Dynamic Vegetation Modeling:
Driving Management Changes Today by Looking into the Past and Future

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Abstract
State-and-transition models—both quantitative and conceptual—can be used to collaboratively document the current knowledge of vegetation dynamics, test alternative management scenarios, and identify data gaps in land management. The national LANDFIRE project, a five-year collaboration among the USDA Forest Service, Department of the Interior, and The Nature Conservancy, will create hundreds of state-and-transition models for vegetation systems across the U.S. LANDFIRE vegetation dynamics models capture historic reference conditions, and can be easily modified for other uses. For example, models can be altered to reflect finer scale reference conditions, describe current conditions, analyze alternative management, conservation, or climate scenarios, or test the effects of fire and other disturbances. This paper demonstrates the state-and-transition modeling tools used in LANDFIRE, including use of VDDT (Vegetation Dynamics Development Tool) software. A case study from Colorado's San Luis Valley shows how the National Park Service, US Fish and Wildlife Service, Colorado State Forest Service, and The Nature Conservancy used models calibrated by local ecological knowledge and fire history data to engage the public and inform management decisions related to fire ecology and conservation.

Keywords
Modeling, vegetation dynamics, fire, LANDFIRE, collaboration, decision support tools, VDDT

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Introduction

Improvements in ecosystem and fire management are generally constrained by limited knowledge and shifting political priorities. Strategies often rely on decision support tools that lack spatial complexity and temporal longevity. Cross-boundary, landscape-scale data are frequently absent, limiting the potential for collaboration and landscape-scale restoration. Temporal perspectives are often restricted to recent history and the near-term future, without incorporating the complexities of long-term land use change, climate variability, and desired future conditions. Dynamic vegetation modeling can facilitate development of collaborative, multi-scaled, long-term visioning. Through the LANDFIRE project, hundreds of state-and-transition models are available for use as management decision-support tools nationwide. This paper outlines the development of vegetation dynamics models for the LANDFIRE project and highlights a case study from the San Luis Valley of Colorado that used vegetation dynamics models to inform management decisions.

LANDFIRE Vegetation Dynamics Models

In October of 2003, the Wildland Fire Leadership Council sanctioned the national implementation of LANDFIRE (www.landfire.gov), a project designed to create a comprehensive suite of standardized, multi-scale spatial data layers and software for the entire U.S. LANDFIRE products are designed to be nationally consistent, locally relevant, and based on current, peer-reviewed scientific literature and methods. The Government Accountability Office (2003) described LANDFIRE as "the only proposed research project so far that appears capable of producing consistent national inventory data for improving the prioritization of fuel projects and communities" and recommended national implementation of the LANDFIRE Project. LANDFIRE data will support the National Fire Plan, the Western States' 10-year comprehensive plan, the President's Healthy Forest Initiative, and The Nature Conservancy's long-term conservation goals. The full suite of LANDFIRE products includes over 20 key geospatial data layers (Box 1), plus ancillary geospatial products and computer models. Products will be systematically delivered from 2005 through 2009.

Box 1: LANDFIRE Primary Data Products

FARSITE Fuel Data
- Fire Behavior Fuel Models (Anderson 1982 and Scott & Burgan 2005)
- Forest Canopy Bulk Density and Base Height
- Forest Vegetation Height and Canopy Cover
- Elevation, Aspect, Slope

Fire Effects Data
- Fuel Loading Models

Fire Regime Data
- Fire Regime Condition Class (FRCC) and Departure Index
- Fire Regime Groups
- Fire Return Intervals
- Fire Severity Classes
- Succession Classes

Vegetation Data
- Environmental Site Potential
- Biophysical Settings
- Existing Vegetation, Height, and Canopy Cover
- Vegetation Models (aspatial)

One LANDFIRE product is quantitative vegetation dynamics models, created for each Biophysical Setting (BpS). BpS are the vegetation communities that encapsulate the mosaic of vegetation structure and composition under the natural range of variability in ecological conditions, including disturbance processes and the influence of American Indians (sensu Landres et al. 1999). For LANDFIRE, BpS are represented by Ecological Systems (Comer et al. 2003), a nationally consistent set of mid-scale ecological units. Ecological Systems are adapted for LANDFIRE to represent variability in geography, fire regimes, and biophysical gradients as necessary. Vegetation dynamics models are created for each final BpS through expert workshops and undergo a rigorous peer review process. Vegetation dynamics models are intended to capture the best available science on vegetation communities, disturbance regimes, and succession rates of all major vegetation types across the United States.

