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Models of Vegetative Change for Landscape Planning: A Comparison of FETM, LANDSUM, SIMPPLLE, and VDDT

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Abstract

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Landscape assessment and planning often depend on the ability to predict change of vegetation. This report compares four modeling systems (FETM, LANDSUM, SIMPPLLE, and VDDT) that can be used to understand changes resulting from succession, natural disturbance, and management activities. The four models may be useful for regional or local assessments in National Forest planning rules. Although these models are limited in their ability to support site-specific decisionmaking, they can prove helpful in understanding and comparing strongly differentiated alternatives. They can also be used to make sure that interdisciplinary planning teams share a common base of knowledge. Since all four models are still evolving, increased validation and documentation should develop over time. This report includes a comparison of the models in terms of purpose, data requirements, use, and outputs. It is intended to provide planners with a general introduction to the use of these models within a landscape assessment process.

Keywords: National Forest planning, spatial modeling, succession modeling, vegetation dynamics, simulation, computer models

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Numerous computer models have been developed to predict vegetative change for landscapes. This project compares four modeling systems (FETM, LANDSUM, SIMPPLLE, and VDDT) by looking at their formulation, data structure, capabilities, and potential applications. It is anticipated that those considering using these models might be working within the National Forest planning process. For that purpose, this report discusses strengths and weaknesses of using these models under a variety of possible planning situations. However, no recommendation is made for use of a particular model. Developers provided materials for comparing their modeling systems.

Background

Models of Vegetative Change for Landscapes

Vegetation changes over time as a result of a combination of natural processes (for example, succession, growth, fire, windthrow, insect and disease cycles, climatic variation) and human-induced processes and activities (for example, timber harvest, grazing, road building, fire suppression, and introduction of exotic species). Over time, these processes result in changing patterns of vegetation within forest landscapes (fig. 1). In recent years, interest has increased in understanding

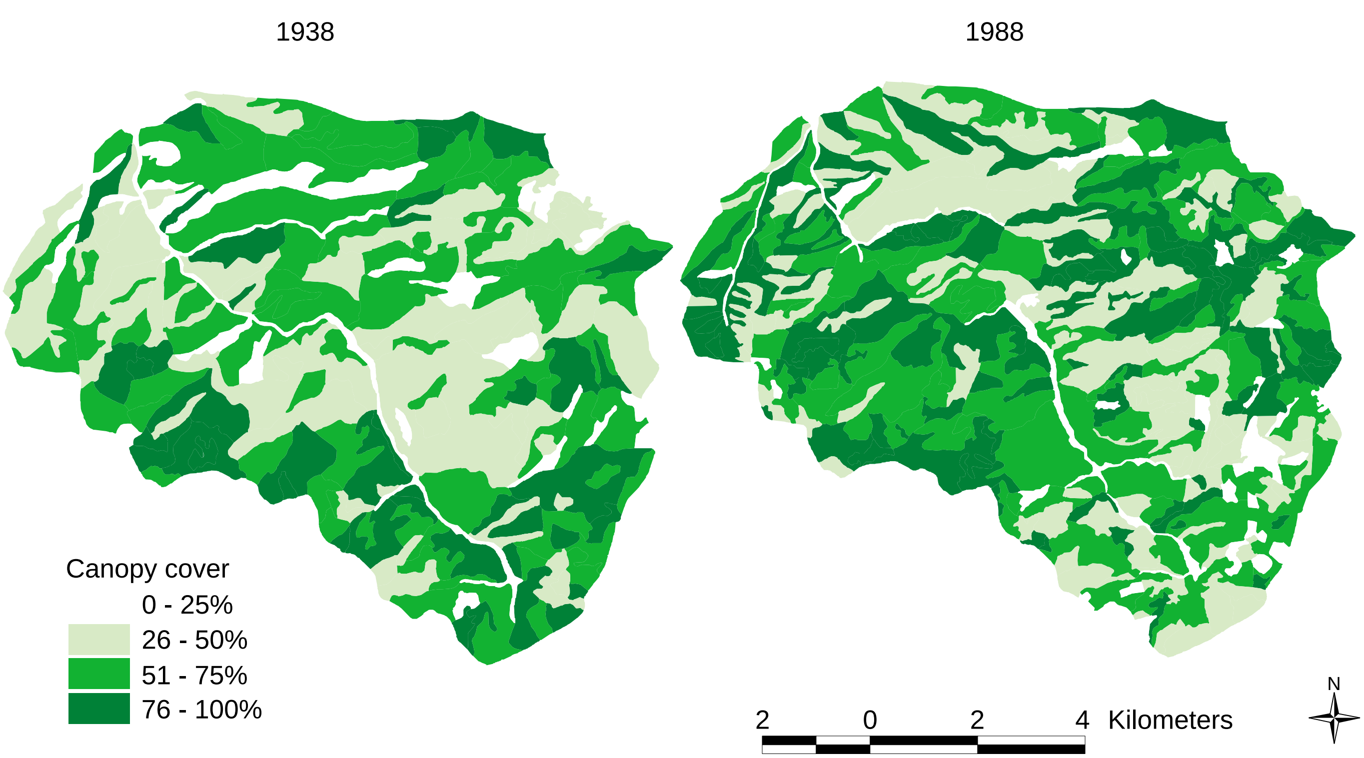

Figure 1—Landscape level vegetation change: canopy cover for Elk Creek, MT, watershed classified from air photos (data from Columbia River Basin Assessment collection).

the range of natural variation in vegetation in North American landscapes prior to European settlement. Although it is generally recognized that restoring landscapes to pre-European vegetation conditions is not always possible or desirable, moving toward that goal may sometimes help to conserve biodiversity and restore ecological processes. Predicting landscape vegetation change under a variety of natural processes and human-induced actions allows us to understand the future consequences of current decisions.

Understanding past vegetation change can involve the use of tree-ring analysis, pollen counts, historic photographs, inventories, surveyor records, and other documents. Predicting how vegetation will change in the future requires the use of some type of modeling process, and a wide variety of models have been developed for this purpose. Because of the variation and complexity of these models, some basic terminology is introduced that will be used throughout this report.

