

Development of State and Transition Model Assumptions Used in National Forest Plan Revision

Eric B. Henderson¹

Abstract—State and transition models are being utilized in forest management analysis processes to evaluate assumptions about disturbances and succession. These models assume valid information about seral class successional pathways and timing. The Forest Vegetation Simulator (FVS) was used to evaluate seral class succession assumptions for the Hiawatha National Forest in Michigan's Upper Peninsula. Forest Inventory and Analysis (FIA) plots located on the Hiawatha were stratified by Ecological Land Type and major forest type. A set of algorithms was developed for FVS to grow and evaluate the size class of the plot at each time step of the simulation. Results were evaluated to determine the amount of time vegetation spends in each state before it succeeds. This information was used as basic input for both the Vegetation Dynamics Development Tool and the Spectrum forest planning model used by the Hiawatha for its 2006 forest plan revision.

Introduction

State and Transition Models

State and transition models are used to describe natural processes on a landscape. They can be thought of as a series of boxes and arrows that define the flow of resources through a process. Consider the model displayed in figure 1. The boxes in the figure 1 model are the different states a stand passes through over time and include a description of the state and the ages, or length of time, that the stand remains in that state before transitioning. The arrows are the transitions, and define how resources (in this case land area) pass between the states. The solid arrows in this diagram are used to represent succession, and the dashed arrows are used to represent disturbance. The probabilities associated with the succession transitions describe the likelihood of passage from one state to the next when the stand is at the end of the time it spends in the state. The probabilities of the disturbances represent the average proportion of the land area that passes from one state to the next at each time step. Transitions can be used to describe movement between states or within the same state such as the 1 percent disturbance associated with state 3.

Forest Planning (Linear Programming) Models

There are two typical linear programming formulations of the forest management problem, namely, Model I and Model II (Johnson and Scheurman 1977). National Forests have largely used a Model I formulation of their management problem (Chequamegon-Nicolet National Forest 2004; White Mountain National Forest 2005). Model I is a straightforward formulation whereby all possible future management activities are explicitly enumerated for each stand being analyzed. The strength of the Model I formulation is that exact management plans for each stand can be determined from the solution, and results can be mapped if desired. One drawback of the Model I formulation is that it is difficult to consider the impacts that result from stochastic events such as fires and disease outbreaks. It is also difficult to consider instances of succession.

A Model II linear programming (LP) formulation groups together stands regenerated in the same period into new management units called "transfer classes." Modifications of the Model II formulation have been used to capture the effects of stochastic disturbance and succession events. These modified models are sometimes called Model III (Boyчук and Martell 1996). The drawback of a Model II or Model III formulation is that the stochastic nature of disturbance outbreaks and the loss of stand autonomy that occurs with grouping acres into transfer classes makes exact mapping of the solution impossible. The Hiawatha National Forest used a Model III formulation in its planning process.

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.

¹ Forest Analyst, USDA Forest Service, Hiawatha National Forest, Escanaba, MI; e-mail: ehenderson@fs.fed.us.

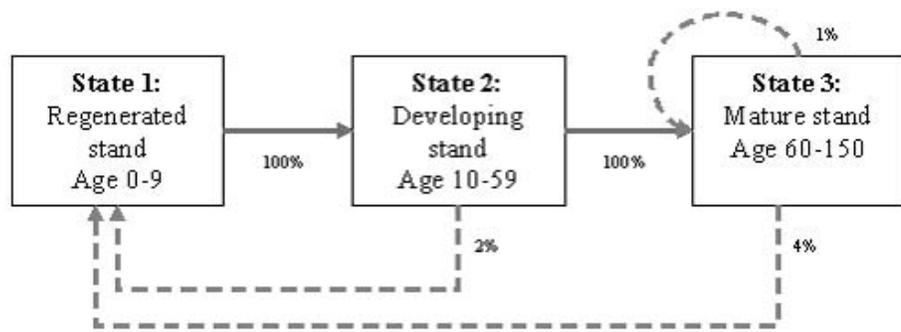


Figure 1—State and transition model example.

