Long-Range Modeling of Stochastic Disturbances and Management Treatments Using VDDT and TELSA

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ABSTRACT. The Vegetation Dynamics Development Tool (VDDT) examines the impact of landscape-scale disturbances while evaluating alternative management treatment levels. VDDT simulates changes in vegetative composition and structure resulting from both management activities and natural disturbances. Vegetation is classified into discrete states and pathway diagrams portray progression between states in the absence of disturbance. Disturbance probabilities for factors such as wildfires, windthrow, and management treatments are defined and also cause transitions between states. The Tool for Exploratory Landscape Scenario Analyses (TELSA) is a spatially-explicit model of vegetative succession, natural disturbances, and management activities. It is designed as a strategic planning tool operating on areas of 10,000 hectares or larger. TELSA uses VDDT model data plus spatial map data as input. All input and output are managed in relational data tables with a graphical user interface. GIS-based tools are incorporated into TELSA to enable spatial analysis of landscape characteristics.

KEYWORDS: Landscape modeling, natural disturbance, simulation, forest dynamics, vegetative succession

INTRODUCTION

Projecting vegetative change is an important part of landscape-level analyses. Vegetation changes for a variety of reasons such as human activity, fires, insects, pathogens, or growth and competition. The interaction of these factors is complex and combined effects are difficult to predict over long time periods.

The decision support tools most appropriate for the long-range planning of activities should be guided by the questions being asked, the available data, and the precision required to make good decisions. Non-spatial modeling tools enable rapid development and assessment and may be suitable for determining the appropriate level of management activities across a broad landscape. Spatial models portraying disturbance contagion, patch-size distribution, and other important spatial features are more complex, more data intensive, and require significantly greater computing power.

Ideally, planners should choose either spatial or non-spatial models depending on their needs. This choice would be facilitated if the two modeling approaches were compatible and if assumptions and parameter choices from non-spatial models were applicable to the more complex spatial models. This would ensure consistency between the conclusions reached by the two modeling approaches.

This paper describes two models that use similar approaches to represent and simulate vegetation dynamics, natural disturbances and management actions. The Vegetation Dynamics Development Tool

(VDDT) is a non-spatial model simulating landscape dynamics. The Tool for Exploratory Landscape Scenario Analyses (TELSA) uses input parameters developed with VDDT to simulate landscape dynamics with detailed spatial representation of landscape characteristics.

THE VEGETATION DYNAMIC DEVELOPMENT TOOL

VDDT is a user-friendly, Windows-based computer tool, which provides a modeling framework for examining the role of various disturbance agents and management actions on vegetation change (Beukema and Kurz, 1998). It allows users to create and test descriptions of vegetation dynamics at the landscape level. VDDT provides a common platform for specialists of different disciplines, e.g., entomology, pathology, ecology, silviculture, and wildlife biology, to collectively define the roles of various processes and agents of disturbance at the landscape scale. Moreover, VDDT allows for rapid gaming and testing of the sensitivity of the system to alternative assumptions. It thus enables learning and communication.

VDDT models typically apply to one or more Potential Vegetation Types (PVT). Combinations of cover type and structural stage define discrete states within each PVT. In the absence of disturbance vegetation progresses from one state to the next in a time-dependent progression referred to as a *successional pathway*. Natural or human disturbances also affect vegetation. Disturbances are defined for each state according to their probability of occurrence and expected impact.

To simulate succession the user partitions the landscape into pixels which are each assigned to a state and age. For each pixel and simulation year VDDT uses a random draw to determine if the pixel merely moves along its successional pathway or has a disturbance applied to it. Disturbances typically cause a pixel to change state or to move forward or backward a set number of years along its pathway. VDDT applies disturbance probabilities to each pixel independently. VDDT models are thus non-spatial and are generally intended for large scale strategic planning

VDDT models can be quickly built and analyzed for a new geographic area. All relevant information about vegetative cover types, structural stages, and disturbance probabilities are contained in user-accessible text files. To allow sensitivity analysis, disturbances are categorized into groups that can be disabled when running simulations. In addition, multipliers can be applied to selected disturbances to analyze the impact of changing disturbance probabilities. Line and bar graphs assist the interpretation of model results. Model results can also be exported to ASCII files and used by other display or analysis software. Other options available in VDDT include the following:

- Attributes such as wildfire smoke emissions and fuel loads can be calculated and displayed.
- To estimate the range and variability of landscape characteristics over time, multiple simulations can be processed and summary statistics displayed.
- Disturbance probabilities can vary from year to year based on climatic or other data. These data can be generated stochastically or entered directly by the user. This enables modeling of infrequent episodic events such as stand replacement wildfires.
- General landscape conditions may affect disturbance levels. Moreover, when landscape thresholds are met, epidemic events (e.g., insect outbreaks) can be triggered.