Modeling Systems Versus Models—A program that predicts future vegetation for a particular landscape is a <u>model</u>. A program that has been designed so that it can be easily modified to predict future vegetation for a number of different landscapes is a <u>modeling system</u>. All four of the programs discussed in this report are best described as modeling systems; however, for simplicity, this report will usually refer to them as models.

None of the models discussed here are fully mature; they are still experimental and continue to be changed as they are applied to new landscapes and planning situations. This creates some problems in describing and comparing the four systems. In general, the discussion applies to the model versions as of fall 1999, and past or future developments are indicated as such.

Vegetation Classification Systems—In forested landscapes, individual trees or plants are the most likely candidates for discrete entity, but they exist in quantities too great for practical use in forest planning. Instead, planners generally use land areas of more or less homogenous vegetation. Vegetation in these areas is <u>classified</u> by continuous variables (for example, canopy cover, leaf-area index, or basal area), or by categorical variables (for example, structural stage or species type), or by a mixture of the two. Landscape vegetation classification systems vary widely, depending on the intended use of the conceptual model.

Classification systems for forest vegetation may be based on (1) potential vegetation, (2) current vegetation, (3) structure, and/or (4) other concepts (O'Hara and others 1996). <u>Potential vegetation</u> is the vegetation that will develop over long time periods in the absence of disturbance, and acts as an indicator of the site. In the Rocky Mountain States, land classes supporting unique potential vegetation types are conventionally referred to as "habitat types" (Pfister and Arno 1990). <u>Current or existing vegetation</u> is based on what is presently there; <u>cover type</u> is often used to describe the predominant species mix. <u>Structure classes</u> are related to the three dimensional distribution of vegetation. Structure classes are sometimes conceptualized as developmental stages (for example, Oliver and Larson 1990), but an absence of stand history data results in structural classification that is usually based on what is there at a particular time. Structure classification commonly uses items such as tree diameter, canopy closure, or canopy layering. All four of the models (FETM, LANDSUM, SIMPPLLE, and VDDT) predict change in classified vegetation, although the classification systems differ.

"Classified vegetation system" is used here in a broad sense. FETM, for example, uses fuel condition classes, which are vegetation-based classes that are assigned attributes for fuel loading, stand characteristics (such as height to crown base), and emission-related factors. LANDSUM uses topographic or biophysical groups to determine which classes of vegetation are eligible for particular pathways. In general forest planning, vegetation classification is often combined with physical site characteristics (soil, elevation, aspect) and management concerns (road access, visibility, recreation opportunity) to form land classes (Davis and others 2000). Vegetation and site as measured by potential vegetation are the primary classification emphases for the FETM, LANDSUM, SIMPPLLE, and VDDT models.

Pathways for Vegetation Development—Changes in classified vegetation can be thought of in terms of pathways of vegetation development. If we observed a patch of forest following a stand-replacement event, we might conceptualize the development of structure classes as stages in a pathway, where times shown represent the <u>transition time</u> required before the patch is converted from one class to another (fig. 2).

After a stand-replacing disturbance event, the "old forest" type might transfer back to the seedling class. If the process is conceived as linear and transition times are deterministic, there is a <u>1-to-1 relationship</u> between the current class and a future class.

Spatial Versus Nonspatial Models—<u>Nonspatial</u> models predict the change in land area for vegetation classes. FETM and VDDT are nonspatial models. <u>Spatial</u> models track the specific places that are in those vegetation classes. LANDSUM and SIMPPLLE are spatial models. VDDT has also been developed into a spatial model called TELSA.

"Spatial" in this report refers to whether the model has a real-time GIS component, rather than to whether the results can be spatially mapped. If, for example, a nonspatial model uses initial vegetation classes that

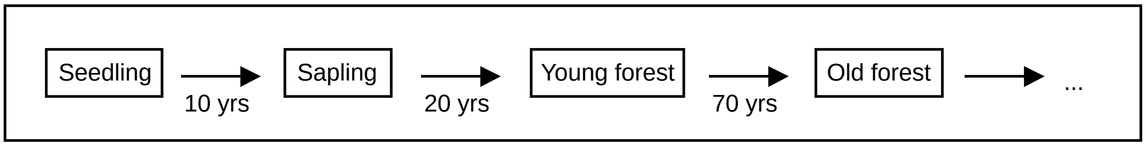

Figure 2—Structural stage development represented as a pathway.

can be linked to a GIS theme, it is often possible to also link the output of predicted vegetation to a GIS theme. If the model incorporates a 1-to-1 relationship of current vegetation types to future vegetation types, this linkage is straightforward; otherwise, more complex assignment is required, and multiple spatial assignments can be made for a single model simulation. Even if a model is spatial, pixels or polygons may not be influenced by spatial context, in other words, the current state of the pixels or polygons around them. SIMPPLLE uses spatial context, while LANDSUM does not.

Units of land are generally modeled either as raster cells (pixels) or as polygons. Classified vegetation mapped from air photos is typically delineated by polygons. Classified vegetation mapped from remote sensing data often originates as pixels, and must be processed into polygons. SIMPPLLE uses polygons. CRBSUM, an earlier version of LANDSUM, modeled with raster cells, while the current version of LANDSUM uses raster cells that contain polygon identifiers. TELSA, the spatial version of VDDT, uses polygon identifiers.

Uncertainty in Models—Deterministic models give the same result every time they are run with the same set of inputs. Stochastic models include at least one random component, and generate different results with the same set of inputs. The distinction is not as clear as it might seem: systematically altering the parameters of a model allows prediction under variation, regardless of whether the alteration occurs manually in a deterministic model or automatically in a stochastic model. However, manual alteration will take more time, limiting the amount of sensitivity analysis that can be done. Most stochastic models also include deterministic components for some processes.

Vegetation change is often conceptualized as having multiple alternative pathways (fig. 3), where fire, climate, insects, disease, harvest, prescribed burning, or other factors influence the particular pathway that a patch follows. Multiple pathways may still be deterministic: for example, one could assume that 2 percent of a vegetation class always experiences fire. If stochastic, the model might include either probabilistic transition times or probabilistic branching, or both. Pathways, whether they are deterministic or stochastic, single or multiple, can be described using either diagrams (fig. 3) or transition matrices (fig. 4). Transition times may be directly applied to individual land classes that contain an age attribute (as is done in LANDSUM), or they may be indirectly represented by assuming a certain proportion of the class experiences transition (as is done in FETM).

