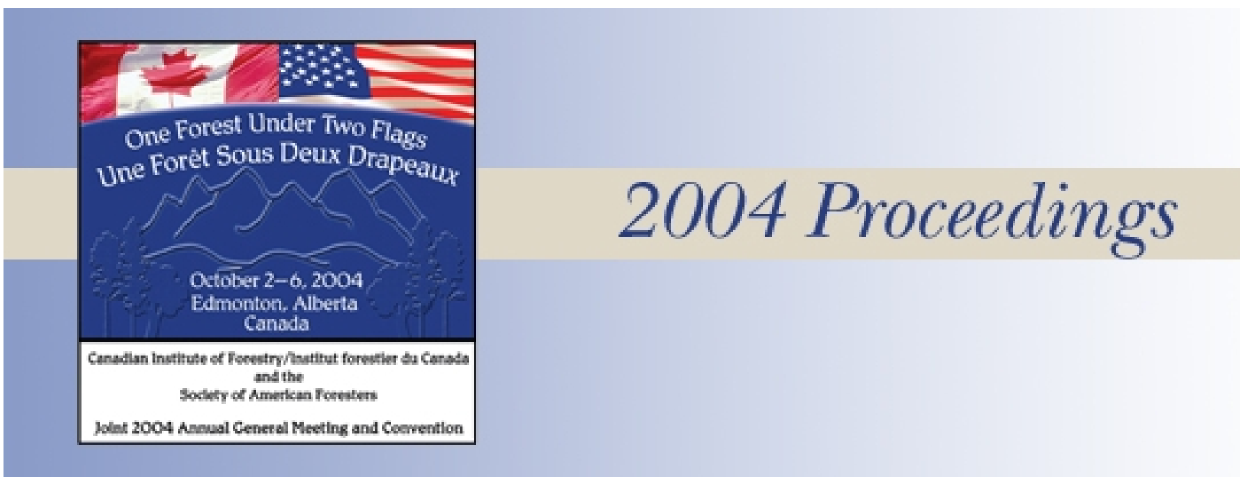
Proceedings Reprint

Citation:

Parresol, B.R.; Stedman, S.C. 2005. Validating the southern variant forest vegetation simulator height predictions on southeastern hardwoods in Kentucky and Tennessee. In: One Forest Under Two Flags, Proceedings of the Joint CIF/SAF Convention, October 2-6, 2004, Edmonton, Alberta, Canada [CD-ROM]. Bethesda, MD: Society of American Foresters. 11 p.



Validating the Southern Variant Forest Vegetation Simulator Height Predictions on Southeastern Hardwoods in Kentucky and Tennessee

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Acknowledgements

We thank Anne J. Ulrey, Stephen K. Forry, James S. Harris, Joey Joiner, Arthur E. Rioux, and Benjamin D. Campbell for their assistance in data collection; a special thanks to Linda Alderdice and Anne J. Ulrey for providing helpful comments about the manuscript.

Abstract

The Forest Vegetation Simulator (FVS) height prediction equations are cornerstones of the model. However, the quality and utility of this FVS function for the southern variant has been largely untested. The objective of this study was to test the Southern Variant of the Forest Vegetation Simulator (SN-FVS) prediction accuracy of the species height-diameter functions on a large independent hardwood dataset in southwestern Kentucky and northwestern Tennessee. Accuracy is the composite of both bias (i.e., average error) and precision. Validation was run on total height measurements taken on 9,236 trees from 301 fixed-area plots across the Fort Campbell forested landscape. There were 36 species with sufficient numbers (>30) to compute test statistics. Along with percent bias, statistics for the mean square error and prediction accuracy at ±25 percent were calculated with the combined effect yielding a unified estimate of prediction accuracy. For all species combined, the average bias was less than the accepted standard of 5 percent and the prediction accuracy was over the accepted standard of 80 percent. The prediction accuracy for individual species resulted in some variation with a few species that were poorly estimated, such as American sycamore (*Plantanus occidentalis*), chinkapin oak (*Quercus muehlenbergii*), and black locust (*Robinia pseudoacacia*).