Model Synthesis

While a Model III LP formulation may capture the effects of disturbance and succession, it requires users define these parameters. Complete knowledge of disturbance and succession is unavailable, but modeling tools have been developed to help determine intelligent estimates. Merzenich and Hemstrom (2000) describe a method to test the assumptions of a Model III formulation with a state and transition model, the Vegetation Dynamics Development Tool (VDDT) (ESSA Technologies Ltd. 2005). The VDDT model allows for simple succession and disturbance assumption analysis as results are obtained quickly in user-friendly format. Refined succession and disturbance probabilities can then be input into the Model III formulation and an optimal timber management schedule can be determined. The Spectrum linear programming model (USDA Forest Service 2000) was used to solve the Model III formulation used in this study.

Stand development rates and the length of time spent in each state influence how soon a stand can be managed and how likely it is to be disturbed. The Hiawatha National Forest formulated desired vegetation conditions based on the amount of area in each state and had an objective to achieve and maintain the desired state conditions. To optimize a management strategy that allows for the quickest achievement and most robust retention of the desired state, accurate estimates of the parameters of those states must be identified. The Forest Vegetation Simulator (FVS) (Dixon 2003) was the model chosen to strengthen the succession assumptions used in the 2006 Hiawatha National Forest Plan revision. FVS is an individual tree semi-distance-independent tree growth model that can be used to predict stand growth in many parts of the United States (Dixon 2003). This study shows how the FVS model can be used to support or supplement specialist-derived succession assumptions used by the VDDT and Spectrum models.

Objectives

The overall objective of forest planning is to develop a management plan that best achieves the forest's desired conditions. Specifically, there are three key questions to answer:

1. What are the desired conditions (what should the forest look like in the long-term)?
2. What are the natural processes to consider when designing a plan to achieve desired conditions?
3. How are desired conditions efficiently achieved?

The first two questions were addressed by a panel of resource specialists seeking to strike a balance between ecological, wildlife, and timber supply issues. Experiential, empirical, and scientific data were evaluated to estimate desired conditions and recommend an initial set of natural processes to consider. Assumptions were then tested and refined using VDDT. The third question was addressed by using the Spectrum forest management model that combined the assumptions derived from the first two questions to arrive at an optimal management strategy for achieving desired conditions.

The objective of the study was to refine the state classes and succession rates used to model the Hiawatha National Forest. To be clear, disturbance probabilities were not

evaluated in this study. State definitions were initially determined by a panel of resource specialists using local knowledge and literature review. FVS was then used to test those assumptions. Specifically, each state was evaluated to determine the average length of time a stand spends in that state before transitioning to a different state. The ages associated with each state were modified as appropriate.

Methods

The Study Area

The Hiawatha National Forest is located in Michigan's Upper Peninsula. It is comprised of approximately 900,000 acres in two distinct geographic units of comparable size. The Eastern Unit is located between St. Ignace, Michigan on Lake Michigan and the southern shore of Lake Superior's Whitefish Bay. The Western Unit is located between Lake Michigan's Big Bay de Noc and the town of Munising, Michigan on Lake Superior. Figure 2 shows the Upper Peninsula of Michigan and the proclamation boundaries of the Hiawatha National Forest.

Ecological Context

The Hiawatha National Forest identified eight succession/disturbance systems within its boundaries, termed Ecological Land Types (ELT):

1. Dry pine (10/20)
2. Rich pine (30)
3. Rich northern hardwood (40/50/90)
4. Transitional (60)
5. Shallow acidic wet (70A)
6. Shallow basic wet (70B)
7. Deep acidic wet (80A)
8. Deep basic wet (80B)