Vegetation models consist of two parts: (1) a comprehensive model description, and (2) a quantitative state-and-transition model. Descriptions are created in a custom database, called Model Tracker (The Nature Conservancy et al. 2005), and describe the indicator species, geographic distribution, biophysical characteristics, succession stages, and disturbance regimes of each BpS. Descriptions also document the assumptions, outstanding questions, contributors, resources, and evolution of each model.

Quantitative state-and-transition models (sensu Westoby et al. 1989) were developed using the Vegetation Dynamics Development Tool software (VDDT; ESSA Technologies Ltd. 2005). VDDT is a quantitative state-and-transition (or "box") modeling tool that combines information about vegetation cover and structure (i.e., states) with information about succession and disturbance (i.e., transitions), such as the probabilities and effects of a perturbation (Figure 1). VDDT applies the input data across a set of independent samples and returns output such as the overall proportion of a vegetation state over time and the likelihood of various transitions included in the model. In LANDFIRE, VDDT models are used as inputs for the model LANDSUM (Keane et al. 2002), which pairs VDDT data with spatial data to simulate disturbances and succession within a spatial context. VDDT model outputs were also used to calculate and map Fire Regime Condition Class (Hann et al. 2005) for the coarser-scale LANDFIRE Rapid Assessment across the conterminous U.S.

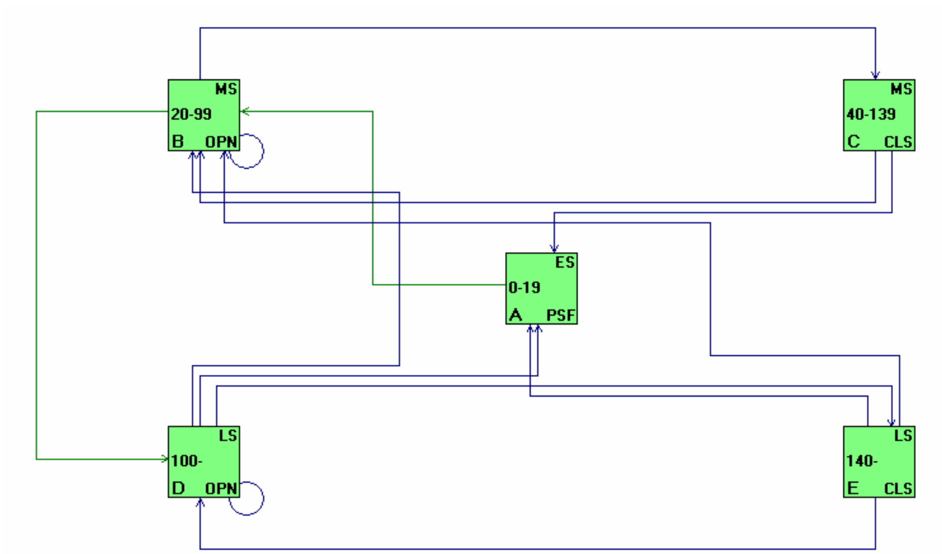

Figure 1: Vegetation Dynamics Development Tool (VDDT) state-and-transition model. Each box represents a state of vegetation composition and structure. Each arrow represents a transition such as succession, fire, or other disturbances.

In LANDFIRE, each BpS can have up to five succession classes, defined by combinations of cover (i.e., species composition) and structure (i.e., height and percent canopy cover). A standard model (Table 1) with generic class labels has been widely adopted, but can be adjusted for any BpS. Succession classes are mutually exclusive by combinations of cover and height for discrete mapping. Definitions of succession classes are informed by literature, local data, and expert knowledge via modeling workshops and peer-review. LANDFIRE vegetation models use this simple structure in order to reduce the number of possible parameters and estimation error, limit model complexity and data requirements, and maintain national consistency to facilitate comparisons across the U.S.

LANDFIRE reference condition vegetation models use two main types of transitions between classes: succession and (natural) disturbance. To attribute succession and disturbance, modelers must define (a) how frequently the transition occurs, and (b) the resulting succession class. In general, succession is defined as the rate of vegetation growth over time. More than one succession pathway can be attributed for any class. For consistency across the U.S., a standard set of disturbance types was used in LANDFIRE vegetation models. The frequency and effects of disturbances in LANDFIRE models were informed by literature, local data, and expert knowledge incorporated through modeling workshops and peer-review.

