6-2010

Project Report No. 67, A Whole-Stand Growth and Yield Model for Unmanaged Loblolly and Slash Pine Plantations in East Texas

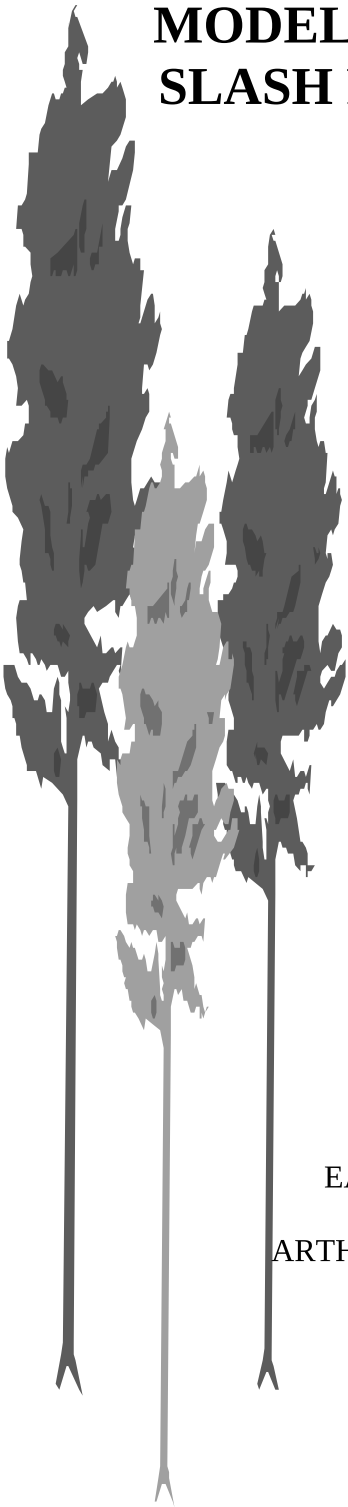
Dean W. Coble
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, dcoble@sfasu.edu

Micky G. Allen II

Jimmie L. Yeiser

I-Kuai Hung
hungi@sfasu.edu

A WHOLE-STAND GROWTH AND YIELD MODEL FOR UNMANAGED LOBLOLLY AND SLASH PINE PLANTATIONS IN EAST TEXAS



BY

MICKY G. ALLEN II

DEAN W. COBLE

JIMMIE L. YEISER

I-KUAI HUNG

REPORT 67

FROM

THE

EAST TEXAS PINE PLANTATION RESEARCH PROJECT

ARTHUR TEMPLE COLLEGE OF FORESTRY & AGRICULTURE

STEPHEN F. AUSTIN STATE UNIVERSITY

NACOGDOCHES, TX 75962

JUNE 2010

INTRODUCTION

The amount of forestland in east Texas has been estimated at 11.8 million acres, with approximately 2.5 million acres classified as pine plantations. The majority of these plantations are owned by forest industry (71 percent), while non-industrial private forest landowners represent the next largest shareholder (23 percent). Pine plantations are typically managed to produce timber, so information is needed to make informed management decisions. Growth is one piece of information that managers often rely upon in their decision-making process.

The purpose of this paper is to develop an updated whole-stand growth and yield model for unmanaged loblolly and slash pine plantations in east Texas that improves upon the whole-stand model of Coble (2009). Specifically, this updated model includes a new equation to predict average stand diameter as well as an improved survival function.

PLANTATION MEASUREMENTS

Data for this study were collected from permanent research plots maintained by the East Texas Pine Plantation Research Project (ETPPRP). The ETPPRP is a long-term comprehensive research program that has investigated the factors affecting the management of loblolly and slash pine plantations in East Texas since 1982 (Lenhart et al. 1985). Each plot is located in a separate plantation and consists of two subplots. Each subplot is 100 feet square (10,000 ft^2 or 0.23 acres). One subplot is utilized for model development and the other is utilized for model evaluation. A 30-foot wide buffer zone surrounds each plot, so each plot occupies 51,200 ft^2 or 1.18 acres. The plots are measured on a three-year cycle, with 1/3 of the plots being measured each year.

On each plot, all planted pine trees within each subplot were measured for: dbh, total height, height to live crown, and crown class. The presence of fusiform rust and visible tree quality was also recorded. The site preparation method, landform, slope, geographic location (latitude and longitude from a GPS), and soil characteristics were also recorded for each subplot. Beginning with the second measurement cycle (1985 – 1987), information about non-planted vegetation was collected for each subplot.

