southeast

Ron Hunt and Bruce Zobel

ABSTRACT. *Most species of the genus* Eucalyptus *that possess rapid growth and good form characteristics are too cold-sensitive for use in the southeastern coastal plain. In recent tests, however, several species, sources, and individuals within sources have demonstrated cold-hardiness combined with*

With determined effort and research, information can be obtained in a few years to either minimize the risks involved while enlarging our pool of information on silvicultural management of eucalypts or to prove that eucalypt plantings are unlikely to succeed and thus lay the issue to rest. The promising performance of certain *Eucalyptus* species in some areas of the Southeast over the last five years shows that the chance of success in acquiring fast-growing, cold-hardy species in the future is high.

to the Southeast, most *Eucalyptus* spp. will grow rapidly on upland pine sites accessible to wet-weather logging. When planted in semitropical and tropical areas in other countries, the eucalypts are managed on six- to 10-year pulpwood rotations. A major advantage of the eucalypts is that most species coppice well, enabling several rotations to be grown without the need for replanting.

In their Australian habitat, *Eucalyptus* species grow under a wide range of edaphic and climatic conditions. Some species grow in regions of freezing temperatures and frequent snow. Though *Eucalyptus* spp. have been planted at a number of locations in the United States, the main successes have been in the southern portions of Florida, Texas, and California (areas generally free of severe freezes). During the past five years considerable interest has developed within the North Carolina State Hardwood Cooperative concerning *Eucalyptus* spp. as a potential fiber

Figure 1. The 4½ year old E. Viminalis *in the left center of the picture is 56 feet tall and 10.8 inches d.b.h. The* Populus deltoides *to the left, planted as a cutting at same time as the viminalis, is 44 feet tall and 6.8 inches d.b.h. and the* Platanus occidentalis *to the right, planted as a 1–0 seedling at same time as the viminalis is 19 feet tall and 3.5 inches d.b.h.*

Research Article

Introduction of *Eucalyptus* spp. into the United States with Special Emphasis on the Southern United States

R. C. Kellison,[1] Russ Lea,[1,2] and Paul Marsh[3]

[1] North Carolina State University, Raleigh, NC, USA
[2] CEO NEON, Inc., Boulder, CO, USA

By 1971, Bruce Zobel and others at the North Carol State University decided to evaluate the introduction eucalyptus into the southern US on a scientific man Working with company members of the Hardwood Resea Cooperative, the plan was to systematically evaluate eucal tus species and sources to determine their adaptability [By 1978, the industrial members of the Florida group uni with the Hardwood Cooperative in pursuit of the goal. eucalyptus dream was pursued until 1985 when the 14-y effort came to an end, following severe freezes on Decem 24, 1983, January 20, 1984, and January 9, 1985.

beneficial to other researchers and practitioners when attempts are again made to introduce the species complex into th

1. Introduction

More than 500 *Eucalyptus* spp. (Myrtaceae) are indigenous to Australia and the bordering islands of Polynesia [1]. They occur in environments from 10°N to 44°S latitude (Mindanao Island, Philippines through Tasmania, Australia), from sea level to 2000 meters elevation (snow line) and from 10 (Northern Territory, Australia) to 375 centimeters of rainfall (Papua New Guinea). These vast differences in climate have allowed a great diversity to develop within the *Eucalyptus* genus. The inherent diversity has resulted in successful introduction of many of the species, for landscape, fuelwood and timber purposes, to areas within the tropical, subtropical, and warm temperate zones of the world [2].

As with other plants and animals, introduction of eucalypts to areas of the world where they are not indigenous sometimes allows for performance that is greatly superior to that exhibited in their native habitat. Reason differences in performance include favorable cli edaphic conditions and the general lack of pe new environment. Notable examples of successf introductions include *E. grandis*, *E. urophylla*, hybrid (Brazil, Colombia, Venezuela, Republic Zimbabwe, South Africa), *E. globulus* (Chile, Portu southern California (USA)), *E. camaldulensis* (Israe Morocco, India, Northern California (USA)), an *nalis* (Argentina, Brazil, Georgia (formerly part of U

Long before the species generated so much e for plantation forestry in parts of the world, other t America, attempts were made to introduce select into California. The occasion was the gold rush The influx of a half million people resulted in a s foodstuff and supplies essential for survival and de (http://ceres.ca.gov/ceres/calweb/geology/goldrush

Hunt & Zobel, 1978 Kellison et al., 2013

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However…

Research efforts were able to establish plantations in southern Florida.

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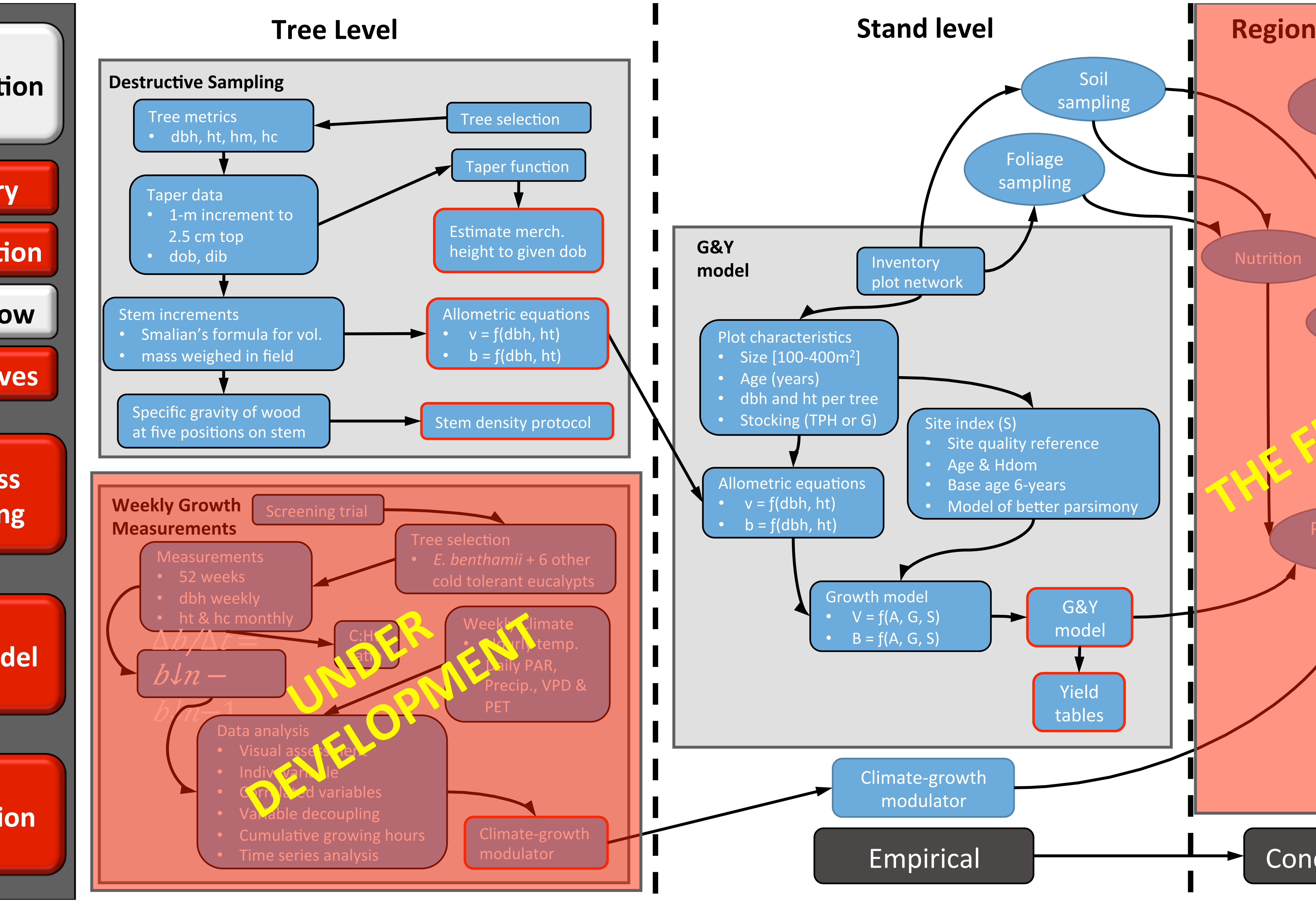
Why *Eucalyptus* in the southeastern United Stat