Table 1. The standard five-box model classes used in LANDFIRE. Canopy cover and succession stages are defined individually for each vegetation type and labels are modified as necessary. Letters represent unique classes and correspond to boxes in the state-and-transition models.

	Canopy Cover	
Succession Stage	**Closed**	**Open**
Early development	A	
Mid-development	B	C
Late-development	E	D

Applications beyond LANDFIRE: A Case Study

Vegetation dynamics models have many applications beyond their use in LANDFIRE. For example, vegetation dynamics models can be refined to capture site-specific, finer-resolution characteristics. Models can be expanded to include states that are outside of the natural range of variability, such as exotic species or heavily managed communities. Model users can also add modern, human-caused disturbances such as forest harvest, species invasion or domestic livestock grazing. Vegetation dynamics models can also be used to test alternative management scenarios and simulate temporal variability, such as that driven by climate change or changes in conservation or management strategies.

The Greater Sand Dunes Landscape

A collaborative, multi-partner landscape in the Greater Sand Dunes of the San Luis Valley in Colorado adapted simple vegetation dynamics models, such as those used in LANDFIRE, to develop consensus on natural ecosystem functions, engage the public in the development of a fire management plan, and test multiple restoration strategies (National Park Service et al. 2005). VDDT models were created by a collaborative, interdisciplinary team of ecologists, biologists, and land managers from The Nature Conservancy, National Park Service, Fish and Wildlife Service, and Colorado State Forest Service.

The Greater Sand Dunes landscape, located in Alamosa and Saguache counties in the San Luis Valley of Colorado, is a complex mixture of federal, state, and private lands. This landscape contains globally significant natural and cultural resources, a variety of vegetation types that harbor an abundance of natural resources, numerous recreational opportunities, and areas of wildland-urban interface. The overall goal of the project was to develop an integrated fire management plan for an approximately 275,000-acre site that includes the Great Sand Dunes National Park and Preserve, Baca National Wildlife Refuge, and The Nature Conservancy's Medano-Zapata Ranch. The integrated fire management plan will provide guidance for fire management in a variety of ecological systems, meet specific management goals, protect human life, property, and other resources at risk, and conserve an irreplaceable landscape along the western flank of the Sangre de Cristo Mountains (National Park Service et al. 2005).

Vegetation models were developed collaboratively to achieve three main objectives: (1) document reference conditions to help arrive at consensus about ecosystem structure and function; (2) determine whether action should be taken to restore fire regimes by comparing reference conditions to current conditions; and (3) test alternative management scenarios to achieve conservation and management objectives.

Reference Condition Models

The Greater Sand Dunes team used simple, standardized vegetation models, such as those created through LANDFIRE[2], as a starting point and refined the models to better reflect local conditions (Barrett 2003a, 2003b). Models were then reviewed by additional experts and used to convey ecosystem processes during the public comment period to develop the Greater Sand Dunes Fire Management Plan (National Park Service 2005). Reference condition models were developed for three forest types: spruce-fir forests, mixed conifer forests, and piñon-juniper woodlands, each thought to be dependent on periodic fire (Rondeau 2001, Loftin 1999).

Wildfires play a dominant role in the spruce-fir forest (Arno 2000, Alington 1998, USFS 1996) and are typically large-scale, stand replacing events (Rondeau 2001). Spruce-fir forests are typically characterized by moderately long to very long fire return intervals (100-400 years) throughout their range with a combination of mixed severity fires and stand replacing fires (Barrett 2003a, b; USFS 1996). An ecological model was developed for spruce-fir forests within the planning area based on expert opinion and a literature review. Ecological modeling for the Greater Sand Dunes area predicted mean fire return intervals of approximately 330 years for replacement fire and approximately 235 years for mixed-severity fire.

Fire plays a dominant role in the maintenance of mixed conifer forests (Arno 2000, Alington 1998, USFS 1996). Because each species within this forest type responds differently to fire, the fire regime influences the structure and composition of a given stand (Rondeau 2001). The exact nature of wildfires within mixed conifer forests depends on factors such as location of the forest, microclimate, and land uses. Because of the steep nature and dry conditions, fuels are limited and fires occur less frequently within the forests of the western Sangre de Cristo Mountains than in other similar forest types in the Southern Rocky Mountains (Alington 1998, Romme 1996).