From these remeasured plots, 1049 loblolly pine and 460 slash pine observations were available for analysis. Each observation provided the following variables:

- Plantation age at the time of measurement (years),
- Average total height of the ten tallest trees on the plot (feet),
- Site Index (feet, base age 25 years),
- Trees per acre,
- Basal area per acre (square feet),
- Cubic foot volume wood and bark per acre,
- Cubic foot volume wood only per acre.

METHODS

This study utilized 1,049 observations from 153 permanent loblolly pine plots (Table 1). From the total 1,240 observations, approximately ten percent (n = 161 observations from 22 plots) were randomly selected and removed from the dataset used for model fitting and reserved for model validation. For slash pine 460 observations were used from 80 permanent plots (Table 2). Ten percent (n = 53 observations from 9 permanent plots) were randomly selected and removed from the model fitting dataset and reserved for model validation.

Whole-stand Model

The Schumacher (1939) model was used to predict future total tree cubic-foot volume per acre (V_2) as a function of future dominant height, plantation age, and basal area per acre:

$$\ln V_2 = a_0 + a_1 \ln H_2 + a_2 \frac{1}{A_2} + a_3 \ln B_2 \qquad (1)$$

where,

H_2 = future average height (feet) of dominant and co-dominant trees,
A_2 = future plantation age (years),
B_2 = future basal area (ft^2) per acre,
a_i, = parameter estimates, and
ln = natural logarithm function.

Future basal area per acre (B_2) and future dominant height (H_2) must be known before equation [1] can be used. The model of Borders et al. (2004) was used to predict current basal area per acre (ft^2, B_1):

$$\ln B_1 = b_0 + b_1 \frac{1}{A_1} + b_2 \ln N_1 + b_3 \ln H_1 + b_4 \ln N_1 \frac{1}{A_1} + b_5 \ln H_1 \frac{1}{A_1} \qquad (2)$$

where,

A_1 = current plantation age (years),
N_1 = current trees per acre,
H_1 = current average height (feet) of dominant and co-dominant trees, and
b_i, = parameter estimates.

To predict future basal area per acre (B_2), Borders et al. (2004) derived a basal area projection equation from equation [2] by isolating the b_1 term in equation [2]:

$$\ln B_2 = c_0 + \frac{A_1}{A_2}\left(\ln B_1 - c_0 - c_1 \ln N_1 - c_2 \ln H_1 - c_3 \frac{\ln N_1}{A_1} - c_4 \frac{\ln H_1}{A_1}\right) + c_1 \ln N_2 + c_2 \ln H_2 + c_3 \frac{\ln N_2}{A_2} + c_4 \frac{\ln H_2}{A_2} \qquad (3)$$

where,

N_2 = future trees per acre,
c_i, = parameter estimates, and
all other variables defined as before.

A Chapman-Richards model (Coble and Lee 2006) was used to predict future dominant height (H_2):

$$H_2 = H_1\left(\frac{1-e^{-d_1A_2}}{1-e^{-d_1A_1}}\right)^{d_2} \qquad (4)$$

where,

d_i, = parameter estimates,

e = exponential function, and

all other variables defined as before.

A negative-exponential survival model (Zhao et al. 2007, their equation [33]) was used to predict future surviving trees per acre (N_2):

$$N_2 = N_1 e^{g_1 SI(A_2^{g_2} - A_1^{g_2})} \qquad (5)$$

where,

SI = site index in feet (index age = 25 years),

g_i = parameter estimates, and

all other variables defined as before.

The following model was used to predict future average stand diameter (D_2, inches):

$$\mathbf{D_2 = Dq_2 - e^{\left(k_0 + k_1A^{-1} + k_2D_1 + k_3H_1 + k_4B_1\right)}} \qquad (6)$$

where,

D_1 = current average stand diameter (inches),

Dq_2 = current quadratic mean diameter (inches),

k_i = parameter estimates, and

all other variables defined as before.

Equations [1-6] were simultaneously fit to the fitting dataset using the MODEL Procedure in SAS/ETS (SAS Institute 2004) to obtain parameter estimates for model validation. After model validation was complete, equations [1-6] were simultaneously fit to the complete dataset to obtain final parameter estimates (Tables 3-4). In all cases, Seemingly Unrelated Regression (SUR) was used to account for correlation across the equations (Borders 1989, Robinson 2004).

