Building the ECON Extension: Functionality and Lessons Learned

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Abstract—The functionality of the ECON extension to FVS is described with emphasis on the ability to dynamically interact with all elements of the FVS simulation process. Like other extensions, ECON is fully integrated within FVS. This integration allows: (1) analysis of multiple alternative tree-removal actions within a single simulation without altering "normal" stand development, (2) imposing financial effects dynamically in response to stand development and activities, (3) scheduling activities based on economic criteria with the Event Monitor, and (4) analyzing alternative rotation lengths within a single simulation. Outputs from ECON include investment decision indices (present net value, internal rate of return, benefit cost ratio, realizable rate of return, soil expectation value, value of forest, and value of trees) and harvested tree and log values. Designing, coding, and integrating the ECON extension into the FVS framework evoked new perspectives about the use and significance of FVS. The importance of FVS as a modeling environment within which multiple management issues can be simultaneously examined was recognized. The prominence of traditional model prediction precision was reassessed relative to the value of quantifying the marginal effects among stand developmental processes. Metrics from the FVS framework render a convergence of evidence for decision making that may be more valuable than prediction of absolute future conditions. The need for FVS to evolve as a framework, not just a growth model, was recognized, and a disciplined approach to extending FVS is proposed.

Introduction

The economic extension (ECON) (Martin 2008) to the Forest Vegetation Simulator (FVS) (Wykoff and others 1982) was developed to aid financial analysis of activities simulated with FVS. Two computer programs, CHEAPO (Medema and Hatch 1982) and CHEAPO II (Horn and others 1986) were developed in the 1980s to quantify economic impacts of timber harvests simulated with FVS. But, CHEAPO and CHEAPO II were "post-processors" designed to run after completion of an FVS simulation. Further, CHEAPO lacked interaction with the biological and management components available within FVS and its extensions during a simulation. For example, financial measures could not be used to "trigger" alternative actions during a simulation. This made economic analysis of silvicultural activities time-consuming and cumbersome by requiring multiple FVS simulations. Renner (2001) linked CHEAPO II with FVS demonstrating a proof-of-concept for an interactive approach (Renner and Martin 2002). But integration of the CHEAPO II code-base was problematical, prompting restructuring and re-writing, thus creating the ECON extension. Like other extensions, ECON interacts with multiple FVS components adding to the simulation framework created by FVS and its many extensions.

Extensions that are integrated into FVS allow simultaneous evaluation of multiple effects from alternative futures. For example (based on Renner 2001), assume two alternative prescriptions for a young mixed species stand: a "No Fuels Treatment" prescription consisting of thinning at 10, 30, 50, and 80 years and a "Fuel Treatment" prescription implementing the same thinning actions but with additional slash disposal. A wildfire is simulated in the stand at age 60 under both prescriptions. Outputs for each prescription over the simulated period include standing inventory (fig. 1) from the base FVS model (Wykoff and others 1982), surface fuels (fig. 2) from the Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003), and net present value (fig. 3) from the ECON Extension (Martin, in review). Examination of the figures reveals the following: standing timber volume is nearly identical between the prescriptions even after wildfire; surface fuels are reduced only temporarily following thinning; and present net value is substantially reduced for the Fuel Treatment prescription. Despite the added expenditure for slash disposal, the Fuel Treatment appeared to have little effect on reducing long-term surface fuel loading or protecting timber from wildfire. Based on metrics provided by FVS, ECON, and FFE managers might conclude that the added costs for slash disposal was both economically and biologically inefficient as a means of wildfire protection.

