Chapter 2: Dynamic Vegetation Modeling of Forest, Woodland, Shrubland, and Grassland Vegetation Communities in the Pacific Northwest and Southwest Regions of the United States

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Chapter Summary

Land management planning at broad scales requires integrative techniques to understand and synthesize the effects of different land management activities and address socioeconomic and conservation concerns. The Integrated Landscape Assessment Project was developed to support the vital but complex task of broad-scale integration of information to assess ecological sustainability at multiple scales. The project supports ecosystem management planning at a regional scale across all lands of Arizona, New Mexico, Oregon, and Washington by simulating landscape dynamics using state-and-transition models (STMs) and linking model output to management planning considerations such as fuel conditions, wildlife habitat, community economics, and climate change. The stakeholders and target users for the

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project products include natural resource planners, decisionmakers, and modelers who can provide additional analyses in support of planning and policy. This chapter reports on the STM component of the project. The STMs were designed for all major potential vegetation types in the study area with a focus on watershed-level prioritization of land management actions. One baseline scenario, depicting vegetation dynamics with no management activity, was applied across the full study area. Other management scenarios were developed for focus areas within the four-state project area. The modeling framework was sometimes linked with other modeling systems (e.g., Forest Vegetation Simulator) and other data sets for validation or calibration, and incorporated expert opinion where data were lacking. The process was flexible and modular to allow alternative data sources for vegetation and other base data to be incorporated. Products resulting from this work include STMs of vegetation dynamics, tools for preparing and initializing models, data summarization and visualization tools, and model output data sets across the four-state study area. Most data, tools, and products will be available online via the Western Landscapes Explorer (www.westernlandscapesexplorer.info).

Introduction

Understanding shifts in ecosystem dynamics in the face of continued human influence is vital for sustaining ecosystems (Christensen et al. 1996). Twentieth-century management practices, including timber harvest and fire suppression, have altered the ecosystem dynamics of many native communities throughout the Western United States. In forested communities, management has resulted in changes to forest structure, composition, and ecological function (Franklin et al. 2002), as well as shifts in natural disturbance regimes such as wildfire and insect outbreaks, particularly in drier environments (Ottmar and Sandberg 2001). In the Southwestern United States, management has contributed to changes in forest and woodland fire regimes, as witnessed by the massive Whitewater-Baldy Fire of 2012, as well as community structure, composition, and function (Allen et al. 2002). In warm, dry shrub steppe and desert environments across the Western United States, invasion by exotic grasses and forbs has promoted frequent, stand-replacing fire (Knapp 1996, Whisenant 1990). In many cooler, upland shrub steppe sites, juniper expansion beyond its historical range has converted historical grassland and shrub steppe communities to woodlands, resulting in loss of sagebrush and other habitat (Burkhardt and Tisdale 1976, Miller et al. 2005).

Management plans are being revised for many of these altered landscapes, and there is an opportunity to provide increased understanding of coupled human-natural systems through methods that incorporate current models for landscape dynamics, agency management treatments, and common conventions for vegetation description. Integrating management methods and accepted concepts, socioeconomic and conservation concerns, and other needs into land management and planning is challenging but provides a means to weigh the influence of a wide range of system drivers, especially those related to vegetation dynamics at regional scales (Christensen et al. 1996, Dale et al. 1998, Hann and Bunnell 2001).

The Integrated Landscape Assessment Project (ILAP) was designed to support ecosystem management planning at a regional scale with a focus on watershed-level prioritization of land management actions across all forests, woodlands, and arid lands of Arizona, New Mexico, Oregon, and Washington. The project explored the dynamics of broad-scale, multiownership landscapes by integrating information about current and future vegetation and fuel conditions, climate change, wildlife habitat, fuel treatment economics, and community economics. These factors were chosen because they are being managed for or considered as part of the management planning process. The stakeholders and target users for the project products included natural resource planners, decisionmakers, and modelers who can provide additional analyses in support of planning and policy. At the heart of the project were state-and-transition models (STMs) depicting vegetation state classes and processes that cause vegetation change over time. The models were built to represent the range of vegetation types from forested to arid lands in all four states, and project changes from vegetation community development, natural disturbances, and management events. One baseline scenario depicting no management except for fire suppression (fire suppression only [FSO]) was modeled for the entire project study area, and several other scenarios were customized for geographic focus areas. Products from the work included vegetation models, spatial data sets describing current vegetation conditions, and projections of vegetation conditions. A number of tools were also developed to facilitate project work and applications beyond the life of the project, such as visualization tools and two decision support frameworks for land management. In this chapter, we describe the data and methods used to construct, parameterize, and run the STMs for ILAP.

State-and-Transition Modeling Framework

In landscape ecology and resource management, STMs have been applied to simulate vegetation change in rangelands, woodlands, and forests. The STMs can be thought of as box and arrow diagrams (fig. 2.1), where boxes represent state classes describing structural and functional attributes, and may include one or more successional phases (Bestelmeyer et al. 2009). Arrows represent the drivers causing state class change, such as succession, disturbance, and management (Westoby et al. 1989). The STMs can be designed to address both broad- and fine-scale research

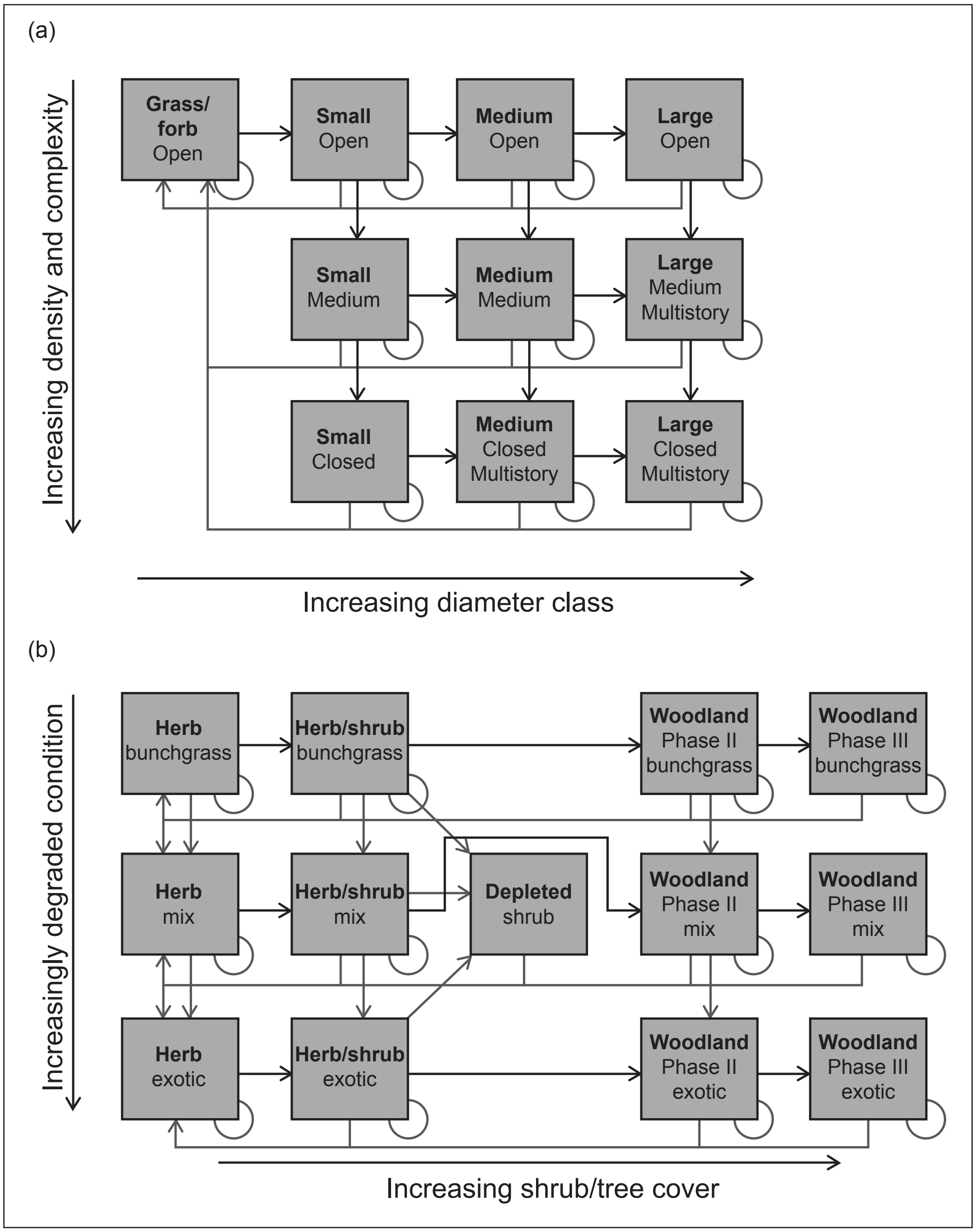

Figure 2.1—Simplified state-and-transition models (STMs), with state classes (boxes) depicting combinations of vegetation cover and structure, and transitions (arrows) showing process that causes vegetation change. Black arrows indicate growth and succession, and grey arrows represent disturbances and management activities. The figure includes (a) a schematic of the basic structure of a forest or woodland STM. Columns in a model represent the progression (left to right) from younger to older trees (and larger size classes). Rows typically represent the progression (top to bottom) from open to closed density classes, based on percentage of canopy cover. (b) An example of an arid land STM of sagebrush-steppe vegetation dynamics. Succession proceeds from left to right as shrubs and trees become dominant (woodland phases from Miller et al. 2005). Fires and other major disturbances return cells to early successional state classes. Rangeland condition is characterized by the composition of the herbaceous layer, ranging from good-condition native bunchgrass (top) to a semidegraded mix of native and exotic species (middle) to an exotic-dominated herbaceous layer (bottom).

questions. They have been used extensively in rangeland management to represent highly dynamic and perturbation-sensitive rangeland ecosystems (Briske et al. 2005, Petersen et al. 2009, Westoby et al. 1989), examine ecosystem resilience and the effects of restoration (Forbis et al. 2006), and project the distribution of state classes on the landscape through time as part of an integrative modeling framework for planning (Baker 1989, Bestelmeyer et al. 2009, Hemstrom et al. 2007, Vavra et al. 2007, Wales et al. 2007). As a decision support tool, STMs allow synthesis of assumptions about vegetation growth, natural disturbance regimes, and management regimes in a single modeling environment (Bestelmeyer et al. 2003, Hemstrom et al. 2007). Models developed under this framework are relatively simple to parameterize and can integrate expert opinion and information derived from data (Provencher et al. 2009, Westoby et al. 1989).

For this project, individual STMs represented vegetation dynamics (alternate state classes, successional processes, disturbance, etc.) within broad units of potential vegetation. Potential vegetation provided a useful basis for building ecological units because common species assemblages, site productivity, and disturbance patterns are represented, and finer classifications (plant association groups and plant associations) commonly used by federal land management agencies for planning and project implementation (e.g., Hall 1998) could also be included. The resolution of potential vegetation is also compatible with the strategic and landscape-scale perspectives of contemporary resource managers. More importantly, potential vegetation units provide concise descriptions of biophysical conditions and disturbance regimes. Within our project area, potential vegetation maps provided the spatial extent in which each STM operated, similar to the use of biophysical setting by the LANDFIRE project (Rollins 2009), or the ecological site descriptions by the Natural Resources Conservation Service (www.nrcs.usda.gov).

Because spatial modeling would be impractical at the scale of the project area, we used nonspatial STMs. However, our modeling process combined spatial layers of potential vegetation, watersheds, and land ownership-management allocation types (hereafter ownership-management) to form discrete spatial units called modeling strata (see "Spatial Data"; fig. 2.2). The features in each layer worked much like a set of interconnected cookie cutters that divided the landscape into modeling strata. Each modeling stratum was linked to an STM model run, and STM results were summarized for each modeling stratum. This allowed STM output to be summarized and mapped onto meaningful landscape units to illustrate changes in modeled state classes through space and time and link to other characteristics of interest (fig. 2.3; chapters 3 through 7). We also used spatial data from the current vegetation layer to initialize STMs with current vegetation conditions in the first time step of the simulations (see "Spatial Data").

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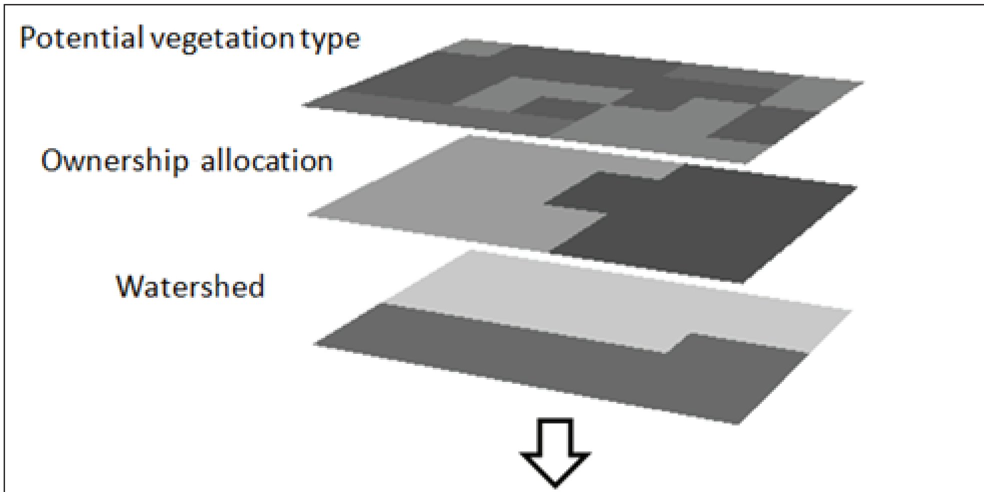

Watershed	PVT	Owner	Modeling Strata	Area
101	OSW_fmh	f5	101_OSW_fmh_f5	10
101	OSW_fmh	o1	101_OSW_fmh_o1	6
102	OSW_fal	f1	102_OSW_fal_f1	15

Figure 2.2—Modeling strata combined land ownership-management, potential vegetation type (PVT), and watershed and provided the basic spatial unit for state-and-transition modeling. Modeling strata organized modeling activities so that divisions of the landscape that share model assumptions were assigned parameters that were specific to the conditions found in sites with those characteristics (e.g., a wildfire rate specific to a PVT and a management rate specific to the ownership-management type).

