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LANDFIRE

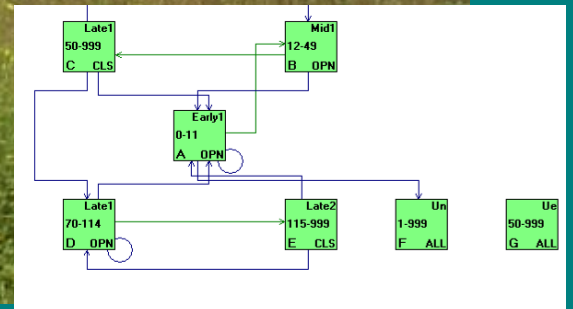# ADAPTING LANDFIRE VEGETATION DYNAMICS MODELS

MANUAL V. 1 -- AUGUST 2009

CONTENTS

CHAPTER 1: PURPOSE OF THIS MANUAL

This manual is intended to help the reader adapt LANDFIRE Vegetation Dynamics Models for use in modeling current and future landscapes. Once adapted, these models may be useful in predicting future vegetation conditions, exploring the impacts of potential environmental changes and comparing the results of different management options. We consider this to be a living document, and we anticipate creating new versions with additional adaptation examples in the future.

LANDFIRE

The LANDFIRE project is a cooperative effort led by the USDA Forest Service, US Department of the Interior and The Nature Conservancy to produce consistent, comprehensive maps and data describing vegetation, fuels and fire regimes for the United States. One of the data products of the project is a set of vegetation dynamics models created through workshops and a review process by experts across the country. Each model describes the key vegetation states and processes for a biophysical setting (BpS) in both quantitative and descriptive terms.

A BpS is the ecological system that is thought to have been dominant on a particular part of the landscape prior to European settlement. It includes both the vegetation and the disturbance regime that would have existed under "reference conditions." The LANDFIRE project uses the term "reference conditions" to refer to the conditions that would have existed just before the influence of European settlement began to impact the landscape in an area, but with the current climatic conditions. The BpS concept is similar to that of Potential Natural Vegetation Groups. Researchers developed 1,733 models for 403 BpS in the contiguous 48 states (regional model variants were developed for BpS that occur over a wide geographic area). Models for the Alaska and Hawaii BpS are currently in development and will be published by the end of 2009. For more information about the LANDFIRE project, or to download data or models, visit http://www.landfire.gov.

VDDT

The models were developed using the Vegetation Dynamics Development Tool (VDDT), modeling software available for download from ESSA Technologies (http://www.essa.com/tools/vddt/). VDDT is an easy-to-use aspatial modeling tool. The LANDFIRE VDDT models include up to five vegetation states or successional classes and the succession and disturbance pathways that connect these states. Each transition pathway is attributed with a probability, and the model uses stochastic processes to determine when transitions occur.

It is important to distinguish these aspatial models from spatial models like LANDSUM, which was also used in the LANDFIRE project. In spatial models, what happens at one point on the landscape influences what happens to all of the points nearby. In aspatial models, every pixel or cell operates independent of its neighbors, according to the rules established by the modeler. This can make the models less realistic, but it also makes them simpler, easier to understand, and less demanding of computing power, data inputs and time.

The LANDFIRE vegetation dynamics models consist of two closely related files: a VDDT model and a text description that defines the BpS, describes its vegetation and where it is found and explains what each of the successional states and pathways in the VDDT model represents on the landscape. The description also explains how the model was developed and documents the sources of the information included in the model. The model descriptions are essential to understanding the VDDT models.

Adapting the Reference Condition Models

Because the LANDFIRE models were designed to reflect reference conditions, they typically cannot be applied to current landscapes without substantial modifications. In many systems, disturbance regimes have been altered from the reference condition regimes. The current landscape may include vegetation types and structures that did not exist on the reference landscape. Human activities such as logging, mowing, planting and herbicide application can cause new types of transitions that were not present in the reference condition models. This document is intended as a guide to adapting the models to apply to current conditions in the relevant BpS.

The LANDFIRE models are a powerful, free resource for land managers, fire planners and scientists because they were created by experts to address specific BpS across the United States. These models can provide a starting point for developing models that help managers understand current landscape conditions and explore future scenarios. Compared to developing ecological models from scratch, adapting the LANDFIRE models will be much faster, easier and more feasible for resource professionals without much prior modeling experience.

Once a model has been adapted to reflect current conditions, it will have many potential applications. Managers can use a model to compare the potential effectiveness and cost-efficiency of a variety of different management options. This type of analysis could be useful in management planning, target-setting and/or budget justification. At the most basic level, a model can help planners assess how the landscape might change over time if current conditions continue. Potential future changes to the landscape or environment, such as changes in logging or grazing practices, the introduction of invasive species or environmental influences related to global climate change, can also be incorporated into the models, allowing for comparison of possible future scenarios. This can help resource professionals plan for an uncertain future and understand what types of mitigation may be useful or possible. The models may be helpful in a range of spheres, including forest and rangeland planning, wildlife habitat management and fire or fuels management.

LIMITATIONS OF THE MODELS

The LANDFIRE reference condition models will likely be most useful in planning for one to several biophysical settings at a time. Because VDDT is an aspatial modeling tool, these models do not address spatial interactions, such as fire spread, within a BpS or among neighboring BpS. The VDDT models can feed into spatial models, but spatial modeling to simulate a real landscape would likely require adapting models for many BpS, which would be a labor-intensive process. The process described in this manual will be especially useful on landscapes with one or two dominant BpS, or in cases where only a handful of BpS are important to the management question being addressed. Examples of the latter situation might include modeling for wildlife habitat values that are present in particular vegetation types or planning for an endangered species that occurs most commonly in a particular BpS. When deciding whether to adapt the LANDFIRE vegetation models for use in a particular application, users should consider whether interactions among BpS are a core element of the problem being addressed. In many cases, these non-spatial models can provide a basic understanding of specific processes of interest without the need for complex and labor-intensive spatial modeling.

WHO SHOULD USE THIS MANUAL

This manual is designed for users who already have a basic understanding of VDDT and the LANDFIRE reference condition models. Although some introductory concepts are reviewed, this manual is not intended to provide an introduction to VDDT or LANDFIRE. Several resources are available for those who are new to VDDT and LANDFIRE. A free online course entitled **LANDFIRE: Concepts, Data, and Methods** is available through the University of Idaho; more information on this course can be found on the LANDFIRE web site (http://www.landfire.gov/training_intro.php). Training in the use of the VDDT software is available from ESSA Technologies (http://www.essa.com). A detailed user guide to VDDT is also available on the ESSA web site.

HOW TO USE THIS MANUAL

This manual comprises two case studies in which LANDFIRE models were adapted to be used in management planning for real landscapes. Chapters 2 and 3 contain step-by-step descriptions of the model adaptation process as applied to a sagebrush system in Utah. The best way to use these chapters is to download the relevant LANDFIRE model database and follow along with the instructions. This will provide an introduction to most of the techniques a user will need to adapt the LANDFIRE models to reflect current conditions.

Chapter 4 contains a second example on a different landscape, a shortleaf pine system in northern Georgia. This example elaborates on the techniques presented in Chapters 2 and 3, as applied to a different set of management questions. The example in Chapter 4 is more focused on the role of fire in this forested system. Chapter 4 does not include step-by-step instructions, as most of the modeling techniques used in that example were explained in detail in Chapters 2 and 3. Again, the best way to understand this example is to download the relevant model and practice adapting it, following along with Chapter 4.

If you need detailed instructions on a particular technique, refer back to Chapter 2 or 3. Simply reading Chapter 4 as a case study may also be helpful.

Chapter 2: Adapting a Reference Condition Model to Current Conditions

Purpose and Overview

In this chapter, we will explore how the LANDFIRE reference conditions can be adapted to current conditions. We will examine a sagebrush model from the Great Basin region and update it to include invasive species, tree encroachment and over-grazing. After running the model we will discuss the results and perform a sensitivity analysis.

The Project and Study Area

The example used here is a simplified version of a model created for a landscape in the Grouse Creek Mountains-Raft River Mountains region of Utah (York et al. 2008). The study area included over one million acres in the northwest corner of Utah, bordered by Nevada and Idaho. Most of this area falls within the Great Basin ecoregion, with a smaller portion reaching into the Columbia Plateau ecoregion to the northwest and is located in Map Zone 17. Elevations range from approximately 4,300 to 9,600 feet. Vegetation types within the study area include salt desert and sagebrush shrublands, pinyon-juniper woodlands, stable and seral aspen, curlleaf mountain mahogany, subalpine conifers, riparian corridors and wet meadows. The project report (York et al. 2008) describes the conservation significance of the study area as follows:

> The Grouse Creek Mountains and Raft River Mountains landscape is considered a conservation priority for The Nature Conservancy and a management priority for the Utah Partners for Conservation and Development. The landscape supports both common and rare species of special management interest: mule deer, pronghorn, pygmy rabbit, greater sage-grouse, ferruginous hawk, northern goshawk, Yellowstone cutthroat trout, Crittenden's springsnail, Cottam's cinquefoil and more. The landscape is home to the third largest historic population of greater sage-grouse in Utah and overlaps with an important raptor migration flyway.

The goal of the project was to use quantitative models to explore the cumulative impact of past land management projects and potential impacts of future management scenarios on the integrity of ecological systems in the study area.

The Reference Condition Model

This project identified 17 BpS within the study area. This example focuses on the Inter-Mountain Basins Montane Sagebrush Steppe BpS, which is described by LANDFIRE vegetation model 1711260. The original LANDFIRE model and description was actually changed twice by staff from The Nature Conservancy before its use in Utah. This shrub-steppe system, dominated by mountain big sagebrush, was divided into two elevational variants not found in LANDFIRE for this project. We will focus on the lower elevation, or "upland" variant, referred to in this project as BpS gr1126up. This system, in its intact condition, provides critical summer habitat for greater sage grouse. About one-tenth of the study area, or approximately 100,000 acres, falls within this BpS.

The original LANDFIRE reference condition model for this BpS is outlined in Figure 1 and Table 1. This model is intended to capture the vegetation dynamics under reference conditions, in the absence of the influences of European settlement. It includes three stages of sagebrush development (Classes A, B and C) and two stages in which trees begin to invade the shrubland (Classes D and E). The primary successional pathway is from A to B to C. An alternative successional pathway from C to D and then E is followed if fire is absent for more than 80 years. This model includes two types of possible disturbance: fire and insects/disease.

A complete description of this model can be found in Appendix A. The VDDT model and description can be downloaded, along with all of the models for Map Zone 17, from the LANDFIRE web site.
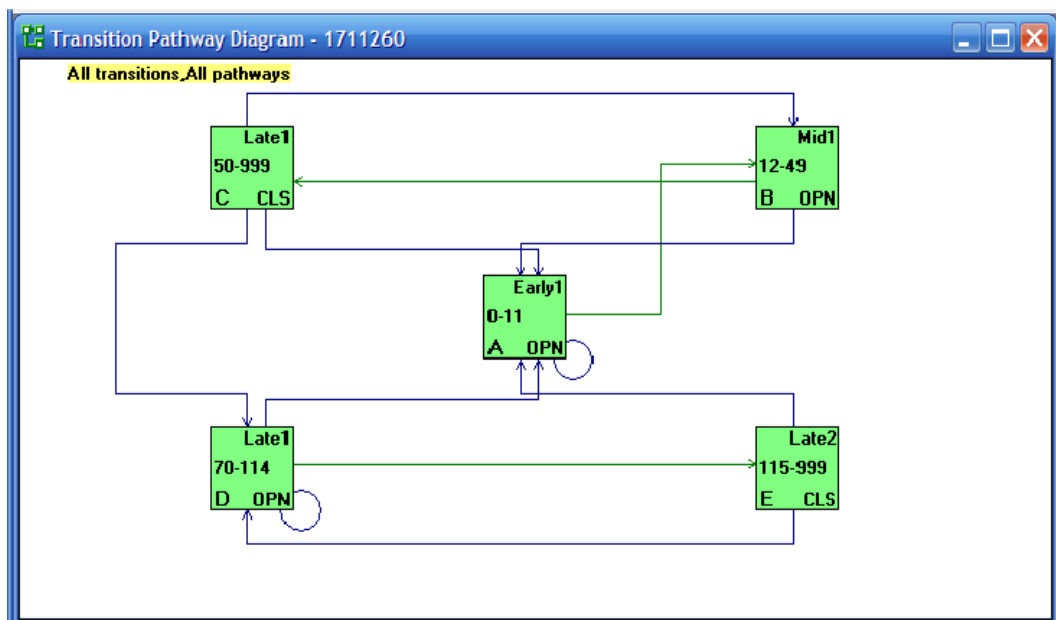

Figure 1: LANDFIRE Reference Condition VDDT Model for BpS 1711260 (used to develop1126up), Upland Montane Sagebrush Steppe, in Map Zone 17, the Inter-Mountain Basins. Green lines represent succession; blue lines represent disturbance or alternate succession pathways.

Class	Age/Structure	Description	% of Reference Landscape Occupied by Class
A	Early seral, open structure	0-.5% canopy of mountain sage/mountain brush, grass/forb cover typically >50%	20
B	Mid-seral, open structure	6-25% cover of mountain sage/mountain shrub, >50% herbaceous cover	50
C	Late seral, open structure	26-45% cover of mountain sage/mountain brush, 50% herbaceous cover, <10% conifer sapling cover	15
D	Late seral, open structure with trees	11-25% cover conifer <10m, 25-40% cover of mountain sage/mountain brush, <30% herbaceous cover	10
E	Late seral, closed structure with trees	26-80% conifer cover 10-25m, 0-20% shrub cover, <20% herbaceous cover	5

Table 1: Class definitions and landscape percentages for LANDFIRE Reference Condition VDDT Model for BpS 1711260, Upland Montane Sagebrush Steppe in the Inter-Mountain Basins.

ADAPTING THE MODEL TO CURRENT CONDITIONS

In order to adapt this reference condition model to address current management questions, the researchers needed information on how this system functions today, e.g. what vegetation conditions and processes exist today that were not found in the presettlement environment? To gather this information, they convened a number of expert workshops. Through this collaborative process, researchers arrived at a conceptual model for the current state of the system. In this example, we'll explore how to adapt the reference condition model to reflect current conditions by adding these new states and the processes that create them.

The Montane Sagebrush Steppe system of today has been altered in several ways from the reference conditions. Some of the major changes have been briefly summarized below.

OVERGRAZING

Overgrazing in some areas has led to the loss of the herbaceous vegetation layer, so that bare ground has taken the place of native grasses and forbs. This can lead to a structure with mature sagebrush in the overstory and bare ground beneath. If the overgrazing occurs before sagebrush has become well established, it can be replaced by early seral

native shrubs such as rabbitbrush. Once the native herbaceous layer has been lost, invasive annual grasses, especially cheatgrass (*Bromus tectorum*, also known as downy brome), may become established in the understory.

CHEATGRASS

Cheatgrass, one of the most widespread and problematic weeds in North America, has come to dominate large areas of the Great Basin following its introduction and spread across the western states in the late 19th and early 20th centuries. When cheatgrass invades sagebrush communities, it severely alters the fire regime, leading to more frequent and more severe fires that facilitate its continued dominance. Cheatgrass invasion can alter the fire regime in sagebrush grassland systems from a 20- to a 100-year fire return interval for the native system to a three- to five-year interval for the invaded system (Ypsilantis 2003). Extensive wildfires in the Great Basin in recent decades have furthered the plant's spread and increasing dominance.

Cheatgrass invasion often vastly decreases plant diversity in an ecosystem, degrading wildlife habitat values. Specifically, cheatgrass invasion in sagebrush grasslands reduces critical winter forage for mule deer and pronghorn and degrades habitat values for sage grouse, a species of special management interest. The costs of cheatgrass invasion in lost forage, degraded wildlife habitat and wildfire damage are enormous. Ranchers and land management agencies spend a great deal of money on cheatgrass control and eradication efforts every year, but the weed continues to spread.

TREE INVASION

Where the montane sagebrush BpS occurs alongside pinyon-juniper woodland, conifers may encroach into the sagebrush steppe, especially after the native herbaceous layer has been lost. This leads to a structure dominated by conifers with few shrubs and very little herbaceous vegetation. Under the reference fire regime, this transition would rarely occur, but in the absence of fire, more of the landscape will move toward this structure.

STEP-BY-STEP INSTRUCTIONS FOR ADAPTING THE MODEL TO CURRENT CONDITIONS

In this example, we will use a simple system to adapt reference condition models to current conditions. If more complexity is needed to adequately describe current conditions, it can be added to the simple model.

1) DOWNLOAD MODELS FROM THE LANDFIRE WEB SITE

We'll begin with an existing LANDFIRE reference condition model, available from the www.landfire.gov site. The model we will use comes from Map Zone 17, the Inter-Mountain Basins.

TO DOWNLOAD MODELS:

a) Go to www.landfire.gov and navigate to the LANDFIRE National Vegetation Dynamics Models page. Currently (July 2009), the page is located at: http://www.landfire.gov/NationalProductDescriptions24.php

b) Under *Download model products by mapping zone*, click on ***Option 2,*** which allows you to download the VDDT models, along with their descriptions and supporting documents.

c) Click on **Map Zone 17** in the interactive map. **Save** the zipped file and extract the contents to a convenient location on your hard drive. This folder includes four files: the Access database that includes the VDDT models, a .pdf document describing the models, a spreadsheet including the model reference conditions and a metadata document.

d) **Open** VDDT and select the Map Zone 17 database you just downloaded, 17VDDT-v1.mdb.

e) Go to **File | Open** and open project 1711260, Inter-Mountain Basin Montane Sagebrush Steppe.

f) Go to **File | Save as** and save the project with a new name. This ensures that you will have a copy of the original reference condition model for future use or comparison.

2) ADD NEW CLASSES

In this example, we will add two new states or boxes to the reference condition model. We'll refer to these states by the following codes:

U_N, for an Uncharacteristic[1] state composed of Native plant species
      and
U_E, for an Uncharacteristic state that includes Exotic species.

These categories not only keep the model as simple as possible, but they also correspond to classes used in the LANDFIRE spatial data products, making it easier to apply these models to real landscapes using available data. However, a modeler may choose to add different classes instead of these two in order to capture the ecological processes adequately. Modelers can add as many new classes as necessary, but it's a good rule of thumb to keep the model as simple as possible.

As described by the modelers for the original project, this system actually has several native uncharacteristic states:

a) The sagebrush and herbaceous vegetation has been replaced by early seral shrubs, especially rabbitbrush.

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[1] In this document, the term "uncharacteristic" refers to vegetation states that were not included in the LANDFIRE reference condition model (because the modelers believed that they would not have occurred on the presettlement landscape). "Characteristic" vegetation falls into one of the classes defined in the reference model.

b) The sagebrush remains, but the herbaceous vegetation has been largely eliminated, typically by overgrazing.

c) The herbaceous vegetation has been eliminated and then pinyon and juniper trees have replaced the sagebrush.

One way to update this model would be to add three new boxes to the model to represent these three native uncharacteristic states. Modelers might choose this approach if there were a management need to keep track of each uncharacteristic state individually and local data that distinguished between these states were available. However, each box that is added to a model multiplies the number of transitions that must be calibrated and tracked and the resulting complexity of the model. Generally speaking, it is preferable to limit the number of boxes in a model to the minimum number needed to track the most meaningful states and transitions.

In order to keep this model simple, all three of these states will be lumped into one native uncharacteristic class (U_N). This class would correspond most closely to the class that the Utah project labeled "Depleted" or "DPL" (because the herbaceous layer is depleted). This model would apply best to sites without adjacent pinyon-juniper forests, where tree encroachment is unlikely.

In this example, only one state includes exotic species. This state comes about when the native herbaceous layer has been lost and cheatgrass becomes established in the understory. We'll call this class U_E (for "uncharacteristic exotic"), but it corresponds to the class that the Utah project labeled "Shrub-Annual Grass" or "ShAG."
Before we can add these new classes to the model, we have to create some new Cover Types. LANDFIRE reference condition models include nine possible Cover Types (three Early-Development, three Mid-Development and three Late-Development).

TO ADD NEW COVER TYPES:

a) Go to **File | Properties | Definitions.**

b) Click on the *Cover Types* tab.

c) Click on **New.**

d) In the row for the new cover type, enter "Un" in the *Abbreviation* field and "Uncharacteristic-Native" in the *Name* field.
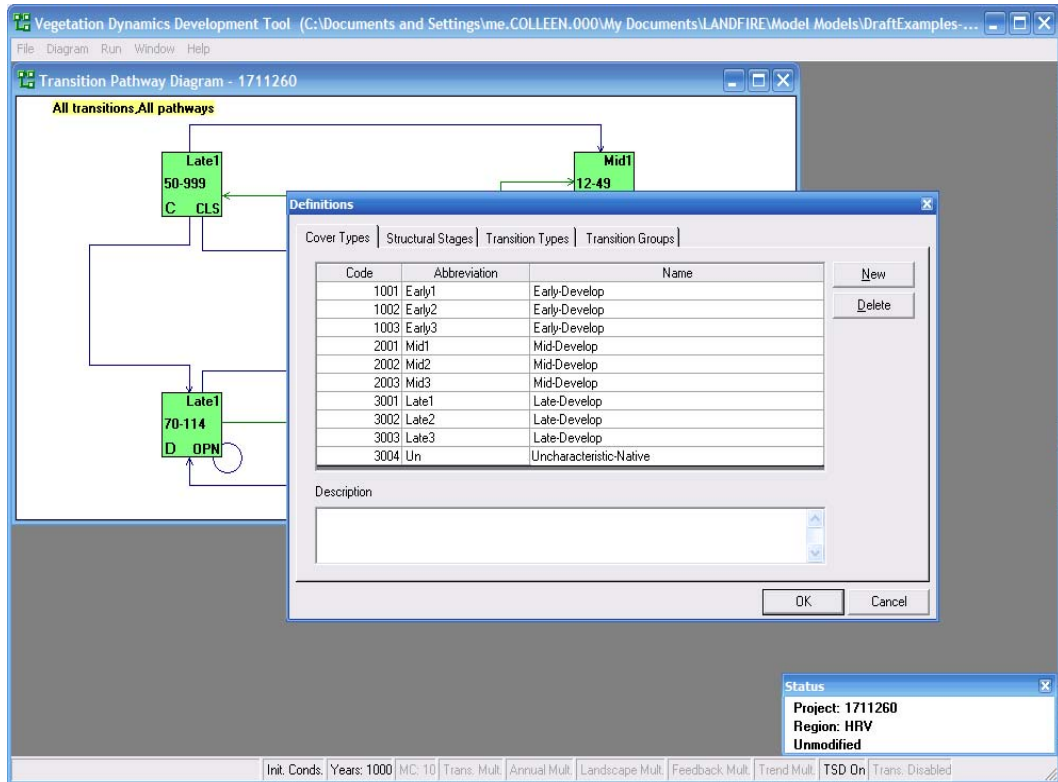
e) Click on **New** again, and give the second new type the abbreviation "Ue" and the name "Uncharacteristic-Exotic."

f) Click **OK** to exit the dialog.

Now we are ready to add the two new states to the VDDT model and attribute them. The Depleted (U_N) class can occur at any age except immediately following a disturbance, so we'll set the age range at 1-999. Cheatgrass won't invade an early successional reference state in this BpS, so we'll set the age range to 50-999. These classes will not succeed to other classes, so we set the deterministic transitions to remain in the same class.