Model Validation

The whole-stand model's equations [1-6] were validated with the 10% validation dataset. Validation was performed at two levels of resolution: 1) all age classes (Table 6), and 2) five-year age classes (from 5 to 30 years) (Tables 7-8). For all age class validation, four criteria (Kozak and Smith 1993) were used:

- Mean bias = Bias = $\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)}{n}$,
- Mean percent bias = %Bias = $\frac{\sum_{i=1}^{n}\left[100\left(\frac{\left(Y_i - \hat{Y}_i\right)}{Y_i}\right)\right]}{n}$,

- Standard error of the estimate = SEE = $\sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{n-q}}$,
- Percent SEE = %SEE = $\left(\frac{\text{SEE}}{\overline{\text{Y}}}\right)100$,

where: Y_i = observed B_2, H_2 and N_2 for observation i,
$\hat{Y}_i$ = predicted B_2, H_2, and N_2 for observation i,
$\overline{Y}$ = mean B_2, H_2 and N_2,
n = number of observations, and
q = number of estimated parameters in equation.

For the five-year age class validation, mean predicted and observed were calculated for each five-year class. For both models, mean bias (defined above) was then calculated by five-year age classes.

RESULTS AND DISCUSSION

The parameter estimates for loblolly and slash pine using the combined dataset were reported for equations [1 – 6] (Tables 3 - 4). All parameter estimates were significantly different from zero at the 0.01 level of significance, except for the $\ln N_1/A_1$ term in equation [2] as well as the $\ln N_2/A_2$ term in equation [3]. Though these two interaction terms were not significantly different, they were not removed as not to alter the mathematical compatibility between the basal area prediction (equation [2]) and projection (equation [3]) equations. All R-square values for each individual equation exceeded 94 percent and the R-square values for the yield model (equation [1]) and the average diameter model (equation [6]) exceeded 99 percent.

Predicted values for V_2, N_2, and d_2 from the updated model were less than one percent of observed values for loblolly and slash pine. For loblolly, the predicted values for B_2 and H_2 were less than four percent of observed values, while slash pine was less than two percent of observed values.

For five-year age classes, loblolly and slash pine mean percent bias values for V_2 where less than 2.5 percent of observed values (tables 7-8). The mean percent bias for B_2 was less than two percent of observed values for loblolly except for the five year age class (mean percent bias -25.61), however, the mean bias for this age class was only -3.11. Mean percent bias of slash pine was less than four percent of observed values except for the five year age class which was less than ten percent. The mean percent bias for N_2 was less than one percent of observed values for loblolly except for the 30 year age class, of which the mean percent bias was 3.85. Mean percent bias for slash pine was less than three percent of observed values except for age class 25 which was less than seven percent. The mean percent bias for H_2 was less than five percent for loblolly and slash pine except for age class 5 where the mean percent bias was less than ten percent of observed values. All age classes for d_2 were less than two percent of observed values for loblolly and slash pine.

LITERATURE CITED

Borders, B.E. 1989. Systems of equations in forest stand modeling. For. Sci. 35(2):548-556.

Borders, B.E., W.M. Harrison, F.Y. Zhang, B.D. Shiver, M. Clutter, C. Cieszewski, and R.F. Daniels. 2004. Growth and yield models for second rotation loblolly pine plantations in the Piedmont/Upper Coastal Plain and Lower Coastal Plain of the southeastern U.S. University of GA School of Forest Resources PMRC Res. Pap. Univ. of G.A, Athens, GA. 64 pp.

Coble, D.W. 2009. A new whole-stand model for unmanaged loblolly and slash pine plantations in east Texas. South. J. Appl. For. 33(2):69-76.

Coble D.W. and Y.J. Lee. 2006. Use of a generalized sigmoid growth function to predict site index for unmanaged loblolly and slash pine plantations in east Texas. In: Proceedings of the 13th Biennial Southern Silviculture Research Conference, 2006; Connor Kristina F., editor. USDA For. Serv. Gen. Tech. Rep. SRS-92. p. 291-295.

Kozak, A., and J.H.G. Smith. 1993. Standards for evaluating taper estimating systems. For. Chron. 69(4):438-444.

Lenhart, J.D., E.V. Hunt, Jr., and J.A. Blackard. 1985. Establishment of permanent growth and yield plots in loblolly and slash pine plantations in east Texas. In: Proceedings of the 3rd Biennial Southern Silvicultural Research Conference, 1985; Shoulders, E., editor. USDA For. Serv. Gen. Tech. Rep. SO – 54, p. 436-437.

Robinson, A. 2004. Preserving correlation while modeling diameter distributions. Can. J. For. Res. 34(1):221-232.

