Validation of the Forest Vegetation Simulator Growth and Mortality Predictions on Red Pine in Michigan

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Abstract—Validating a model's performance is an essential part of model development and revision. Previously, the only subregional validation of LS-TWIGS and FVS-LS was done on hardwood stands on 5- and 10-year growth. This paper examines validation results for red pine in Michigan. Red pine covers a large percentage of Michigan timberlands and is considered one of its most important commercial softwood species. Validation was run on two red pine sites in Michigan. In simulations that included calibration (scaling), FVS-LS almost always predicted d.b.h. within ±1 inch for projections up to 27 years long. FVS-LS predicted mortality and density better for the Upper Peninsula site than the Lower Peninsula site.

The red pine timber industry is an important part of the Michigan economy. In 1992 red pine production was valued at $25.3 million (Potter-Witter 1995). Red pine covers 897,200 acres of Michigan timberland, 641,200 acres in the Lower Peninsula, and 256,000 acres in the Upper Peninsula (Leatherberry and Spencer 1996). Average net annual growth (1980 through 1987) was 78,310,000 ft^3 and removals were 15,980,000 ft^3 (Leatherberry and Spencer 1996).

Given the importance of red pine in the Lake States it is important that landowners have a model that correctly predicts growth to compare alternative treatments. The Lake States TWIGS variant of the Forest Vegetation Simulator (FVS-LS) (Bush and Brand 1995) uses the growth and mortality functions based on Lake States TWIGS. One important difference is that Lake States TWIGS uses annual increments, while FVS-LS calculates 10-year growth by multiplying the annual increment by 10 and then scaling back if the growth period is less than 10 years. FVS-LS is an individual tree distance independent model. This paper will explore FVS-LS prediction of individual tree and stand level attributes on two long-term red pine study sites in Michigan.

The only subregional validation of Lake State TWIGS for Michigan involves upland hardwoods in the northern Lower Peninsula (Guertin and Ramm 1996). It found 5-year diameter growth was predicted within ± 0.3 inch for the five species studied. Mean errors for basal area projections were within ± 5 ft^2/acre for all species and mean error for trees per acre (TPA) was within ± 20 TPA for almost all species studied. A followup study 5 years later on FVS-LS found that 10-year diameter growth was predicted within ± 0.5 inch for all of the seven hardwood species (Canavan 1997). This study is the first to validate red pine projections for Michigan.

Data

The validation data were collected from two long-term study sites in Michigan, one on the Hiawatha National Forest and one on the W. K. Kellogg Experimental Forest. The Hiawatha National Forest is on the eastern side of the Upper Peninsula. The Kellogg Experiment Forest, on the Lower Peninsula in southwestern Michigan, is owned and managed by Michigan State University's Department of Forestry.

The Hiawatha site was planted in 1938 with approximately 6 by 6 foot spacing. In 1962 it became a thinning study set up as a randomized complete block design with four blocks. Each block contained 16 treatments, with each treatment being 0.10 acre (table 1). This study examined 12 of the treatments. Measurements were taken in 1962, 1965, 1969, 1976, 1982, and 1992 and thinned in 1962, 1969, 1976, 1982, and 1992, except for a few plots in which basal areas were too low to thin in 1982 and 1992.

The Kellogg study site was planted in 1936 and 1937 with approximately spacing of 7 by 8 feet. In 1960 it became a thinning study with nine thinning treatments applied in a randomized complete block design with four replications of each treatment (table 2). These treatments

Table 1—Hiawatha National Forest thinning treatment.

Treatment	Description
BAr30	30 ft^2/acre residual BA after thinning
BAr45	45 ft^2/acre residual BA after thinning
BAr60	60 ft^2/acre residual BA after thinning
BAr80	80 ft^2/acre residual BA after thinning
BAr100	100 ft^2/acre residual BA after thinning
BAr130	130 ft^2/acre residual BA after thinning
BAr160	160 ft^2/acre residual BA after thinning
Row2	Every other row removed
Row3	Every third row removed
Row4,2	Every fourth row removed; at second thinning remove center row of remaining 3 rows
Row4	Every fourth row removed
Control	Control - no thinning

In: Crookston, Nicholas L.; Havis, Robert N., comps. 2002. Second Forest Vegetation Simulator Conference; 2002 February 12–14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Table 2—W.K. Kellogg Forest thinning treatments.