TO ADD NEW CLASSES TO THE MODEL:

a) Select **New Class** from the **Diagram** menu to open the *New Class* dialog. VDDT assigns letter labels to the new classes as they are added. In this case, the new U_N class is automatically labeled Class F by the software. When we add another class for the U_E state, it will be labeled G automatically.

b) From the **Cover Type** drop-down list, select **Un – Uncharacteristic Native**.
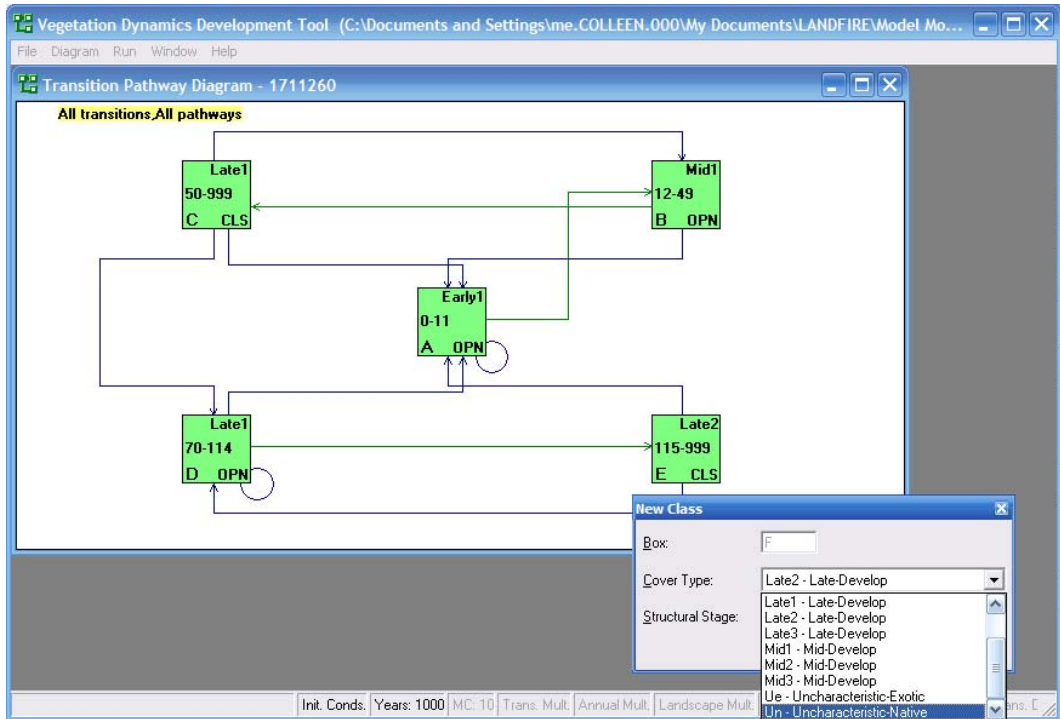
c) From the **Structural Stage** drop-down menu, select **ALL – AllStructures**, since this class can have open or closed canopy vegetation.

d) Click **OK** to exit the dialog. A new box with the attributes you just selected should appear in the diagram.
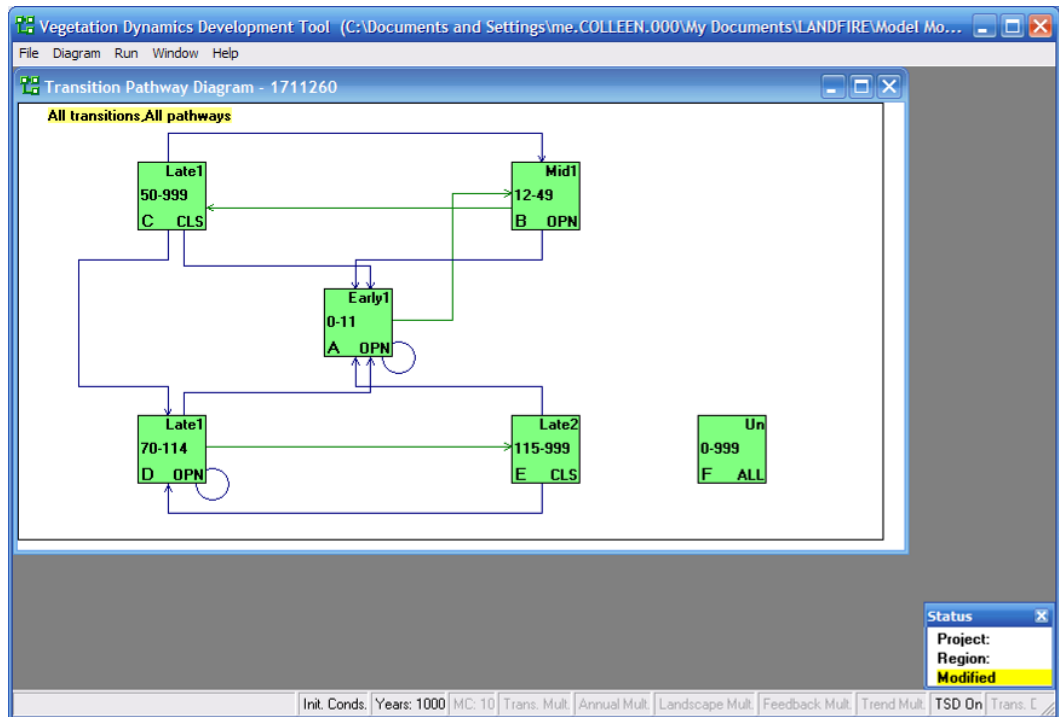
e) Double-click on the new *Box* (Class F) to open the *Class Properties* dialog.

f) Under *Deterministic transitions*, we need to set the *Timing* and *ToClass* attributes. This type can occur any time from age one up. Type "1" under Start Age and "999" (the maximum possible age allowed in VDDT, used to represent classes that have no end age) under End Age.

g) This class will not automatically succeed to any other type over time; vegetation will remain in this class until some type of probabilistic transition occurs. As a result, the *ToClass* should be F. Make sure the *Box* field shows "F."

h) Click **OK** to exit the dialog. You may see a warning that the age boundaries of the class have changed. Click **Yes** to automatically update the disturbance ages.

i) Repeat these steps to add a second new class (G) with *Cover Type* **Ue** and *Structural Stage* **ALL**. Attribute the class so that the age range is 50-999 and the *ToClass* is G.

The model will look like this after the two new classes are added:
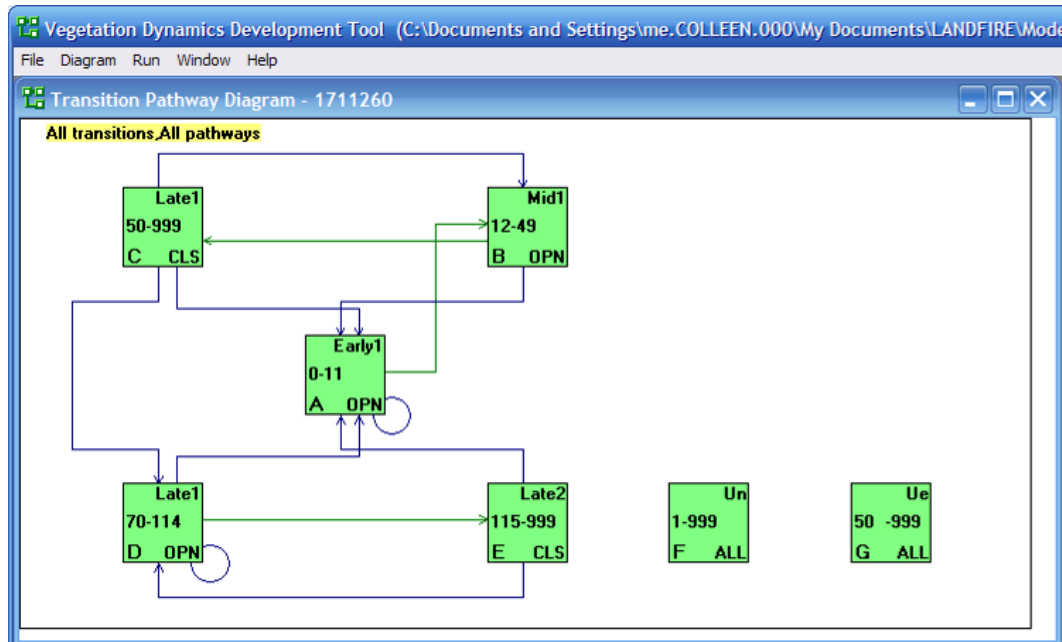
## 3) ADD NEW SUCCESSION AND DISTURBANCE PATHWAYS

We'll begin by creating pathways into the new classes. This system transitions to class U_N through overgrazing in Class A, B or C. We need to add a probabilistic (disturbance) pathway called "Excessive-Herbivory" from Classes A, B and C to Class F. We begin by adding a new transition type and a new transition group through the *Definitions* dialog box.

a) Go to **File** | **Properties** | **Definitions**.

b) Click on the ***Transition Types*** tab.

c) Click on **New** and type in "Excessive-Herbivory."
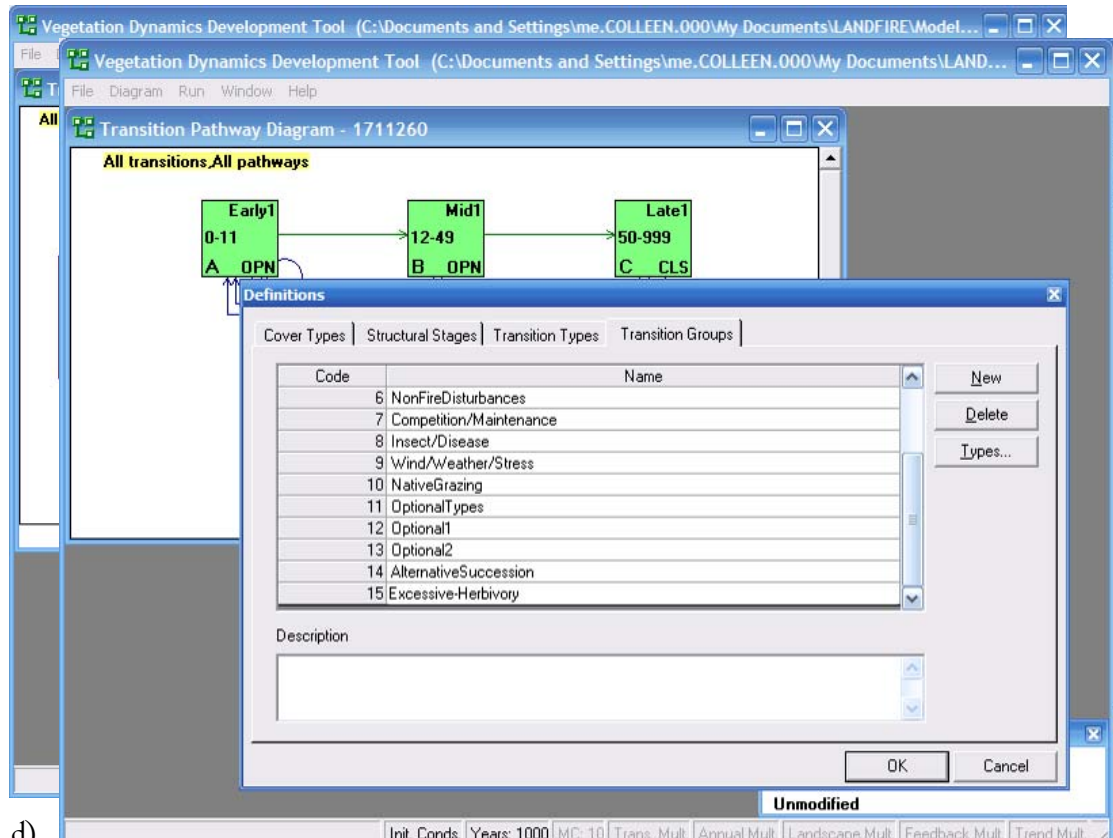
d)

d) Repeat these steps on the ***Transition Groups*** tab.

e) Now we need to assign the new transition type *Excessive-Herbivory* to the new transition group *Excessive-Herbivory*.

f) Make sure *Excessive-Herbivory* is highlighted on the ***Transition Groups*** tab, and click on **Types**. The dialog box below will appear, showing all of the possible transition types.

g) Highlight **Excessive-Herbivory** and click on the arrow to move it onto the *Selected* list.
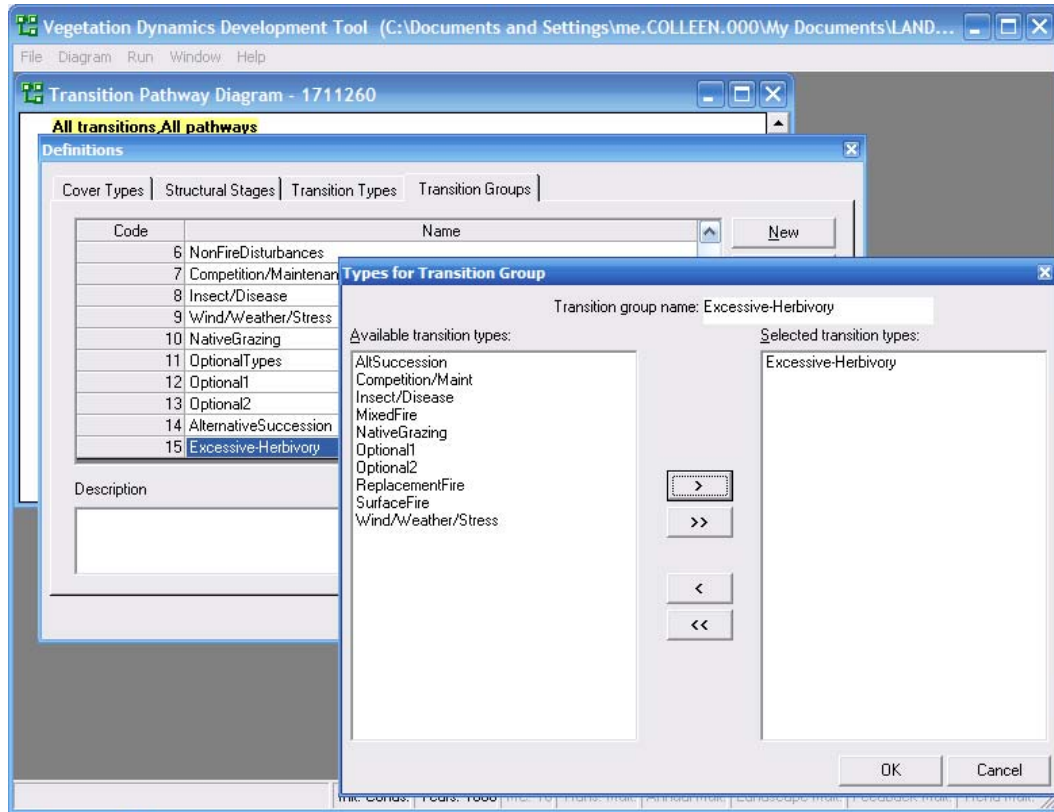
h) Click **OK** to exit the dialog, and save the project. The new transition type is now available to use in the model.

Now we'll use this new transition type to create a new pathway from Class A (Early Successional) to Class F (Native Uncharacteristic). In the original 1126up model, this pathway led from Class A to an early seral shrub (rabbitbrush) class. Our simplified version of the model does not include the early seral shrub class, so the pathway has been redirected to Class F, though this is not strictly ecologically accurate. The rate of overgrazing in this early successional class was historically high due to past stocking rates. However, the research conducted for this project suggested that the rate of overgrazing is currently very low: on the order of one in 1,000 acres converted to the uncharacteristic native state in a typical year. This Excessive-Herbivory occurs where livestock aggregate around stock tanks and salt blocks, or where pastures are grazed too hard. We'll use a probability of 0.001 to represent this in the model.

TO ADD A NEW TRANSITION PATHWAY BETWEEN CLASSES:

a) Begin by opening the *Class Properties* dialog by double-clicking on *Box A* in the *Transition Pathway Diagram.*

b) Click on **New**, and choose **Excessive-Herbivory** from the *Transition Type* drop down menu.
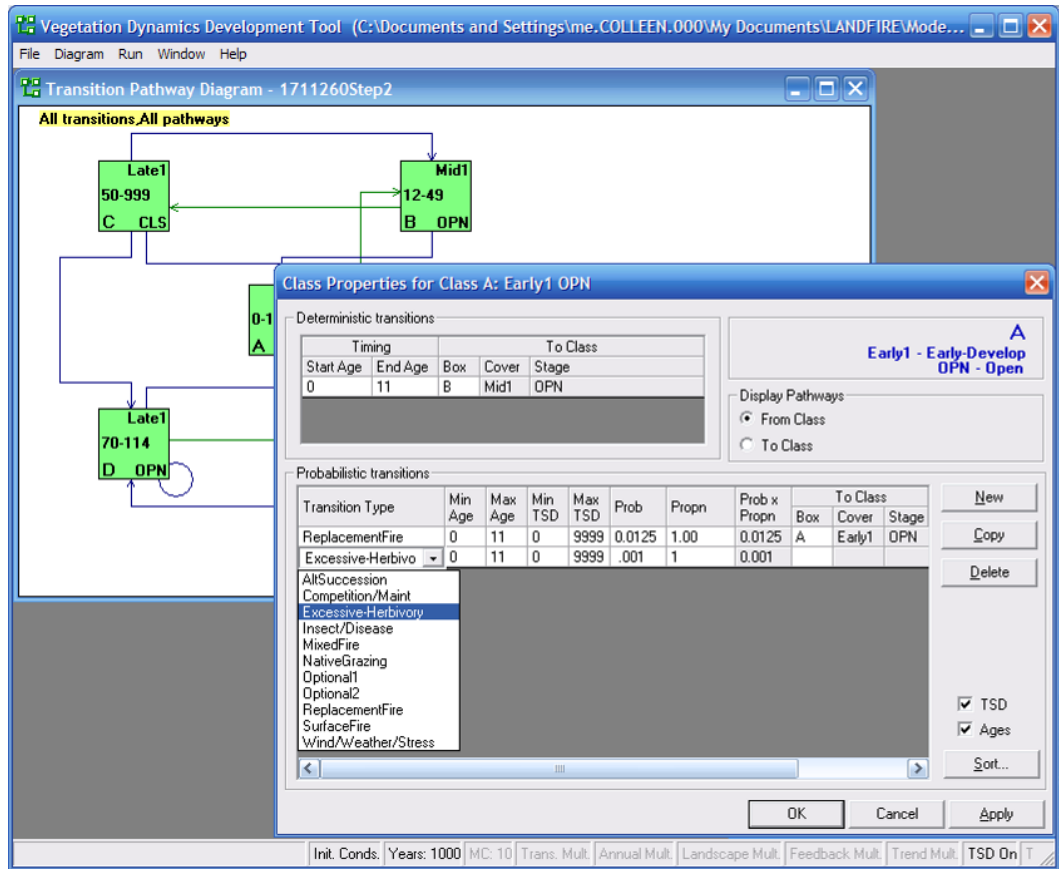
c) By default, the Min and Max ages will be set to the age limits of the class, which is what we want.

d) Under *Prob,* type "0.001," the probability of a transition due to overgrazing in this class.

e) Under **To Class/Box**, type "F." This transition will cause the system to move into box F, the Native Uncharacteristic state.

f) The other properties can be left on their default settings. Click **OK** to exit the dialog.

The *Transition Pathway Diagram* should show a new arrow from box A to box F representing the new transition:
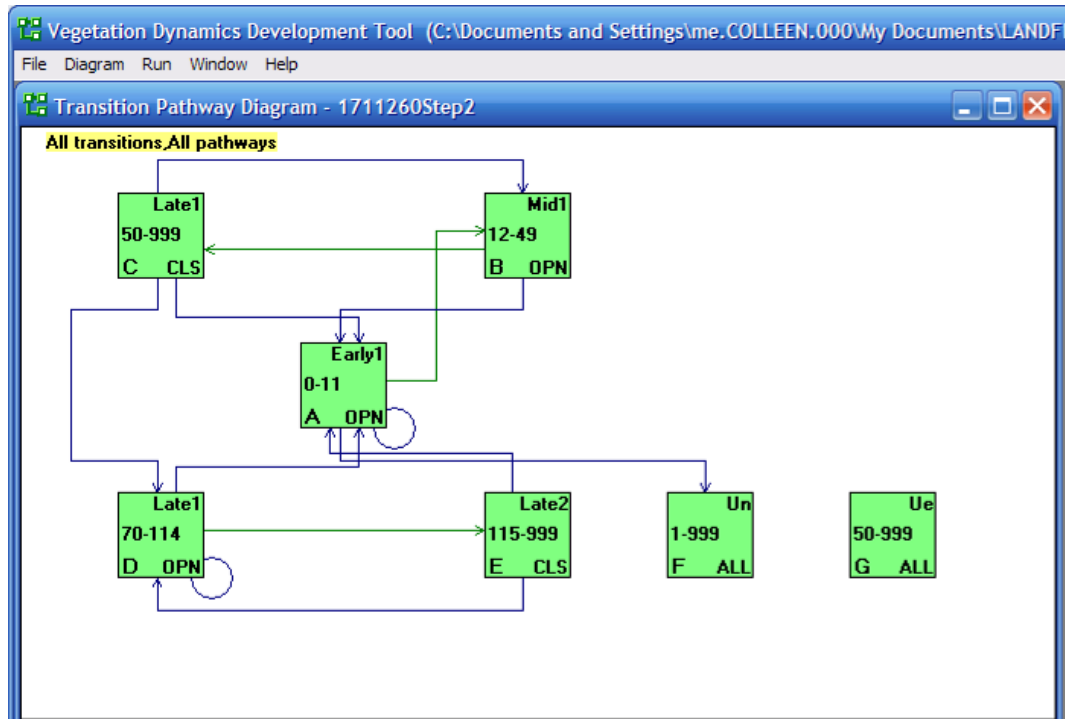
Repeat these steps to add an Excessive-Herbivory transition from Class C to Class F. The probability of this transition is also 0.001.

The modelers felt that there were two possible results of overgrazing in Class B, a mixed shrub/grass stage. The most likely outcome is that the system would remain in this class and experience accelerated woody succession (not modeled here). The modelers estimated that this outcome would result about 75 percent of the time. The other possible result of overgrazing is a transition to the Uncharacteristic-Native class (box F). This happens about 25 percent of the time. To capture this dynamic, we will set up the transitions using Proportions as well as Probabilities.

TO ADD NEW TRANSITION PATHWAYS USING PROPORTIONS:

a) Open the Class B *Class Properties* dialog, and add a new **Excessive-Herbivory** pathway. This will represent the primary pathway that stays in Class B.

b) Under *Prob,* type "0.001," the overall probability of overgrazing in this class.

c) Areas that are overgrazed in this class have about a 75 percent chance of staying in this class. We will represent this second layer of probability using the *proportion* field, which allows us to separate the overall probability of a pathway into two parts: the probability of the transition occurring (represented using *Prob* field), and then the subsequent probability that one or more branching pathways will be followed in response to the transition (represented by the *Propn* field). In general the proportion values specified for pathways associated with a particular transition should sum to one. In this example under *Propn,* type "0.75." VDDT will multiply the probability (0.001) and proportion (0.75) to generate an overall probability for this pathway.

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d) Under **To Class/Box**, type "B" to indicate that this transition will cause the system to stay in this box.

e) The other properties can be left on their default settings. Instead of closing this dialog, click **New** and add a second Excessive-Herbivory pathway.

f) Under *Prob,* type "0.001." Under *Propn,* type "0.25."

g) Under **To Class/Box**, type "F" to indicate that this transition leads to Class F. The dialog should look like the one below.
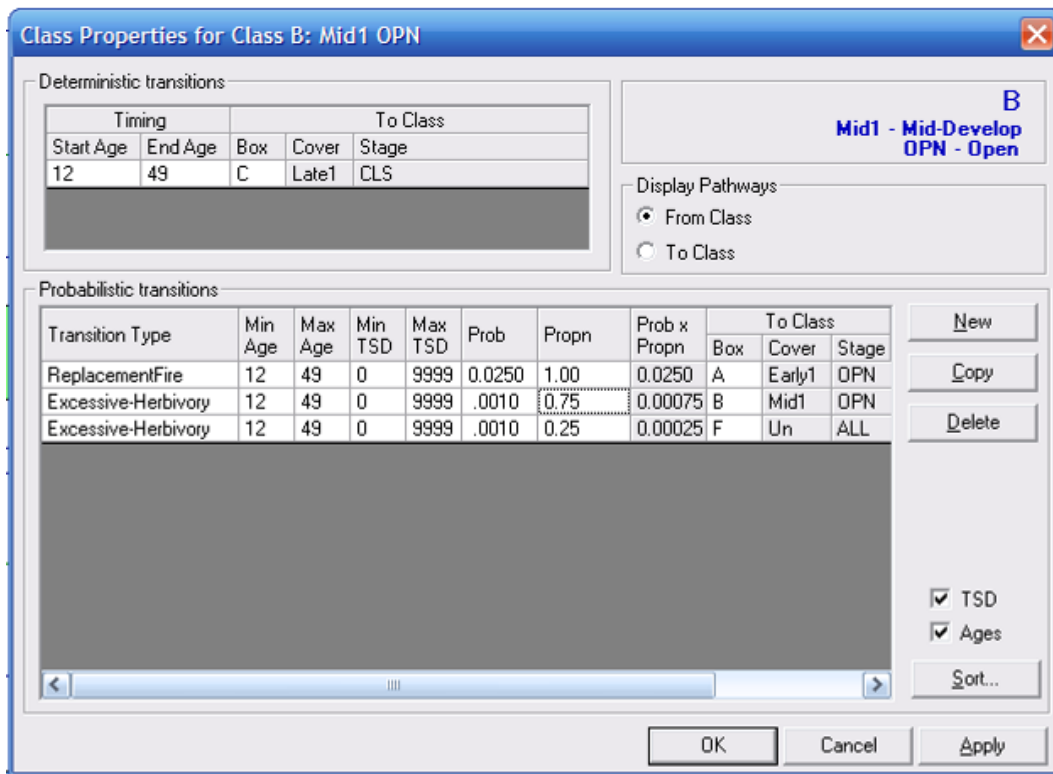
h) Because the proportions for the two Excessive-Herbivory transitions add up to one, the use of proportions has not changed the total probability of overgrazing in this class, which is set at 0.001. Click **OK** to exit the dialog.

Two types of disturbance are possible in Class F. The first, Replacement Fire, at a probability of 0.02 (a 50-year Fire Return Interval, or FRI), will keep the system in this class. The second disturbance is invasion by non-native grasses, which will cause a transition to Class G, Uncharacteristic Exotic. Adding this transition will require creating another new Transition Type and Transition Group.

**Add probabilistic transitions for Class F:**
a) In the *Class Properties* dialog for Class F, add a new Replacement Fire pathway leading to Class F with a probability of 0.02 (Propn = 1).

b) Follow the procedure under "To add a new transition type and group" above to create a new Transition Type and Transition Group, both named "AG-Invasion." This transition type represents invasion by exotic annual grasses (especially cheatgrass). Assign the new Transition Type to the new Transition Group.

c) In the *Class Properties* dialog for Class F, add a new AG-Invasion pathway leading to Class G. The probability for this transition is 0.005 (Propn = 1). Note that cheatgrass invasion can occur in any class, but at lower probabilities. For simplicity, this model only includes the transition from Class F to Class G, but other models developed for the Great Basin have included cheatgrass invasion in all classes.