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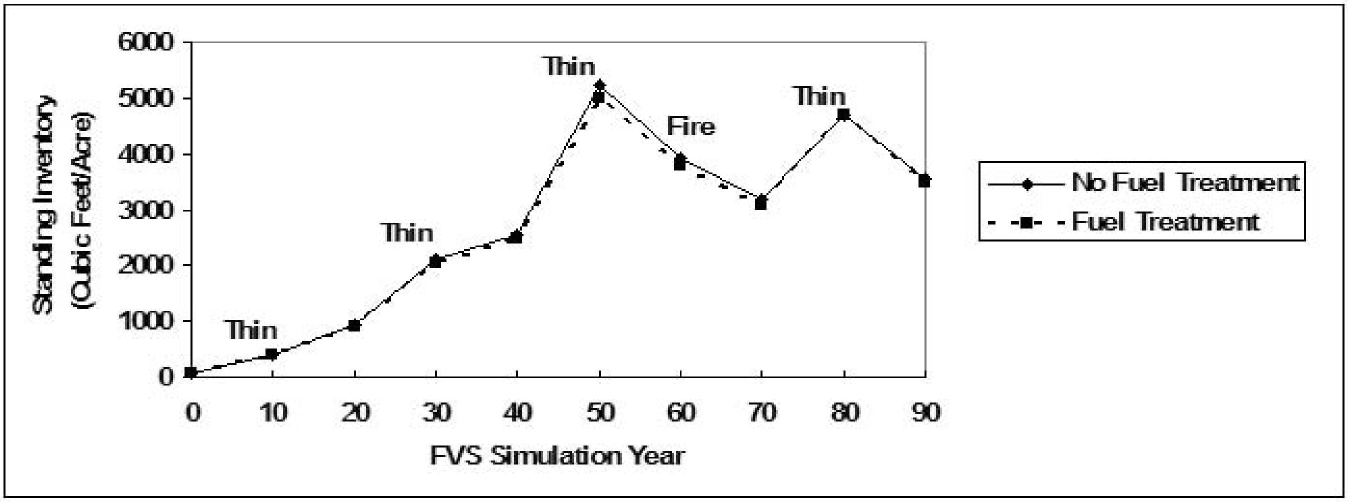

Figure 1—Standing inventory for Fuel Treatment and No Fuel Treatment alternative prescriptions.

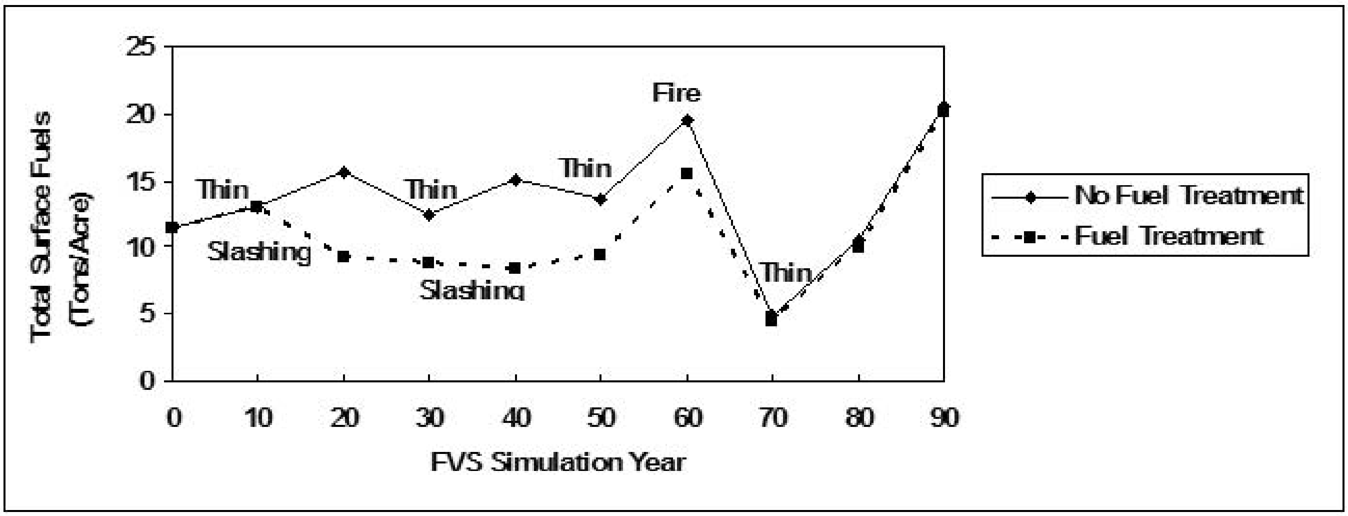

Figure 2—Total surface fuels for Fuel Treatment and No Fuel Treatment alternative prescriptions.