Keywords

Forest Vegetation Simulator (FVS), accuracy testing, bias, growth and yield, validation statistics, tree height prediction.

Introduction

The accuracy of forest growth and yield forecasts affects the quality of forest management decisions (Rauscher et al. 2000). Users of growth and yield models want assurance that model outputs are reasonable and mimic local/regional forest structure and composition and accurately reflect the influences of stand dynamics such as competition and disturbance. As such, simulation models should be subjected to a process of evaluation in order to build confidence in their validity (Reynolds et al. 1981, Vanclay et al. 1996). Operational validation, as defined by Rykiel (1996), tests whether the model output conforms with its stated purpose. Operational validation may be viewed from two perspectives: (1) hypothesis testing and (2) confidence interval estimation (Rykiel 1996, Rauscher 2000). Confidence interval estimation expresses the degree of reliability that can be placed in model predictions through estimates of the direction, magnitude, and variability of the prediction error and is the approach used in this study.

Examples of growth and yield model evaluation research for the eastern United States have been reported for old field loblolly pine (*Pinus taeda*) plantations in the piedmont of South Carolina (Buford 1991); loblolly pine on cut-over sites in the southeastern United States (Clutter and Gent 1993); softwood and hardwood forests in the Lake States (Holdaway and Brand 1986); hardwood forests in Illinois (Kowalski and Gertner 1989); spruce-fir and hardwood forests of the northeastern United States (Schuler et al. 1993); upland hardwood forests of northern lower Michigan (Guertin and Ramm 1996) and lower peninsula red pine in southwestern Michigan (Smith-Mataeja and Ramm 2002). Growth and yield model performance evaluations for the upland and bottomland hardwood forests in the southern region of the United States have only recently been performed (Rauscher et al. 2000). In each case, model prediction accuracy was determined and can be used to compare to the prediction accuracy results of this study.

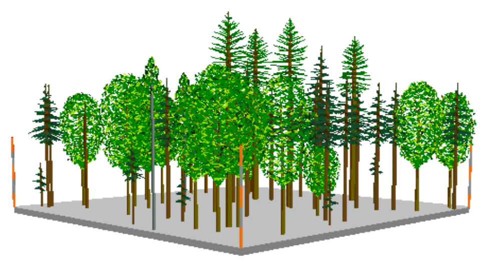
The Growth and Yield Unit of the USDA Forest Service Forest Management Service Center in Ft. Collins, CO has developed a growth and yield model management system called the Forest Vegetation Simulator (FVS). FVS is used by the National Forest System as well as by other federal and state agencies, universities, and the forest industry.

Forest Vegetation Simulator. PROGNOSIS (Stage 1973) is the original model that evolved into the Forest Vegetation Simulator. In the early 1980's, the National Forest System selected the individual-tree, distance-independent model form, as implemented in PROGNOSIS, to be the nationally supported framework for growth and yield modeling. FVS can simulate growth and yield for most major forest tree species, forest types, and stand conditions. FVS can also simulate a wide range of silvicultural treatments and disturbance regimes. Variants of FVS provide growth and yield models for specific geographic areas of the United States. The Southeast Variant (SE) was the original variant created for the South (Lilly 2000), applicable only to Alabama, Georgia, and South Carolina. The need to have a variant that covered the entire southern U.S. region from Virginia to Oklahoma/Texas resulted in the development of the new Southern Variant. The Southern Variant (Donnelly et al. 2001), which supplants the Southeast Variant, applies to the following states (order roughly from northeast to southwest): VA, NC, SC, GA, FL, AL, MS, LA, TN, KY, AR, TX, and OK. A synopsis of FVS is displayed in Exhibit A. The Growth and Yield Unit of the Forest Management Service Center (FMSC) in Fort Collins, CO, maintains, supports, and continuously updates FVS. For information and to download FVS and supporting documents visit the FMSC website at www.fs.fed.us/fmsc/fvs/. Stakeholders in the recently developed Southern Variant of the Forest Vegetation Simulator (SN-FVS) (Donnelly et al. 2001) have called for this variant to be evaluated in order to build confidence in its validity.

