Development of FVS^{Ontario}: A Forest Vegetation Simulator Variant and Application Software for Ontario

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Abstract—The Ontario Ministry of Natural Resources is leading a government-industry partnership to develop an Ontario variant of the Forest Vegetation Simulator (FVS). Based on the Lake States variant and the Prognosis^{BC} user-interface, the FVS^{Ontario} project is motivated by a need to model the impacts of intensive forest management strategies and the multiple ecological and social objectives faced by today's resource managers. Currently, the large tree diameter model and the small tree height model of the Lake States variant have been replaced with localized equations from data sets from the Great Lakes and Boreal forest zones of the province. A companion application, "Tree List Manager" has also been created to develop FVS tree-lists from the data collected through various field-cruising methods. Current efforts with the model involve the identification of equation weaknesses, improvement of user control on silvicultural treatments, and development of methods for populating stand species- and diameter-distributions for inventory polygons through enhanced forest inventory attribution using high resolution digital imagery combined with LiDAR and Individual Tree Crown classification approaches.

Ontario's Landbase

The province of Ontario, Canada, is made up of four main climactic forest types, ranging from sparsely-treed spruce in the northerly Hudson's Bay Lowland zone; wide expanses of jack pine and black spruce in the Boreal forest zone; white and red pine and tolerant hardwood species typical of the Great Lakes-St. Lawrence zone; and tolerant and mid-tolerant hardwood stands of the Deciduous zone (fig. 1). Productive forests supporting forest management activities represent 53 percent (56.8 million hectares) of Ontario's total landbase of 107.6 million ha.

Table 1 summarizes the leading species within the productive landbase and clearly shows that boreal black spruce (see table 1 for scientific names) and jack pine forests represent by far the largest area, with shade-intolerant groups like poplar and white birch representing an additional 18 and 9 percent respectively. Other important species in the transition between the Boreal and Great Lakes-St. Lawrence zones include balsam fir, white spruce, and cedar which, when combined, account for about 6 percent. The areal percentage of leading deciduous species in the Great Lakes-St. Lawrence and Deciduous zones is much smaller than the species leading in the Boreal zone: white and red pine, hard maple, oaks, yellow birch, other hardwoods and eastern hemlock comprise only about 12 percent of the productive landbase. Although these species represent much smaller portions of Ontario's total productive forest area, they account for the most species-diverse forest conditions within the province and are managed with a wide range of silvicultural practices and systems.

Shade-intolerant species in the Boreal zone are most commonly managed with the clear cut silvicultural system (table 2), the management system that most closely represents natural wildfire disturbance; nature's regeneration method for these predominantly even-aged species which require full light conditions to regenerate and grow to maturity. Species like white and red pine, poor-quality tolerant hardwood forests and mid-tolerant species like oak and yellow birch are managed through the application of the uniform shelterwood system. The shelterwood system, with its series of partial cuts, best emulates low-intensity ground fire disturbances, which along with wind, is the dominant natural regeneration method for these species. Uneven aged tolerant hardwood stands of good stem quality and site quality are managed with the single-tree selection silvicultural system. The single-tree selection system, with its series of partial cuts, best emulates the gap-phase replacement dynamics that normally occur in these ecosystems.

In: Havis, Robert N.; Crookston, Nicholas L., comps. 2008. Third Forest Vegetation Simulator Conference; 2007 February 13–15; Fort Collins, CO. Proceedings RMRS-P-54. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Figure 1—$\mathrm{FVS}^{\mathrm{Ontario}}$ has been parameterized for the province's Boreal and Great Lakes-St. Lawrence forest zones. From north to south, the four forest zones of Ontario shown here are: Hudson's Bay Lowland, Boreal, Great Lakes-St. Lawrence and Deciduous.

Table 1—Summary of leading species within Ontario's productive forest landbase.

Species	Common name	% Productive landbase area	
Picea mariana	black spruce	39.5	North
Pinus banksiana	Jack pine	14.2	
Populus tremuloides	poplars	18.1	
Populus balsamifera			
Betula papyrifera	white birch	9.5	
Abies balsamea	balsam fir	2.8	
Picea glauca	white spruce	1.0	
Thuja occidentalis	cedar	2.4	»
Pinus strobes	white pine	2.4	
Pinus resinosa	red pine	0.5	
Acer saccharum	hard maple	5.7	
Quercus sp.	oaks	0.9	
Betula alleghaniensis	yellow birch	0.5	South
Fagus sp.	basswood, beech	1.5	
Tilia sp.	("other hardwoods")		
Tsuga canadensis	eastern hemlock	0.5	

Table 2—Summary of prevalent stand management systems within Ontario.

Management system	Average annual harvest		Forest zone
	Hectares	Percent	
Clearcut	57,723	75	Boreal
Single tree selection	8,663	11	Great Lakes—St. Lawrence
Uniform shelterwood	6,769	9	
Seed tree	3,787	5	

Regeneration methods in Ontario include planting, aerial seeding and natural stem recruitment. This range of strategies may also rely on some level of mid-rotation thinning to accelerate tree diameter growth and to reduce the potential of stand stagnation.

Ontario's requirements from a growth and yield model are large. The model must be able to simulate stand development across a wide range of climatic and geological conditions, permit single and multi-species stand projections and provide for wide range silvicultural treatments to be simulated and evaluated.

Role of FVS^Ontario in Assisting Forest Management

Ontario's Growth and Yield program began evaluating suitable growth and yield models for the province's varied range of species and silvicultural methods in the 1990s. The Prognosis-FVS (Stage 1973) family of models rose to the top of the list as the most appropriate in meeting the majority of the required elements. These desirable elements include a modeling system that:

- Represents our current understanding of the dynamic forest ecosystem and how it responds over time to management interventions;
- Reduces uncertainty in strategic forest estate model inputs by providing empirical yield trajectories;
- Provides a monitoring target to test our assumptions with (for example, stand yield following different silvicultural treatments and successional pathways when no treatments are applied);
- Provides a modeling framework to integrate our existing modeling components such as taper equations, site index curves and ecological land classification;
- Provides a "gaming" or "what-if" tool to develop and compare various silvicultural treatments;
- Identifies gaps in our Growth and Yield "toolbox" and data;
- Visually animates a stand through time to inform and instruct professionals and the general public; and
- Provides Ontario with an appropriate tool to transform a static inventory into a dynamic one.