One advantage of stochastic models is that most natural processes that affect vegetation change are stochastic. Therefore, users may have greater confidence in stochastic models of those processes. That is, users may distrust the use of a deterministic model to

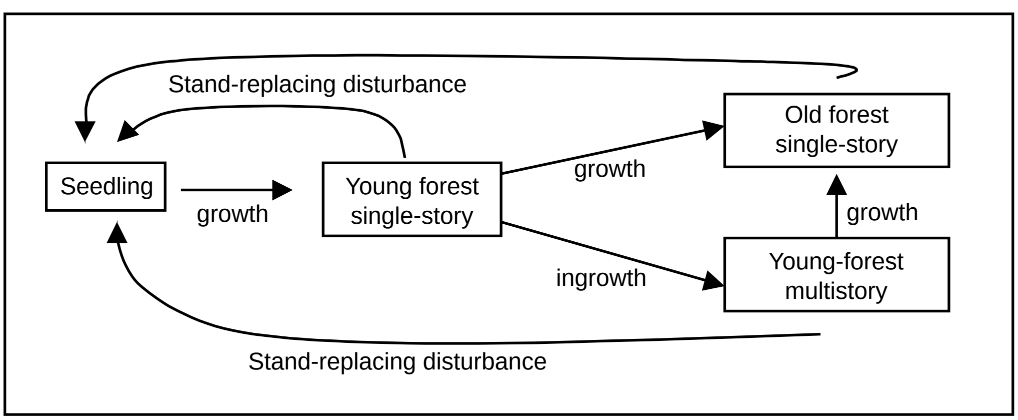

Figure 3—Multiple pathways for changes in structural stage.

Classes after transition

Initial classes	Seedling	Young forest single-story	Young forest multistory	Old forest single-story
Seedling	<no change>	growth		
Young forest single-story	stand-replacing disturbance	<no change>	ingrowth	growth
Young forest multistory	stand-replacing disturbance		<no change>	growth
Old forest single-story	stand-replacing disturbance			<no change>

Figure 4—Multiple pathways represented as a transition matrix. Probabilities (or proportions) would be assigned to each cell.

represent a process they know is stochastic. Despite this advantage, stochastic models also have limitations:

- The probabilities and possible outcomes of stochastic processes may not be well known or may vary widely over time and space.
- The user may have difficulty processing and comprehending the information for a large number of possible futures.

Many stochastic models use post-processors to simplify the large amount of information that is generated. FETM, LANDSUM, SIMPPLLE, and VDDT are all stochastic models with some deterministic components.

FETM, LANDSUM, SIMPPLLE and VDDT: A Brief Description

FETM is the **F**ire **E**missions **T**radeoff **M**odel; version 3.3 is described in this report. FETM was developed to examine tradeoffs between prescribed fire and other fires in the context of emissions. The processes modeled are succession, harvest, fuel treatment, and fire; the classification system used is fuel condition classes. In addition to those condition classes, outputs include fire emission for four weather classes. FETM is stochastic and nonspatial, and it was first applied to a 485,000 hectare landscape in northeastern Oregon. The initial developer was the engineering firm CH_2M Hill (1998), and the current Forest Service contact is Ken Snell of Region 6.

LANDSUM is the **LAND**scape **SU**ccession **M**odel. LANDSUM and its predecessor CRBSUM were developed as research tools to investigate landscape fire succession modeling, but the models can be used as management tools. The processes modeled are succession, harvest, disease, and fire; the classification system used is structural stages and cover types within potential vegetation types. In addition to classified vegetation, outputs can include summaries of land area affected by processes by year, harvest area, and if accompanied by a user-supplied volume table, harvest volume. LANDSUM is stochastic and spatial. The earlier raster version of the model, CRBSUM, was applied to very large landscapes as part of the Interior Columbia River Basin Assessment. The first application of the polygon-based LANDSUM model was applied to nested landscapes of 89,000 ha and 23,000 ha within central Idaho. A number of people within the Forest Service have worked on the model, but the primary developer is Robert Keane of the Fire Sciences Laboratory, Rocky Mountain Research Station, in Missoula, MT.

SIMPPLLE is taken from **SIM**ulating vegetative **P**atterns and **P**rocesses at **L**andscape sca**LES**. SIMPPLLE was designed as a management tool to understand how processes and vegetation interact to affect landscape change. The processes modeled are succession, harvest, disease, insects, and fire; the classification system used is current species, potential vegetation, density, and structure. In addition to classified vegetation, outputs include maps and charts of processes. SIMPPLLE is stochastic and spatial (polygon-based). Two variants, the Upper Clark Fork and the Headwaters of the Missouri, have been used in assessments of landscapes of 3,000 to 30,000 hectares. The primary developer is Jimmie Chew of the Rocky Mountain Research Station.

VDDT is the **V**egetation **D**ynamic **D**evelopment **T**ool. VDDT was developed to facilitate improved understanding of vegetation change through the use of successional pathway modeling. The processes modeled could include succession, harvest, disease, insects, and fire; the classification system used is cover type and structural stage. The primary output is classified vegetation. VDDT was developed to support the modeling effort in the Interior Columbia River Basin Ecosystem Management Project. A spatial version of VDDT is known as TELSA (Tool for Exploratory Landscape Scenario Analyses). The chief developers of VDDT are Sarah Beukema and Werner Kurz of Essa Technologies (Vancouver, BC), and the Forest Service contact is Jim Merzenich of the Pacific Northwest Region.

Relationship to National Forest Planning

All four models predict future conditions. Thus, one criterion that could be used to evaluate them would be the accuracy of predictions. However, if the models are to be used in practical planning, other criteria also become important. In this section, the elements of a proposed Forest Service Planning Rule (USDA Forest Service 2000) that relate to vegetative modeling are discussed. In the following section, some criteria are suggested that could correspond with the possible use of the models under the proposed Rule.

The Rule contained a number of changes from the current planning regulations. Ecological sustainability would have been the first priority for planning. Planning would occur at multiple stages:

- Regional ecosystem assessments
- Local analyses
- Land and resource management plans (LRMPs)
- Site-specific projects

Only the latter two steps were envisioned as decisionmaking, and thus subject to judicial review and NEPA with its required formal public participation. However, increased collaboration was emphasized for all planning, with input from scientists, tribes and other agencies, and the general public. By the guiding principles, plans and planning should be understandable. Plans should promote a shared vision of desired conditions, and planners should engage people in the collaborative development of “landscape goals” (USDA Forest Service 2000).