The objective of this study was to test the operational prediction accuracy of the SN-FVS species height-diameter functions on a large independent dataset. The critical nature of accurately predicting height is evidenced by the influence height has on the other modules of FVS: site index estimation, relative height computations, competition indices, growth relationships, volume calculations, and so on, hence our rationale for the primary study focusing on height prediction. Additional SN-FVS module validation work is planned.

Exhibit A

FVS: Forest Vegetation Simulator

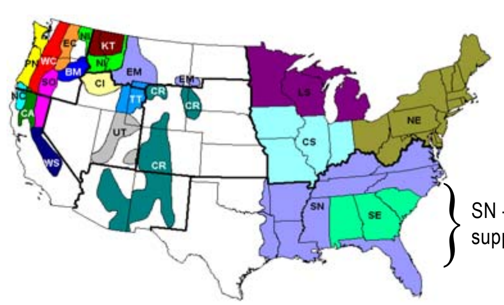


What Is It?

- Suite of growth and yield software tools
- Individual-tree distance-independent model
- Stands are the population unit
- Simulates nearly any type of management
- Accommodates most species compositions
- 21 geographic variants (so far)

Geographic Variants

Each has its own set of species, growth and mortality functions, volume calculation procedures, etc.



SN – southern variant; supplants the SE

Data

Fort Campbell, Kentucky, straddles the borders of southwestern Kentucky and northwestern Tennessee (Figure 1) in portions of four counties (Christian and Trigg Counties in Kentucky and Montgomery and Stewart Counties in Tennessee). Fort Campbell occupies roughly 104,520 acres of land, of which approximately 48,200 acres are currently under forest management, with 36,600 acres in mixed hardwoods and 11,600 in pine plantations. The area surrounding Fort Campbell today is a mix of woodlands, farmlands, and urban development. Fort Campbell lies within the Western Highland Rim Physiographic Province, a transition area between Kentucky farmlands to the north, the steeply dissected and wooded rim of the Cumberland River to the south and west, and gently rolling hills of low to moderate relief to the east. The forest resources on Fort Campbell (Figure 2) are managed on an ecosystem approach that mimics natural processes in support of the military training mission, and for the protection of threatened and endangered species. The structure and composition of the Fort Campbell forest provides the ideal setting for testing the SN-FVS.

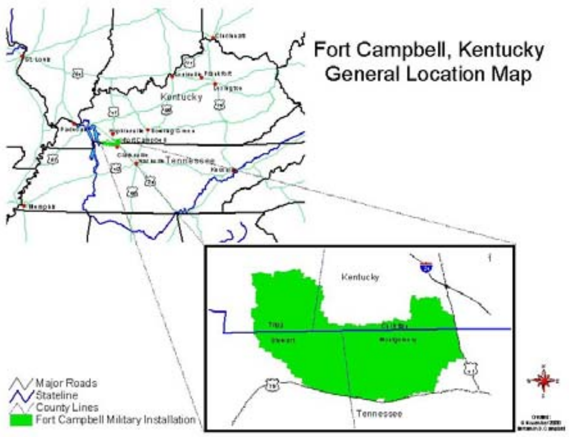


Figure 1. The location of Fort Campbell in Kentucky and Tennessee.

Figure 2. Typical CFI hardwood plot on Fort Campbell.