Treatment	Description
Row2	Cut every 2nd row, BA 85
Row3	Cut every 3rd row, BA 100,105
Row4	Cut every 4th row, BA 115, 120
Row4,2	Cut every 4th row, middle row, BA 110
BAr90	90-95 ft^2/acre residual BA after thinning
BAr70	70-75 ft^2/acre residual BA after thinning
BAr110	110-115 ft^2/acre residual BA after thinning
BAr130	130-135 ft^2/acre residual BA after thinning
Control	Control – no thinning

were also 0.10 acre each. Measurement and thinning occurred in 1960, 1964, 1967, 1972, 1980, 1985, and 1991.

For both study sites diameter at breast height (d.b.h) of each tree was measured, and height was measured on three to five trees in each plot. Basal area and trees per acre were calculated for each plot.

Methods

Two types of simulations were run for each treatment. One with FVS calibration turned off, abbreviated 'NA' for no ancillary data, meaning that past diameter growth data were not used to scale the growth equations. The other type of simulation included FVS calibration, abbreviated 'D'. All runs included plot name, age, site index (base age 50 years), d.b.h. (1965, Hiawatha; 1964, Kellogg), height if measured, and the year the tree was thinned. The ΔD simulations also included diameter growth, which was calculated from the diameter from the simulation start date and subtracting the previous diameter measurement. The Hiawatha growth measurements were from age 25 to 28, and Kellogg growth measurements were from age 27 to 31. Hiawatha had a 3-year growth measurement and Kellogg a 4-year growth measurement period that FVS used to scale or calibrate the growth equations to more closely match the growth that was occurring in the plantation at that time. Three growth and stand-level characteristics were used to calculate prediction error by treatment and projection length. The three characteristics used were individual tree d.b.h., stand basal area, and trees per acre. Each tree's projected future d.b.h. was compared to its actual d.b.h. Also, each stand's projected basal area and trees per acre were compared to its actual basal area and trees per acre. Mean error and standard deviation were then calculated from the difference between actual and predicted measurements. In the FVS tree list, all trees were coded with the species code "RP" indicating red pine plantation trees.

Results

The Hiawatha simulations projected growth from 1965 through 1992, with cycle boundaries at 1969, 1976, 1982, and 1992. The Kellogg simulations projected growth from 1964 through 1991, with cycle boundaries at 1967, 1972, 1980, 1985, and 1991.

D.B.H. Error

The sample size for each d.b.h. error calculation was dependent on the treatment and cycle. Treatments with heavy thinning had smaller sample sizes. Sample size also decreased over time as trees were thinned during each cycle (tables 3 and 4).

Hiawatha—FVS-LS on average predicted diameter growth with better accuracy for the ΔD simulations than for the NA simulations (table 3). For both types of simulations FVS-LS overpredicted diameter growth, except in treatments with low residual basal area. Both simulation types showed low mean errors (less than 1 inch) in almost all of the treatments. Those treatments that did have an error over 1 inch were all in the 27-year projection period and tended to be in treatments with larger residual basal areas. No treatment had an error greater than 1.78 inches in d.b.h. In almost all the runs, as the length of the projection increased so did the error.

Kellogg—Unlike the Hiawatha results, FVS did not necessarily predict diameter growth with better accuracy for the ΔD simulations than for the NA simulations (table 4). FVS-LS overpredicted growth for all trees in the NA projections except for the thin every fourth row treatment (row 4) where growth was underpredicted. In both runs as projection length increased so did the error. The NA and ΔD simulations with projections lengths of 3 and 8 years all had a d.b.h. mean error of less than 1 inch. Almost all of the ΔD simulations had an error of less than 1 inch, except for the longer projection lengths in the control, thin every fourth row, and 70 ft^2/acre thinnings. Only treatments thin every second row and thin to a basal area of 90 ft^2/acre of the NA simulation had error of more than 2 inches. These errors occurred in the 27-year interval.

Basal Area Error

Mean error and standard deviation were calculated for the four plots for each treatment and projection length.

Hiawatha—ΔD simulations projections were more precise than the NA simulations. The absolute mean error was two to three times as great is the NA as in the ΔD simulations. As with the d.b.h. mean error projections, the ΔD simulations were more likely to underpredict in treatments with low residual basal areas, and tended to overpredict in treatments with high residual basal areas (table 5).

