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Survival Predictions for Major Lake States Tree Species

Roland G. Buchman

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
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St. Paul, Minnesota 55108
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SURVIVAL PREDICTIONS FOR MAJOR LAKE STATES TREE SPECIES

Roland G. Buchman, *Biometrician*

A tree's likelihood of surviving competition from its neighbors and the cumulative tree risks within a stand provide essential forest management information. Such information partially explains the development of the stand and the products available. Past diameter growth and current diameter, individual tree characteristics commonly recorded during a forest inventory, are the essential elements for obtaining tree survival information from the model used in this paper.

The model and survival information in this paper are supported by an extensive data set (table 1). The model is based on the logistic function, which has been extensively used for mortality modeling (Buchman 1979, Hamilton 1980, Monserud 1976); however, it includes a special adaptation that more realistically reflects the survival behavior of small trees and large, slow-growing trees (Buchman *et al.* in press). Individual tree survival rate predictions for many Lake States species have been reported elsewhere (Buchman 1979, Lanford 1975, Letourneau 1979). However, none of these studies used a data set with the strength of this study. Furthermore, the models used in the earlier studies failed to produce realistic survival responses for large, slow-growing trees.

The survival predictions presented in this paper reflect an individual tree's survival under normal or regular life stresses. This includes competition with neighboring trees for moisture, nutrients, and light. It also includes outside effects of endemic pest levels and moderate moisture deficits. However, these predictions do **not** apply when outside effect of pests or environmental conditions exist at catastrophic levels.

This paper presents a model with coefficients for 10 Lake States tree species to enable prediction of an individual tree's probability of survival. The performance of the model is documented on a regional basis across the Lake States and on a local basis for particular forest areas or stands.

METHODS

Data Base

Permanent growth plot tree records were available for the major forest tree species of the Lake States from research cutting experiments, demonstration woodlots, industrial continuous forest inventories, and personal records of forest growth (Christensen *et al.* 1979). Records for a tree were used if three measurements were available on that tree, with it being alive on the first two and not cut before the third measurement. The period between pairs of measurements had to be at least 2 but no more than 6 years.

The first two measurements were used to calculate diameter growth rate (DGR) by dividing the difference in the two diameters by the number of intervening years; zero was recorded if the calculated growth was negative. The second diameter was used as the diameter at breast height (DBH) value. The third measurement was used to record tree status (alive or dead but not cut).

Many trees had more than three measurements that met the time and status requirements. These trees were used as two or more observations of tree status, diameter growth rate, and diameter (table 1).

The data were assembled into DGR-DBH classes for each species using 0.02-inch (0.05-cm) increments for DGR and 1-inch (2.54-cm) increments for DBH. Mean DGR, mean DBH, and number of trees were determined for each class.

Once DGR-DBH classes had been established, we calculated the survival rate (SR) for each class. In

Table 1.--Tree survival data sources

(In number of tree records)

Tree species	Total[1]	North Central Minnesota (research)	Wisconsin (timber harvest forest)	Wisconsin (private woodlot)	Wisconsin (forest industry)	North East Wisconsin (research)	Lower Michigan (research)
Jack pine	2,960	1,206	2	0	191	0	1,561
Red pine	39,998	20,096	114	0	265	1,300	18,223
White pine	2,394	1,531	710	0	149	4	0
Balsam fir	6,776	1	63	0	399	6,313	0
Red maple	2,233	14	548	690	520	461	0
Elm	4,337	26	622	872	201	2,616	0
Basswood	4,056	62	746	485	381	2,382	0
Sugar maple	17,211	0	3,202	682	854	12,473	0
Quaking aspen	6,008	3,684	129	5	825	1,365	0
Paper birch	1,626	24	29	0	321	1,252	0

[1] Number of tree records, several records for some trees.

general, each class had two or more interval lengths for status measurements. Hence, annual survival rates were calculated using the formula:

$$SR = [\Sigma_i X_i/\Sigma_i N_i]^{[\Sigma_i N_i/\Sigma_i i\cdot N_i]} \qquad (1)$$

where N_i and X_i are the number of trees alive at the beginning and at the end of the status observation interval and i is the interval length (years).