- Eucalyptus is highly diverse with more than 800 species
- Highly productive across the world
- Multipurpose wood properties
- Responsive to the manipulation of site resources
- Quick to clone
- Potential to provide raw material for pulp, paper, biomass and biofuels production for the SE US ?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Tree Level
Destructive Sampling
Tree metrics
• dbh, ht, hm, hc
Tree selection
Taper function
Taper data
• 1-m increment to 2.5 cm top
• dob, dib
Estimate merch. height to given dob
Stem increments
• Smalian's formula for vol.
• mass weighed in field
Allometric equations
• v = ƒ(dbh, ht)
• b = ƒ(dbh, ht)
Specific gravity of wood at five positions on stem
Stem density protocol
Weekly Growth Measurements
Screening trial
Tree selection
• E. benthamii + 6 other cold tolerant eucalypts
Measurements
• 52 weeks
• dbh weekly
• ht & hc monthly
Weekly climate
PET
Data analysis
• Cumulative growing hours
• Time series analysis
Climate-growth modulator
UNDER DEVELOPMENT
Stand level
Soil sampling
Foliage sampling
G&Y model
Inventory plot network
Plot characteristics
• Size [100-400m²]
• Age (years)
• dbh and ht per tree
• Stocking (TPH or G)
Site index (S)
• Site quality reference
• Age & Hdom
• Base age 6-years
• Model of better parsimony
Allometric equations
• v = ƒ(dbh, ht)
• b = ƒ(dbh, ht)
Growth model
• V = ƒ(A, G, S)
• B = ƒ(A, G, S)
G&Y model
Yield tables
Climate-growth modulator
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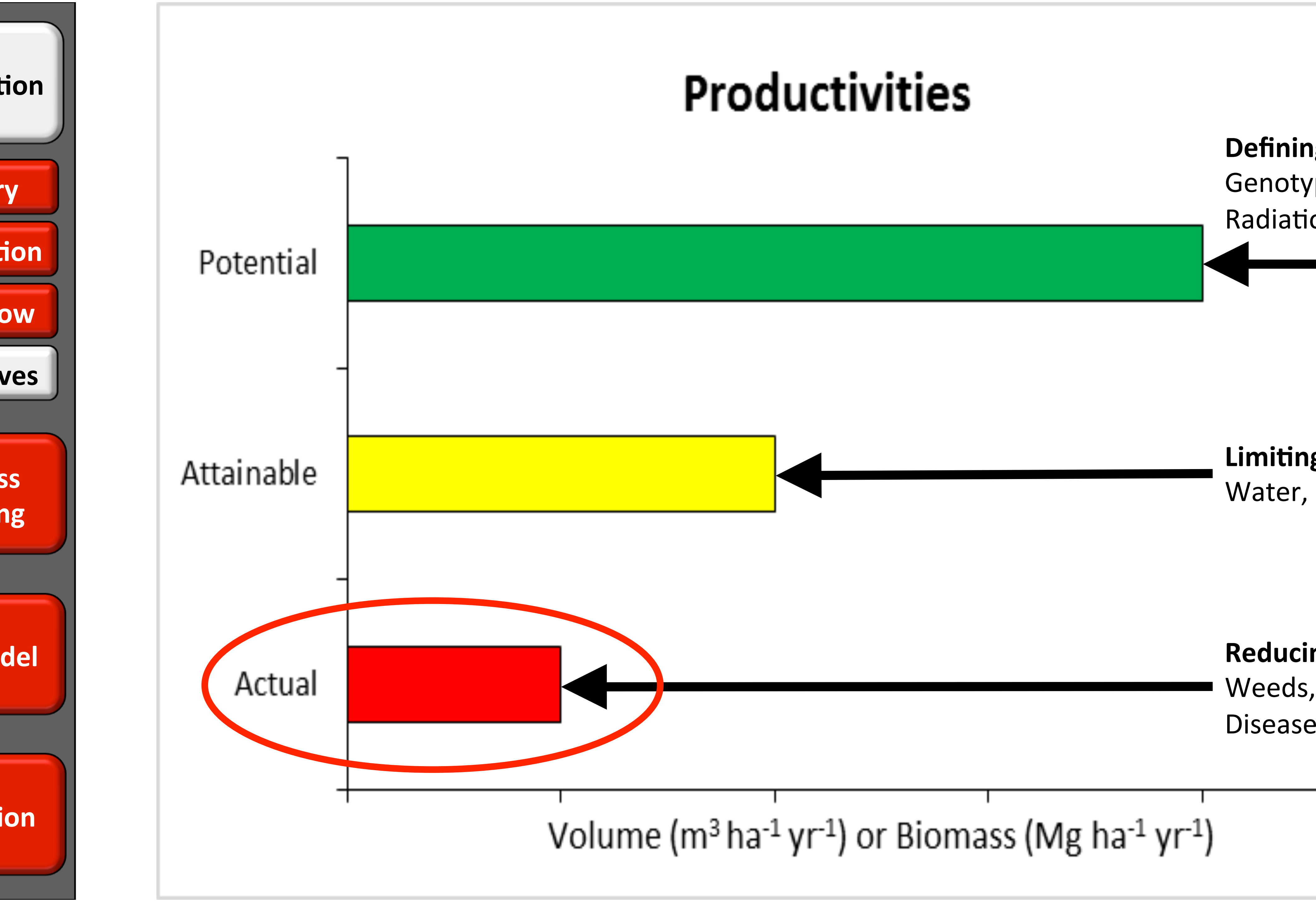
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Objectives

1. Develop a total stem biomass equation using total height, diameter at breast height and age (maybe not) as the independent variables.

2. Using an inventory plot network, develop a growth function at the stand level for *E. benthamii* using site index, basal area and age as the independent variables.

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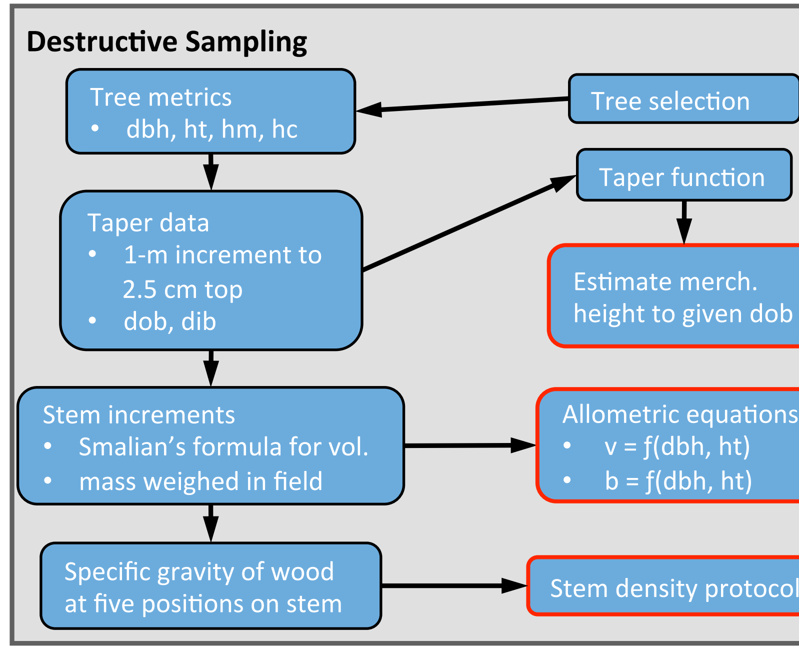
Aboveground biomass sampling

Objectives

1. Develop **biomass equation** with total stem dry weight as the dependent variable and total stem height, diameter at breast height and age as the independent variables.
2. Develop **total stem** allometric equations for Section Maidenaria.