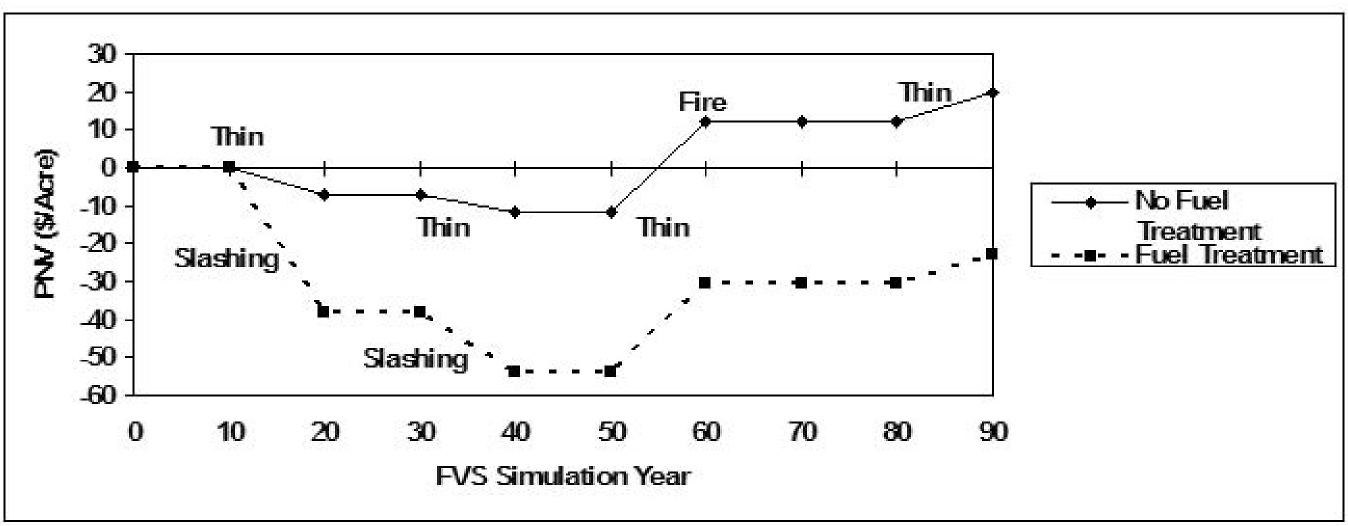

Figure 3—PNV for Fuel Treatment and No Fuel Treatment alternative prescriptions.

This paper describes: (1) the functionality of the ECON extension, (2) the economic questions that motivated the design of ECON, and (3) lessons learned during the development and integration of ECON into FVS. Familiarity with both FVS and economic analysis is assumed. Operational details about ECON can be found in the ECON User's Manual (Martin 2008).

Functionality

Operation of FVS is managed using keywords that users prepare to communicate input parameters and to control model actions. In the case of ECON, users enter keywords that specify the costs and revenues that govern the financial valuation of activities simulated by FVS. Keywords permit specifying the following costs: (1) costs that occur annually regardless of stand actions, such as land rents, road maintenance, taxes, etc.; (2) costs resulting from regeneration and site preparation events simulated by FVS regeneration sub-models; and (3) pre-commercial and commercial thinning and harvest costs resulting from FVS thinning keywords. Additionally, a special cost keyword can expense any activity that can be accessed using the Event Monitor (Crookston 1990), such as burning, fertilizing, or pruning events. Similarly, keywords permit specifying: (1) revenues that occur annually regardless of stand actions, such as recreation leases, non-timber vegetation revenues (e.g., mushrooms), etc., and (2) revenues from commercial timber harvests. Multiple revenue keywords can be used to specify different dollar values for individual species, different tree and log diameter classes, and different units of measure (number of harvested trees, harvested board feet, or harvested cubic feet). Another keyword allows specifying criteria for determining pre-commercial from commercial harvests based on harvested tree size and harvested volume. Finally, a special revenue keyword can accrue revenue from any activity assessed using the Event Monitor, such as valuing carbon sequestration or bough production.