Models that predict future conditions could be used at any of the four proposed stages. For example, broad-scale assessments can “describe historic conditions, current status, and future trends of ecological, social, and/or economic conditions, their relationship to sustainability, and the principal factors contributing to those conditions and trends” (USDA Forest Service 2000). Local analyses provide descriptions of current and likely future conditions for smaller areas of land. Decisions in land and resource management plans “may include, but are not limited to, the desired watershed and ecological conditions and aquatic and terrestrial habitat characteristics” (USDA Forest Service 2000).

Forest planning is often complicated by the difficulty of integrating local, regional, and national planning, as it is not always clear which level should occur first or at which level decisions should be made. With the proposed Rule, the spatial scale of planning was flexible to accommodate different issues and regions; the exception to this was the LRMPs, the National Forest Plan revisions, which are required by the enabling National Forest Management Act.

The proposed Rule did not specify what must be included in broad-scale assessments and local analyses, leaving instead a flexible process where data and analysis would be chosen relative to the issue. No particular analysis or analytical tools were required, and many of the requirements of the previous rules had been dropped. However, the proposed Rule specified that the “best available science” be considered in planning and suggested the use of peer review “where appropriate.” In addition, it stated that the responsible official should “acknowledge incomplete or unavailable information, scientific uncertainty, and the variability inherent in complex systems” (USDA Forest Service 2000).

Criteria for Comparing Models

The Forest Service’s need for landscape assessment is unlikely to be met with a single model. A model that is appropriate for use in local analysis may be inappropriate for a regional assessment. A model useful for estimating risk and uncertainty of management options may not be best suited for collaborative planning. A model that simulates fire accurately may not simulate harvest effectively. Models cannot simultaneously be based on minimum analytical requirements and the best available scientific information.

In a general sense, the four vegetation simulation models could be used:

- To understand and predict the dynamics of vegetation-related change within landscapes
- To communicate these to other members of planning teams, to other landowners and agencies, and to the general public
- To compare alternative outcomes for landscapes
- To aid in developing a consensus on desired future condition, and on the actions necessary to reach those desired conditions
- To meet legal and institutional requirements for planning and management

As FETM, LANDSUM, SIMPPLLE and VDDT could conceivably be used within a variety of planning situations, a fair number of comparison criteria could be used to assess their usefulness.

Model Purpose and Structure—Criteria related to the intended purpose of the model include the factors already discussed:

- The development objective
- Vegetation classification system used
- Processes modeled
- Treatment of uncertainty
- Incorporation of spatial factors
- Possible inputs and outputs
- Incorporation of management choices

Model Use—In addition, the type of planning situation the model was designed for will influence:

- Difficulty of gathering and formatting input data
- Ease of formulating different scenarios
- Compatibility with other modeling systems
- Documentation and training
- User interface

Vegetation change is site-specific, and frequently pathways and processes must be adjusted for individual landscapes. In addition, users will place more confidence in projections they helped develop, regardless of actual accuracy. Therefore, ease of model customization may be an important criterion:

- Adaptability of vegetation classification system
- Adaptability of pathways, probabilities, and transition times

Both ease of use and customization may be dependent on software and hardware platforms:

- Operating systems and tested/supported platforms
- Programming language
- Other software requirements
- Required storage space
- Required memory

It is possible that a model intended for small landscapes would not be equally well suited to modeling large river basins. In general, trying to limit the complexity of analysis means that models for larger land areas must have lower resolution than models for smaller land areas. Some traits that might be important in choosing a model include:

- Maximum number of vegetation classes
- Maximum number of polygons or cells (if spatial)
- Intended minimum mapping unit and landscape size
- Planning horizon (timeframe) and planning periods (time steps)
- Flexibility of the above
- Run times for various sized problems

Model Validation—The models all predict future vegetation. Although it is not the only area of importance, accuracy should still be a concern. Even when the primary purpose is to serve as a centerpiece for discussions on desired future conditions, inaccuracy of projections can undermine the confidence of the planners and the public. Some traits that users might look for in models include:

- Size, source, and quality of the data set used to build pathways and projections
- Validation against independent data sets
- Comparison against other means of projection

User confidence might also be enhanced by:

- Explanation and documentation of model assumptions, with references where appropriate
- Sensitivity analysis showing how the model behaves when default parameters are varied
- Peer review of model structure, results, and applications

The following section presents a detailed discussion of the four models in relation to these criteria.

Detailed Comparison and Discussion

Classification Systems and Processes

VDDT was developed to be a modeling system that would easily allow users to develop the relationships between vegetation classes and processes (Beukema and Kurz 1998). Users work with a combination of input boxes and graphic displays of processes (fig. 5) to develop the pathways for a potential vegetation type.

VDDT was also used to develop the pathways used in CRBSUM, the precursor to LANDSUM (Keane and others 1996), so the two systems are extremely similar in concept. Both VDDT and CRBSUM were developed as part of the Interior Columbia River Basin Project (USDA and USDI 1997), which assessed an area of over 80 million hectares. CRBSUM and LANDSUM classify by structure type and cover type within potential vegetation type.