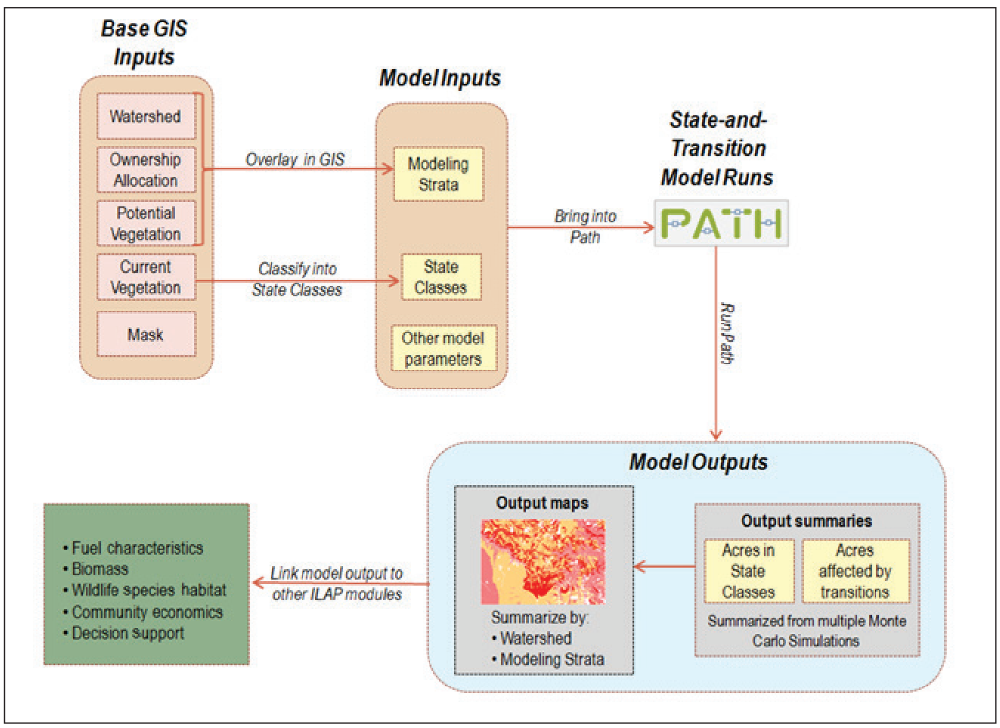

Figure 2.3—Flow diagram illustrating the data inputs and outputs for the state-and-transition modeling process. Base geographic information system (GIS) layers were processed to comprise model inputs, which were brought into the Path modeling platform. Path model output was used to summarize vegetation dynamics in graphical and map form, and output was linked to other characteristics of interest by other project modules. ILAP = Integrated Landscape Assessment Project.

The individual state classes (boxes) within ILAP STMs represented cover types, usually the dominant species or vegetation assemblage, and structural stages, based on physical attributes such as vegetation height, percentage cover, and canopy layers. For example, in a forest STM (fig. 2.1a), a state class may represent ponderosa pine of the 25- to 38-cm diameter class in multiple structural stages, depending on whether it had open-, mid-, or closed-canopy cover. In a shrub steppe model (fig. 2.1b), a state class may represent shrub steppe with native bunchgrasses and sagebrush, where grass cover was open and shrub cover was sparse. To link these conceptual STM state classes to current landscape conditions, we utilized spatial data of current vegetation. The spatial data in the current vegetation map (cover type and structure) was allocated to each of the state classes within a STM, forming the modeling initial conditions (see "Data Processing"). These initial conditions provided the starting point (initial time step) from which a given STM simulated vegetation dynamics (fig. 2.2).

The transitions (arrows) in the STMs simulated successional processes such as growth and development, natural disturbances such as wildfire and insect outbreaks, and management actions such as prescribed fire, seeding of native bunchgrasses, and tree harvesting. Transitions were classified as either deterministic or probabilistic. Deterministic transitions occurred at a specific vegetation age, whereas probabilistic transitions were defined by an annual transition probability. Transitions could be linked to other transition types using a "time-since-disturbance" clock, allowing the modeler to simulate interaction effects, such as a the delayed onset of an insect outbreak with tree size, or the undesirable effect of livestock grazing following a major disturbance. Some transitions moved vegetation from one state class to another; for instance, a stand-replacing disturbance may move vegetation from a dense forest to a grass/forb state class. Other transitions resulted in vegetation remaining in the same state class, such as surface fires, mild insect activity, drought, and some types of grazing.

The STMs were developed in the Vegetation Dynamics Development Tool (VDDT), version 6.0.25 (ESSA Technologies Ltd. 2007), and simulations were run using the Path landscape model (Path), version 3.0.4 (Apex Resource Management Solutions 2012; Daniel and Frid 2012). The software simulated vegetation dynamics by dividing the landscape into cells and simulating movement among state classes according to user-defined transition probabilities at each time step (ESSA Technologies Ltd. 2007, Kurz et al. 1999). VDDT is a nonspatial STM framework that has been used to support broad landscape modeling efforts such as the Interior Northwest Landscape Analysis System (Barbour et al. 2007) and the LANDFIRE project (www.landfire.gov; Rollins 2009). More recently, it has been folded into the Path landscape model interface (Apex Resource Management Solutions 2012; Daniel and Frid 2012), which facilitates running multiple STMs concurrently over large and diverse landscapes.

State-and-Transition Model Collection and Development

Using and adding to the collection of STMs for major vegetation types in the study area was part of the original vision for the project and its timeline.

A collection of STMs representing the major vegetation types already existed for much of the study area; using and adding to this collection was part of the original vision for producing project results rapidly. The STMs used for this project were catalogued and run in three overarching groups: forests, woodlands, and arid lands (nonforested types), which were further divided by geographic regions. In the U.S. Department of Agriculture Forest Service (USDA FS) Southwestern Region 3 (Arizona and New Mexico; AZ/NM hereafter), forest and woodland areas were generally defined as areas with the potential to support mature trees and a canopy cover >10 percent, and dominant species composition was used to separate forests from woodlands. In USDA FS Pacific Northwest Region 6 (Oregon and Washington; OR/WA hereafter), forested areas were generally defined using a ≥10 percent tree cover cutoff, with the exception of juniper communities and locations identified as burned or cut. In both regions, arid lands included areas that contained <10 percent tree cover historically and have the potential to support shrub and herb vegetation. Model sources included the USDA FS Region 6, USDA FS Region 3, the LANDFIRE project, the USDI Bureau of Land Management (USDI BLM), and The Nature Conservancy (TNC). Many existing STMs did not require modifications, but for those that did, modifications included calibration of transitions and vegetation state classes using the Forest Vegetation Simulator (FVS; see Forest Vegetation Simulator Calibration), modifying fire probabilities based on the Monitoring Trends in Burn Severity (MTBS) data (see "Wildfire Probabilities"), reconciling multiple model versions using expert opinion and literature, and altering transition probabilities and model state classes based on expert review and scientific literature. New models were developed for many of the AZ/NM arid lands and for some OR/WA arid land vegetation types. In all, 275 STMs were adapted or constructed for the project.

Oregon and Washington Forest Models

Modeled Vegetation Types

The ILAP effort compiled or constructed 53 STMs that covered all major forested vegetation types in OR/WA (table 2.1). The FVS was used for model calibration in the Washington Coast Range, Washington West Cascades, and Washington North Cascades areas of OR/WA (table 2.1; see Forest Vegetation Simulator Calibration).

Table 2.1—Descriptions of forested vegetation types modeled in Oregon and Washington[a]

Potential vegetation type	Description
Douglas-fir-dry	Dry Douglas-fir with ponderosa pine as a long-lived, early-seral species.
Douglas-fir-moist	Moist Douglas-fir with ponderosa pine and incense cedar as long-lived early-seral species. Pacific madrone, big leaf maple, and Oregon white oak are also common.
Douglas-fir-white oak	Douglas-fir on sites too dry for western hemlock and white fir. Oregon white oak and Pacific madrone are also common.
Douglas-fir-xeric	Douglas-fir on sites too dry to support western hemlock or white fir but moister than Douglas-fir/white oak.
Grand fir-cool/moist	Grand fir and Douglas-fir on mid- to high-elevation sites in eastern Oregon and Washington.
Grand fir-valley	Grand fir and Douglas-fir on low-elevation, warm, dry sites in western Washington.
Grand fir-valley (Oregon)	Grand fir and Douglas-fir on low-elevation, warm, dry sites in western Oregon. Big leaf maple, Oregon white oak, and Pacific madrone may also be common.
Grand fir-warm/dry	Grand fir and Douglas-fir on low- to mid-elevation, warm, dry sites in eastern Oregon and Washington.
Lodgepole pine-dry	Lodgepole pine found on pumice parent material but without the presence of ponderosa pine.
Lodgepole pine-wet	Lodgepole pine found in cold-air pockets and riparian zones with transitions to meadows, willow, and quaking aspen.
Mixed conifer-cold/dry	Mixed conifer at mid to high elevations in Oregon's eastern Cascades.
Mixed conifer-dry	Mixed conifer at mid elevations in the eastern Cascades.
Mixed conifer-dry (pumice soils)	Mixed conifer at mid elevations in Oregon's eastern Cascades and defined by the pumice parent material.
Mixed conifer-moist	Mixed conifer at mid to high elevations in the eastern Cascades.
Mountain hemlock-cold/dry	Mountain hemlock at high elevations in the eastern Cascades. Lodgepole pine is a frequent seral species.
Mountain hemlock-cold/dry (coastal/west Cascades)	Mountain hemlock at high elevations west of the Cascades or in the coastal ranges. Lodgepole pine is a frequent seral species.
Mountain hemlock-intermediate	Mountain hemlock with temperature and moisture intermediate to the cold/dry vegetation type. Alaska cedar and Pacific silver fir may also be present.
Mountain hemlock-wet	Mountain hemlock at high elevations on wetter locations. Lodgepole pine is infrequent.
Oregon white oak	Oregon white oak and ponderosa pine in southwestern Oregon. Sites are too warm and dry to support Douglas-fir.

Table 2.1—Descriptions of forested vegetation types modeled in Oregon and Washington[a] (continued)

Potential vegetation type	Description
Oregon white oak-ponderosa pine**	Oregon white oak and ponderosa pine in the eastern Cascades. Sites are too warm and dry to support Douglas-fir.
Pacific silver fir-intermediate**	Pacific silver fir and Douglas-fir at mid to high elevations of the coastal and Cascade mountain ranges.
Pacific silver fir-warm	Pacific silver fir and Douglas-fir at lower elevations of the coastal and Cascade mountain ranges.
Pacific silver fir-wet	Pacific silver fir and Douglas-fir on very moist sites at mid to high elevations in western Washington.
Ponderosa pine-dry**	Ponderosa pine and Douglas-fir found at lower elevations in Washington's east Cascades or limited areas of southwestern Oregon.
Ponderosa pine-dry, with juniper**	Ponderosa pine and Douglas-fir found at lower elevations in Oregon's east Cascades where western juniper may encroach.
Ponderosa pine-lodgepole pine	Ponderosa pine and lodgepole pine found on pumice parent material.
Ponderosa pine-xeric	Ponderosa pine on sites that are transitional to dry woodland species such as curl-leaf mountain mahogany and western juniper.
Shasta red fir-dry	Mixed conifer at mid to high elevations in the eastern Cascades. Shasta red fir is the dominant late-seral species.
Shasta red fir-moist	Douglas-fir at moist, high-elevation locations in southwestern Oregon. Shasta red fir is the dominant late-seral species.
Sitka spruce	Near-coastal, low-elevation forest dominated by Douglas-fir and with Sitka spruce and western hemlock as late-seral species.
Subalpine fir*	Subalpine fir at high elevations in western Washington. A variety of species may be codominant in this type.
Subalpine fir-cold/dry	Subalpine fir at high elevations in eastern Oregon and Washington. A variety of species may be codominant in this vegetation type.
Subalpine parkland**	Subalpine fir at the highest elevations still capable of supporting trees. Tree distribution is patchy and surrounded by shrubby or herbaceous communities.
Subalpine woodland	Subalpine forests in eastern Oregon, historically dominated by white bark pine or limber pine at the highest elevations still capable of supporting trees. Tree distribution is patchy and surrounded by shrubby or herbaceous communities.
Tan oak-Douglas-fir-dry	Douglas-fir and tan oak on moderately dry sites in southwestern Oregon.
Tan oak-Douglas-fir-moist	Douglas-fir and tan oak on moist sites in southwestern Oregon.
Tan oak-moist	Tan oak on moist sites in coastal Oregon.

