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Performance of the SEAPROG Prognosis Variant of the Forest Vegetation Simulator

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Abstract

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This paper reports the first phase of a recent effort to evaluate the performance and use of the FVS-SEAPROG vegetation growth model. In this paper, we present our evaluation of SEAPROG's performance in modeling the growth of even-aged stands regenerated by clearcutting, windthrow, or fire. We evaluated the model by comparing model predictions to observed values from two sets of long-term permanent plots. We examined six variables: trees per acre, quadratic mean diameter, basal area per acre, height of the largest 40 trees per acre, cubic-foot volume per acre, and board-foot volume per acre. The differences between observed and predicted values were large enough to have important implications for the interpretation and use of the model's predictions. Of even greater importance was the evidence for considerable bias in quadratic mean diameter, basal area, height, and volume, all of which were systematically underestimated. Our results appear to validate the concerns expressed by users.

Keywords: Growth and yield, forest management, growth projection, modeling, southeast Alaska.

Summary

SEAPROG is a Prognosis variant of the Forest Vegetation Simulator, and it is the primary vegetation growth model used for forest management in southeast Alaska. SEAPROG is widely available and there exists a large corps of trained users, but the model is used much less than expected. We identified two reasons limiting the use of SEAPROG: user perceptions that the model predictions frequently are unrealistic and that the model has not been calibrated to predict the outcome of the more complex silvicultural systems being prescribed today, such as two-age and uneven-age management. We concluded that SEAPROG use would continue to decline if these issues were not resolved. This paper reports the first phase of our recent effort to evaluate the performance and use of SEAPROG. We present our evaluation of SEAPROG's performance in predicting the growth of even-aged stands regenerated after clearcutting, windthrow, or fire. We evaluated the model by comparing model predictions to observed values from two sets of long-term permanent plots. We examined six variables: trees per acre, quadratic mean diameter, basal area per acre, height of the largest 40 trees per acre, cubic-foot volume per acre, and board-foot volume per acre. The differences we found between observed and predicted values were large enough to have important implications for the interpretation and use of the model's predictions. Of even greater importance was the evidence for considerable bias in quadratic mean diameter, basal area, height, and volume, all of which were systematically underestimated. Our results appear to validate the concerns expressed by users.

Introduction

This paper reports on a recent effort to evaluate the performance and use of FVS-SEAPROG, a vegetation growth model used in southeast Alaska (Dixon and others 1992). We prepared it in response to concerns voiced by many SEAPROG users in southeast Alaska—silviculturists who had tried to use SEAPROG, but found its predictions unrealistic, its user interface difficult to master, and its ability to model complex stand structures limited. We were asked to evaluate the performance of SEAPROG for even-age and uneven-age management and, where possible, compare its predictions to observed growth data. In this paper, we present our evaluation of SEAPROG's performance in modeling the growth of even-aged stands regenerated after clearcutting, windthrow, or fire. We hope that our findings will lead to further improvements to SEAPROG and wider use of growth models as management tools.

Forest managers are being challenged to produce an increasing number of values from a decreasing area of forested lands available for active management. Most forest values derive from the combination of physical setting and vegetation composition and structure, which fundamentally affect the function of the system and the production of goods and services we desire. The manipulation of forest vegetation is often the common denominator reaching across discussions of wildlife and fish habitat, visual quality, wood production, recreational opportunities, biological diversity, and a host of other forest management issues.

Because most values of concern are at least partly vegetation dependent, it follows that any analysis and evaluation of management options must proceed from reliable predictions of vegetation composition and structure. The range of management options considered and the complexity of silvicultural prescriptions have increased dramatically over the past decade, and this has created a demand for more capable vegetation dynamics models. For example, concerns over deer habitat in southeast Alaska have led to increased emphasis on maintaining understory plant communities (Zaborske and others 2002). Controversies over clearcutting have led to wider use of partial cutting and the need to predict the growth of stands with varying levels and patterns of green-tree retention. Managers are being asked to integrate and evaluate tradeoffs among multiple values such as wood production, wood quality, and understory plant diversity and abundance. In this context, there is a clear need for exible, reliable, easy-to-use models of vegetation development that predict the dynamics of trees and understory plants, as well as key interactions with disturbance agents.

The primary vegetation model for southeast Alaska is FVS-SEAPROG, a geographic variant of the Forest Vegetation Simulator (Dixon and others 1992). The SEAPROG variant was developed in 1984 by staff at the Forest Management Service Center in Fort Collins, Colorado, in cooperation with Wilbur (Bill) Farr and others at the Forestry Sciences Laboratory in Juneau. SEAPROG is an adaptation of the Prognosis stand development model (Stage 1973), which was originally developed for the Inland Empire area of Idaho and Montana. Data used to develop the SEAPROG model came from forest inventories on the Tongass National Forest (Juneau, Stikine, Sitka, and Prince of Wales areas), the Makah Indian Reservation, and the Queen Charlotte Islands. Other data sources included young-growth stand exams, young-growth surveys, and Farr's young-growth stand-density study (DeMars 2000). The geographic area covered by SEAPROG includes the Tongass National Forest, other forested lands in southeastern Alaska, coastal British Columbia, the Queen Charlotte Islands, and the northwestern tip of the Olympic Peninsula (Dixon and others 1992).