[2] The Greater Sand Dunes team used Fire Regime Condition Class (FRCC) models as a starting point. FRCC models were the precursor to LANDFIRE vegetation models, use the same standardized structure, and are available at www.frcc.gov. FRCC models are coarser resolution than LANDFIRE models.

The mean fire return interval for the Greater Sand Dunes mixed conifer forests, therefore, is assumed to be slightly longer. Based on expert and local land manager knowledge of the Greater Sand Dunes area and a literature review (primarily Alington (1998) and Romme (1996)), a reference condition ecological model was developed for mixed conifer forests within the planning area. These forests are estimated to have mean fire return intervals of 550 years for replacement fire and approximately 90 years for mixed-severity fire.

Historically, fire has played a role in influencing the structure, composition, and maintenance of piñon-juniper woodlands within the planning area (Arno 2000, Romme 1996, USFS 1996). Based on expert and local land manager knowledge of the Greater Sand Dunes area, a reference condition ecological model was developed for piñon-juniper woodlands within the planning area (depicted in Figure 1). The mean fire return intervals were estimated to be 425 years for replacement fire and 170 years for mixed-severity fire. The estimate for replacement fire is consistent with a literature review, which found two studies of piñon-juniper woodlands that had estimated high severity fire return interval of 400 and 480 years, respectively (Baker and Shinneman 2004).

Comparison with Current Conditions

Comparisons between reference model outputs and current conditions were used to inform management priorities for integrated fire management. Current conditions were evaluated using local spatial and summary data of existing vegetation and fire history. The VDDT model outputs that were compared to current conditions included fire frequency, fire severity, and the proportion of the landscape in different succession stages (Figure 2). All three of the forested communities were found to be within the natural range of variability in fire frequency and fire severity today, indicating that fire suppression, grazing, and other landscape management activities have not had as strong of an impact on these communities (National Park Service et al. 2005) as in some other portions of the American Southwest (Romme 1996). This was contrary to the expectations of the collaborative modeling team, which anticipated having to implement large-scale fuel reduction activities in the piñon-juniper communities to restore ecological conditions.

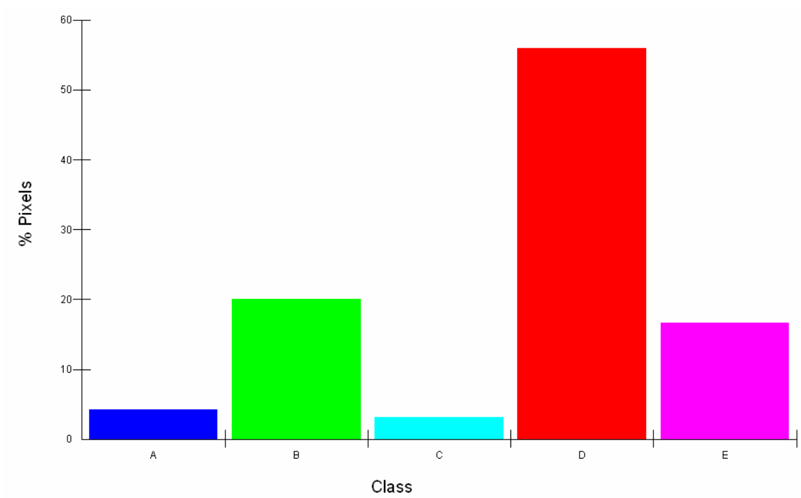

Figure 2: Output from the piñon-juniper reference condition model. Class letters correspond to states in the model. Class A is early succession, dominated by grasses and forbs. Classes B and D are open canopy (<30% cover) in mid-and late-development stages, respectively. Classes C and E are closed canopy (>30% cover) in mid- and late-development stages, respectively. The y-axis shows the proportion of the landscape in each class.

Testing Alternative Management Scenarios

Although the majority of the Greater Sand Dunes Landscape was found to be within the natural range of variability in fire regimes, a small portion of the piñon-juniper woodlands in the region had been altered by chaining and overgrazing in the mid-twentieth century, resulting in a mosaic of vegetation composition and structure that was not within the natural range of variability. In some areas, management activities resulted in uncharacteristic, non-reference condition states, including uncharacteristic amounts of cover of sagebrush and young piñon and juniper trees.