The Interior Columbia River Basin Project used 126 cover types, 25 potential vegetation types and 7 structural stages for forest, and 29 potential vegetation types and 8 structural types for range. Vegetation classes, processes, pathways, and probabilities were developed from a series of workshops with “experts,” which probably resulted in some classes and processes being better represented than others (Keane and others 1996). Stage and others (1995) compared the experts’ projections with the Forest Vegetation Simulation model and concluded that pathways differed, and CRBSUM assumed faster growth, but transition times were reasonable. When CRBSUM was adapted into the polygon-based LANDSUM for a landscape in the Salmon National Forest, it was found that the pathways

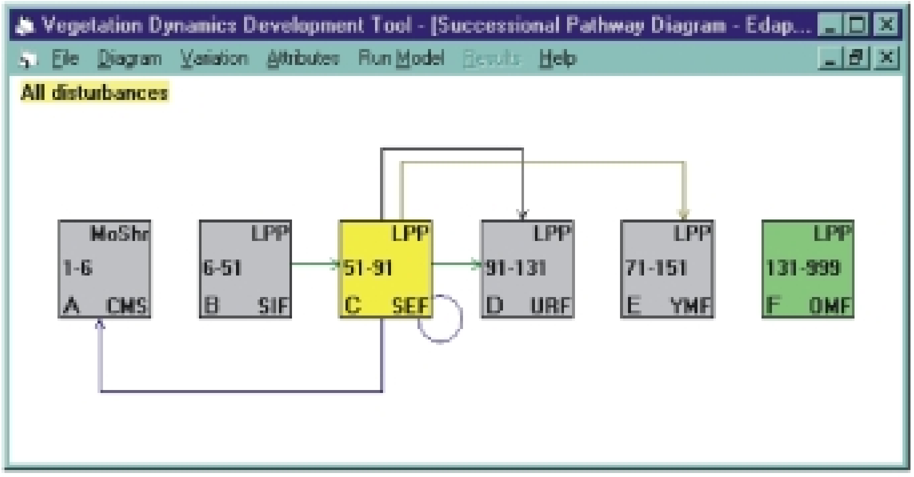

Figure 5—Example screen from the VDDT model.

developed for the Interior Columbia River Basin needed to be altered for the higher resolution landscape simulations (Keane and others 1997).

The most recent version of SIMPPLLE uses a graphical interface similar to VDDT's to represent structural stages and processes. SIMPPLLE's classification scheme has typically used habitat type groups, predominant species classes (cover type), structure classes (size and layering), and canopy closure (density) classes. A simple exercise in the Swan Valley included 14 cover classes, 13 structure classes, and 5 canopy closure classes. Like VDDT and LANDSUM, the classification system is designed to be flexible with the application. Most applications have been in western Montana. SIMPPLLE's processes were developed by Jimmie Chew of the Rocky Mountain Research Station with some input from other resource professionals.

The typical classification system used in SIMPPLLE is less extensive but more detailed than that of VDDT/LANDSUM. For example, the Swan Valley SIMPPLLE exercise used both a Larch/Douglas-fir/Ponderosa pine and a Larch/Douglas-fir/Grand fir type. The LANDSUM model would have used a single Larch cover type to represent both. VDDT/LANDSUM and SIMPPLLE both use potential vegetation type, cover type, and structural stage to classify vegetation, and SIMPPLLE also uses canopy density.

FETM classifies vegetation into "fuel condition classes" (FCCs). The recent application of FETM to the 1.2 million acre Grande Ronde River Basin contained 206 different FCCs. These FCCs cannot be edited or deleted, but users may add additional classes. In the Grande Ronde project, fuel condition classes were created by stratifying the landscape by vegetation type (cover), age class (to represent structure), loading class (low, medium, high), and an activity class. Users develop a transition matrix to represent the development of vegetation; the transition matrix allows the user to specify what percentage of each FCC develops into other FCCs in response to a process. The transitions are deterministic. The developers caution that it would be inappropriate to use the original transition matrix for other study areas (CH_2M Hill 1998).

The processes modeled by the four systems vary (table 1). FETM, for instance, has a small number of processes that it models, but it allows six different levels of prescribed fire treatment, lets the user set the weather condition for prescribed fire, and computes fire emissions for four different weather classes.

Description of Simulations

LANDSUM, although it has a large number of processes modeled, has a fairly simple structure. It starts at year one, and works through each polygon in the coverage. Each polygon, depending on its potential vegetation type and its current cover type and structural stage, is eligible for a given set of processes. Each possible process (including simple succession) has a probability associated with it, with the total sum of probabilities for a polygon summing to one. A random number is drawn from a uniform probability distribution to determine which process occurs. The polygon's cover type and structural stage is updated. The program moves on to the next polygon. After all polygons have been updated, the program moves on to the next year and starts again with the first polygon. VDDT is essentially the same as LANDSUM, but the basic modeling elements are the vegetation classes instead of the polygons.

LANDSUM's modeling of processes, with the exception of fire, is essentially nonspatial; one should get similar results by running VDDT for each initial vegetation class, and then mapping the results to

Table 1—Processes modeled in recent applications.

Process	VDDT/LANDSUM	SIMPPLLE	FETM
Thinning	X	X	X
Regeneration harvest	X	X	X
Mechanical fuel treatment	X	X	X
Prescribed fire	X	X	X
Fire	X	X	X
Natural succession	X	X	X
Root disease	X	X	
Mountain pine beetle	X	X	
Western spruce budworm	X	X	
Other	X	X	
Total processes/treatments	~250	~20	~6

polygons. Or, in other words, the polygons in any initial class (= unique combination of potential vegetation class, current cover class, and structure class) are all equally likely to develop into a future class, regardless of their location within the landscape. LANDSUM version 2 includes spatial simulation of fire.

SIMPPLLE has a modeling process similar to LANDSUM, but also uses (1) the polygon's spatial context and (2) the polygon's past processes to adjust process probabilities. With spatial context, SIMPPLLE uses the current state of each neighboring polygon to adjust the probability of insect and disease processes in the next time period, where neighbors are those polygons that share a border to the polygon under consideration. For the past process adjustment, SIMPPLLE uses the state of the polygon one time period ago to affect the projection of the next time period's state. SIMPPLLE allows two deterministic options: turning off disturbances to get natural succession only, or using the process with the highest probability (Stalling 1999).

Within a single time step, SIMPPLLE's modeling process for disease and insect outbreak limits the influence of neighboring polygons to those that are immediate neighbors. The fire process spreads from polygon to polygon within a single time step, with the fire spread being influenced by vegetation, elevation, and suppression assumptions. The default process probabilities, and the use of neighboring polygons and past history to adjust probabilities, are not well documented.

FETM's modeling process starts with the user-supplied initial vegetation classes (FCCs) and the acres in each class. Six transition tables, one for each possible treatment (succession, fire, prescribed fire, mechanical treatment, thinning, regeneration harvest), specify the proportion of each FCC that will transfer to one or more FCCs annually. Thus, vegetation development is influenced both by the proportions of land area assigned to the six different transition tables and by the transition matrix contents. If one specifies a 2 percent level of prescribed fire, and the prescribed fire transition table contains transitions for 25 FCCs, 2 percent of each of those 25 FCCs will use the prescribed fire transition matrix.