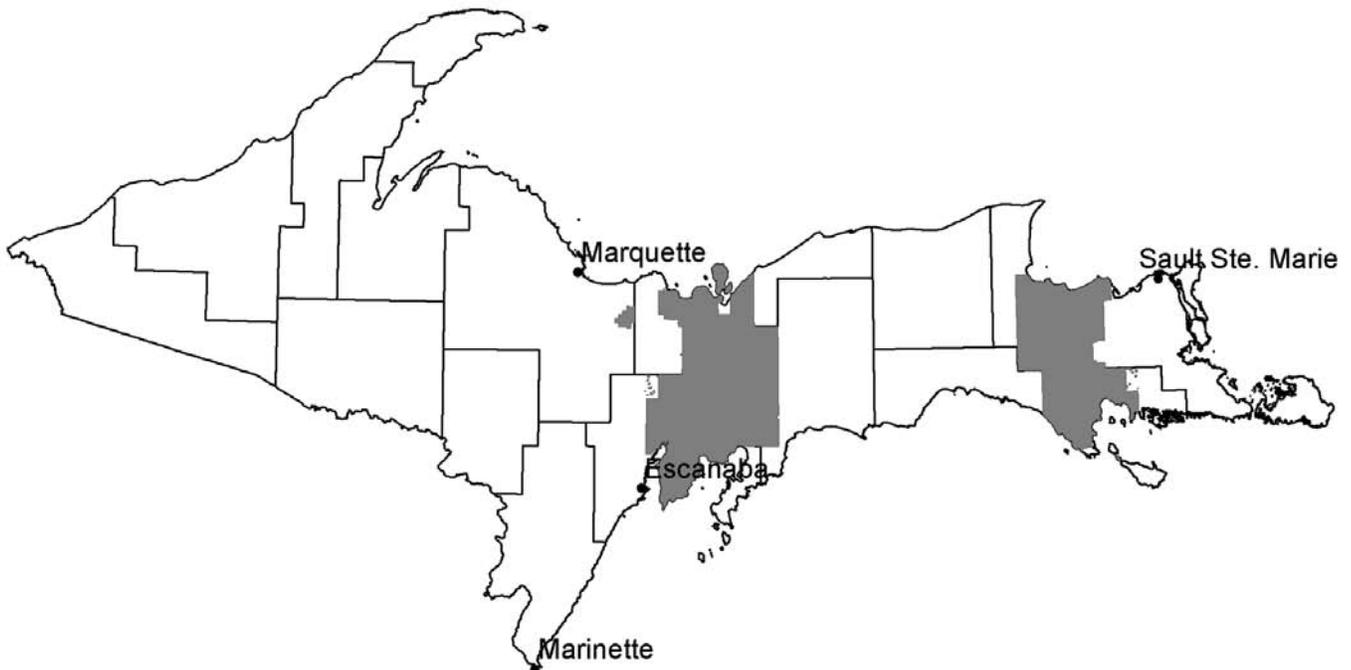


Figure 2—Hiawatha National Forest proclamation boundary in Michigan's Upper Peninsula.