The Forestry Program within the Fort Campbell Directorate of Public Works is charged with inventorying all forested land area on the installation through its Continuous Forest Inventory (CFI) permanent sample plots. The validation data were collected from 301 fixed-area, circular, CFI plots (0.2 acres in size) located across the installation in the spring and summer of 2002. For this study, total heights of 9,236 trees were measured with an optical reading SUUNTO clinometer version PM-5/360 PC. It was read directly to the nearest one-degree or one percent. A nomographic height correction technique was employed where no slope angle measurement was necessary. A reading of the top point and that of the ground point were recorded. Depending on the situation, their sum or difference gave the apparent height in feet. In addition, diameter breast height (DBH) was measured to the nearest 0.1 inch with a diameter tape and species was recorded. Table 1 gives descriptive statistics of the hardwood species tallied on the plots. There were 55 species present and 36 species with greater than 30 observations. The minimum DBH was 4.6 inches for all species. The maximum DBH was typically in the neighborhood of 20 inches, across all measured species, and varied from 6.1 inches for downy serviceberry (*Amelanchier arborea*) to 35.8 inches for sugar maple (*Acer saccharum*). Height values were extremely variable, with a fair number of species having a range well over 100 ft; for example, white ash (*Faxinus americana*) minimum 18 ft to maximum 132 ft (range 114 ft), mockernut hickory (*Carya tomentosa*) minimum 15 ft to maximum 119 ft (range 104 ft), southern red oak (*Quercus falcata*) minimum 17 ft to maximum 122 ft (range 105 ft), and sweetgum (*Liquidambar styraciflua*) minimum 6 ft to maximum 128 ft (range 122 ft).

Analyses

Tree DBH and species and plot identifier were input into the SN-FVS and predicted heights were generated for all trees. For species with a total count of 30 or more individuals the following statistics were calculated

$$Bias\% = 100 \times \frac{\sum_{i=1}^{n} (H_i - \hat{H}_i) / \bar{H}}{n} \tag{1}$$

$$MSE = \frac{\sum_{i=1}^{n} (H_i - \hat{H}_i)^2}{n} \tag{2}$$

$$PA - xx = 100 \times \frac{C_{\pm xx}}{n} \tag{3}$$

where H_i is observed height, $\hat{H}_i$ is predicted height, $C_{\pm xx}$ is the count or number of predictions within ±*xx* percent of the observed value, and *n* is the number of observations.

Table 1. Descriptive statistics on the trees from the 2002 Fort Campbell, KY inventory (*n*=number of trees, SD=standard deviation, min=minimum value, max=maximum value).