Kellogg—Unlike with the Hiawatha results, in most cases the NA simulations projected more precisely than the ΔD simulations. The ΔD projections were more likely to underpredict basal area, while the only NA projection that underpredicted was the thin every fourth row treatment. The difference in the absolute mean error between the two simulation types was not as large as that in the Hiawatha simulations (table 6).

Trees Per Acre Error

As with the basal area calculations of mean error, the TPA mean error is based on a sample size of four for each treatment.

Table 3—Hiawatha mean error ($\bar{e}$) and standard deviation (s) of mean error for estimated diameter at breast height by treatment and projection length for the two types of simulation. Error expressed as predicted value minus observed value.

				NA simulation		ΔD simulation	
Treatment	**Projection length**	**Age**	**n**	$\bar{e}$	**s**	$\bar{e}$	**s**
BAr30	65-69 = 4yrs	32	59	–0.52	0.23	–0.47	0.27
	65-76 = 11yrs	39	30	–0.77	0.30	–0.78	0.51
	65-82 = 17yrs	45	21	–0.99	0.45	–0.97	0.74
	65-92 = 27yrs	55	21	–0.59	0.62	–0.58	1.02
BAr45	65-69 = 4yrs	32	85	–0.28	0.25	–0.44	0.73
	65-76 = 11yrs	39	46	–0.48	0.50	–0.37	0.49
	65-82 = 17yrs	45	29	–0.91	0.62	–0.80	0.61
	65-92 = 27yrs	55	29	–0.26	2.59	–0.11	2.56
BAr60	65-69 = 4yrs	32	121	–0.05	0.57	–0.04	0.56
	65-76 = 11yrs	39	71	–0.26	0.97	–0.29	0.96
	65-82 = 17yrs	45	47	–0.54	1.40	–0.60	1.42
	65-92 = 27yrs	55	47	–0.30	1.72	–0.41	1.76
BAr80	65-69 = 4yrs	32	173	0.13	0.22	0.05	0.21
	65-76 = 11yrs	39	110	0.07	0.40	–0.15	0.36
	65-82 = 17yrs	45	73	–0.26	0.47	–0.56	0.45
	65-92 = 27yrs	55	58	–0.24	0.63	–0.65	0.59
BAr100	65-69 = 4yrs	32	220	0.19	0.17	0.12	0.17
	65-76 = 11yrs	39	146	0.28	0.31	0.08	0.34
	65-82 = 17yrs	45	105	0.33	0.77	0.04	0.82
	65-92 = 27yrs	55	84	0.62	1.51	0.22	1.55
BAr130	65-69 = 4yrs	32	302	0.29	0.38	0.17	0.38
	65-76 = 11yrs	39	218	0.51	0.58	0.18	0.58
	65-82 = 17yrs	45	162	0.53	0.97	0.08	0.98
	65-92 = 27yrs	55	130	0.68	1.25	0.08	1.27
BAr160	65-69 = 4yrs	32	395	0.38	0.54	0.20	0.54
	65-76 = 11yrs	39	305	0.73	0.71	0.31	0.72
	65-82 = 17yrs	45	241	0.89	1.00	0.32	1.03
	65-92 = 27yrs	55	200	1.27	1.37	0.53	1.41
Row2nd	65-69 = 4yrs	32	231	0.19	0.29	0.08	0.29
	65-76 = 11yrs	39	138	0.26	0.53	–0.03	0.53
	65-82 = 17yrs	45	96	0.21	0.73	–0.19	0.73
	65-92 = 27yrs	55	79	0.56	1.54	0.00	1.53
Row3rd	65-69 = 4yrs	32	332	0.31	0.23	0.13	0.23
	65-76 = 11yrs	39	212	0.56	0.47	0.10	0.49
	65-82 = 17yrs	45	158	0.61	0.67	–0.03	0.72
	65-92 = 27yrs	55	129	1.16	2.12	0.32	2.13
Row4,2	65-69 = 4yrs	32	331	0.36	0.46	0.19	0.45
	65-76 = 11yrs	39	224	0.71	1.09	0.28	1.10
	65-82 = 17yrs	45	159	0.97	1.75	0.36	1.80
	65-92 = 27yrs	55	129	1.55	2.60	0.73	2.69
Row4th	65-69 = 4yrs	32	366	0.35	0.40	0.16	0.41
	65-76 = 11yrs	39	218	0.69	0.82	0.17	0.87
	65-82 = 17yrs	45	161	0.71	1.15	0.00	1.23
	65-92 = 27yrs	55	118	1.06	1.92	0.10	2.03
Control (no thin)	65-69 = 4yrs	32	470	0.36	0.33	0.18	0.34
	65-76 = 11yrs	39	470	0.76	0.49	0.38	0.52
	65-82 = 17yrs	45	470	0.95	0.77	0.54	0.81
	65-92 = 27yrs	55	470	1.78	2.25	1.51	2.26