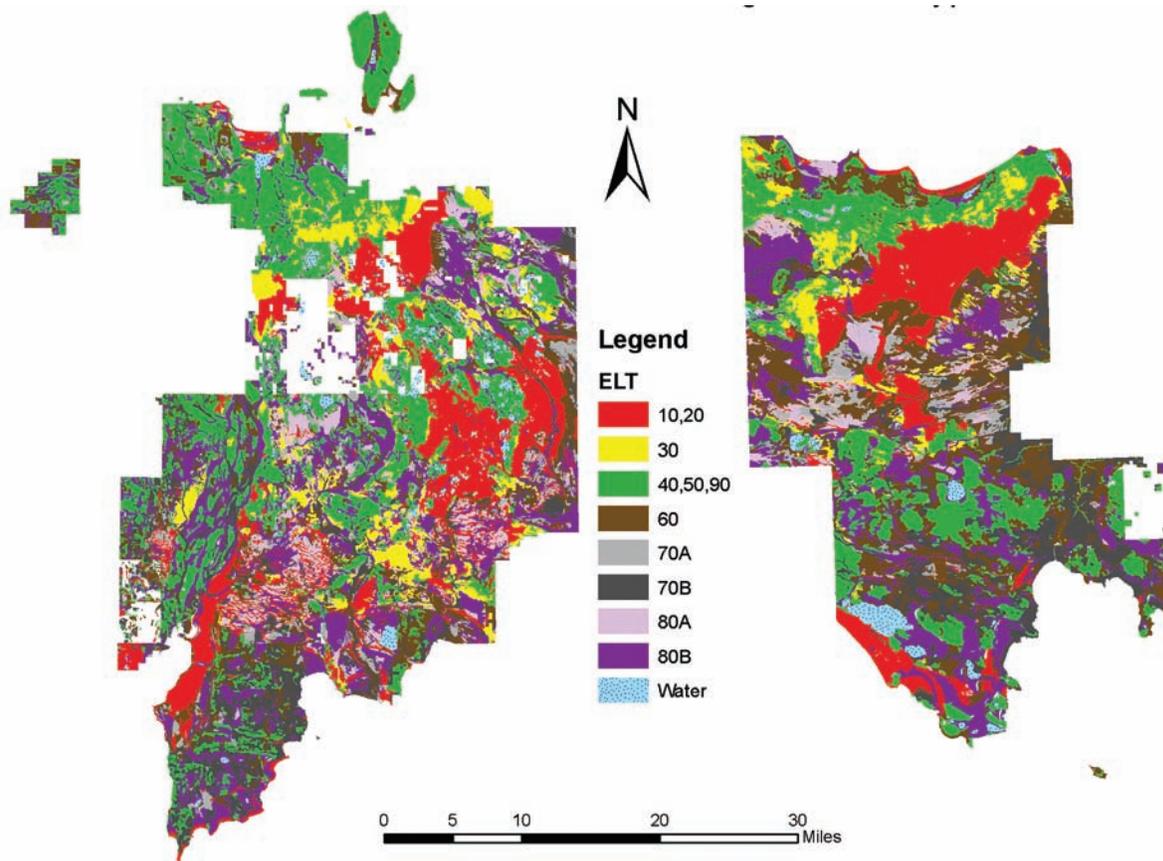


Figure 3—Hiawatha National Forest Ecological land types.

Each ELT has a distinct ecological function. Within each ELT soils are similar, vegetation growth is similar, and disturbance regimes are similar. However, there is a distinct difference between ELTs. A unique set of assumptions, and thus a different VDDT and Spectrum model, was developed for each of the ELTs. A map of the ELTs within the Hiawatha National Forest proclamation boundary is shown in figure 3.

Seral Classes

The panel of resource specialists identified the successional states that occur within each Ecological Land Type. Successional states were combinations of seral stage and size classes called “seral classes.” For instance, a “mid” seral stage with a size class of “1” was called a “mid-1” seral class. Seral stage was dependent on major forest type and consisted of aspen, jack pine, mid and late seral stages. Mid and late seral stages were defined differently for each ELT; for example dry pine (10/20) mid seral was an oak/jack pine mix, whereas the rich northern hardwood (40/50/90) mid seral was red pine. There were five size classes used to determine seral class:

- 1: Stand is composed of trees 0–4.5 feet in height
- 2: Trees 4.5 feet tall to 5 inches in diameter
- 3: Trees 5–9 inches in diameter
- 4: Trees 9–18 inches in diameter
- 5: Trees 18 inches and greater in diameter

Within each ELT, up to twenty seral classes were identified. Not all seral stages were identified in each ELT.

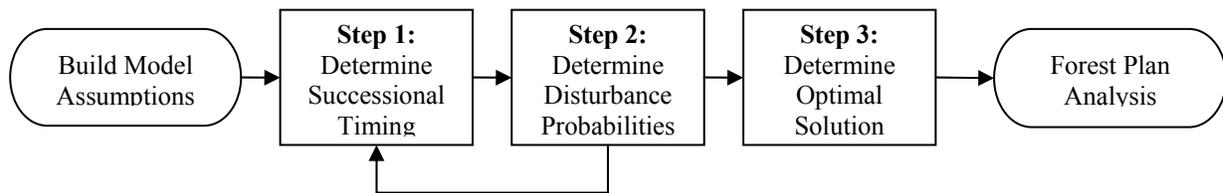


Figure 4—Flowchart of Hiawatha National Forest model development.

Model Development

The process used by the Hiawatha National Forest to develop models for the 2006 management plan revision is shown in figure 4. Within each ELT, seral class successional pathways and disturbance probabilities were determined (Step 1) using resource specialist knowledge and literature review. In Step 2, VDDT was used to fine-tune the successional pathway portion of the assumptions developed at Step 1. The Spectrum linear program model was then used to determine a management scenario to move the forest to its desired ecological condition in an economically-efficient way (Step 3). This resulted in a set of outputs used by the forest to evaluate the management strategy for implications to flora, fauna, economics, and other stakeholders in the forest.