With suitable calibration, an individual-tree growth model such as SEAPROG should be able to predict growth with some degree of confidence for many forest types and stand structures. SEAPROG can predict the growth of common conifers in southeast Alaska (Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) as well as less common conifers such as Pacific silver fir (*Abies amabilis* (Dougl. ex Loud.) Dougl. ex Forbes), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), shore (lodgepole) pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*), and white spruce (*Picea glauca* (Moench) Voss). The hardwoods red alder (*Alnus rubra* Bong.) and black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw) are also included (Dixon and others 1992, Van Dyck 1999). The exibility of this model is intended to permit the simulation of alternative management practices in a wide array of vegetation types.

During the Tongass Land Management Plan (TLMP) revision, the accuracy of SEAPROG growth and yield projections was a concern. Some planners suspected that the model overestimated growth because much of the data used to calibrate the model came from low-elevation, moderately to highly productive sites. On the other hand, users from the Alaska Native corporations, whose timberlands tend to be highly productive, reported that the model underestimated growth on their lands, when compared with observed growth.

We know of at least three prior efforts to evaluate or validate SEAPROG performance and one study that provides an indication of its ability to predict growth on wet, low-productivity sites. First, between 1985 and 1987, model predictions were compared with observed growth on six of the “Taylor plots” (a set of nine permanent plots established in older even-aged stands in the 1920s by R.F. Taylor) (Dixon and others 1992). In that test, the first 10 years of growth data were used to calibrate the model for each plot. Predicted trees per acre varied from 3 percent less to 11 percent more than observed values, dominant tree heights varied from 8 percent less to 10 percent more, and quadratic mean diameters varied from 6 percent less to 2 percent more (Dixon and others 1992). Golnick and others (1995) reviewed the results from this test and detected no apparent bias in board-foot volume predictions. Second, from the late 1980s through the early 1990s, Wilbur Farr worked with the Washington office timber management group to evaluate and improve the performance of the mortality model. Unfortunately, at the time of Farr’s death this work was unfinished. Third, in 1995, as part of the TLMP revision, the model was reviewed with respect to the reliability of growth-and-yield predictions in young stands, the effect of projections on the allowable sale quantity (ASQ), and the suitability of the model for predicting the results from partial cutting of old-growth forests (Golnick and others 1995). Although an extensive statistical analysis was not carried out, the reviewers concluded that the growth-and-yield projections for young-growth stands were reliable and that the ASQ was not highly sensitive to changes in those predictions. However, they also concluded that SEAPROG was not suited to projections of the results of partial cutting because of the absence of data from partially cut stands to validate the model results (Golnick and others 1995).

A recent study of the productivity of forested wetlands (Julin and D'Amore 2003) showed that SEAPROG growth predictions agreed closely with observed growth in 18 stands 15 to 46 years after clearcutting. The authors concluded that on these poorly productive sites, representing the least productive of sites actively managed for wood production, the model shows no tendency to overestimate or underestimate growth.

Based on these prior evaluations of SEAPROG, our first objective was an evaluation of SEAPROG's strengths and weaknesses in modeling relatively simple even-age management options. The second objective was to evaluate model performance in more complex management scenarios involving uneven-age management. We expected to complete the first step and to move on quickly to the second. As it turned out, we found significant problems with the model performance in even-age management scenarios, and we chose to focus on those issues. In this paper, we report our findings from:

1. A survey of SEAPROG users in order to compile a list of perceived strengths and weaknesses of the simulator and to determine how resource managers are using it.
2. A comparison of SEAPROG growth predictions with actual stand-growth data from two long-term young-growth studies, including trees per acre, quadratic mean diameter, basal area, height, cubic-foot volume, and board-foot volume.

Methods

User Perceptions

During 1998 we canvassed SEAPROG users in the USDA Forest Service (USFS) Alaska Region, Alaska Native corporations, and the private sector to determine the frequency of model use, how the model was being used, and what shortcomings users perceived. This user group was identified by using attendee lists from local USFS-sponsored SEAPROG training sessions and from a directory of USFS silviculturists in the Alaska Region. We made no attempt to quantify responses by issue or type of problem noted—the responses were simply compiled and summarized in a narrative (see below).

Comparisons of Observed and Predicted Growth

Simulations—We used growth data from Farr's stand-density study and the Taylor plots to evaluate SEAPROG predictions for moderately to highly productive sites. Stands in Farr's study are currently 25 to 115 years old, and the Taylor plots range from 120 to 175 years old. We used data from 259 of 271 plots located at 67 installations in southeast Alaska. Of the 259 plots, 208 had been thinned. Twelve plots were grossly overstocked (2,000 to 6,667 trees per acre, quadratic mean diameter 1.9 to 4.5 in), and we excluded them from the analysis (fig. 1). Detailed information on both sets of plots and their treatment histories may be found in DeMars (2000). We produced two tree tables for each plot: the first containing observed tree data collected immediately following plot establishment and treatment (if any), the second containing observed tree data from the latest plot remeasurement. All calculations of stand-level variables (e.g., trees per acre, basal area, volume) were done within SEAPROG. The first set of observations (at plot establishment) was used to provide the starting conditions for the SEAPROG growth simulations. The second set of observations (latest remeasurement) was compared with the SEAPROG predictions.