Once cheatgrass has invaded, an area is much more likely to burn. The modelers estimated that the mean FRI for cheatgrass invaded stands in this setting is approximately four years, and that all the fires would be stand-replacing. Thus, we need to add a replacement fire pathway to Class G. This is the only type of disturbance possible in Class G.

Add probabilistic transitions for Class G:
a) In the *Class Properties* dialog for Class G, add a new Replacement Fire pathway leading to Class G with a probability of 0.25 (Propn = 1).

b) When you are finished, the diagram should look like this:
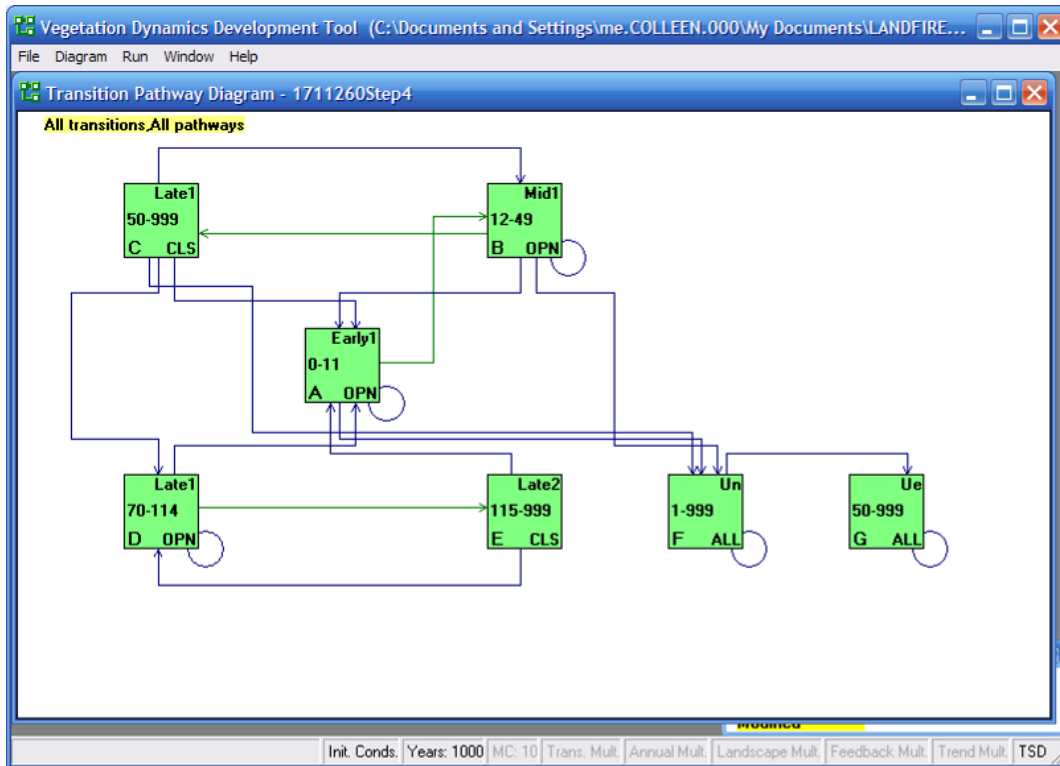
4) RUN THE MODEL

To verify that the model functions as expected, we will do a test run. In this scenario, we will start with the current conditions found in this BpS in the study area in 2006. We will run the model for 50 years to represent a baseline future scenario in which no active management is practiced.

ADJUST THE RUN SETTINGS

a) Go to **Run | Settings** to open the *Run Settings* dialog box.

b) On the **General** tab, type "50" for number of time steps, "1000" for number of cells and "10" for number of simulations. In this example, each time step will represent one year, and each cell will represent 100 acres. On a smaller landscape, we would have the option to adjust the number of cells so that each cell would represent an acre, hectare, or other unit of real area. In this case, we are simulating a landscape with about 100,000 acres in this vegetation type. VDDT does not allow simulations with more than 50,000 cells, and even that number of cells would add an unnecessary amount of computing time for each run. One thousand cells is a sufficient number to allow a good distribution of stochastic events without taking very long to run.

c) Click on the **Initial Conditions** tab. We will start with the current condition class distribution, as calculated from maps created for the study from 2006 satellite imagery. Under *Propn,* fill in the following initial values. Note that this landscape is highly departed from the reference conditions (shown in Table 1), with 25 percent of this BpS in uncharacteristic vegetation types.

Class	Propn
A	0
B	0.43
C	0
D	0.32
E	0
F	0.02
G	0.23

d) Make sure the box is checked for **Randomize initial TSD to a maximum of:** and type in "80" for the maximum TSD value. A rule of thumb is to set this to be the largest minimum TSD used in the model.
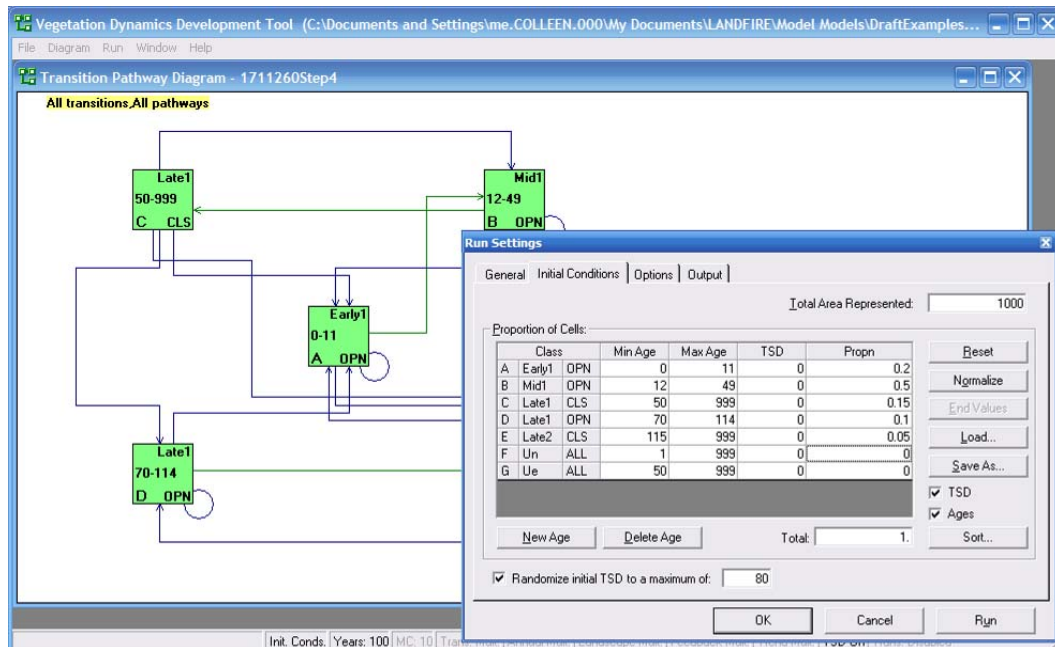
e) In the **Total Area Represented** box, type "100000" to represent the 100,000 acres in this vegetation type in the study area. This setting will not affect how the model runs, but it will allow us to graph model outcomes in terms of acres instead of proportions if we choose.

f) Click on the **Options** tab. Make sure the **Use Time Since Disturbance (TSD)** box is checked. Click the **Select** button to open the *Time Since Disturbance Groups* dialog box.
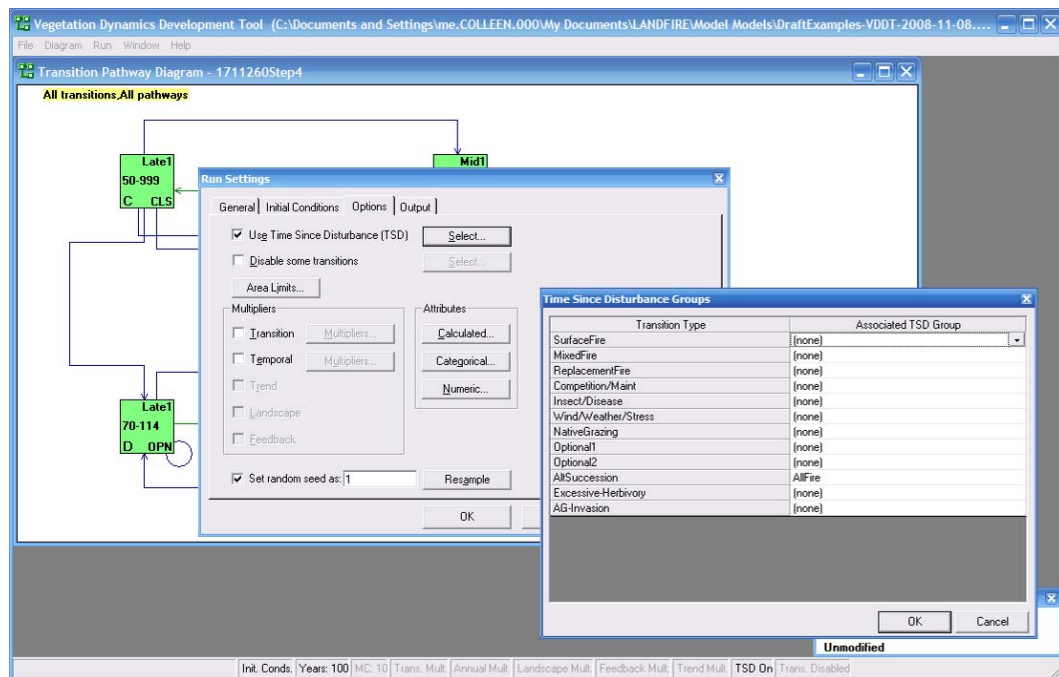
g) Make sure **AllFire** is selected as the **Associated TSD Group** for the **AltSuccession Transition Type**. Click **OK** to close this dialog.

h) Make sure that the **Disable some transitions** box is unchecked.

i) Make sure that all of the boxes under **Multipliers** are unchecked.

j) Click **OK** to close the *Run Settings* dialog and save the model.

RUN THE MODEL AND EXAMINE THE RESULTS

a) Go to **Run | Start Model** to run the model.

b) When the model has finished running, click on **Run | Final Conditions** to view the proportions of classes on the landscape at the end of the 50-year run. Your results should be similar to these:

Class	Propn
A	0.15
B	0.35
C	0.09
D	0.05
E	0.10
F	0.03
G	0.24

Experiment with changing some of the transition probabilities and observe the effects on the model's outcomes. To alter the probability of cheatgrass invasion, simply open the Class Properties dialog for Class G and change the Probability assigned to the **AG-Invasion** transition. To change the rate of overgrazing, it is necessary to change the probabilities assigned to the **Excessive-Herbivory** transition everywhere that transition occurs (in Classes A, B and C). Changes can be made to all of these pathways at once using the **Diagram | Probabilistic Transitions** dialog. In the next chapter, we will learn how to use the advanced "**Probability Multipliers**" option to vary the probability of any transition type up and down for all of its associated pathways.

SENSITIVITY ANALYSIS

Note that the results given above predict that the area invaded by cheatgrass will not increase substantially over the next 50 years, even in the absence of active management. This seems contrary to most experience in the Great Basin in recent years, though cheatgrass invasion rates are much lower in mountain sagebrush systems than in lower elevation systems. Historically, rates of Excessive-Herbivory were much higher than they are today. This led to more of the Depleted class on the landscape, which allowed for higher rates of cheatgrass invasion. But even under current grazing regimes, most stakeholders believe that the amount of cheatgrass on the landscape is increasing. This could indicate a problem with one or more of the model parameters, such as the probability of cheatgrass invasion.

Uncertainty around transition probabilities is very common, whether modeling historic, present or future conditions. One way to address this uncertainty is through sensitivity analysis. In this approach, a model parameter is systematically varied to see how much different degrees of change in that parameter will affect the model outcome. If a large change in a parameter has only a small impact on the model outcome, then uncertainty about the real value of that parameter is not a cause for concern. But if variations in a parameter lead to large changes in the model outcome, then the uncertainty in that parameter may have a substantial impact on whether the model produces meaningful results for managers.

A simple sensitivity analysis was performed on this model, varying the probabilities for two key probabilistic transitions: Excessive-Herbivory and annual grass invasion. The results are presented below. Changes that are more than one standard deviation away from the results of the basic model are indicated by an asterisk.

Scenario	Reference Conditions	Current/ Initial Conditions	Basic Model (Excessive-Herbivory Prob.= 0.001)	Excessive-Herbivory Prob.= 0.0005	Excessive-Herbivory Prob.= 0.002	Excessive-Herbivory Prob.= 0.01
Class	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %
A	20	0	15	15	15	*12
B	50	43	35	35	35	*28
C	15	0	9	9	8	*6
D	10	32	5	5	5	5
E	5	0	10	10	10	10
F	0	2	3	2	4	*14
G	0	23	24	24	24	25

Note: Landscape totals may not sum to 100 percent due to rounding.

The amount of the landscape in uncharacteristic classes does not show meaningful change when the rate of overgrazing is halved or doubled. Even with ten times the modeled rate of overgrazing, the landscape does not show large shifts. With the probability of overgrazing at 0.01, ten times higher than the local experts estimated, the amount of the landscape in uncharacteristic classes increases by about 40 percent over 50 years, but the amount that has been invaded by cheatgrass remains about the same.

Scenario	Reference Conditions	Current Conditions	Basic Model (AG Invasion Prob.= 0.005)	AG Invasion Prob.= 0.01	AG Invasion Prob.= 0.025	AG Invasion Prob.= 0.05
Class	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %
A	20	0	15	15	15	15
B	50	43	35	34	35	35
C	15	0	9	9	9	9
D	10	32	5	5	5	5
E	5	0	10	10	10	10
F	0	2	3	2	1	1
G	0	23	24	24	25	26

The overall outcome of the model does not vary greatly with changes in the rate of cheatgrass invasion, but the proportion of the landscape in cheatgrass vs. the uncharacteristic native class is quite sensitive to changes in the invasion rate. Viewing the results of these two sensitivity analyses together, it appears that both the rate of overgrazing and the rate of cheatgrass invasion must have been greater than those in the current model over the past century in order for today's landscape to develop.

The table below shows the results of varying the rates of both overgrazing and cheatgrass invasion together.

Scenario	Reference Conditions	Current Conditions	AG Invasion Prob.= 0.05; Exc. Herb. Prob. = 0.005	AG Invasion Prob.= 0.05; Exc. Herb. Prob. = 0.008	AG Invasion Prob.= 0.06; Exc. Herb. Prob. = 0.008	AG Invasion Prob.= 0.07; Exc. Herb. Prob. = 0.006
Class	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %	Landscape %
A	20	0	16	13	14	16
B	50	43	38	32	32	36
C	15	0	10	9	9	10
D	10	32	10	9	9	10
E	5	0	3	4	4	3
F	0	2	4	5	5	4
G	0	23	19	27	28	22

Varying probabilities is one of the simplest ways to explore management options using this model; by running the model with different rates of overgrazing and comparing the results, decision-makers can explore what may happen to the landscape if the rate of overgrazing increases. They may also gain a better understanding of the benefits that might be obtained through policies or programs aimed at improving grazing practices.

CHAPTER SUMMARY

In this chapter, we have adapted a reference condition model to approximate current landscape conditions by adding new state classes and transition pathways. We have also learned to adjust disturbance probabilities and conduct a simple sensitivity analysis. In the next chapter, we will address how this model can be adapted to include active management options and explore the effects and cost-effectiveness of alternative management scenarios.

CHAPTER 3: ADDING MANAGEMENT ACTIONS

PURPOSE AND OVERVIEW

One of the most important ways that modified LANDFIRE vegetation models can be useful to planners and land managers is in comparing alternative management options and scenarios. In this chapter, we will add some management activities to the montane sagebrush model described in Chapter 2 and use the model to compare the costs and benefits of different combinations of management options.

Managers typically have a wide range of treatments and options available to them. For the purposes of creating a simple and comprehensible model, it is helpful to limit the number of possible treatments that are modeled. In the study on which this example is based, 19 different management transition types were originally modeled; for simplicity, we will include only three types of treatment in this example. The original study also considered the impacts of land ownership on management costs and options. Both the cost and feasibility of various management options frequently differ between public and private ownerships. For example, prescribed fire is much more common on public lands because public agencies typically have more capacity to plan and implement burns.

Similarly, mechanical and chemical treatments may be much cheaper on private lands because private landowners do not need to comply with the rigorous standards of environmental review that public agencies face. For the sake of brevity and simplicity, we will address only public lands in this example. We will complete the following steps in this chapter:

1. Add to the model three types of management actions: prescribed fire, mechanical thinning and removal of invasive species. Attribute these transitions with baseline probabilities and pathways for each modeled state, or class, in which that treatment may be applied.

2. Experiment with changing the treatment probabilities to allocate management effort among the different classes and treatment types.

3. Explore the use of probability multipliers for comparing different management scenarios more efficiently.

4. Use area limits to control how many acres receive each management treatment.

5. Assign costs to each treatment. Explore the use of scenario analyses to compare the cost effectiveness of various treatments.

The first step in using this updated model to explore management scenarios is to add the possible management actions. We will add transition types representing three different types of management action, or treatments, to the model. These treatments and their attributes were taken from the montane sagebrush model developed for the Utah study (see Chapter 2).

1. Mechanical thinning of woody vegetation by mowing or brush beating, called **Canopy-Thinning** by the modelers. This treatment was included as a management option in Class C (mature sagebrush) or D (sagebrush with trees beginning to invade). This treatment will set the treated area back to an earlier Class with less woody vegetation.

2. Prescribed fire, called **RxFire** in the model. This treatment was included as a management option in Classes C (mature sagebrush), D (sagebrush with trees beginning to invade) and E (conifer forest or woodland). This treatment is intended to set the treated area back to Class A (regenerating native grasses), but it is successful only about half of the time.

3. Restoration of shrublands that have been invaded by exotic annual grasses, especially cheatgrass. This treatment, called **ShAG-Restoration** by the modelers, involves herbicide and reseeding with non-invasive grasses. This treatment is applied in Class G (cheatgrass invaded). It is successful in moving the treated area into Class A 90 percent of the time.

ADD NEW TRANSITION TYPES AND GROUPS

a) Go to **File | Properties | Definitions**

b) Click on the *Transition Types* tab.

c) Click on **New** and type in "Canopy thinning."

d) Repeat these steps on the *Transition Groups* tab.
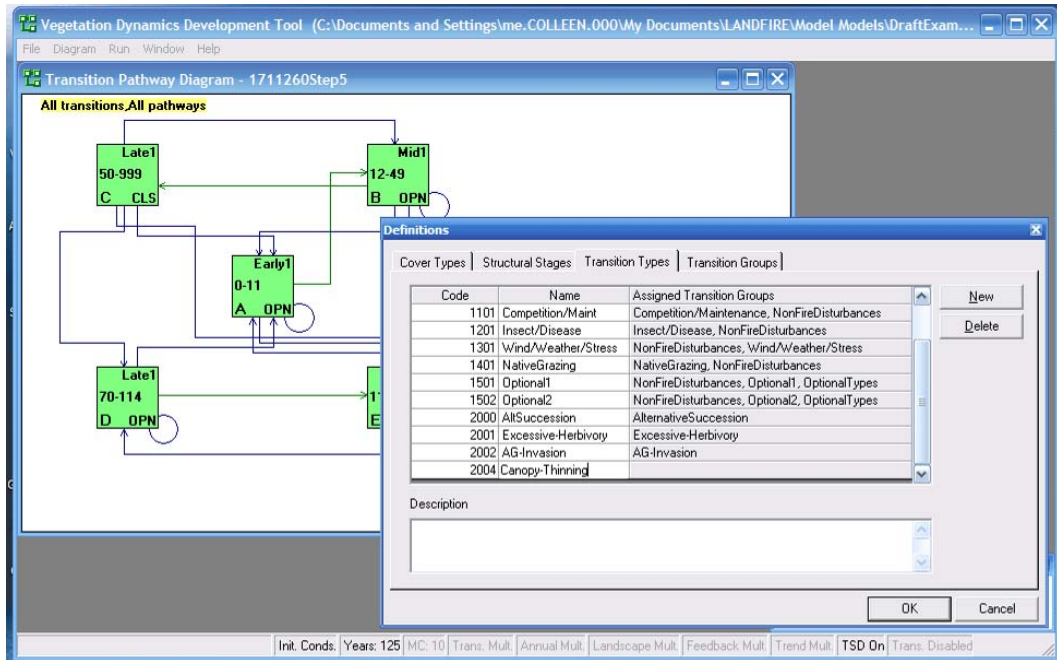
e) Now we need to assign the new transition type *Canopy-Thinning* to the new transition group *Canopy-Thinning*.

f) Make sure **Canopy-Thinning** is highlighted on the ***Transition Groups*** tab, and click on **Types**. The dialog box below will appear, showing all of the possible transition types.

g) Highlight **Canopy-Thinning** and click on the arrow to move it onto the *Selected* list.
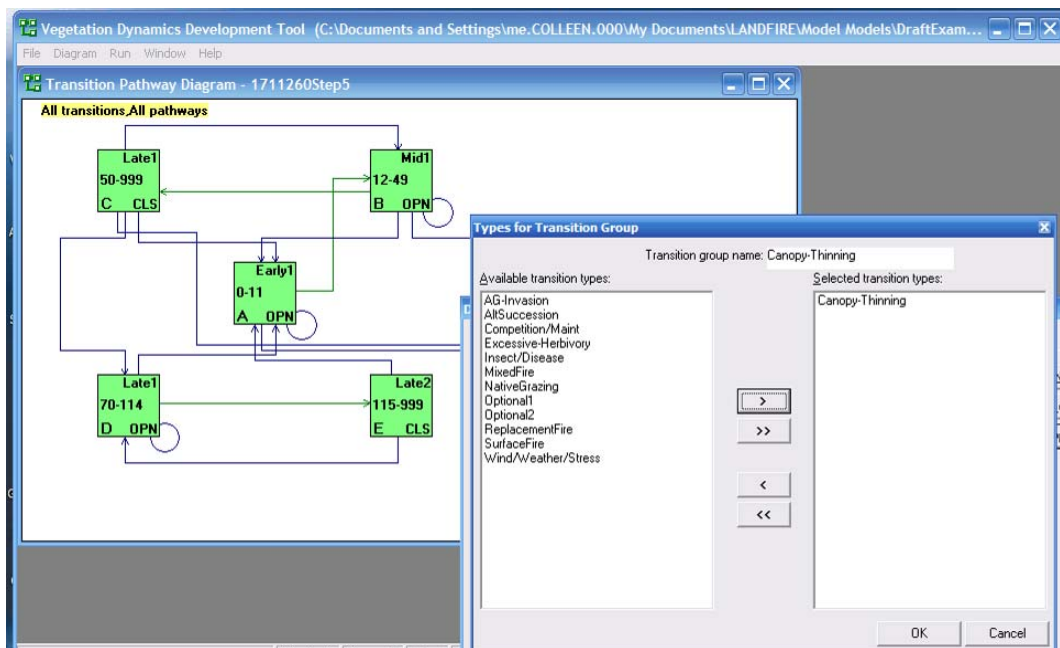
h) Click **OK** to exit the dialog, and save the project.

i) Repeat these steps to add "RxFire" as a new Transition Type and Transition Group, and assign the *RxFire* Transition Type to the *RxFire* Transition Group.

j) Repeat these steps to add "ShAG-Restoration" as a new Transition Type and Transition Group, and assign the *ShAG-Restoration* Transition Type to the *ShAG-Restoration* Transition Group.

The three new management transition types are now available to use in the model.

Now we'll define the possible pathways for the new transition types, beginning with **Canopy-Thinning**. The modelers used canopy thinning to improve the wildlife habitat value of this system by increasing the diversity of vegetation beneficial to wildlife.

Canopy thinning in Class C was used to move the system to Class A (native grass dominated) 50 percent of the time and to Class B (mixed sagebrush-native grasses) 50 percent of the time. The modelers used thinning in Class D to create Class A 45 percent of the time, Class B 45 percent of the time and Class C 10 percent of the time.