FVS as a Tool to Evaluate Succession Assumptions

The processes described in this paper were used between Step 1 and Step 2 of figure 4. The succession assumptions used in the VDDT and Spectrum model were tested and strengthened with the FVS model.

Data Sources—Forest Inventory and Analysis (FIA) plots located on the Hiawatha National Forest were stratified by Ecological Land Type (ELT) and major forest type and used as input to the FVS model. Data from three FIA cycles was used (1980, 1993, and 2001). There were 26 major ELT/forest type groups identified and evaluated that had at least six FIA plots on Hiawatha National Forest lands.

Calibration—Several FVS calibration exercises were conducted to ensure that the FVS Lakes States variant accurately represented growth specific to the Hiawatha National Forest. This process is described in detail in a document contained in the Hiawatha National Forest planning record (Henderson 2005). Calibration methods used in this study were based on methods developed for other forest plan revision efforts, such as those used on the Chattahoochee-Oconee National Forest (Keyser and Stephens 2002) and the Black Hills National Forest (Vandendriesche 2004). Briefly, the calibration dynamics considered in this model consisted of:

- Local diameter growth calibration based on single-tree re-measurement in different FIA cycles.
- Evaluation of actual maximum stand density index values entered as a constraint (based on Michigan FIA data).
- Evaluation of actual maximum basal area values entered as a constraint (based on Michigan FIA data).
- Evaluation of the largest diameter a species of tree will attain (based on state-wide inventory data) and fitting a senescence curve to approximate that maximum size (using the TreeSzCp keyword).
- Allowing for appropriate in-growth of natural regeneration using the REPUTE software (Vandendriesche 2005) to evaluate in-growth conditions at different stand ages.

Algorithm Development—State transitions were captured in FVS through the use of keywords to track the approximate state of each plot at each time step. Three algorithms were developed to address three possible successional trajectories; one for single-species even-aged stands (such as aspen or jack pine), one for multiple-species single-aged stands (such as balsam fir and white spruce mixed stands), and one for multiple-species, multi-aged stands (such as a northern hardwoods system). The algorithms are unique to the

state definitions developed by the Hiawatha National Forest, so only one (single-species even-aged) is included here as an example. Each forest using the methods in this paper will need to develop their own algorithms for their own vegetation definitions.

For even-aged, single forest type plots:

- Determine whether the stand is still the same forest type:
 - » If the basal area of the trees in the forest type of interest is less than 30% of the total basal area of the plot and the number of trees per acre of the forest type of interest is less than 20% of the total trees per acre, the plot is removed from calculation (it is assumed to have succeeded to a different forest type or seral stage).
- Determine whether it is regeneration (size class 1):
 - » If the plot has not succeeded, then
 - » If the average height of the trees between the 30th and 70th tree of the forest type of interest (based on trees per acre) is less than 4.5 feet and the number of trees per acre shorter than 4.5 feet is greater than the number of trees per acre taller than 4.5 feet, then the stand is size class 1
- Determine size classes 2–5:
 - » If the size class is not 1 then
 - » The size class (2–5) with the greatest basal area of the forest type of interest is used to designate the size class of the stand

Size and Scope of the Analysis – Each of the 26 major forest type groups was run through FVS for a 100-year time frame, using five-year time steps. These runs were done in the absence of any management practices, and were known as “natural growth runs.” Appropriate calibration keywords (discussed above) were used to model more realistic growth. The outputs were assumed to represent the conditions of a stand on a simple successional trajectory. The keywords developed for the appropriate algorithm were added to capture the successional state at each time step.

Results and Discussion

Quantifying the Outputs

Each FIA plot’s state at each point in time was output from FVS. Outputs from all plots were then combined and evaluated to determine the average time at which transitions between states occurred. First, outliers and forest type changes were removed from the output files. Three metrics were then calculated, graphed and provided for review by the specialists on the forest. These consisted of the average state, modal state and the number of plots used to calculate the state at all ages represented by the simulation. The existing assumptions were then superimposed (graphically) onto the FVS outputs to give the specialist panel a visual idea of the differences in the assumptions. Figure 5 is an example of the aspen successional pathway in the dry pine ELT (10/20). The solid diamonds represent the FVS output at each age. The hollow squares are the original assumptions that were tested. Each of the 26 successional pathways was run through FVS and quantified in this manner.