FVS^Ontario Development

A few years before similar efforts began in Ontario, work was begun by the British Columbia Ministry of Forests and Range (BCMoFR) to develop Prognosis^BC, a metric variant of FVS for interior British Columbia (Snowdon 1997). Prognosis^BC was initially based on the North Idaho variant of the model and was tailored to the province's southern interior forests. BCMoFR subsequently developed its own metric user interface (UI) driven by the needs of BC practitioners, along with a refit of all the FVS submodels. The Ontario Ministry of Natural Resources subsequently approached the BCMoFR, the USDA Forest Service and ESSA Technologies Ltd. to explore opportunities to leverage the benefits of work already developed, namely the source code for the Prognosis^BC interface and the source code for the Lake States (LS) variant of the FVS model. The LS-FVS variant was originally developed from the growth model—TWIGS (Miner and others 1988); a model that had some history of testing and application in Ontario (Payandeh and Papadopol 1994).

The LS variant of the model was linked into a cosmetically modified version of Prognosis^BC and renamed FVS^Ontario. Figure 2 illustrates the linkage of two Prognosis^BC UI components (SimProg and ViewProg) with the base LS variant model (Bush and Brand 1995). SimProg allows users to easily enter (and subsequently store and modify) stand conditions and perform silvicultural treatments. ViewProg allows simulation results to be viewed in tabular and graphic output forms.

A detailed exercise was undertaken by research modelers to use Ontario growth and yield plot data to determine how well the LS variant growth equations represented growing conditions north of the model's Great Lakes origins. Results of the validation exercise (Lacerte and others 2004) indicated that the LS variant did not adequately represent growing conditions throughout Ontario for the species tested, and that model calibration would be required. Comparisons of model and data predictions were particularly poor for the LS mortality model applied in Ontario.

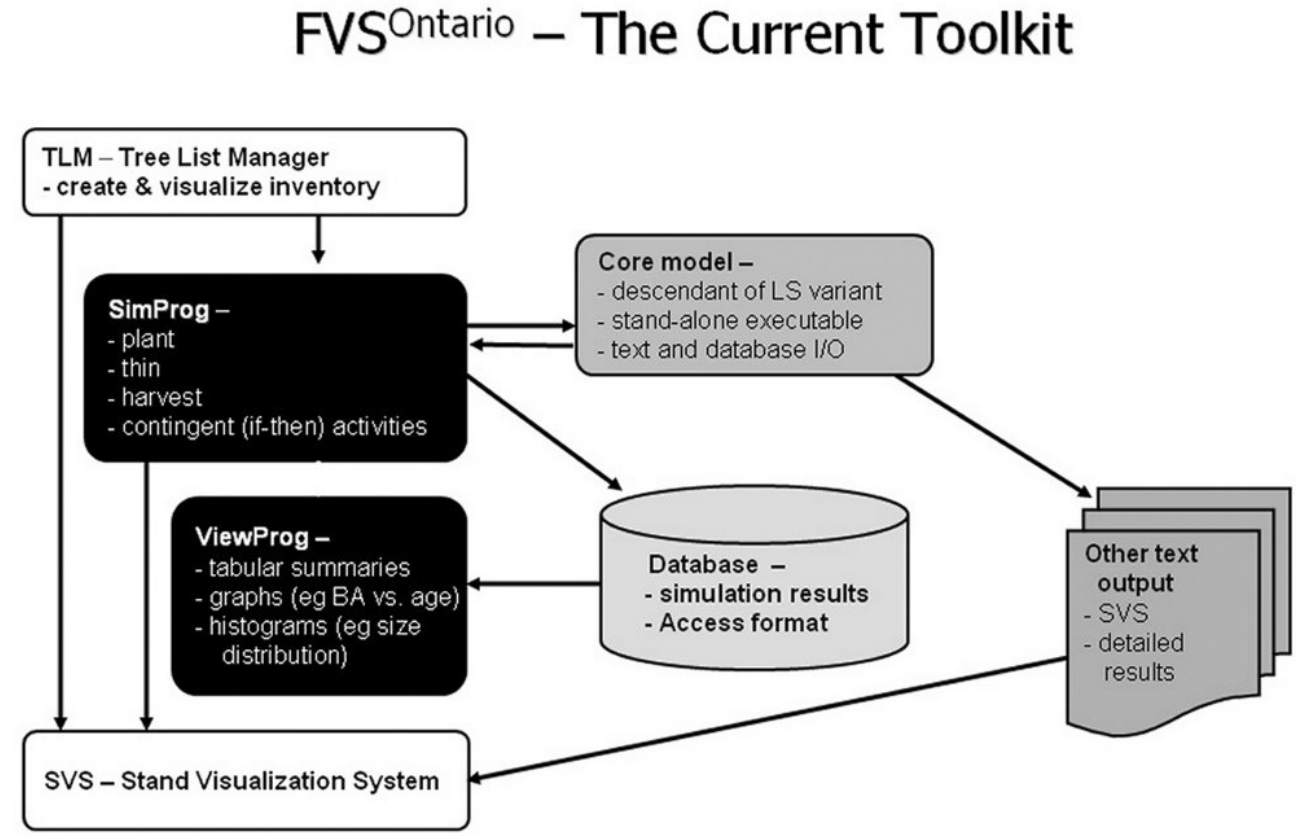


Figure 2—FVS^Ontario modeling system combines the core FVS model with SimProg and ViewProg interface programs, an Access database and SVS for visualization. TLM is used to create inventory treelists or SVS diagrams.

The next round of calibration of the large- and small-tree models was undertaken with a moderate number of Ontario growth and yield plots (Lacerte and others 2006a) and showed improved performance of the new model forms. These findings were later demonstrated in a validation report (Lacerte and others 2006b). However, with additional testing it became apparent that the revised model forms, while an improvement over the original LS equations, did not provide credible predictions across the full range of site conditions found in Ontario. These model shortcomings were the result of a reduced calibration data set available for the first round of 2006 calibration efforts.

Late in 2006, Ontario's maturing government-industry cooperative growth and yield efforts provided the FVS^Ontario team with a data set of over 172,000 remeasurement observations (Woods and Penner 2007) , about 66 percent more observations than were available to Lacerte in 2004. Accordingly, the submodels were recalibrated and model forms evaluated once more. As a result of the additional data, many model forms were modified from those of Miner and others (1988) and Lacerte and others (2006a).