Species Coefficients

These annual survival rates were modeled using

$$SR = b_1-[1/(1+e^n)] \qquad (2)$$

where n is $b_2 + b_3 \cdot DGR^{b_4} + b_5 \cdot (DBH-1)^{b_6} \cdot e^{-b_7 \cdot (DBH-1)}$ and $b_1,\ldots, b_7$ are numerical constants. Data for each species were analyzed separately to provide species-specific coefficients for $b_1,\ldots, b_7$.

Note that b_1 sets the maximum SR for a species and cannot exceed 1. Its value was established as a composite survival rate calculated from fast-growing trees of the species. b_2, in concert with b_1, sets the SR for 1 inch trees showing no perceptible growth. Its value was set by extending a free hand curve from the SR data points back to the 1 inch point. The remainder of the coefficients were obtained using nonlinear least-square regression techniques weighted by number of trees. b_3 and b_4 describe the effect of DGR on survival rate for trees that are neither fast growers nor nongrowers. b_5, b_6, and b_7 describe the SR line for those trees growing little or not at all in diameter. Coefficients were calculated for each species.

REGIONAL PERFORMANCE

The data for each species came from across the Lake States (table 1); the coefficients developed could well be termed "regional".

Coefficient Adjustment

The model was applied to the data for each species using the tentative species coefficients developed through regression analysis. Total surviving trees for each DGR and DBH class were counted and compared with those predicted by the model. Adjustments were made in b_3 and b_4 coefficients to shift predicted totals where the differences between the counts and the predictions showed a series of positive or negative values. These adjustments had little effect on the size of the sum of the squared residuals. For the remainder of the paper, model refers to equation (2) and the particular species coefficients (table 2).

DGR Results

Tree-record data were assembled into 12 DGR classes for each species; annual survival rates were predicted by the model and calculated from the data for each class (table 3). Predicted rates were determined by applying the model to the data for each species to get the survival probability for each tree-record within the class, summing these probabilities to get ΣX_i; and then using the SR (1) equation. Calculated rates were obtained by summing the tree status codes (alive = 1, dead = 0) to get ΣX_i and again applying SR (1). In each case N_i is the number

Table 2.--Model (2)[1] coefficients for predicting annual tree survival from diameter growth rate (DGR) and diameter at breast height (DBH)

Species	Coefficients						
	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Jack pine	0.9966	0.5902	0.1800E+2	0.7110E+0	0.1144E-1	0.4764E+1	0.6834E+0
Red pine	.9997	1.9953	.5797E+2	.1012E+1	.2648E+0	.1626E+1	.1273E+0
White pine	.9989	1.6150	.1568E+4	.2268E+1	.8712E+0	.4320E+0	.1012E+0
Balsam fir	.9984	1.9241	.2871E+2	.1021E+1	.4421E+1	.3640E+1	.1672E+1
Red maple	.9964	1.0260	.3686E+3	.1725E+1	.3448E+0	.1968E+1	.2919E+0
Elm	.9941	0.5794	.1163E+2	.6440E+0	.2655E+0	.2963E+1	.4715E+0
Basswood	.9979	1.1097	.2839E+2	.1045E+1	.4035E+0	.2039E+1	.2769E+0
Sugar maple	.9979	2.4852	.6076E+2	.1205E+1	.8503E+0	.1010E+1	.2394E+0
Quaking aspen	.9908	0.3772	.3455E+2	.1089E+1	.9314E-1	.3419E+1	.5346E+0
Paper birch	.9991	1.9539	.8379E+1	.3982E+0	.1710E+1	.2444E+1	.8923E+0

[1] $SR = b_1 - [1/(1+e^n)]$

where n is $b_2 + b_3 \cdot DGR^{b_4} + b_5 \cdot (DBH - 1)^{b_6} \cdot e^{-b_7 \cdot (DBH-1)}$

and $b_1, \ldots, b_7$ are species constants.

of tree records at the beginning of the status recording interval (table 3).