Table 4—Kellogg mean error ($\bar{e}$) and standard deviation (s) of mean error for estimated diameter at breast height by treatment and projection length for the two types of simulation. Error expressed as predicted value minus observed value.

				NA simulation		ΔD simulation	
Treatment	**Projection length**	**Age**	**n**	$\bar{e}$	**s**	$\bar{e}$	**s**
BAr70	64-67 = 3yrs	31	150	0.16	0.76	-0.35	0.77
	64-72 = 8yrs	36	150	0.31	1.64	–0.52	1.87
	64-80 = 16yrs	44	77	1.01	3.18	–1.29	3.31
	64-85 = 21yrs	49	69	1.13	3.68	–1.15	3.48
	64-91 = 27yrs	55	69	1.63	4.20	–1.67	4.39
BAr90	64-67 = 3yrs	31	168	0.21	1.46	0.00	1.48
	64-72 = 8yrs	36	115	0.94	2.98	0.41	2.72
	64-80 = 16yrs	44	91	1.77	3.86	0.85	3.92
	64-85 = 21yrs	49	83	1.92	4.40	0.84	4.48
	64-91 = 27yrs	55	83	2.17	4.68	0.97	4.77
BAr110	64-67 = 3yrs	31	205	0.08	1.01	–0.10	1.02
	64-72 = 8yrs	36	135	0.26	1.68	–0.23	1.71
	64-80 = 16yrs	44	104	1.23	3.45	0.36	3.49
	64-85 = 21yrs	49	93	1.59	4.19	0.59	4.24
	64-91 = 27yrs	55	93	1.98	4.56	0.85	4.61
BAr130	64-67 = 3yrs	31	255	0.18	1.14	0.01	1.14
	64-72 = 8yrs	36	184	0.61	2.10	0.18	2.09
	64-80 = 16yrs	44	147	1.61	3.54	0.85	3.53
	64-85 = 21yrs	49	131	1.81	4.05	0.92	4.06
	64-91 = 27yrs	55	131	1.94	4.32	0.96	4.34
Row2nd	64-67 = 3yrs	31	159	0.18	1.35	–0.08	1.35
	64-72 = 8yrs	36	159	0.70	2.34	0.23	2.35
	64-80 = 16yrs	44	106	1.38	3.55	0.27	3.72
	64-85 = 21yrs	49	85	1.64	4.37	0.35	4.48
	64-91 = 27yrs	55	85	2.08	4.62	0.63	4.87
Row3rd	64-67 = 3yrs	31	194	0.02	0.64	–0.25	0.64
	64-72 = 8yrs	36	122	0.07	0.97	–0.65	0.97
	64-80 = 16yrs	44	98	0.83	2.85	–0.47	2.90
	64-85 = 21yrs	49	81	1.34	4.02	–0.22	4.05
	64-91 = 27yrs	55	81	1.49	4.30	–0.30	4.34
Row4,2	64-67 = 3yrs	31	250	0.06	0.69	–0.18	0.69
	64-72 = 8yrs	36	171	0.62	1.93	0.03	1.94
	64-80 = 16yrs	44	123	1.09	3.02	0.00	3.09
	64-85 = 21yrs	49	109	1.22	3.51	–0.07	3.61
	64-91 = 27yrs	55	109	1.40	4.12	–0.04	3.86
Row4th	64-67 = 3yrs	31	232	–0.10	0.27	–0.21	0.19
	64-72 = 8yrs	36	158	–0.18	0.74	–0.47	0.56
	64-80 = 16yrs	44	110	–0.42	1.21	–0.97	0.74
	64-85 = 21yrs	49	86	–0.75	1.45	–1.39	0.73
	64-91 = 27yrs	55	86	–0.53	2.27	–1.23	1.72
Control (no thin)	64-67 = 3yrs	31	293	0.18	0.69	–0.06	0.70
	64-72 = 8yrs	36	293	0.45	0.80	–0.10	0.82
	64-80 = 16yrs	44	293	1.09	1.57	0.25	1.64
	64-85 = 21yrs	49	293	1.51	2.19	0.60	2.27
	64-91 = 27yrs	55	293	1.96	2.76	1.04	2.83