The amount of land assigned to the FETM's fire transition matrix is stochastic, and influenced by weather data and fire history data. The percentage of land assigned to the prescribed fire transition table is set deterministically at up to 6 different levels. Modifications are currently being made to the model to allow more flexible implementation of treatments.

Model Inputs and Outputs

FETM Inputs (CH_2M Hill 1998)—

- Fuel condition classes for the landscape characterized by fuel loading by time lag fuels, stand characteristics (height to base of ladder fuels, total height, height to base of live crown, stand density), and emission factors
- Transition matrices for each process (fire, succession, other treatments)
- Personal Computer Historical Analysis (PCHA) data files
- Interagency Initial Attack Assessment (IIAA) data files. Both the PCHA and IIAA database files are used as part of the National Fire Management Analysis System process, and are derived from national databases containing historical fire incidents

LANDSUM Inputs (from Keane and others 1996; Keane and others 1997)—

- Polygon GIS theme with attributes for each polygon
  - ➢ Potential vegetation
  - ➢ Cover type
  - ➢ Structural stage

- ASCII data files for
  - ➢ Driver file (contains input and output file names)
  - ➢ Simulation file (number of time steps)
  - ➢ Successional file (pathways)
  - ➢ Scenario file (management assumptions)
  - ➢ Volume file (optional, if harvest volumes are desired)

SIMPPLLE Inputs (Jimmie Chew, personal communication)—

- Polygon GIS theme containing attributes for
  - ➢ Cover type
  - ➢ Potential vegetation groups
  - ➢ Structure class
  - ➢ Density class
- Pathways and probabilities for processes
- Scenario assumptions such as fire suppression activities, weather conditions, and management treatments

VDDT Inputs (Beukema and Kurz 1998)—

- Five ASCII text files listing codes
  - ➢ COVER.TXT and COVERC.TXT (long and short descriptions of the vegetation cover types)
  - ➢ STRUCTUR.TXT (description of structure types)
  - ➢ DISTCODE.TXT and DISTGRP.TXT (description of disturbances and disturbance groups)

As the user builds the model, additional ASCII files are generated that control model runs, including files describing pathways, probabilities, and probability multipliers.

Outputs are similarly variable (table 2). FETM and VDDT, as nonspatial models, do not directly produce maps, although VDDT has been developed into the spatial model TELSA. FETM is the only model that can directly produce a calculation of smoke emissions, but both SIMPPLLE and LANDSUM have been used to estimate emissions by matching vegetation classes to FCCs.

Use of Models

All of the models were built with the intention of being adaptable to other landscapes. Anyone considering using these models on a new landscape should be cautioned that a substantial investment of time would be required for adaptation. The learning curve for software use will most likely be outweighed by the problems of formulating the initial vegetation classes, determining land area in those classes (if a nonspatial model) or developing a GIS theme of the classified vegetation (if a spatial model), specifying the development pathways for each combination of a class and a process, setting appropriate probabilities or proportions, and gathering other necessary input data. The difficulty of this modeling effort will be determined by the availability of information, the correspondence of default processes and probabilities to the sample landscape, and the degree of accuracy (or user confidence) required.

I believe that adapting these models to new landscapes would require input from both local managers and the model developers. Adapting FETM to a landscape would probably require input from people knowledgeable in ecology and disturbance processes (to develop the transition matrix) and fire management (to develop the emissions-related data), along with *some help* from the developers. Adapting SIMPPLLE to a landscape would probably require input from people knowledgeable in ecology and disturbance processes (to review the pathways and processes) and *some help* from the developer. Adapting LANDSUM to a landscape would probably require input from people knowledgeable in ecology and disturbance processes (to review pathways and processes) and *substantial help* from the developer. Adapting VDDT to a landscape would probably require input from people knowledgeable in ecology and disturbance processes (to review pathways and processes) and *a small amount*

Table 2—Outputs from the models (X = yes; O = in development).

Outputs	FETM	LANDSUM	SIMPPLLE	VDDT
Area in vegetation classes at a particular time	X	X	X	X
Maps of classified vegetation at a particular time		X	X	
Area affected by processes at a particular time	X	X	X	X
Maps of processes at a particular time		X	X	
Graphs of classified vegetation by time	X	X	X	X
Graphs of processes by time	X		X	X
Auto averaging of outputs for multiple simulations			X	O
Harvest volume		X	X	
Emissions (smoke)	X	O	O	

of help from the developer. An additional option might be to contract for help from a group such as the Fire Modeling Institute, which provides training and assistance with projects.

All of the models, as with all software developed by the Federal government, are available without cost. However, support and training are not necessarily free. The VDDT model has a user guide (Beukema and Kurz 1998) and a set of training exercises, and was developed by a consulting company, ESSA Technologies. The FETM model has a user guide and was developed by a consulting company (CH_2M Hill). For both VDDT and FETM, Forest Service researchers serve as the primary contacts for the models. The other two models, SIMPPLLE and LANDSUM, are the products of Forest Service researchers, and user's guides do not exist. There is a booklet for SIMPPLLE describing possible output, some additional information in a dissertation (Chew 1995), and a Web site at http://www.fs.fed.us/rm/missoula/4151/SIMPPLLE/index.htm. LANDSUM does not have documentation per se, but there is some for the earlier version CRBSUM (Keane and others 1996). SIMPPLLE has also been used twice for a module of the Continuing Education for Ecosystem Management course, a joint program between the University of Idaho and the University of Montana. All of the models have some additional documentation in the form of conference proceedings or Forest Service publications (see References).

Hardware and software requirements vary (table 3). Computing power continues to be less of a problem each year, as cost per computation unit decreases, and should not be a problem for most landscapes. For example, Keane and others (1996) reported CRBSUM run times of 30 to 50 hours for 822,000 pixels, representing 200 million acres simulated for 100 years, but LANDSUM can now simulate 1,000 years for a 100,000 ha landscape in about 1 to 2 hours (Keane, personal communication). As one would expect, the nonspatial models run faster. FETM reports a 1-minute run time for 205 vegetation classes, 100 years of simulation, and 30 iterations on a Pentium II with WinNT.