- The time interval since a previous disturbance may affect subsequent disturbances. An option to vary disturbance probabilities based on the interval since the last disturbance enables one to model, for example, the flammable fuel buildup that results from the absence of either fire or a fuel reducing treatment.
- Each simulation may run for up to 1000 time steps. Ending conditions may be saved and then used as input for additional simulations.
- Individual VDDT models may contain up to 500 states. A VDDT model can thus apply to either a single Potential Vegetation Type (PVT) or to all of the PVTs that may exist in a large geographic area such as a National Forest.

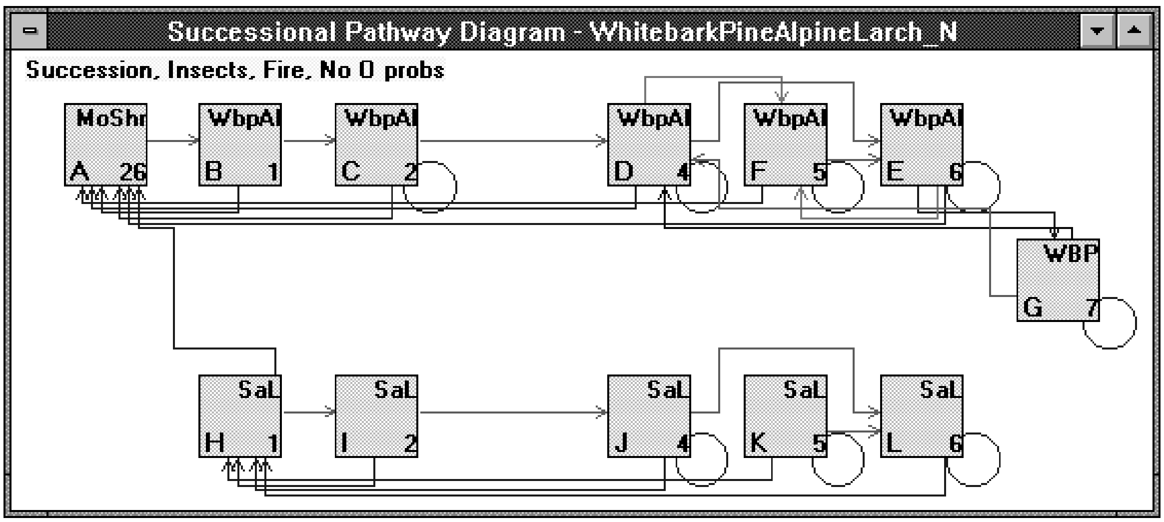

Figure 1: Example of a successional pathway diagram developed with VDDT. Each box represents a successional state. Arrows leaving sides of boxes represent successional pathways; those leaving the top and bottom of boxes represent disturbance pathways. Circular lines represent disturbances that alter successional times without changing the state.

THE TOOL FOR EXPLORATORY LANDSCAPE SCENARIO ANALYSES

Spatial characteristics of landscapes, such as fragmentation, patch-size distribution, and connectivity are largely determined by management actions and their interaction with natural disturbances. TELSA is a spatially explicit model of vegetation succession, natural disturbances, and forest management activities (Kurz, et al. 1999). It is a strategic planning tool designed to support adaptive management by projecting the consequences of alternative scenarios at the scale of landscape units (i.e., 10,000 to 200,000 hectares) over time frames of decades to centuries. TELSA includes ArcView-based data preparation and analysis tools, a simulation model, and user-interfaces that all interact with a central Microsoft Access™ database. TELSA runs on Windows NT 4.0, Windows 95 or Windows 98 operating systems.

TELSA was designed to operate in large landscapes containing thousands of polygons. Maps delineating forest stands and other key landscape features must be provided as input. Polygon attributes must provide sufficient information (e.g., ecological zone, cover type, age, etc.) to assign each polygon to a vegetative state defined in the associated VDDT models. Pathways and probabilities defined with VDDT are then used by TELSA to describe vegetative succession and the role of natural disturbances.

Silvicultural systems, disturbance probabilities, adjacency rules, activity limits, and various other factors can vary within a TELSA model based on the *planning zone*. Examples of planning zones include riparian reserves, old-growth management areas, general forest, and wilderness areas

Natural disturbance events can affect only parts of a stand or cross many stand boundaries. Thus, a procedure is used to subdivide large stands into smaller *simulation polygons*. Forest cover polygons are first subdivided by intersecting their boundaries with the boundaries of user-defined planning zones. The resulting polygons are further subdivided into smaller entities using a Voronoi tesselation (Okabe et al. 1992). This results in irregularly shaped simulation polygons that are of a size compatible with the smallest disturbance events.