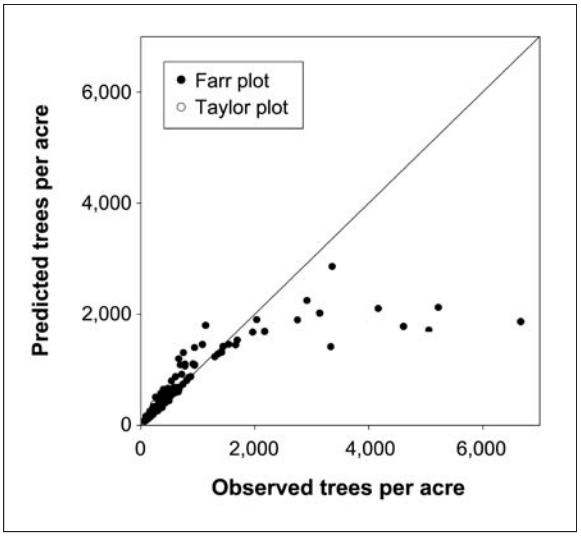

Figure 1—Predicted trees per acre versus observed values, with the overstocked plots included. The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

A projection cycle is a period for which SEAPROG predicts changes in tree characteristics, and a complete SEAPROG projection may include one or more cycles (Wykoff and others 1982). Predicted values may be biased when projection-cycle lengths other than 10 years are used (Wykoff and others 1982). To determine the appropriate number of years to run the model for each plot, we calculated for each plot the number of growing seasons from the initial to the final measurement date. Partial growing years sometimes occurred in our data because it is not always possible to remeasure plots outside the growing season (roughly April through September). Because the model accepts only whole numbers for cycle lengths, the number of growing seasons was rounded to the nearest whole growing season. This resulted in some discrepancies between the final simulation year and the final remeasurement year, but the final output better re ected the actual growth period. When the partial growing year equaled 0.5, the run duration was simply assigned to the difference between initial year and final year (table 1). Once we determined the growth period in whole years, the number of cycles was determined by using cycle lengths as close to 10 years as possible. Preference was given to longer and fewer growth periods. For example, five cycles of 11 years and one of 10 years would be used for a growth period of 65 years, rather than five cycles of 9 years and two of 10 years.

SEAPROG allows users to adjust the growth-model coefficients by calibrating the model with prior-growth information. Calibration requires height-growth data for roughly 5 years and diameter-growth data for roughly 10 years prior to the start of the simulation. Data are required from five trees for each species to be calibrated. Although we had the data available, we chose not to use the calibration option because users indicated they did not typically have the past growth data and, hence, did not use that feature. Our intent was to evaluate SEAPROG performance as practitioners typically used it.

Table 1—Examples of cycle-length assignments used in the simulations

Installation number	Plot number	First measure date	Last measure date	Growth period	Cycle lengths
				- - - - - - *Years*	- - - - - -
49	2680	7/27/84	10/8/98	14.3	14 = 7, 7
46	3180	8/9/76	5/19/98	21.4	21 = 11, 10
50	2750	6/14/84	10/10/98	14.6	15 = 8, 7
20	1740	7/2/76	9/27/98	22.5	22 = 11, 11
36	2340	8/12/75	6/12/99	23.5	24 = 12, 12
48	2040	9/20/79	9/17/85	6.0	6 = 6

Analysis of results—We compared observed and predicted values for trees per acre (TPA), quadratic mean diameter (QMD), basal area per acre (BA), height of the largest 40 trees per acre (HT40), total-stem cubic-foot volume per acre (CFV), and board-foot volume per acre (based on 32-foot logs, BFV). For each pair of values we calculated a residual, r_i as follows:

$$r_i = Y_i - \hat{Y}_i ,$$

where $\hat{Y}_i$ is the predicted value and Y_i is the observed value. This differs from the typical residuals $(Y_i - \hat{Y}_i)$ computed in the course of fitting linear models with least-squares methods where, by definition, the mean of the residuals ($\bar{r}$) is zero:

$$\bar{r} = \frac{\sum r_i}{n} = 0 .$$

Our use of residuals in model validation can yield a nonzero residual mean, and we used the sign and magnitude of this mean as an estimate of model bias, *B*:

$$B = \bar{r} = \frac{\sum r_i}{n} .$$

This method of computing residuals yields an intuitively satisfying estimate of bias, where a negative bias is associated with model underestimates and a positive bias is associated with model overestimates. We computed two estimates of the total average error of the model predictions, the mean absolute residual (MAR) and the root mean squared residual (RMSR):

$$\text{MAR} = \frac{\sum |r_i|}{n} ,$$

$$\text{RMSR} = \left[\frac{\sum r_i^2}{n} \right]^{1/2} .$$

The MAR weights each residual equally, ignoring sign, and the RMSR gives relatively more weight to large residuals that result from gross model misbehavior.

We produced scatter diagrams of observed versus predicted values, residuals versus observed values, and residuals versus selected site and stand attributes (stand age, site index, elevation, and slope). We examined the graphs for the patterns and magnitudes of departures from the ideal case where the SEAPROG predictions would equal the observed values (that is, predicted = observed, residual = 0).

Results

User Perceptions

In general, SEAPROG has not been used much in southeast Alaska except for some limited modeling of young-growth thinning. Many of the silviculturists reported using SEAPROG only for the preparation of their certification prescriptions. The most common reasons given for the limited use were difficulty of use, problems with the program used to summarize stand examination data for input to SEAPROG, lack of user confidence in model predictions, and the perceived inability to reliably predict the results of using silvicultural systems other than even-age management with clearcutting. The users identified slope and elevation as the independent variables most often associated with unrealistic model output. These variables should be the first priority for a sensitivity analysis. Users also questioned the reliability of the ingrowth and mortality functions, and stated that too many trees survive in moderately dense modeled stands.