Comparison of predicted annual survival rate with the calculated rate shows them to be within 0.005 of each other in 103 of the 120 classes (table 3). Seven classes show differences greater than 0.01. Jack pine and quaking aspen show the greatest differences.

One can approximate the effect of prediction errors using the table entries. To illustrate, suppose you have 100 trees in a selected DGR class and the number of years in your prediction interval is 5. If the calculated survival rate is 0.9829 and the predicted survival rate is 0.9878 (these are the quaking aspen entries for DGR of 0.14 in table 3), the calculated number of trees surviving after 5 years is 91.7 ($0.9829^5 \times 100$) while the predicted number is 94.0 ($0.9878^5 \times 100$). The consequences of the errors in prediction on a stand depend on the mix of trees by species and DGR classes and will be more complicated to evaluate. The differences for adjoining classes often have opposite signs and will provide offsetting errors within the stand.

DBH Results

Tree-record data were assembled into as many as 21 DBH classes by species. The number of records and the DBH distribution for a species determined its number of classes. Two survival rates were calculated for each DBH class using the same procedures as for DGR classes (table 4).

Comparison of predicted annual rate with the calculated rate shows them to be within 0.005 of each other in 115 of the 152 classes. Fourteen show differences greater than 0.01. Differences are largest for small trees, with 0.06 for jack pine, 0.04 for balsam fir, 0.15 for red maple, and 0.12 for quaking aspen.

The consequences of the errors in prediction can be evaluated similarly to that for DGR. However, differences for adjoining DBH classes do not negate each other to the extent they do for DGR classes.

LOCAL PERFORMANCE

Coefficients based on regional data may be applicable to local forested areas or stands. To evaluate this, the performance of the model was tested on data for each species for at least one local forest area (table 5).

Survival results were calculated for each plot within the stand by accumulating the individual predicted tree probabilities (table 5). The observed survival was counted. Predicted survival was determined using the model on each tree's measured DGR and

Table 3.--Measured and predicted annual tree survival rates by diameter growth rate (DGR) for 10 Lake States tree species

