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A SURVIVAL MODEL FOR SHORTLEAF PINE TREES GROWING IN UNEVEN-AGED STANDS[1]

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Abstract-A survival model for shortleaf pine (*Pinus echinata* Mill.) trees growing in uneven-aged stands was developed using data from permanently established plots maintained by an industrial forestry company in western Arkansas. Parameters were fitted to a logistic regression model with a Bernoulli dependent variable in which '1" represented individual tree survival and "0" represented individual tree mortality. Predictions from the model can be interpreted as probabilities of survival. The most important independent variable for prediction of survival probability was the ratio of quadratic mean stand d.b.h. to tree d.b.h. The data were used to evaluate the performance of the model by d.b.h. classes. The model was developed for use in an individual-tree growth simulator for uneven-aged shortleaf pine forests.

INTRODUCTION

Despite the economic importance and wide distribution of shortleaf pine relatively little effort has been directed at modeling individual tree survival. Lynch and others [in press(a)] developed a model for individual tree shortleaf pine survival in even-aged forest stands. Individual tree level equations for shortleaf pine dynamics are part of Central States Twigs (Miner and others 1989) and a multipurpose forest projection system for southern forests developed by Boulton and Meldahl (1990). Apparently, no survival models have previously been developed specifically for shortleaf pine managed in uneven-aged stands, though Murphy and Shelton (1996) developed a survival model for individual trees in uneven-aged loblolly pine (*Pinus taeda* L.) stands. This paper will present results from the development of a model for survival of individual shortleaf pine trees growing in forest stands under uneven-aged management.

Shortleaf pine has a greater natural range than any of the other southern pines and is second only to loblolly in volume (Willet 1986) The species is especially important in the Ouachita mountain region of western Arkansas and eastern Oklahoma. Forecasts of stand dynamics for uneven-aged shortleaf pine stands are important on many acres of forest land managed by public agencies, non-industrial private owners, and certain forest industries in western Arkansas and eastern Oklahoma. Though the uneven-aged system produces somewhat lower merchantable volume than even-aged management it has traditionally been utilized by certain forest industries in the West-Gulf region to produce dimension lumber (Guldin and Baker 1988). Attractive features of the system include low-cost regeneration and relatively high sawtimber volume growth. These features make uneven-aged management of southern pine a viable alternative, especially on lower-quality sites (Guldin and Baker 1988, Shelton and Murphy 1994). A discussion of selection management for shortleaf pine in the Ouachita mountains has been given by Murphy and others (1991). Baker and others (1996) have elucidated the principles of uneven-aged management for loblolly and shortleaf pine.

Most of the information currently available for stand dynamics of shortleaf pine growing in naturally regenerated stands is based on data from even-aged stands. USDA Miscellaneous Publication 50 (USDA Forest Serv. 1929) includes normal yield tables for shortleaf pine which were based on data obtained from fully-stocked temporary plots. Yield tables developed by Schumacher and Coile (1960) were developed from 74 "well-stocked" temporary plots. Murphy and Beltz (1981) and Murphy (1982) developed growth and yield equations for shortleaf pine based on Forest Inventory and Analysis plots, most of which were located in unmanaged forests. Murphy (1986) gives a comprehensive account of the growth and yield information available for shortleaf pine prior to 1986. Lynch and others 1999b and Huebschmann and others (1998) describe the Shortleaf Pine Stand Simulator (SLPSS), an individual tree model for even-aged shortleaf pine stands which contains a prediction equation for probability of tree survival. This model is based on remeasured plots located in the Ozark and Ouachita National Forests and distributed over a range of ages, densities and site qualities.

Murphy and Farrar (1985) have developed equations describing the growth and yield of uneven-aged shortleaf pine stands. These equations describe growth and yield on a stand-level basis. Since the equations describe net yields, there are no explicit predictions for survival or mortality. Murphy and Farrar (1988) proposed a framework for growth and yield model development in uneven-aged loblolly-shortleaf stands which used the Weibull distribution to predict tree diameter distributions. This framework also consisted of stand-level equations.