TELSA assesses the implications of forest management actions that affect the spatial characteristics of landscapes. For example, the size and spatial arrangement of *management units*, i.e. areas in which a specific activity occurs, affect the distribution of patches, the size of openings, and amount of interior forest habitat. To implement scenarios with different spatial assumptions about forest management systems, an automated approach to design and distribute management units within the landscape was developed.

Management units consist of one to many contiguous simulation polygons with similar ecological characteristics. TELSA allows users to define criteria for the size and spatial arrangement of management units. The model then generates these by combining the appropriate simulation polygons.

Since TELSA is a spatial model, it requires information about the size-class distribution of the various disturbance types, e.g., the expected number of wildfires by area class. In addition, the between-year variability for each disturbance type and any external trends that affect natural disturbances, e.g., climate change or suppression efforts, are defined by the user and can be varied between scenarios.

TELSA enables users to define scenarios with no management activities thus generating “no action” or “historic condition” reference scenarios. Users can also specify scenarios with only succession and management actions but no natural disturbances. Such scenarios may be useful for comparing results to those obtained from models that do not represent natural disturbances. By simulating multiple Monte-Carlo runs of scenarios, users can generate the range and variability of landscape indicators for these scenarios.

Once scenarios are defined, users specify the scenarios to simulate, how many Monte-Carlo simulations of each scenario to execute, the years for which to save the results for the entire landscape, and which spatial analyses to conduct upon completion of the model simulations. The complete set of scenarios can then be executed with the simulation model and the results can be analyzed with TELSA’s spatial analysis tool. This tool calculates various spatial statistics for the landscape, including the count, size, and area distribution of patches and interior forest habitat, and the length of edge between different patches. Upon completion of the runs and analyses, users can review the results through interfaces that create graphs, tables, summary statistics, or maps. Additional scenarios can then be created and analyzed.

DISCUSSION

The first version of the VDDT tool was developed for the Interior Columbia River Basin Project (Quigley and Arbelbide 1997) to define pathway diagrams for forest and rangeland vegetation complexes. These data were then used as input to the Columbia River Basin Succession model (CRBSUM, Keane et al. 1996). VDDT has since been developed further and applied to a wide range of vegetation types. TELSA was developed to support strategic planning in British Columbia and has been applied to case studies in the southern interior of BC (Klenner et al. in press), in northwestern BC, and in northern Alberta. Both VDDT and TELSA are now being used to evaluate alternative levels of fuel treatment scenarios across all major fuel types in the United States (Weise et al. 1999). VDDT has also been used to assess the historical fire regime in Yosemite National park (Arbaugh et al. 1999). Both tools can be applied readily to other regions and ecosystem types where users can provide parameters on vegetation dynamics and natural disturbances.

Given the complexity of forest ecosystem dynamics and the wide range of information requirements for landscape-unit planning, the VDDT/TELSA approach emphasizes the cooperation between different groups of experts and stakeholders. For example, the successional pathway diagrams that describe vegetation dynamics can be developed by one group of experts familiar with the ecology of the landscape unit. Other groups can define the details of management systems, planning zones, and other aspects of the simulated scenarios. Planning teams and stakeholders can then review and compare the results of the scenarios and explore the impacts of the assumptions on key indicators.

TELSA's approach to succession modeling is simple but effective and minimizes the need for detailed inventory information for each polygon in the landscape. Such information is typically not available for parks and other areas that are not managed for timber. TELSA is therefore suited to assist managers in evaluating the effects of fire suppression or prescribed burning on vegetation dynamics and landscape characteristics.

Both VDDT and TELSA incorporate feedback between landscape conditions and the area affected by natural disturbances by defining disturbance probabilities as a function of the vegetative state. This feedback is achieved through changes in the amount of forest area that is in different states. For example, simulating fire suppression and a reduction in wildfire activity may result in a larger proportion of the landscape in older seral stages. If these states have higher probabilities of insect disturbance, fire suppression will increase insect activity in the same landscape.

VDDT and TELSA are not optimization tools. Instead they assess the consequences of the interaction between management plans and assumptions about succession and natural disturbances. Some planners may prefer to use decision support tools that define the "optimum solution" even if these tools require the assumption that natural disturbances do not have a significant effect on landscape structure and composition. While this assumption may be justified in some ecological systems (Gustafson 1996), disturbance agents such as wildfire and bark beetles can have significant impacts on landscape characteristics. Moreover, forest management guidelines in British Columbia and in other jurisdictions include definitions of desired seral-stage distributions, patch-size distributions, and the amount of interior old-growth habitat, all of which will be affected by the interactions between forest management and natural disturbances. Forest management plans based on the assumption that natural disturbances will not occur will yield projected future conditions that are of little relevance.

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