DGR[1] (In/Yr)	Survival rate[2]	Jack pine	Red pine	White pine	Balsam fir	Red maple	Elm	Basswood	Sugar maple	Quaking aspen	Paper birch
		Species									
0.00	Mea.	0.7237	0.9666	0.9331	0.9296	0.9336	0.9165	0.9480	0.9685	0.7990	0.9425
	Pre.	.7114	.9665	.9301	.9361	.9321	.9152	.9501	.9680	.8027	.9435
	Base[3]	60	981	87	259	66	352	217	1,008	189	158
.02	Mea.	.8301	.9929	.9383	.9551	.9539	.9471	.9711	.9811	.8450	.9912
	Pre.	.8693	.9916	.9417	.9625	.9566	.9634	.9684	.9804	.8588	.9900
	Base	103	1,237	73	464	79	156	139	521	348	200
.04	Mea.	.9348	.9975	.9776	.9809	.9935	.9711	.9813	.9871	.9171	.9896
	Pre.	.9289	.9969	.9624	.9788	.9762	.9739	.9783	.9875	.9076	.9940
	Base	104	2,224	88	550	132	352	263	1,206	369	209
.06	Mea.	.9643	.9992	.9864	.9907	.9911	.9832	.9876	.9930	.9552	.9972
	Pre.	.9616	.9991	.9902	.9877	.9917	.9806	.9876	.9933	.9468	.9964
	Base	101	3,777	111	648	168	290	200	1,084	428	204
.08	Mea.	.9576	.9992	.9925	.9930	.9948	.9869	.9894	.9945	.9794	.9978
	Pre.	.9762	.9995	.9981	.9922	.9955	.9841	.9923	.9958	.9695	.9970
	Base	178	5,038	128	663	207	342	271	1,642	389	180
.10	Mea.	.9890	.9994	.9985	.9949	.9977	.9864	.9960	.9977	.9767	.9979
	Pre.	.9836	.9997	.9989	.9948	.9963	.9883	.9954	.9971	.9806	.9976
	Base	337	5,682	158	1,002	278	408	378	2,236	436	196
.12	Mea.	.9990	.9997	.9937	.9969	.9935	.9861	.9990	.9988	.9828	.9984
	Pre.	.9897	.9997	.9989	.9964	.9964	.9890	.9965	.9976	.9857	.9978
	Base	274	4,317	115	622	194	233	210	1,020	365	124
.14	Mea.	.9874	.9997	.9960	.9979	.9990	.9896	.9959	.9978	.9829	1.0000
	Pre.	.9920	.9997	.9989	.9972	.9964	.9906	.9971	.9978	.9878	.9978
	Base	331	4,551	173	557	215	313	368	1,724	409	96
.16	Mea.	.9961	.9997	1.0000	.9963	.9956	.9907	.9961	.9979	.9849	.9970
	Pre.	.9935	.9997	.9989	.9976	.9964	.9910	.9973	.9978	.9893	.9979
	Base	314	3,549	194	481	197	251	286	1,403	460	68
.18	Mea.	.9957	.9996	.9947	.9975	.9974	.9889	.9994	.9986	.9864	1.0000
	Pre.	.9945	.9997	.9989	.9979	.9964	.9924	.9976	.9979	.9901	.9980
	Base	298	2,802	169	388	171	275	378	1,361	479	56
.20	Mea.	.9962	.9998	.9987	.9989	.9985	.9965	.9980	.9982	.9897	1.0000
	Pre.	.9952	.9997	.9989	.9981	.9964	.9927	.9977	.9979	.9904	.9981
	Base	376	1,998	180	356	152	348	425	1,418	467	56
Rest[4]	Mea.	.9972	.9996	.9995	.9985	.9957	.9961	.9978	.9967	.9914	1.0000
	Pre.	.9962	.9997	.9989	.9983	.9964	.9935	.9979	.9979	.9907	.9983
	Base	484	3,811	918	783	374	1,014	918	2,587	1,669	77

[1] Upper limit of DGR interval, first interval contains trees of no measurable growth.

[2] Measured annual survival rate and the predicted annual survival rate.

[3] Number of tree records.

[4] Includes all trees growing more than 0.2 inch per year.

DBH; the resulting probabilities for surviving 1 year were raised to the nth power to get the probability of surviving for n years.

Performance, as measured through several statistics calculated from the number of trees, is based on plot results within the stand. The observed and predicted stand average of the number of trees surviving after n years is presented along with the initial number of trees. The standard deviation of the differences between observed and predicted trees per plot is shown. Finally, the slope of the line for regressing estimated trees from observed trees is given. A slope value of one shows that differences between the observed and predicted tree counts are uniform for the range of plot tree counts.

The observed and estimated number of trees surviving within each stand agree closely (table 5). Although jack pine and quaking aspen show several

Table 4.--Measured and predicted annual tree survival rates by diameter class (DBH) for 10 Lake States tree species