Large Tree Diameter Model

A number of potential independent variables were evaluated for their ability to predict dbh growth. Most dbh-prediction equations appear to avoid height terms (for example, Lessard and others 2000), probably due in part to heights being measured on a sub-sample only, coupled with the significant measurement errors often found with height estimation. The final large tree diameter growth equation follows an exponential model that predicts annual diameter growth, subsequently scaled as required to the FVS cycle length:

$$ln(DG) = \beta_0 + \beta_1 ln(Dbh) + \beta_2 Dbh + \beta_3 BAL + \beta_4 HT + \beta_5 SI + \beta_6 BA + \beta_7 Dbh_q + \beta_8 AGS \quad [1]$$

The model terms include site index (SI), dbh, *ln*(dbh), quadratic mean diameter (QMD), stand basal area (BA), basal area in larger trees (BAL), height, and for some species a binary variable, "acceptable growing stock" (AGS). For some species that are extensively planted, separate equations were fit for natural and plantation stems (fig. 3).

Within the shade-tolerant hardwood group (hemlock, hard and soft maple, yellow birch, red oak, beech, white and black ash, basswood, ironwood, and black cherry), tree quality is identified in the stand exam as either acceptable (AGS) or unacceptable (UGS) growing stock. AGS is a partially subjective assignment that identifies individual trees that exhibit characteristics of high vigor and good stem quality. For the shade-tolerant hardwoods the AGS term is assigned a value of 1 if a tree is recorded as AGS, and a value of 0 otherwise. Including this term in the model assumes that these trees will maintain this quality over a cutting cycle, and empirical evidence supports this assumption. Since quality observations may not always be available during the stand exam, model equations without an AGS term (fig. 4) are also provided.

Predictions of diameter growth are constrained so that they do not exceed the 90th percentile of observations taken from the fitting data, preventing unrealistic extrapolation of growth estimates outside the range of data.

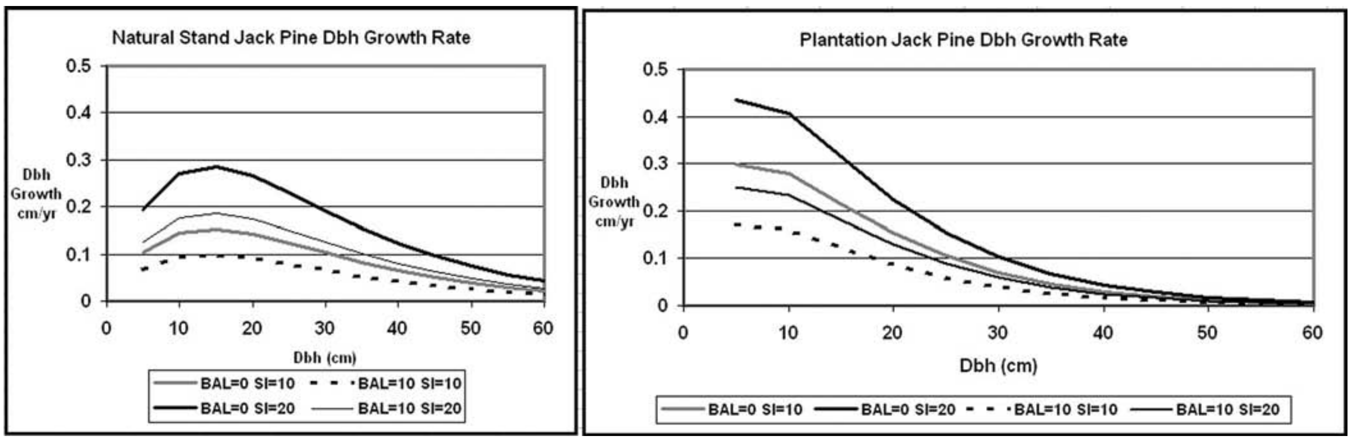


Figure 3—Models of annual diameter growth (cm yr¬–1) are fitted separately for naturally regenerated and plantation Jack pine. Model behavior is shown here for a variety of combinations of SI and stand BAL

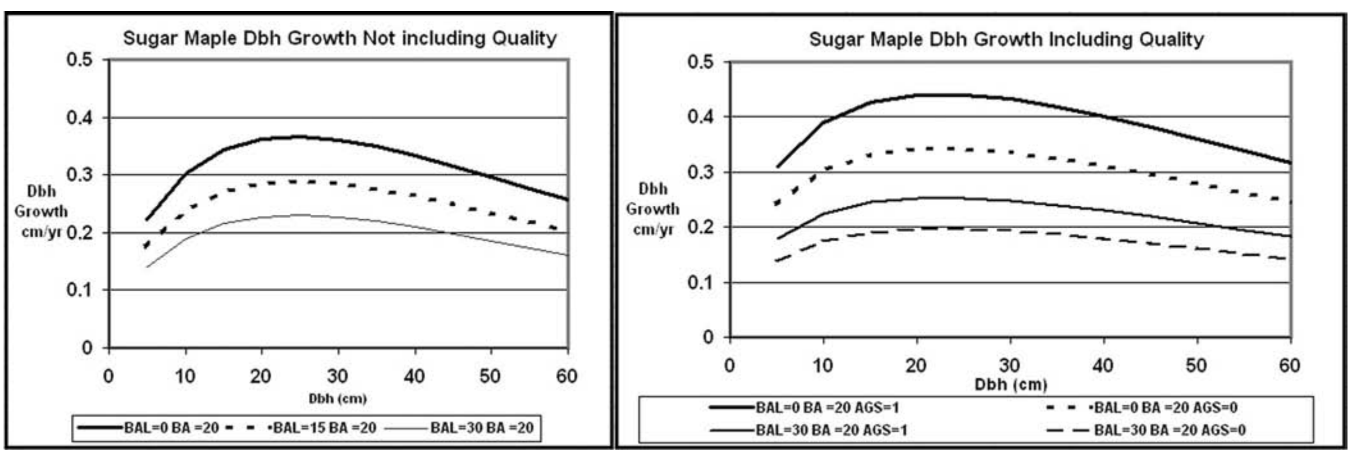


Figure 4—Models of annual diameter growth (cm yr¬–1) are fitted separately for sugar maple, with and without AGS criteria.

Large Tree Height Model

The LS-FVS large tree height model was modified to:

$$HT = 1.3 + \left(\beta_0 + \beta_1 SI + \beta_2 Dbh_q + \beta_3 BA\right)\left(1 - e^{\beta_4 Dbh^{\beta_5}}\right) \qquad [2]$$

Height model linear terms include Site Index, QMD and stand BA; dbh is present as the exponential allometric variable in equation 2.

Over the course of model development, the height equations have been revised to reflect the expanded dataset available. For species within the shade-tolerant hardwood group (hemlock, hard and soft maple, yellow birch, red oak, beech, white and black ash, basswood, ironwood, and black cherry), site index is often difficult to assess due to the mix of ages and species and the difficulty of finding trees that have not been suppressed at some point. Therefore, height equations with and without an SI term are fit to these species. For all other species, an SI term is included in the model. In addition, QMD and BA are admitted on a case by case basis only if they are statistically significant ($\alpha = 0.05$) for the species.