ADD NEW TRANSITION PATHWAYS BETWEEN CLASSES:

Add Canopy Thinning in Class C

a) Begin by opening the *Class Properties* dialog by double-clicking on **Box C** in the *Transition Pathway Diagram*.

b) Click on **New**, and choose **Canopy-Thinning** from the *Transition Type* drop down menu.
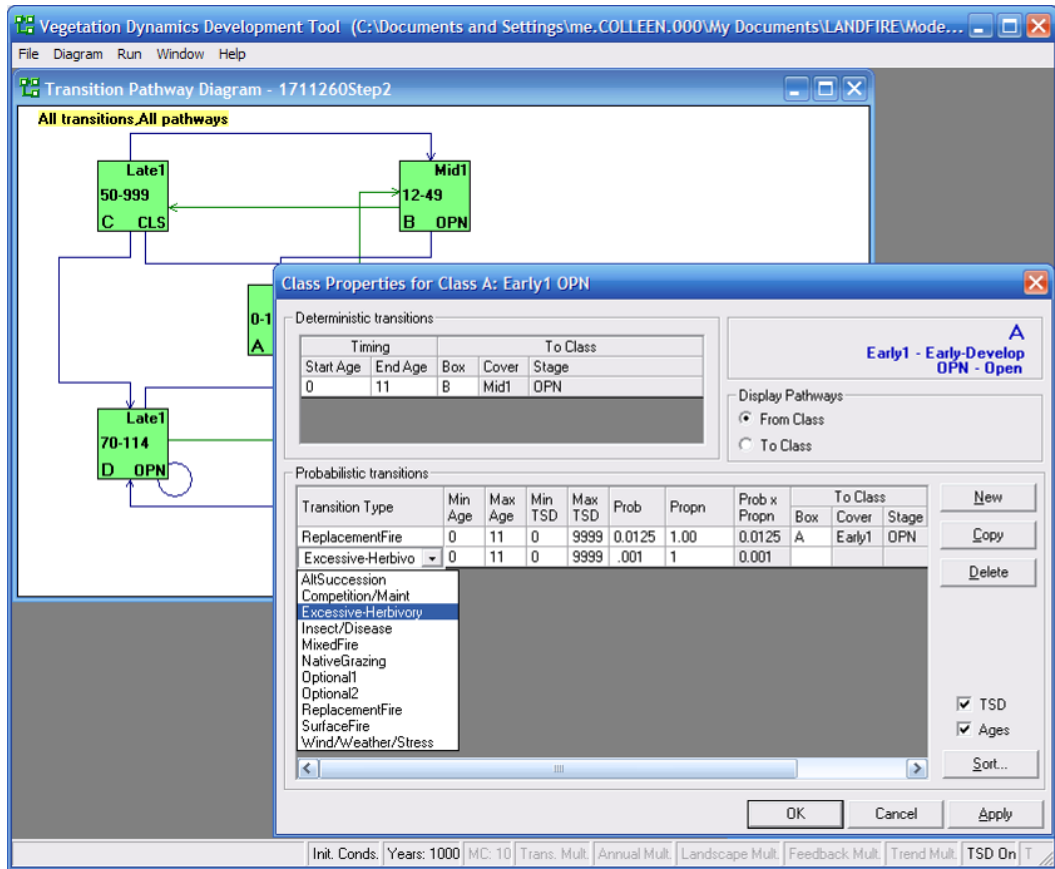
c) Leave the *Min and Max Age* and *Min and Max* TSD fields at their default settings.

d) Initially, we will give all of the management pathways a probability of 0.01, to indicate that one percent of the landscape in each Class will receive each treatment each year. We will adjust these probabilities later, when we compare management scenarios. Under *Prob*, type "0.01." It may seem odd to use probabilities when modeling management actions, since these actions are not random. Later in this chapter we'll discuss how to adjust the model so that we specify a target for the desired number of acres that are treated each year.

## Using the *Proportion* field for transitions with multiple outcomes

a) Under *Propn,* type "0.5." this represents the assumption that 50 percent of the area that receives this treatment will transition to Class A.

b) Under **To Class/Box**, type "A."

c) Now repeat these steps to create an identical transition to Class B. The Class Properties dialog should look like this when you're done:
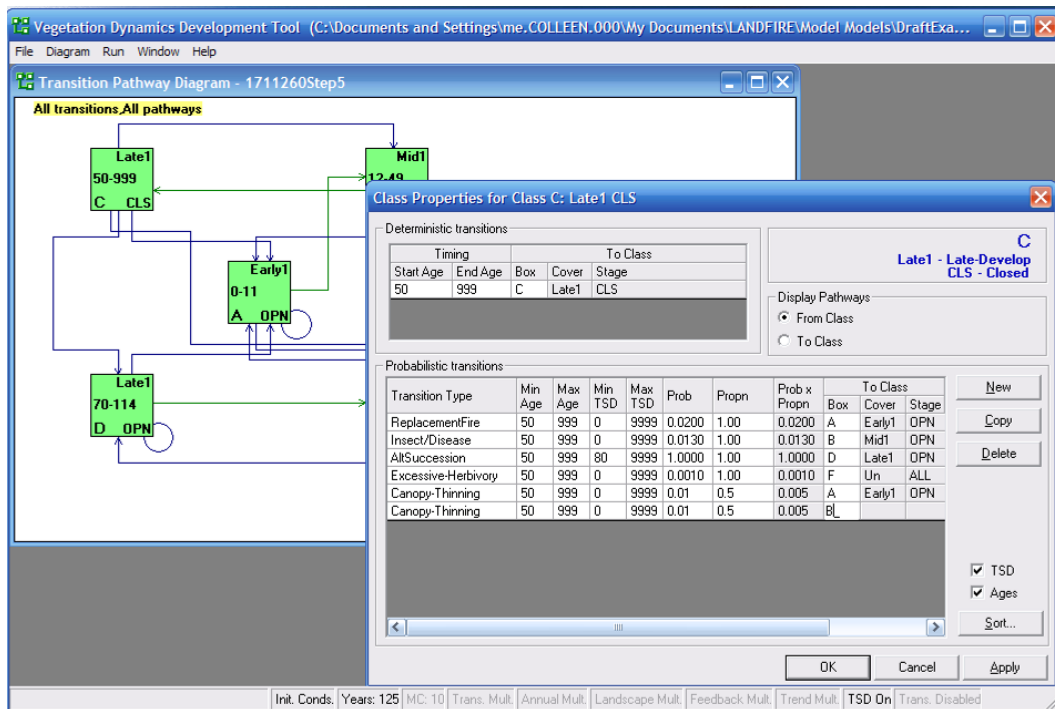
Together, these two transitions represent our assumption that, on average, one percent of the landscape in Class C will be thinned each year and, on average, half of that treated area will transition to Class A and the other half to Class B. This use of the *Proportion* field is a handy way to manage transitions that can have more than one outcome.

d) The other properties can be left on their default settings. Click **OK** to exit the dialog.

The *Transition Pathway Diagram* should show new arrows from Box C to Boxes A and B representing the new transitions:
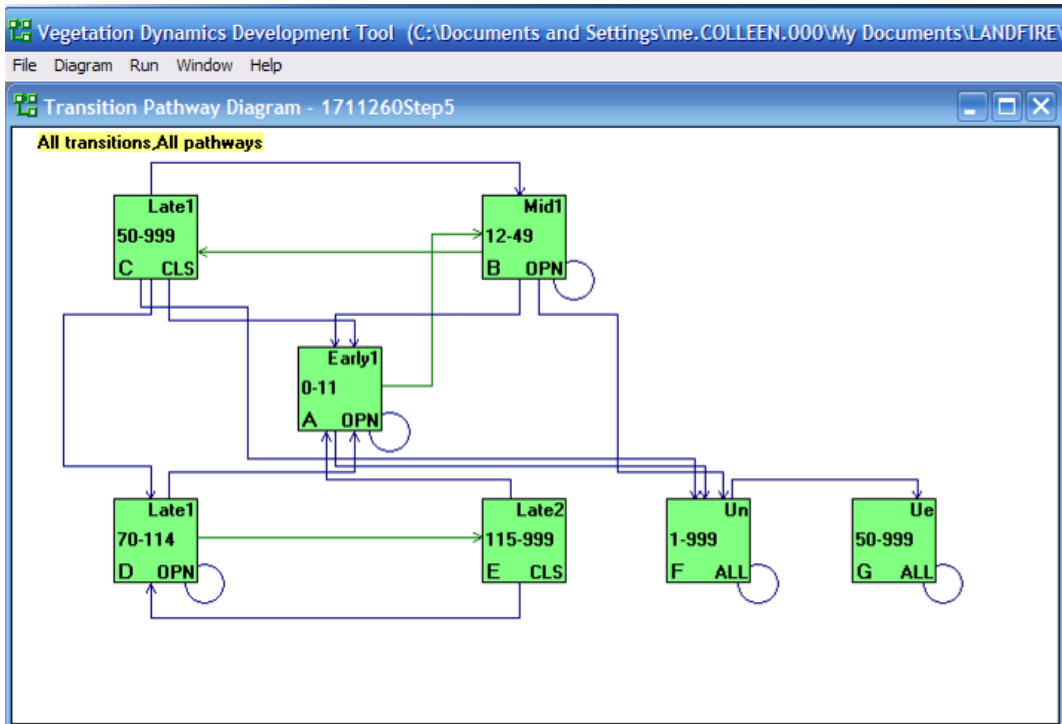
Add Canopy Thinning in Class D

Repeat these steps to add **Canopy-Thinning** transitions from Class D to Classes A, B and C. The probabilities for these transitions should all be 0.01. The proportions for the transitions to Classes A and B should be 0.45, and the proportion for the transition to Class C should be 0.1. Note that these proportions add up to one, so that the overall probability of Canopy Thinning in Class D is not altered from the value we selected (0.01).

Add RxFire in Classes C, D and E

Follow the steps outlined above to add **RxFire** transitions to Classes C, D and E, using the probabilities, proportions and pathways shown below. Prescribed fire will set the treated area back to the early successional state 50 percent of the time because of the patchy nature of fire. The other 50 percent of the time, the fire will not burn the woody vegetation, which will remain in the same successional state.

From Class	To Class	Prob	Propn
C	A	0.01	0.5
C	C	0.01	0.5
D	A	0.01	0.5
D	D	0.01	0.5
E	A	0.01	0.5
E	E	0.01	0.5

Add ShAG Restoration in Class G

Follow the steps outlined above to add two **ShAG-Restoration** transitions to Class G. The successful transition should lead to Class A with a probability of 0.01 and proportion of 0.9. The unsuccessful transition should lead to Class G with a probability of 0.01 and proportion of 0.1. Restoration activities will successfully restore the system to the early successional state 90 percent of the time. In other words, 90 percent is the success rate and 10 percent is the failure rate of the management action.

We have set the probabilities for each treatment to 0.01. This probability would represent a situation in which each treatment is applied to an average of one percent of the landscape that is in the appropriate successional classes each year. Now we'll run the model to see what impact this level of treatment might have on the landscape.

RUN THE MODEL

When running potential management scenarios, managers will typically have local data on current landscape composition. If recent local data are not available, the LANDFIRE data may be used to estimate how much of the BpS of interest in the study area is currently in each successional class. In this example, our model is designed so that the initial conditions for the modeling can be pulled directly from the LANDFIRE spatial data, with the landscape proportion for Class F calculated from the area mapped as

"Uncharacteristic Native" and the proportion for Class G calculated from the area mapped as "Uncharacteristic Exotic" in the succession class map.

In this scenario, we will set the initial conditions to the current class distribution for the upland Montane Sagebrush Steppe system in the study area, with approximately 43 percent of the landscape in Class B, 32 percent in Class D, two percent in Class F and 23 percent in Class G, with cheatgrass established. We will run the model for 50 years to simulate the mid- to long-term effects of various management decisions.

ADJUST THE RUN SETTINGS

a) Go to **Run | Settings** to open the *Run Settings* dialog box.

b) Make sure that model is set to run for 50 time steps and 10 simulations over 1,000 cells. Remember that each cell represents 100 acres. Make sure that the initial conditions are set to the current condition class distribution, as described in Chapter 2 and given below.

Class	Propn
A	0
B	0.43
C	0
D	0.32
E	0
F	0.02
G	0.23

Make sure that all of the other run settings match those used in Chapter 2.

RUN THE MODEL AND EXAMINE THE RESULTS

a) Go to **Run | Start Model** to run the model.

b) When the model has finished running, click on **Run | Final Conditions** to view the proportions of classes on the landscape at the end of the 50-year run. Your results should be similar to those in the "with mgmt" column below:

Class	% of landscape with mgmt	% of landscape without mgmt
A	20	15
B	47	35
C	7	9
D	3	5
E	6	10
F	3	3
G	15	24

For comparison, the "without mgmt" column shows the final landscape percentages that resulted from running the model before management actions were added (see Chapter 2). Because we used probabilities to set the initial rate of these management transitions, we don't know how much area was actually burned, thinned and restored over the model run. To find out, we can graph the transitions that occurred over the model run.

GRAPH THE MODEL RESULTS

a) Go to **Run | Graph Results** to open the *Graph Results* dialog box.

b) Under **Display Variable**, highlight **Transition Groups**.

c) Under **Graph Type**, select **Line**. Set the **Start Timestep** at "0" and the **End Timestep** at "50" to graph the entire model run.
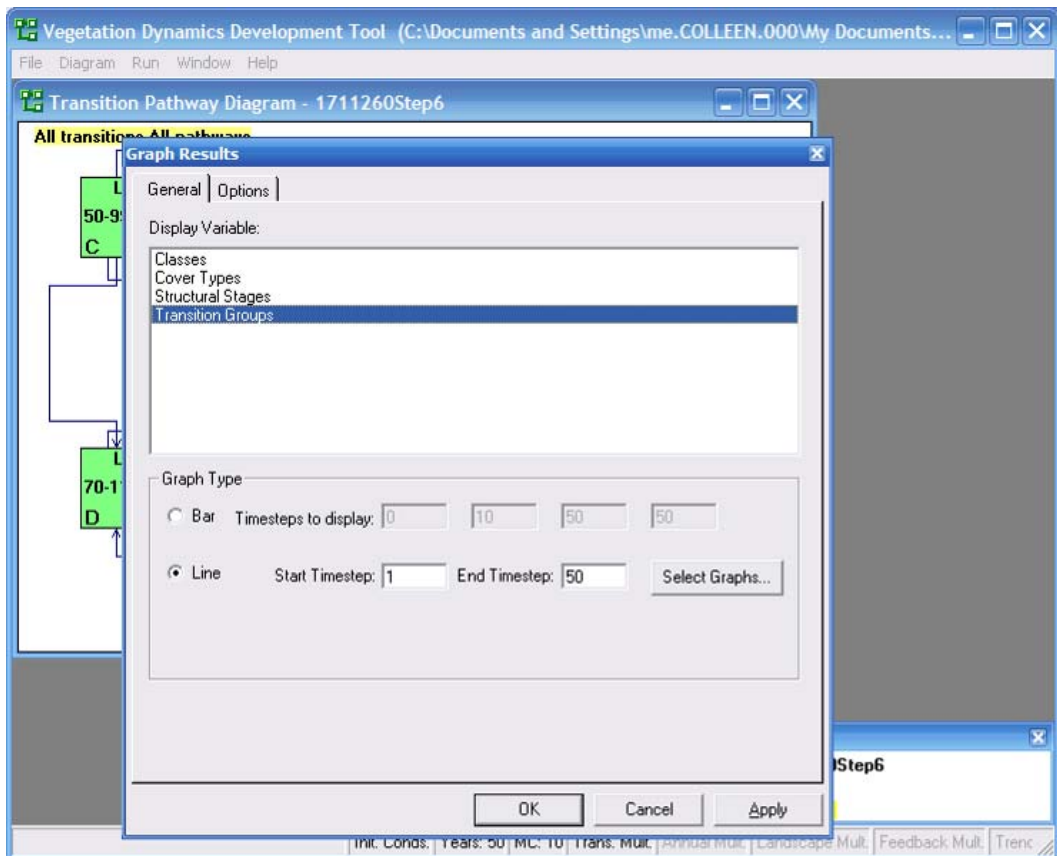
d) Click the **Select Graphs** button to open the *Graphs for Transition Groups* dialog box.

e) We want to graph the three management transitions. Hold the **Control** key down, and highlight **Canopy-Thinning**, **RxFire**, and **ShAG-Restoration**. Click the right arrow **button** to move these three transition types into the list of *Selected Probabilistic Transition Groups*.
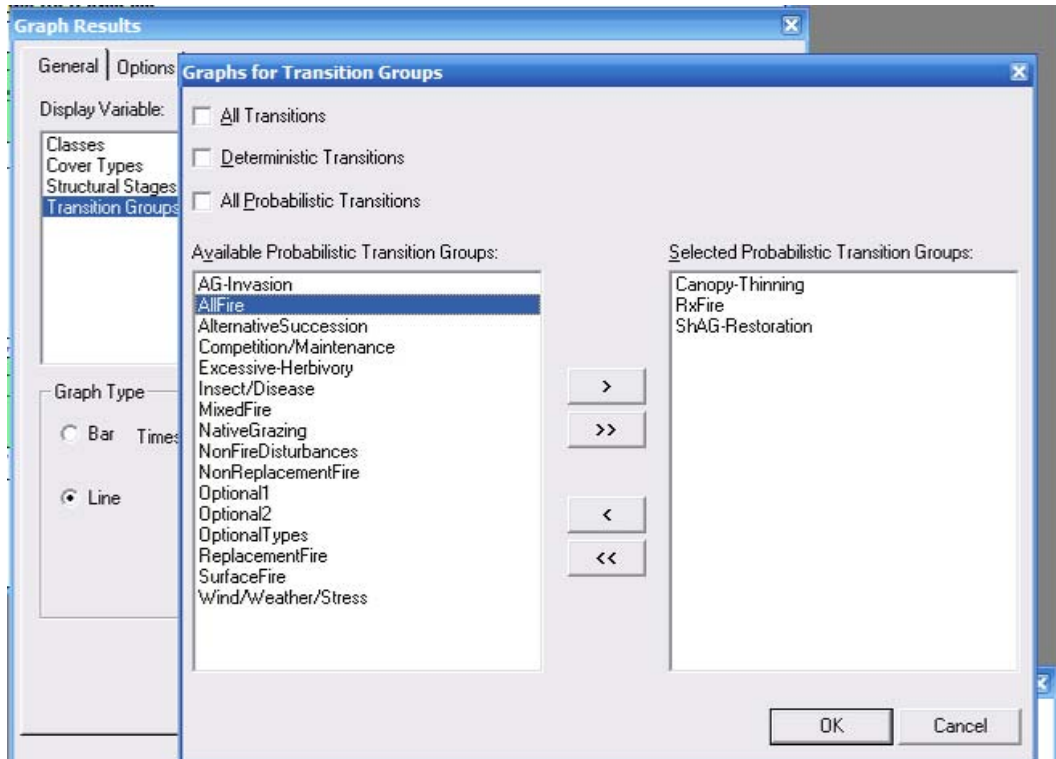
f) Click **OK** to close the *Graphs for Transition Groups* dialog box. Switch to the **Options** tab of the *Graph Results* dialog. Select **Average, minimum, maximum** from the **Display series for:** drop-down list.

g) Under **Y-axis settings**, check **Display area values**. This will graph the model results in terms of the area that undergoes each transition. If this box were not checked, the graphs would display in terms of the percent of cells that undergo each transition. Since we entered the landscape area (**Total Area Represented** under **Run Settings| Initial Conditions**) in acres, the units for the graph will be acres as well.

h) Under **Line graph settings**, check **Show interval mean values** and enter the following **Interval end time steps:** "10," "20," "30" and "40." Also check **Include mean for all lines**. This will allow us to see the average area treated with each management action in each 10-year segment of the model run. If no interval end time steps were entered, the program would only show average values for the run as a whole.
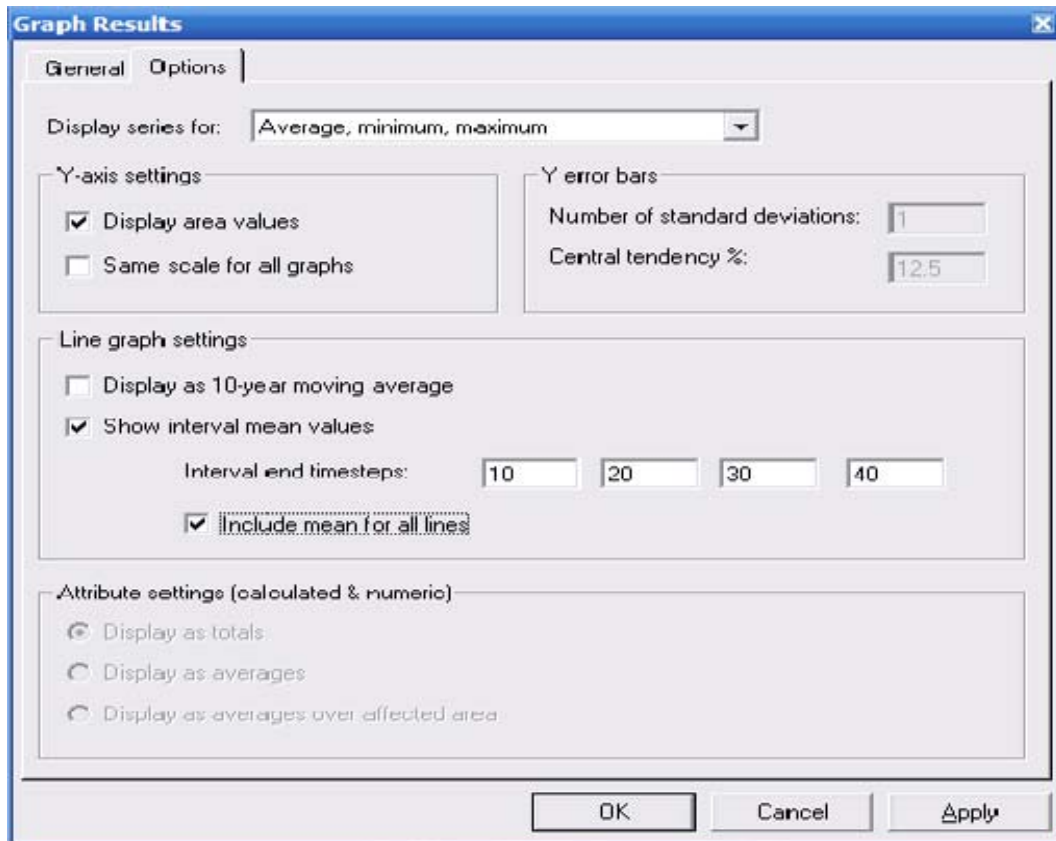
i) Click **OK** to create the graphs. They should resemble the graphs below. To see the average area per year that underwent each treatment type for each 10-year segment of the model run, click anywhere on the graph of the treatment type.
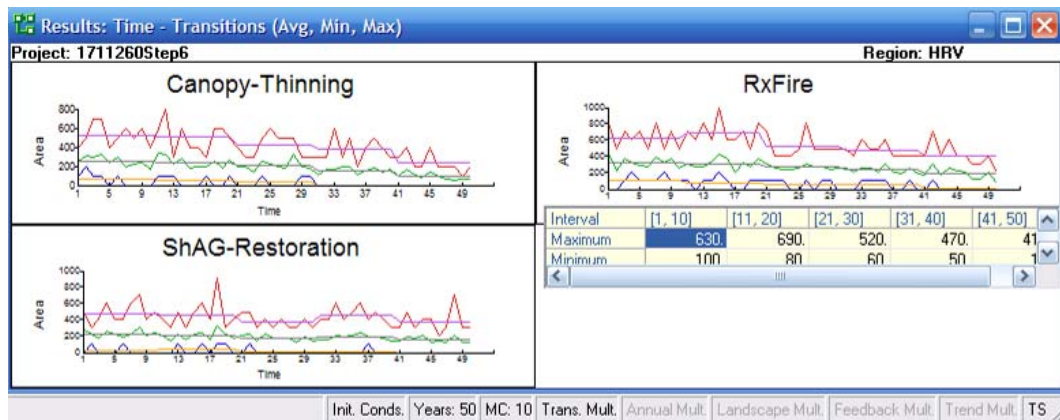
Examine the average rates of these transitions over the model run. For prescribed fire, the area treated per year declined from an average of around 330 acres per year in the first 10 years to less than 190 acres per year in the last 10 years, as the area of the landscape in the classes eligible for prescribed fire declined. This aspect of VDDT modeling is important to understand: if probabilities are used to set the levels of management transitions, then the areas treated will vary as the landscape changes over time. Also note the probabilistic variation in the amount of prescribed fire that occurs each year. The

graph shows that the area receiving prescribed fire in any given year can vary from zero to about 1,000 acres. Later in this chapter we will use area limits to reduce the amount of variability in the rates of management actions.

Though the level of management in the initial draft of this model will reduce the amount of cheatgrass invasion within this system, it is not necessarily the most effective or cost-efficient set of management options. In the next section we will vary the rates at which management actions are applied to compare the effectiveness of different treatments and estimate the minimum level of management required to prevent the spread of cheatgrass. First we'll learn how to compare the impacts of different treatments by disabling some of the treatments.