Table 5—Hiawatha mean error ($\bar{e}$) and standard deviation (s) of mean error for estimated trees per acre and basal area by treatment and projection length for two types of simulation. Error expressed as predicted value minus observed value.

			BA NA		BA ΔD		TPA NA		TPA ΔD	
Treatment	**Projection length**	**Age**	$\bar{e}$	**s**	$\bar{e}$	**s**	$\bar{e}$	**s**	$\bar{e}$	**s**
BAr30	65-69 = 4yrs	32	–7.06	2.44	–6.46	3.19	–0.18	0.02	–0.18	0.02
	65-76 = 11yrs	39	–6.75	1.92	–6.69	4.51	–0.25	0.02	–0.25	0.02
	65-82 = 17yrs	45	–7.20	1.76	–6.97	4.52	–0.27	0.03	–0.27	0.03
	65-92 = 27yrs	55	–5.48	3.38	–5.22	8.14	–0.43	0.04	–0.43	0.04
BAr45	65-69 = 4yrs	32	–5.32	1.71	–4.02	1.14	–0.26	0.04	–0.26	0.05
	65-76 = 11yrs	39	–6.32	1.73	–5.03	0.62	–0.38	0.06	–0.38	0.06
	65-82 = 17yrs	45	–9.17	2.83	–8.12	1.57	–0.37	0.05	–0.37	0.05
	65-92 = 27yrs	55	–6.50	5.90	–4.85	4.48	1.91	4.96	1.91	4.96
BAr60	65-69 = 4yrs	32	–2.25	2.62	–2.05	1.65	2.14	4.97	2.14	4.97
	65-76 = 11yrs	39	–6.38	4.92	–6.91	4.12	1.91	4.93	1.91	4.93
	65-82 = 17yrs	45	–10.01	3.83	–10.83	5.23	1.90	4.92	1.90	4.92
	65-92 = 27yrs	55	–8.57	7.15	–10.32	10.21	1.55	4.88	1.55	4.88
BAr80	65-69 = 4yrs	32	4.45	2.25	1.96	0.71	–0.52	0.02	–0.52	0.02
	65-76 = 11yrs	39	1.22	5.18	–4.38	1.29	–0.91	0.04	–0.91	0.04
	65-82 = 17yrs	45	–5.87	3.55	–11.87	1.40	–0.93	0.03	–0.93	0.03
	65-92 = 27yrs	55	–5.68	5.29	–13.36	2.29	–1.17	0.05	–1.18	0.05
BAr100	65-69 = 4yrs	32	7.01	3.98	3.09	1.56	–0.66	0.08	–1.10	0.85
	65-76 = 11yrs	39	8.92	4.51	2.46	6.43	–1.21	0.14	–1.22	0.16
	65-82 = 17yrs	45	6.94	3.81	–2.11	7.99	1.16	4.94	1.14	4.92
	65-92 = 27yrs	55	11.63	7.34	1.75	14.33	3.30	5.68	3.28	5.66
BAr130	65-69 = 4yrs	32	14.33	2.06	7.55	1.66	–0.94	0.06	–1.05	0.12