Logistic Model

The logistic model is often used to develop prediction equations for event probabilities (Hosmer and Lemeshow 1989, Neter and others 1989). Hamilton (1974), Hamilton and Edwards (1976), and Monserud (1976) describe the use of the logistic model for development of individual-tree mortality or survival models. The model can be written as:

$$P_j = (1 + \exp[-(b_0 + b_1x_{1j} + b_2x_{2j} + \ldots + b_mx_{mj})])^{-1} \qquad (1)$$

where
P_j is the annual probability for survival of tree j,
x_{ij} is the value of independent variable x_i for tree j,
b_0 is an estimated coefficient representing the intercept, and
b_i is an estimated coefficient associated with x_{ij}.

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When regression techniques are used to estimate parameters for individual-tree survival models, the dependent variable is "I" for trees that survive the measurement period and "0" for trees that do not survive the measurement period. Remeasured plot data are usually obtained for intervals longer than one year. Since it is often desired to use these data to model annual survival probabilities, the following formulation has been suggested by Hamilton and Edwards (1976) and Monserud (1976):

$$P_j^t = (I + \exp[-(b_0 + b_1 x_{1j} + b_2 x_{2j} + \ldots + b_m x_{mj})])^{-t} \qquad \textbf{(2)}$$

where
t is the number of years in the measurement period, and
P_j^t is the probability that tree j survives a t year period.

The use of iteratively re-weighted nonlinear regression is recommended for estimation of the coefficients in this model (Hamilton 1974, Hamilton and Edwards 1976, Monserud 1976). The weight used should be the inverse of $P^t(1-P^t)$ where P^t is the probability of survival fort years predicted by the model. When this weight is used, maximum likelihood estimates are obtained. McCullagh and Nelder (1989) show that iteratively re-weighted regression provides maximum likelihood estimates for a class of models, which includes the survival model above.

DATA

Data were obtained from permanently established 0.2 acre plots located in southwestern Arkansas maintained by Deltic Farm and Timber of El Dorado, AR. The majority of the plots were located in Arkansas south of U.S. interstate Highway 40 and west of U.S. Highway 65. The first measurements were made following the 1965 growing season. Subsequent measurements were made during the dormant season at 5 or 6 year intervals. New plots have been added to the permanent plot system to replace lost plots or when new property has been acquired.

D.b.h. was measured on all living trees 5.1 inches or larger on each plot. USDA Miscellaneous Publication 50 (USDA Forest Service 1929) was used to determine site index for each plot. Though the concept of site index is usually associated with even-aged stands, researchers such as Murphy and Farrar (1985) have evaluated relative site quality using site index. Baker and others (1998) state that in uneven-aged stands of loblolly or shortleaf pine, site index is an approximation since trees currently in dominant or codominant positions have probably been in the understoty at some point in the past. Trees used for determination of site index in uneven-aged stands should have rlng patterns that do hot show signs of suppression. Total height measurements were made at the ends of the 1988 and 1993 growing seasons. Prior to 1988, only merchantable heights were recorded.

For this analysis, all plots containing loblolly pine were discarded. Plots used in the study were allowed to contain up to 30 percent hardwood. Growth intervals for a given plot were also eliminated from the data used for analysis for: timber stand improvement or harvest during the interval, more than 20 percent of plot initial basal area per acre lost to mortality, or merchantable shortleaf pine basal area below 30 ft^2/acre or more than 90 ft^2/acre. Since adequate reproduction is required to sustain uneven-aged management, plots with growth intervals having densities in excess of 90 ft^2/acre were deemed not able to sustain uneven-aged management.

In order to eliminate autocorrelation problems in parameter estimation due to time dependencies, only one growth period was retained for each plot. Some growth periods were eliminated to avoid over representation of some site and basal area classes. Table I gives summary statistics for the 152 plots used in the analysis. Equation 1 is designed to predict probability of survival on an individual-tree basis. Therefore, data from individual shortleaf pine trees were used to estimate coefficients in equation 2. A summary of the data from 3,722 shortleaf pine trees located on 152 remeasured plots in uneven-aged shortleaf pine stands is given in table 2.