Small Tree Diameter Model

The small tree diameter growth model is implemented for trees smaller than 7.6 cm dbh as a rearrangement of the large tree height dubbing model (equation 2), simulating height growth (described below) and then solving for change in diameter. Although this expression loses the least squares solution property of the original formulation, it maintains compatibility between diameter and height. Predicted change in dbh is also constrained by the 90^th percentile of height growth from the original height equation.

Small Tree Height Model

Annual growth of small trees (<7.6 cm dbh) is modeled with an exponential formulation:

$$ln(HG) = \beta_0 + \beta_1 ln(HT) + \beta_2 HT + \beta_3 SI + \beta_4 BAL \qquad [3]$$

and includes terms for SI, BAL, HT and *ln*(HT). The small tree height growth model is similar to the conifer small tree height growth model of Lacerte and others (2006a): height growth increases as a function of height up to a maximum and then declines. Increasing SI has a positive effect on height growth and increased BAL a negative effect. The SI and BAL terms are included only if they are statistically significant ($\alpha = 0.05$). As with the large tree diameter growth model, predictions of height growth are constrained so that they do not exceed the 90^th percentile of observations taken from the fitting data, preventing extrapolation outside the range of data and unrealistic growth estimates.

FVS^Ontario User Interface

Modifications and additions to the original Prognosis^BC UI have been underway over the past few years for FVS^Ontario. While FVS^Ontario shares many of the same functional screens as Prognosis^BC, a great deal of effort has been invested in modifying and adding additional functionality required for Ontario species and silvicultural systems.

The FVS^Ontario screens include the following interface screens: site quality information for the species being modeled (fig. 5), input data source (existing stand or bare ground regeneration) (fig. 6), juvenile spacing treatments (fig. 7), thinning from above or below and by diameter class (figs. 8 and 9), single-tree selection (fig. 10), uniform shelterwood treatments (fig. 11) and seed tree harvest (fig. 12). In addition, a set of two forms were created to permit manual keyword entry (fig. 13) to allow users access to the full flexibility of the FVS modeling system.

FVS^Ontario provides a variety of output styles: tabular and graphical stand summaries (fig. 14), stand visualization through linkage to the Stand Visualization System (McGaughey 2002) and stand and stock tables (fig. 15).

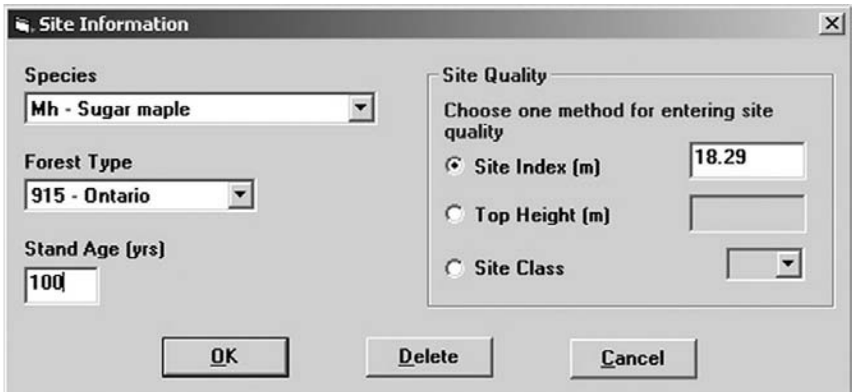


Figure 5—The FVS^Ontario site quality user interface form.

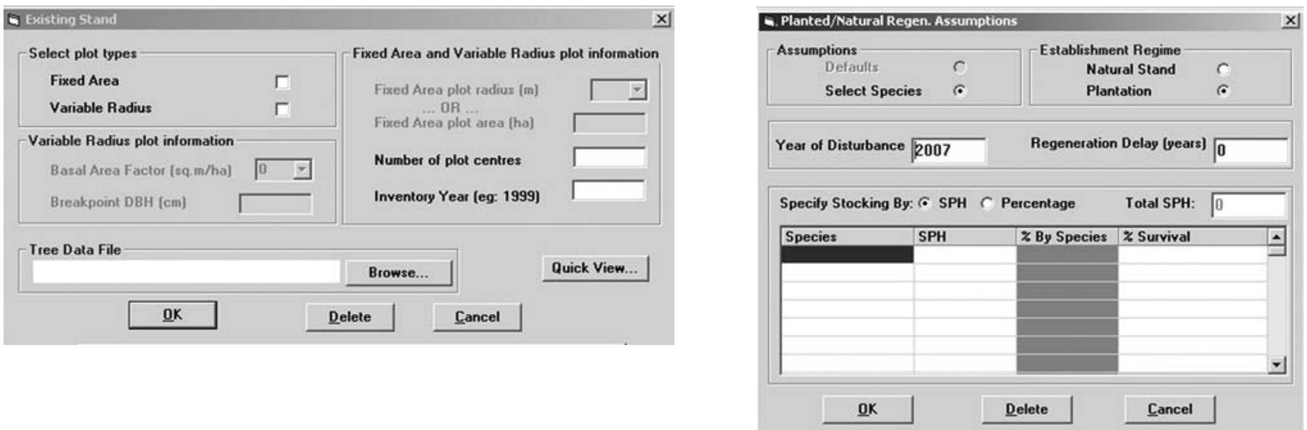


Figure 6—FVS^Ontario tree input format forms allow a model run to be initialized with an existing inventory (left) or through bare ground planting (right).

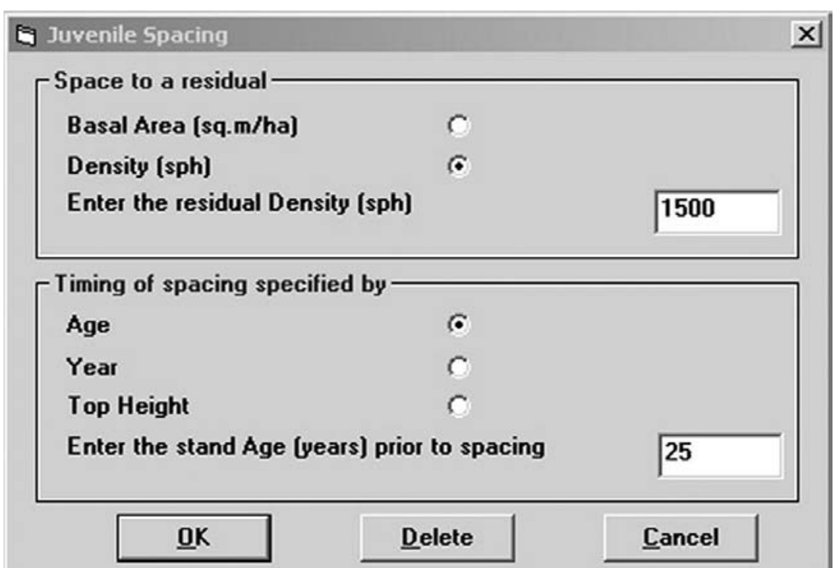


Figure 7—The FVS^Ontario juvenile spacing treatment interface allows spacing thinning using a variety of criteria.