Table 2.1—Descriptions of forested vegetation types modeled in Oregon and Washington[a] (continued)

Potential vegetation type	Description
Ultramafic	Vegetation type defined by serpentine and peridotite soil parent materials. Jeffrey pine, Douglas-fir, and incense cedar are common species.
Western hemlock-coastal	Western hemlock and Douglas-fir found in a relatively narrow strip along the coast in southwestern Oregon.
Western hemlock-cold	Western hemlock and Douglas-fir on very moist sites in the higher, colder portions of the western hemlock zone.
Western hemlock-hyperdry	Western hemlock and Douglas-fir on the very driest sites still capable of supporting western hemlock. Often transitional to Douglas-fir and grand fir vegetation types.
Western hemlock-intermediate	Western hemlock and Douglas-fir at lower to middle elevations on well-drained but not dry sites.
Western hemlock-moist	Western hemlock, Douglas-fir, and western redcedar on moist and productive sites west of the Cascade crest.
Western hemlock-moist (coastal)	Western hemlock, Douglas-fir, and western redcedar on moist and productive sites in the coastal mountain ranges.
Western hemlock-wet	Western hemlock, Douglas-fir, and western redcedar on wet sites from poor soil drainage or concave topography.
Western redcedar/western hemlock-moist	Western hemlock, Douglas-fir, and western redcedar in northeastern Washington.
White fir-cool	White fir and Douglas-fir in southwestern Oregon. In this area, white fir has replaced Pacific silver fir in mid- to high-elevation forests.
White fir-intermediate	White fir and Douglas-fir in southwestern Oregon with intermediate temperature and moisture.
White fir-moist	White fir and Douglas-fir in southwestern Oregon.

[a] Model source is indicated as a superscript where: * = new model built for the project, and ** = model built by the U.S. Department of Agriculture Forest Service (USDA FS) and Washington State Department of Natural Resources. Vegetation types with no superscript represent models that were developed by the USDA FS.

Modifications to these STMs included calibration of existing growth and succession transition rates and the omission or addition of state classes, depending on the STM and potential vegetation. In addition, wildfire probabilities under current climate, vegetation, and fire suppression conditions were computed from MTBS data for most models of potential vegetation on the east side of the Cascade Mountains (table 2.1; see "Wildfire Probabilities").

Model Structure

The ILAP models necessarily abstracted the broad range of structural variety found in forests into four density classes and six diameter size classes (table 2.2). Models typically included growth and development transitions, natural disturbance transitions, and management transitions (fig. 2.1a, table 2.3). Growth and development transitions increased forest age and complexity. Natural disturbance transitions differed across modeling zones (fig. 2.4), but most models included disturbances related to wind, wildfire, insects, or fungal pathogens. Depending on disturbance severity, the effects of a transition ranged from simply delaying deterministic growth to returning vegetation to an open, seedling-sapling state class. Management transitions also varied across models and included regeneration harvest, salvage harvest following a natural disturbance, precommercial thinning, commercial thinning, thinning from below, and others. Transitions can be customized to better fit the management plans of landownership types or other conditions by altering rates and the removal or addition of transition types as necessary.

Table 2.2—Structural attributes modeled in forest state-and-transition models for Oregon and Washington

Density classes		Size classes	
Density (percent canopy cover)	Model density classes	Diameter at breast height range	Model size classes
		Centimeters	
<10	Grass/shrub	Nonstocked	Grass/shrub
10 to 40	Open	<13	Seedling/sapling
40 to 60 >60	Medium	13 to 25	Pole
	Closed	25 to 38	Small
		38 to 51	Med
		51 to 76	Large
		>76	Giant

Table 2.3—Probabilistic transition types used in Oregon and Washington forest state-and-transition models

Transition type	Transition description
Natural transitions:	
Insects and disease	All insect and disease damage to trees, usually delaying growth or transitioning to postdisturbance state classes
Succession	All succession types, representing both the growth of trees and changes to tree species composition within a stand
Wildfire	All wildfire transitions
Alternate succession	Alternative successional pathways, such as when snags fall over and result in a change in state class
Insects and disease-low-severity	Low-severity effects of insects and diseases (background levels) that delay deterministic growth from one state class to another
Forest Vegetation Simulator (FVS) growth	Probabilistic growth transitions derived from the FVS to replace deterministic growth transitions
Canopy growth	Canopy growth that increases stand density after a set number of years without any disturbance or management
Hemlock looper	Damage related to hemlock looper insect outbreaks
Mistletoe	Damage related to dwarf mistletoe
Mountain pine beetle	Damage related to mountain pine beetle insect outbreaks
Natural regeneration	Natural conifer regeneration
Other bark beetles	Damage related to bark beetles other than the western pine beetle, such as Jeffrey and mountain pine beetles
Root disease	Damage related to root diseases
Spruce budworm and tussock moth	Damage related to spruce budworm and tussock moth insect outbreaks
Understory development	Understory development that moves stands from single to multistory state classes after a certain number of years following a fire or management treatment
Mixed-severity wildfire	Wildfire that kills 25 to 75 percent of the forest canopy
Nonlethal wildfire	Wildfire that kills less than 25 percent of the forest canopy
Stand-replacing wildfire	Wildfire that kills more than 75 percent of the overstory
Windthrow	Damage related to severe windthrow
Wooly adelgid	Wooly adelgid insect outbreaks causing subalpine fir mortality
Western pine beetle	Damage related to western pine beetle insect outbreaks
Management transitions:	
Timber harvest	All harvest types including partial, salvage, selection, and regeneration
Partial harvest	All partial harvest types including selection

Table 2.3—Probabilistic transition types used in Oregon and Washington forest state-and-transition models (continued)

Transition type	Transition description
Grazing and miscellaneous	The effects of grazing on seedling/sapling development, generally accelerating the transition from a postdisturbance state class to seedling/sapling and pole-sized state classes in dry forests
Precommercial thinning	Precommercial thinning in which vegetation and trees are removed to increase available resources for the most vital and valuable trees
Prescribed fire	Prescribed fire transitions of all severity levels
Partial harvest-medium and closed stand	Partial harvest (commercial thinning from below) in medium and closed stands
Partial harvest-open stand	Partial harvest (light maintenance thinning) to maintain an open canopy
Partial harvest-pole stand	Partial harvest in pole-sized stands, representing fuel treatments that do not generally produce a commercial product and are applied after the normal age of a precommercial thin
Replant-postdisturbance	Replanting with seedlings after harvesting or disturbance
Regeneration harvest	Regeneration harvest, including clearcut or shelterwood
Salvage harvest	Salvage harvest following stand-replacing disturbance, often followed by replanting
Selection harvest	Selection harvest that represents a periodic individual tree selection of mature stands

Model Sources

Most OR/WA forest STMs were adapted from existing models, built through the Interagency Mapping and Assessment Project (IMAP; http://ecoshare.info/projects/interagency-mapping-and-assessment-project/), with state classes and transitions informed primarily through local, expert opinion. Forest Service ecologists worked with silviculturists and other specialists to develop and parameterize most of the models (table 2.1). Preexisting models did not exist for several modeling zones (Washington Coast Range, Washington West Cascades, Washington North Cascades, and Washington Northeast) and, in those cases, new models were derived from existing models in neighboring regions. Model adaptation involved maintaining general model state classes but altering disturbance regimes and vegetation growth and development. Changes to growth and development transition probabilities were informed by simulations in FVS (see "Forest Vegetation Simulator Calibration"), and in some cases, vegetation state classes were omitted or added. Disturbance regimes were derived from both expert opinion and existing literature.

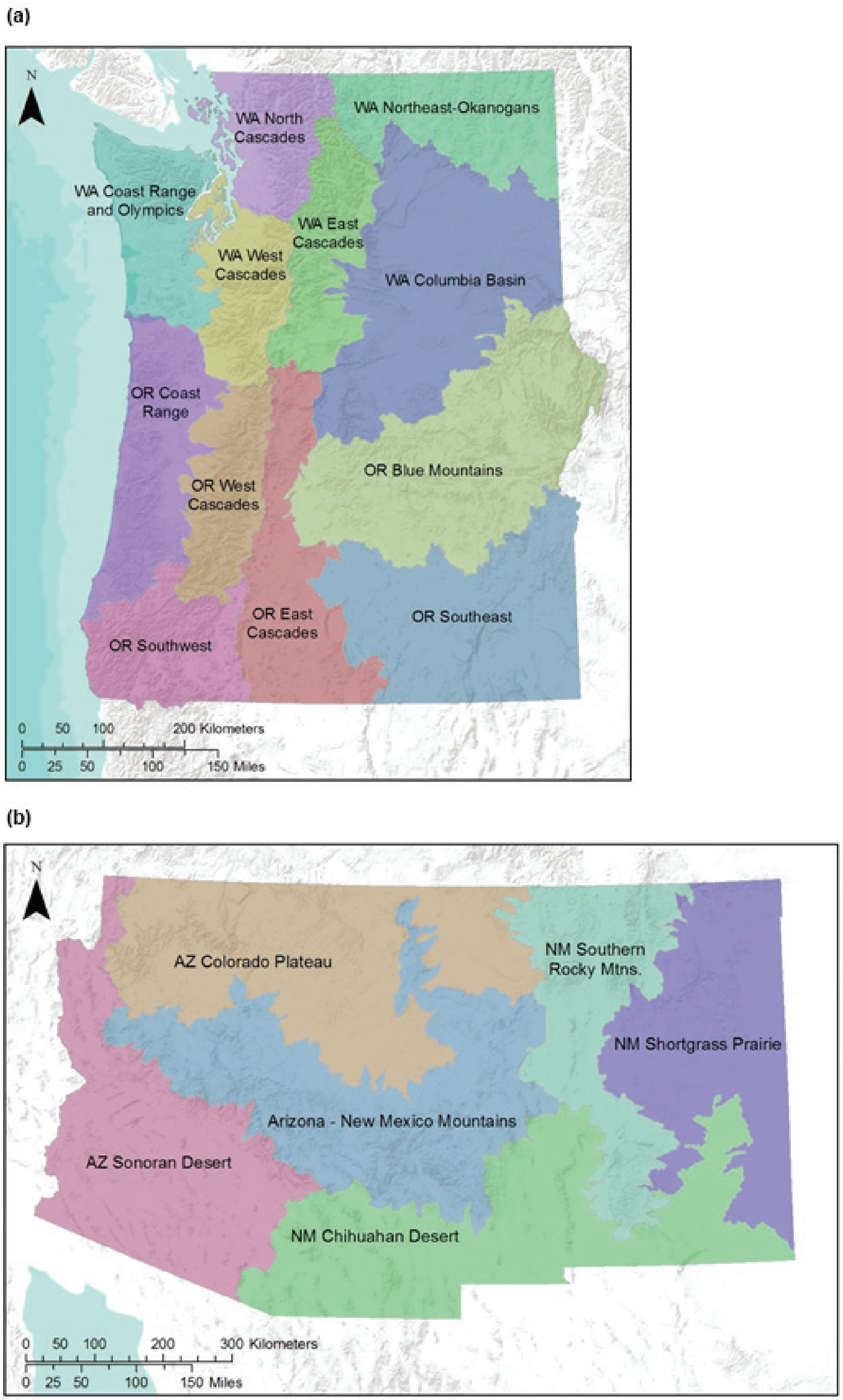

Figure 2.4—State-and-transition modeling zones in (a) Oregon and Washington (OR/WA), and (b) Arizona and New Mexico (AZ/NM). ILAP = Integrated Landscape Assessment Project.

Oregon and Washington (OR/WA) Arid Land Models

Modeled Vegetation Types

We adapted or constructed 19 STMs characterizing contemporary vegetation dynamics for all major nonforested systems (called arid lands) in OR/WA (table 2.4). The model set primarily covered rangeland vegetation types, but also included other nonforested systems such as subalpine meadows and montane/canyon shrublands. Detailed documentation of OR/WA arid land models is available on the Western Landscapes Explorer website (www.westernlandscapesexplorer.info)

Model Structure

Arid land state classes for OR/WA STMs were defined by combinations of cover types and structural stages (fig. 2.1b). Arid land cover types generally specified the dominant shrub and the dominant grass functional group(s). Alternative state classes within STMs were distinguished primarily by dominant life form (grass/shrub/tree) and composition of the herbaceous layer, which often indicated the level of degradation compared to historical plant communities. Grass functional groups included native grass (i.e., bunchgrass), robust grass (grass species that are fairly tolerant of grazing pressure, and therefore often indicate semidegraded conditions), and exotic grass, including cheatgrass and medusahead. Structural stages indicated the cover of the dominant life form, and included herbaceous stages, open, mid and closed shrub steppe, woodland phases I, II, and III (Miller et al. 2005) that characterized the level of site dominance by western juniper, and others (table 2.5).

Growth and succession were represented as deterministic transitions, and other processes such as wildfire, insects, and management activities were represented as probabilistic transitions (table 2.6). Wildfire probabilities were derived from the MTBS data for potential vegetation groups and three levels of exotic grass invasion (native, semidegraded, and degraded), reflecting changes in fire return interval with the introduction of exotic species (see "Wildfire Probabilities" and www.westernlandscapesexplorer.info). Management transitions were built into the models but were deactivated for the baseline ILAP FSO scenario.