Inflation and other financial conditions can alter costs and prices over time. To accommodate such events, costs and prices can be appreciated or depreciated. These changes, known as value rate changes, can be specified individually on all cost and revenue keywords. Multiple value rate changes can be entered for each keyword allowing rate changes to be altered over time and applied for specific periods. Value rate changes can also be used to depreciate a cost or price to zero, thus terminating a cost or revenue. For example, an annual weed control charge required for the first ten years of stand establishment could be terminated at the end of ten-years using value rate keyword records.

ECON can be started at any time, even within an FVS cycle, which permits ECON to start after growing an inventory to the current year or after some initial stand treatment. The investment period over which costs and revenues are evaluated can also be re-initialized during a simulation, permitting analysis of multiple management regimes within a single simulation. Costs and revenues are accumulated and discounted annually within each investment period, and the following economic measures can be computed and reported at the end of each FVS cycle:

- Present net value (PNV)
- Internal rate of return (IRR)
- Benefit cost (BC) ratio
- Realizable rate of return (RRR)
- Soil expectation value (SEV)
- Value of forest
- Value of trees

PNV, IRR, BC ratio, RRR, and SEV are defined and computed as per standard economic and management practices (Davis and Johnson 1987). "Value of forest" is the term used to describe the PNV of cash flows from managing the existing stand (trees) plus the SEV, where SEV represents the inherent value of the land to produce perpetual timber crops under a specified management regime. SEV is discounted for the delay period until the existing stand is harvested and the future regime represented by SEV can be initiated. "Value of trees," also known as "reprod value," is the PNV of cash flows from harvested trees separate from the inherent value of the land. Relevance of "value of forest" and "value of trees" metrics is discussed below. These computed decision indices along with undiscounted and discounted costs and revenues are passed from ECON to the Event Monitor and are available for use in scheduling activities or defining new variables.

The integration of ECON with FVS permits additional functionality beyond that possible with the CHEAPO post-processers, including: (1) the ability to evaluate multiple harvest scenarios within a single simulation, (2) the ability to schedule management activities based on economic measures with the Event Monitor (Crookston 1990), and (3) the ability to dynamically initiate and value future management prescriptions. Central to ECON design is that only simulated activities are valued, i.e., standing inventory is not valued, as was the case with the CHEAPO post-processors. Harvest costs and revenues are applied only to harvests resulting from execution of FVS thinning keywords.

To allow modeling of multiple alternative harvest scenarios in a single FVS simulation, the "PRETEND" keyword was developed. This ECON keyword is used in conjunction with FVS thinning keywords. When active, the PRETEND keyword allows harvests to be simulated but prevents removal of the harvested trees from the FVS internal tree list upon execution of a thinning keyword. Normal (i.e., without harvest) stand development in the current or future cycles is not affected because the internal tree list is not changed. This allows the modeler to analyze any number of different hypothetical, or pretend, harvests completely independent of and unaffected by previous "pretend" harvests. Each "pretend" harvest is restricted to the FVS cycle in which it occurs and hence has no effect on either past or future actual (harvests that remove trees from the FVS internal tree list) or "pretend" harvests. Any number of PRETEND keywords can be submitted by the user, permitting activation and inactivation of the PRETEND functionality at will during a simulation. In this way, both actual and "pretend" harvests can each occur in different cycles. When the PRETEND keyword is active ECON metrics (PNV, etc.) computed from the harvest costs and revenues are confined to that cycle, allowing the user to examine mutually exclusive harvest alternatives at different time periods. Hence, multiple hypothetical harvest scenarios can be analyzed in a single simulation without changing the normal stand development.