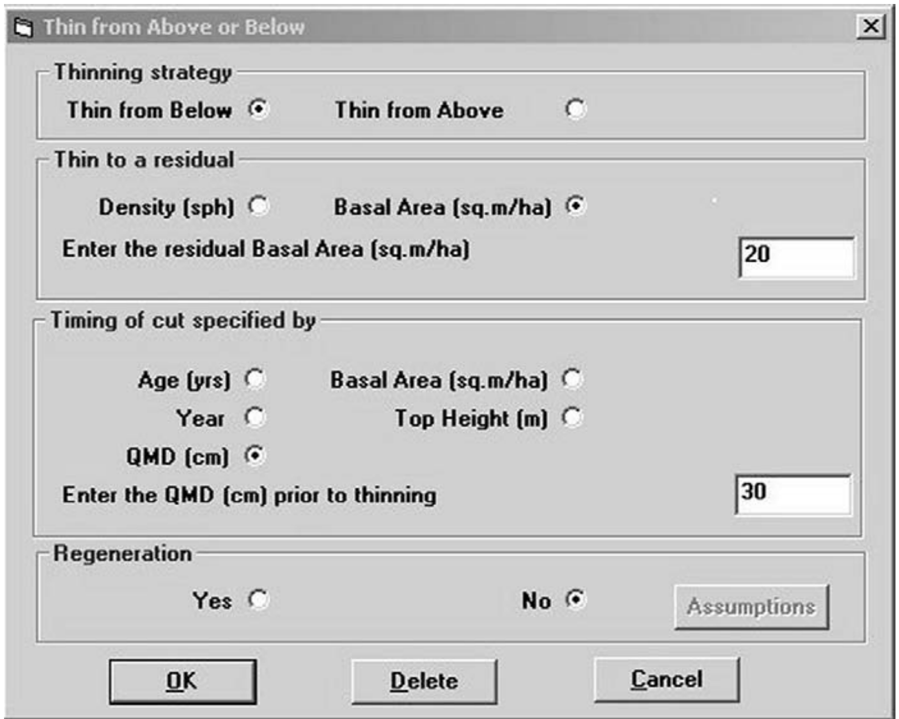


Figure 8—The FVS^Ontario thinning form allows thinning from above or below according to different criteria.

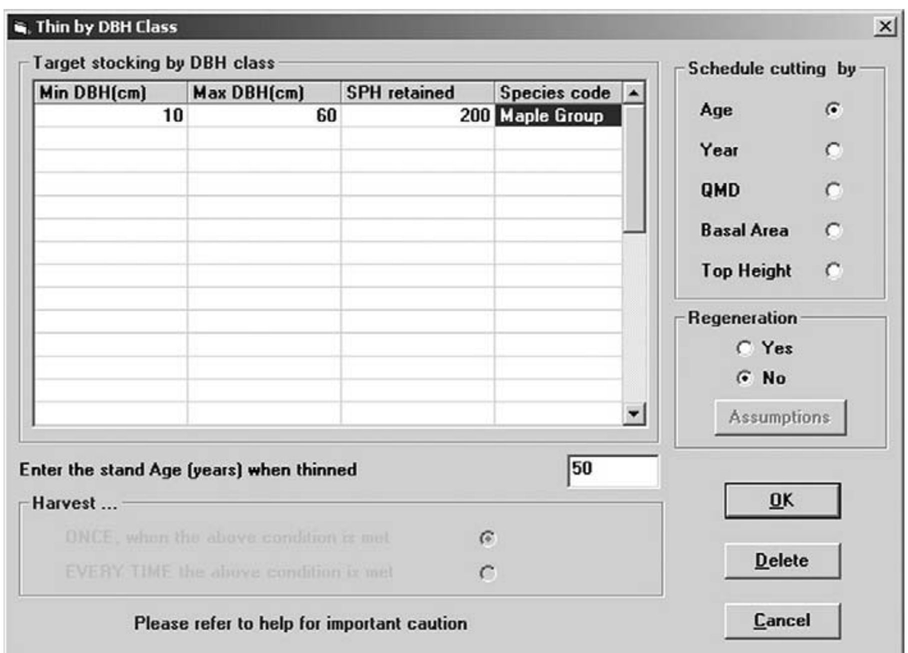


Figure 9—FVS^Ontario allows thinning by diameter class and species and can be scheduled by different criteria.