Updated Assumptions

Parts of eight successional pathways were modified based on the FVS outputs. Table 1 displays the original ages of the successional pathways as well as the revised ages resulting from this analysis. Generally, modifications involved a 15–20 year shift in age classes. Notable exceptions were the jack pine in the dry pine ELT (10/20) that shifted only 5 years and the late seral in the rich northern hardwood ELT (40/50/90) that involved a 60-year shift. These shifts were based on a sample of over 40 plots in the dry pine ELT and over 120 plots in the rich northern hardwood ELT. In other instances, the FVS model runs either supported the initial estimates, or there was insufficient data to cause the panel to change the assumptions.

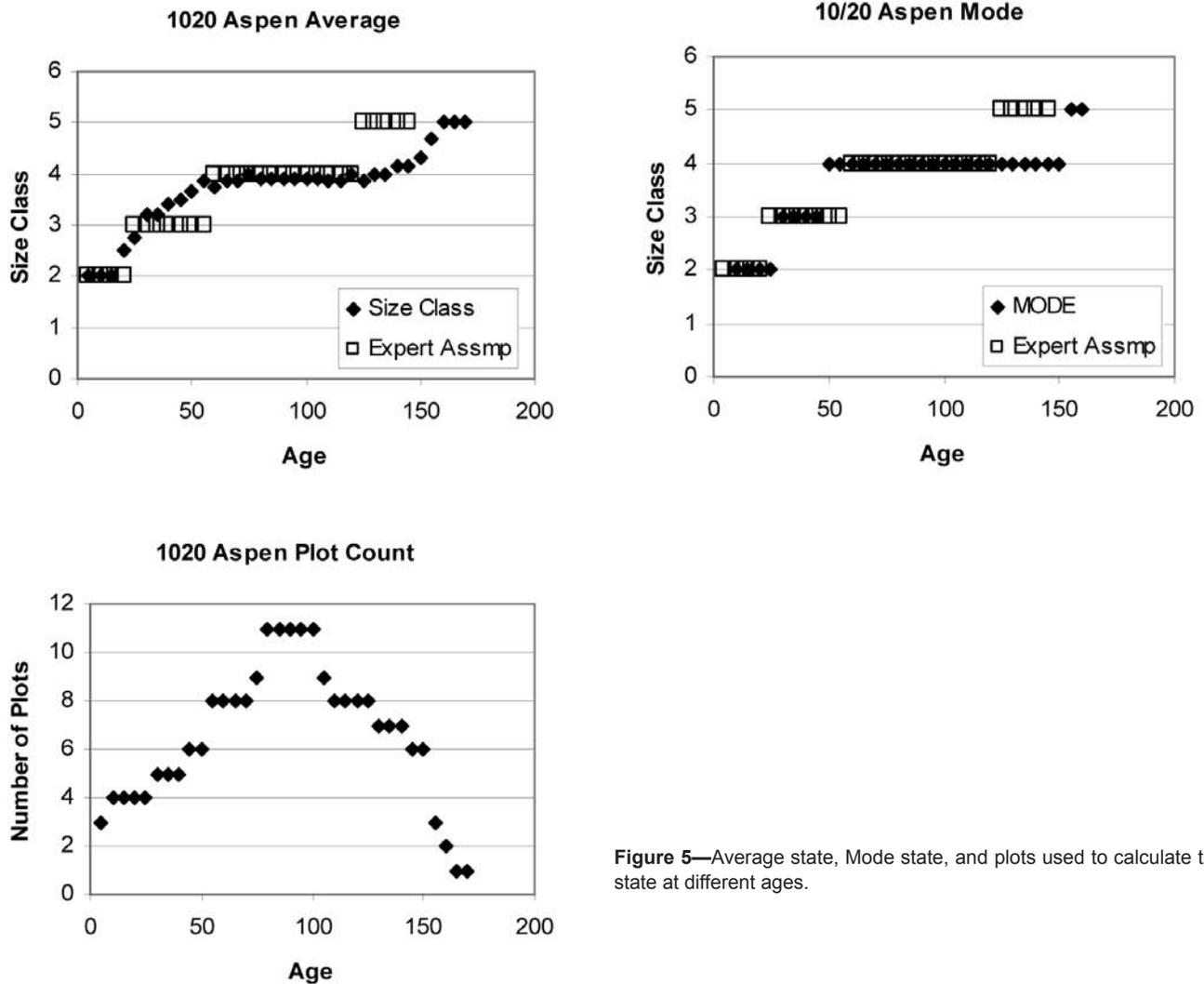


Figure 5—Average state, Mode state, and plots used to calculate the state at different ages.