Model Sources

The ILAP arid lands STMs were obtained from a variety of sources and were adapted for use across all OR/WA arid lands (table 2.4). Final models often incorporated information from multiple sources, including expert opinion, literature, and data. The STMs developed by USDA FS ecologists for the Blue Mountains of northeastern Oregon were the primary source for many ILAP arid land models, because the model set covered most of the major potential vegetation in eastern Washington and Oregon, and because the models were thoroughly documented by the original

Table 2.4—Descriptions of arid land vegetation types modeled in Oregon and Washington[a]

Potential vegetation type	Vegetation description
Bitterbrush-no juniper	Upland sites dominated by bitterbrush shrub steppe, often with some sagebrush
Bitterbrush-sand	Dry, sandy deposits of the Columbia River basin with bitterbrush, other shrubs, and needle-and-thread
Bitterbrush-with juniper	Upland sites dominated by bitterbrush shrub steppe, often with some sagebrush, and with potential for juniper encroachment
Bluebunch wheatgrass-Sandberg bluegrass	Low-elevation grasslands dominated by bluebunch wheatgrass and Sandberg bluegrass
Idaho fescue-prairie junegrass	Mid-elevation grasslands growing on productive plateau, canyon, and ridge sites, dominated by Idaho fescue
Low sagebrush-mesic, no juniper*	Upland sites with soils that are shallow or have a restrictive layer supporting low sagebrush steppe
Low sagebrush-mesic, with juniper*	Upland sites with soils that are shallow or have a restrictive layer supporting low sagebrush steppe and with potential for western juniper encroachment
Montane and canyon shrubland	Low- to mid-elevation montane shrub community with a diversity of species, including mountain snowberry, mallow ninebark, and many others
Mountain big sagebrush-no juniper*	Cool, moist sites with mountain big sagebrush that are outside of the range of juniper (most of Washington)
Mountain big sagebrush-with juniper*	Cool, moist sites with mountain big sagebrush steppe and high potential for juniper encroachment
Mountain mahogany	Rocky sites dominated by curl-leaf mountain mahogany
Rigid sagebrush and low sagebrush-xeric	Shallow soil sites supporting rigid sagebrush, low sagebrush and/or buckwheat
Salt desert shrub-lowland**	Lowland salt desert shrub flats, dominated by greasewood and salt grass and intermittently flooded, usually on Pleistocene lake beds
Salt desert shrub-upland**	Salt desert shrub sites above playas, dominated by saltbush and sparse grasses
Subalpine meadows-green fescue	Montane to subalpine grasslands occurring on mountain slopes and ridges, dominated by green fescue
Threetip sage	Highly productive three-tip sagebrush steppe sites
Western juniper woodland	Sites historically and currently considered western juniper woodlands
Wyoming big sagebrush-no juniper*	Warm, dry low- to mid-elevation sites supporting Wyoming big sagebrush steppe
Wyoming big sagebrush-with juniper*	Warm, dry mid-elevation sites supporting Wyoming big sagebrush steppe with enough moisture for potential juniper encroachment

[a] Model source is indicated with a superscript where: * = U.S. Department of the Interior, Bureau of Land Management, and ** = The Nature Conservancy of Nevada. Vegetation types without a superscript were developed by the U.S. Department of Agriculture, Forest Service.

Table 2.5—Major structural stages used in Oregon and Washington arid land state-and-transition models

Name	Description
Herbland	Grassland with few shrubs and trees (shrub cover less than 5 percent, tree cover less than 2 percent)
Open shrub	Open shrub steppe (shrub cover greater than 5 to 15 percent, tree cover less than 2 percent)
Mid shrub	Mid shrub steppe (shrub cover greater than 15 to 25 percent, tree cover less than 2 percent)
Closed shrub	Closed shrub steppe (shrub cover greater than 25 percent, tree cover less than 2 percent)
Depleted shrub	Depleted shrubland with high shrub cover and overgrazed herbaceous layer (shrub cover greater than 25 percent, herb cover less than 5 percent, tree cover less than 2 percent)
Woodland-phase I	Phase I juniper invasion, consisting of shrub steppe with shrubs or grasses dominant and scattered juniper (juniper cover greater than 2 to 10 percent)
Woodland-phase II	Phase II juniper invasion, with shrubs/grasses codominant with juniper (juniper cover greater than 10 to 20 percent)
Woodland-phase III	Phase III juniper invasion—juniper woodland with herbaceous understory and few shrubs (juniper cover greater than 20 percent)

Source: Shrub cover cutoffs are from Karl and Sadowski (2005), and woodland phases are from Miller et al. (2005).

model creators.[2] Models developed by Evers (2010) for the Malheur High Plateau region of southeastern Oregon were our primary source for sagebrush steppe STMs. Lastly, we adapted models from TNC of Nevada (Provencher and Anderson 2011) for salt desert shrub communities and from TNC of Idaho (Landscape Toolbox Project; www.landscapetoolbox.org) for three-tip sagebrush communities.

Arizona and New Mexico Forest and Woodland Models

Modeled Vegetation Types

We included five forested and seven woodland potential vegetation types in AZ/NM (table 2.7). The AZ/NM forest and woodland models were developed to examine ecosystem sustainability (Weisz et al. 2009) and for forest planning.

Model Structure

The AZ/NM forested and woodland STMs were similar in structure to the OR/WA models (fig. 2.1a), but contained fewer, more generalized state classes. Structural stages characterized canopy cover and tree size class, and sometimes included dominance and the number of canopy layers. Canopy cover classes included grass/forb/shrub (0 to 10 percent tree cover), open (10 to 30 percent tree cover), and closed

[2] Swanson, D. unpublished documentation.

Table 2.6—Probabilistic transitions used in Oregon and Washington arid land state-and-transition models

Transition type	Transition description
Natural transitions:	
Alternative succession	Recovery of herbaceous species (from exotics to natives) following rest from grazing
Browse	Browsing of palatable shrubs (e.g., bitterbrush and mountain mahogany)
Drought	A multiyear drought that, when combined with grazing, may result in degradation of rangeland condition
Insects and disease	General transition for insects or disease that can kill shrubs or trees
Insect-cyclical outbreak	Cyclical transition that simulates outbreaks of sagebrush-defoliating insects, occurring at an interval of 20 to 48 years
Natural recovery	Natural reseeding of native species. Species differ depending on the model
Severe drought	Severe drought that can kill sagebrush, occurring only once every 100 to 200 years
Wildfire-mixed-severity	Mosaic fire that results in a heterogeneous burn pattern
Wildfire-nonlethal	Surface fire (only modeled in phase III juniper woodlands with exotic grass)
Wildfire-stand-replacing	Stand-replacing wildfire that leads to early successional (herbaceous) state classes
Livestock grazing transitions:	
Graze-degrade	Grazing-related degradation that is unrelated to disturbance
Postdisturbance graze-degrade	Heavy grazing following major disturbance (within 2 years of fire or drought) that can lead to grazing-related degradation. The transition probability is 10-fold higher than graze-degrade
Maintenance graze	Maintenance grazing that does not affect vegetation composition or structure
Moderate graze	Moderate grazing that decreases herbaceous cover and alters succession but does not cause degradation. This can either accelerate or delay succession, depending on the model
Juniper cutting	Mechanical treatment (i.e., chain saw removal) of juniper
Shrub treatment	Mechanical treatment of depleted sagebrush, leading an open sagebrush stand
Prescribed fire	Prescribed fire treatment
Seed-exotic	Seeding of a degraded site with nonnative grass (i.e., crested wheatgrass)
Seed-native	Seeding of a degraded site with native species
Agriculture	Conversion of native vegetation to agricultural land

Table 2.7—Descriptions of forest and woodland vegetation types modeled in Arizona and New Mexico[a]

Potential vegetation type	Description
Forest models:	
Ponderosa pine forest*	Warm, dry forests with ponderosa pine, border pinyon, juniper species, and evergreen oak species
Ponderosa pine-evergreen oak*	Ponderosa pine, Apache pine, Chihuahuan pine, and evergreen oak forests
Mixed conifer with aspen*	Mixed-conifer forests occurring in small patches at a broad elevation range, with Douglas-fir, Engelmann spruce, white fir, and big tooth maple as the dominant species, and quaking aspen as an important seral component
Mixed conifer dry**	Dry mixed-conifer forest containing Douglas-fir and white fir associations and with Arizona fescue in the understory
Spruce-fir forest*	Engelmann spruce, subalpine fir, and corkbark fir forests, containing quaking aspen as an important seral species and twinflower as an important understory component
Woodland models:	
Pinyon-juniper woodland**	Pinyon-juniper woodlands occurring in either mild or cold climates, with Arizona orange, rubber rabbitbrush, Apache plume, and Toumey oak as the dominant shrub species
Pinyon-juniper sagebrush**	Pinyon-juniper woodlands occurring as mix of trees and shrubs in cold climates, typically above the Mogollon Rim in northern Arizona and New Mexico, with sagebrush or blackbrush in the shrub layer
Pinyon-juniper evergreen shrubland**	Pinyon-juniper woodlands occurring below the Mogollon Rim in southern Arizona and New Mexico with crucifixion thorn, Sonoran scrub oak, pointleaf manzanita, alderleaf mountain mahogany, and gray oak as the dominant evergreen species
Pinyon-juniper grassland**	Pinyon-juniper woodlands occurring in either cold or mild climates, with understory typically dominated by grass species, and less abundant shrubs and trees occurring as individuals or occasionally in small groups
Juniper grassland**	Woodlands comprised of one or several juniper species (e.g., oneseed, alligator, and Pinchot's juniper), with an understory dominated by grass species
Madrean pine-oak woodland*	Woodland bounded by semidesert grasslands at the lowest elevations and montane forests at higher elevations. Emory oak, Arizona white oak, Mexican blue oak, and gray oak are the common oak species, and Douglas-fir, ponderosa pine, and Chihuahuan pine are the common conifer species
Madrean encinal woodland**	Oak woodlands occurring in isolated mountain ranges grading into semidesert grasslands at lower elevations and pine-oak woodlands at higher elevations, with Emory oak, Mexican blue oak, Arizona white oak, and gray oak as the common species

[a] Models described below were adapted and calibrated by the U.S. Department of Agriculture Forest Service Southwest Region. Original model source is indicated by a superscript where: * = The Nature Conservancy, and ** = LANDFIRE.

(>30 percent tree cover). Tree size classes included seedling/sapling (<13 cm diameter at breast height [DBH]), small (13 to 25 cm DBH), medium (25 to 50 cm DBH), large or very large (>50 cm DBH). Where canopy layers were included, the number of canopy layers was either single storied or multistoried. Transitions represented growth and development, natural disturbance, and management transitions (table 2.8). The AZ/NM forest and woodland models did not contain any deterministic transitions; all succession transitions were calibrated using FVS runs based on Forest Inventory and Analysis (FIA) plot data (Weisz et al. 2010) and treated as probabilistic transitions. Wildfire probabilities for some models came from field plot data across the national forests in the region and expert opinion, and for others were derived using the Fire and Fuels Extension (FFE) of FVS (Reinhardt and Crookston 2003). Wildfire transition multipliers describing interannual variation in fire weather were derived from an analysis of the MTBS data (see "Interannual Variation Using Monte Carlo Multipliers").

Model Sources

Individual national forests in AZ/NM developed their own versions of forest and woodland models based largely on LANDFIRE and TNC efforts to describe potential natural vegetation and vegetation dynamics in AZ/NM (table 2.9). The models used for ILAP were adapted from those model variants developed at each national forest in AZ/NM.

Arizona and New Mexico Arid Land Models

Modeled Vegetation Types

The Integrated Landscape Assessment Project compiled and developed models to simulate contemporary vegetation dynamics for all arid land (nonforested) potential vegetation in AZ/NM (table 2.9). The AZ/NM arid lands encompassed a broad range of temperate life zones, from very dry lowland desert scrub to upland chaparral and montane meadow systems. Detailed documentation of AZ/NM arid land models is available on the Western Landscapes Explorer website (www.westernlandscapesexplorer.info).