Disable Some Transitions

a)   Go to **Run | Settings** to open the *Run Settings* dialog box.

b)   Click on the **Options** tab and check **Disable some transitions**. Click the **Select** button to open the *Select Transitions to Disable* dialog box. Highlight **Canopy-Thinning**, **RxFire,** and **ShAG-Restoration**, and click the **right arrow** button to move these three over into the *Disabled Transition Groups* list. Click **OK** to exit the dialog.
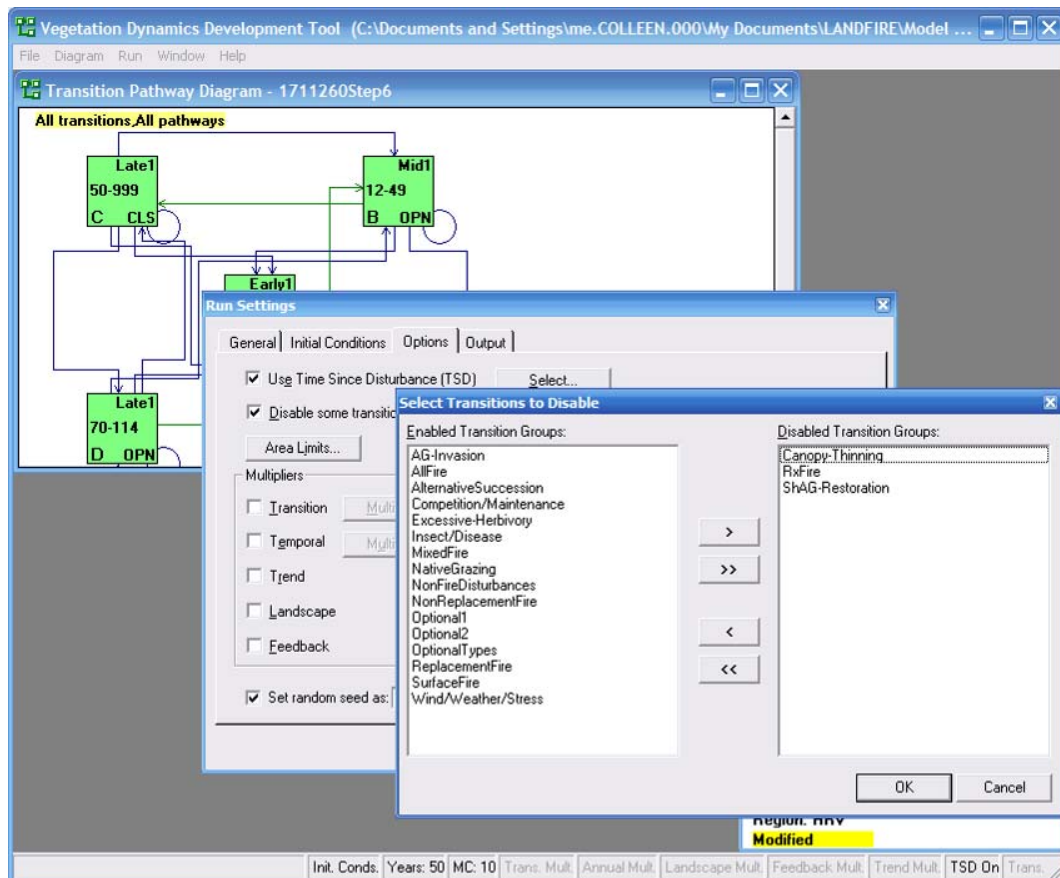
c)   Run the model. When the model has finished running, click on **Run | Final Conditions** to view the proportions of classes on the landscape at the end of the 50-

year run. Your results should be identical to what they were before the management transitions were added:

Class	% of landscape without mgmt
A	15
B	35
C	9
D	5
E	10
F	3
G	24

CHANGE TREATMENT PROBABILITIES

To assess the impacts of each treatment, we will apply one treatment at a time, beginning with prescribed fire.

a) Start by turning the **RxFire transition** back on by reversing the steps we used to disable it for the last run (through the *Run Settings* dialog box). Leave the Canopy-Thinning and ShAG-Restoration transitions disabled for now.
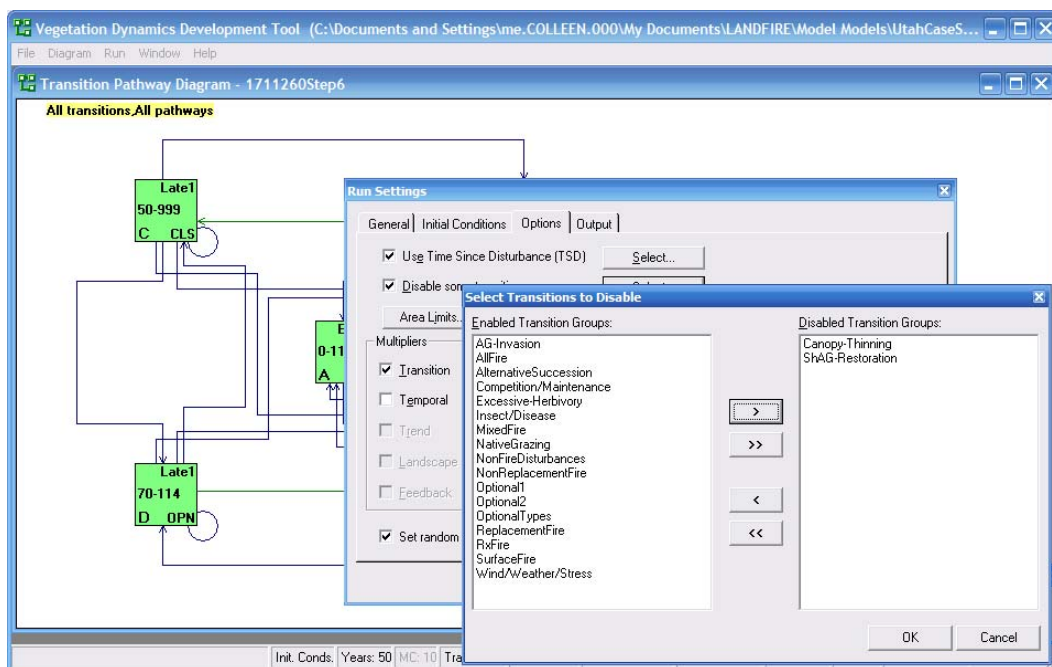
We want to start from current conditions and run the model for 50 years, just as we did in the last run, so leave the other Run Settings unchanged. Run the model and examine the results. They should be similar to the "RxFire Only" column in the following table.

Class	Reference Conditions	Current Conditions	Final Conditions, No Management	Final Conditions, RxFire Only
A (%)	20	0	15	16
B (%)	50	43	35	38
C (%)	15	0	9	8
D (%)	10	32	5	4
E (%)	5	0	10	8
F (%)	0	2	3	3
G (%)	0	23	24	24

Applying prescribed fire on one percent of the landscape annually has very little impact on the trends we see over the 50-year time horizon. Would more prescribed fire have a greater impact in preventing the landscape from moving further away from the reference conditions? If so, how much prescribed fire would be necessary to have a substantial impact? We will try increasing the percent of the landscape that receives this treatment to see how much impact that has.

b) **Open** the *Class Properties* dialog box for Class C, and change the probabilities for the RxFire transitions to 0.1. This represents a scenario in which 10 percent of the landscape in Class C receives prescribed fire each year. Leave the proportions unchanged, as the success rate of this treatment will not change.
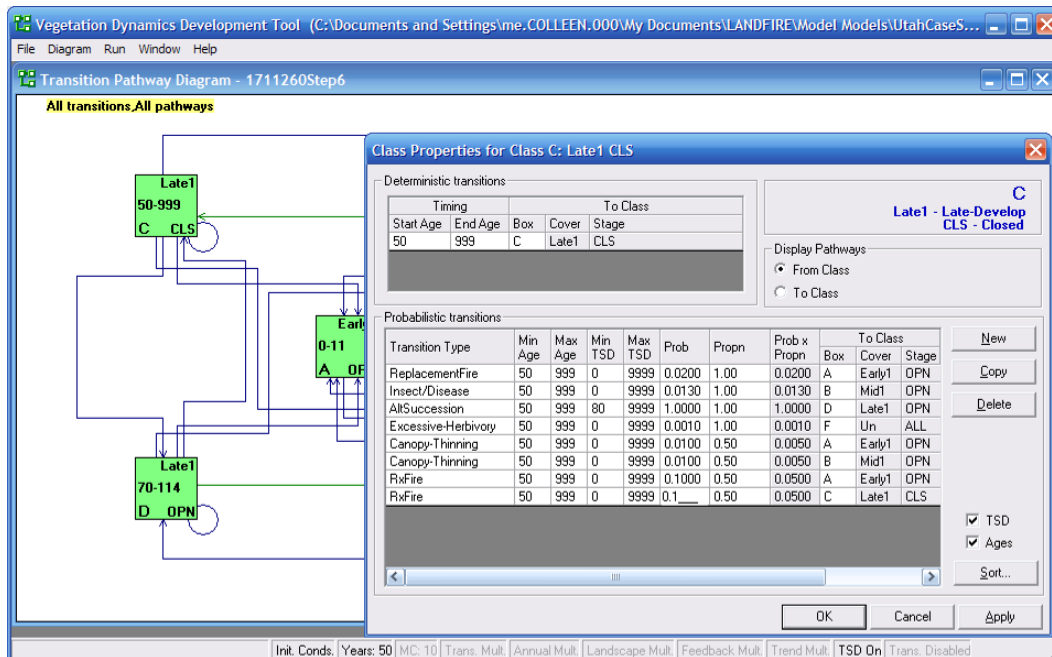
Your results should resemble those on the RxFire 10 percent column below.

Class	Reference Conditions	Final Conditions, No Management	Final Conditions, RxFire 1%	Final Conditions, RxFire 10%
A (%)	20	15	16	19
B (%)	50	35	38	50
C (%)	15	9	8	3
D (%)	10	5	4	1
E (%)	5	10	8	1
F (%)	0	3	3	3
G (%)	0	24	24	24
Ecological Departure (%)*	0	31	29	27

*See box below for an explanation of Ecological Departure.

The model predicts that increasing the amount of prescribed fire will decrease the amount of the landscape in the late successional sagebrush and forested states and increase the amount of the landscape in the early to mid-successional states. We can follow the same steps to compare the results of alternative treatment scenarios.

ECOLOGICAL DEPARTURE

Note that the final row of this table includes a measure of ecological departure from the reference conditions. This metric gives a summary of how departed the final conditions resulting from each model run are from the reference landscape conditions. It is calculated by comparing the reference percentage of each succession class (S-Class) to the percentage resulting from a given model run. The smaller percentages for each class are summed, and the total is subtracted from 100 to determine the departure index. This departure index is represented using a zero to 100 percent scale, with zero representing a landscape identical to the reference conditions and 100 representing maximum departure. This index is closely related to the LANDFIRE FRCC Departure Index (for more information, see http://www.landfire.gov/NationalProductDescriptions11.php).
Ecological departure is included here as a helpful shorthand assessment of how much various management options would move the landscape toward or away from the reference conditions. In most situations, moving the landscape toward reference conditions is a management goal, but it is worth noting that this may not be the only or even the primary goal. In this example, managers may feel that limiting the area infested with cheatgrass is a higher priority than restoring the landscape toward reference conditions.

COMPARE ALTERNATIVE TREATMENTS

a) In the *Run Properties* dialog, disable *RxFire* and enable *Canopy-Thinning*. Run the model, and record the final conditions.

b) Now change the probabilities for Canopy-Thinning to 0.1 in both classes where thinning can occur (C and D). Run the model again and compare the results from both runs.

Class	Reference Conditions	Final Conditions, No Management	Final Conditions, Canopy Thinning 1%	Final Conditions, Canopy Thinning 10%
A (%)	20	15	16	18
B (%)	50	35	38	50
C (%)	15	9	7	3
D (%)	10	5	4	1
E (%)	5	10	8	2
F (%)	0	3	3	3
G (%)	0	24	24	24
Ecological Departure (%)	0	31	30	26

Canopy thinning is even more effective than prescribed fire at moving this system from later to earlier successional classes. However, neither of these treatments alone has any meaningful impact on the amount of cheatgrass invasion.

c) Follow the steps above to compare the results of two different levels of restoration treatment. Disable the *Canopy-Thinning* transition and enable *ShAG-Restoration*, then run the model with the *ShAG-Restoration* probabilities first at 0.01 and then at 0.1.

d) Your results should resemble those shown below.

Class	Reference Conditions	Final Conditions, No Management	Final Conditions, ShAG Restoration 1%	Final Conditions, ShAG Restoration 10%
A (%)	20	15	17	21
B (%)	50	35	40	51
C (%)	15	9	9	9
D (%)	10	5	5	5
E (%)	5	10	10	10
F (%)	0	3	3	3
G (%)	0	24	16	<1
Ecological Departure (%)	0	31	24	11

The restoration treatment is quite effective at reducing the cheatgrass invasion when applied to 10 percent of the invaded area annually. However, this option may not be feasible, since this treatment involves several steps, requires application of herbicide, and is fairly expensive. This option also does not reduce the amount of the landscape that has

transitioned to forest (Class E). It appears that a combination of treatments might be most efficient in moving the landscape back toward the reference conditions. Experiment with different combinations of the three treatments to see which combination(s) are most effective.

After trying multiple treatment scenarios, repeatedly changing multiple probabilities in multiple classes may begin to seem cumbersome. In the next section, we'll use probability multipliers to make adjusting multiple probabilities simpler.

USE PROBABILITY MULTIPLIERS

Adjusting the probabilities for disturbances class by class can be tedious and time-consuming when comparing many alternate scenarios and increases the risk of user error. One way to simplify this process is to use transition probability multipliers to change the probability of a given transition type for all classes in the model at once.

a) To begin, reset the probabilities for all three management transitions (*RxFire*, *Canopy-Thinning* and *ShAG-Restoration*) to 0.01.

b) Open the *Run Settings* dialog. In the section titled *Multipliers*, check the **Transition** box, and click on the **Multipliers** button to open the *Transition Probability Multipliers* dialog.
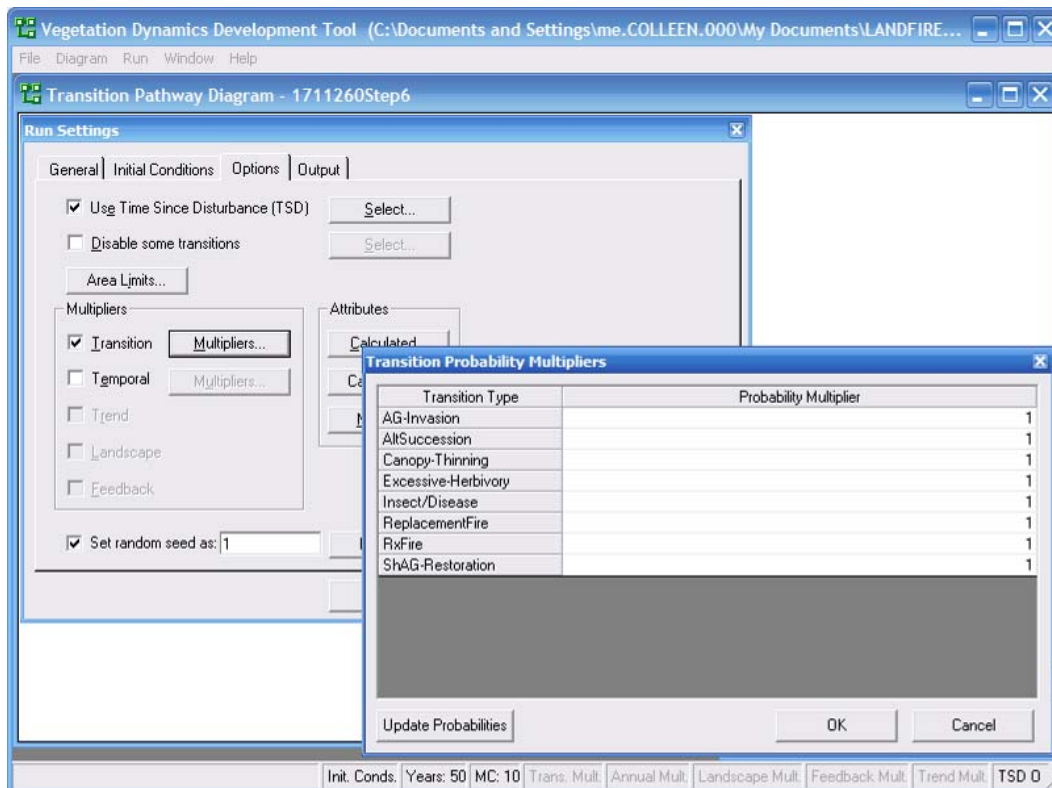
The multipliers in this table can be used to increase or decrease the probability of a given transition type for all classes in the model at once. This option allows us to compare different treatment rates more easily, without having to open each Class Properties dialog and change the probabilities one by one.

c) Type "10" in the *Probability Multiplier* field for RxFire and "5" in the field for ShAG-Restoration. This will temporarily multiply all of the prescribed fire probabilities by 10, changing them from 0.01 to 0.1. The restoration probabilities will be multiplied by five, going from 0.01 to 0.05. Click **OK**, and run the model. **Note:** Do **not** click the **Update Probabilities** button unless you want to make permanent changes to the transition probabilities. For the purpose of comparing alternate scenarios, temporary changes are more useful.
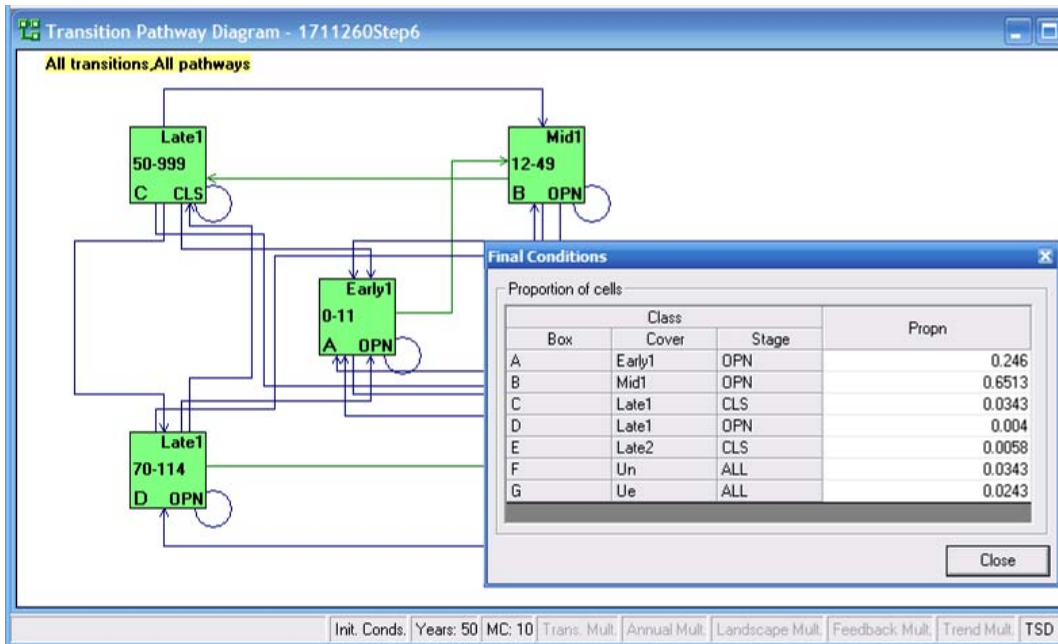
This combination of treatments has succeeded in reducing the cheatgrass infestation to just over two percent of the landscape in this BpS, but the reference Classes D and E have almost disappeared from the landscape. Experiment with different combinations of multipliers, along with enabling and disabling the management transitions to see what combination results in a future landscape most similar to the reference conditions.
For future runs, set the probability multipliers for all three management transitions to five. Leave the other multipliers at one and save the model.

AREA LIMITS

So far, we have been altering the models primarily by adding new transitions and changing the probabilities of these transitions. This probabilistic view is useful because VDDT models are built on a probabilistic framework. However, in the real world, management actions are typically planned and executed based on a specific area (e.g., number of acres or range of acreages) to be treated, rather than a probability that the treatment will occur. In this section we will use Area Limits in VDDT to control the maximum area that will undergo a specific transition.

Perhaps we know that the management team for this landscape has the capacity to apply prescribed fire on a maximum of 1,000 acres per year and to restore a maximum of 200 acres that have been invaded by cheatgrass.

a) Open the *Run Settings* dialog and make sure that the **Transition Multipliers** box is checked. This will set the probabilities for all of the management transitions to 0.05. In this scenario, there is no capacity for thinning of woody vegetation, so disable the Canopy-Thinning transition. Run the model, and take note of the Final Conditions.

b) Before we apply the area limits, it would be helpful to know how much area is receiving each treatment without the area limits. Make a line graph showing the rates of the two management transitions (**RxFire** and **ShAG-Restoration**) over time. Under this scenario, the area receiving prescribed fire each year declines from an average of about 1,500 acres per year in the first 10 years to about 600 acres per year in the last 10 years. The area of cheatgrass restoration gradually declines from over 900 acres per year in the first 10 years to less than 150 acres per year, as the invaded area shrinks over time.
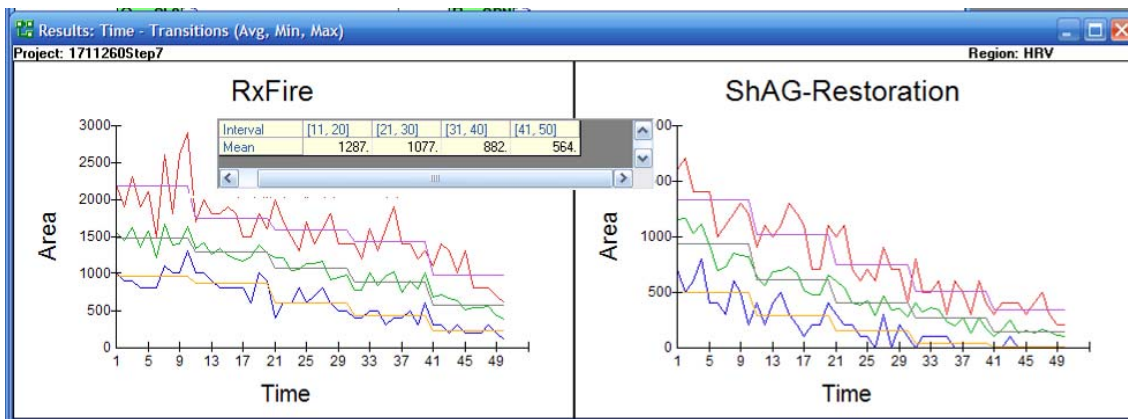
c) Go to **Run|Settings|Options**. Click the **Area Limits** button to open the *Area Limits* dialog. On the **Transition Types tab**, type "1000" under both **Minimum Area** and **Maximum Area** for **RxFire** and "200" under both **Minimum Area** and **Maximum Area** for **ShAG-Restoration**. This will constrain VDDT to keep the treated area as close to these limits as possible, within the confines of the other model properties. Note that the inputs in this dialog are in real area, rather than in cells or pixels. VDDT automatically converts between acres for the input and output values and the cells it uses in its calculations. In this case, the inputs are in acres because we defined the landscape area in acres.
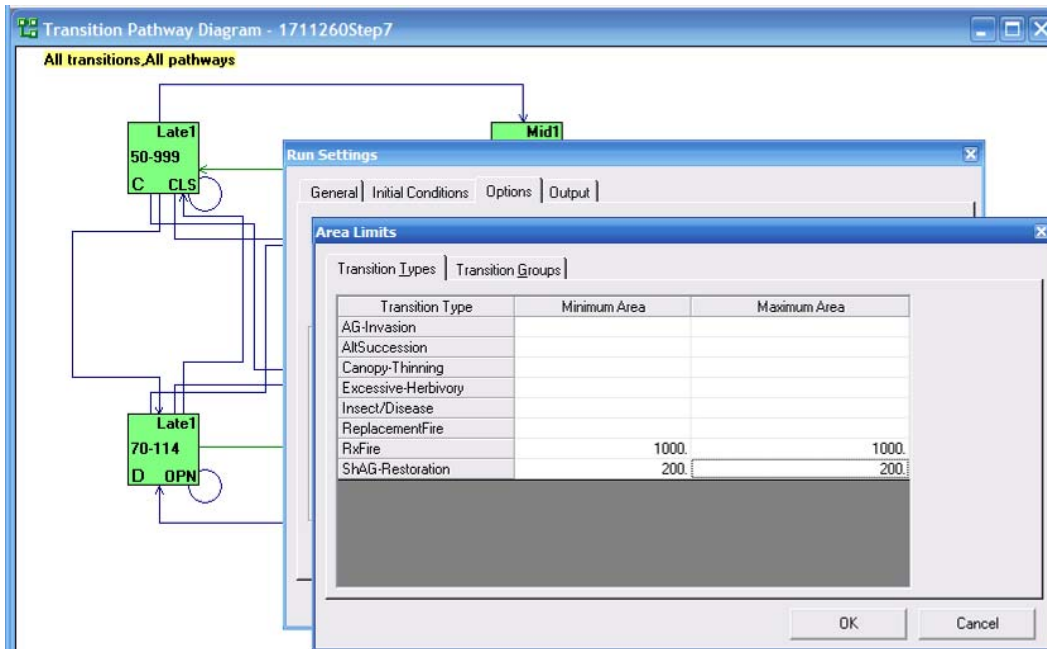
d) Click **OK** and run the model. Compare the results with area limits to those without area limits.

Class	Reference Conditions	Final Conditions without Area Limits	Final Conditions with Area Limits
A (%)	20	24	24
B (%)	50	60	50
C (%)	15	6	4
D (%)	10	2	2
E (%)	5	3	3
F (%)	0	3	3
G (%)	0	3	14
Ecological Departure (%)	0	19	21

The scenario using area limits was less effective in reducing the cheatgrass infestation, presumably because the area of cheatgrass that could be treated in the early years of the model run was limited.