ANALYSIS

Estimation of Coefficients

Several variables potentially related to individual tree survival in uneven-aged shortleaf stands were examined. These included shortleaf basal area per acre, hardwood basal area per acre, total basal area per acre (shortleaf plus hardwood basal area), site index, d.b.h. of the subject tree, and ratio of plot quadratic mean d.b.h. to individual tree d.b.h. PROC LOGISTIC (SAS Institute 1989) was used to screen variables using a model similar to equation 1; the dependent variable was 1 for trees surviving the measurement period and 0 for trees not surviving the plot measurement period. Within PROC LOGISTIC a stepwise procedure is available which uses the adjusted chi-square statistic and the 0.05 significance level. According to this procedure, neither site index nor basal area per acre were significantly related to individual shortleaf pine tree survival in these uneven-aged forests. Murphy and Shelton (1998) found that site index was significantly related to individual-tree survival in uneven-aged loblolly stands. However, basal are per acre was not significantly related to survival for the loblolly pine data examined by Murphy and Shelton (1998). Lynch and others [in press(a)] developed a survival model for even-aged shortleaf pine stands in which stand basal area was significantly related to individual-tree survival. This model is used in a distance-independent individual tree simulator for even-aged shortleaf pine stands (Lynch and others [in press(b)], Huebschmann and others 1998). Levels of basal area per acre for the data of Lynch and others [in press(a)] ranged from about 30 square feet per acre to approximately 170 square feet per acre. It may be that the wider range of basal areas occurring in the even-aged data allowed the effect of basal area per acre on survival to show significance. Uneven-aged management of the southern pines maintains stands under a much narrower range of densities than even-aged management.

After data screening the following final model form resulted:

$$P_j^t = (1 + \exp[-(b_0 + b_1 R_j)])^{-t} \qquad \textbf{(3)}$$

where
$R_j = D_q/D_j$
D_q = quadratic mean d.b.h. (inches) for the stand containing tree j, and
D_j = d.b.h. (inches) for tree j.

Although useful to determine model form, PROC LOGISTIC cannot be used to estimate coefficients in equation 3 because remeasurement perlod lengths for the data

Table I-Data summary for 152 remeasured plots in uneven-aged stands In southwest Arkansas

Variable	Average	Standard deviation	Minimum	Maximum
Trees per acre				
Shortleaf pine				
Initial	122.4	48.5	40	285
Mid-period	139.2	57.7	40	305
Final	137.1	58.1	40	300
Hardwoods				
Initial	17.4	18.1	0	65
Mid-period	25.4	22.1	0	125
Final	24.5	21.4	0	I25
Basal area (ft^2 per acre)				
Merchantable shortleaf pine (d.b.h. 5.1 in. or greater)				
Initial	55.0	15.3	30.1	90.0
Mid-period	60.9	16.2	32.7	95.2
Final	66.9	17.8	32.6	102.0
Shortleaf pine sawtimber (d.b.h. 9.1 in. or greater)				
Initial	30.4	14.1	2.6	75.2
Final	42.1	15.0	5.7	77.2
Hardwoods (d.b.h. 5.1 in. or greater)				
Initial	6.5	6.4	0	30.1
Mid-period	7.6	6.7	0	30.6
Final	8.6	7.3	0	35.1
Shortleaf site index (ft, base age 50 yr)	56.3	7.3	35	74

Table 2—Summary of data obtained from 152 mmeasumd plots In uneven-aged shortleaf pine stands containing 3,722 shortleaf pine trees In southwest Arkansas, used for estimation of coefficients in model for probability of survival

Variable	Average	Standard deviation	Minimum	Maximum
Stand-level				
Periodic shortleaf mortality (trees/ac)	2.2	3.9	0	20
Plot or stand quadratic mean diameter *(in.)*	*9.0*	I.2	6.6	13.2
Tree-level				
Tree d.b.h. (in.)	8.7	2.5	5.1	19.4
Ratio of plot or stand quadratic mean diameter to tree d.b.h.	1.10	.27	.43	2.36

analyzed in this study were 5 or 6 years. Therefore PROC NLIN (SAS Institute 1969) was used to estimate parameters in equation 3 with iteratively m-weighted regression as described above in the description of the logistic equation.

The final parameter fitting process resulted in:

$$P_j^t = (1+\exp[-(7.31384 - 1.42614\ R_j)])^{-t} \qquad (4)$$
$$(0.5303) \quad (0.4264)$$

Standard errors for coefficient estimates appear in parentheses beneath the estimated values in equation (4). Values of student's t-statistic obtained by using the standard errors in equation 4 indicate that the estimates are significantly different from zero at the 0.05 significance level. When used in an individual-tree growth simulator with annual time steps, the exponent representing the length of the survival period will be set to $t=1$.