ECON produces two types of output at each FVS cycle - summary measures and harvest values. The Economic Analysis Summary Table (fig. 4) displays the undiscounted and discounted costs and revenues, and computed decision indices (PNV, etc.) over the investment period. When the PRETEND keyword is active, costs and revenues from a "pretend" harvest are reported only in the respective cycle, they are not accumulated across cycles. Costs and revenues not associated with "pretend" harvests accrue across all cycles of the investment period. The decision indices computed depend on the type of analysis being conducted, i.e., is SEV being computed or is SEV input by the user. A Harvest Volume and Gross Value Table can be generated (fig. 5) whenever a harvest occurs during a cycle. This figure summarizes harvest volumes and revenues by species and by tree diameter at breast height (dbh) and log small-end diameter inside bark (dib). Reported harvest characteristics include trees per acre, tons per acre, cubic, and board foot volumes, along with the dollar value for each characteristic. Reported characteristics and values are controlled by harvest revenue keywords that permit pricing by species, size classes, and units of measure. Harvest characteristics and values are produced for both actual and "pretend" harvests.

Motivating Questions

Five economic questions motivated the development of ECON. Addressing these questions required functionality not in the CHEAPO systems, such as the ability to analyze multiple harvest possibilities within the same simulation or to dynamically initiate silvicultural actions using the Event Monitor. Although ECON can be used to address many potential economic issues, these five financial questions guided its development:

1. When is the economically efficient time to harvest an existing stand?
2. What is the value of forestland for timber production?
3. Given an existing stand and its forestland value, when is the economically efficient harvest time?
4. Given harvest deferral of an existing stand until a target condition is achieved, what is the forestland value for timber production that maintains the target condition?
5. Given an existing immature stand having a known land value, what is the value of the immature trees ("reprod" value)?

These questions are elaborated below with the intent of emphasizing the dynamic nature of the procedures used in their analysis. Worked examples of the questions, including

A) FVS/ECON EXTENSION VERSION 1.0

STAND ID: Compute_SEV MANAGEMENT CODE: NONE - Dynamically initiate and value a proposed prescription

ECONOMIC ANALYSIS SUMMARY TABLE (DISCOUNT RATE: 4.0%)

YEAR	INVEST-MENT PERIOD	PRETEND MODE IS ACTIVE	UNDISCNTED VALUES COSTS	UNDISCNTED VALUES REVENUES	PRESENT VALUES COSTS	PRESENT VALUES REVENUES	PNV	INTERNAL RATE OF RETURN %	B/C RATIO	REALIZABLE RATE OF RETURN %	SEV	VALUE OF FOREST	VALUE OF TREES
2004	10	NO	0	0	0	0	0						
2014	20	NO	0	0	0	0	0						
2024	30	NO	0	0	0	0	0						
2034	31	NO	1062	6361	315	1886	1571	> 50.0	5.99	10.2			
2035	9	NO	50	0	48	0	-48		0.00		-162		
2044	19	YES	60	0	48	0	-48		0.00		-92		
2054	29	YES	50	0	48	0	-48		0.00		-71		
2064	39	YES	50	0	48	0	-48		0.00		-61		
2074	49	YES	50	0	48	0	-48		0.00		-56		
2084	59	YES	684	1622	137	228	91	6.3	1.66	4.9	101		
2094	69	YES	1110	3337	149	317	168	6.7	2.13	5.1	180		

B) FVS/ECON EXTENSION VERSION 1.0

STAND ID: Evaluate_SEV MANAGEMENT CODE: NONE - Economically efficient time to implement a future prescription

ECONOMIC ANALYSIS SUMMARY TABLE (DISCOUNT RATE: 4.0%, FOREST/TREE VALUES BASED ON USER-SUPPLLIED SEV: $154)

YEAR	INVEST-MENT PERIOD	PRETEND MODE IS ACTIVE	UNDISCNTED VALUES COSTS	UNDISCNTED VALUES REVENUES	PRESENT VALUES COSTS	PRESENT VALUES REVENUES	PNV	INTERNAL RATE OF RETURN %	B/C RATIO	REALIZABLE RATE OF RETURN %	SEV	VALUE OF FOREST	VALUE OF TREES
2004	10	YES	1181	1407	1131	1352	221	> 50.0	1.20	5.9		391	237
2014	20	YES	1454	1828	946	1187	241	46.6	1.25	5.2		356	202
2024	30	YES	1620	2328	723	1022	298	21.2	1.41	5.2		375	221
2034	40	YES	1753	3082	543	914	370	14.8	1.68	5.4		422	268
2044	50	YES	1801	3868	395	775	380	11.4	1.96	5.4		415	261