Users also noted that SEAPROG mainly supported the analysis of conifer response, and did not adequately model the response of many hardwood species or the response of shrubs and ground-layer vegetation. Most of the issues users were dealing with were related to silvicultural treatment effects on wildlife and visual quality. Users seeking to maintain deer habitat wanted the ability to model understory shrub and herbaceous plant response to canopy openings and to schedule precommercial thinning to maximize release of understory plants and minimize hemlock regeneration.

Many users wanted SEAPROG to predict the effects of various levels of green-tree retention on residual tree growth, growth of the new cohort, and species composition. Furthermore, they wanted SEAPROG to link more easily with the Stand Visualization System (SVS) (McGaughey, n.d.), the Landscape Management System (LMS) (McCarter and others 1998), and geographic information systems (GIS) in order to visualize how individual stands and landscapes will appear immediately after treatment and as the stands develop.

When modeling the growth of mixed western hemlock-Sitka spruce stands from 15 to 20 years old to harvest age, users reported that, contrary to field observations, SEAPROG gradually eliminates hemlock from the stand. The effect becomes noticeable by 40 to 50 years and becomes more pronounced over time. The same users reported that, in their experience, about one-third of the area within naturally regenerated stands will be covered with codominant western hemlock at 60 years. They suspected that the model assumes a uniform mixture of hemlock and spruce within the stand and that the spruce is allowed to out-compete the hemlock because of the superior growth rate of spruce. In real stands, the distribution of trees by species may be more clumped and variable, which allows hemlock to persist.

Comparisons of Observed and Predicted Growth

Trees per acre—The residuals ranged from -287 to 659 TPA and their mean (bias) was 30 TPA, indicating that SEAPROG predictions were slightly higher on average than the observed trees per acre. Estimation of total error yielded a mean absolute residual of 45 TPA and a root mean squared residual of 103 TPA. Examination of the scatter diagrams (figs. 2a and 2b) revealed a change in the model behavior at a threshold of roughly 1,250 TPA. Below that density, SEAPROG generally overestimated TPA, in many cases by several hundred trees per acre. At higher densities

SEAPROG began to underestimate TPA, and the divergence between observed and predicted values increased greatly with increasing observed TPA. From our initial results that included the 12 overstocked plots, it appeared that the model consistently reduced density to below 3,000 TPA (fig. 1).

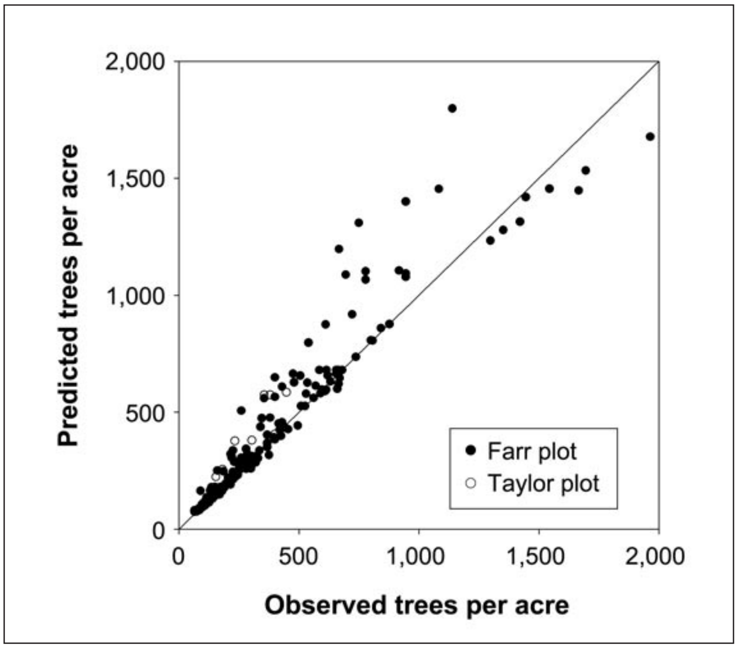

Figure 2a—Predicted trees per acre versus observed values (overstocked plots excluded). The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

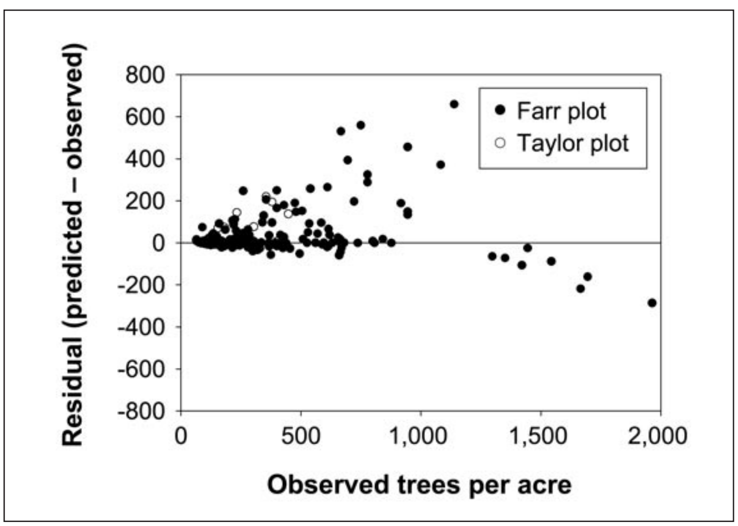

Figure 2b—Trees-per-acre residuals plotted over observed values.