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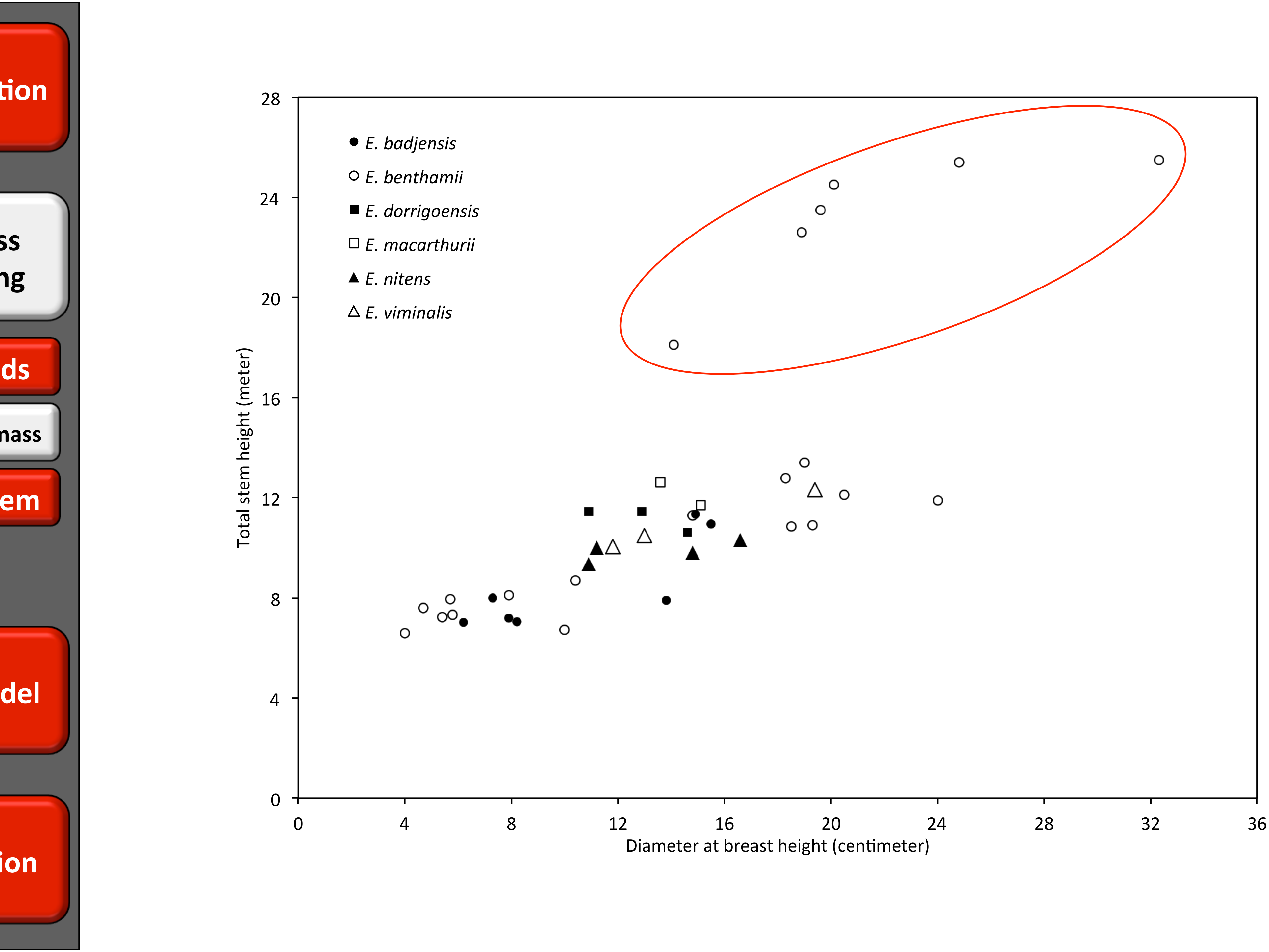
Aboveground Biomass Sampling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E. badjensis
E. benthamii
E. dorrigoensis
E. macarthurii
E. nitens
E. viminalis
Total stem height (meter)
Diameter at breast height (centimeter)

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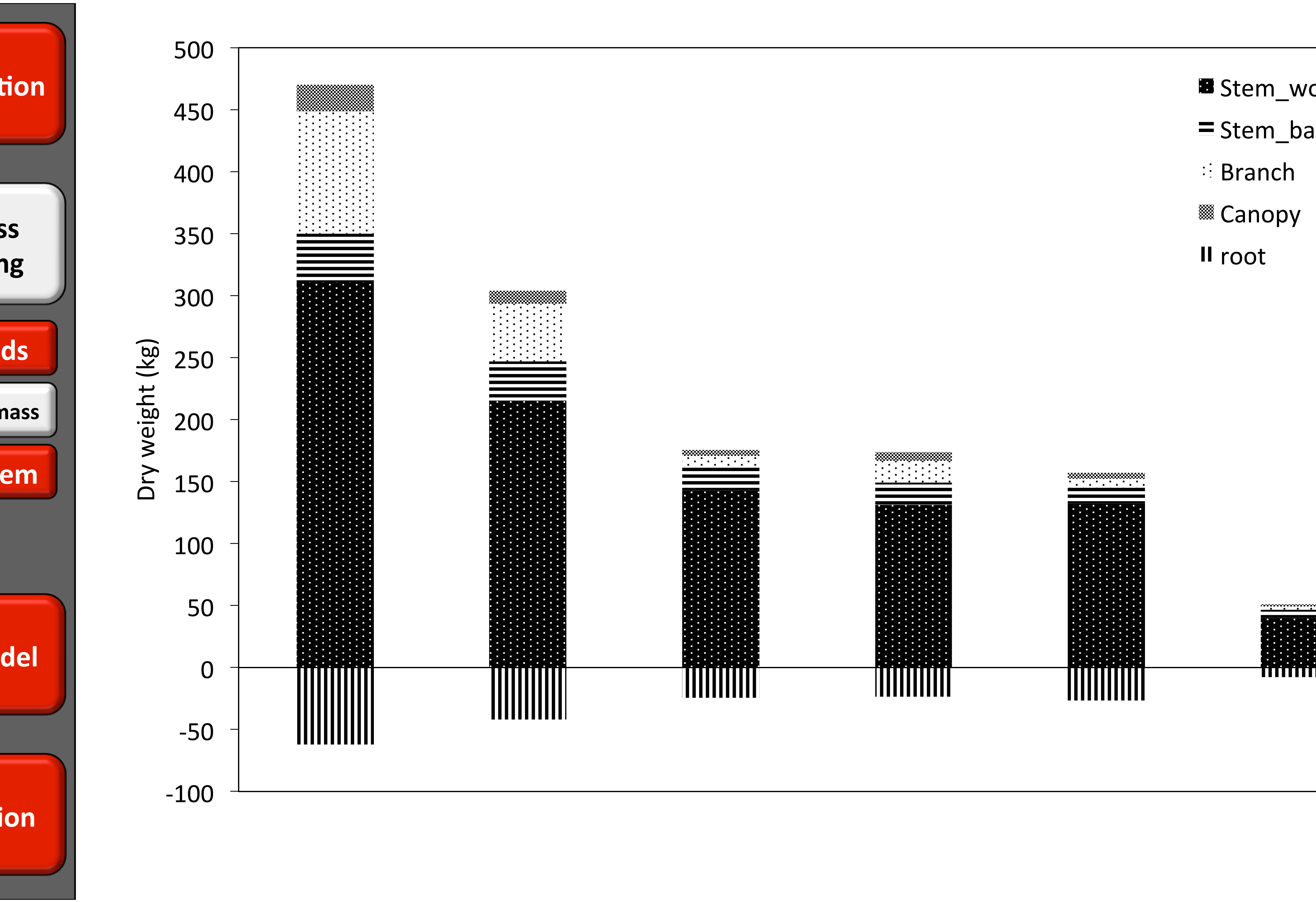
Belowground Biomass Sampling



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Dry weight (kg)
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300
250
200
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50
0
-50
-100
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Branch
Canopy
root

Compartments (dry weight, kg)	**n**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Canopy	6	8.4	7.1	1.6	21.6
Branches	6	30.2	37.0	2.9	98.6
Stem wood	6	162.2	91.7	40.0	310.9
Stem bark	6	21.1	12.0	6.5	39.0
Coarse roots	6	31.0	18.8	7.7	62.3

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Equation form			Pseudo-R^2
	0.7065	1.7953	0.9643
	0.6174	1.7993	09658
	0.0002	3.8283	0.9670
	0.0015	2.7600	0.9791
	0.0747	1.9432	0.9740
	0.3303	2.0833	0.9778
	0.4002	2.0656	0.9784

