UPDATING INDIANA ANNUAL FOREST INVENTORY AND ANALYSIS PLOT DATA USING EASTERN BROADLEAF FOREST DIAMETER GROWTH MODELS[1 2]

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Abstract—The Forest Inventory and Analysis (FIA) program of the North Central Research Station (NCRS), USDA Forest Service, has developed nonlinear, individual-tree, distance-independent annual diameter growth models. The models are calibrated for species groups and formulated as the product of an average diameter growth component and a modifier component. The regional models for the Eastern Broadleaf (Continental)—Province 222, defined by R.G. Bailey, are calibrated using periodic Forest Inventory and Analysis data within that ecoregion. Average annual diameter growth is the dependent variable. The independent variables include crown ratio, crown class, stand basal area larger than the subject tree, physiographic class, latitude, and longitude. North Central Forest Inventory and Analysis has begun implementing annual inventories in a number of states of the region. The diameter growth models have been applied to annual data from Indiana to test their effectiveness on an independent data set that was collected under a survey design that differs from the one on which the models were calibrated. The bias of estimates increased with increasing values of crown ratio and with decreasing values of crown class.

INTRODUCTION

The North Central Research Station has developed nonlinear, individual-tree, distance-independent annual diameter growth models formulated as the product of an average diameter growth component and a modifier component and calibrated for species groups (Lessard and others submitted). The models may be used in two ways: (1) to update information on FIA plots not visited in the current year as a method of eliminating any lag in estimates of current conditions; and (2) to predict future forest resources.

Regional diameter growth models were developed for species groups within two ecoregions, the Laurentian Mixed Forest and the Eastern Broadleaf Forest (Lessard and McRoberts, in preparation). The objective of this study is to apply the Eastern Broadleaf Forest regional models to an independent data set, Indiana annual FIA data, and analyze the prediction performance.

PROVINCE 222

The diameter growth models are calibrated on FIA data from the Eastern Broadleaf Forest (Continental)—Province 222, defined by Bailey (1995). Province 222 is a subdivision of the Hot Continental Division. Most precipitation in Province 222 occurs during the growing season and generally decreases in quantity as distance from the Atlantic Ocean increases. This province favors drought-resistant oak-hickory associations. Province 222 lies to the east of the prairie regions, south and west of the Laurentian Mixed Forest—Province 212 in the northern areas, and west of the Appalachian Mountains in the southern regions. It extends from the Minnesota/Canadian border in the north through Missouri and Tennessee in the south.

CALIBRATION DATA

The diameter growth models were calibrated using FIA data across all ownership categories on land classified as timberland. Timberland was defined as non-reserved forestland that is producing or is capable of producing 20 ft^2/ac/yr of industrial wood. The FIA periodic 10-point cluster survey design and the data collection were described by Hansen and others (1992). ArcView GIS was used to overlay Bailey's eco-region map (Bailey and others 1994) on the FIA plot locations to select plots within Province 222. Growth models were calibrated using FIA data from the following states (the parentheses refer to the year of the inventory): Michigan (1980, 1993), Wisconsin (1983, 1996), Minnesota (1990, 1993), Illinois (1985, 1998), Indiana (1986, 1998), Iowa (1974, 1990), Ohio (1978, 1990), Missouri (1972, 1989), Kentucky (1974, 1987), and Tennessee (1989, 1996).

INDIANA ANNUAL DATA

Data from both the old periodic 10-point cluster design and the new 4-point annual design plots were collected during the last periodic inventory in Indiana (1998). The new standard plot design is a cluster of four fixed-area subplots (24-foot radius) superimposed on four fixed-area micro-plots (6.8-ft radius). All trees 5.0 in dbh and larger are measured on the subplots and all trees 1.0-4.9 in dbh are measured on the micro-plots. Under the annual system, plots to be measured in each cycle are divided into five sub-cycles. Each sub-cycle is inventoried in a single year to complete the full inventory cycle in five years.

Two measurement intervals were included in the Indiana annual data set: (1) 1,358 trees (69 plots) in the 1998-1999 data (the last periodic, cycle 4 to cycle 5, sub-cycle 1); and (2) 1,503 trees (63 plots) in the 1998-2000 data (the last periodic, cycle 4 to cycle 5, sub-cycle 2).