SAS institute. 2004. SAS/ETS 9.1 User’s Guide. SAS Institute Inc., Cary, NC, USA.

Schumacher, F.X. 1939. A new growth curve and its application to timber yield studies. J. For. 37:819-820.

Zhao, D., B. Borders, M. Wang, and M. Kane. 2007. Modeling mortality of second-rotation loblolly pine plantations in the Piedmont/Upper Coastal Plain and Lower Coastal Plain of the southern United Stated. For. Eco. Manage. 252(1-3):132-143.

Table 1. Observed stand characteristics for east Texas unmanaged loblolly pine plantation data sets for the whole-stand model.

	Model development data set (n=910 observations from 153 plots)				Model validation data set (n=139 observations from 22 plots)			
Variables	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
A	15.0	7.0	2.0	36.0	14.8	7.6	3.0	37.0
H	46.0	20.0	5.0	95.0	45.7	21.5	5.0	93.0
SI	70.0	10.0	31.0	105.0	69.2	11.4	30.0	108.0
TPA	451.8	148.3	83.0	1002.0	415.9	140.8	187.0	758.0
BA	93.4	53.4	0.5	220.7	84.4	50.6	0.5	178.7
Dq	6.0	2.5	0.1	12.9	5.9	2.7	0.1	11.3
V (ib)	1665.3	1343.3	0.0	5541.9	1529.7	1249.6	0.0	5449.7
V (ob)	2015.4	1628.0	0.1	6715.9	1851.4	1514.4	0.0	6607.7

A = plantation age (total years), H= average height of dominant and co-dominant trees (feet), SI = site index (base age = 25 years), TPA = trees per acre, BA = loblolly pine basal area per acre (BAPA, ft2), Dq = quadratic mean diameter (inches), V = total tree cubic-foot volume per acre, ib = inside-bark, and ob = outside-bark.

Table 2. Observed stand characteristics for east Texas unmanaged slash pine plantation data sets for the whole-stand model.

	Model development data set (n=417 observations from 71 plots)				Model validation data set (n=43 observations from 9 plots)			
Variables	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
A	13.6	6.4	2.0	33.0	16.2	7.8	3.0	35.0
H	42.8	19.7	3.0	91.0	49.3	20.1	10.0	88.0
SI	77.8	14.7	26.0	138.0	77.3	11.6	57.0	124.0
TPA	364.6	174.0	57.0	1002.0	380.9	178.4	105.0	706.0
BA	62.9	40.6	0.5	162.3	82.1	45.7	2.7	184.6
Dq	5.7	2.6	0.1	11.7	6.4	2.3	1.3	10.3
V (ib)	1126.1	1012.8	0.0	4477.9	1675.1	1376.2	6.2	4889.2
V (ob)	1479.1	1278.8	0.1	5523.1	2166.6	1701.8	11.0	5930.5

A = plantation age (total years), H= average height of dominant and co-dominant trees (feet), SI = site index (base age = 25 years), TPA = trees per acre, BA = loblolly pine basal area per acre (BAPA, ft2), Dq = quadratic mean diameter (inches), V = total tree cubic-foot volume per acre, ib = inside-bark, and ob = outside-bark.

Table 3. Parameter estimates and fit statistics of east Texas loblolly pine plantation predictive equations for the whole-stand model.

Equation	Parameter	Parameter Estimate	Standard Error	Pr(Parameter= 0)	R^2	RMSE
1 (lnV_2)	a_0	-1.55001	0.0385	< 0.0001	0.9979	0.0458
	a_1	1.17517	0.0111	< 0.0001		
	a_2	0.365194	0.0936	0.0001		
	a_3	0.968431	0.00468	< 0.0001		
2 (lnB_1)	b_0	-5.01504	0.2388	< 0.0001	0.9686	0.2134
	b_1	-15.3252	1.8322	< 0.0001		
	b_2	0.547455	0.0293	< 0.0001		
	b_3	1.530782	0.0297	< 0.0001		
	b_4	-0.11523	0.272	0.6719		
	b_5	5.377753	0.1591	< 0.0001		
3 (lnB_2)	c_0	-3.11547	0.3502	< 0.0001	0.947	0.1406
	c_1	0.574833	0.0454	< 0.0001		
	c_2	1.081433	0.0417	< 0.0001		
	c_3	0.853897	1.0704	0.4253		
	c_4	5.386267	0.1826	< 0.0001		
4 (H_2)	d_1	0.073828	0.00367	< 0.0001	0.9475	4.1127
	d_2	1.445346	0.0392	< 0.0001		
5 (N_2)	g_1	-7.98E-06	2.14E-06	0.0002	0.9767	21.9728
	g_2	1.994009	7.77E-02	< 0.0001		
6 (D_2)	k_0	-1.13025	0.067	< 0.0001	0.9991	0.0624
	k_1	-3.30026	0.3346	< 0.0001		
	k_2	-0.04476	0.0104	< 0.0001		
	k_3	0.0134	0.00157	< 0.0001		
	k_4	-0.00525	0.000387	< 0.0001		