Model Structure

Model structure varied considerably, depending on model source (table 2.9). In general, cover types indicated the dominant life form(s), such as perennial grass, forb, sagebrush, or juniper. Structural stages defined the cover range in each of the three major vertical structure layers: grass/forb, low to mid shrub, and tall shrub/tree. Cover ranges of each vertical layer were specified as absent (zero percent), sparse (1 to 10 percent), open (>10 to 25 percent), mid (>25 to 60 percent), and

Table 2.8—Probabilistic transition types used in Arizona and New Mexico forest and woodland state-and-transition models

Transition type	Transition description
Natural transitions:	
Growth and succession	Forest succession and growth transition where models are calibrated by the Forest Vegetation Simulator
Nonlethal fire	Wildfire resulting in less than 25 percent top kill
Mixed-severity fire	Wildfire resulting in 25 to 75 percent top kill
Stand-replacing fire	Wildfire resulting in 75 to 100 percent top kill
Wildfire—low conditions	Wildfire under low burning conditions, as modeled by the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS)
Wildfire—moderate conditions	Wildfire under moderate burning conditions, as modeled by the FFE-FVS
Wildfire—high conditions	Wildfire under high burning conditions, as modeled by the FFE-FVS
Insects and disease	Transition caused by forest insect and disease agents
Wind/weather/stress	Transition caused by wind, weather, and stress
Alternative succession	Transition resulting from a lack of disturbance
Elk herbivory	Elk browsing, according to summer range mapping
Natural regeneration	Natural regeneration and recruitment by species
Management transitions:	
All initiate regeneration	All management activities that initiate tree regeneration
All prescribed burning	All management activities related to prescribed burning, typically low severity
All fuel treatments	All fuel treatment management activities
Intermediate thin—low basal area	Precommercial thinning of intermediate intensity to a low basal area that takes place as part of the maintenance of a stand in preparation for a commercial harvest
Intermediate thin—moderate basal area	Precommercial thinning of intermediate intensity to a moderate basal area that takes place as part of the maintenance of a stand in preparation for a commercial harvest
Intermediate thin—41 cm limit	Precommercial thinning of intermediate intensity of trees less than 41 cm (diameter cap) that takes place as part of the maintenance of a stand in preparation for a commercial harvest
Shelterwood	Harvest in which some large trees are retained to provide some shade and other protection to remaining trees. Trees may be removed in several harvests over a 10- to 15-year period to encourage regeneration of medium to low shade-tolerant species
Free thin to target basal area	Free thin of all sizes to a target basal area to reduce risk and allow growth in the residual, by favoring the removal of suppressed, defect, and excess trees beyond the target basal area of each size class
Thin from below to target basal area	Thin from below to a target basal area. Trees of sizes below the target size class are thinned from the stand. Typically results in a state class change to a more open larger size class

Table 2.8—Probabilistic transition types used in Arizona and New Mexico forest and woodland state-and-transition models (continued)

Transition type	Transition description
Thin under 41 cm to target basal area	Thinning trees under 41 cm in diameter to achieve a target basal area. Typically results in a state class change to a more open larger size class, where repeat entries result in a closed, single-storied stand
Group selection/ matrix thin	Group selection with a matrix thin in which groups of trees are removed from an area over a period of several entries and trees in the surrounding matrix are thinned to a target basal area
Shelterwood seed cut to target basal area	Shelterwood harvest to achieve a target basal area in which retained trees also provide seed for regeneration
Clearcut-legacy trees	Clearcut in which some trees are retained (also called clearcut with reserves)
Clearcut-coppice	Clearcut to produce even-aged stand of species that regenerate by sprouting from the roots or stem base (coppice)
Plant seedlings	Replant with seedlings following harvest or disturbance
Prescribed fire	Application of controlled fire
Thin under 23 cm to target basal area	Thinning trees under 23 cm in diameter to achieve a target basal area

closed (>60 percent). Processes modeled in AZ/NM arid land models included a range of natural processes, livestock grazing practices, and management activities (table 2.10).

Model Sources

Southwestern arid land models came from a variety of sources (table 2.9). Eleven new models for the major vegetation types in the Chihuahuan Desert and Shortgrass Prairie modeling zones (fig. 2.4b) were constructed by Natural Heritage New Mexico. Models for many Colorado Plateau, Sonora-Mojave, and interior chaparral types were adapted from The Nature Conservancy in Nevada and Arizona. LANDFIRE reference condition models (www.landfire.gov; Rollins 2009) were the basis for many STMs in the Sonoran desert and other regions. In most of these cases, substantial additions were made to the models to include contemporary state classes and transitions not represented in the reference condition models, such as tree and exotic grass invasion (see documentation for details).

Wildfire is an important natural disturbance in nearly all ILAP models and differs regionally. We developed methods to use wildfire records from the Monitoring Trends in Burn Severity program (MTBS).

Model Parameters

Wildfire Probabilities

The STM framework provided a means to customize transitions to region-specific disturbance probabilities. Wildfire is an important natural disturbance in nearly all ILAP models and differs regionally. We developed methods to use wildfire records

Table 2.9—Descriptions of arid land vegetation types modeled in Arizona and New Mexico

Potential vegetation type	Vegetation subclasses	Description
Intermountain salt scrub*		Warm, dry desert scrub environments dominated by saltbush, greasewood, and other shrub species, often occurring in alkaline or calcareous soils above playas
Colorado Plateau/ Great Basin grassland*	No juniper	Xeric Colorado Plateau grasslands characterized by drought-tolerant bunchgrasses such as blue grama and scattered shrubs
	Juniper potential	Xeric Colorado Plateau grasslands characterized by drought-tolerant bunchgrasses and scattered shrubs, occurring adjacent to juniper woodlands
Sagebrush shrubland*		Dry, open sagebrush shrublands with scattered semiarid grasses such as blue grama and Indian ricegrass, sometimes with rabbitbrush
Sand sheet shrubland**		Sand sheets of the Colorado Plateau characterized by joint fir species at low cover, with sparse grasses
Interior chaparral***		Mid-elevation chaparral with a diverse community of shrubs, including oak, manzanita, ceanothus species, and others
Mountain mahogany mixed shrubland**		Mid-elevation rocky outcrops dominated by curlleaf mountain mahogany, sometimes with sagebrush, oak, manzanita, and ceanothus species
Gambel oak shrubland**		Mid- to upper-elevation shrublands with Gambel oak as the dominant overstory species and serviceberry or sagebrush forming the understory
Montane/subalpine grassland **		Montane and subalpine grasslands characterized by Arizona fescue, mountain muhly, Kentucky bluegrass, and other grasses
Sonora-Mojave creosote-bursage desert scrub*	Sand	Sonoran dunes and sand flats dominated by white bursage, big galleta, and creosote bush
	Valleys	Creosote bush—white bursage desert scrub found in valleys of the Sonoran desert
	Mountains	Creosote bush and white bursage desert scrub found on low-elevation mountain slopes in the Sonoran desert
Sonoran paloverde-mixed cactus desert scrub* **	Mountains	Mountain slopes with paloverde, desert ironwood, saguaro and other cacti
	Bajada/foothills	Alluvial fans and pediments with paloverde, desert ironwood, saguaro and other cacti
Sonoran mid-elevation desert scrub**		Mixed desert scrub consisting of varying assemblages across its range, occurring at elevations between paloverde-mixed cactus and chaparral vegetation types above the Sonoran desert

Table 2.9—Descriptions of arid land vegetation types modeled in Arizona and New Mexico (continued)

Potential vegetation type	Vegetation subclasses	Description
Sonoran mixed salt Desert scrub*		Sonoran desert valleys dominated by saltbush, with sagebrush, creosote bush, or white bursage as codominants
Mojave mid-elevation desert scrub*		Mixed desert scrub dominated by blackbrush but including other codominants, occurring between the creosote-bursage desert scrub and montane woodlands above the Mojave desert
Chihuahuan desert scrub		Chihuahuan desert scrub occupying a variety of land forms, dominated by creosote bush, tarbush, and acacia
Chihuahuan salt desert scrub		Chihuahuan desert scrub found in basin bottoms where salts and other minerals have accumulated in the soil, characterized by saltbush and other species
Semidesert grassland	Piedmont	Semidesert grasslands on coalesced alluvial fan piedmonts, characterized by black grama, bush muhly, and fluffgrass
	Foothill	Semidesert grasslands on colluvial foothill slopes, dominated by sideoats grama, curlyleaf muhly, New Mexico feathergrass, and bullgrass
	Lowland	Semidesert grasslands found in lowland basins and playas, with tobosagrass, burrograss, alkali sacaton, big sacaton, or vine mesquite
	Sandy plains	Semidesert grasslands typical of sand sheets, with black grama, dropseed, and muhly species
Great Plains grassland	Mixed-grass prairie	Southern Great Plains grasslands dominated by warm-season grasses, including sideoats grama, blue grama, switchgrass, and bluestem
Shortgrass prairie	No juniper	Western and southern Great Plains grasslands characterized by blue grama, buffalograss, New Mexico feathergrass, James' galleta, and other grama species
	Juniper potential	Western and southern Great Plains grasslands found on the edges of the prairie adjacent to juniper woodlands
Sandsage		Scrubland vegetation typical of sandy, wind-deposited soils and characterized by sand sagebrush
Shinnery oak		Scrubland vegetation typical of sandy, wind-deposited soils and dunes, with shinnery oak as the dominant shrub

[a] Model source is indicated as a superscript, based on the primary source of the model, including: *The Nature Conservancy (TNC) – Nevada, ** LANDFIRE , and *** TNC – Arizona. Vegetation types with no superscript indicate models that were built specifically for the project.

Table 2.10—Probabilistic transition types used in Arizona and New Mexico arid land state-and-transition models

Transition type	Transition description
Mosaic fire	Mosaic fire that results in a patchy burn pattern or partial mortality
Stand-replacing fire	Wildfire that results in high mortality of shrubs or trees
Surface fire	Wildfire that burns the herbaceous or shrub layer under tall shrubs or trees
Drought	Decrease in precipitation for 1 or more years
Exotic invasion	Invasion by exotic species, including cheatgrass, red brome, buffelgrass, and others
Freeze	Freezing temperatures that kill frost-intolerant species, such as some cacti
Increased winter precipitation	Increased winter precipitation that causes increased shrub growth compared to grasses
Natural recovery	Natural recovery of the herbaceous layer from exotic to native species
Oak expansion	Expansion of shinnery oak into grasslands
Perennial establishment	Invasion by and growth of perennial grass species
Prairie dog establishment	Prairie dog colony establishment
Prairie dog extinction	Prairie dog colony extinction
Recreation—off-highway vehicles (OHV)	Recreation by OHV that results in vegetation and soil disturbance
Shrub encroachment	Invasion by shrubs, particularly mesquite, into grasslands
Tree encroachment	Encroachment by juniper into shrublands or grasslands
Very wet year	Periodic flooding of low-lying basins
Weather and stress	Abiotic stress
General livestock grazing	A general transition for livestock grazing
Excessive grazing	Excessive livestock grazing that can degrade range condition
Managed grazing	Managed livestock grazing that alters succession
Graze-mesquite invasion	Invasion of grasslands or shrublands by mesquite owing to livestock grazing
Native grazing	Grazing by native wildlife
Abandoned agriculture	Abandonment of agricultural planting
Herbicide treatment	Herbicide applied singly or in combination with mowing or seeding
Prescribed fire	Application of controlled fire
Root plowing	Conversion of native species to agriculture
Tree lopping	Chainsaw removal of trees
Tree thinning	Thinning of trees, occurring singly or in combination with herbicide and seeding

from the Monitoring Trends in Burn Severity program (MTBS) (Eidenshink et al. 2007, www.mtbs.gov) as a basis for many wildfire probabilities. We used the MTBS data to calculate wildfire probability in southwestern Oregon, all eastern OR/WA forests, and all OR/WA arid lands. The MTBS data set included burn perimeters and burn severity classes for all fires over 405 ha in the Western United States over a 25-year timespan (1984 to 2008). To obtain wildfire probabilities, MTBS burn perimeter polygons were overlaid in a geographic information system (GIS) with our potential vegetation map. We grouped potential vegetation into groups representing similar fire regimes (e.g., dry forests, moist forests, semidesert shrub steppe, mesic shrub steppe) to increase our wildfire sample size in each category. We then calculated the number of hectares burned each year for each potential vegetation group and calculated annual fire probabilities by dividing the area burned in each potential vegetation group by the area in the group and the number of years in the fire record. These annual values became the wildfire probabilities in our models. For OR/WA arid lands, we included an additional spatial data layer containing exotic annual grass to account for variation in fire return interval from invasion by exotic species. This exotic grass layer was developed from the current vegetation layer (see "Spatial Data") and was categorized into low (0 to 10 percent), moderate (10 to 25 percent), and high (>25 percent) exotic grass cover. We combined the exotic grass data layer with potential vegetation groups and MTBS fire perimeters to obtain fire probabilities for each combination of potential vegetation group and exotic grass level.

The MTBS data set provided a tractable improvement to reliance on expert-opinion derived wildfire transition rates. However, there were limitations to the MTBS data and our derivatives. Fire-severity information was available as part of the MTBS data but was not used for this study owing to inconsistencies with data reporting and image classification. Fire probabilities derived from MTBS data likely underestimated fire activity in an area, as some fires may not have been reported throughout the 25-year record, and no fires under 405 ha were included in the data set. We did not have a sufficient sample size in western OR/WA to conduct similar analyses. However, we did not consider this to be critical, because fire intervals are quite long in these moist forest types. MTBS data were not used to obtain fire probabilities for forests and woodlands in AZ/NM because local analysts were already able to provide inventory plot data, local severity mapping, and FFE-FVS to estimate wildfire effects and probabilities. In addition, the MTBS data set for arid lands of AZ/NM appeared to be incomplete and therefore were not used to derive fire probabilities. Note that the MTBS data produced wildfire probabilities that assumed a continuation of fire suppression at current rates, and thus fire suppression was incorporated into the models inherently through the probabilities rather than explicitly as a separate disturbance or probability multiplier.

Forest Vegetation Simulator Calibration

We used FVS to calibrate forest succession transitions for all forest and woodland STMs in AZ/NM and some forest models in OR/WA. The FVS is an individual tree growth and yield model system that predicts distance-independent tree mortality and tree growth in terms of tree diameter, height, crown ratio, and crown width over time (Dixon 2006, Hoover and Rebain 2011, Moeur and Vandendriesche 2010). The FVS model system uses empirically derived life-history equations to simulate stand dynamics over time and has been used to support management decisionmaking at scales from the local project-level to regional assessments (Crookston and Dixon 2005). Forest Inventory and Analysis (USDA FS 2012) plot data provide long-term data collected from private and public forest land in the United States and served as reference data for input to FVS.