To examine management options for the altered portions of the piñon-juniper woodlands, the team implemented two changes to the VDDT models. First, uncharacteristic states were added to the model to represent the conditions observed today that are not within the natural range of variability (Figure 3), including non-native species, uncharacteristic amounts of sagebrush cover, and uncharacteristic canopy cover of piñon and juniper seedlings and saplings. Second, alternative management scenarios were added to the reference condition VDDT models to test the effects, duration, and extent of different management tools. Management tools included in the model were grazing rest periods, prescribed fire, and mechanical thinning. Results of the management simulation modeling demonstrated that using multiple tools would have the desired restoration effects, but that treatments would need to continue for many decades to restore conditions completely.

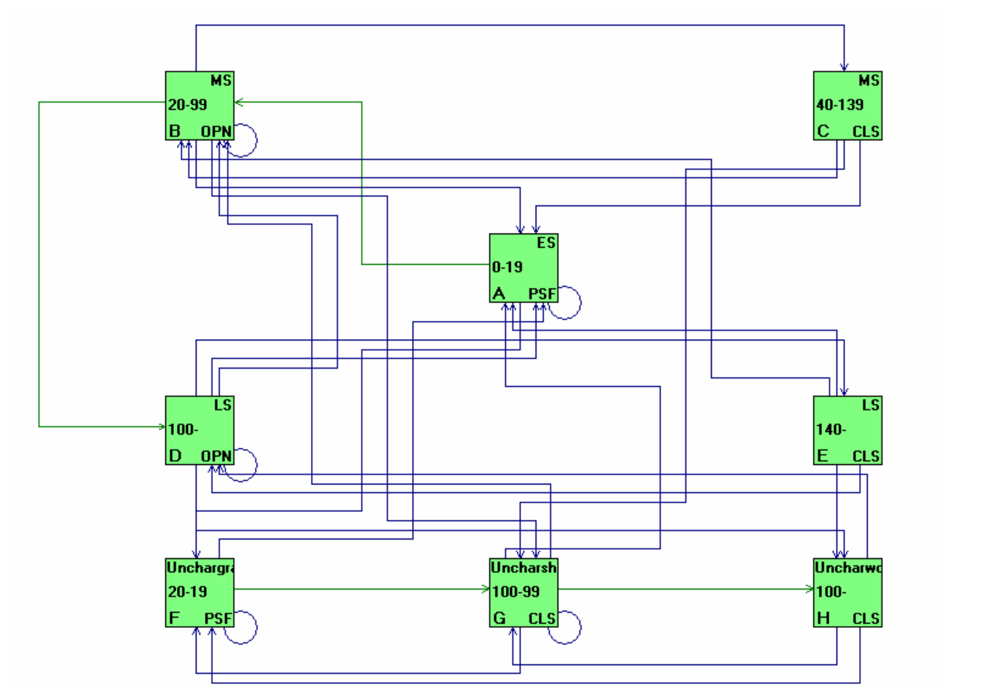

Figure 3: Alternative management scenario model. The five boxes at top are the same succession classes that appear in the reference condition model (figure 1). The three additional states are uncharacteristic vegetation composition and canopy cover resulting from twentieth century management activities.

Conclusions

In the Greater Sand Dunes Landscape, dynamic vegetation models were useful tools for determining what, if any, management action needed to be taken to restore altered fire regimes and vegetation mosaics. Perhaps more importantly, vegetation models also served as a forum for developing consensus about natural ecosystem processes among diverse land managers. Models were used as communication tools both within the collaborative, interdisciplinary team and to external audiences of stakeholders, including residents, volunteer fire departments, and private land owners. The dynamic vegetation models for the Greater Sand Dunes Landscape will be continually refined and added to as management objectives change and as scientific knowledge of vegetation communities improves.

The hundreds of vegetation dynamics models developed through the LANDFIRE project (www.landfire.gov) not only document and synthesize the best available knowledge about ecosystem structure and function across the United States, but also make available consistent data and decision-support tools for finer-scale work. Vegetation dynamics models can help foster public support, build consensus among partners about natural ecosystem functions, and support decision-making about the conservation and management of ecosystem processes. Using dynamic, malleable, user-friendly tools such as vegetation and disturbance modeling software facilitates adaptive management, assessment of alternative future scenarios and measurement of the success of management and conservation strategies over time.

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