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MODEL FORM

The form of the diameter growth model is:

$$E(\Delta DBH) = AVERAGE * MODIFIER \text{ , where} \tag{1a}$$

$$AVERAGE = \beta_1 \exp(-\beta_2 \, DBH) \, DBH^{\beta_3} \text{ , and} \tag{1b}$$

$$MODIFIER = \exp[\beta_4 (CR - 4) + \beta_5 (BAL - 50) + \beta_7 (CC - 3) + \beta_8 (PC - 5) + \beta_{10} (LNG - 89) + \beta_{11} ((LNG - 89)^2)/10 + \beta_{12} (LAT - 40) + \beta_{13} ((LAT - 40)^2)/10], \tag{1c}$$

where DBH is diameter at breast height, CR is crown ratio (percent of tree height consisting of crown), CC is crown class in five categories ranging from dominant to suppressed, BAL is plot basal area per acre for trees larger than that of the subject tree, PC is physiographic class coded in the data set as 3, 4, 5, 6, or 7 (corresponding with xeric, xeromesic, mesic, hydromesic, and hydric, respectively), LNG is longitude, and LAT is latitude. The modeling methodology and assessment of fit are documented in Lessard and others (in review).

BIAS ASSESSMENTS FOR MODELS APPLIED TO INDIANA ANNUAL DATA

Residual analysis was conducted to examine the adequacy of the diameter growth model predictions for an independent data set. The Eastern Broadleaf Forest regional models were applied to the FIA Annual Indiana data to obtain predicted diameter growth rates (in/yr) for individual trees. Predicted growth rates were compared to average annual observed change in DBH, calculated as the ratio of the difference in DBH at the two measurements and the number of years in the measurement interval. Residuals were calculated as differences between observed and predicted annual changes in diameter. To examine how well the models fit the data, percentile statistics (25^{th}, 50^{th}, 75^{th}) were computed for the residuals by species group, and by classes of DBH, CR, BAL, CC, longitude, and latitude. Models were judged to be unbiased if zero was included in the range of values between the 25^{th} and 75^{th} percentiles for the residuals.

RESULTS AND CONCLUSIONS

The models were generally unbiased when the residuals were examined by species group (table 1), and by classes of DBH (table 2), CR (table 3), BAL (table 4), CC (table 5), LNG (table 6), and LAT (table 7). Several exceptions did occur. The models overestimated growth rates for cottonwood, however there were only 17 cottonwood trees in the data set used to test the models. Median residuals generally increased with increasing CR classes and with decreasing CC sizes. However, the inter-quartile range of residual values included zero for all but the largest and smallest classes of CR (table 3) and for the smallest CC with only 3 observations (table 5).

To examine the trend found in the residuals with respect to CR more closely, median average annual growth rates were calculated by CR class for both the Indiana Annual data and the Eastern Broadleaf Forest Periodic data and compared Indiana Annual data growth rates were less than those of the calibration data for small CC values and greater for large CC

Table 1—Analysis of residuals (calculated as the observed minus predicted values) sorted by species group

Species group	No. of trees	Percentile		
		25^{th}	50^{th}	75^{th}
		In/yr	*In/yr*	*In/yr*
Softwoods				
Eastern white pine	36	-0.117	-0.031	-0.003
Red pine	22	-0.068	-0.048	0.012
Jack pine and Virginia pine	93	-0.022	0.037	0.099
Shortleaf pine	55	-0.017	0.022	0.059
Tamarack	5	-0.011	0.016	0.017
Eastern redcedar	100	-0.026	0.021	0.111
Other softwoods	9	-0.061	-0.031	0.000
Hardwoods				
Select white oak	158	-0.065	-0.027	0.018
Other white oak	32	-0.063	-0.031	0.046
Northern red oak	48	-0.083	-0.011	0.037
Other red oak	163	-0.050	0.004	0.087
Select hickory	72	-0.061	-0.009	0.046
Other hickory	160	-0.046	-0.004	0.042
Hard maple	272	-0.043	-0.003	0.050
Soft maple	217	-0.079	-0.024	0.056
Boxelder	23	-0.104	-0.005	0.137
American beech	40	-0.043	-0.006	0.050
White and green ash	144	-0.073	-0.007	0.061
Black ash	7	-0.102	-0.052	0.014
Aspen	14	-0.091	0.038	0.122
Cottonwood	17	-0.182	-0.097	-0.035
American basswood	39	-0.018	0.013	0.069
Butternut and walnut	77	-0.057	-0.014	0.053
Black cherry	153	-0.084	-0.014	0.075
Elm	168	-0.060	-0.005	0.060
Hackberry	28	-0.056	-0.015	0.089
Sycamore	27	-0.110	-0.040	0.014
Yellow-poplar	117	-0.067	0.058	0.246
Sweetgum	35	-0.026	0.032	0.113
Tupelo	40	-0.046	0.002	0.071
Sassafras	125	-0.059	-0.029	0.006
Flowering dogwood	29	-0.029	-0.007	0.017
Other commercial hardwoods	68	-0.089	-0.025	0.064
Noncommercial hardwoods	69	-0.033	0.010	0.066