Figure 4—Economic Analysis Summary Tables from two different simulations. A) In this simulation SEV was computed over time for a future stand after the existing stand was harvested in year 2034. The most economical efficient future prescription is achieved with a 69 year rotation period when SEV equals $180. B) In this simulation the preferred harvest time for an existing stand was assessed assuming a known land value (shown by "USER-SUPPLIED SEV: $154"). The most economically efficient harvest time is year 2034 when the "value of forest" is greatest ($422), ten years earlier than maximum PNV.

HARVEST VOLUME AND GROSS VALUE TABLE

YEAR = 2034 - PRETEND HARVEST: NO

SPECIES	SMALL-END DIB MIN	SMALL-END DIB MAX	TREE DBH MIN	TREE DBH MAX	TPA REMOVED	TPA VALUE $	TONS/ ACRE	CU FT REMOVED	CU FT VALUE $	BD FT REMOVED	BD FT VALUE $	TOTAL VALUE $
DF			6.0	10.0	14	0						0
DF			10.0	20.0	65	0						0
DF			20.0	999.9	10	0						0
DF	4.0	10.0								5203	780	780
DF	10.0	16.0								14497	4349	4349
DF	16.0	18.0								1055	369	369
DF	18.0	20.0								115	46	46
DF	0.0	999.9						3783	0			0
WH			0.0	999.9	10	0						0
WH	6.0	10.0								407	20	20
WH	10.0	20.0								5889	589	589
WH	20.0	999.9								795	199	199
WH	6.0	10.0						111	0			0
WH	10.0	20.0						925	0			0
WH	20.0	999.9						104	0			0
Totals					99	0		4923	0	27960	6353	6353

Figure 5—Example of the Harvest Volume and Gross Value Table for a single FVS cycle. Note that the harvested Douglas-fir (DF) was grouped by both tree dbh and log dib, and that harvested western hemlock (WH) was grouped by different log dibs for cubic foot than for board foot volume. The grouping is controlled via keywords.

keyword files and economic output tables, can be found in the ECON User's Manual (Martin, in review).

Economically Efficient Harvest Time

The first motivating question, determining the economically efficient time for harvest, requires examination of alternative harvest schedules. Harvests can be scheduled in each FVS cycle with the PRETEND keyword. Using PRETEND, each FVS cycle represents an independent and mutually exclusive alternative unaffected by harvests from previous cycles. Examination of the economic decision indices (PNV, IRR, etc.) computed for each cycle can then be used to choose among the alternative harvests. Further, the prescribed harvests need not be simply a traditional final harvest each cycle. For example, if the silvicultural objective is to maintain some level of continuous tree cover in the stand, then the harvest prescription might be changed each cycle to retain a different residual density or tree size. In this way non-economic stand objectives can also be evaluated for their financial impacts.

Value of Forestland for Timber Production

The second question, identifying the value of forestland for timber production, requires that we examine the SEV for alternative perpetually repeating stand treatments. Typically bare ground is the starting point for this analysis, and the stand is regenerated, grown forward in time, and thinned or otherwise treated until it becomes merchantable for final harvest. Upon reaching merchantability, a series of "pretend" harvests are examined for their SEV at different points in time. Each simulated "pretend" cycle represents a different mutually exclusive management regime, e.g., the stand can be managed as a repeating series of 80-year cutting-cycle stands or a repeating series of 90-year cutting-cycles, but not both. The SEV at each cycle is based on the costs and revenues from activities to establish the merchantable stand plus the costs and revenues from "pretend" harvests at each cycle. When the PRETEND keyword is active, costs and revenues from harvests are not accumulated between cycles; they are valued only in their respective cycles. Hence, the SEV at each cycle shows the present value of the land parcel to produce like-managed stands in perpetuity, unaffected by the harvests from previous cycles.