Common Name	Genus	Species	*n*	Mean height	SD height	Min height	Max height	Mean DBH	SD DBH	Min DBH	Max DBH
Ash, White	*Fraxinus*	*americana*	434	64.9	19.11	18	132	9.4	4.29	4.6	31.6
Beech, American	*Fagus*	*grandifolia*	28	64.8	19.41	30	106	12.2	5.50	4.7	27.2
Beech, Blue	*Carpinus*	*caroliniana*	54	35.5	7.49	21	55	6.2	1.45	4.7	12.8
Birch, River	*Betula*	*nigra*	32	62.1	22.41	10	98	10.8	4.25	5	21
Boxelder	*Acer*	*negundo*	117	46.5	14.38	4	81	8.2	3.22	4.6	20.9
Buckeye, Ohio	*Aesculus*	*glabra*	5	34.6	3.97	28	38	6.0	0.79	5.1	6.7
Cherry, Black	*Prunus*	*serotina*	461	55.6	17.15	8	108	8.4	3.57	4.6	29.6
Cottonwood, Eastern	*Populus*	*deltoides*	3	99.0	11.53	90	112	24.0	5.24	19.4	29.7
Dogwood, Flowering	*Cornus*	*florida*	249	31.3	6.43	8	47	5.7	1.09	4.6	10.1
Elm, American	*Ulmus*	*americana*	134	51.6	16.88	22	105	7.9	3.34	4.6	19.9
Elm, Rock	*Ulmus*	*thomasii*	6	35.8	4.26	31	42	6.0	0.80	5	6.9
Elm, Slippery	*Ulmus*	*rubra*	160	47.5	15.34	19	95	7.8	3.26	4.6	23.6
Elm, Winged	*Ulmus*	*alata*	85	47.1	11.38	27	78	7.0	2.08	4.6	13.6
Gum, Black	*Nyssa*	*sylvatica*	363	48.0	15.99	5	102	8.1	3.54	4.6	31
Hackberry	*Celtis*	*occidentalis*	141	53.1	19.90	10	107	9.0	4.05	4.6	22.1
Hickory, Bitternut	*Carya*	*cordiformis*	56	63.3	23.47	21	116	9.9	4.06	4.8	19.3
Hickory, Mockernut	*Carya*	*tomentosa*	315	62.0	20.49	15	119	9.6	4.23	4.6	23.4
Hickory, Pignut	*Carya*	*glabra*	141	67.5	20.36	31	128	9.9	4.04	4.6	21.6
Hickory, Shagbark	*Carya*	*ovata*	185	67.1	21.29	10	119	9.8	4.12	4.6	23.2
Honeylocust	*Gleditsia*	*triacanthos*	23	66.0	19.60	30	96	12.1	4.39	4.6	19.4
Hophornbeam, Eastern	*Ostrya*	*virginiana*	51	42.5	8.62	21	63	5.6	0.84	4.6	8.6
Locust, Black	*Robinia*	*pseudoacacia*	31	73.5	22.92	31	108	11.5	5.18	5.2	27.6
Maple, Red	*Acer*	*rubrum*	871	55.5	16.62	7	105	8.8	4.05	4.6	32.7
Maple, Silver	*Acer*	*saccharinum*	5	60.0	19.34	29	81	11.0	5.25	6	19.2
Maple, Sugar	*Acer*	*saccharum*	492	59.7	16.43	15	117	8.9	4.21	4.6	35.8
Mulberry, Red	*Morus*	*rubra*	23	37.3	10.89	18	62	6.9	2.07	4.6	12
Oak, Black	*Quercus*	*velutina*	390	73.0	20.74	18	132	12.4	5.51	4.6	28.8
Oak, Blackjack	*Quercus*	*marilandica*	9	45.7	11.75	34	75	7.8	2.59	5.6	14.1
Oak, Cherrybark	*Quercus*	*pagoda*	27	74.2	22.85	43	114	13.8	7.69	4.6	32.5
Oak, Chestnut	*Quercus*	*prinus*	8	78.5	13.06	58	99	13.5	3.16	7.4	18
Oak, Chinkapin	*Quercus*	*muehlenbergii*	39	61.1	18.37	21	93	8.7	3.54	4.7	18.9
Oak, Northern Red	*Quercus*	*rubra*	84	80.5	21.47	40	114	14.1	5.95	4.7	31
Oak, Overcup	*Quercus*	*lyrata*	2	40.5	45.96	8	73	10.7	6.29	6.2	15.1
Oak, Pin	*Quercus*	*palustris*	83	83.2	25.64	26	126	14.1	5.92	4.7	28
Oak, Post	*Quercus*	*stellata*	280	61.2	18.31	19	106	12.0	5.09	4.6	30.4
Oak, Scarlet	*Quercus*	*coccinea*	166	71.3	18.94	28	125	11.4	4.99	4.6	27.7
Oak, Shingle	*Quercus*	*imbricaria*	80	55.8	18.24	19	99	9.4	3.69	4.9	19
Oak, Southern Red	*Quercus*	*falcata*	650	69.4	21.07	17	122	12.8	5.74	4.6	35.3
Oak, White	*Quercus*	*alba*	604	65.9	21.50	20	133	11.2	5.56	4.6	32.9
Oak, Willow	*Quercus*	*phellos*	21	53.9	21.03	20	100	9.3	6.71	5	28.4
Osage-Orange	*Maclura*	*pomifera*	6	37.8	12.48	17	54	9.6	2.04	6.8	11.8
Persimmon, Common	*Diospyros*	*virginiana*	107	51.0	10.67	26	89	6.6	1.85	4.6	16.4

Table 1. Continued.