Discussion

This analysis adequately validated the initial assumptions used in the Hiawatha National Forest plan revision and is included in the plan project record to serve as supporting documentation. Though most initial assumptions were confirmed, this analysis helped modify areas where specialist opinion was not clear. In the end, better assumptions about forest processes and growth will lead to a better forest plan and more informed management decisions.

This study evaluated the amount of time vegetation remains in a specific size class, but ignored transitions to different seral stage trajectories. If after growing out of a size class the plot was a part of the same seral stage, it was used for further analysis. If the plot was a part of a different seral stage, it was ignored. However, timing and proportions of seral stage changes can be used as inputs to VDDT and Spectrum to create more realistic models. The FVS analysis presented here, with slight modification, can be used to identify proportions and timing of transitions to different seral stages.

For future planning projects, FVS may be run prior to the initial resource specialist meeting, i.e., before Step 1 of figure 4. This may allow for final decisions to be made earlier in the planning process without as many iterations between specialist review and model testing. Earlier information can lead to more efficient use of time and an expedited planning process.

Table 1—Original and revised ages of successional pathways.

| ELT | Size class | Aspen | | Jack pine | | Mid seral | | Late seral | |
|----------|------------|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|
| | | Original ages | Revised ages ^a |
| 10 20 | 1 | 1–5 | | 1–5 | 1–10 | 1–10 | | 1–10 | |
| | 2 | 6–25 | | 6–25 | 11–25 | 11–30 | | 11–30 | |
| | 3 | 26–60 | | 26–60 | | 31–60 | | 35–50 | |
| | 4 | 61–125 | | 61–125 | | 61–125 | | 51–125 | |
| | 5 | 126–150 | | 126–150 | | 126–250 | | 125+ | |
| 30 | 1 | 1–5 | | 1–5 | | 1–10 | | 1–10 | |
| | 2 | 6–25 | | 6–25 | | 11–30 | | 11–40 | |
| | 3 | 26–50 | | 26–50 | | 31–55 | 31–45 | 41–65 | |
| | 4 | 51–100 | | 51–100 | | 56–90 | 46–115 | 66–100 | |
| | 5 | 101–150 | | 101–150 | | 91–400 | 116–400 | 101+ | |
| 40 50 90 | 1 | 1–5 | | | | 0–5 | | 0–5 | |
| | 2 | 6–20 | | | | 6–25 | | 6–30 | |
| | 3 | 21–45 | | b | | 26–55 | | 31–90 | |
| | 4 | 46–90 | | | | 56–125 | | 91–250 | 91–190 |
| | 5 | 91–150 | | | | 126–300 | | 250+ | 190+ |
| 60 | 1 | 0–5 | | 0–5 | | 1–10 | | 1–10 | |
| | 2 | 6–25 | | 6–25 | | 11–30 | | 11–40 | |
| | 3 | 26–55 | | 26–55 | | 31–60 | | 41–80 | |
| | 4 | 56–100 | | 56–100 | | 61–100 | | 81–180 | 81–150 |
| | 5 | 101–150 | | 101–150 | | 101–400 | | 181+ | 150+ |
| 70 A | 1 | 1–5 | | 1–5 | | 1–5 | | 1–10 | |
| | 2 | 6–30 | | 6–30 | | 6–40 | | 11–40 | |
| | 3 | 31–60 | | 31–60 | 31–75 | 41–75 | | 41–90 | 41–120 |
| | 4 | 61–110 | | 61–110 | 76–110 | 76–150 | | 91–225 | 121–225 |
| | 5 | 111–150 | | 111–150 | | 151–200 | | 226+ | |
| 70 B | 1 | 1–5 | | | | 1–10 | | 1–10 | |
| | 2 | 6–30 | | | | 11–40 | | 11–40 | |
| | 3 | 31–60 | | b | | 41–75 | | 41–90 | 41–70 |
| | 4 | 61–110 | | | | 76–150 | | 91–200 | 71–200 |
| | 5 | 111–150 | | | | 151–250 | | 201+ | |
| 80 A | 1 | | | | | 1–10 | | 1–20 | |
| | 2 | | | | | 11–40 | | 21–60 | |
| | 3 | b | | b | | 41–80 | | 61–100 | |
| | 4 | | | | | 81–150 | | 101–200 | |
| | 5 | | | | | 151–250 | | 201+ | |
| 80 B | 1 | | | | | 1–10 | | 1–15 | |
| | 2 | | | | | 11–35 | | 16–50 | |
| | 3 | b | | b | | 36–75 | | 51–100 | 51–85 |
| | 4 | | | | | 75–150 | | 101–200 | 86–200 |
| | 5 | | | | | 151–250 | | 201+ | |