Model run time should be related to both scope (extent) and resolution (detail). Most models should not be scale independent. For example, the probability of a fire occurrence in a landscape should be related to the size of the minimum mapping unit used. Probabilities should also always be expressed in relation to time. For any given vegetation class, the probability of spruce budworm occurring within 1 year should not be equal to the probability of spruce budworm occurring within 10 years.

Because probabilities are related to temporal and spatial resolution, users should stay with the resolution used by developers. Temporal resolution is 1 year in VDDT, FETM, and LANDSUM, and 10 years for SIMPPLLE. Spatial resolution is not clearly specified for any process for any of the models, and is not applicable to VDDT and FETM since the user must input their own pathways and probabilities. For the spatial models, the landscape applications have been based on available vegetation coverages typically developed from air photo or remote sensing imagery using scales from 1:12,000 to 1:24,000. The spatial and temporal extent is more amenable to mutability for different user needs, as the primary effect of increasing the number of time periods, vegetation classes, or polygons is an increase in run time. Only extremely detailed models might run into software limitations; for example, VDDT allows up to 480 classes within a potential vegetation type and 1,000 time steps.

Validation of Models

Modelers often separate <u>verification</u>, or the internal validity of a model, from <u>validation</u>, the process of checking a model's accuracy against a set of data independent from that used to develop it. Verification often includes some <u>sensitivity analysis</u>, or looking at how model outputs change in response to alterations of model inputs or parameters. <u>Calibration</u> is the process of altering parameters to increase accuracy for local conditions. Because these four models are intended to be used by people other than their developers, it is also important to consider user <u>confidence</u>, or the subjective belief in the model's accuracy. User confidence may be enhanced by verification or validation, but it is also possible that it has little relation to actual accuracy.

In the Forest Service's proposed planning process, regional and local assessments will not directly result in decisions and so will not be subject to NEPA (USDA

Table 3—Hardware and software requirements.

Requirements	FETM	SIMPPLLE	LANDSUM	VDDT
Machine	PC	Workstation (PC in development)	PC or Workstation	PC
Operating system	Win95 / WinNT3.1+	UNIX	Win95	Win95 / WinNT3.51+
Recommended memory	Pentium 166, 40+MB RAM	128 MB RAM, 90 MB disk space	Pentium 100, 32+ MB, 100 MB disk space	Pentium, 8+MB RAM
Recommended storage	50 MB	Depends on landscape	Depends on landscape	5 MB
Other recommendations	CD for installation	ArcView	Good editor	mouse
Other software needed	MS Access for database files			

Forest Service 2000). However, the assessment process will include collaboration and public involvement (USDA Forest Service 2000). Thus, if FETM, LANDSUM, SIMPPLLE, or VDDT are to be used in the assessment process, confidence in the model by both the users and by the public is an important concern. Each Forest Service region may wish to more clearly define the role of landscape assessment (and vegetation projection within landscape assessment) so that an appropriate amount of effort is spent on validation and calibration.

Validation is not an easy process for any of these models. Both of the spatial models, LANDSUM and SIMPPLLE, specifically state that they are not intended to be capable of accurately predicting where and when a process occurs. Thus, an appropriate validation for these models would be to test nonspatial results for landscapes. For example, was the land area affected by mountain pine beetles in the years 1990 to 2000 within the range model predictions? Unfortunately, historical vegetation input data are difficult to obtain. The occurrence of historical disturbance processes is also difficult, if not impossible, to obtain. Historical data also are often not in accessible electronic formats.

CRBSUM and SIMPPLLE have both had some attempts at verification. For CRBSUM, Keane and others (1996) provide a discussion of a sensitivity analysis, a validation that projected a historical data set forward to current conditions, and model limitations. The validation showed poor results, which the authors believe was the result of problems with the historical data set. Results for CRBSUM cannot be reasonably extrapolated to fine-scale applications of LANDSUM, as was shown with a hierarchical comparison discussed in Keane and others (1997). A sensitivity analysis of SIMPPLLE was the subject of a master's thesis (Stalling 1999), and the original model was the subject of a dissertation (Chew 1995). Neither paper documents model assumptions or attempts validation.

Strengths and Weaknesses

The two spatial models, LANDSUM and SIMPPLLE, are intended to be used to understand the range of possible future vegetative conditions and disturbances, rather than to portray the future landscape that will occur. Potential users should be careful how they use maps in this situation because maps tend to convey the idea that particular conditions occur in particular places. Developers and users of these models need to continue to stress that any individual future landscape depicted is representative, and that the probabilities and pathways have not been validated. Thematic maps showing predicted probabilities may be more apt than maps of individual future landscapes; predicted probability maps should also be careful to state the timeframe associated with the prediction. If the user is careful in how results from the models are presented, the models may prove to be useful tools in communicating the dynamics of vegetation change.

Although all of the models simulate vegetation change for landscapes, they are not direct substitutions for one another. FETM demonstrates emission tradeoffs between fire and the timing and intensity of treatments. VDDT is helpful for developing an understanding of vegetation pathways, with an interface useful for easy alterations; LANDSUM and FETM do not have this capacity. The only overlap in these models is between LANDSUM and SIMPPLLE (in the capacity to model and display future landscapes) and between SIMPPLLE and VDDT (in the graphical interface used to show pathways).

The two approaches for putting in development pathways, graphic (fig. 3) or by transition matrix (fig. 4), have different advantages. The graphic pathways used by SIMPPLLE and VDDT allow easy visualization of state changes, but can also be used to create very complicated multiple-loop pathways. The transition matrices make it easier to see what proportion of a class moves into another, but do not allow easy understanding of how an initial class may develop through time.

In using general forest planning models, often only a tiny fraction of the time involved is spent in analysis. Almost all of the work involves delineation of the current landscape, developing future vegetation pathways, and checking over the resulting predictions for reasonableness. There are possible ways to shorten this process: developing standard classification systems and maintaining regional “libraries” of predictions for the standardized classes. As it is, users of FETM, LANDSUM, SIMPPLLE, and VDDT are likely to be faced with the choice of either using models developed for other areas or spending considerable amounts of time adapting the models for new areas.