To see the impact of area limits on the area treated each year, make a line graph of the two management transition groups.
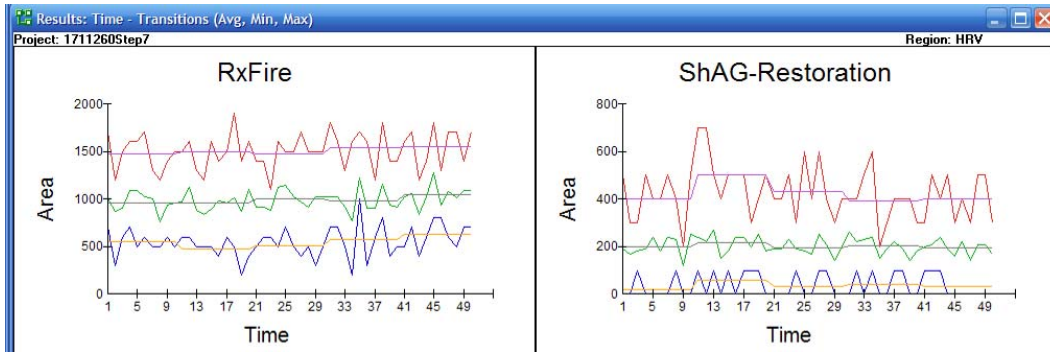
Note that the use of area limits does not alter the probabilistic nature of the model. The amount of each transition will still vary from year to year, but the average areas treated will be much closer to the set limits. This greater level of predictability can make models much more relevant for management planning.

Area limits can be used to compare alternative allocations of management effort or budget. For example, prescribed fire costs approximately $15 per acre in this system, while cheatgrass restoration costs approximately $139 per acre. If the total budget for management treatments in this system is $30,000 per year, the budget could be allocated 100 percent to prescribed fire, to burn 2,000 acres, 100 percent to cheatgrass restoration, to restore 215 acres, or any other allocation along this continuum could be selected. By adjusting the area limits appropriately, the results of those different allocations can be compared, and managers can select an allocation that provides the most desirable results.

ASSIGN COSTS TO TREATMENTS WITH CALCULATED ATTRIBUTES

Budget limitations can be addressed more directly in VDDT through the use of calculated attributes. In this section, we will use calculated attributes to track costs of the three alternative management treatments and predict the optimal budget allocation for minimizing the size of the cheatgrass infestation over time.

In the original project, the per acre costs of various management options were estimated by partners at a workshop. The estimated costs of conducting the three treatments included in the model to this point on public lands are given below.

Treatment	Cost/Acre
RxFire	$15
Canopy-Thinning	$35
ShAG-Restoration	$139

These estimates include the costs of associated planning and archeological surveys, where required. The original project compared two cost scenarios: one using the costs under current standard practice and an alternative scenario in which costs are reduced to a minimum. For simplicity, we will address only the standard cost scenario here.

a) Open the *Run Settings* dialog and select the **Options** tab. For this section, make sure that all transitions are enabled (uncheck the **Disable some transitions** box). Also, turn off

the transition multipliers (uncheck the **Transition Multipliers** box), and remove the area limits applied in the last section.

b) In the section titled *Attributes*, click on the **Calculated** button to open the *Calculated Attributes* dialog.

c) On the **Definitions** tab, click the **New** button to create a new calculated attribute. Type "Costs" in the **Name** column and "$" in the **Units** column to indicate that the costs are given in dollars.
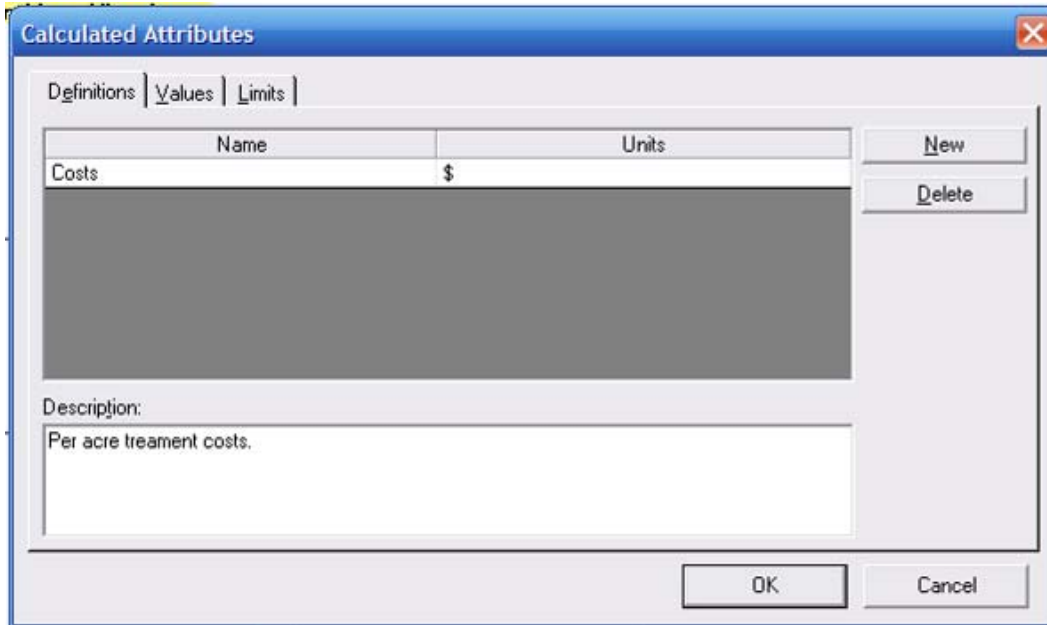
d) We will need to define the costs for each management transition in each class where it can occur. In this case, the costs are the same in each class, but the software allows us to define costs or other calculated attributes separately for each class. We'll start with Canopy Thinning in Class C. On the **Values** tab, click **New**. Select **Costs** from the **Attribute** drop-down list. Class C is defined as Late1 cover type with a Closed structural stage. Select those values from the drop-down lists. Select **Canopy-Thinning** from the **Transition Type** drop-down list. For **Value/unit area**, type "35," and click **OK** to save this value. Remember that our area unit is acres because that is the unit we used to define the landscape size.
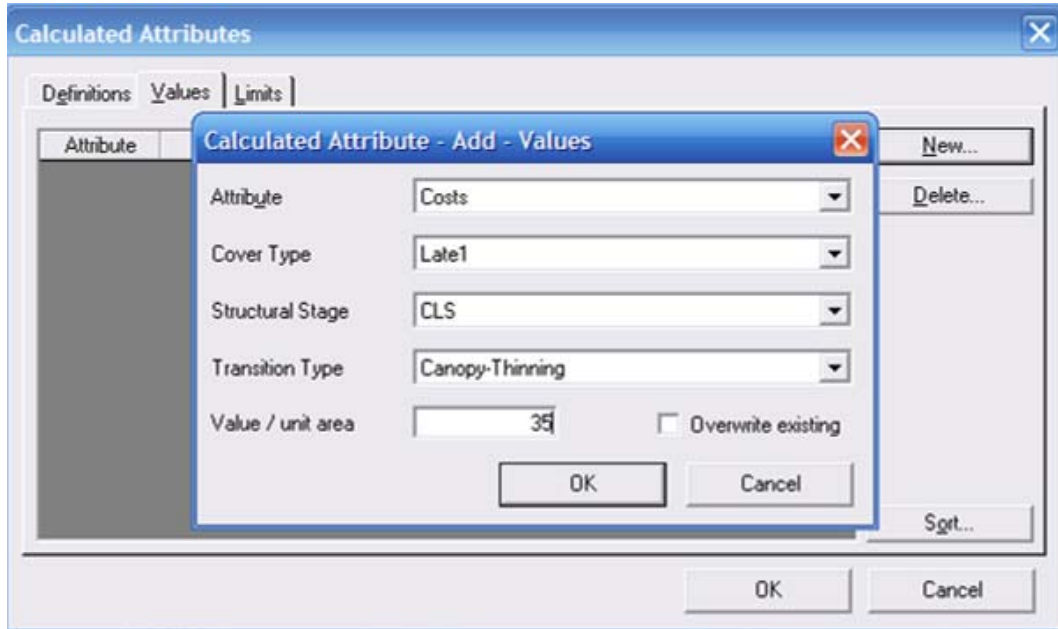
e) Repeat this process to add a value for Canopy-Thinning in Class D (Late1 Open). Follow the same procedure to add a value of "15" for the RxFire transition type in Classes C, D and E (Class E is Late2 Closed). Then add a value of "139" for the ShAG-Restoration transition in Class G (Ue All). When you are finished, your Values grid should look like this:
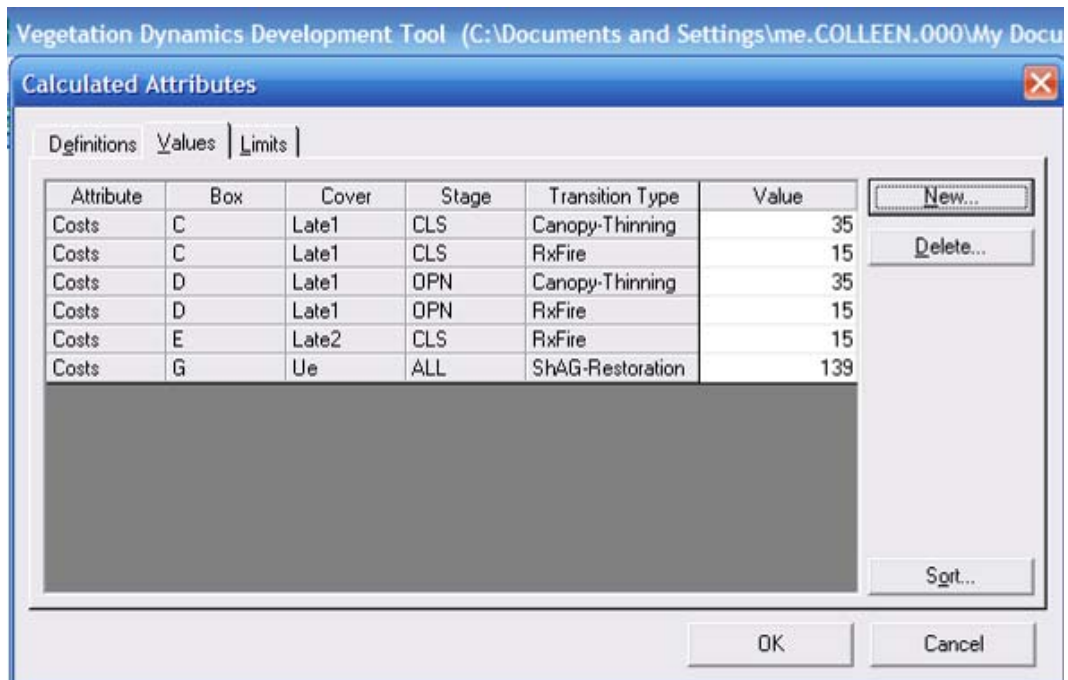
f) Click **OK**, and save the project. Run the model, and open the *Graph Results* dialog. There will be a new category of variable called **Attributes-Calculated** available to graph. Make a line graph of the Costs attribute (**SelectGraphs|Costs**) to see how costs change over

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time.
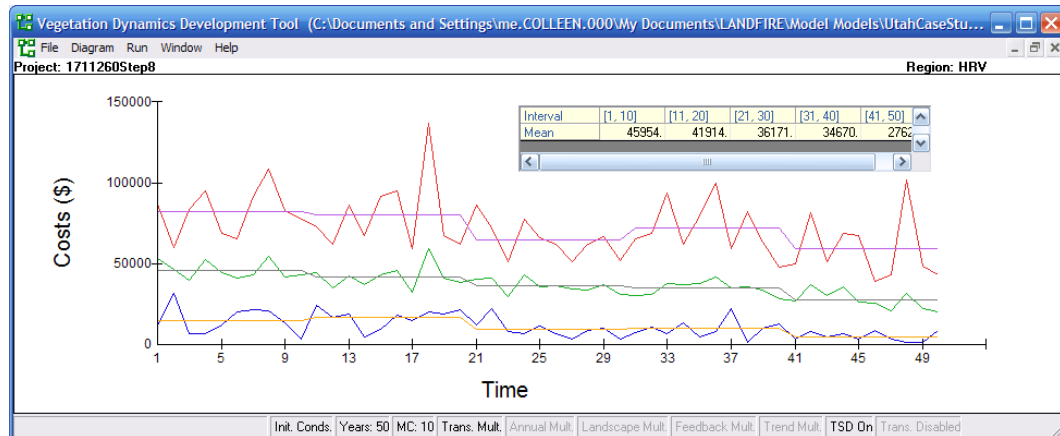
The mean cost of our baseline treatment scenario (treating one percent of the eligible area for each treatment each year) is about $46,000 per year over the first 10 years, falling to about $28,000 per year over the last 10 years. Let's assume that the budget for management prescriptions in this system is only $20,000 per year. To keep management costs within a fixed budget, we can add limits to the calculated attributes.

g) Open the *Calculated Attributes* dialog again (**Run|Settings|Options|Calculated Attributes**). On the **Limits** tab, type "20000" in the *Min and Max Costs* field. Note that it is possible to vary the budget over time by adding breakpoints. If we knew that the budget for management activities would be fixed for 10 years and then drop to zero, we could add a breakpoint to divide the run into two periods of time with a cost limit of $20,000 for the first 10 years and zero dollars after that. For this run, however, we will stick to a simple stable budget. Click **OK**, and run the model.

h) Graph the costs over time. Your results should be similar to these:
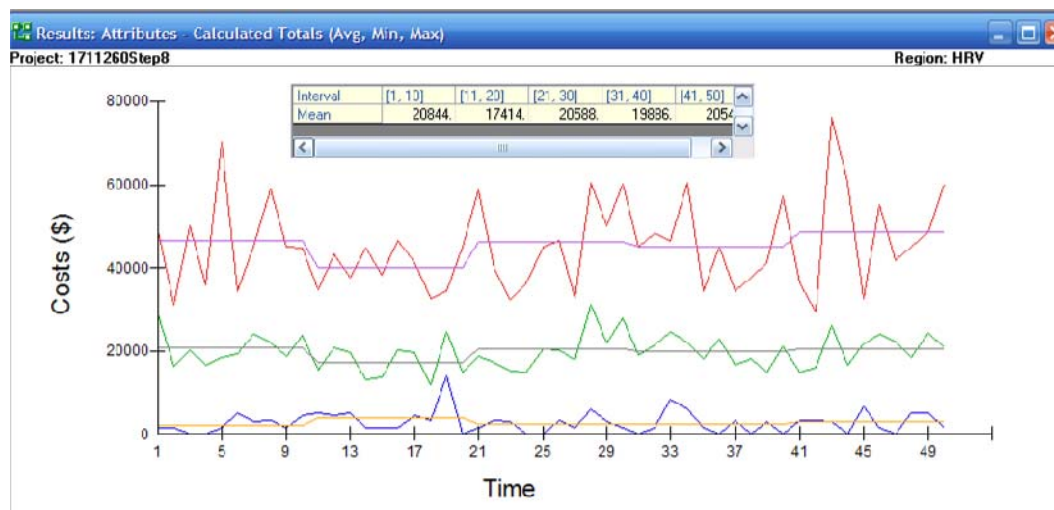
Note that the attribute limit led to a mean cost near $30,000, not a strict limit of $30,000 in costs for each year in each simulation.

Now that the cost limit is in place, we can use probabilities and/or area limits to adjust the level of each treatment that is applied within our fixed budget.

ADJUST TREATMENT LEVELS WITHIN FIXED COST LIMITS

Within the cost limits we have just applied, we can use the techniques discussed above (probability multipliers and/or area limits) to allocate effort among the different treatment options. If area limits are applied, the calculated attribute (cost) limits will take precedence over the area limits in VDDT. This means that if we set a minimum area for restoration, this will not cause a budget overrun. The minimum will be applied only if it can be met within the cost limits; otherwise, as many acres as possible will be treated within the budget.

When cost limits are used, transition probabilities can be applied to allocate efforts within the budget proportionally among the treatments without exceeding the budget limits. Experiment with running the scenarios from the Probability Multipliers and Area Limits sections with cost limits, and try to find the scenario that comes closest to the reference conditions within the $30,000 budget.

The results from three scenarios using the $30,000 budget are shown on the next page. Concentrating the limited resources on restoration and prescribed fire seems to be the best strategy for maintaining a landscape most similar to reference conditions and with a low level of cheatgrass infestation, although without further examination of the data it would be difficult to say whether the results for restoration only are significantly different from those of restoration and prescribed fire combined.

Class	Ref. Conditions	Init. Conditions	$30,000 Budget; Probabilities: RxFire = 0.01 Thinning = 0.01 Restoration = 0.01	$30,000 Budget; Probabilities: RxFire = 0.01 Thinning = 0.01 Restoration = 0.001	$30,000 Budget; Probabilities: RxFire = 0.01 Thinning = 0.01 Restoration = 0.05	$30,000 Budget; Restoration only
A (%)	20	0	19	21	19	19
B (%)	50	43	44	48	41	43
C (%)	15	0	6	3	9	8
D (%)	10	32	3	1	4	4
E (%)	5	0	7	3	9	8
F (%)	0	2	3	3	3	3
G (%)	0	23	17	21	15	15
Ecological Departure (%)	0	47	23	25	22	23
Mean acres per year treated with RxFire			207	502	60	0
Mean acres per year thinned			158	366	50	0
Mean acres per year restored			152	64	197	207

OTHER MANAGEMENT OPTIONS

While this case study has focused primarily on three types of active management prescription, this model could be used to explore other management options. For example, the prescriptions we have discussed are not very effective at reducing the amount of Class F, the Depleted class. Land moves into this class through poor grazing practice and, as modeled, only moves out through invasion of annual grasses to Class G, the shrub-annual grass or U_E . The baseline level of overgrazing in the absence of management is approximately 0.08 percent of the landscape, or 120 acres per year. What would happen if we could reduce the amount of overgrazing, perhaps through better education, enforcement or incentives?

The model could be adapted to incorporate this scenario by adjusting the probability multiplier for Excessive Herbivory or by setting an area limit on Excessive Herbivory. Experiment with these changes without active management or with a reduced level of active management. Would it make sense to divert some of the budget from active management to improving grazing practices?

CHAPTER SUMMARY

In this chapter, we have used a reference condition model that has been adapted to represent current conditions and added management actions. We used ecological departure and treatment costs to evaluate different management strategies. In the next chapter, we will explore a different set of management issues using a shortleaf pine model.

CHAPTER 4: EVALUATING ALTERNATIVE MANAGEMENT SCENARIOS

PURPOSE AND OVERVIEW

In this chapter, we will explore how the LANDFIRE reference conditions models can be adapted to address management questions on a landscape very different from the Great Basin system we looked at in Chapters 2 and 3. The modeling work presented in this chapter was a collaborative effort undertaken especially for this manual by The Nature Conservancy's Global Fire Team in cooperation with Mike Brod, wildlife manager for the Chattahoochee-Oconee National Forests and Margit Bucher, fire manager for the Nature Conservancy's North Carolina Chapter (referred to later as "the partners").

STUDY AREA

The study area for this project is the Chattooga River Ranger District of the Chattahoochee-Oconee National Forests, an area approximately 275,000 acres in size located in northeastern Georgia. The study area falls within the Tallulah Foothills land type association (LTA), in a transitional zone between the Southern Appalachian Piedmont and the Blue Ridge Mountains. The focus for this project is the Southern Appalachian Low-Elevation Pine Forest, modeled for LANDFIRE as model 5413530. A description of the reference condition model is included in Appendix B. This BpS was historically characterized by woodlands dominated by shortleaf pine, with variable components of Virginia pine, oaks and hickories. The LANDFIRE modelers estimated that the mean fire return interval (FRI) for this system was approximately four years under reference conditions.

Within the boundaries of the District, approximately 15,400 acres were mapped as the Southern Appalachian Low-Elevation Pine Forest BpS by the LANDFIRE project. Of this area, about 1,000 acres are mapped as agricultural or developed lands on the LANDFIRE existing vegetation map (EVT). The remaining 14,400 acres constitute the area where this model will be applied, which will be referred to as the "target landscape."

TARGET LANDSCAPE

Due to fire suppression and other forest management practices over the past century, the target landscape has been substantially altered and now includes large areas of uncharacteristic* forest types dominated by hardwoods, white pine and loblolly pine. Fire suppression is thought to have driven these changes by limiting the regeneration of shortleaf pine and allowing hardwoods and uncharacteristic pine species to become established. Data extracted from the LANDFIRE EVT layer suggest that approximately 32 percent of the target landscape circa 2000 could be classified as one of the reference condition model classes. The majority of the landscape would be classified as uncharacteristic vegetation, especially oak and mesic hardwood forest.

The table on the next page shows the EVTs mapped by LANDFIRE on the target landscape.

| | | % of Target |
Characteristic EVTs	Acres	Landscape
Southern Appalachian Montane Pine Forest/Woodland	1471	10.2
Southern Appalachian Low-Elevation Pine	240	1.7
Southern Piedmont Dry Oak Pine Forest	2737	19.0
Eastern Serpentine Woodland	8	0.1
Central Appalachian Pine Oak Rocky Woodland	3	0.0
Plantation	153	1.1
Total	**4614**	**32.1**
Uncharacteristic EVTs		
Southern Appalachian Oak Forest	8236	57.2
Southern Piedmont Mesic Forest	52	0.4
Southern Appalachian Cove Forest	1162	8.1
Ruderal Hardwood Pine	330	2.3
Total	**9780**	**68.0**

GOAL

The goal of this modeling effort is to compare the potential outcomes of a range of alternative management scenarios for the target landscape over a planning horizon of 50 years.

OVERVIEW OF MODELING PROCESS

To do this, the we will follow the steps below.

1. Adapt the reference condition model to reflect current conditions, including an appropriate range of management actions.

2. Run the model developed in step one, using the current management regime to predict the range of possible future landscapes if current management patterns are continued.

3. Vary the rates of prescribed fire and thinning to estimate how much management would be needed on a yearly basis to restore a target amount of the landscape (50 percent, 75 percent or 95 percent) to resemble reference conditions.

   This chapter will present an overview of the modeling process and results without the step-by-step instructions included in Chapters 2 and 3. All of the techniques used in this chapter were presented in detail in the earlier chapters. In each scenario, the area receiving each management treatment, the costs of management activities, and the final composition of the target landscape will be tracked.

THE REFERENCE MODEL

The reference condition model for this system is available at www.landfire.gov (make sure to download the model set for Map Zone 54, including both VDDT models and descriptions). The complete model description is included in Appendix A, but the descriptions of the S-Classes are excerpted below for easy reference. The primary successional pathway in this model is from regenerating forest (Class A) to mid-successional shortleaf pine woodland (Class C) to late successional shortleaf pine woodland (Class D), with frequent surface fires in each class. If fire is absent for nine years, the system can transition to an alternate succession pathway where Virginia pine is dominant (Classes B and E). Under reference conditions, this system is maintained by frequent surface fire, with replacement fire, southern pine beetles (p=0.0071) and wind/ice storms (p=0.0071) also playing substantial roles in shaping the landscape.

S-CLASS DESCRIPTIONS FROM MODEL 5413530: SOUTHERN APPALACHIAN LOW-ELEVATION PINE FOREST

Class A   30%   Early1 - All Structures

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 1 - 90%
Upper Layer Canopy Height: Tree 0m - Tree 5m
Tree Size Class: Sapling >4.5ft; <5″DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	*Pinus virginiana*	Virginia pine	Upper
PIEC2	*Pinus echinata*	Shortleaf pine	Upper
VACCI	*Vaccinium*	Blueberry	Upper

Description
Class age 0-10 years. Dense seedling and sapling stands with variable herbaceous or woody understory vegetation. Stands originating from Virginia pine forests may have dense pine seedlings with very little understory. Shortleaf-originating stands may include hickory, yellow poplar, dogwood, blueberry, blackberry, huckleberry, grasses and forbs.

Class B   4%   Mid1 - Closed

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 51 - 100%
Upper Layer Canopy Height: Tree 5.1m - Tree 10m
Tree Size Class: Pole 5-9″ DBH

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	*Pinus virginiana*	Virginia pine	Upper
VACCI	*Vaccinium*	Blueberry	Low-Mid

Description

Class age 11-30 years. Poletimber and small sawtimber stands dominated by Virginia pines with minor components of shortleaf pine and other woody and herbaceous vegetation. Stands are often dense.

Class C   30%   Mid1 - Open

Structural Information

Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 31 - 50%
Upper Layer Canopy Height: Tree 5.1m - Tree 25m
Tree Size Class: Pole 5-9″ DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIEC2	Pinus echinata	Shortleaf pine	Upper
PIVI2	Pinus virginiana	Virginia pine	Upper
QUERC	Quercus	Oak	Low-Mid
CARYA	Carya	Hickory	Low-Mid

Description

Class age 11-30 years. Canopy trees are dominated by shortleaf pine, relatively open with grassy understory. Oak and hickory may also be present in canopy or midstory. Virginia pine may be present in pockets protected from fire.

Class D   35%   Late1 - Open

Structural Information

Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 31 - 70%
Upper Layer Canopy Height: Tree 25.1m - Tree 50m
Tree Size Class: Medium 9-21″DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIEC2	Pinus echinata	Shortleaf pine	Upper
QUERC	Quercus	Oak	Mid-Upper
CARYA	Carya	Hickory	Mid-Upper
COFL2	Cornus florida	Flowering dogwood	Middle

Class age 31 years+. Canopy is dominated by shortleaf pine. Some open park-like stands with grassy understories; overstory contain varying amounts of pine, oak and hickory. Variable midstory development possible with dogwood, oak and hickories.

Class E   1%   Late1 - Closed

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 51 - 100%
Upper Layer Canopy Height: Tree 10.1m - Tree 25m
Tree Size Class: Medium 9-21″DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	Pinus virginiana	Virginia pine	Upper
VACCI	Vaccinium	Blueberry	Low-Mid

Description
Class age 31 years+. Small sawtimber stands dominated by Virginia pines with gaps occurring from tree mortality caused by native insects, wind, ice and snow.