Transition Multipliers

Transition multipliers are values that increase or decrease probability values simultaneously for all transitions of one type. Transition multipliers operated at modeling strata and regional levels to simulate variation owing to vegetation type and land ownership or management. They were used to (1) deactivate a transition completely (multiplier equals zero), (2) decrease a transition rate (multiplier between zero and one), or (3) increase a transition rate (multiplier greater than 1). For the ILAP default FSO scenario, all management transitions were deactivated using a multiplier of zero, but for other scenarios, such as the resilience scenario developed for focus area analyses, multipliers were used to adjust the average probability of a management event, such as a thinning from below, to levels corresponding to management prescriptions in the scenario. Transition multipliers were linked to our modeling strata via the ownership-management layer, so management transitions could be adjusted differently for each ownership-management combination. In addition, transition multipliers could be used to generate trends for selected transitions.

Interannual Variation Using Monte Carlo Multipliers

The modeling framework provided a means to simulate year-to-year variability in STM simulations using Monte Carlo multipliers (MCMs). We incorporated interannual model variation for fire weather, insect outbreaks, and severe drought (in a small number of OR/WA arid land models) to simulate stochastic or cyclic variation in fire weather, insect outbreaks, and other disturbances by creating a stream of randomly generated multiplier sequences. The interannual multipliers were applied to individual model simulations and selected transition types, and augmented the software's built-in variability. The MCM sequences were generated using the MCM builder tool in VDDT (ESSA Technologies Ltd. 2007) for the desired number of model simulations.

Fire weather is a major driver of fire behavior (Agee 1993) and is one of the determinants of total land area burned in any year, as well as fire severity. We assumed fire weather was a random occurrence for this project, and generated an annual sequence of multipliers for each Monte Carlo simulation. Our multipliers were based on the MTBS fire occurrence data, assuming that 80 percent of years were normal fire years, 15 percent of years were high fire years, and 5 percent of years were severe, in terms of area burned.

Insect outbreaks were also modeled using MCMs but were assumed to occur as semirandom occurrences in OR/WA dry forest types and sagebrush arid land models. The onset of an outbreak was determined randomly or within a range of years since the previous disturbance, but once an outbreak occurred, its behavior was controlled by the boundaries established in the MCM multiplier streams. The MCM streams generated for insects were constrained by (1) the probability of a low to normal, high, and severe outbreak year occurring; (2) minimum and maximum lengths of outbreaks; (3) minimum and maximum length of time between outbreak peaks; (4) time since the peak of the previous outbreak; and (5) length of time it takes to develop and then diminish outbreak conditions. In this way, the initiation, length, and severity of an outbreak were randomized but informed by the previous outbreak occurrence. The OR/WA forest models included mountain pine beetle, western spruce budworm, and Douglas-fir tussock moth outbreaks, and multipliers varied among modeling zones. The OR/WA arid lands modeled sagebrush defoliating insect outbreaks (such as Aroga moth) and severe drought using MCMs. Interannual variation was not considered for insect outbreaks in the AZ/NM models, although insect/disease transitions were included in some models.

Spatial Data

The STM modeling framework required several spatial data layers, described below. These spatial layers were used to form modeling strata, the spatial basis of our modeling, and provided a means to quantify abundance and distribution of current vegetation to initialize the STMs. Modeling strata were formed by the overlay of three spatial layers, including potential vegetation, ownership-management, and watershed, and one STM was run for each. State-and-transition models were run for about 30,000 modeling strata across the entire project area. The initial vegetation conditions (vegetation composition and structure at time step zero) assigned to each modeling stratum came from the current vegetation layer attributes (see “Data Processing”).

Modeling Zones

We divided the four-state study area into 18 modeling zones (fig. 2.4), representing manageable spatial units for mapping and modeling. In AZ/NM, our mapping zone boundaries corresponded to the Multi-Resolution Landcover Consortium mapzones (Homer et al. 2004), modified to match watershed boundaries. In OR/WA, our modeling zones corresponded to level III ecoregions (Omernik 1987), with the boundaries modified to follow watershed boundaries (see "Watershed").

Potential Vegetation

Potential vegetation maps identified which STMs applied to each pixel in the modeled area. We used existing datasets where they were available and constructed our own where they were not. Our potential vegetation maps were categorical raster maps, and represented a vegetation classification that corresponded with the STMs. Within OR/WA, these vegetation concepts are called potential vegetation types, which represent environmental zones where vegetation tends to exhibit consistent dynamics through time (e.g., similar growth rates, species composition through succession, disturbance regimes). Within AZ/NM, the vegetation concepts illustrated in the potential vegetation map correspond with potential natural vegetation types refined by historic fire regimes or the equivalent of biophysical settings or ecological systems (Winthers et al. 2005).

In OR/WA, we used existing maps of potential vegetation for some locations, including maps of plant association groups (western OR), and vegetation zones (WA forests). For the parts of OR/WA that lacked potential vegetation data, and for all of AZ/NM, we mapped vegetation plots using a modeling technique called Random Forest Nearest Neighbor (RFNN) (Crookston and Finley 2008). RFNN links mapped pixels to forest inventory plots. It is one type of imputation, which is a general term for the technique of filling in missing values in a dataset with known values in the same dataset (Eskelson et al. 2009). RFNN uses a random forest model that illustrates the relationship between vegetation composition and explanatory environmental variables to match the best plot to each pixel. Explanatory variables fall within three broad categories: soil, climate, and topography. In OR/WA, we used Current Vegetation Survey plots from the USDA FS, LANDFIRE, plots from the USDI BLM, and other local supplemental datasets. In AZ/NM, we used all of the plots that were used for existing vegetation maps, plus supplemental plot data from the US Department of Defense. Each plot was assigned to a potential vegetation type through either a crosswalk or a keying process that assigned potential vegetation to plots based on plant community composition. Potential vegetation maps were drafted multiple times, based on expert review feedback. RFNN model accuracy was assessed through error matrices built comparing cross-validated model predictions with actual potential vegetation values for the plots. Map accuracy was further assessed by expert review. In some areas in AZ/NM, mapped potential vegetation data from national forests was layered on top of our modeled potential vegetation surface, a procedure recommended by our expert reviewers to improve local credibility and utility to forest managers on national forests.

Current Vegetation

Current vegetation maps provided information on state classes within each potential vegetation type. As with the potential vegetation maps, we used existing maps where available, otherwise we developed new maps. Current vegetation maps were raster layers, where each pixel value corresponded with a single vegetation survey plot identifier. Summarized variables from those plots were attached to the grid attribute table, yielding a multivariate map. These variables described vegetation composition and structure and included four variables for forests and 22 for arid lands.

For the forests of OR/WA, maps of current vegetation (map date 2006) were available through the Landscape Ecology Modeling Mapping and Analysis (LEMMA) team within the USDA FS (http://lemma.forestry.oregonstate.edu/). These maps were created using the gradient nearest neighbor imputation mapping technique (GNN) (Ohmann and Gregory 2002). GNN differs from RFNN only in the statistical method it uses to link plots to pixels, relying on an ordination model describing vegetation-environment relationships (canonical correspondence analysis). These maps were built from the same explanatory variables used for potential vegetation, with the addition of LANDSAT spectral reflectance. All maps from the LEMMA team are extensively assessed for accuracy. Within AZ/NM, we created maps of current forest vegetation RFNN. These maps were functionally identical to the GNN maps from R6 for the purpose of initializing STMs. The environmental explanatory variables used for our new maps were similar to those used by the LEMMA team, but our forest inventory plot data set was smaller and included only FIA annual plots, following procedures developed through the Nationwide Forest Imputation Study (Grossmann et al. 2009).

We also built current vegetation maps for the arid lands of AZ/NM and eastern OR/WA using the RFNN technique. The environmental explanatory data used to inform these models was the same as for forests, but the plot datasets differed. Within OR/WA, we obtained plot data primarily from the public LANDFIRE plot reference database, and the USDI BLM, with a few other minor sources. Within AZ/NM, we relied on LANDFIRE as well, supplemented by data from the USDI BLM and New Mexico Natural Heritage program. All new current vegetation maps were evaluated for statistical accuracy using cross-validated predictions for the plots and expert review. In AZ/NM, woodlands were mapped with arid lands instead of forests.

Ownership-Management

The ownership-management spatial layer differentiated landowners and management goals, allowing different treatment levels to be applied to different management areas within a single ownership. To derive the ownership-management allocation layer for OR/WA, we collected available management plans and layers from federal and state land management agencies. We used six ownership/stewardship categories: USDI BLM, USDA FS, other federal lands (e.g., National Park Service, Department of Defense, U.S. Fish and Wildlife Service), state, private, and tribal. Within each ownership category, management plans were matched to mapped management data. The management data were classified into visual resource classes that capture the visual management objectives for a particular portion of land. We defined our visual resource objective based on categories and definitions created by the USDI BLM, and added one category that reflected an additional management class (table 2.11). We intersected the geographic boundaries of the land ownership types with the boundaries of management categories to construct the comprehensive set of ownership and management intensity classes represented in the ownership-management layer. This process generated 30 combinations of ownership-management in OR/WA. The ownership-management layer for AZ/NM was compiled using the protected area database for the United States (www.protectedlands.net/padus/preview.php) stewardship codes combined into the same categories used in OR/WA.

Watershed

Watersheds divide the landscape into commonly used units for reporting model results. Watersheds were defined as 5th-field or 10-digit hydrologic unit codes (HUCs), and were acquired from the standardized watershed boundary data set (WBD) (USGS and USDA NRCS 2011). The WBD uses the federal standards for delineation of hydrologic unit boundaries for delineating watershed boundaries. Watersheds generally represent drainage areas between 20 000 and 100 000 ha. In OR/WA, there are about 950 watersheds with an average size of 45 023 ha. In AZ/NM, there are about 1,020 watersheds with an average size of 60 560 ha.

Mask

A mask layer was applied to exclude lands not modeled, including riparian, barren, water, urban, and developed agricultural areas. The 2008 Pacific Northwest Gap Analysis Project (GAP) (available at www.oregon.gov/DAS/EISPD/GEO/sdlibrary.shtml) land cover map was used to create the mask as it was available across all four states, had been recently updated, and used a consistent classification system.

Table 2.11—Management categories used to define management objectives for the ownership-management spatial data layer[a]

Management category	Objectives	Description
Category 1	Protection/ preservation	VRC 1 protected lands (primarily national forests)—the objective was to preserve the existing character of the landscape with no management or very limited management activity. Examples include wilderness areas and congressional reserves.
Category 3	Retention	VRC 2 lands—the management objective was to retain the existing character of the landscape. The level of change to the landscape was low and management activities were minimal. Any changes repeated the basic elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape. Examples include late-successional reserves and state natural areas.
Category 4	Partial retention	VRC 3 lands—the objective was to partially retain the existing character of the landscape. The level of change to the characteristic landscape was moderate, and changes repeated the basic elements found in the predominant natural features of the landscape. Examples include state wildlife management areas and federal adaptive management areas.
Category 5	Modification	VRC 4 lands—allows management activities that cause major modifications of the existing character of the landscape. The level of change to the characteristic landscape can be high. Examples include federal matrix lands, and general ecological management on state lands.
Category 6	Modification private	This category was outside of the scope of the USDI BLM definitions and was used to define management on private industrial lands. These lands typically are heavily managed with high volumes of timber harvest and other commercial activities.

[a] Visual Resource Class (VRC) definitions developed by the U.S. Department of the Interior, Bureau of Land Management (USDI BLM) are largely used as a basis to create the categories. USDI BLM categories 1 and 2 were combined to simplify the classification system.

After extracting vegetation categories that were not modeled, the grid was resampled from a 30- to a 300-m cell size to remove the excessive fragmentation caused by linear features, such as riparian areas and highways. Small polygons <405 ha were removed, then resampled back to 30 m.

Several steps were performed to integrate spatial layers, calculate initial vegetation conditions, and set up STM model runs in Path, a process we refer to as the “data rollup.”

Data Processing

To run the STMs developed for the project area, we developed a process to handle large data sets and run many STMs simultaneously. The process was specifically designed to allow flexibility in updating any of the data layers that form the foundation of the modeling effort, as updated vegetation maps or new data become available.

Several steps were performed to integrate spatial layers, calculate initial vegetation conditions, and set up STM model runs in Path, a process we refer to as the “data rollup.” We developed several software tools to automate the data rollup process (available online at www.westernlandscapesexplorer.info). The first step employed a series of clipping, data format conversion (where needed), and combining operations customized in the GIS data rollup tool. This step assigned a modeling stratum, current vegetation cover, and current vegetation structure class to each raster cell. The second step used the Data Rollup Query Tool to transform the modeling strata and associated current vegetation conditions from separate spatial data sets into the tabular summary required by the modeling software. The tool used a rule set of if/else statements to assign all modeled pixels in the landscape to a model state class in the applicable STM based on vegetation cover, dominant species, and other criteria. The result was a current vegetation map classified into model state classes.

In OR/WA forest models, the process of assigning mapped pixels to model state classes involved an additional step not required for OR/WA arid land models or AZ/NM models. First, each pixel was assigned a cover type based on the importance value of the dominant tree species, then assigned a structural stage based on tree density. In many cases, not all the resulting cover and structure combinations occurred in the STMs. These pixels were subjected to a reclassification scheme until all pixels were assigned to existing STM state classes.