DBH[1] (In)	Survival rate[2]	Jack pine	Red pine	White pine	Balsam fir	Red maple	Elm	Basswood	Sugar maple	Quaking aspen	Paper birch
		Species									
1	Mea.	0.9043	0.9356		0.9966				0.9312		
	Pre.	.8444	.9295		.9545				.9498		
	Base[3]	62	18	0	208	0	0	0	53	0	0
2	Mea.	.9676	.9475		.9823	0.7986	0.8651	0.8867	0.9683	0.8804	0.9790
	Pre.	.9556	.9513		.9789	.9433	.8443	.8889	.9745	.7599	.9782
	Base	426	133	0	1,337	7	29	34	620	31	423
3	Mea.	.9720	.9808		.9932	.8864	.8922	.9428	.9875	.8786	.9942
	Pre.	.9712	.9768		.9949	.9763	.9112	.9486	.9856	.8391	.9949
	Base	851	320	0	1,678	4	127	63	794	161	364
4	Mea.	.9826	.9841	.9686	.9961	.9697	.9441	.9758	.9904	.9063	.9974
	Pre.	.9779	.9983	.9532	.9960	.9700	.9446	.9667	.9908	.9061	.9964
	Base	482	1,254	48	1,276	43	279	192	1,709	581	235
5	Mea.	.9840	.9954	.9592	.9962	.9873	.9819	.9822	.9946	.9443	.9894
	Pre.	.9867	.9958	.9626	.9943	.9828	.9759	.9858	.9943	.9490	.9955
	Base	447	3,080	109	850	169	371	318	2,490	706	136
6	Mea.	.9857	.9988	.9748	.9909	.9948	.9909	.9897	.9966	.9740	1.0000
	Pre.	.9918	.9985	.9768	.9916	.9941	.9884	.9931	.9963	.9740	.9965
	Base	376	5,374	101	659	342	406	413	2,817	884	162
7	Mea.	.9822	.9995	.9899	.9882	.9929	.9950	.9946	.9957	.9838	.9953
	Pre.	.9913	.9992	.9878	.9919	.9939	.9913	.9957	.9970	.9842	.9961
	Base	198	6,336	95	403	291	429	451	2,234	991	135
8	Mea.	.9731	.9997	.9979	.9819	.9935	.9968	.9971	.9965	.9836	1.0000
	Pre.	.9850	.9995	.9918	.9894	.9939	.9917	.9969	.9970	.9860	.9966
	Base	47	5,639	120	187	270	460	466	1,717	906	71
9	Mea.	.9790	.9996	.9958	.9730	.9966	.9948	.9985	.9973	.9850	.9954
	Pre.	.9855	.9996	.9937	.9932	.9942	.9923	.9973	.9970	.9883	.9954
	Base	30	4,971	128	109	258	437	439	1,142	693	47
10	Mea.	.9849	.9997	.9916	.9785	.9931	.9835	.9974	.9969	.9872	.9956
	Pre.	.9878	.9996	.9978	.9944	.9912	.9914	.9971	.9965	.9882	.9961
	Base	41	3,950	120	66	219	429	410	845	512	51
11	Mea.		.9996	.9930		.9941	.9834	.9970	.9979	.9918	
	Pre.		.9996	.9966		.9913	.9902	.9963	.9964	.9876	
	Base	0	2,805	138	0	181	385	347	611	306	0
12	Mea.		.9998	.9924		.9918	.9837	.9962	.9963	.9869	
	Pre.		.9996	.9974		.9913	.9874	.9952	.9965	.9887	
	Base	0	2,023	155	0	129	284	225	476	146	0
13	Mea.		.9996	.9933		1.0000	.9785	.9925	.9994	.9885	
	Pre.		.9996	.9980		.9922	.9864	.9957	.9963	.9861	
	Base	0	1,440	171	0	75	188	148	369	91	0
14	Mea.		.9998	.9963		.9971	.9847	.9962	.9977		
	Pre.		.9995	.9963		.9920	.9809	.9949	.9967		
	Base	0	948	181	0	69	126	110	286	0	0
15	Mea.		.9997	.9975		.9895	.9671	.9978	.9984		
	Pre.		.9995	.9971		.9908	.9843	.9936	.9958		
	Base	0	715	176	0	59	93	101	277	0	0
16	Mea.		1.0000	9988		.9948	.9908	.9951	.9970		
	Pre.		.9994	.9980		.9927	.9751	.9936	.9951		
	Base	0	461	182	0	117	92	87	223	0	0
17	Mea.		1.0000	.9964			.9818	.9869	.9969		
	Pre.		.9994	.9975			.9715	.9911	.9949		
	Base	0	251	174	0	0	47	69	146	0	0
18	Mea.		1.0000	1.0000			.9817	1.0000	.9982		
	Pre.		.9993	.9988			.9719	.9884	.9949		
	Base	0	134	137	0	0	47	38	125	0	0
19	Mea.		1.0000	.9932			.9755	1.0000	.9976		
	Pre.		.9990	.9979			.9706	.9927	.9939		
	Base	0	60	122	0	0	105	39	93	0	0
20	Mea.		.9963	1.0000				.9851	1.0000		
	Pre.		.9984	.9988				.9801	.9966		
	Base	0	55	70	0	0	0	103	66	0	0
21	Mea.			1.0000					.9873		
	Pre.			.9959					.9941		
	Base	0	0	167	0	0	0	0	117	0	0