DETAILED MODELING PROCESS

1) ADAPTING THE MODEL TO ACCOUNT FOR CHANGES IN FOREST COMPOSITION (EXCLUDING INVASIVE EXOTICS IN THE UNDERSTORY)

To update the reference condition model to an approximation of current conditions, two new states that did not occur on the presettlement landscape were added:
Box F, Uncharacteristic Native (U_N) Open, includes stands where hardwoods, white pine, and/or loblolly pine dominate the midstory. The overstory is dominated by shortleaf and/or Virginia pine, but these species are not regenerating because of fire exclusion. This class occurs in the absence of fire for 70 years. "Open" in the Class name refers to the uncharacteristic species, which have not yet come to dominate the canopy. When all species are considered, the canopy is typically closed. The system enters this S-Class when the absence of fire for 70 years allows white pine and hardwood species to invade shortleaf or Virginia pine stands.

From the Uncharacteristic Native (U_n), a surface or mixed fire would move the system to Class D by killing the midstory, and a replacement fire would move the system back to Class A. Though wildfire has essentially been excluded from this system, prescribed fire is typically effective at moving the system to Class D about 50 percent of the time. Thinning the midstory also moves the system to Class D. Pine beetle outbreaks are especially likely ($p = 0.05$) in this class because the pines are likely to be stressed, aging and/or decadent due to fire exclusion. A pine beetle outbreak would move a stand to Class G, below. A severe ice storm in this class would thin out the canopy, but not enough to regenerate shortleaf pine, so the stand would remain in Class F.

At age 200, this class succeeds to Class G, as the last of the shortleaf pines die off.

Box G, Uncharacteristic Native (U$_N$) Closed, includes stands where the canopy is entirely composed of hardwoods, white pine and/or loblolly pine. Shortleaf and Virginia pine have been lost from the stand. This class occurs in the absence of fire for 200 years, when the last pines have died out.

Once in this box, all natural disturbances, wildfires and prescribed fire will maintain this class, because there is no seed source to permit shortleaf pine to come back. Thus, this class can include all successional stages of hardwood/loblolly/white pine forest, from early regeneration (age zero) through mature stands.
Restoration of this class to characteristic vegetation requires thinning the canopy and planting shortleaf seedlings.
- A new cover type, Uncharacteristic Native (U$_N$), was added to the model, just as in Chapter 2. Two new model classes with the following attributes were added.

Class	Cover Type/Structure	Age Range	"To Class"
F	U$_N$ Open	70-199	G
G	U$_N$ Closed	0-999	G

NATURALLY OCCURRING TRANSITIONS

Because we are assuming that wildfire will not play a meaningful role in this system going forward, we will not add any wildfire transitions. But weather and pine beetles will continue to strike Class F. The probability of a wind or ice storm occurring in Class F was estimated at 0.01, the same as in the mature shortleaf class (D). Because the pines in Class F are older and becoming decadent, the probability of a severe pine beetle outbreak was estimated to be fairly high (p=0.05).
- The following naturally occurring transitions were added to Class F.

Class	Transition Type	Prob	"To Class"
F	Insect/Disease	0.05	G
F	Wind/Weather/Stress	0.01	F

Wind and weather disturbances may impact Class G, but the damage will not cause a transition out of Class G. Once in Class G, the only way to transition back to one of the other classes is to reintroduce the characteristic pine species. As a result, no natural transitions are modeled for Class G.

Management Transitions

This basic model captures three types of management actions that can cause transitions from one class to another: prescribed fire, mechanical thinning and thinning followed by planting of pine seedlings. The effects of prescribed fire vary depending on the initial conditions of the forest. For example, prescribed fire in Class A is always stand-replacing, setting the model age back to 0. In Class B, prescribed fire typically thins the canopy, promoting regeneration of shortleaf pine and causing a transition to Class C. Less frequently, prescribed fire in Class B can be stand-replacing, causing a transition to Class A, or it can be a light surface fire than causes no transition. The likelihood of each of these pathways occurring following a prescribed fire is specified using the *Proportion* field in the transition properties dialog, as in Chapter 3. Prescribed fire cannot be targeted to particular classes, so the probability of this transition type should be the same for all classes. In this case, it is set to an arbitrary standard value of 0.01 for the initial model runs. This probability can be varied across all classes using a probability multiplier, the method that will be used to run the scenarios for this example.

Thinning in Class F or thinning and planting in Class G is a targeted management action that allows for careful control of the outcome. Since the outcome of this type of treatment is very predictable, the *Proportion* field is not needed for Thin or Thin/plant. The table below shows the range of management transitions that were added to the Basic model.

From Class	Transition Type	Prob	Propn	"To Class"	Rel. Age
A	RxFire	0.01	1	A	-10
B	RxFire	0.01	0.20	A	0
B	RxFire	0.01	0.70	C	0
B	RxFire	0.01	0.10	B	0
C	RxFire	0.01	0.90	C	0
C	RxFire	0.01	0.10	A	0
D	RxFire	0.01	0.90	D	0
D	RxFire	0.01	0.10	C	0
E	RxFire	0.01	0.60	E	0
E	RxFire	0.01	0.40	C	0
F	RxFire	0.01	0.50	F	0
F	RxFire	0.01	0.50	D	0
G	RxFire	0.01	1	G	0
F	Thin	0.01	1	D	0
G	Thin/plant	0.01	1	D	0

2) RUNNING THE MODEL USING CURRENT MANAGEMENT LEVELS

Establishing Initial Conditions

See Appendix C for a summary of how the EVTs were grouped to get an initial distribution of model classes for the target landscape.
The initial conditions used for the futuring runs are given in the table below:

Model Class	% of
A	2
B	3
C	15
D	9
E	3
F	2
G	66

Note that distinguishing Class F was especially difficult, because the defining feature of that class is the composition of the midstory, which is typically not captured in the imagery that is used to define the EVTs in LANDFIRE. Some of the pine forest EVT that was assigned to Classes B-E may really be Class F. Some of the hardwood (especially oak) EVTs that were assigned to class G may include pines as a small portion of the overstory, qualifying those areas as class F. In practice, local inventory or map information can be used to generate a more accurate estimate of current conditions.

RUNNING THE MODEL

The goal of the initial model run was to see what the landscape would look like if current management was continued for 50 years into the future. The local partners indicated that the Forest Service has recently been burning approximately 5,000 acres per year, out of a total of 220,000 acres of forest that could be burned in the District. Since the prescribed fire program does not specifically target the Low-Elevation Pine system, it was assumed that the target landscape would have the same likelihood of receiving a fire treatment as the rest of the District (p= 5000/220,000 = 0.023). For this run, a probability multiplier of 2.3 was applied to the RxFire transition to simulate this treatment rate. The current rate of thinning is approximately 500 acres per year. Because this treatment is more targeted, it was assumed that the whole 500 acres would fall within the target landscape. Area limits were used to restrict the amount of thinning to 500 acres. (See Chapter 3 for detailed instructions on how to apply area limits.)

Wildfire (Replacement, Mixed and Surface Fires) was disabled for all model runs because it was assumed that wildfires are almost always extinguished before having a significant impact on the landscape. Thin/plant transitions were also disabled for this run, since planting is not a part of current management. (See Chapter 3 for detailed instructions on disabling transitions.)

The following table shows the results of running the model for 50 years, first under current management practices and then with no management. The initial conditions calculated from the LANDFIRE succession map and the reference conditions as estimated by the LANDFIRE modelers are included for comparison.

	Reference Conditions	Initial Conditions	Current Mgmt after 50 years	No Mgmt after 50 years
Model Class	% of Landscape	% of Landscape	% of Landscape	% of Landscape
A	30	2	2	1
B	4	3	8	9
C	30	15	7	4
D	35	9	13	9
E	1	3	2	3
F	0	2	1	3
G	0	66	67	71
Ecological Departure (%)	0	70	73	81
Mean annual cost (Constant 2008 $)*	N/A	N/A	65,000	0

*Note that treatment cost is calculated only for the target landscape, which constitutes a minority of the prescribed fire conducted across the District as a whole. Prescribed fire across the District adds another approximately $210,000 per year in costs at current burning rates. See Appendix B for details on how treatment costs were calculated.

Current management is predicted to be unsuccessful in moving the landscape toward reference conditions: after 50 years, the same minority (32 percent) of the landscape is in characteristic vegetation classes. The overall ecological departure is slightly higher, but the difference is not meaningful. Current management does succeed in preventing more of the landscape from moving into the uncharacteristic classes, as would happen in the absence of management, but current management does nothing to help restore the shortleaf pine system. Prescribed fire and thinning can prevent additional areas from moving into the uncharacteristic classes, but they have no effect on areas already in Class G. Because shortleaf pine regeneration will not occur in Class G, thinning with planting is necessary to move areas out of this class.

It should be noted that the results of this model run are quite sensitive to the proportion of the landscape that is initially in Class G. The key distinction between Classes F and G is the presence of a seed source for characteristic pines, especially shortleaf pine. This distinction is difficult to estimate reliably from remote sensing data, since a small number of remnant pines in the overstory might be enough to provide a seed source and allow pine regeneration following fire or thinning. However, an area with only a few remaining pines is likely to be mapped as hardwood forest and assigned to Class G for this modeling exercise. If more reliable data on the presence of shortleaf pine were available, the predictive ability of this model would be improved. If detailed inventory data are not available, managers should consider the feasibility of doing field surveys prior to treatments. This could allow for a more efficient allocation of resources between prescribed fire and thinning/planting. If there is less Class G on the landscape than was estimated, then less thinning and planting is necessary, which could free up resources for more prescribed fire.

3) VARYING THE RATES OF PRESCRIBED FIRE AND THINNING

The next step of the modeling exercise was to estimate how much management effort would be required to reach the following goals:

A.   Less than 50 percent of the landscape in the Uncharacteristic classes.

B.   Less than 25 percent of the landscape in the Uncharacteristic classes.

C.   Less than five percent of the landscape in the Uncharacteristic classes.

D.   Ecological departure of less than 10 percent.

By experimenting with different combinations of treatments, estimates of the minimum treatment level required to reach each goal were generated. These results are given in the following table.

	Reference Conditions	Initial Conditions	Goal A: 50% Unchar.	Goal B: 25% Unchar.	Goal C: <5% Unchar.	Goal D: <10% Departure
			Current RxFire; Thin/plant 80 acres per year	2x current RxFire; Thin/plant 150 acres per year	3x current RxFire; Thin/plant 200 acres per year	8x Current RxFire; Thin/plant 200 acres per year
Model Class	% of Landscape	% of Landscape	% of Landscape	% of Landscape	% of Landscape	% of Landscape
A	30	2	3	6	10	28
B	4	3	12	13	4	7
C	30	15	8	14	20	23
D	35	9	24	41	51	42
E	1	3	2	2	1	0
F	0	2	4	3	2	0
G	0	66	46	21	3	0
Ecological Departure (%)	0	70	60	40	30	10
Mean ann. cost ($)			63,000	119,000	163,000	235,000

* Note that cost is calculated only for the target landscape, which constitutes a minority of the prescribed fire conducted across the District as a whole. Prescribed fire across the District adds another approximately $210,000 per year for Goal A, $420,000 per year for Goal B, $630,000 per year for Goal C and $1,680,000 per year for Goal D.

Key Conclusions

- The current rate of prescribed fire results in a mean FRI of approximately 44 years. Eight times the current rate of prescribed fire, the rate required to meet Goal D, would approximate a 5.4-year FRI. Recall that the reference FRI for this system was estimated at four years by the LANDFIRE modelers.

- Thinning in Class F was not a cost-effective treatment under any of the tested scenarios. The current rate of prescribed fire was effective in preventing additional area from entering Class F, without the need for thinning. Since prescribed fire is much lower in cost than thinning, the modeling suggests that resources are better allocated to fire instead of thinning in Class F.

- The modeling results suggest that thinning followed by planting is a crucial component for any treatment plan to succeed in moving this landscape back toward reference conditions. Neither thinning alone nor prescribed fire will be effective in moving the landscape out of Class G, since that class has no capacity to regenerate the characteristic pine species. The amount of thinning/planting that will be required is sensitive to the amount of the landscape that is in Class G at the beginning of the modeling period. If our estimate that the landscape is about two-thirds in Class G is correct, then about 200 acres per year of thinning/planting is sufficient to nearly eliminate the uncharacteristic classes over the 50-year period. Higher rates of thinning/planting in the earlier years of the run would allow the uncharacteristic classes to be eliminated sooner. For example, increasing the rate of thinning/planting to 250 acres per year would eliminate the uncharacteristic classes in about 40 years.

- The current management system does not allow prescribed fire to be targeted to a specific BpS. As a result, the only way to increase the rate of prescribed fire in the target landscape is to increase the amount of prescribed fire across the entire District. This means that reaching Goals C and D through the scenarios shown above would be extremely expensive and probably logistically impractical. To reach Goal D under the current system would require burning 40,000 acres annually, with a total treatment cost of about $1.9 million per year in 2008 dollars. However, if managers were able to target the prescribed fire to the parts of the landscape where it is most desirable, these costs could be greatly reduced. If 1,000 acres of the current 5,000 acres per year that are burned were targeted within this BpS, it would result in an effective tripling of the rate of burning in the target landscape. Under these conditions, Goal C could be achieved for an average of $373,000 per year, compared with $743,000 per year with untargeted burning.

Chapter Summary

In this chapter we adapted a LANDFIRE reference condition model for current conditions and added management actions. We then ran the model with different treatment combinations to try to achieve target conditions. This example illustrates how evaluating different treatment scenarios with a model can provide managers with useful decision support information.

REFERENCES

Mack, R.N. and D.A. Pike. 1983. The demography of *Bromus tectorum:* variation in time and space. Journal of Ecology 71:69-93.

York, E., G. Green and L. Provencher. 2008. Spatial Modeling of the Cumulative Effects of Land Management Actions on Ecological Systems of the Grouse Creek Mountains-Raft River Mountains Region, Utah. Final Report to the Utah Partners for Conservation and Development.

Ypsilantis, W.G. 2003. Risk of Cheatgrass Invasion after Fire in Selected Sagebrush Community Types. Bureau of Land Management Resource Notes No. 63. Accessed from http://www.blm.gov/nstc/resourcenotes/rn63.html on January 30, 2009.

APPENDIX A: DESCRIPTION OF LANDFIRE NATIONAL MODEL 1711260, INTER-MOUNTAIN BASINS MONTANE SAGEBRUSH STEPPE

Model Date: 03/16/05   Report Date: 7/13/09

Modelers		Reviewers	
Gary Medlyn	gary_medlyn@nv.blm.gov		
Crystal Kolden	ckolden@gmail.com		

Vegetation Type
Upland Savanna and Shrub-Steppe

Map Zone 17

Geographic Range
Montane and subalpine elevations across the western US from 1,000m in eastern OR and WA to over 3,000m in the Southern Rockies, and within the mountains of NV, western UT, southeast WY and southern ID.

Biophysical Site Description
This ecological system occurs in many of the western states, usually at middle elevations (1,000-2,500m). Within the Great Basin mapping zone, elevation ranges from 1,370m in ID to 3,200m in the White Mountains of CA (Winward and Tisdale 1977, Blaisdell et al. 1982, Cronquist et al. 1994, Miller and Eddleman 2000). However, elevations are predominantly between 1,525 and 2,750m in the mountains of NV and western UT. The climate regime is cool, semi-arid to sub-humid, with yearly precipitation ranging from 25-90cm/year (Mueggler and Stewart 1980, Tart 1996). Much of this precipitation falls as snow. Temperatures are continental with large annual and diurnal variation. In general this system shows an affinity for mild topography, fine soils and some source of subsurface moisture. Soils generally are moderately deep, to deep, well-drained and of loam, sandy loam, clay loam or gravelly loam textural classes. Soils often have a substantial volume of coarse fragments and are derived from a variety of parent materials. This system primarily occurs on deep-soiled to stony flats, ridges, nearly flat ridge tops and mountain slopes. Soils are typically deep and have well- developed dark organic surface horizons (Hironaka et al. 1983, Tart 1996). However, at the high ends of its precipitation and elevation ranges mountain big sagebrush occurs on shallow and/or rocky soils. All aspects are represented, but the higher elevation occurrences may be restricted to south- or west-facing slopes.

At lower elevations, mountain big sagebrush occurs on upper fan piedmonts, where it typically intermixes with Wyoming big sagebrush on north-facing slopes. On mountain side slopes at this elevation, it occurs on north-facing slopes. Where pinyon and juniper are present, it is usually on south-facing slopes with pinyon and juniper generally increasing on north-facing slopes within the sagebrush community. At mid-level elevations, mountain sagebrush begins to move into more southerly slopes intermingling with black sagebrush and low sagebrush and with mountain mahogany occurring on north-facing slopes. With continued elevation gain, curlleaf mountain

mahogany generally crowds it out. Mountain big sagebrush then occupies drier sites at higher elevations.

Vegetation Description

Vegetation types within this ecological system are usually <1.5m tall and dominated by *Artemisia tridentata* ssp. *vaseyana*, *Artemisia cana* ssp. *viscidula* or *Artemisia tridentata* ssp. *spiciformis*. A variety of other shrubs can be found in some occurrences, but these are seldom dominant. They include *Artemisia rigida, Artemisia arbuscula, Ericameria nauseosa, Chrysothamnus viscidiflorus, Ephedra viscidiflorus, Symphoricarpos oreophilus, Purshia tridentata, Peraphyllum ramosissimum, Ribes cereum* and *Amelanchier alnifolia*. The canopy cover is usually between 20-80%. The herbaceous layer is usually well represented, but bare ground may be common in particularly arid or disturbed occurrences. Graminoids that can be abundant include *Festuca idahoensis, Festuca thurberi, Festuca ovina, Elymus elymoides, Deschampsia caespitosa, Danthonia intermedia, Danthonia parryi, Stipa* spp, *Pascopyrum smithii, Bromus carinatus, Elymus trachycaulus, Koeleria macrantha, Pseudoroegneria spicata, Bromus anomalus, Achnatherum therburianum, Poa fendleriana or Poa secunda.* Forbs are often numerous and an important indicator of health. Forb species may include *Castilleja, Potentilla, Erigeron, Phlox, Astragalus, Geum, Lupinus, Eriogonum, Balsamorhiza sagittata, Achillea millefolium, Antennaria rosea, Eriogonum umbellatum, Fragaria virginiana, Artemisia ludoviciana, Hymenoxys hoopesii (=Helenium hoopesii)*, etc. Mueggler and Stewart (1980), Hironaka et al. (1983) and Tart (1996) described several of these types. This ecological system is critical summer habitat for greater sage grouse. Moreover, resprouting bitterbrush in mountain big sagebrush types is potentially important to wildlife in early stand development.

BpS Dominant and Indicator Species

Symbol	Scientific Name	Common Name
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush
PUTR2	*Purshia tridentata*	Antelope bitterbrush
SYOR2	*Symphoricarpos oreophilus*	Mountain snowberry

Disturbance Description

Mean fire return intervals (FRI) in and recovery times of mountain big sagebrush are subjects of lively debate in recent years (Welch and Criddle 2003). Mountain big sagebrush communities were historically subject to stand replacing fires with a mean return interval ranging from 40yrs+ at the Wyoming big sagebrush ecotone, and up to 80yrs in areas with a higher proportion of low sagebrush in the landscape (Crawford et al. 2004, Johnson 2000, Miller et al. 1994, Burkhardt and Tisdale 1969 and 1976, Houston 1973, Miller and Rose 1995, Miller et al. 2000). Under pre-settlement conditions mosaic burns generally exceeded 75 percent top kill due to the relatively continuous herbaceous layer. Therefore, replacement fire with a mean FRI of 40-80yrs was adopted here. Brown (1982) reported that fire ignition and spread in big sagebrush is largely (90%) a function of herbaceous cover. These communities were also subject to periodic mortality due to insects, disease, rodent outbreaks, drought and winterkill (Anderson and Inouye 2001, Winward 2004). Periodic mortality events may result in either stand-replacement or patchy die-off depending on the spatial extent and distribution of these generally rare (50-100yrs) events. Recovery rates for shrub canopy cover vary widely in this type, depending on post-fire weather conditions, sagebrush seed-bank survival, abundance of resprouting shrubs (e.g., snowberry, bitterbrush) and size and severity of the burn. Mountain big sagebrush typically reaches five percent canopy cover in 8-14yrs. This may take as little as four years under favorable conditions and longer than 25yrs in unfavorable situations (Pedersen et al. 2003, Miller unpublished data). Mountain big sagebrush typically reaches 25 % canopy cover in about 25yrs, but this may take as few as nine years or longer than 40yrs (Winward 1991, Pedersen et al. 2003, Miller unpublished

data). Mountain snowberry and resprouting forms of bitterbrush may return to pre-burn cover values in a few years. Bitterbrush plants less than 50 years old are more likely to resprout than older plants (Simon 1990).

VDDT Fire Frequency Results

Severity	Avg FI	Min FI	Max FI	Percent of All Fires
Replacement	49	15	100	100
Moderate (Mixed)				
Low (Surface)				
All Fires	49			100

Scale Description

This type occupies areas ranging in size from 10s-10,000s of acres. Disturbance patch size can also range from 10s-1,000s of acres. The distribution of past burns was assumed to consist of many small patches in the landscape.

Non-Fire Disturbances / Interactions Modeled

Insects/Disease

Adjacency or Identification Concerns

In MZ16, BpS 1126 was separated into two very distinct montane sagebrush steppe not distinguished by NatureServe: Inter-Mountain Basins Montane Sagebrush Steppe dominated by mountain big sagebrush (1126big) and Inter-Mountain Basins Montane Sagebrush Steppe dominated by low sagebrush (1226low). Both systems cover large high-elevation areas in the Intermountain West. Mountain big sagebrush is a tall shrub with a mean FRI from 10-70yrs, whereas high-elevation low sagebrush is a dwarf shrub with a mean FRI of 200yrs+. For MZs 12 and 17, mountain big sagebrush communities fall into this model (BpS 1126), while mountain low sagebrush communities fall into BpS 1124.

The NatureServe description does not distinguish between mountain big sagebrush that can be invaded by conifers at mid-to-high elevations (i.e. within the tolerance of pinyon and juniper) and mountain sagebrush steppe that is too high elevation for pinyon to encroach. The ability for pinyon to invade has a large effect on predicted historic range of variability (HRV) and management.

This type may be adjacent to forests dominated by aspen, Douglas-fir, limber pine and bristlecone pine. It also occurs adjacent to pinyon-juniper woodlands. The ecological system, where adjacent to conifers, is readily invaded by conifers (Douglas-fir, sub-alpine fir, whitebark pine, limber pine, pinyon-pine and juniper spp) in the absence of historic fire regimes (Miller and Rose 1999). This type probably served as an ignition source for adjacent aspen stands. Mountain big sagebrush is commonly found adjacent to or intermingled with low sagebrush and mountain shrublands.

Uncharacteristic conditions in this type include herbaceous canopy cover <40 percent and dominance of the herbaceous layer by mules ears (Wyethia amplexcaulis) on clayey soils. At lower elevational limits on southern exposures there is a high potential for cheatgrass invasion/occupancy where the native herbaceous layer is depleted. This post-settlement, uncharacteristic condition is not considered here.

Issues or Problems

This was initially 1126_a (Mountain Big Sagebrush) model from MZ16, which was itself based on Rapid Assessment models R2SBMT and R2SBMTwc where the reviewers and modelers had very different opinions on the range of mean FRIs and mountain big sagebrush recovery times (see Welch and Criddle 2003). It is increasingly agreed upon that a MFI of 20yrs, which used to be the accepted norm, is simply too frequent to sustain populations of greater sage grouse and mountain big sagebrush ecosystems whose recovery time varies from 10-70yrs. Reviewers consistently suggested longer FRIs and recovery times. The revised model is a compromise with longer recovery times and FRIs. Modeler and reviewers also disagreed on the choice of FRG: II (modeler) vs. IV (reviewers). For MZs 12 and 17, modelers place this system in Fire Regime Group IV.

If conifers are not adjacent to this system, such as in the Tuscarora range, Santa Rose range and similar regions, use a three-box model with the following percentages per box: 20% A, 45% B and 35 % C.

Native Uncharacteristic Conditions

None indicated.

Comments

BpS 1126 for MZs 12 and 17 was based on BpS 1126_a (Mountain Big Sagebrush) from LF MZ16. BpS 1126_a is essentially PNVG R2SBMTwc (mountain big sagebrush with potential for conifer invasion) developed by Don Major (dmajor@tnc.org), Alan R. Sands (asands@tnc.org), David Tart (dtart@fs.fed.us) and Steven Bunting (sbunting@uidaho.edu). R2SBMTwc was itself based on R2SBMT developed by David Tart. R2SBMtwc was revised by Louis Provencher (lprovencher@tnc.org) following critical reviews by Stanley Kitchen (skitchen@fs.fed.us), Michele Slaton (mslaton@fs.fed.us), Peter Weisberg (pweisberg@cabnr.unr.edu), Mike Zielinski (mike_zielinski@nv.blm.gov) and Gary Back (gback@srk.com).

The first three development classes chosen for this PNVG correspond to the early-, mid- and late seral stages familiar to range ecologists. The two classes with conifer invasion (Classes D and E) approximately correspond to Miller and Tausch's (2001) phases two and three of pinyon and juniper invasion into shrublands.