Quadratic mean diameter—The residuals ranged from -4.8 to 1.8 in and their mean (bias) was -1.1 in, indicating that SEAPROG predictions were lower on average than the observed diameters. Estimation of total error yielded a mean absolute residual of 1.3 in and a root mean squared residual of 1.6 in. Examination of the scatter diagrams (figs. 3a and 3b) revealed that SEAPROG consistently overestimated QMD when the observed QMD was less than 5 in, usually underestimated QMD when the observed QMD was between 5 and 16 in, and consistently underestimated QMD when the observed QMD was greater than 16 in.

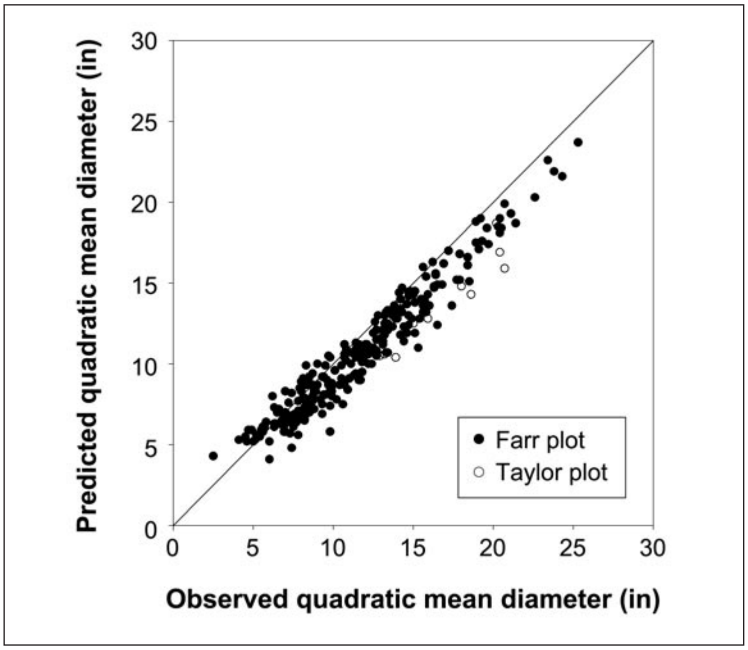

Figure 3a—Predicted quadratic mean diameter versus observed values. The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

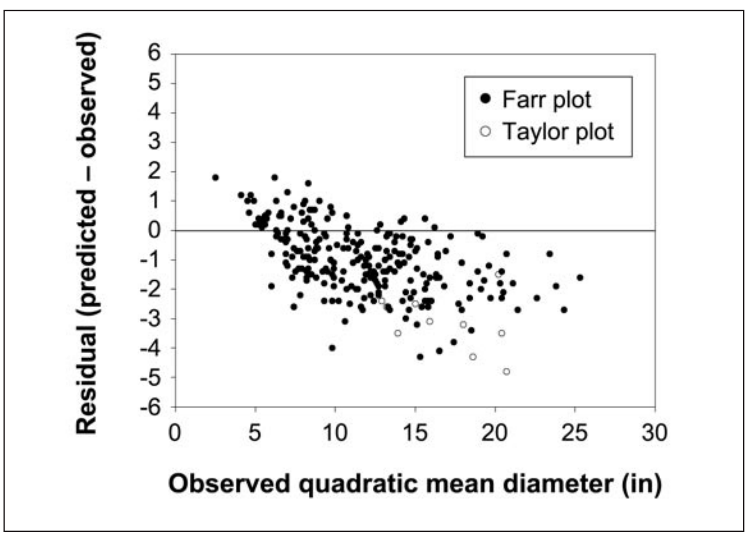

Figure 3b—Quadratic mean diameter residuals plotted over observed values.

Basal area—The residuals ranged from -118 to 109 ft^2/ac and their mean (bias) was -20.4 ft^2/ac, indicating that SEAPROG predictions were generally lower than the observed basal areas. Estimation of total error yielded a mean absolute residual of 32.7 ft^2/ac and a root mean squared residual of 40.2 ft^2/ac. Examination of the scatter diagrams (figs. 4a and 4b) did not disclose any marked change in the model's behavior over the range of observed basal area. SEAPROG tended to underestimate basal area across the entire range, with perhaps a slightly greater tendency to underestimate at basal areas greater than 300 ft^2/ac.

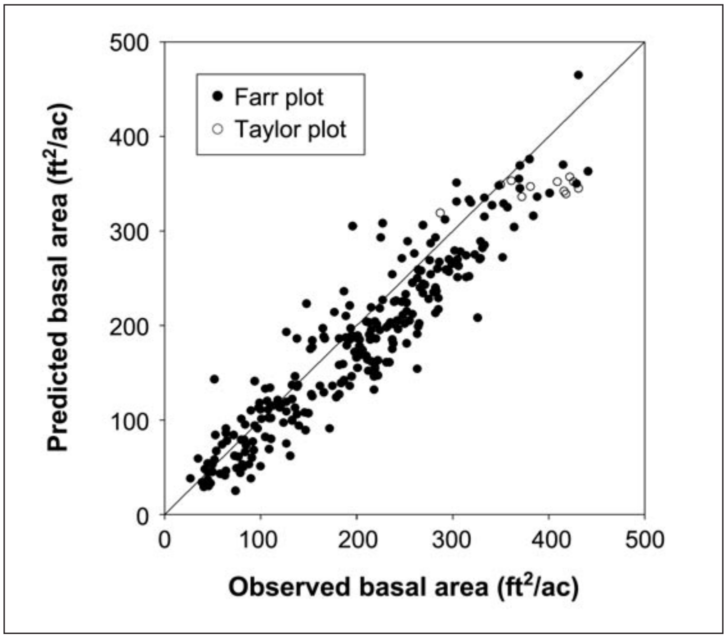

Figure 4a—Predicted basal area per acre versus observed values. The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