[1] Midpoint of DBH interval, last entry for a species includes that DBH and larger trees.

[2] Measured annual survival rate and predicted annual rate.

[3] Number of tree records.

Table 5.--Performance of survival rate prediction model for selected forest areas

	Stand Description									Survival Results				
Sp[1]	Area and origin[2]			Plots	SP[3] SI	Basal Area All	Basal Area SP	DBH SP	Beg. obs.	Yrs[4]	End obs.	End pre.	Std dev.[5]	Slope
				no.	ft	ft²/ac		in.	---No. of trees---					
JP	LP	MICH	RP	50	--	92	92	5.9	487	11	268	328	.5178E+2	1.001
	LP	MICH	RP	10	50	74	74	4.9	542	4	506	480	.2168E+2	0.918
	NE	MINN	RM	49	--	102	65	8.8	163	5	152	142	.1346E+2	0.923
	NE	MINN	RM	49	--	111	68	9.2	157	7	134	128	.1628E+2	0.885
	NW	MINN	RP	20	65	90	90	5.4	589	5	530	530	.2385E+2	1.037
WP	NE	WISC	TN	17	58	83	69	11.9	97	6	94	93	.4670E+1	0.980
	NE	WISC	TN	12	58	76	58	13.9	52	13	49	49	.4690E+1	1.091
RP	NC	MINN	RN	45	52	101	101	10.8	165	5	163	164	.3090E+1	1.005
	NC	MINN	RN	45	52	109	109	13.2	121	5	121	121	.1050E+1	0.996
	NE	WISC	SP	8	65	163	163	6.9	650	6	635	640	.9520E+1	1.030
	NE	WISC	SP	8	65	185	185	9.4	465	6	456	454	.5020E+1	0.989
	NC	MINN	RP	54	70	105	105	8.8	257	5	256	255	.3120E+1	0.988
	NC	MINN	RP	54	70	120	119	10.4	221	4	220	220	.3230E+1	1.008
BF	NE	WISC	RN	25	62	94	37	3.3	582	5	573	566	.6100E+1	0.991
	NE	WISC	RN	10	62	63	55	4.2	538	6	516	518	.1430E+2	0.978
	NE	MINN	RN	46	--	66	17	7.1	61	5	52	56	.9970E+1	0.932
	NE	MINN	RN	42	--	76	21	7.0	77	7	59	66	.1250E+2	1.096
RM	SE	WISC	WN	37	--	97	16	12.0	21	1	21	20	.7500E+0	0.965
		WISC	IN	40	--	59	16	7.5	48	5	46	46	.2650E+1	1.024
	UP	MICH	SN	42	--	64	12	7.8	33	11	32	31	.2330E+1	0.965
EL	NE	WISC	RN	12	77	91	34	8.2	86	6	80	78	.2460E+1	0.988
	NE	WISC	RN	12	77	108	37	9.1	80	5	77	74	.2700E+1	0.981
BW	NE	WISC	RN	12	74	91	9	7.0	29	6	26	26	.1950E+1	0.982
	NE	WISC	RN	12	74	108	11	8.2	26	5	26	25	.8500E+0	0.977
	NE	WISC	FN	49	--	91	31	8.1	84	5	80	81	.6230E+1	0.981
SM	NE	WISC	RN	12	67	91	26	4.8	181	6	168	169	.4870E+1	0.921
	NE	WISC	RN	12	67	108	32	5.5	168	5	162	163	.3340E+1	1.024
	EC	WISC	RN	10	--	70	23	5.4	130	3	120	128	.9260E+1	0.877
	EC	WISC	RN	10	--	84	30	6.0	141	5	139	138	.1060E+1	0.989
	NE	WISC	RN	20	59	73	43	6.9	151	2	150	150	.1680E+1	0.984
	NE	WISC	RN	22	59	82	49	7.7	132	3	131	131	.1700E+1	1.010
	NE	WISC	FN	49	--	93	22	8.1	53	5	52	52	.2910E+1	0.971
	UP	MICH	SN	50	--	90	35	10.2	58	9	56	56	.3520E+1	1.005
QA	NE	WISC	RN	20	--	105	50	5.6	267	5	235	224	.1739E+2	0.893
	NW	MINN	FN	48	--	59	31	8.3	86	7	75	77	.9490E+1	0.946
	UP	MICH	SN	49	--	55	20	8.3	49	11	36	39	.1102E+2	0.970
	NW	MINN	RN	28	80	96	90	7.0	347	5	287	297	.2596E+2	0.958
	NW	MINN	RN	28	80	121	114	9.0	259	5	221	222	.1385E+2	0.950
PB	NE	WISC	RN	20	--	105	9	3.1	177	5	170	170	.5130E+1	1.001
		WISC	IN	46	--	57	9	7.2	35	5	34	34	.1730E+1	0.982
	UP	MICH	SN	38	--	66	15	7.5	47	11	46	45	.4300E+1	0.947