The intersection of watershed, ownership-management, and potential vegetation often yielded modeling strata with very little area. Because STMs do not yield reliable results when applied at very small spatial scales, some additional processing was needed to handle the smallest modeling strata. We set our minimum modeling stratum size to 405 ha and developed a two-tiered strategy to cope with small modeling strata. Wherever possible, we reassigned pixels from small modeling strata to larger, similar modeling strata within the same watershed. To reassign pixels to other modeling strata, we made decisions using two relative similarity indices, one for potential vegetation and another for ownership-management categories. The two indices ranked all pair-wise combinations of each category with respect to their relative similarity in multiple dimensions. The potential vegetation similarity index reflected overlap in elevation of the potential vegetation, species compositional similarity from the current vegetation map, and similarity in moisture regime (e.g., dry vs. mesic). The ownership-management similarity index was constricted in a similar fashion, scoring pair-wise similarity from information on management activities that may or may not occur within each ownership-management category. When there was no reasonable reassignment, we removed the small modeling strata from our analysis. This size constraint process is optional, and minimum size can be altered. All functionality necessary to create and use a similarity index for lumping modeling strata was contained within the LumpStrata script programmed using R statistical software (R Development Core Team 2008).

Once current vegetation pixels were properly assigned to state classes, there were logistical issues of moving initial conditions for hundreds or thousands of modeling strata into the Path software. To facilitate this process, we developed the Get into Path (GIP) tool to automatically upload the STMs, initial conditions, and transition multipliers for each modeling unit into the Path software. The result was a set of organized parameter scenarios customized for ILAP modeling that were ready for simulation (all of the tools described in this section are available at www.westernlandscapesexplorer.info).

Model Execution

All models were run using the baseline FSO scenario that represented vegetation dynamics under no management activities except continued fire suppression. In this scenario, all management transitions were deactivated. Grazing transitions were included in arid land and dry forest models, where applicable. In addition, some areas were analyzed with multiple scenarios, which included management actions such as timber harvesting, prescribed fire, seeding, and other treatments (see "Example Outputs"). Thirty Monte Carlo simulations were run for each modeling stratum, using a model resolution of 4 ha.

All models were run using the baseline FSO scenario that represented vegetation dynamics under no management activities except continued fire suppression. In addition, some areas were analyzed with multiple scenarios, which included management actions such as timber harvesting, prescribed fire, seeding, and other treatments.

Model Output

Output Summarization

Output from the Path model runs was exported outside of the Path interface as comma separated variable (csv) text files. Each of these files was quite large, sometimes having one or more rows for each combination of state class/transition, time step (150 or 300 years for arid lands and forests, respectively), and Monte Carlo simulation (30). We developed the SumPath summarization package programmed in the R statistical software package (R Development Core Team 2008) to calculate summary statistics (mean, median, minimum, and maximum area) for each state class and transition at each time step, summarized over the Monte Carlo runs. Summaries for each modeling stratum were unified in a single state class file and single transition file for each modeling zone.

Output Visualization

Model output can take the form of graphs, tables, and maps. For any output format, data can be summarized across the entire area of interest, by potential vegetation, or by ownership. We used several basic visualization tools to summarize output for all modeling strata.

Pivot charts—

If the data set is small enough, output from the model runs can be assessed using a Microsoft® Office Excel-based graphing tool developed for the project (available at www.westernlandscapesexplorer.info). The graphing tool allows an average Excel user to graph the results of the summarized text files in Excel based on modeling zone, potential vegetation, ownership-management, and watershed. It also allows the user to group state classes into fewer categories with meaningful interpretations, such as broad forest structural groups or levels of exotic grass invasion. The tool builds a pivot table in Excel, and a graph is automatically generated based on this table. This prebuilt graph can be changed to suit the user's needs based on any of the information available in the pivot table. The Excel tool currently graphs changes in state classes but not changes in transitions over time.

Maps—

Spatial display of model output can occur at a variety of scales, including the scales of modeling strata and whole watersheds (fig. 2.5). However, our process generated STM results that were spatially aggregated into modeling strata at a minimum; our maps were not meant to be used on a pixel-by-pixel basis (see "Limitations"). One method of displaying output spatially was in the form of risk maps, depicting conversion of areas to undesirable state classes such as dense, dry forest types or exotic-dominated grasslands. Risk maps were constructed to show the accumulation of cover or structural type(s) of interest through time. Maps also displayed temporal information in different ways, either depicting model results for a single year or indicating the magnitude and direction of change from the beginning to the end of the simulation.

Example Results

Although STM results are available across the four-state study area, the following examples illustrate STM projections and interpretations from a subset of the forest and arid land output in OR/WA. The forest example is taken from the Washington East Cascades (WEC) modeling zone, an area of approximately 2 million ha. The arid land example is from the southeastern Oregon modeling zone and spans about 5.3 million ha.

Washington Dry Forest Example

In this example (fig. 2.4), we ran two scenarios with 30 simulations each: (1) an FSO scenario where all types of management other than fire suppression did not occur, and (2) a resilience scenario where the intent was to actively manage drier forest types assuming fire suppression continued into the future. We were unable to obtain data on resilience-promoting activities in the area and therefore used our

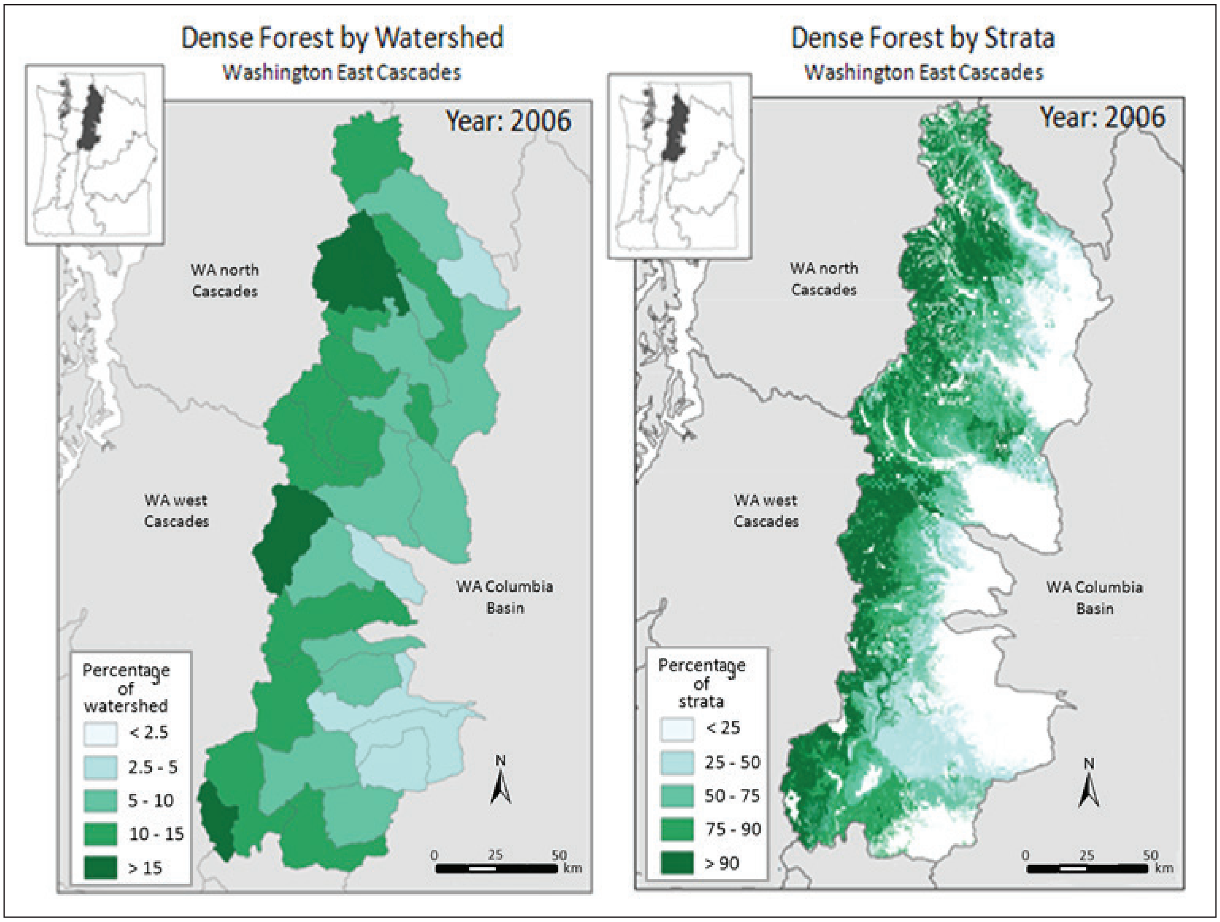

Figure 2.5—Example output (dense forest in eastern Washington [WA]), showing two spatial resolutions of output: the watershed level (left) and the modeling stratum level (right).

knowledge of the environment to generate example treatment rates. The resilience scenario largely utilized prescribed fire and thinning from below to try to create more resilient and open dry forests, although other treatments were also included. This scenario should not be viewed as an example of what land managers in the area might actually do in the area; rather, it demonstrates a small set of the kinds of analyses that can be done with our process.

Current forest conditions—

Model initial conditions, derived from a classification of the current vegetation map (see "Data Processing"), provided a means to understand current conditions across the landscape. Grouping the STMs and displaying the current vegetation data by ownership provided a unique perspective on the landscape. More than half of the landscape was in drier forest types like oak, ponderosa pine, or dry mixed conifer, and federal lands had the greatest proportion and area of these dry forest types (fig. 2.6).

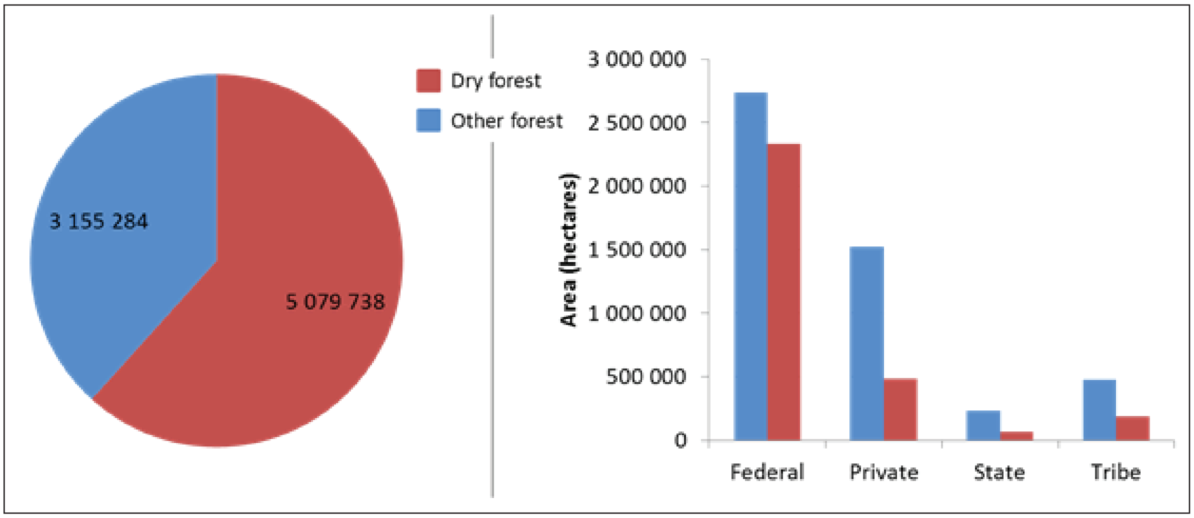

Figure 2.6—Hectares of dry forest across the landscape (left) and by ownership (right). Dry forests were composed of vegetation types such as oak, ponderosa pine, and dry mixed conifer. More mesic forests were assigned to the "other forest" category.

Trends in dense forests through time—

Because federal lands comprised such a large proportion of the landscape, we focused on these lands for the remainder of the forest example. In comparing the distribution of forest structures (i.e., tree diameter size classes and percentage canopy cover) across all federal lands, we found an increase in the average amount of open forest under the resilience scenario (fig. 2.7) relative to the FSO scenario. In contrast, forests became denser under the FSO scenario owing mostly to fire suppression effects. As we ran 30 simulations per scenario, we were also able to illustrate trends based on a range of potential future conditions and variation around those trends. Model results across all 30 model simulations suggested an increase in the amount of open forest with resilience activities, although the rate of increase varied among the simulations (fig. 2.8).

In this example, the FSO scenario generated declining amounts of dense forest in areas that are currently dense and prone to wildfire and insect outbreaks (fig. 2.9a). However, closed forests increased through time (green colors) in areas that were initially open, owing to recent active management, and where halting forest management resulted in the forests becoming more dense. In contrast, little of the landscape increased in density through time under the resilience scenario, owing to a high rate of active management across forested lands outside reserves and wilderness (fig. 2.9b).