Economically Efficient Stand Management

The third question is a combination of questions one and two, i.e., assess the harvest date of an existing stand while considering the "opportunity cost" of delaying initiation of a future management regime. "Value of forest" is the metric used to identify the economically efficient time to convert the existing stand to the desired future repeating management regime. It provides a "normalized" measure for evaluating mutually exclusive alternatives of different length and size (Davis and Johnson 1987, pp. 317-320). The process for addressing this question is similar to the process described for question one, but the SEV of the land parcel is included in the analysis. Alternative "pretend" harvest prescriptions for the existing stand are conducted each cycle and the "value of forest" is examined to determine the economically efficient harvest period. The "value of forest" takes into account the delay until the future regime represented by SEV can be implemented, i.e., the opportunity cost. Calculation of "value of forest" is "normalized" over time by discounting the SEV until the time that the future regime is implemented and adding it to the PNV from the existing stand at each "pretend" cycle. The above process can also be applied to issues that arise with uneven-aged management. Bullard and Straka (1998) discuss the question of evaluating the forest value of a perpetual uneven-aged management prescription that is "off cycle." That is, the SEV of the perpetual cutting cycle is known, but the current scheduled entry time is in the middle of a cutting cycle. Hence SEV needs to be "normalized" as provided by the "value of forest" metric.

Forestland Value for Timber Production that Maintains the Target Condition

The fourth question is to determine when a target condition is achieved in an existing stand and then to select the most economically efficient future management regime that will perpetually re-create the desired target condition. This question requires dynamic evaluation of both the existing stand and the future management treatments. For example, assume an existing “wild” stand is grown until a specified number of large trees have developed, whereupon it is harvested but large legacy trees are reserved. Upon harvest a new “managed” stand is regenerated and examined over time to identify the most economically efficient rotation age that will again produce the desired legacy trees. The process to address this question starts with use of the Event Monitor to track development of the existing stand until the target number of large trees develops and to trigger a harvest and regeneration initiating the new “managed” stand. The Event Monitor also triggers activation of ECON, initiating a new investment period for computing and discounting economic indices. The managed stand is monitored by the Event Monitor until it has developed sufficiently to re-create the desired legacy features. From that point in time “pretend” harvests, each retaining the desired legacy trees, are simulated forward over multiple cycles. Each “pretend” cycle represents a different mutually exclusive alternative which achieves the desired condition but with a different harvest or rotation age. The most economically efficient regime can then be identified based on the highest SEV. The Event Monitor permits analysis of multiple stand decisions within a single FVS simulation by dynamically scheduling management activities and re-initializing the ECON investment period. Evaluation of other future management prescriptions based on some unknown, but computable target condition, would be similar to that used in this instance.

Value of the Immature Trees

The last question is the value of existing trees, separate from the land’s potential for timber production, i.e., the “reprod” value of the trees. Stands that are stocked but have yet to attain merchantable size may have value beyond that of their land value, or SEV, because they are closer to harvest age. The value of the immature trees is dependent on the stand’s planned harvest date and the delay in implementing the future management prescription, denoted by the SEV. This question is addressed in a similar manner to question three, in that a SEV value for the stand is input and “pretend” harvests are simulated each cycle. Each “pretend” cycle then represents a different alternative harvest age for the stand. “Value of trees” at each cycle is the present value of the trees separate from the land assuming the stand is harvested in the given cycle. The result of such an analysis can be used to estimate the market value of existing trees when assessing land purchase or tree damage (e.g., by trespass, wind, or fire).

Lessons Learned

Building the ECON extension made evident that FVS had evolved significantly from its beginnings as an individual tree growth model (Stage 1973). A paradigm shift has occurred among both users and developers; FVS is not just for projecting tree growth but provides a framework for simulating multiple elements of the forest environment. This framework permits users to simulate diverse forest community processes, not just tree growth, and provides descriptive interpretations of the resulting alternative futures. Three insights about FVS emerged from the construction, integration, and testing of ECON:

1. The modeling framework is as important as individual tree growth prediction.
2. Relative comparisons may be more germane than absolute predictions.
3. The FVS code-base needs to be modernized to facilitate continued evolution.