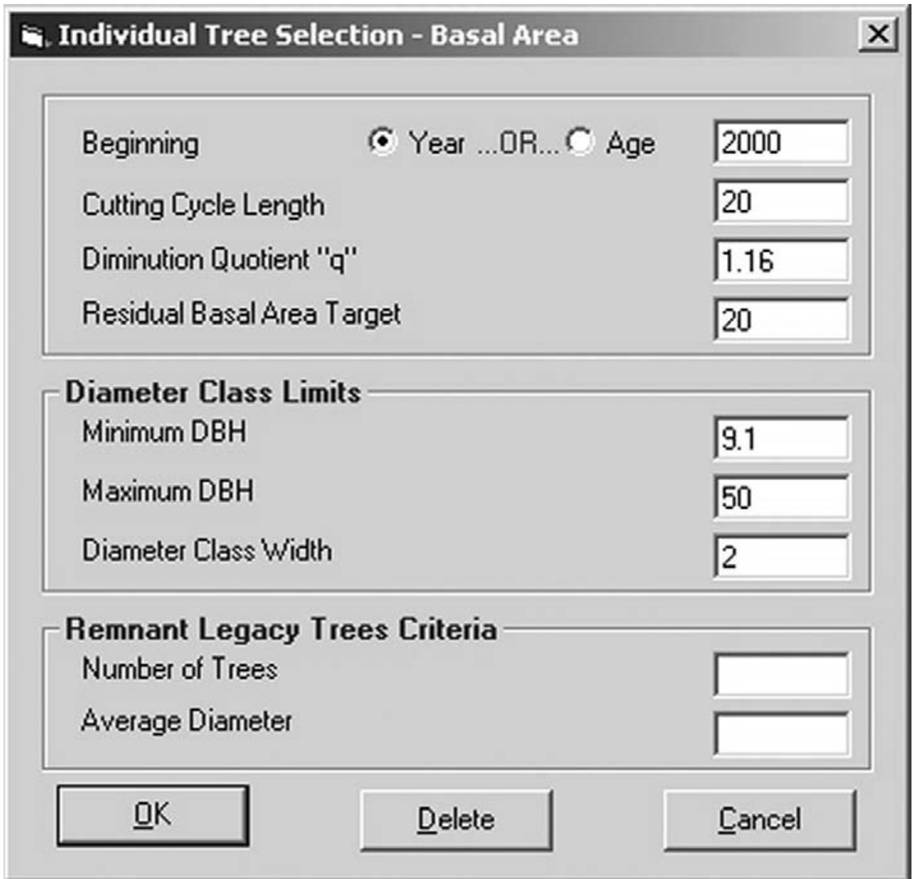


Figure 10—FVS[Ontario] allow single-tree-selection treatments, modeled after the same treatment form offered by the Suppose interface.

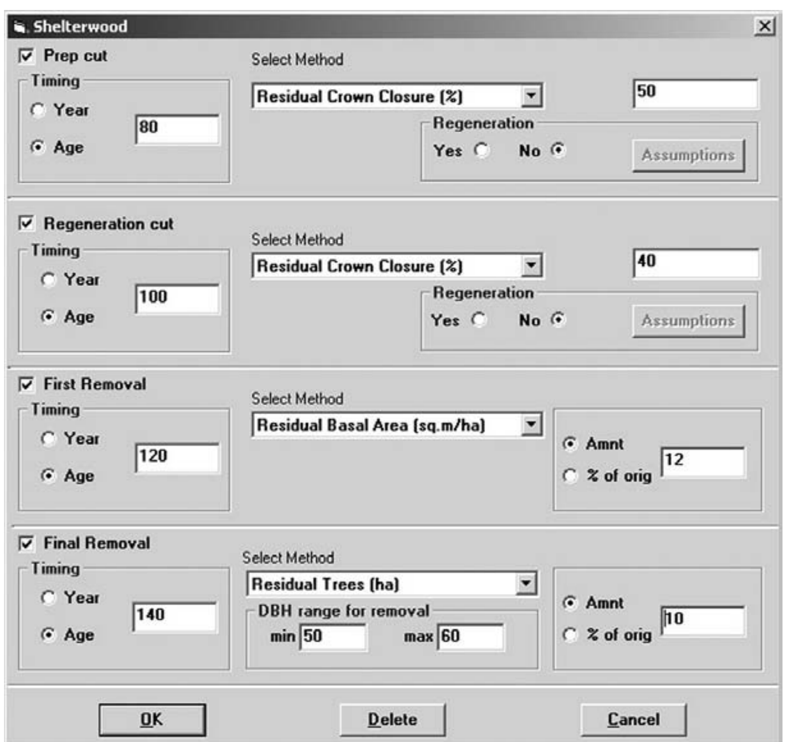


Figure 11—FVS[Ontario] allows users to carry out up to four stand entries in a uniform shelterwood treatment system.

Figure 12—FVS^Ontario allows a simple two entry seed tree harvest treatment.

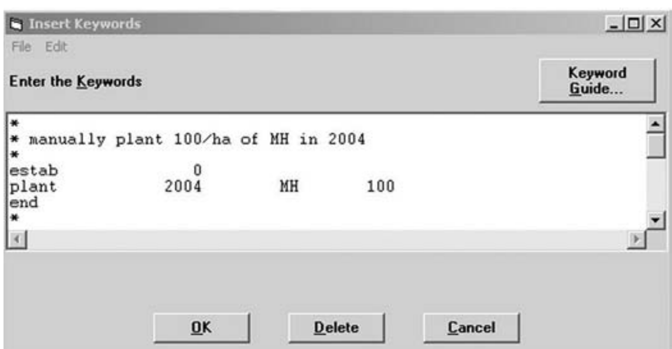
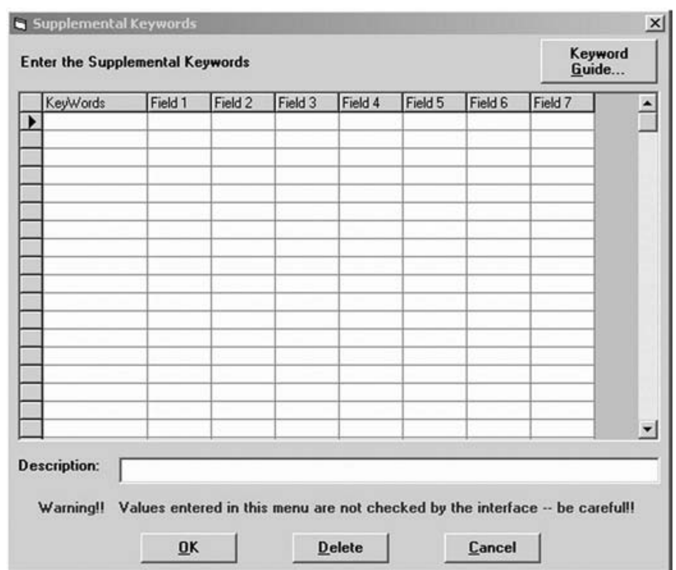
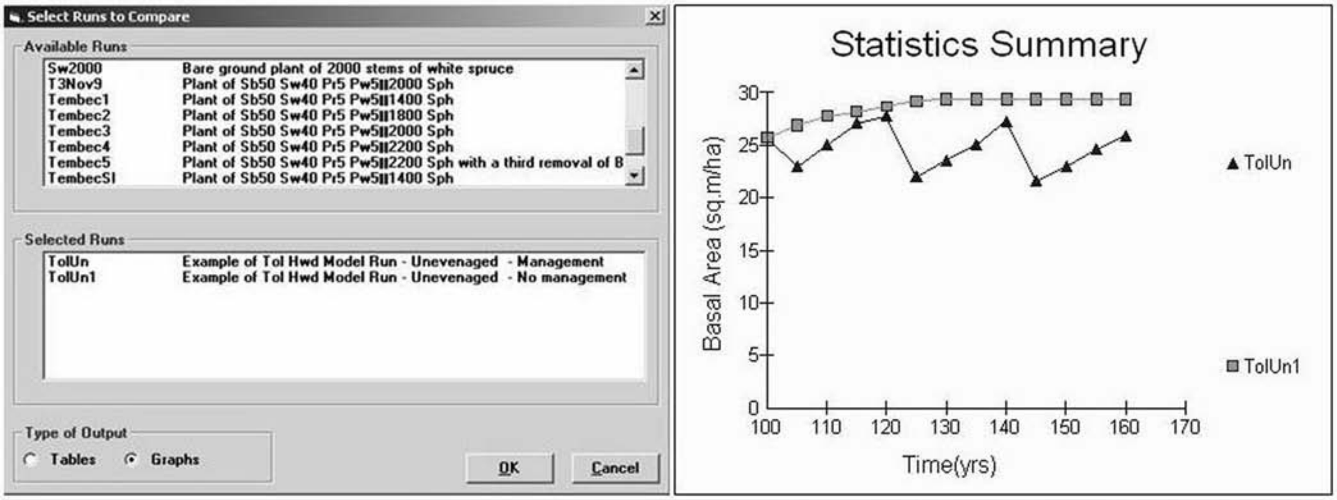