Common Name	Genus	Species	*n*	Mean height	SD height	Min height	Max height	Mean DBH	SD DBH	Min DBH	Max DBH
Pine, Loblolly	*Pinus*	*taeda*	10	37.2	16.95	12	79	7.6	3.17	4.9	15
Poplar, Lombardy	*Populus*	*nigra*	4	70.3	7.63	63	81	18.3	2.97	16	22.6
Redbud, Eastern	*Cercis*	*canadensis*	87	33.8	8.93	11	50	6.3	1.61	4.6	13.4
Redcedar, Eastern	*Juniperus*	*virginiana*	439	38.3	8.98	7	70	7.5	2.69	4.6	23.8
Sassafras	*Sassafras*	*albidum*	133	45.5	13.06	12	86	6.3	1.83	4.6	19.4
Serviceberry, Downy	*Amelanchier*	*arborea*	1	31.0		31	31	6.1		6.1	6.1
Sourwood	*Oxydendrum*	*arboreum*	22	37.8	9.91	14	59	6.0	1.47	4.7	11.4
Sweetgum	*Liquidambar*	*styraciflua*	694	63.8	21.03	6	128	9.0	4.05	4.6	23.3
Sycamore, American	*Platanus*	*occidentalis*	97	79.4	23.31	33	128	12.1	5.97	4.6	30.5
Tree-of-Heaven	*Ailanthus*	*altissima*	8	54.6	15.25	33	70	7.7	2.65	5	13.5
Walnut, Black	*Juglans*	*nigra*	110	64.0	17.26	27	109	9.2	3.81	4.6	21.8
Willow, Black	*Salix*	*nigra*	13	42.2	7.60	25	52	6.0	1.24	4.8	8.1
Yellow-poplar	*Liriodendron*	*tulipifera*	597	70.5	23.86	6	138	10.8	5.47	4.6	33.8

Percent bias (*Bias%*) measures the average error in percent of estimating the true value of a quantity and precision refers to the clustering of values about their own average. The mean square error (*MSE*) and prediction accuracy at ±25 percent (*PA*-25) statistics were calculated because they combine the effect of bias and precision to yield a unified estimate of prediction accuracy. The *PA*-25 statistic gives the proportion of predictions that come within ±25 percent of the observed values and is an arbitrary but reasonable goal for height prediction. For other variables such as diameter or basal area the normal standard is to use ±15 percent (*PA*-15) (see Rykiel 1996, Rauscher et al. 2000), but height is more variable and difficult to project. We also calculated *PA*-15, *PA*-20, *PA*-25, and *PA*-30, for comparative purposes, but our standard of choice is *PA*-25. In general, the greater the bias and the less the precision, the less accurate is the estimator, which translates into a larger *MSE* and a smaller *PA*-25 value.

Results

The validation results are listed in Table 2. For all species combined, average percent bias was 4.2 percent, within the accepted standard of ±5 percent. One-third of the individual tree species exhibited a positive bias greater than 5 percent, indicating that the SN-FVS model under predicts actual tree height for several species. The measure of prediction accuracy, *PA*-25, was 82.4 percent, with 80 percent being considered an acceptable standard. On an individual tree species basis, however, 42 percent failed the acceptable 80 percent standard and only one species, eastern redcedar (*Juniperus virginiana*), met the standard for *PA*-20. The average *MSE* was 143.61 ft^2, which is an acceptable measure of variability, but river birch (*Betula nigra*), black locust (*Robinia pseudoacacia*), pin oak (*Quercus palustris*) and American sycamore (*Platanus occidentalis*) exhibit at least twice that variability.

Table 2. Validation statistics on height estimates from SN-FVS from input of southeastern hardwood stands in Kentucky and Tennessee.