^a Only modified successional pathways show revised ages.^b Successional pathways not defined in this ELT.

References

- Boychuck, D.; Martell, D. 1996. A multi-stage stochastic programming model for sustainable forest-level timber supply under risk of fire. *Forest Science*. 42:10–26.
- Chequamegon-Nicolet National Forest. 2004. Final environmental impact statement Appendix B. R9-CN-FEIS. Park Falls, WI: U.S. Department of Agriculture, Forest Service, Chequamegon-Nicolet National Forest. 74 p. Online: http://www.fs.fed.us/r9/cnnf/natres/final_forest_plan/feis_appendices/CNNF_2004_FEIS_APP_B_DescriptionAnalysisProcess.pdf
- Dixon, Gary E., comp. 2003. *Essential FVS: A user's guide to the Forest Vegetation Simulator*. Internal Report. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 193 p.
- ESSA Technologies Ltd. 2005. Vegetation Dynamics Development Tool user guide, Version 5.1. Vancouver, BC: ESSA Technologies Ltd. 188 p. Online: <http://www.essa.com/downloads/vddt/VDDT-51-User-Guide.pdf>
- Henderson, Eric B. 2005. Yield table development for the Hiawatha National Forest. Hiawatha National Forest 2006 planning record. Escanaba, MI. 35 p.
- Johnson, K. N.; Scheurman, H. L. 1977. *Techniques for prescribing optimal timber harvest and investment under different objectives—Discussion and synthesis*. Forest Science Monograph. 18.
- Keyser, C.; Stephens, R. 2002. Calibrating FVS for the Chattahoochee-Oconee National Forest planning effort. In: Crookston, N. L., Havis, R. N., comps. Second Forest Vegetation Simulator conference; 2002 February 12–14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 45–51.
- Merzenich, J.; Hemstrom, M. 2000. Ecosystem modeling using Spectrum and RELMDSS: Analyzing vegetative succession for forest plan revisions. In: Seventh symposium on systems analysis in forest resources; Traverse City, MI; 1997 May 28–31. Gen. Tech. Rep. NC-205. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 22–26.
- U.S. Department of Agriculture, Forest Service 2000. Spectrum user's manual. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Inventory and Monitoring Institute. 230 p. Online: http://www.fs.fed.us/institute/planning_center/download_center.html#spectrum
- Vandendriesche, D. 2004. Description of the analysis process regarding the construction of vegetative yield profiles. In: Black Hills National Forest Phase II Amendment. Custer, SD: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Black Hills National Forest. 130 p. Online: http://www.fs.fed.us/r2/blackhills/projects/planning/assessments/phase_II/constrect_veg_yield_profiles.pdf
- Vandendriesche, D. 2005. Advance FVS topics for forest planning. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. Online: http://www.fs.fed.us/fmso/fvs/documents/gtrs_advance-topics.php
- White Mountain National Forest. 2005. Final environmental impact statement Appendix B. Laconia, NH: U.S. Department of Agriculture, Forest Service, White Mountain National Forest. 54 p. Online: http://www.fs.fed.us/r9/forests/white_mountain/projects/forest_plan_revision/pdf_documents/FEIS_PDF/B_FEIS_analysis.pdf