The proposed Forest Service planning rules suggested multiple components of National Forest planning (regional ecosystem assessments, local analyses, land and resource management plans [LRMPs], and site-specific projects). The four models discussed here may be unsuited to creating LRMPs and site-specific projects, because they are not intended to directly support decisionmaking and because they lack validation. Unlike many decision support systems (Mowrer 1997) these models lack the ability to realistically constrain management activities by such concerns as road networks, topography, or budgets. The four models do not have the ability to predict what vegetation will occur in particular places at particular times, even in the short term. Succession/growth is the only process backed by a substantial amount of research, and even it can be unpredictable.

The purpose of regional assessments and local analyses is, as yet, undefined. The four models have the potential to be helpful, but we can't know precisely what they can contribute without understanding the purpose of the regional or local assessment process. Forest managers already know that disease, fire, insects, harvesting, and growth affect the composition of the forest landscape. Thus, a model that confirms this will happen is unlikely to lead to new insights. Perhaps it would be useful to know how much land will be affected by these processes, or to know which land will be affected, or to know how vegetation will change as a result. But the latter item is an assumption in all four of these models, and the former items require an understanding of the accuracy of the models.

The strengths of these models lie in the comparison of strongly differentiated alternatives, rather than in prediction. If planners (or the public) are choosing between alternatives of no management and aggressive treatment, these models may still capture the general consequences well enough to aid in decisionmaking.

It might be useful for managers, before using the models, to speculate on how they might alter decisions based on model outcomes. It may be helpful to provide them with a few simple results from previous uses of the particular model. Modeling is time consuming and expensive. If other concerns constrain their ability to make choices, projecting future vegetation may not be a worthwhile use of resources.

Recommendations for Future Development and Research

In general, documentation for the models could be improved. VDDT is the only model with both a user's manual and a tutorial data set; it also needs less documentation than the others because it is a framework with no built-in data. If the Forest Service is interested in developing these models to the point where they can be easily adapted to new areas, it must support documentation and training with adequate funding and personnel time. Given current trends, transferring SIMPPLLE to a PC-based platform would increase accessibility; this development is already underway.

If the models had been adapted to the same sample landscapes, potential users would have a better basis for comparison. At least two efforts are underway to do this. One is the development of a Landscape Fire Succession modeling Web site (contact: Dr. Robert Keane, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT). The other is the adaption and comparison of FETM, VDDT/TELSA, and SIMPPLLE (with MAGIS) for a number of sample landscapes (contact: David Weise, Pacific Southwest Research Station, Riverside, CA).

Model builders should be careful that the inclusion of stochastic elements leads to improved understanding. Where modelers choose to include stochastic elements, they should make it as easy as possible for users to make sense of the large number of sample landscapes that will result. Conducting multiple runs and summarizing the results should be automated.

The emissions projection capability of FETM, the user interface for pathway development of VDDT, and the polygon-projection capabilities of SIMPPLLE and LANDSUM are not incompatible. They could be combined into a single model. Choices would have to be made regarding the vegetation classification system, the time resolution (annual versus 10-year), and the inclusion of spatial context or stand history. This could create a model that was unwieldy and overly complex and would require substantial initial investment and cooperation. However, in the long run it might save on development costs compared to supporting four individual models.

Regardless of whether models are combined, it would be helpful if Forest Service Regional Offices and Research Stations cooperated on developing common databases on the occurrence of disturbance processes. It would also be helpful if model developers documented their assumptions. Otherwise, each new model of vegetation change must start from scratch, from literature reviews to compiling "expert opinion." In addition, it is important for modelers to collaborate with researchers in other disciplines to ensure that the best state of knowledge is incorporated in model assumptions.

If the Region continues to support the development and use of vegetation change models like these four, it would be helpful to have an organized way for users to share their experiences. In particular, it will be important to explore effective methods of synthesizing results and communicating with the public. Developers should not bear responsibility for coordinating this effort. A simple Web site or discussion list could improve communication without much cost.

SIMPPLLE has been used in combination with the tactical planning model MAGIS. Developers of models of vegetation change need to continue to explore such avenues of cooperation. Otherwise, the Forest Service may find there is no integration between regional assessments and forest plans, and no integration between local analysis and project plans.

The proliferation of vegetation classification systems has created substantial difficulties. In some cases, standardized classification systems would help to alleviate these problems. However, it should be recognized that research on vegetation development that is tailored to a particular classification scheme may be limited in its potential development. To avoid this problem, researchers should be encouraged to relate processes to continuous variables instead of categorical variables where possible. For example, it would be better if data collected on root disease were related to a density index (LAI, basal area, SDI, and so forth) instead of density classes.

The primary structural differences between SIMPPLLE and LANDSUM is (1) the inclusion of spatial context (in other words, the interaction among polygons), and (2) the use of stand history. If a landscape with good data on past processes can be found, the effect on accuracy of these two features can be tested.

We have little knowledge about how the public relates to GIS polygon maps. It might be useful to work with social scientists to assess the relative effectiveness of graphs, polygon maps, and 3-D computer visualizations for communicating various concepts about vegetation change. The data may not exist to support extensive accuracy assessment for these models. Nonetheless, it would be possible to do more than has been done. Accuracy assessment should be directed at assembling independent data sets for validation, rather than toward extensive sensitivity analysis of these particular models. If past experience is a guide, all four of these models will be obsolete within a few years. However, historical data sets would remain useful for all the models yet to come.

Conclusion

FETM, LANDSUM, SIMPPLLE, and VDDT, can be used in the general process of understanding vegetation change for forest landscapes. The four models only partially overlap, as FETM and VDDT are specialized toward fuel modeling and pathway development, respectively. Although the models might be useful in either regional or local assessments, users must first define the purpose of vegetation projection within the planning process to make informed choices with regard to these models.

If the primary purpose is to better understand the future development of particular forest ecosystems, better documentation, verification, and validation is necessary. If the primary purpose is to educate nonprofessionals about the general dynamics of forest ecosystems, better user interface, documentation, and research on effective communication techniques would be advisable. If the primary purpose is to lay the foundation for forest or project planning, the models need to be compatible with decisionmaking methods.

In spite of the need for future development and research, all four of these models can be used at present to make sure that interdisciplinary planning teams share a common base of knowledge. As with all assessment and planning, the true value of these models lies not directly in output, but in what people learn during the modeling process.

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Appendix: Developer Contacts

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RMRS

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