Common Name	Genus	Species	*n*	Bias%	MSE	PA-15	PA-20	PA-25	PA-30
Ash, White	*Fraxinus*	*americana*	434	10.1	163.00	57.1	74.2	86.9	93.1
Beech, Blue	*Carpinus*	*caroliniana*	54	-6.1	48.70	55.6	66.7	74.1	77.8
Birch, River	*Betula*	*nigra*	32	-1.8	355.53	37.5	56.3	65.6	68.8
Boxelder	*Acer*	*negundo*	117	-2.8	144.46	48.7	61.5	74.4	80.3
Cherry, Black	*Prunus*	*serotina*	461	5.0	142.48	55.5	70.7	81.1	87.9
Dogwood, Flowering	*Cornus*	*florida*	249	-6.9	43.20	57.0	68.7	76.7	83.1
Elm, American	*Ulmus*	*americana*	134	-2.0	143.76	43.3	56.7	70.9	81.3
Elm, Slippery	*Ulmus*	*rubra*	160	-9.6	142.52	43.8	57.5	63.1	70.0
Elm, Winged	*Ulmus*	*alata*	85	1.9	64.37	63.5	78.8	85.9	90.6
Gum, Black	*Nyssa*	*sylvatica*	363	-2.6	103.45	54.5	68.0	76.3	83.2
Hackberry	*Celtis*	*occidentalis*	141	-3.4	162.90	46.1	60.3	66.7	75.2
Hickory, Bitternut	*Carya*	*cordiformis*	56	2.4	172.95	48.2	66.1	75.0	80.4
Hickory, Mockernut	*Carya*	*tomentosa*	315	2.1	123.41	62.2	74.9	84.4	88.6
Hickory, Pignut	*Carya*	*glabra*	141	8.2	165.95	58.2	78.0	86.5	92.9
Hickory, Shagbark	*Carya*	*ovata*	185	8.4	170.67	60.0	75.1	88.1	96.2
Hophornbeam, Eastern	*Ostrya*	*virginiana*	51	4.3	66.19	49.0	74.5	84.3	90.2
Locust, Black	*Robinia*	*pseudoacacia*	31	15.7	431.12	29.0	35.5	51.6	74.2
Maple, Red	*Acer*	*rubrum*	871	1.3	129.47	55.1	70.3	80.1	85.9
Maple, Sugar	*Acer*	*saccharum*	492	2.3	106.78	66.1	79.3	87.4	92.7
Oak, Black	*Quercus*	*velutina*	390	10.2	205.49	55.9	71.8	85.6	92.8
Oak, Chinkapin	*Quercus*	*muehlenbergii*	39	11.7	251.70	41.0	56.4	64.1	87.2
Oak, Northern Red	*Quercus*	*rubra*	84	12.7	238.31	46.4	71.4	86.9	94.0
Oak, Pin	*Quercus*	*palustris*	83	10.5	347.06	42.2	65.1	75.9	84.3
Oak, Post	*Quercus*	*stellata*	280	5.8	134.44	58.2	72.9	85.0	92.5
Oak, Scarlet	*Quercus*	*coccinea*	166	12.4	212.38	48.8	70.5	84.3	96.4
Oak, Shingle	*Quercus*	*imbricaria*	80	-1.3	121.41	60.0	75.0	83.8	87.5
Oak, Southern Red	*Quercus*	*falcata*	650	7.5	187.05	52.8	70.6	82.8	92.2
Oak, White	*Quercus*	*alba*	604	4.4	136.93	64.4	79.0	87.9	92.2
Persimmon, Common	*Diospyros*	*virginiana*	107	8.7	106.04	58.9	76.6	86.9	93.5
Redbud, Eastern	*Cercis*	*canadensis*	87	-9.5	91.97	48.3	60.9	70.1	75.9
Redcedar, Eastern	*Juniperus*	*virginiana*	439	-1.6	40.12	68.3	80.6	86.3	91.8
Sassafras	*Sassafras*	*albidum*	133	3.8	157.98	39.8	50.4	70.7	78.2
Sweetgum	*Liquidambar*	*styraciflua*	694	4.4	130.11	62.4	77.8	87.8	92.1
Sycamore, American	*Platanus*	*occidentalis*	97	16.2	320.38	40.2	54.6	72.2	90.7
Walnut, Black	*Juglans*	*nigra*	110	9.8	159.33	50.0	70.0	82.7	88.2
Yellow-poplar	*Liriodendron*	*tulipifera*	597	1.4	169.23	65.5	79.1	88.4	91.6
All			9236	4.2	143.61	57.1	72.2	82.4	88.8