	65-76 = 11yrs	39	21.75	4.71	6.67	2.42	0.66	4.98	0.53	4.95
	65-82 = 17yrs	45	17.55	4.07	–0.05	3.63	2.90	5.79	2.80	5.81
	65-92 = 27yrs	55	20.09	4.79	–1.74	7.34	2.33	5.82	2.22	5.83
BAr160	65-69 = 4yrs	32	22.74	4.87	10.83	3.55	8.66	19.89	7.86	19.74
	65-76 = 11yrs	39	40.34	5.60	14.23	9.06	7.28	19.84	6.26	19.70
	65-82 = 17yrs	45	41.40	10.75	10.65	15.08	9.17	24.81	8.16	24.68
	65-92 = 27yrs	55	53.92	18.01	16.45	22.81	10.62	23.40	9.63	23.05
Row2nd	65-69 = 4yrs	32	6.70	1.36	2.08	0.87	1.67	4.90	1.58	4.84
	65-76 = 11yrs	39	6.80	6.07	–2.15	5.18	1.34	4.97	1.31	4.94
	65-82 = 17yrs	45	3.64	9.68	–6.47	8.45	1.23	4.93	1.20	4.89
	65-92 = 27yrs	55	9.25	13.25	–4.45	10.91	3.33	5.58	3.30	5.54
Row3rd	65-69 = 4yrs	32	15.91	2.03	5.93	1.01	1.14	4.76	0.52	4.43
	65-76 = 11yrs	39	21.86	4.09	1.37	1.47	7.61	7.62	6.97	7.18
	65-82 = 17yrs	45	18.78	5.80	–5.12	3.22	6.92	7.27	6.15	6.72
	65-92 = 27yrs	55	28.68	15.58	–1.19	11.69	18.17	15.14	17.23	15.31
Row4,2	65-69 = 4yrs	32	17.58	3.03	7.59	2.28	8.66	19.84	7.99	19.55
	65-76 = 11yrs	39	24.27	1.25	4.92	2.75	17.65	17.88	16.68	17.60
	65-82 = 17yrs	45	19.98	5.89	–1.23	6.59	28.08	34.29	31.14	30.62
	65-92 = 27yrs	55	30.73	9.90	1.55	12.46	44.24	37.51	43.47	36.87
Row4th	65-69 = 4yrs	32	19.18	2.32	6.90	2.55	6.04	9.56	4.91	9.39
	65-76 = 11yrs	39	24.73	3.79	1.46	6.08	17.86	11.42	17.08	11.49
	65-82 = 17yrs	45	18.32	5.32	–8.47	6.46	19.90	14.78	19.02	14.87
	65-92 = 27yrs	55	20.64	3.44	–10.62	8.82	24.25	16.49	23.26	16.39
Control (no thin)	65-69 = 4yrs	32	25.44	0.58	11.15	5.11	7.77	14.36	5.25	14.97
	65-76 = 11yrs	39	57.49	1.85	23.65	9.55	10.16	22.68	2.75	25.55
	65-82 = 17yrs	45	69.89	2.38	30.33	12.50	24.20	28.10	14.00	29.35
	65-92 = 27yrs	55	89.13	9.46	65.13	18.05	177.55	51.76	179.50	63.05