Table 2—Analysis of residuals (calculated as the observed minus predicted values) sorted by 5-inch dbh class

DBH class	Number of trees	Percentile 25th	50th	75th
In		*In/yr*	*In/yr*	*In/yr*
1-5	228	0.061	0.004	-0.041
5-10	1,502	0.064	-0.006	-0.055
10-15	606	0.064	-0.002	-0.054
15-20	213	0.032	-0.030	-0.082
20-25	83	0.082	-0.023	-0.096
25+	30	0.087	-0.006	-0.089

Table 3—Analysis of residuals (calculated as the observed minus predicted values) sorted by crown ratio

Crown ratio class	Number of trees	Percentile 25th	50th	75th
Percent		*In/yr*	*In/yr*	*In/yr*
0-9	33	-0.047	-0.073	-0.103
10-19	288	0.011	-0.032	-0.067
20-29	697	0.031	-0.022	-0.066
30-39	771	0.065	-0.002	-0.055
40-49	470	0.071	-0.001	-0.052
50-59	219	0.113	0.025	-0.034
60-69	104	0.159	0.065	0.004
70-79	55	0.231	0.064	-0.034
80-99	25	0.150	0.130	0.049

Table 4—Analysis of residuals (calculated as the observed minus predicted values) sorted by BAL

BAL class	Number of trees	Percentile 25th	50th	75th
Ft^2/ac		*In/yr*	*In/yr*	*In/yr*
0-50	989	-0.069	-0.007	0.076
51-100	804	-0.064	-0.021	0.043
101-150	376	-0.047	-0.003	0.055
151-200	142	-0.035	0.005	0.048
201-250	97	-0.051	-0.009	0.019
251-300	132	-0.035	0.018	0.065
301-350	109	-0.010	0.026	0.075
351-400	13	0.021	0.246	0.246

Table 5—Analysis of residuals (calculated as the observed minus predicted values) sorted by CC

BAL class	Number of trees	Percentile 25th	50th	75th
		In/yr	*In/yr*	*In/yr*
1	3	0.286	0.185	0.147
2	79	0.154	0.052	-0.011
3	1,457	0.074	0.004	-0.057
4	626	0.048	-0.017	-0.060
5	497	0.027	-0.020	-0.052

Table 6—Analysis of residuals (calculated as the observed minus predicted values) sorted by longitude

Longitude	Number of trees	Percentile 25th	50th	75th
Degrees		*In/yr*	*In/yr*	*In/yr*
-87.55	230	0.076	0.004	-0.051
-87.05	364	0.066	-0.005	-0.063
-86.55	1,066	0.041	-0.013	-0.057
-86.05	301	0.085	0.012	-0.043
-85.55	405	0.080	-0.005	-0.058
-85.05	296	0.072	0.005	-0.067

Table 7—Analysis of residuals (calculated as the observed minus predicted values) sorted by latitude

Latitude	Number of trees	Percentile 25th	50th	75th
Degrees		*In/yr*	*In/yr*	*In/yr*
38.05	475	0.069	0.015	-0.034
38.55	521	0.034	-0.014	-0.053
39.05	461	0.057	-0.017	-0.064
39.55	302	0.085	0.008	-0.049
40.05	92	0.129	0.019	-0.057
40.55	124	0.092	-0.001	-0.083
41.05	441	0.043	-0.021	-0.064
41.55	246	0.074	-0.003	-0.071

values. This follows the underestimation and overestimation patterns of the residuals (table 3).

In the context of their intended applications, the annual diameter growth models may be considered generally unbiased. However, because diameter growth rates with respect to CR tended to change from the time during which the calibration data were collected to the time the annual data was collected, exploration of methodology to capture these changes may improve the diameter growth predictions. Inclusion of climate variables in the model or application of model updating (e.g. Bayes) may improve the quality of diameter growth predictions.

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