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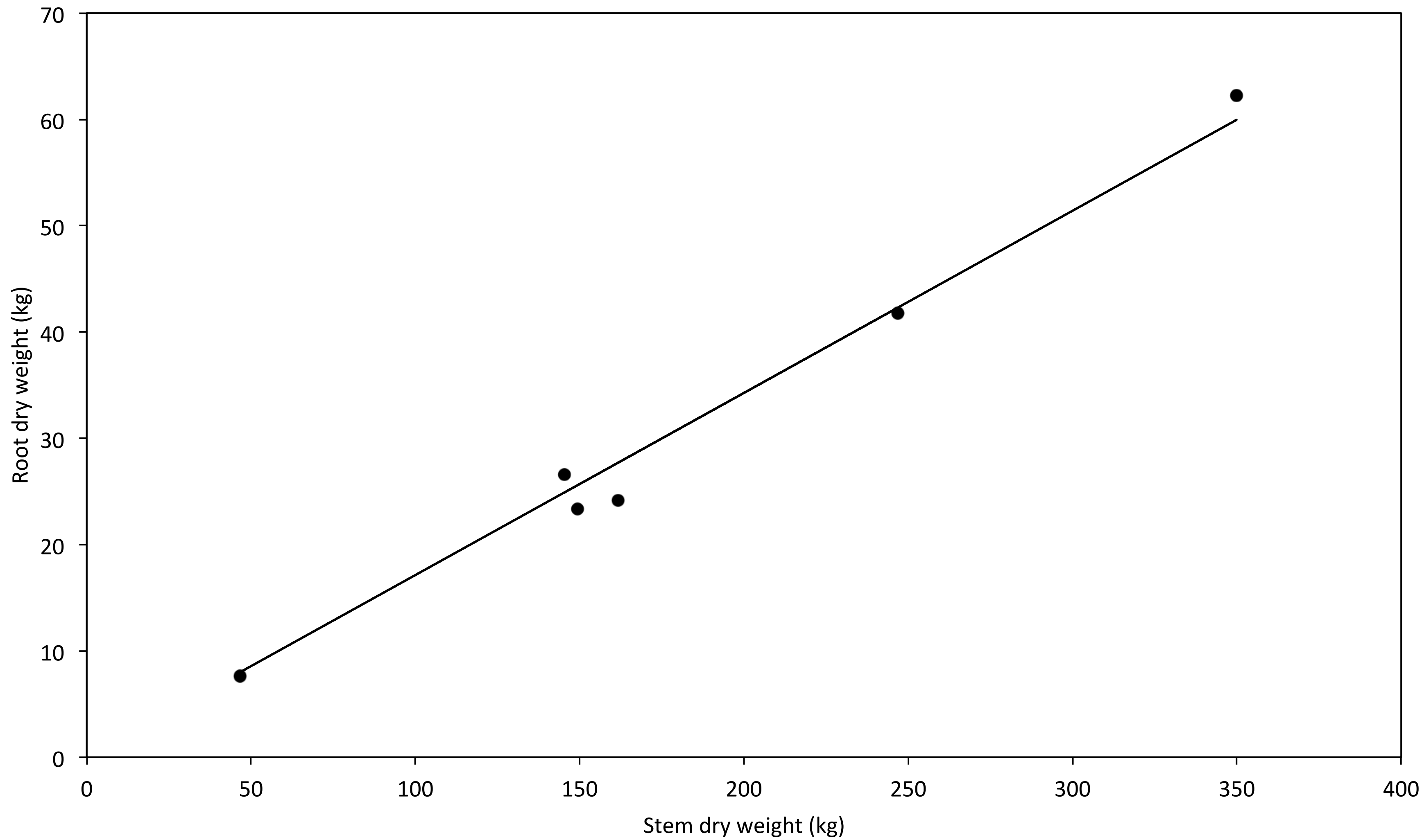

Equation form		R^2
$S_{roots} = \beta_1 * S_{stem\ with\ bark} + \varepsilon$	0.17136	0.9958

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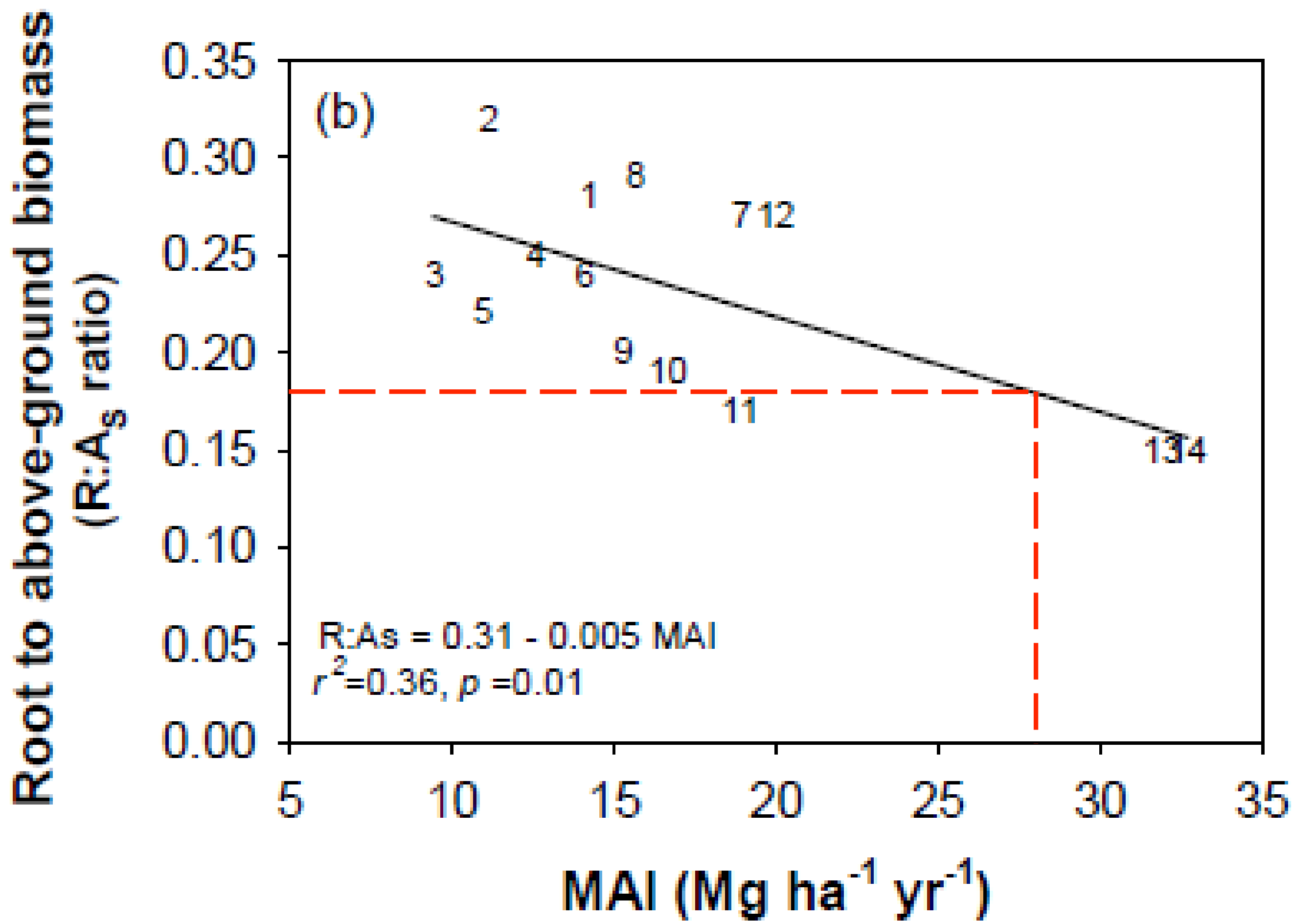

Stape et al., 2004

Total stem volume & biomass

Summary statistics

Variables	n	Mean	Standard error	Minimum	Maximum
Per tree basis					
Diameter at breast height (cm)	40	13.9	0.98	4.0	32.3
Height (m)	40	11.8	0.84	6.6	25.5
Double bark thickness (cm) at breast height	40	2.3	0.23	0.4	7.6
Total stem volume (m^3)					
Outside-bark	40	0.1190	0.0248	0.0051	0.8210
Inside-bark	40	0.0992	0.0202	0.0045	0.6660
Total stem green weight (kg)					
Outside-bark	40	113.8	26.2	3.0	852.0
Inside-bark	39	98.9	22.1	2.6	701.3
Total stem biomass (kg)					
Outside-bark	39	53.2	11.3	2.1	349.9
Inside-bark	39	46.3	10.0	1.8	310.9