Table 6—Kellogg mean error ($\bar{e}$) and standard deviation (s) of mean error for estimated trees per acre and basal area by treatment and projection length for two types of simulation. Error expressed as predicted value minus observed value.

			BA NA		BA ΔD		TPA NA		TPA ΔD	
Treatment	**Projection length**	**Age**	$\bar{e}$	**s**	$\bar{e}$	**s**	$\bar{e}$	**s**	$\bar{e}$	**s**
BAr70	64-67 = 3yrs	31	0.70	6.04	–5.45	9.29	14.59	22.38	14.31	22.93
	64-72 = 8yrs	36	4.49	6.04	–8.06	9.29	21.64	22.38	21.04	22.93
	64-80 = 16yrs	44	7.47	6.00	–12.88	10.40	21.49	18.90	21.33	18.99
	64-85 = 21yrs	49	6.73	6.91	–16.82	11.25	23.79	19.09	23.60	19.17
	64-91 = 27yrs	55	14.85	11.35	–13.76	15.34	25.92	23.58	25.68	23.68
BAr90	64-67 = 3yrs	31	1.95	13.88	–5.11	13.95	14.54	33.12	14.29	33.23
	64-72 = 8yrs	36	10.29	13.88	–3.93	13.95	36.64	33.12	36.39	33.23
	64-80 = 16yrs	44	18.24	21.85	–4.95	20.09	46.03	44.37	45.64	44.58
	64-85 = 21yrs	49	16.37	22.02	–9.99	20.38	45.67	44.44	45.22	44.67
	64-91 = 27yrs	55	21.76	20.77	–9.84	19.26	45.11	44.51	44.60	44.76
.										
BAr110	64-67 = 3yrs	31	–1.64	9.32	–9.39	9.52	14.44	23.65	14.14	23.77
	64-72 = 8yrs	36	0.54	9.32	–14.59	9.52	16.51	23.65	16.09	23.77
	64-80 = 16yrs	44	12.21	25.25	–12.06	23.58	41.12	43.78	40.47	43.73
	64-85 = 21yrs	49	13.94	30.61	–13.20	26.91	45.59	48.59	44.98	48.25
	64-91 = 27yrs	55	22.03	35.32	–10.39	31.29	47.46	51.33	46.75	50.88
BAr130	64-67 = 3yrs	31	3.14	19.88	–5.20	15.85	16.73	40.22	16.20	39.99
	64-72 = 8yrs	36	11.13	19.88	–6.26	15.85	33.72	40.22	33.18	39.99
	64-80 = 16yrs	44	27.11	38.89	–0.86	32.35	65.65	62.44	65.21	62.25
	64-85 = 21yrs	49	25.00	42.41	–6.27	33.62	67.79	64.00	67.28	63.72
	64-91 = 27yrs	55	71.86	122.48	35.42	116.64	99.33	118.96	98.72	118.77
Row2nd	64-67 = 3yrs	31	0.81	22.97	–6.81	24.12	14.63	62.45	14.53	62.58
	64-72 = 8yrs	36	9.47	22.97	–5.67	24.12	36.76	62.45	36.51	62.58
	64-80 = 16yrs	44	16.02	35.61	–13.83	31.92	41.22	71.95	41.05	71.88
	64-85 = 21yrs	49	13.37	37.69	–16.82	31.93	41.15	71.77	41.00	71.65
	64-91 = 27yrs	55	22.24	44.20	–14.57	38.96	43.25	76.55	43.06	76.39
Row3rd	64-67 = 3yrs	31	–0.57	5.28	–8.67	4.73	2.00	5.11	1.72	5.30
	64-72 = 8yrs	36	0.10	5.28	–15.17	4.73	1.65	5.11	1.34	5.30
	64-80 = 16yrs	44	9.77	12.20	–15.83	13.21	21.06	32.54	20.62	32.09
	64-85 = 21yrs	49	12.49	17.68	–14.71	20.56	28.37	37.59	27.96	37.06
	64-91 = 27yrs	55	15.41	18.63	–17.87	23.59	27.87	37.33	27.41	36.73
Row4,2	64-67 = 3yrs	31	1.23	12.66	–9.57	11.35	1.68	49.73	0.79	48.74
	64-72 = 8yrs	36	10.00	12.66	–10.78	11.35	33.36	49.73	31.88	48.74
	64-80 = 16yrs	44	10.91	18.50	–21.93	15.38	47.30	47.66	45.56	46.12
	64-85 = 21yrs	49	8.45	18.75	–28.76	15.73	49.20	51.86	47.47	50.47
	64-91 = 27yrs	55	12.66	20.42	–32.41	17.42	48.17	51.12	46.25	49.65
Row4th	64-67 = 3yrs	31	–5.12	19.59	–9.87	4.44	–2.39	4.43	–1.61	2.47
	64-72 = 8yrs	36	–7.49	19.59	–17.45	4.44	–4.05	4.43	–2.92	2.47
	64-80 = 16yrs	44	–13.12	30.82	–28.77	6.74	–2.72	2.70	–1.64	0.22
	64-85 = 21yrs	49	–19.19	33.07	–35.04	5.99	–2.04	1.25	–1.51	0.20
	64-91 = 27yrs	55	–16.36	40.27	–35.04	8.06	–0.01	5.73	0.58	5.11
Control (no thin)	64-67 = 3yrs	31	6.79	3.73	–6.22	1.94	9.14	9.09	7.43	8.36
	64-72 = 8yrs	36	21.12	3.73	–11.68	1.94	10.01	9.09	5.40	8.36
	64-80 = 16yrs	44	48.39	9.64	–7.80	5.51	54.26	24.50	45.45	22.54
	64-85 = 21yrs	49	60.88	16.26	–2.45	11.17	93.61	46.19	82.89	43.23
	64-91 = 27yrs	55	72.89	13.61	6.56	9.13	133.44	15.76	121.49	14.45

Hiawatha—The FVS simulations had a mean error of ± 10 TPA for almost all treatments accept for the high residual basal area treatments. The worst prediction accuracy for FVS was the control treatment (no thinning). The control treatment, with a 27-year prediction interval, overpredicted by more than 175 trees per acre. There was little difference between the accuracy of the NA and ΔD simulations (table 5).