Table 4. Parameter estimates and fit statistics of east Texas slash pine plantation predictive equations for the whole-stand model.

Equation	Parameter	Parameter Estimate	Standard Error	Pr(Parameter= 0)	R^2	RMSE
1 ($\ln V_2$)	a_0	-1.13746	0.0614	< 0.0001	0.9971	0.055
	a_1	1.133877	0.0167	< 0.0001		
	a_2	0.144324	0.1546	0.3511		
	a_3	0.951868	0.00595	< 0.0001		
2 ($\ln B_1$)	b_0	-5.87189	0.2909	< 0.0001	0.9638	0.2134
	b_1	-11.4125	2.4911	< 0.0001		
	b_2	0.638598	0.0347	< 0.0001		
	b_3	1.573939	0.0358	< 0.0001		
	b_4	0.003847	0.3566	0.9914		
	b_5	4.341575	0.257	< 0.0001		
3 ($\ln B_2$)	c_0	-1.98195	0.3714	< 0.0001	0.9707	0.1117
	c_1	0.598637	0.0422	< 0.0001		
	c_2	0.839835	0.0496	< 0.0001		
	c_3	3.504201	1.1485	0.0024		
	c_4	2.094633	0.2544	< 0.0001		
4 (H_2)	d_1	0.05549	0.0052	< 0.0001	0.9505	4.0467
	d_2	1.283431	0.0488	< 0.0001		
5 (N_2)	g_1	-0.00003	-7.45E-06	0.0006	0.9808	23.8028
	g_2	1.764638	0.0881	< 0.0001		
6 (D_2)	k_0	-1.30434	0.1038	< 0.0001	0.9991	0.0667
	k_1	-2.89574	0.5128	< 0.0001		
	k_2	-0.07899	0.017	< 0.0001		
	k_3	0.016032	0.0024	< 0.0001		
	k_4	-0.0047	0.000563	< 0.0001		

Table 6. Loblolly and slash pine mean bias, mean percent bias (% bias), standard error of the estimate (SEE), percent standard error of the estimate (%SEE), and number of samples (*n*) for the whole-stand model.

Component and Model	*N*	Mean bias[1]	Mean %bias	SEE	% SEE
V_2					
Slash	43	31.41	0.18	95.89	3.56
Loblolly	139	-8.73	-0.38	93.50	3.91
B_1					
Slash	43	3.18	3.45	10.15	10.72
Loblolly	139	-3.88	-5.87	18.86	18.60
B_2					
Slash	43	0.49	1.28	7.55	7.97
Loblolly	139	-0.89	-3.95	11.90	11.73
H_2					
Slash	43	1.02	1.96	4.57	7.94
Loblolly	139	0.70	2.06	5.23	9.73
N_2					
Slash	43	7.39	0.14	24.66	6.99
Loblolly	139	1.60	0.41	17.44	4.39
D_2					
Slash	43	-0.01	-0.05	0.08	0.14
Loblolly	139	0.00	-0.18	0.08	0.14

[1]Bias = (observed - predicted), and SEE = standard error of the estimate.

Table 7. Loblolly pine mean bias, mean percent bias (% bias), standard error of the estimate (SEE), percent standard error of the estimate (%SEE), and number of samples (*n*) for the whole-stand model by age class.