Equation forms

Combined variable	
Logarithmic	$Y=\beta_2 D^{\beta_3} H^{\beta_4} + \varepsilon$

Avery & Burkhart, 2002

Schumacher & Hall, 1933

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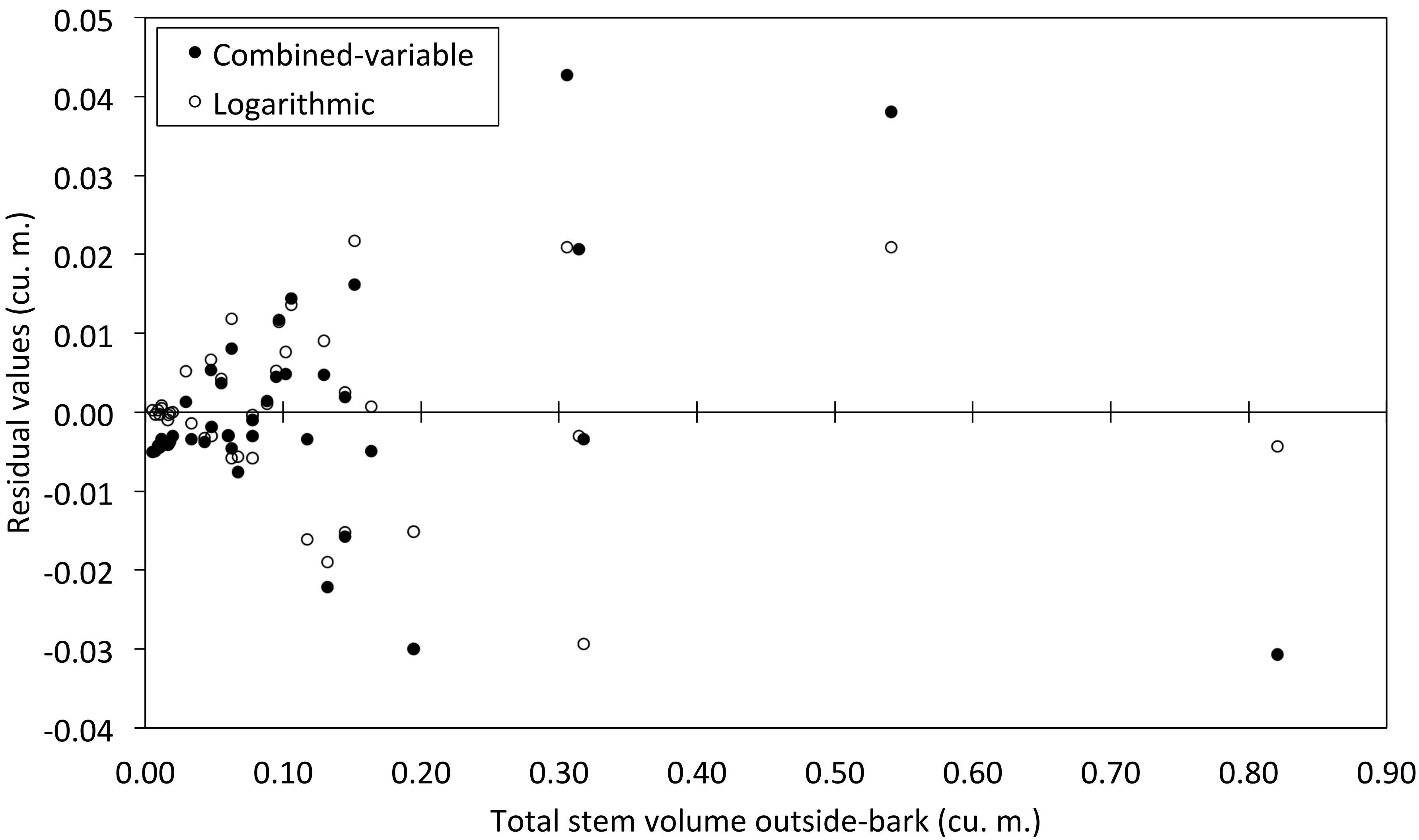

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Parameter	Estimate	Approx. Std. Error	Approximate 95% Confidence Limits	
Volume outside-bark (m^3)				
	0.000053	0.000005761	0.000041	0.000061
	1.7307	0.0435	1.6426	1.8187
	1.1236	0.0398	1.043	1.2043
Volume inside-bark (m^3)				
	0.000053	0.000005601	1.000041	0.000064
	1.6726	0.0429	1.5857	1.7595
	1.1231	1.0391	1.0439	1.2023
Green weight outside-bark (kg)				
	0.0281	0.00438	0.0192	0.037
	1.6527	0.0567	1.5378	1.7675
	1.4149	0.0571	1.2992	1.306
Green weight inside-bark (kg)				
	0.0308	0.00504	0.0206	0.041
	1.6653	0.0615	1.5406	1.79
	1.3134	0.0598	1.1922	1.4346
Dry weight outside-bark (kg)				
	0.0253	0.00365	0.0179	0.0327
	1.4894	0.0552	1.3775	1.6014
	1.3494	0.0532	1.2415	1.4574
Dry weight inside-bark (kg)				
	0.0194	0.00280	0.0137	0.0251
	1.4880	0.0543	1.3778	1.5081

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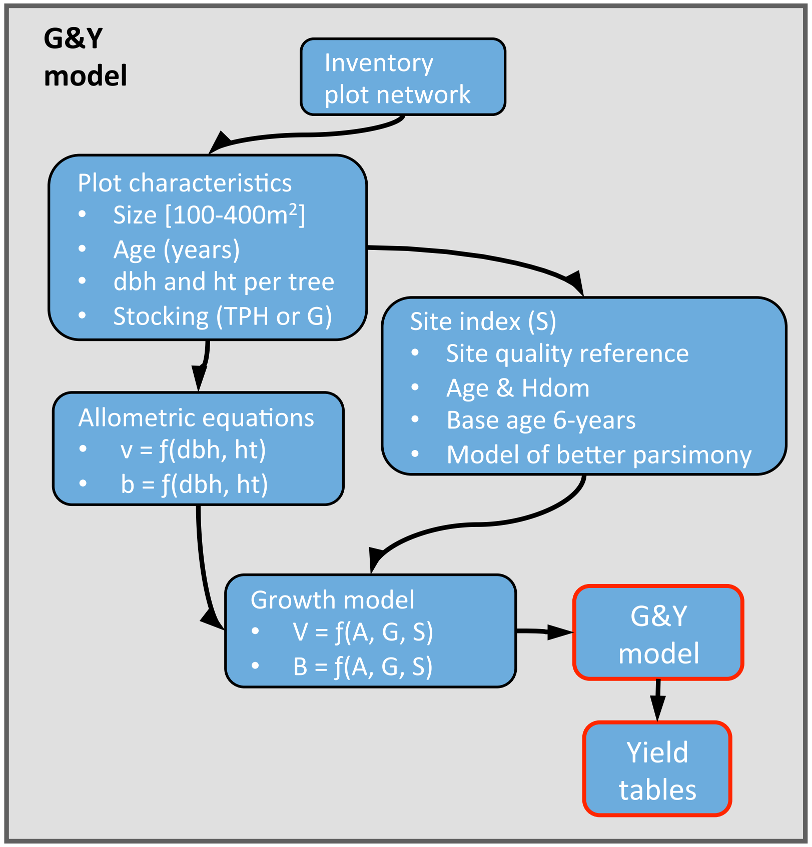

G&Y model

Objectives

1. Establish a **permanent inventory plot network** for *E. benthamii* across SE US.
2. Develop **site index guide curve** for *E. benth*amii in SE US to evaluate site quality.
3. Develop empirical **G&Y model** for *E. benthamii* volume and biomass in SE US using site index, basal area and age as the independent variables.
4. Present **yield tables** for *E. benthamii* volume and biomass in SE US for extension work.

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FPC RW24 *Eucalyptus* Biomass Trial Netwo

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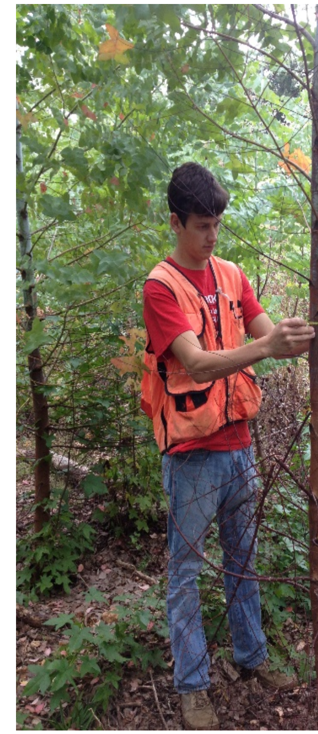
Inventory Data Collection

- Plot centers installed between two dominant or co-dominant trees.
- DBH measured for all stems within the plot boundary.
- Height measured as follows

Sampling Methodology

- Soil samples were taken between the rows and between trees within the rows.
- Foliage samples were taken from dominant or co-dominant trees using FPC Sampling Protocol.
- Wood samples collected using 8mm diameter increment borer for bulk density analysis.



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Eucalyptus benthamii Inventory Plot Network