Species such as yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), mockernut hickory (*Carya tomentosa*), white oak (*Quercus alba*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*) were estimated within acceptable standards of accuracy and precision and displayed average or lower variability. We can also see in the table that there are a number of species that had high bias and low precision, such as American sycamore (*Platanus occidentalis*), chinkapin oak (*Quercus muehlenbergii*), and black locust (*Robinia pseudoacacia*) and most of these species also displayed at least twice the average variability. Other species exhibited a combination of both low bias and low precision such as sassafras (*Sassafras albidum*) and hackberry (*Celtis occidentalis*) or high precision and high bias such as common persimmon (*Diospyros virginiana*) and northern red oak (*Quercus rubra*). In fact, most of the oaks followed this last pattern of having an acceptably high *PA*-25 value (>80 percent) and a significant positive bias (>5 percent).

Discussion

Bias% for individual trees ranged from -9.5 to 16.2 where 33 percent of the species displayed a positive bias greater than 5 percent. Conversely, only 10 percent showed a negative bias less than -5 percent. As such, the SN-FVS tends to underestimate actual tree heights more so than it overestimates them. It is unclear why this is the case, there are ample numbers of sampled trees and the minimum and maximum DBH range is wide and scattered to produce an acceptable set of predicted heights. Regardless, a conservative height estimate is more desirable than overestimating tree height, which, in turn, affects site index estimation, competition indices, growth relationships, volume calculations and so on.

Overall, the *PA*-25 prediction accuracy was 82.4 percent; however, 42 percent of the individual tree species did not attain the 80 percent acceptability level. This is probably the result of three causes: (1) a wide variety of land conditions from forested wetlands to xeric sites were sampled across the installation; (2) the impact of erratic weather events such as flooding, high winds and ice damage; and (3) the influence both positive and negative of riparian areas on tree growth. All three sources affect individual tree height especially for species that occur across all sites and conditions with varying degrees of success. For example, an 8-inch southern red oak (*Quercus falcata*) that occurs in a wetland and has ice damage has a significantly different height than one that occurs in a rich alluvial stream bank or one that is present on a xeric ridge top. Similarly, the majority of species with low prediction accuracy are more commonly associated with wetter, bottomland sites, again, suggesting the influence of water, wind and ice on individual tree species height.

The mean square error (*MSE*) statistic measures variability and combines the effect of bias and precision to yield a unified estimate of prediction accuracy. Individual tree species with a low precision and high bias are expected to exhibit a high degree of variability. However, tree species such as slippery elm (*Ulmus rubra*), eastern redbud (*Cercis canadensis*) and flowering dogwood (*Cornus florida*) exhibit average or low variability in conjunction with high bias and low precision numbers. These conflicting results suggest that perhaps additional work may be necessary to more accurately predict tree heights for these species. Another area of concern exists for individual tree species that exhibit high precision combined with high bias (i.e., not accurate) such as northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*) and black oak (*Quercus velutina*).

Conclusions

FVS is continually being updated and evaluations such as this help point to areas where additional research is needed. Overall, for all species combined, the results are reasonable given the high variability normally associated with estimation of tree height. On an individual tree species basis, however, the results are less than desirable; 42 percent of the species failed to meet the acceptable precision standard while 50 percent of the species were not within the accepted standard of ±5 percent for accuracy. Secondly, with this data the SN-FVS tended to underestimate actual tree heights 3-times more often than it overestimated heights. Thirdly, inconsistencies with precision, accuracy and variability statistics (or combination thereof) indicate that species such as northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), black oak (*Quercus velutina*), slippery elm (*Ulmus rubra*), eastern redbud (*Cercis canadensis*) and flowering dogwood (*Cornus florida*) may need additional work to more accurately predict tree heights.

Users of any system need to understand that the more information that can be provided or input, the better will be the results. This study demonstrates that at least some tree heights should be measured. The ideal situation, of course, is to have heights for all the trees. All of the FVS variants can calibrate for local conditions if sufficient information is input. In this evaluation only the minimal data input was used. In a broad sense the results were realistic taken over all species. Given the continuum of stand conditions that can exist, it is recommended that some tree heights (as a rule-of-thumb we suggest 20 percent or more of the trees) be measured and input into the SN-FVS.

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