Model **Evaluation**

Hamilton and Edwards (1976) used a chi-square test to evaluate logistic models for individual-tree survival. Hosmer and Lemeshow (1969) and Neter and others (1969) describe procedures for evaluation of logistic models using the chi-square test. Their recommendations applied to evaluation of a tree survival model using d.b.h. classes would result in the following test statistic:

$$X^2 = \Sigma\,[(O_{j0}-E_{j0})^2/E_{j0} + (O_{j1}-E_{j1})^2/E_{j1}] \qquad (5)$$

where
X^2 is the chi-square statistic,
E_{j0} is the expected number of trees in d.b.h. class j dying,
O_{j0} is the observed number of trees in d.b.h. class j dying,
E_{j1} is the expected number of trees in d.b.h. class j surviving,
O_{j1} is the observed number of trees in d.b.h. class j surviving, and
Σ represents summation over all d.b.h. classes.

Expected versus observed survival and mortality by d.b.h. classes are given in table 3 together with chi-square contributions. The contribution to chi-square from mortality is much higher than for survival. In these managed stands, most trees survive during the measurement interval. Thus the chi-square denominator is much higher for survival than for mortality. As a result the chi-square contribution of observed vs. expected survival is much lower than that for mortality. The total chi-square statistic is 12.75 (0.17 + 12.57).

The hypothesis to be tested is that the logistic model fits the observed survival and mortality data. Simulation studies by Hosmer and Lemeshow (1960) indicated that two degrees of freedom should be subtracted from the number of categories when chi-square computations are based on the same data used to estimate model coefficients. Thus, table 3 indicates that the appropriate number of degrees of freedom is **15-2=13.** A chi-square statistic of X^2 = 12.75 and 13 degrees of freedom yields a pvalue of 0.47. Since p-value = 0.47 > 0.05 = significance level, we fail to reject the hypothesis that the logistic equation 4 fits the observed survival and mortality data. Since the pvalue is much greater than the significance level, we accept equation 4 as an adequate survival model for shortleaf pine trees in the uneven-aged stands used for this analysis. Because some plots were measured on a 5 year interval and others were measured on a 6 year interval, it is difficult to compute an exact'over-all annual mortality rate from table 3. However, the table indicates that the annual rate is probably somewhere between 0.4 and 0.3 percent.

Table 3—Survival and mortality expected from a logistic survival model versus observed survival and mortality by d.b.h. classes for the plot remeasurement period with chi-square contributions

	Number of survivors			Mortality		
D.b.h. (in.)	Observed	Expected	Chi-square	Observed	Expected	Chi-square
5	144	141.521	0.0434	2	4.479	1.3720
6	665	665.365	.0002	19	16.635	.0072
7	606	604.626	.0023	12	13.172	.1043
6	546	546.242	.0001	10	9.756	.0060
9	501	499.415	.0050	6	7.565	.3312
10	363	365.765	.0201	a	5.215	1.4674
11	261	284.481	.0426	7	3.519	3.4446
12	215	214.530	.0010	2	2.470	.0895
13	122	120.692	.0142	1	1.306	1.3076
14	102	101.994	3.5×10^{-7}	0	1.006	3.6×10^{-5}
15	55	54.466	.0052		.532	.5318
16	19	19.621	.0340	1	.179	3.7739
17	6	7.933	.0006	0	.067	.0668
16	4	3.966	.0003	0	.032	.0321
19	3	2.975	.0002	0	.025	.0247
Total	3654	3654.019	.1692	66	67.961	12.5793

SUMMARY AND CONCLUSIONS

Data from remeasured plots located in uneven-aged shortleaf pine stands were used to estimate coefficients in a logistic model, which can be used to predict the probability of individual shortleaf pine tree survival. The model uses the ratio of quadratic mean stand d.b.h. to individual tree d.b.h. to predict the probability of individual tree survival. A chi-square test indicated that the model tits the data in an acceptable manner.

This logistic model can be used to predict annual survival probabilities for individual shortleaf pine trees growing in uneven-aged stands. This survival model is being used as part of a distance-independent individual-tree growth model for uneven-aged shortleaf pine stands which is currently under development. Foresters who apply uneven-aged management concepts to shortleaf pine stands should find the model to be useful for management planning.

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