Component	Age Class	*n*	Mean	Mean bias[1]	Mean %bias	SEE	% SEE
V_2	5	17	289.59	1.90	-2.08	10.28	3.55
	10	28	1054.08	2.53	0.51	55.58	5.27
	15	33	2195.19	11.03	0.40	117.08	5.33
	20	32	3282.61	-20.30	-0.69	114.63	3.49
	25	16	3975.43	5.51	0.20	90.66	2.28
	30	13	4347.39	-86.06	-2.06	163.51	3.76
B_1	5	17	6.48	0.08	-1.29	1.83	6.07
	10	28	39.09	-0.12	-7.71	7.98	11.61
	15	33	88.36	-3.36	-5.55	22.95	21.29
	20	32	117.75	-7.60	-7.39	27.70	21.46
	25	16	131.78	-1.36	-2.18	24.14	17.62
	30	13	133.89	-12.47	-9.47	28.96	21.15
B_2	5	17	30.18	-3.11	-25.61	8.58	28.44
	10	28	68.78	-2.01	-0.60	11.94	17.36
	15	33	107.77	-0.56	-1.32	11.87	11.02
	20	32	129.05	0.11	-1.69	18.05	13.99
	25	16	137.01	1.22	0.89	8.56	6.25
	30	13	136.89	-1.52	-1.03	12.53	9.15
H_2	5	17	23.53	1.56	9.48	4.53	19.27
	10	28	38.79	1.75	4.40	3.75	9.67
	15	33	51.45	-0.53	-1.29	5.53	10.74
	20	32	64.47	0.13	0.09	7.22	11.20
	25	16	73.38	0.63	0.83	3.23	4.41
	30	13	80.62	1.95	2.22	6.15	7.62
N_2	5	17	475.35	-0.54	-0.15	8.69	1.83
	10	28	428.57	3.37	0.61	9.25	2.16
	15	33	440.46	2.86	0.63	15.41	3.50
	20	32	379.06	-1.76	-0.47	23.49	6.20
	25	16	295.13	-2.46	-0.86	27.74	9.40
	30	13	285.85	10.63	3.85	18.10	6.33
D_2	5	17	3.07	-0.04	-1.83	0.12	0.50
	10	28	5.21	0.01	-0.01	0.09	0.24
	15	33	6.48	0.01	0.16	0.07	0.14
	20	32	7.75	0.01	0.20	0.06	0.09
	25	16	9.13	-0.03	-0.37	0.10	0.14
	30	13	9.29	0.00	0.04	0.09	0.11

[1]Bias = (observed - predicted), and SEE = standard error of the estimate.

Table 8. Slash pine mean bias, mean percent bias (% bias), standard error of the estimate (SEE), percent standard error of the estimate (%SEE), and number of samples (*n*) for the whole-stand model by age class.

Component	Age Class	*n*	Mean	Mean bias[1]	Mean %bias	SEE	% SEE
V_2	5	4	405.82	-2.57	-1.27		
	10	7	1106.19	-7.13	-1.26	52.10	4.71
	15	11	2381.79	-18.29	-1.20	102.30	4.30
	20	10	3385.89	89.23	2.17	166.89	4.93
	25	5	4260.59	91.84	1.94	235.55	5.53
	30	6	4165.30	43.44	0.58	164.51	3.95
B_1	5	4	8.58	-0.98	-10.50		
	10	7	40.13	6.28	11.68	23.50	35.72
	15	11	79.07	4.94	6.17	14.76	15.61
	20	10	102.73	2.11	1.89	9.73	8.50
	25	5	128.80	4.30	3.84		
	30	6	112.38	-0.06	0.41		
B_2	5	4	37.23	4.10	9.59		
	10	7	65.80	0.82	3.20	13.05	19.83
	15	11	94.56	-3.16	-3.37	8.25	8.72
	20	10	114.47	3.66	3.39	11.50	10.05
	25	5	128.18	1.35	0.95		
	30	6	105.93	-1.64	-1.25	8.63	8.15
H_2	5	4	25.00	1.26	6.11	6.96	27.83
	10	7	38.43	0.61	1.35	2.56	6.66
	15	11	56.73	2.25	3.99	4.61	8.12
	20	10	63.50	0.02	-0.46	6.55	10.32
	25	5	71.60	0.85	1.09	7.16	10.00
	30	6	81.83	0.86	0.96	3.12	3.81
N_2	5	4	507.75	13.32	1.26	27.47	5.41
	10	7	397.00	13.05	1.33	33.12	8.34
	15	11	348.91	9.02	2.28	25.79	7.39
	20	10	358.90	8.43	0.63	28.76	8.01
	25	5	340.60	-2.86	-6.43	34.01	9.98
	30	6	203.33	0.63	-1.23	21.59	10.62
D_2	5	4	3.63	0.03	0.74		
	10	7	5.63	0.04	0.78	0.10	0.26
	15	11	7.06	0.01	0.07	0.07	0.12
	20	10	7.80	0.00	-0.01	0.04	0.06
	25	5	8.42	-0.06	-0.76		
	30	6	9.67	-0.12	-1.28	0.36	0.44