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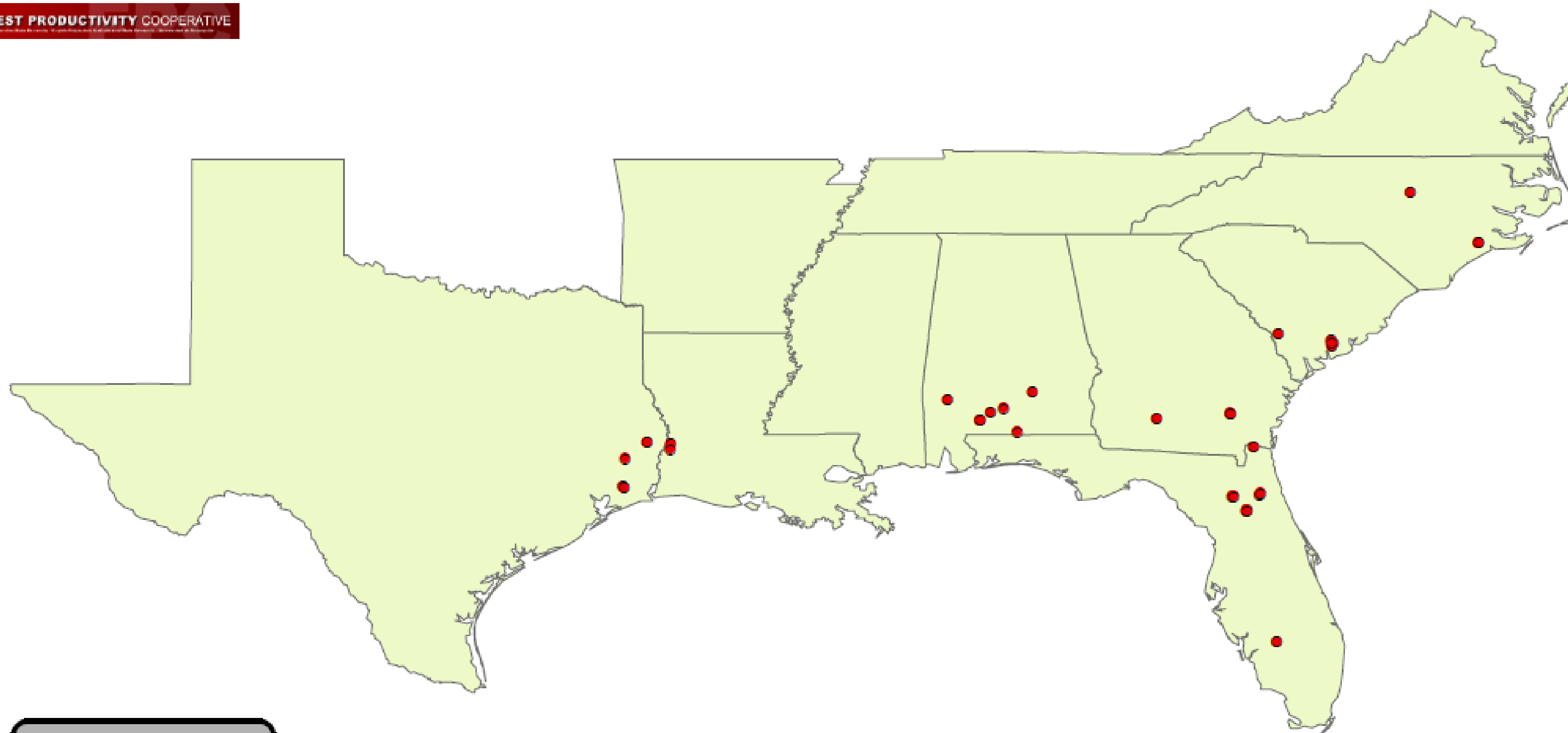


Legend

IBSS Sites

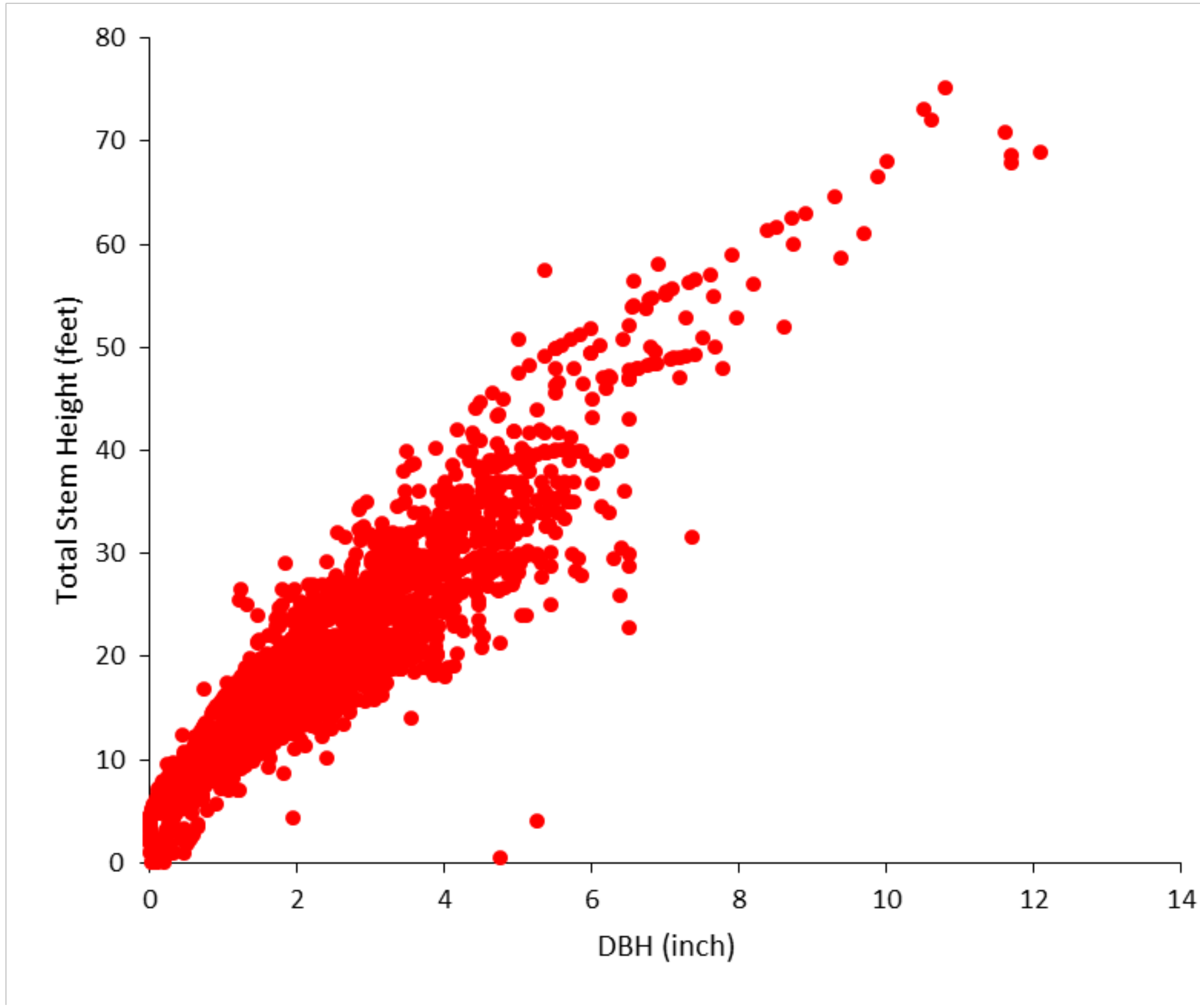
States

Author: Kevin B. Hall
Date: April 9, 2014
Coordinate System: GCS North American 1983
Datum: North American 1983
Units: Degree

0 105 210 420 630 840 Mil

Raw data

- 6 states (NC, SC, GA, FL, AL, TX)
- 71 inventory plots
- 2619 trees



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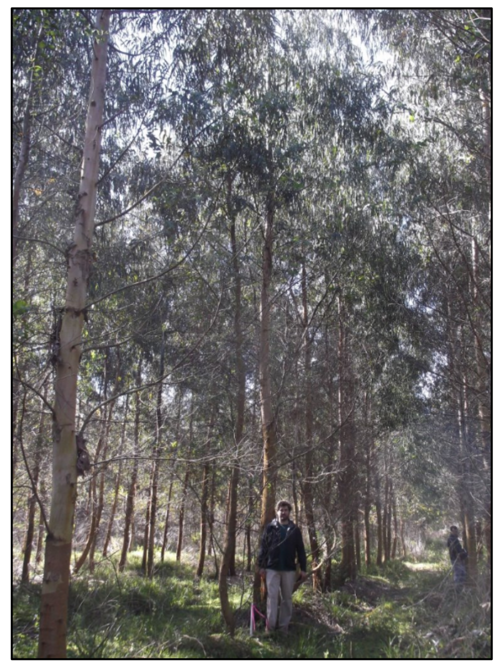
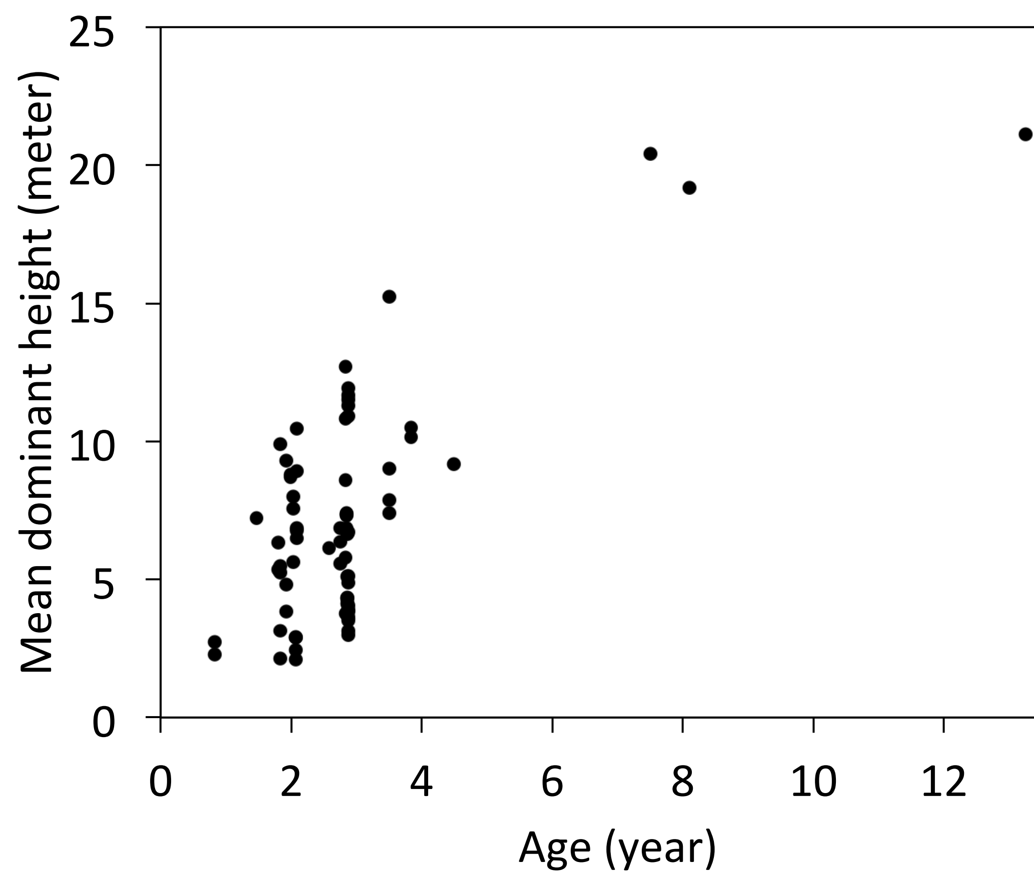
Age (year)	Number of plots	Stocking (tpha)	Basal area (m^2 ha^{-1})	Dom. height (meter)	Volume (m^3 ha^{-1})	Dry weight (Mg ac^{-1})
1	2	1473	0.15	2.5	0.2	0.1
2	25	1503	3.62	6.1	12.1	5.4
3	34	1282	3.90	6.9	15.4	6.9
4	7	1488	10.09	9.3	47.3	21.1
5	1	1238	14.49	9.2	52.2	21.2
8	2	859	18.92	19.8	137.4	61.2
13	1	828	24.36	21.1	191.7	83.8