Kellogg—The two simulations showed little difference in mortality prediction. NA and ΔD simulations showed an increase in error as the projection intervals increased.

Treatments with higher residual basal areas, which often had more mortality, showed the greatest error in the prediction of mortality. The worst prediction accuracy for FVS was the control treatment (no thinning). The control treatment with a 27-year prediction interval overpredicted by more than 130 trees per acre (table 6).

Discussion

Prediction was more accurate for the Hiawatha site than the Kellogg site. This is probably because the original equations were developed from plantations in the northern portions of the Lake States (Miner and others 1988).

These validation runs used version 6.2 of the FVS-LS variant with a revision date of 12/01/95. FVS variants are continuously being updated and improved. These same data runs through a current version of the model would yield different results. There are many ways users can make adjustments in an FVS simulation to produce more realistic results. One example of this involves using serial correlation of diameter growth. This feature improves estimates from cycle to cycle by assuming that the error terms from a previous cycle are correlated with error terms of the next cycle. In other words, the error term is not randomly distributed at each cycle. So that trees that were growing well previously continue to grow well, and those that are not growing well continue to grow poorly (Dixon 2002). This feature improves the overall distribution of diameter growth in a stand. This feature was turned off by default in the version used for this validation project. It could have been turned on by the use of a keyword; however, it was not. This feature is now on by default in a more current version of the program.

Overall, the d.b.h. mean errors were better predicted for runs that used past growth (ΔD) information to scale the equations than those that did not (NA). The d.b.h. mean error for the ΔD simulations were on average ± 1 inch. However, for the Kellogg site, prediction of density (BA) and d.b.h. did not show much if any advantage to using the past growth information to scale the equations. The scale factors for Kellogg ranged from 0.42 to 0.75 with a mean of 0.56. The Hiawatha scale factors ranged from 0.47 to 1.163 with a mean of 0.78. On average, these were biased low. This is due to the methodology of how the diameter growth equations were applied. The first thinning occurred (1962, Hiawatha; 1960, Kellogg) at the start of the growth measurement period. If there was any release delay of the trees (after the thinning) then FVS would not have captured the impact of the thinning in the growth measurement period. The scale factor applied to the thinned stand may have scaled down growth too much for the thinned stand. A longer measurement period may have given more accurate results. However, for the Hiawatha site the calibrated runs did improve the accuracy of the predicted d.b.h. of trees and the density. A second reason that the scale factors were biased low was because mortality trees were recorded as "dead" trees in the input tree list instead of "recent mortality" trees. If the trees had been recorded as recent mortality trees, then FVS would have included them in the stand density calculations that then would have effected how the scale factors were calculated. It is important that users realize the impact that the scale factor has on future tree simulated growth. The problem with the measurement periods in these simulations was that they were too short and reflected the prethinned growth, therefore scaling down (slowing) the original growth equations. In addition trees were marked as "dead" instead of "recently dead," making FVS incorrectly predict past density. A third problem is that the repeated growth measurements were not adjusted for bark. Because diameter increments included bark growth, this added another bias to the results.

Mean error for trees per acre were similar between the scaled and nonscaled simulations for both sites. It was expected that FVS would overpredict mortality, because of typically lower mortality in red pine plantations. However, it actually underpredicted. The inventory history indicates that some trees died by snow or ice storms, but no description was given for other trees. However, from the previous inventory, most trees seemed to put on good growth prior to the cycle that death occurred. From this it is assumed that many of the trees died from stochastic events such as wind, ice, snow, insect, or disease. This suggests that when running simulations, in order to get reasonable estimates of mortality, it is imperative to include stochastic mortality events that are typical for the region and species modeled.

For the typical user of FVS who may not have a complete understanding of the system, it is important to realize that many adjustments can be made to FVS to produce more accurate runs. FVS is a complicated growth and yield program. The more the user understands the capabilities of FVS, and the process it uses to compute growth, the better estimates the user will obtain. At the beginning of the research, one of this study's authors was a novice FVS user and found that even without making many adjustments to improve estimates of growth, FVS-LS did perform well in the prediction of individual tree diameters, stand density, and mortality in most cases.

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