Figure 13—FVS^Ontario allows users to enter keywords in either free-form, as files (above), or in a structured grid (right).





Run_ID	Year	Time (yrs)	SPH	Total Gross Volume (cu.m)	Merch. Gross Volume (cu.m)	Basal Area (sq.m)	QMD (cm)	Top Height (m)	SPH (harv.)	Merch. Gross Volume (harv.)	Basal Area (harv.)	SPH (post-h)	Total Gross Volume (post-h)	Merch. Gross Volume (post-h)	Basal Area (post-h)	QMD (post-h)
TolUn	2006	100	909	180.9	169.3	25.7	18.9	22.6	35	37.2	4.6	874	142.4	132.1	21.1	17.5
TolUn	2011	105	907	160.7	149.1	23	18	22.6	0	0	0	907	160.7	149.1	23	18
TolUn	2016	110	867	176.4	164.1	25	19.1	22.9	0	0	0	867	176.4	164.1	25	19.1
TolUn	2021	115	835	193.3	180	27.1	20.3	23.2	0	0	0	835	193.3	180	27.1	20.3
TolUn	2026	120	764	203.5	189.8	27.8	21.5	23.8	126	55.9	7.4	638	145.1	133.9	20.4	20.2
TolUn	2031	125	697	158.3	146.6	22	20	23.8	0	0	0	697	158.3	146.6	22	20
TolUn	2036	130	660	169.5	157.4	23.6	21.3	24.1	0	0	0	660	169.5	157.4	23.6	21.3
TolUn	2041	135	625	180.5	168.1	25	22.5	24.4	0	0	0	625	180.5	168.1	25	22.5
TolUn	2046	140	615	204.6	190.4	27.3	23.8	24.7	106	53.3	7.1	509	146.7	137.1	20.2	22.5
TolUn	2051	145	692	164.3	153.4	21.6	19.9	24.4	0	0	0	692	164.3	153.4	21.6	19.9
TolUn	2056	150	655	185.3	172.7	23	21.1	24.7	0	0	0	655	185.3	172.7	23	21.1
TolUn	2061	155	635	209.8	195.4	24.6	22.2	25	0	0	0	635	209.8	195.4	24.6	22.2
TolUn	2066	160	603	224.9	209.8	25.9	23.4	25.3	0	0	0	603	224.9	209.8	25.9	23.4
TolUn1	2006	100	909	180.9	169.3	25.7	18.9	22.6	0	0	0	909	180.9	169.3	25.7	18.9
TolUn1	2011	105	850	195.9	183.3	26.9	20.1	22.9	0	0	0	850	195.9	183.3	26.9	20.1
TolUn1	2016	110	783	203.5	190.8	27.8	21.2	23.2	0	0	0	783	203.5	190.8	27.8	21.2
TolUn1	2021	115	717	209.7	196.7	28.2	22.4	23.5	0	0	0	717	209.7	196.7	28.2	22.4
TolUn1	2026	120	660	218.3	204.9	28.7	23.5	23.8	0	0	0	660	218.3	204.9	28.7	23.5
TolUn1	2031	125	610	222.8	209.4	29.2	24.7	24.1	0	0	0	610	222.8	209.4	29.2	24.7
TolUn1	2036	130	558	226.6	213.3	29.4	25.9	24.4	0	0	0	558	226.6	213.3	29.4	25.9
TolUn1	2041	135	511	227.3	214	29.4	27	24.7	0	0	0	511	227.3	214	29.4	27
TolUn1	2046	140	469	228.8	215.7	29.4	28.2	25	0	0	0	469	228.8	215.7	29.4	28.2
TolUn1	2051	145	432	233.2	219.7	29.4	29.4	25.3	0	0	0	432	233.2	219.7	29.4	29.4
TolUn1	2056	150	400	243.4	228.7	29.4	30.6	25.6	0	0	0	400	243.4	228.7	29.4	30.6
TolUn1	2061	155	368	252.7	237.1	29.4	31.9	25.6	0	0	0	368	252.7	237.1	29.4	31.9
TolUn1	2066	160	343	266.7	249.4	29.4	33.1	25.9	0	0	0	343	266.7	249.4	29.4	33.1

Figure 14—Some examples of simple FVS^Ontario graphic and tabular outputs.