Site Index

$$\ln h_{dom} = \beta_0 + \beta_1 t^{-1}$$

- Mean dominant height defined as the 100 largest diameter trees per hectare determined for each permanent plot (min. two trees).
- Base age 6 years



Avery & Burkhart, 2002

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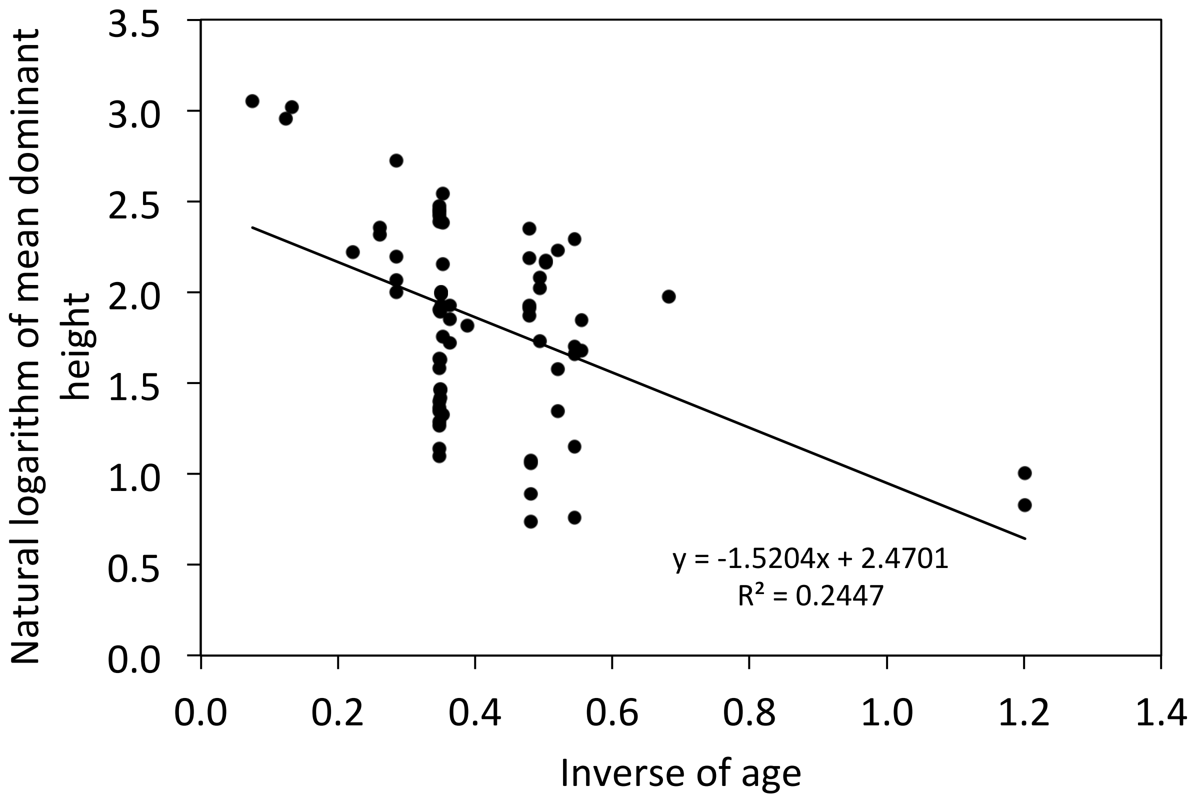
Site Index



$$\ln S = \ln h_{dom} + 1.5204(1/ag$$

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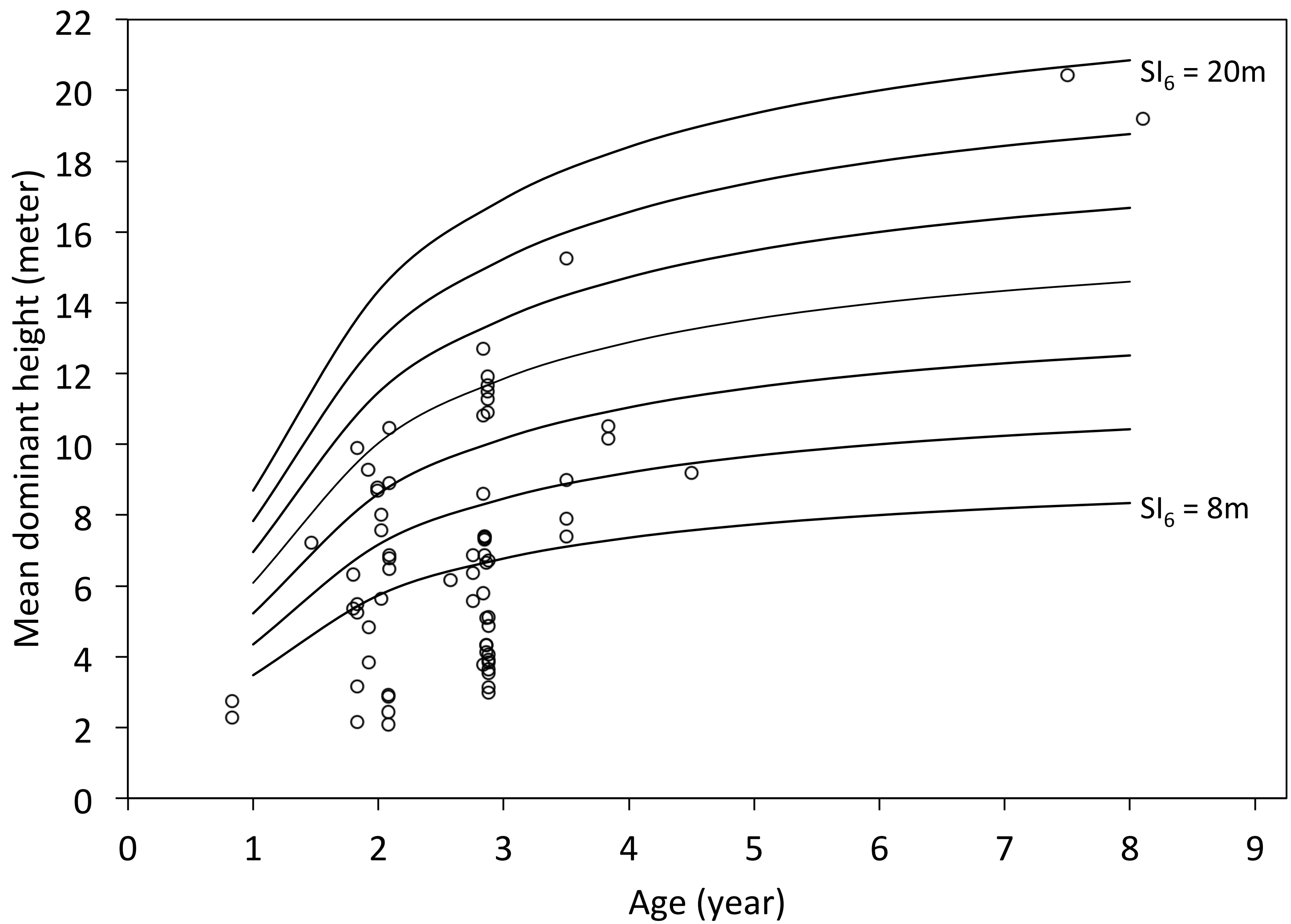