The FVS framework includes extensions for modeling regeneration processes (Ferguson and Crookston 1991), insect and disease incidence (Crookston and others1990; Frankel 1998; Monserud and Crookston 1982), understory vegetation dynamics (Moeur 1985), fuel dynamics and potential fire behavior (Reinhardt and Crookston 2003), and landscape interactions (Crookston and Stage 1991). These extensions impart unique value to the FVS system by allowing examination of a wide range of biological processes in relation to silvicultural activities and providing multiple descriptive measures for evaluating their implications. The ECON extension is the newest addition to this suite of tools and adds descriptive measures for assessing economic effects. The example in the Introduction (figs. 1–3) illustrated this multi-descriptive capability, wherein ECON and the FFE extensions combine to provide metrics for evaluating environmental and economic effects of stand development that may be peripheral to timber production.

In the past, growth models were principally viewed as predictors of future harvest volume; volume prediction is still emphasized when the overriding objective is the commercial production of short-rotation timber crops. Under these circumstances growth models are judged solely on the perceived accuracy of their yield predictions. It is becoming more common, however, to have multiple, and even competing, objectives for the same forest stand, resulting in silvicultural prescriptions that have both timber and non-timber goals. Evaluation of such actions requires the consideration of numerous potential environmental impacts. The collection of multiple decision criteria available through FVS and its numerous extensions allows such evaluation and provides a basis for relative comparisons among alternatives. But, appraising the fidelity of these multiple metrics in the same sense as judging the accuracy of volume predictions is problematical. The interdependency of environmental processes, the often long projection periods, and the stochastic nature of many processes all contribute to uncertainty in the resulting predictions. But the array of metrics provides a convergence of evidence that can be used by the decision-maker to weigh alternatives. In this sense, simulation outputs are deemed less a prediction of future conditions than a quantification of marginal effects. And it is these marginal differences that may be more valuable for planning activities than the expectation of absolute future conditions.

The FVS framework needs to modernize to meet future needs. Detailed procedures to facilitate this modernization are beyond the scope of this paper, but the subject is introduced to motivate additional emphasis on code modernization as FVS is maintained and extended. Although the code-base has undergone numerous changes since its creation, major new concepts in application design and development have developed. FVS was originally designed with an algorithmic architecture and it retains this architecture today. A more modern approach to application design uses an object-oriented architecture. Where algorithmic design highlights the ordering of procedures, object-oriented design emphasizes agents that incorporate both state (data) and operations. These new techniques aid the handling of application complexity by focusing on computer code elements (objects) that resemble real-world objects better than algorithmic processes. This focus permits re-use of existing code thus eliminating its duplication in multiple procedures, and provides a mechanism (inheritance) for formalizing similarities between objects of similar behavior (Booch and others 2007). Some of these new techniques have already been used in parts of FVS, as exemplified by the Event Monitor functionality. These new techniques permit crafting program code that not only controls machine computations, but also better communicates the intent and logic of the developer (Eckel 2000). New techniques also exist for improving the design of existing applications. Refactoring is a set of disciplined practices and design patterns for revising systems structure and organization without changing behavior or introducing computer bugs. It has been used to improve the design and enhance the extension of many existing systems (Fowler and others 1999). Refactoring techniques could be used to ease the burden of both code maintenance and the addition of new functionality to FVS. Object-oriented design would also aid “plug and play” code additions. Plug and play techniques appear especially applicable for substituting alternative growth engines, such as engines that focus on plantation tree growth and address commercial management questions in contrast to more physiologically-based process engines to aid modeling of potential climatic changes. Improvements to code architecture could not only aid application deployment but also advance the latest science through more rapid delivery of ecological knowledge. Enhancing the code-base to accommodate increasingly complex simulations will foster the continued extension of FVS to new environmental and ecological findings.

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