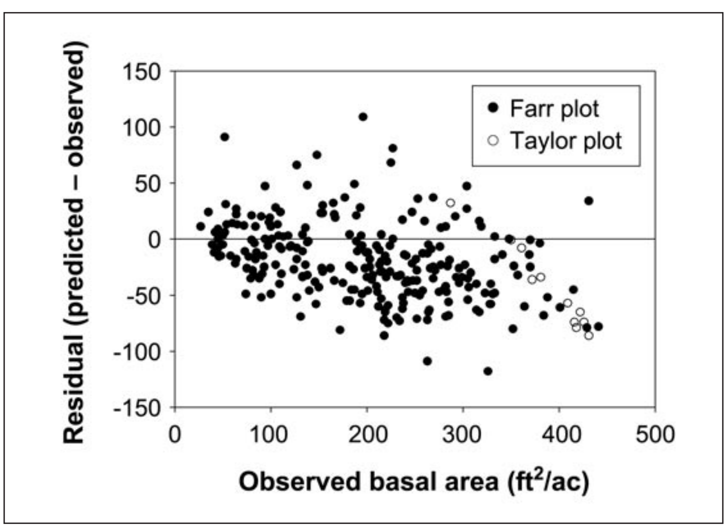

Figure 4b—Basal area residuals plotted over observed values.

Top height—The residuals ranged from -25 to 26 ft and their mean (bias) was -1.8 ft, indicating that SEAPROG predictions were lower on average than the observed tree heights. Estimation of total error yielded a mean absolute residual of 4.7 ft and a root mean squared residual of 6.3 ft. Examination of the scatter diagrams (figs. 5a and 5b) showed that SEAPROG tended to underestimate tree heights across the entire range of observed tree heights, but it was interesting to note that Taylor (older) plots accounted for the five most extreme height overestimates.

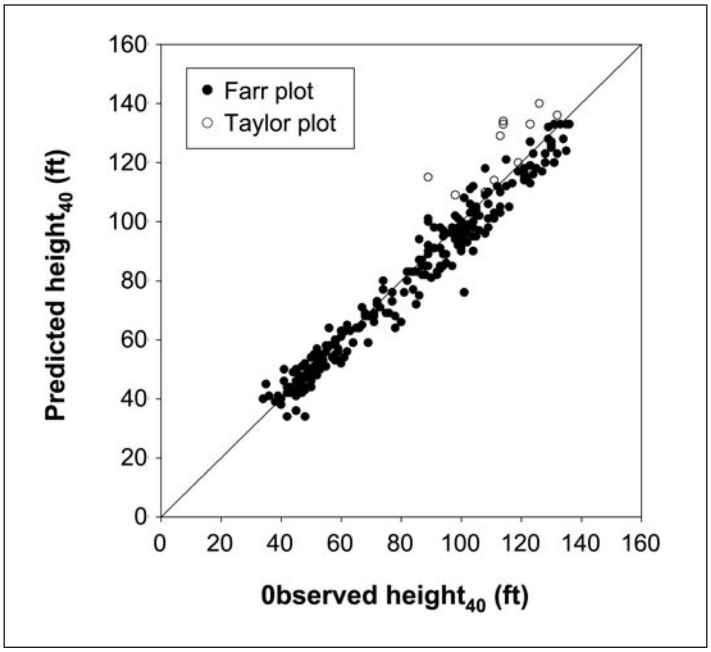

Figure 5a—Predicted height of the largest 40 trees per acre versus observed values. The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

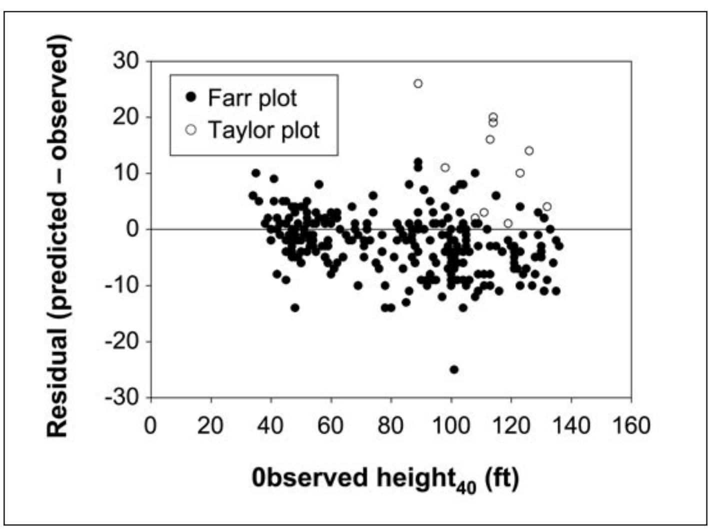

Figure 5b—Height residuals plotted over observed values.