G&Y Model

- Volume/Biomass (dependent)
- Age (years)
- Basal area per hectare
- Site index at base age 6 years

$$\ln Y = \beta_0 + \beta_1 (1/age) + \beta_2 \ln G + \beta_3$$

Age class (year)	Plot Count	Basal area (m^2 ha^{-1})	SI_6 (meter)	Volume (m^3 ha^{-1})	Green weight (Mg ac^{-1})	Dry weight (Mg ac^{-1})
1	2	0.15	12.4	0.2	0.2	0.1
2	25	3.62	10.4	12.1	9.6	5.4
3	34	3.90	9.1	15.4	12.9	6.9
4	7	10.09	10.9	47.3	41.2	21.1
5	1	14.49	10.0	52.2	42.1	21.2
8	2	18.92	18.7	137.4	132.3	61.2
13	1	24.36	18.3	191.7	188.2	83.8

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Parameter	Estimate	Standard Error	t Stat	P-value
Volume outside-bark (m^3 ha^{-1})				
	0.76045	0.033429	22.7484	< 0.0001
	-1.12667	0.06038	-18.6597	< 0.0001
	0.99291	0.008309	119.4973	< 0.0001
	0.07700	0.003537	21.77477	< 0.0001
Green weight outside-bark (Mg ha^{-1})				
	0.418678	0.041891	9.994402	< 0.0001
	-1.42	0.075665	-18.767	< 0.0001
	0.98680	0.010412	94.77161	< 0.0001
	0.097048	0.004432	21.89801	< 0.0001
Dry weight inside-bark (Mg ha^{-1})				
	-0.02384	0.044083	-0.54076	0.59047
	-1.22434	0.079624	-15.3765	< 0.0001
	0.92340	0.010957	84.27274	< 0.0001
	0.08809	0.004664	18.88931	< 0.0001

$$\ln Y = \beta_0 + \beta_1 (1/age) + \beta_2 \ln G + \beta_3 S + \varepsilon$$

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Basal area
20 m^2 ha^{-1}

VOB (m^3 ha^{-1})

A_yr/S_m	10	12	14	16	18	
1	29.3	34.2	39.9	46.5	54.3	63
2	51.5	60.1	70.1	81.8	95.4	111
3	62.1	72.5	84.6	98.6	115.1	134
4	68.3	79.6	92.9	108.4	126.4	147
5	72.2	84.2	98.3	114.6	133.7	156
6	75.0	87.5	102.0	119.0	138.8	162
7	77.0	89.8	104.8	122.3	142.6	166
8	78.6	91.7	106.9	124.7	145.5	169

DWOB (Mg ha^{-1})

A_yr/S_m	10	12	14	16	18
1	11.0	13.1	15.7	18.7	22.3
2	20.3	24.2	28.9	34.5	41.1
3	24.9	29.7	35.4	42.3	50.4
4	27.6	32.9	39.2	46.8	55.8
5	29.3	35.0	41.7	49.8	59.3
6	30.5	36.4	43.5	51.8	61.8
7	31.5	37.5	44.7	53.4	63.6
8	32.1	38.3	45.7	54.5	65.0

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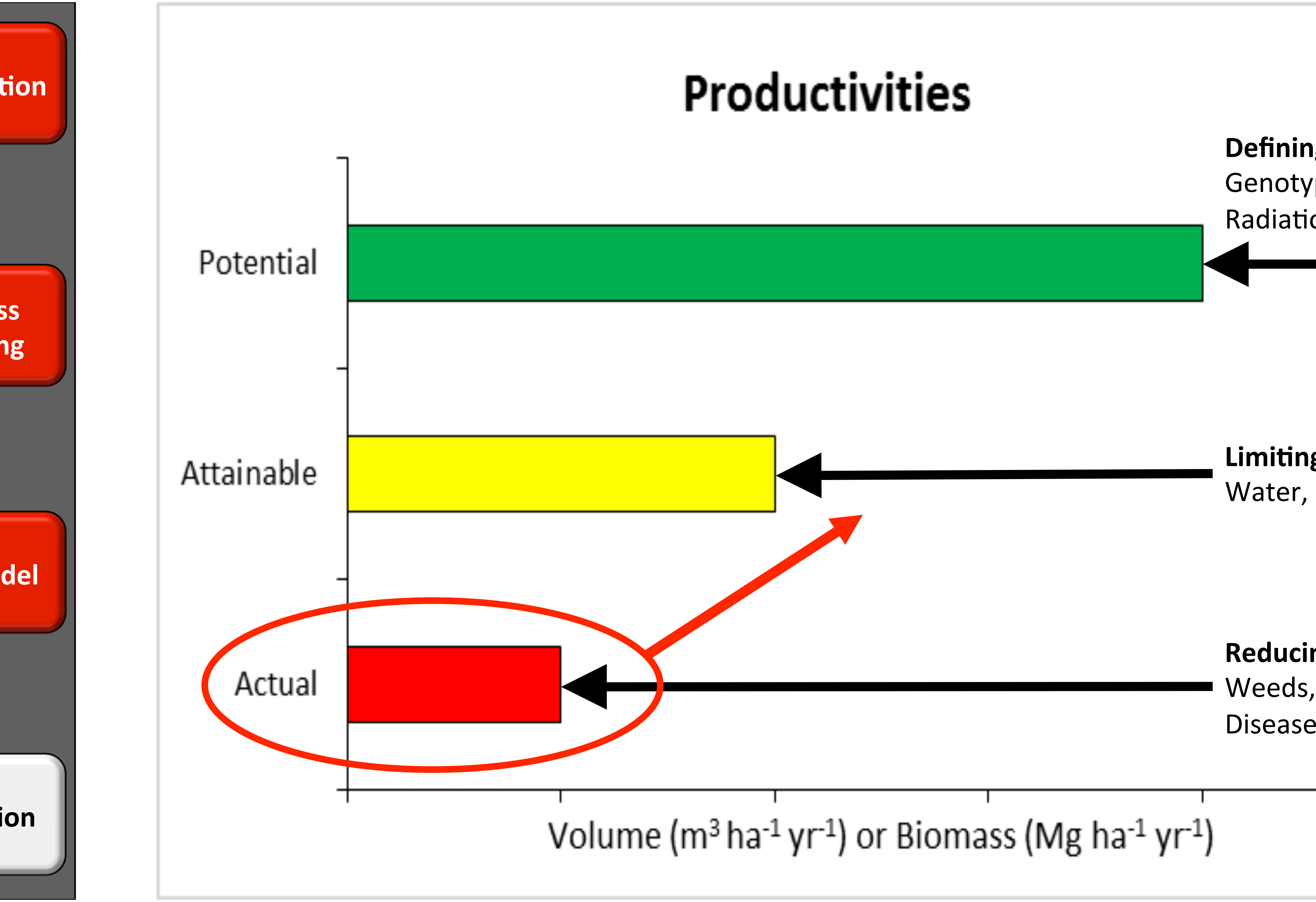
Mean Annual Increment by site index

Response variables	Site index (base age six years)					
	10	12	14	16	18	20
VOB (m^3 ha^{-1})	12.5	14.6	17.0	19.8	23.1	27.0
VIB (m^3 ha^{-1})	10.7	12.4	14.5	16.8	19.6	22.7
GWOB (Mg ha^{-1})	10.1	12.3	15.0	18.2	22.1	26.8
GWIB (Mg ha^{-1})	9.2	11.0	13.2	15.8	18.9	22.6
DWOB (Mg ha^{-1})	5.1	6.1	7.2	8.6	10.3	12.3
DWIB (Mg ha^{-1})	4.3	5.2	6.2	7.5	9.0	10.8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Preliminary Conclusions

- Establishment of the IBSS *E. benthamii* Permanent Plot Network.
- Development of site quality classification system using Site Index.
- "Simple" Growth & Yield Model to estimate volume & biomass.

Continued Work

- Investigate polymorphic Site Index Guide Curves.
- Investigate site characteristics and potential associations with yield.
- Complete nutrient analysis using FPC soil and foliage sampling protocol.

Thank you

Questions ?

USDA

United States Department of Agriculture
National Institute of Food and Agriculture

IBSS

FOREST PRODUCTIVITY COOPERATIVE
North Carolina State University · Virginia Polytechnic Institute and State University · Universidad de Concepción

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