Succession Classes

Class A   20%   Early Development 1 - Open

Structural Information
Upper Layer Lifeform: Shrub
Upper Layer Canopy Cover: 0 - 5%
Upper Layer Canopy Height: Shrub 0m - Shrub 0.5m
Tree Size Class: None

Upper Layer Lifeform is not the dominant life form
Dominant vegetation is herbaceous with scattered shrubs. Herbaceous cover is 0-80%.

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PSSP6	*Pseudoroegneria spicata*	Bluebunch wheatgrass	Upper
FEID	*Festuca idahoensis*	Idaho fescue	Upper
SYOR2	*Symphoricarpos oreophilus*	Mountain snowberry	Lower
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush	Lower

Description

Herbaceous vegetation is the dominant life form. Herbaceous cover is variable but typically <50% (50-80%). Shrub cover is 0-5%. Replacement fire (mean FRI of 80yrs) setbacks succession by 12yrs. Succession to Class B after 12yrs.

Class B   50%   Mid Development 1 - Open

Structural Information
Upper Layer Lifeform: Shrub
Upper Layer Canopy Cover: 6 - 25%
Upper Layer Canopy Height: Shrub 0m - Shrub <3.1
Tree Size Class: Seedling <4.5ft

Upper Layer Lifeform is not the dominant life form
Herbaceous cover is the dominant life form with canopy >50%. Shrub cover is 6-25% and the upper life form.

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush	Upper
PUTR2	*Purshia tridentata*	Antelope bitterbrush	Upper
CONIFER	<NOT FOUND IN NRCS>	<NOT FOUND IN NRCS>	Lower
SYMPH	*Symphoricarpos*	Snowberry	Lower

Description

Shrub cover 6-25%. Mountain big sagebrush cover up to 20%. Herbaceous cover is typically >50%. Initiation of conifer seedling establishment. Replacement fire mean FRI is 40yrs. Succession to class C after 38yrs.

Class C   15%   Late Development 1 - Closed

Structural Information
Upper Layer Lifeform: Shrub
Upper Layer Canopy Cover: 26 - 45%
Upper Layer Canopy Height: Shrub 0m - Shrub >3.1m
Tree Size Class: None

Symbol	Scientific Name	Common Name	Canopy Position
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush	Upper
PUTR2	*Purshia tridentata*	Antelope bitterbrush	Upper
SYMPH	*Symphoricarpos*	Snowberry	Low-Mid
CONIFER	<NOT FOUND IN NRCS>	<NOT FOUND IN NRCS>	Mid-Upper

Description

Shrubs are the dominant life form with canopy cover of 26-45%+. Herbaceous cover is typically <50%. Conifer (juniper, pinyon-juniper, ponderosa pine or white fir) cover <10%. Insects and disease every 75yrs on average will thin the stand and cause a transition to class B. Replacement fire occurs every 50yrs on average. In the absence of fire for 80yrs, vegetation will transition to class D. Otherwise, succession keeps vegetation in Class C.

Class D　　　10%　　　　　　　　　　　**Late Development 1 - Open**

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 10 - 25%
Upper Layer Canopy Height: Tree 0m - Tree 10m
Tree Size Class: Sapling >4.5ft; <5″DBH

Upper Layer Lifeform is not the dominant life form
Shrub cover generally decreasing but remains between 26-40% Conifers cover 10-25%.

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
CONIFER	<NOT FOUND IN NRCS>	<NOT FOUND IN NRCS>	Upper
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush	Mid-Upper
PUTR2	*Purshia tridentata*	Antelope bitterbrush	Mid-Upper
SYMPH	*Symphoricarpos*	Snowberry	Low-Mid

Description

Conifers are the upper life form (juniper, pinyon-juniper, ponderosa pine, limber pine or white fir). Conifer cover is 11- 25%. Shrub cover generally less than mid-development classes, but remains between 26-40%. Herbaceous cover <30%. The mean FRI of replacement fire is 50yrs. Insects/diseases thin the sagebrush, but not the conifers, every 75yrs on average, without causing a transition to other classes. Succession is from C to D after 50yrs.

Class E　　　5%　　　　　　　　　　　**Late Development 2 - Closed**

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 26 - 80%
Upper Layer Canopy Height: Tree 0m - Tree 10m
Tree Size Class: Pole 5-9″ DBH

Symbol	Scientific Name	Common Name	Canopy Position
CONIFER	<NOT FOUND IN NRCS>	<NOT FOUND IN NRCS>	Upper
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush	Mid-Upper
PUTR2	*Purshia tridentata*	Antelope bitterbrush	Mid-Upper
SYMPH	*Symphoricarpos*	Snowberry	Mid-Upper

Description

Conifers are the dominant life form (juniper, pinyon-juniper, ponderosa pine, limber pine or white fir). Conifer cover ranges from 26-80% (pinyon-juniper 36-80%) (Miller and Tausch 2000), juniper 26-40% (Miller and Rose 1999), white fir 26-80%). Shrub cover 0-20%. Herbaceous cover <20%. The mean FRI for replacement fire is longer than in previous states (75yrs). Conifers are susceptible to insects/diseases that cause diebacks (transition to class D) every 75yrs on average.

REFERENCES

Anderson, J.E. and R.S. Inouye 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs 71: 531-556.

Brown, D.E., ed. 1982. Biotic communities of the American Southwest--United States and Mexico. Desert Plants: Special Issue. 4(1-4): 342.

Burkhardt, W.J. and E.W. Tisdale. 1969. Nature and successional status of western juniper vegetation in Idaho. Journal of Range Management 22(4): 264-270.

Burkhardt, W.J. and E.W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57: 472-484.

Crawford, J.A., R.A. Olson, N.E. West, J.C. Mosley, M.A. Schroeder, T.D. Whitson, R.F. Miller, M.G. Gregg and C.S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57: 2-19.

Hironaka, M., M.A. Fosberg and A.H. Winward. 1983. Sagebrush-Grass Habitat Types of Southern Idaho. University of Idaho Forest, Wildlife and Range Experiment Station, Bulletin Number 35. Moscow, ID. 44 pp.

Houston, D.B. 1973. Wildfires in northern Yellowstone National Park. Ecology 54(5): 1111-1117. Johnson, K. 2000. *Artemisia tridentata* ssp. *vaseyana*. In: Fire Effects Information System [Online], USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2004, September 17].

Miller, R.E. and N.L. Fowler. 1994. Life history variation and local adaptation within two populations of *Bouteloua rigidiseta* (Texas grama). Journal of Ecology. 82: 855-864.

Miller, R.F. and J.A. Rose. 1995. Historic expansion of Juniperus occidentalis (western juniper) in southeastern Oregon. The Great Basin Naturalist 55(1): 37-45.

Miller, R.F. and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. Journal of Range Management 52: 550-559.

Miller, R.F., T.J. Svejcar and J.A. Rose. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management 53(6): 574-585.

Miller, R.F. and R.J. Tausch. 2001. The role of fire in juniper and pinyon woodlands: a descriptive analysis. Proceedings: The First National Congress on Fire, Ecology, Prevention and Management. San Diego, CA, Nov. 27- Dec. 1, 2000. Tall Timbers Research Station, Tallahassee, FL. Miscellaneous Publication 11: 15-30.

Mueggler, W.F. and W.L. Stewart. 1980. Grassland and shrubland habitat types of Western Montana. USDA Forest Service GTR INT-66.

NatureServe. 2007. International Ecological Classification Standard: Terrestrial Ecological Classifications. NatureServe Central Databases. Arlington, VA. Data current as of 10 February 2007.

Pedersen, E.K., J.W. Connelly, J.R. Hendrickson and W.E. Grant. 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. Ecological Modeling 165: 23-47. Simon, S.A. 1990. Fire effects from prescribed underburning in central Oregon ponderosa pine plant communities: first and second growing season after burning. Pages 93-109 in: Fire in Pacific Northwest Ecosystems. Thomas E. Bedell, editor. Department of Rangeland Resources, Oregon State University, Covallis, OR. 145 pp.

Tart, D.L. 1996. Big sagebrush plant associations of the Pinedale Ranger district. Pinedale, WY: USDA Forest Service, Bridger-Teton National Forest. Jackson, WY. 97 pp.

Welch, B.L. and C. Criddle. 2003. Countering Misinformation Concerning Big Sagebrush. Research Paper RMRS-RP-40. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 28 pp.

Winward, A.H. 1991. A renewed commitment to management in sagebrush grasslands. Pages 2-7 in: Management in the Sagebrush Steppes. Oregon State University Agricultural Experiment Station Special Report 880. Corvallis OR.

Winward, A.H. 2004. Sagebrush of Colorado; taxonomy, distribution, ecology, & management. Colorado Division of Wildlife, Department of Natural Resources, Denver, CO.

APPENDIX B: DESCRIPTION OF LANDFIRE NATIONAL MODEL 5413530, SOUTHERN APPALACHIAN LOW-ELEVATION PINE FOREST

Model Date: 07/26/07   Report Date: 7/13/09

Modelers		Reviewers	
Malcolm Hodges	mhodges@tnc.org		
Dan Chan	dchan@gfc.state.ga.us		
Louis Hyman	louis.hyman@forestry.alabama.gov		

Vegetation Type
Forest and Woodland

Map Zone 54

Geographic Range
This system is found primarily in the Appalachian regions of KY and the Southern Blue Ridge in northern GA, western NC, southeastern TN, the Cumberlands of AL, parts of the Interior Low Plateau (e.g., the Knobs Region of KY) and southwestern VA (NatureServe 2007).

Biophysical Site Description
Occurs on a variety of topographic and landscape positions, including ridge tops, upper and mid-slopes, in mountain valleys and lower ranges. Bedrock may be a variety of types, but system is limited to acidic substrates (NatureServe 2007). This system consists of shortleaf pine- and Virginia pine-dominated forests in the lower elevation southern Appalachians and adjacent Piedmont and Cumberland Plateau, extending into the Interior Low Plateau of KY and TN. Fire is important in maintaining shortleaf pine-dominated types. The natural habitat of Virginia pine is xeric fire refuges such as exposed rock outcrops with patchy and light fuels. It is thus somewhat comparable to Table Mountain pine, but at lower elevations. Under natural conditions, it would occupy minor land area as a type but would have scattered individuals surviving in mixture with shortleaf pine.

This system is common to the Southern Appalachians but less so in the adjacent Piedmont, typically occupying xeric to dry sites at elevations generally below 700m on ridge tops, western, south and southwestern aspects. Occasionally Virginia pine is also found dry-mesic sites as pioneering vegetation.

Vegetation Description
Vegetation consists of closed to open forest dominated by shortleaf pine (*Pinus echinata*) or Virginia pine (*Pinus virginiana*). Pitch pine (*Pinus rigida*) may sometimes be present. Hardwoods may be abundant at times, especially dry-site oaks such as *Quercus falcata*, *Quercus prinus* and *Quercus coccinea.* Other overstory components vary with moisture regimes but could include several other pine species, red and white oaks, other hardwoods and/or eastern red cedar. Many stands are strongly even-aged and density-dependent based on age.

The hardwood component may be partly the result of fire suppression. The shrub layer may be well-developed, with *Vaccinium pallidum, Gaylussacia baccata*, or other acid-tolerant species most

characteristic. Herbs are usually sparse but may include *Pityopsis graminifolia* and *Tephrosia virginiana*. Herbs probably were more abundant and shrubs less dense when fires occurred more frequently, and the communities of this system may have been grassy under more natural conditions, with *Schizachyrium scoparium* being a typical component, possibly with *Danthonia* sp (NatureServe 2007). Virginia pine is an aggressive invader following disturbance and might be considered uncharacteristic vegetation on some sites. The frequency of its occurrence in the Southern Appalachian forested landscapes today is undoubtedly greater than in pre-settlement times. Its niche appears best fitted to xeric sites on thin soils (e.g. "necklace" stands adjacent to bluff lines in the Cumberlands and Appalachians). Virginia pine is increasingly at risk of mortality to disturbance agents as it matures. Older trees are particularly susceptible to pine beetle attacks due to slow radial growth and relatively high growing densities on often poor sites. Older trees are also more prone to windthrow. Few stands reach 100yrs of age with most stands "breaking up" at 50 to 75yrs of age.

BpS Dominant and Indicator Species

Symbol	Scientific Name	Common Name
PIVI2	*Pinus virginiana*	Virginia pine
PIEC2	*Pinus echinata*	Shortleaf pine
QUFA	*Quercus falcata*	Southern red oak
QUPR2	*Quercus prinus*	Chestnut oak
QUCO2	*Quercus coccinea*	Scarlet oak
CAGL8	*Carya glabra*	Pignut hickory
VAPA4	*Vaccinium pallidum*	Blue ridge blueberry
GABA	*Gaylussacia baccata*	Black huckleberry

Disturbance Description

Fire is an important influence and may be the only factor determining the occurrence of this system, which would be a hardwood forest without fire. Fires were probably frequent and of low-intensity, or a mix of low- and high-intensity. Fire is important in determining the dominance of the two pines and the presence of the hardwood components and the overall vegetation structure. Shortleaf pine (*P. echinata*) when mature is resistant to fire, while Virginia pine (*P. virginiana*) is less adapted to fire with thinner bark and higher mortality rates (particularly in young stands) and *P. virginiana* seedlings are easily killed by fire and will not resprout. It can, however, survive repeated low-intensity fires. The natural occurrence of *P. virginiana* on infertile, thin soils allows the community to persist in a specialized edaphic niche. It is a prolific seeder and is able to pioneer on these and other disturbed sites. *P. virginiana* often develops "red heart" rot, caused by *Fomes pini*, at ages beyond about 60yrs. Virginia pine is very shallow rooted and susceptible to windthrow. Heavy snow and ice can create significant stand openings. Initial openings give rise to further windthrow and even larger openings as trees fall into gaps.

Under present conditions, the Southern pine beetle is an important factor in this system. Beetle outbreaks can kill pines without creating conditions for pines to regenerate.
In the absence of fire to maintain the ecosystem, natural Virginia pine stands could succeed to varying vegetation cover: (a) xeric oaks such as scarlet oak, chestnut oak, blackjack oak and post oak; (b) mountain laurel, sourwood, red maple and huckleberry and (c) eastern white pine overstory.

Effects of logging and past clearing as well as fire suppression make understanding of this system´s natural character and dynamics difficult. Some pine-dominated areas appear to be successional stands established in former hardwood forests after logging or cultivation, and would not be expected to have the same dynamics or ecosystem characteristics as natural pine forests maintained by fire. In natural pine forests, logging may allow pines to regenerate or may change the composition to weedy hardwoods. It might alter canopy composition as well as structure (NatureServe 2007).

VDDT Fire Frequency Results

Severity	Avg FI	Min FI	Max FI	Percent of All Fires
Replacement	25	25	125	13
Moderate (Mixed)	144			2
Low (Surface)	4	5	15	84
All Fires	3			100

Scale Description
Spatial scale and pattern are generally characterized as large patch. Most remnants in relatively natural condition are probably small patches. In its most natural setting, topography generally limits the patch size of the ecological community.

Non-Fire Disturbances / Interactions Modeled
Insects/Disease, Wind/Weather/Stress

Adjacency or Identification Concerns
Examples with significant hardwood component may be classified as Southern Piedmont Dry Oak-(Pine) Forest (CES202.339 -- BpS1368). NatureServe (2007) also notes that this system probably usually bordered and intermixed with Southern Appalachian Oak Forest (CES202.886-- BpS1315) and Southern and Central Appalachian Cove Forest (CES202.373 -- BpS1318) may be present in more mesic areas. It may also intergrade into Southern Appalachian Montane Pine Forest and Woodland (CES202.331 -- BpS1352) at high elevations.
The relationship between this system and Southern Appalachian Montane Pine Forest and Woodland (CES202.331 -- BpS1352) may need further clarification. Southern Appalachian Low-Elevation Pine Forest (CES202.332) is distinguished by its occurrence as large patches on lower terrain (generally below 700 m [2300 feet]) and less extreme topography. The vegetation of the two systems may overlap but pitch pine and Table Mountain pine are more typical of the former, while shortleaf pine and Virginia pine are more typical of the latter (NatureServe 2007).
This system (CES202.332) at its western extent in central TN would be distinguished from equivalent Ozarkian systems (e.g., Ozark-Ouachita Shortleaf Pine-Oak Forest and Woodland (CES202.313 -- BpS1367)) by the presence of *Pinus virginiana* and *Quercus prinus*, which do not cross the Mississippi River (NatureServe 2007).

Issues or Problems
None indicated

Native Uncharacteristic Conditions
Absence of fire without pine reproduction may lead to succession to hardwood forest types. Effects of logging and past clearing as well as fire suppression make understanding this system´s natural character and dynamics difficult. Some pine-dominated areas appear to be successional

stands established in former hardwood forests after logging or cultivation, and would not be expected to have the same dynamics or ecosystem characteristics as natural pine forests maintained by fire. In natural pine forests, logging may allow pines to regenerate or may change the composition to weedy hardwoods. It might alter canopy composition as well as structure (NatureServe 2007).

Comments

NOTE: 1/31/09: As a result of final QC for LANDFIRE National by Jennifer Long, the user-defined min and max fire return intervals for mixed-severity fire were deleted because they were not consistent with the modeled fire return interval for this fire severity type.

This BpS is really a combination of RA model descriptions for R8PIVlap - Appalachian Virginia Pine and R8PIECap - Appalachian Shortleaf Pine. The RA modeler for each was Roger D. Fryar, and each was reviewed by Ron Stephens, rstephens@fs.fed.us.

Succession Classes

Class A   30%   Early Development 1 - All Structures

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 0 - 90%
Upper Layer Canopy Height: Tree 0m - Tree 5m
Tree Size Class: Sapling >4.5; <5" DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	*Pinus virginiana*	Virginia pine	Upper
PIEC2	*Pinus echinata*	Shortleaf pine	Upper
VACCI	*Vaccinium*	Blueberry	Upper

Description
Class age 0-10yrs. Dense seedling and sapling stands with variable herbaceous or woody understory vegetation. Stands originating from Virginia pine forests may have dense pine seedlings with very little understory. Shortleaf-originating stands may include hickory, yellow poplar, dogwood, blueberry, blackberry, huckleberry, grasses and forbs.

Class B   4%   Mid Development 1 - Closed

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 51 - 100%
Upper Layer Canopy Height: Tree 5.1m - Tree 10m
Tree Size Class: Pole 5-9″ DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	*Pinus virginiana*	Virginia pine	Upper
VACCI	*Vaccinium*	Blueberry	Upper

Description

Class age 11-30yrs. Poletimber and small sawtimber stands dominated by Virginia pines with minor components of shortleaf pine and other woody and herbaceous vegetation. Stands are often dense.

Class C   30%   Mid Development 1 - Open

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 31 - 50%
Upper Layer Canopy Height: Tree 5.1m - Tree 25m
Tree Size Class: Pole 5-9″ DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIEC2	*Pinus echinata*	Shortleaf pine	Upper
PIVI2	*Pinus virginiana*	Virginia pine	Upper
QUERC	*Quercus*	Oak	Low-Mid
CARYA	*Carya*	Hickory	Low-Mid

Description

Class age 11-30yrs. Canopy trees are dominated by shortleaf pine, relatively open with grassy understory. Oak and hickory may also be present in canopy or midstory. Virginia pine may be present in pockets protected from fire.

Class D   35%   Late Development 1 - Open

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 31 - 70%
Upper Layer Canopy Height: Tree 25.1m - Tree 50m
Tree Size Class: Medium 9-21″DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIEC2	*Pinus echinata*	Shortleaf pine	Upper
QUERC	*Quercus*	Oak	Mid-Upper
CARYA	*Carya*	Hickory	Mid-Upper
COFL2	*Cornus florida*	Flowering dogwood	Middle

Description

Class age 31yrs+. Canopy is dominated by shortleaf pine. Some open park like stands with grassy understories; overstory contains varying amounts of pine, oak and hickory. Variable midstory development possible with dogwood, oak and hickories.

Class E   1%   Late Development 1 - Closed

Structural Information
Upper Layer Lifeform: Tree
Upper Layer Canopy Cover: 51-100%
Upper Layer Canopy Height: Tree 10.1m - Tree 25m
Tree Size Class: Medium 9-21″DBH

Indicator Species

Symbol	Scientific Name	Common Name	Canopy Position
PIVI2	*Pinus virginiana*	Virginia pine	Upper
VACCI	*Vaccinium*	Blueberry	Low-Mid

Description
Class age 31yrs+. Small sawtimber stands dominated by Virginia pines with gaps occurring from tree mortality caused by native insects, wind, ice and snow.

REFERENCES

Brown, James K. and Jane Kapler Smith, eds. 2000. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 257 pp.

Little, E.L., Jr. 1971. Atlas of United States trees, volume 1, conifers and important hardwoods: U.S. Department of Agriculture Miscellaneous Publication 1146, 9 pp., 200 maps. [Online]. Available: http://esp.cr.usgs.gov/data/atlas/little.

NatureServe. 2007. International Ecological Classification Standard: Terrestrial Ecological Classifications. NatureServe Central Databases. Arlington, VA, U.S.A. Data current as of 15 April 2007.

Schmidt, Kirsten M., James P. Menakis, Colin C. Hardy, Wendel J. Hann and David L. Bunnell. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-GTR-87. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 41 pp. + CD.

USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2002, December). Fire Effects Information System, [Online]. Available: http://www.fs.fed.us/database/feis/.

USDA Forest Service, Southern Forest Research Station, Southern Forest Resource Assessment, [Online]. Available: http://www.srs.fs.fed.us/sustain.

APPENDIX C: MODELING ASSUMPTIONS FOR THE CHATTOOGA RIVER PROJECT

The target landscape includes all the area within the Chattooga River Ranger District that was mapped as the Southern Appalachian Low Elevation Pine BpS, except for areas mapped as the following existing vegetation types (EVTs):

> Developed

> Agricultural

> Riparian

Within the study area, pixels were assigned to the new model classes based primarily on the LANDFIRE EVT map.

The following EVTs were included within the Characteristic vegetation classes (A-E):

> Southern Appalachian Montane Pine Forest and Woodland (EVT 2352)

> Southern Appalachian Low Elevation Pine Forest (EVT 2353)

> Southern Piedmont Dry Oak Pine Forest (EVT 2363)

> Eastern Serpentine Woodland (EVT 2375)

> Central Appalachian Pine Oak Rocky Woodland (EVT 2377)

> Plantation (EVT 2535)

The following EVTs were included within the Uncharacteristic vegetation classes (F-G):

> Southern Appalachian Oak Forest (EVT 2315)

> Southern Piedmont Mesic Forest (EVT 2316)

> Southern Appalachian Cove Forest (EVT 2318)

> Ruderal Hardwood Pine Forest (EVT 2533)

The table following shows how the EVTs were assigned to model classes.

EVT	Total Acres in each EVT that fall within the So. App. Low Elev. Pine BpS	Assigned Model Class	Acres Assigned by Class
Developed	721	none	
Agriculture	294	none	
So. Appalachian Oak Forest	8,236	G	8,236
So. Pied Mesic Forest	52	G	52
So. Appalachian Cove Forest	1,162	G	1,162
So. Appalachian Montane and Low Elevation Pine Forest	1,711	A	300
		B	400
		C	300
		D	300
		E	411
So. Piedmont Dry Oak Pine Forest	2,737	C	1,738
		D	1,000
East. Serpentine Woodland	8	E	8
Cent. Appalachian Pine Oak Rocky Woodland	3	E	3
Cent. Interior and Appalachian Riparian	1	none	
Ruderal Hardwood Pine	330	F	330
Plantation	153	B	77
		C	76
Total Acres	**15,409**		**14,393**

Wildfire is no longer a significant driver in this system. Most wildfires are extinguished quickly, before they impact more than a few hundred acres. As a result, the naturally occurring fire transitions included from the LANDFIRE reference condition model were disabled and no wildfire transitions were used in the new classes that were added to the model.

Time since disturbance (TSD) is counted from the last fire of any type (prescribed fire or wildfire) that occurred in a given pixel. Note that this requires changing the definition of the AllFire transition group from the definition used in the LANDFIRE models. To do this, go to File|Properties|Definitions to open the *Definitions* dialog box. Highlight AllFire and click Types. Under Available transition types, highlight RxFire, and click the right arrow button to add this type to the list of selected transition types. Click OK twice to exit both dialog boxes and save the model. Now the AllFire group includes all types of fire included in the model.

The way prescribed fire is currently applied in the District does not allow for targeting specific forest types (either BpS of Model Classes). However, local experts estimated that about 20% of the District consists of cover types that are very unlikely to burn, either because prescribed fire will not reach them, or because they are not flammable. Thus, prescribed fire probabilities for the District are calculated by dividing the annual area burned by the burnable area of the District (80% of 275,000 acres = 220,000 acres). The probability of prescribed fire in the target landscape is assumed to be the same as that for the District as a whole.

APPENDIX D: TREATMENT COSTS

Current treatment costs were estimated by the partners as given in the table below.

Treatment	Cost/Acre
Prescribed Fire	$45
Thinning	$500
Thinning/Planting	$600

It was assumed that treatment costs would remain stable (in constant, or inflation-adjusted, 2008 dollars) over the 50-year time horizon of the model. Changing economic and market conditions may alter the relative costs of the treatments. For example, several proposals to build biomass power plants in the region have circulated in recent years. If such a plant were to come online and create a market for small-diameter wood that could substantially reduce the costs of the thinning and thinning/planting treatments.