Cubic-foot volume—The residuals ranged from -3,826 to 3,989 ft^3/ac and their mean (bias) was -407 ft^3/ac, indicating that SEAPROG predictions were generally lower than the observed cubic-foot volume per acre. Estimation of total error yielded a mean absolute residual of 982 ft^3/ac and a root mean squared residual of 1,259 ft^3/ac. The scatter diagrams (figs. 6a and 6b) showed that as the observed volume increased, the model's underestimation of volume became more pronounced.

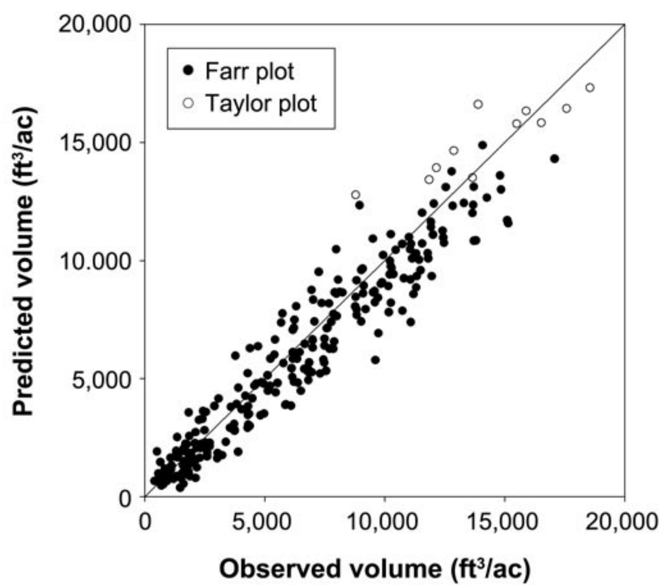

Figure 6a—Predicted cubic-foot volume per acre versus observed values. The line represents the equation y = x, the ideal case where the predicted values equal the observed values.

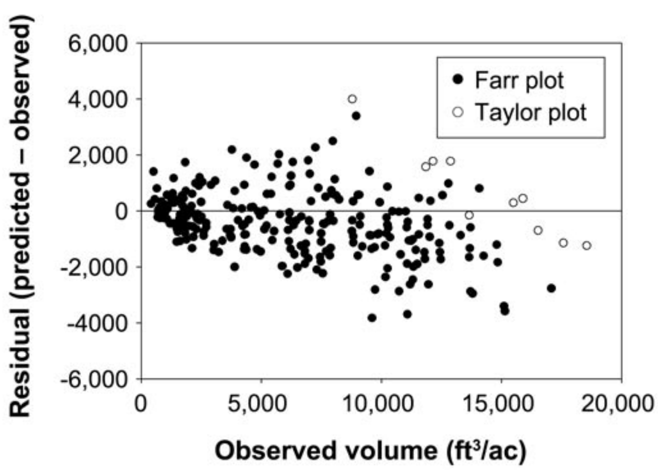

Figure 6b—Cubic-foot volume residuals plotted over observed values.

Board-foot volume—The residuals ranged from -21,834 to 18,414 board feet per acre (bf/ac) and their mean (bias) was -3,622 bf/ac, indicating that SEAPROG predictions were lower on average than the observed board-foot volume per acre. Estimation of total error yielded a mean absolute residual of 5,057 bf/ac and a root mean squared residual of 7,060 bf/ac. As with cubic-foot volume, examination of the scatter diagrams (figs. 7a and 7b) revealed an increasing tendency to underestimate board-foot volume as the observed volume increased.

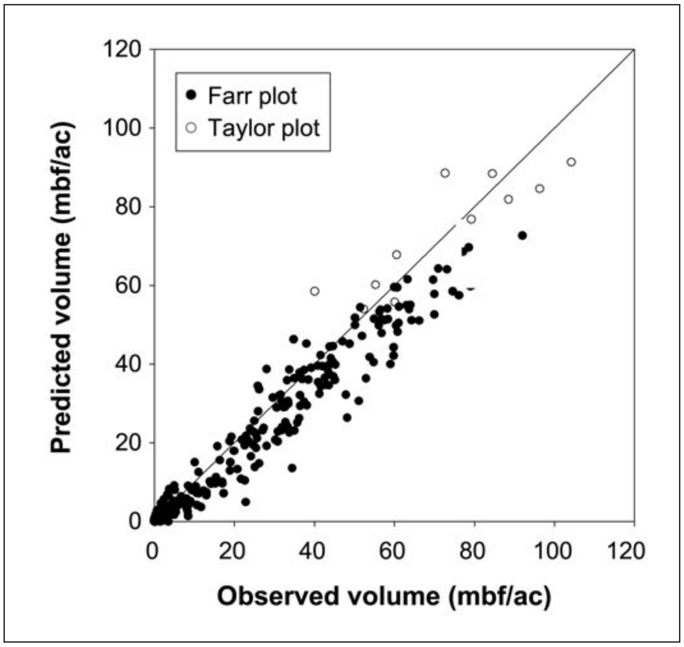

Figure 7a—Predicted board-foot volume per acre versus observed values. The line represents the equation y = x, the ideal case where the predicted values equal the observed values. (Note: mbf/ac = thousand board feet per acre.)