[1] Species: JP (Jack pine), WP (white pine), RP (red pine), BF (balsam fir), RM (red maple), EL (elm-american), BW (basswood), SM (sugar maple), QA (quaking aspen), PB (paper birch)

[2] Origin:

Column 1

F (federal)
I (industry - private)
R (research)
S (state DNR)
T (timber harvest forest)
W (woodlot - individual)

Column 2

N (natural stand)
P (plantation)
M (mixed)

[3] Site index at age 50 is given for species being analyzed when uniform value was obtained among the plots.

[4] Years in the interval between measuring DGR and DBH and recording status; i.e., the projection interval.

[5] Standard deviation among the plots within the stand.

large differences, with offsetting positive and negative results, each has good agreement on half the stands.

The standard deviation of errors among the plots within each stand shows few large plot errors. The size of these errors is not related to the number of trees on the plot, as shown by the closeness of the slopes to one. Furthermore, the standard error of the mean difference, approximated by dividing the standard deviation by $\sqrt{\text{plot number}}$, is small except for several jack pine stands.

DISCUSSION

The coefficients calculated for the 10 tree species were developed from a data base having strength both in number of trees and in the geographical distribution of plots. The breadth and depth of the data base means that the model can be confidently applied to the broad range of conditions in the Lake States.

Analysis of the model based on DGR reveals very close agreement between predicted and calculated annual survival rates on a regional basis. Projections based on this model show excellent agreement with actual survival when applied for intervals of up to 6 years. Stands, with trees in several growth classes, also show excellent agreement between predicted and calculated survival.

Analysis of the model based on DBH reveals some discrepancies between predicted and calculated survival rates, especially among the small trees for four species. This coincides with the weakest part of the data set. The DBH analysis results, when considered in conjunction with the DGR analysis, suggest the model will perform well except for sites with many small trees.

The model's performance in individual stands, with few exceptions, shows good agreement between observed and predicted tree survival. This suggests that the composition of the regional data base reflects the condition of local stands and supports use of the model over the broad range of Lake States conditions.

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A model and species' coefficients are reported for predicting individual tree survival for 10 Lake States species. Tree attributes are diameter growth rate and diameter at breast height. Regional and local performances are summarized.

KEY WORDS: Mortality rates, mortality models, survival model, mortality coefficients, tree risk.