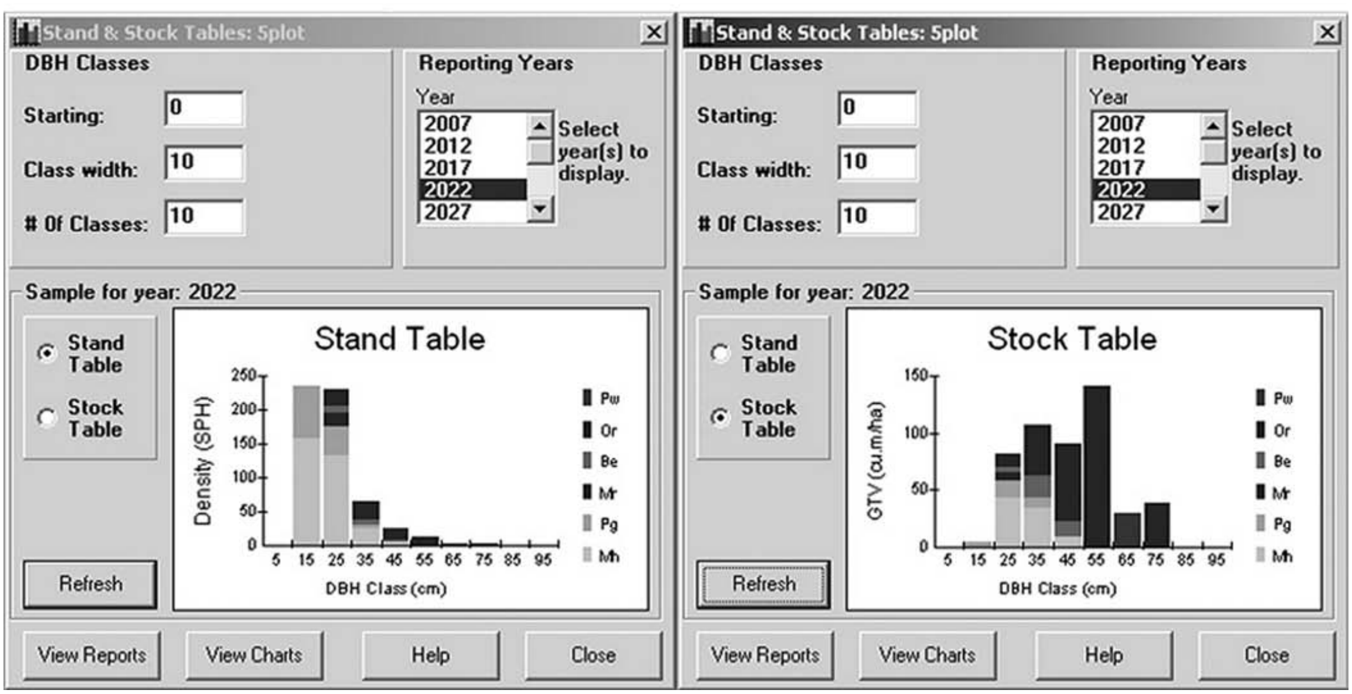


Figure 15—FVS^Ontario can produce stand and stock table figures and tables with user-defined size classes.

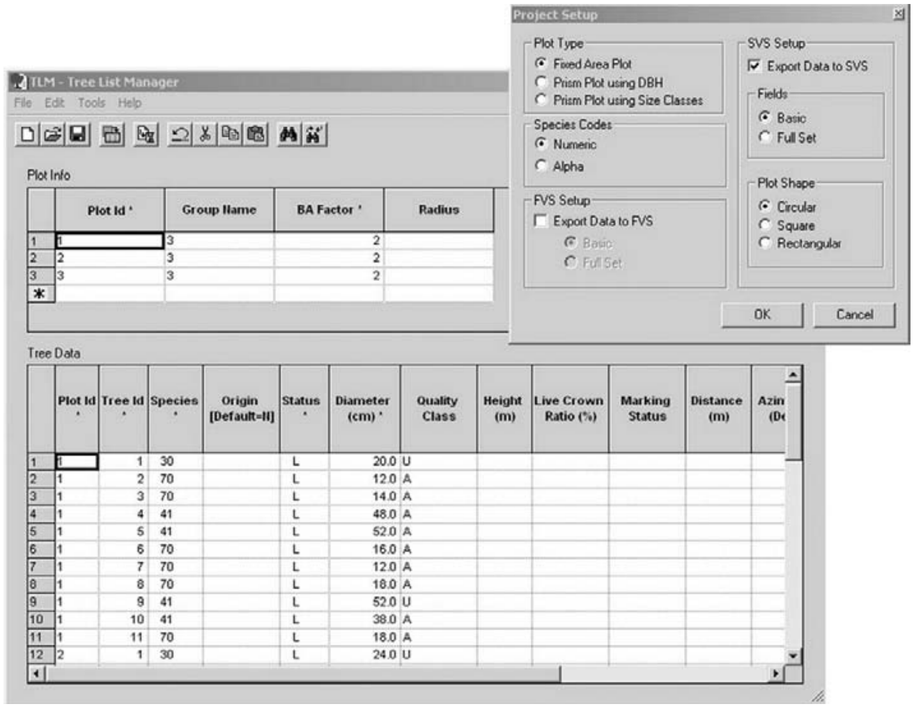


Figure 16—The companion Tree List Manager (TLM) software allows users to create or import inventories, producing FVS-ready treelists

Tree List Management Software

To support the necessary linkage between field-collected data and the stand projection, a software utility called the Tree List Manager Software (TLM) has been developed. TLM supports the entry of both fixed-area plot data and variable radius samples collected by a variety of methods (fig. 16). FVS-ready tree lists can be created directly through an Excel-like grid interface, or indirectly by importing from Excel, Access or DBF files. Users have the option of either exporting the compiled inventory as an FVS^{Ontario} treelist or as an SVS file.

Future Directions

FVS^{Ontario} has matured to the point where increased user testing and refinement is required. An expanded user group of resource managers is being provided the model along with training packages and online technical support to help determine the model's strengths and areas for refinement.

An increased technology transfer effort is also planned to support this new version of the model, and SVS continues to play a key role in visually explaining forest management practices to the lay population. The value of "cartoon" representations of time zero silvicultural treatments and fifty-year projections of the treatment have proven beneficial to increasing public participation in the forest management process.

Ongoing refinements to the model forms are provided by provincial program staff and through an extremely productive partnership with Michigan Technological University (MTU). With the help of MTU partners, new modeling approaches for growth and mortality are being explored using Ontario permanent sample plot data. As is the case with most variants, natural regeneration and mortality functions are a weakness in FVS^{Ontario}, and efforts will be focused on improving these areas.

Populating a stand level inventory with tree list information continues to be a challenge in Ontario and elsewhere. Recent advancement in Light Detection and Ranging Radar (LiDAR) technology may help to bridge this critical gap. In the past, LiDAR point density levels necessary to predict stand and tree attributes were prohibitively expensive and technologically limited. With the new 100 kHz sensors currently on the market, it is widely believed that these advances will soon provide a means to impute tree list information across forest inventory polygons. Optical tree crown classification methods based on the current suite of multi-band digital imagery products also holds great promise to bridge the gap between stand level inventories and individual tree model requirements. (Gougeon and Leckie 2003). Perhaps this goal may ultimately be achieved through the merging of these two technologies

Conclusions

FVS^{Ontario} has been developed through the cooperative partnerships of the Ontario Ministry of Natural Resources, BC Ministry of Forests and Range, USDA Forest Service, ESSA Technologies Ltd., Canadian Forest Service and Forest Analysis Ltd. All of these groups have openly provided software, advice or expertise to develop FVS^{Ontario} to its current state. This admirable arrangement has permitted Ontario to quickly develop a modeling system that will permit empirically-based growth estimates to provide support to sustainable management decisions now and into the future.

Acknowledgments

We express our appreciation to Don Vandendriesche at the Forest Management Service Center, who developed the Event Monitor keywords necessary to implement Individual Tree Selection.

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