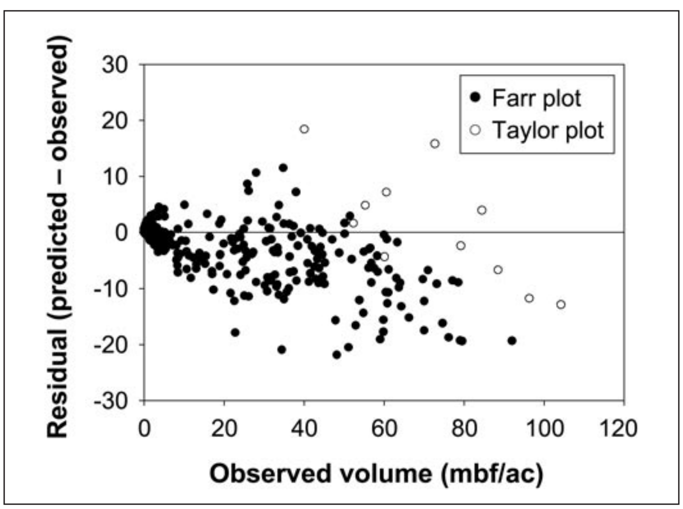

Figure 7b—Board-foot volume residuals plotted over observed values. (Note: mbf/ac = thousand board feet per acre.)

Effects of site and stand attributes—We examined the distribution of residuals over total stand age, site index, elevation, and slope, but did not find the effects of slope and elevation reported by users. Most of the plots were younger than 85 years, and we observed no strong patterns in residuals below that age. The small number of plots older than 85 years made it difficult to determine whether the height overestimation for the Taylor plots was due to their age or some feature of those plots, but we noted 11 plots from 100 to 120 years old where height was underestimated, so it does not seem likely that this is purely an age effect. When the plot site index (50-year basis) was 105 ft or greater, we observed a much greater tendency to underestimate QMD, BA, and both volume measures. The distributions of TPA and height residuals were not related to site index. Elevation had little effect on any of the residual distributions, which is not surprising given the limited range of elevation represented by the sample (all but four plots were below 500 feet above sea level). Slope varied more widely (0 to 50 percent), but it had no discernible effect on residuals.

Discussion

The low level of use and the lack of user confidence in SEAPROG predictions are troubling. Annual training sessions hosted by the Alaska Region and the continuing improvements to the model's graphical user interface should make potential users more comfortable with using the model. Recently improved linkages to GIS and visualization systems should address user concerns with the difficulty of displaying model predictions with those systems. Attempts to create a broader group of users—including wildlife biologists, fish biologists, and others concerned with the effects of vegetation management on forest resources—could also lead to wider use and application. These efforts will likely be in vain, however, until users view SEAPROG as reliable and able to model a wider range of silvicultural options and the response of all layers of forest vegetation.

No model is perfect, and users must expect and tolerate some deviation from a perfect relationship between observed and predicted values. Hopefully the deviation will be of a reasonable magnitude for the purpose at hand and will be free of systematic bias, that is, overall the deviations cancel out each other and the mean residual is close to zero. The magnitudes of the residuals we observed in our analysis—for all variables—were large enough to have important implications for the interpretation and use of the model's predictions. Of even greater importance was the evidence for substantial bias in quadratic mean diameter, basal area, height, and volume, all of which were systematically underestimated. Our results appear to validate the concerns expressed by users and suggest that the first task at hand is a search for the sources of the observed errors and a revision or recalibration of SEAPROG.

We recommend three additional tasks that could lead to greater reliability and use of SEAPROG. The first would be to conduct a sensitivity analysis of the independent site and stand variables used by the model to determine where unrealistic results occur. With the empirical data available to us, we were unable to duplicate the behavior reported by users. This was due to the limited range of elevation, slope, and stand age represented in the Farr and Taylor plots. To support future model development and validation efforts, additional permanent plots could be added to the Farr study to expand the range of site conditions represented. The second task is to evaluate existing information on tree growth and yield following partial cutting of old-growth stands and, where feasible, use it to calibrate SEAPROG. Examples include results from the retrospective Alternatives to Clearcutting (ATC) study (Deal and Tappeiner 2002), the experimental portion of the ATC study (McClellan and others 2000), and operational partial retention harvests. Finally, there is a need to incorporate into the model information on the response of understory plants to silvicultural treatments. This includes both intermediate treatments in young-growth stands and regeneration harvests in old-growth stands.

Another important effort is underway to incorporate the dynamics of damage agents into SEAPROG. Paul Hennon is working with the Forest Health Technology Enterprise Team (a detached unit of State and Private Forestry, Washington office) to incorporate a recently developed model of mistletoe spread (Trummer 1996, Trummer and others 1998) and a model of decay development following bole wounding of Sitka spruce and western hemlock (Hennon and DeMars 1997). Mistletoe and decay fungi are major damage agents in southeast Alaska, and this effort should improve the utility of the model.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	.3048	Meters
Acres (ac)	.405	Hectares
Square inches (in^2)	645	Square millimeters
Square feet (ft^2)	.0929	Square meters
Square miles (mi^2)	2.59	Square kilometers
Cubic feet (ft^3)	.0283	Cubic meters
Square feet per acre (ft^2/ac)	.229	Square meters per hectare
Cubic feet per acre (ft^3/ac)	.06997	Cubic meters per hectare
Trees per acre	2.471	Trees per hectare

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