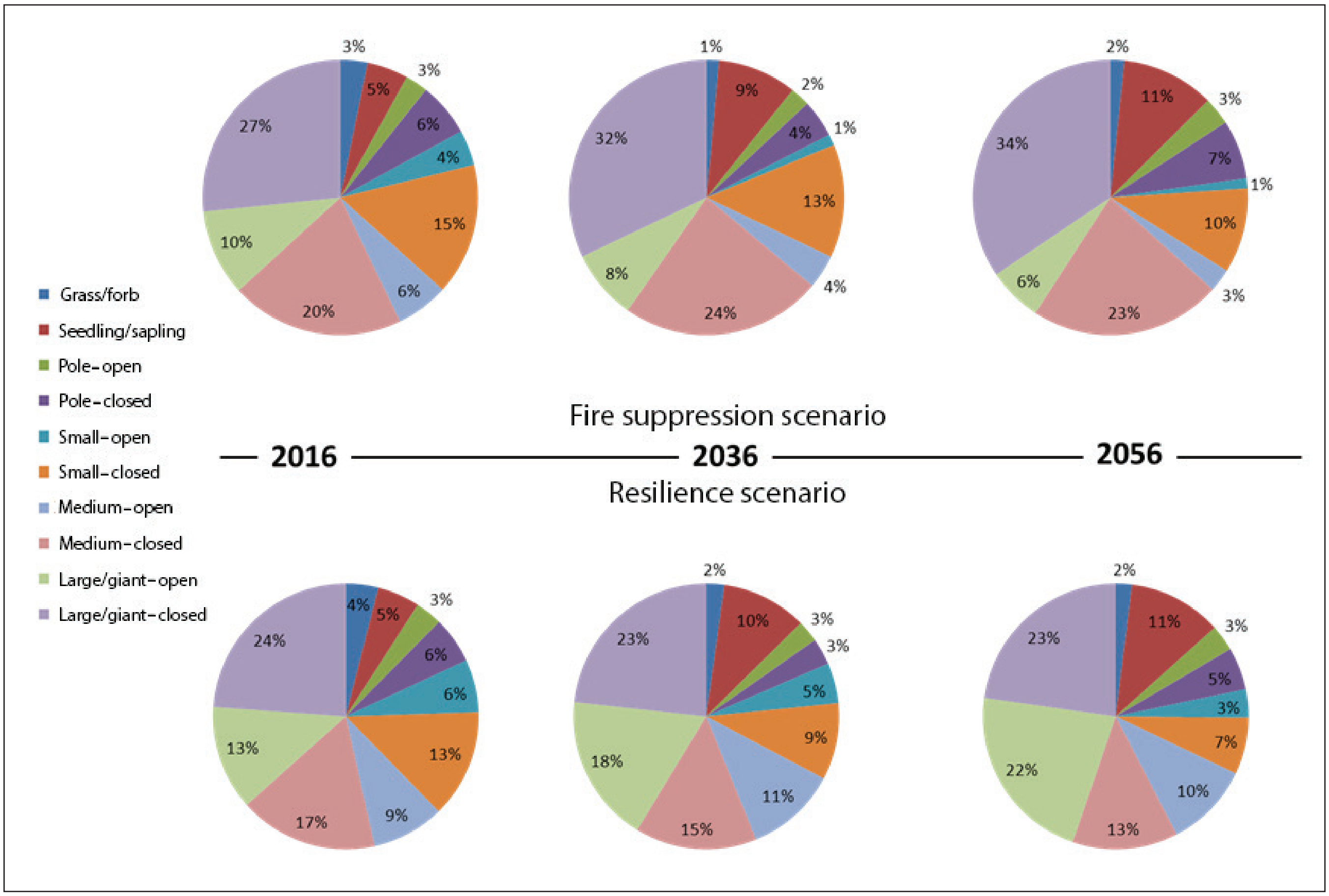

Figure 2.7—Projected trends in forest structure through time on federal lands under two different management scenarios. Structural stages represent the following tree diameter ranges in centimeters: sapling/shrub >0 to 13; pole >13 to 25; small >25 to 38; medium >38 to 51; and large/giant >51. Open and closed refer to canopy cover, where open structures have 10 to 40 percent canopy cover and closed structures have more than 40 percent canopy cover.

Although graphs can highlight overall trends, displaying output spatially provides the geographic context helpful in identifying areas likely to increase or decrease in open and dense forest through time (fig. 2.9). The use of potential vegetation, watershed, and ownership-management spatial layers allowed the creation of maps at the modeling stratum scale. Such maps should be used with some caution, however, as the information they depict may appear to have been generated by spatial rather than nonspatial modeling processes. Our nonspatial STM framework assumed that dynamics occur anywhere within the modeling strata, and the spatial maps illustrate results summarized to the scale of the modeling strata. Therefore, mapped results should be interpreted at the modeling strata scale, not at an individual pixel scale.

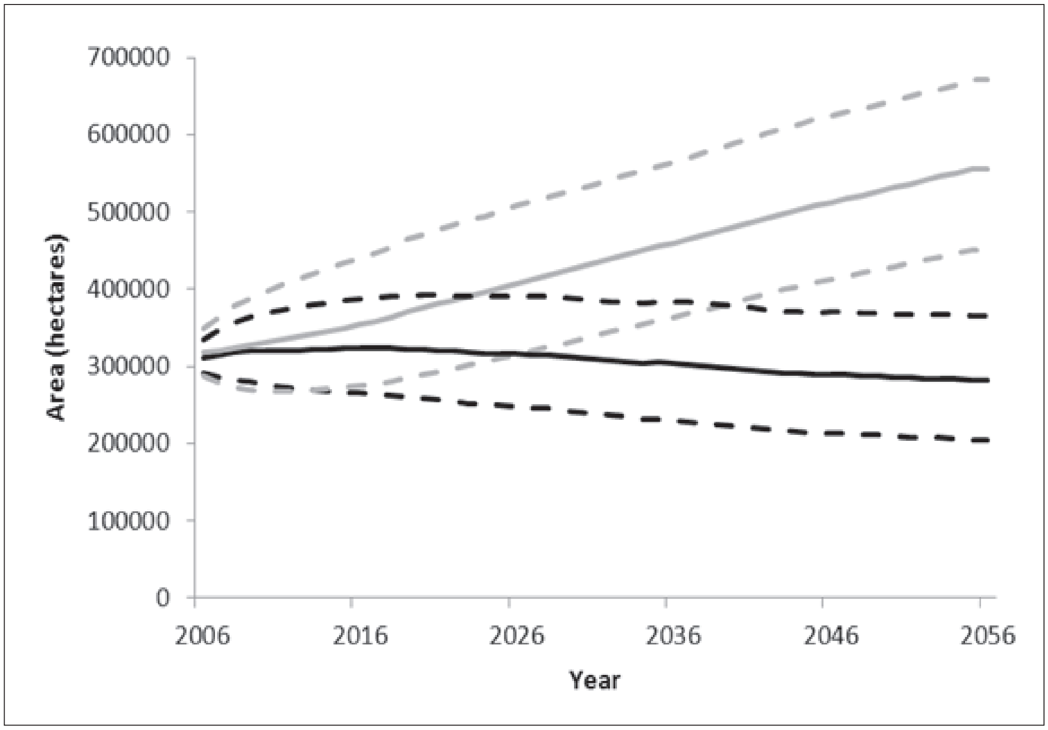

Figure 2.8—Projected trends in open (10 to 40 percent canopy cover) and closed (>40 percent canopy cover) forest under the resilience scenario on federal lands. Solid lines represent average trends; dashed lines indicate variation around the average. Lower dashed lines within a shade represent the minimum hectares for a given time step and simulation run. Upper dashed lines within a shade represent maximum hectares for a given time step and simulation run.

Arid Lands Example

We ran three scenarios to illustrate analysis using ILAP data in arid lands in southeastern Oregon: (1) a scenario with no grazing or active management (ungrazed/unmanaged), (2) a scenario where heavy livestock grazing occurred but no active management was implemented (grazed/unmanaged), and (3) a scenario with heavy livestock grazing and active restoration management that included postfire seeding of native grasses and juniper removal treatments (grazed/managed). These scenarios were intended to inform management by providing starting points for more refined scenarios with varying treatment levels and grazing intensities. Each scenario was run for 30 Monte Carlo simulations to project vegetation 50 years into the future (year 2050).

Comparison of management scenarios—

Under the unmanaged/grazed scenario, the warm, dry Wyoming big sagebrush types became dominated by exotic grasses (fig. 2.10). This resulted from our assumption that grazing (particularly in combination with fire and drought disturbances) reduced the presence of native grasses and provided a competitive

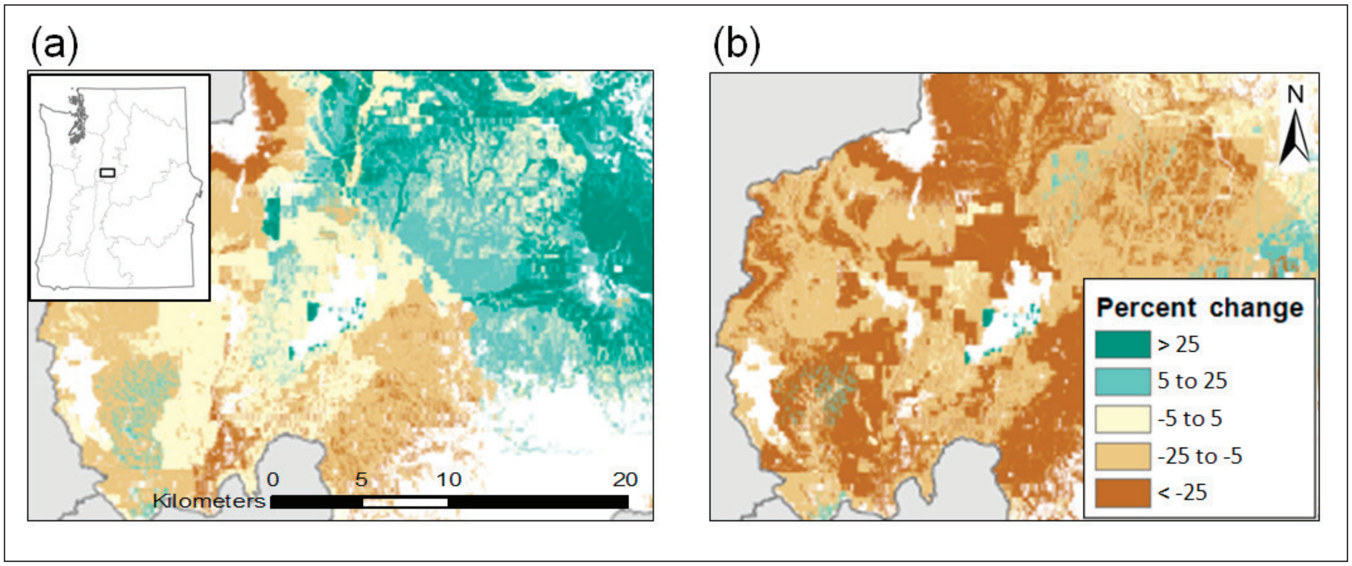

Figure 2.9—Trends in closed forest through time (after 50 years) in a portion of the Washington East Cascades modeling zone under the (a) fire suppression only scenario, and (b) resilience scenario. Colors represent those areas that either cumulatively increased or decreased in the amount of closed forest relative to current (2006) conditions.

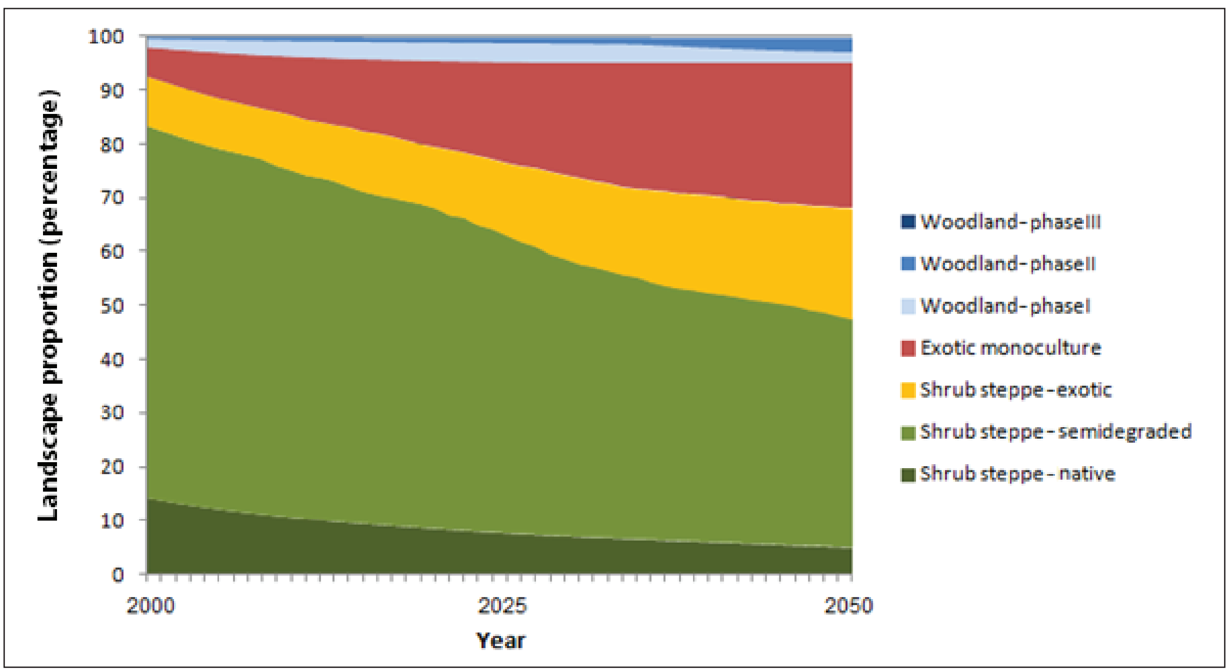

Figure 2.10—Trends in native and exotic vegetation in Wyoming big sagebrush under the grazed/unmanaged scenario in the Oregon southeast modeling zone.

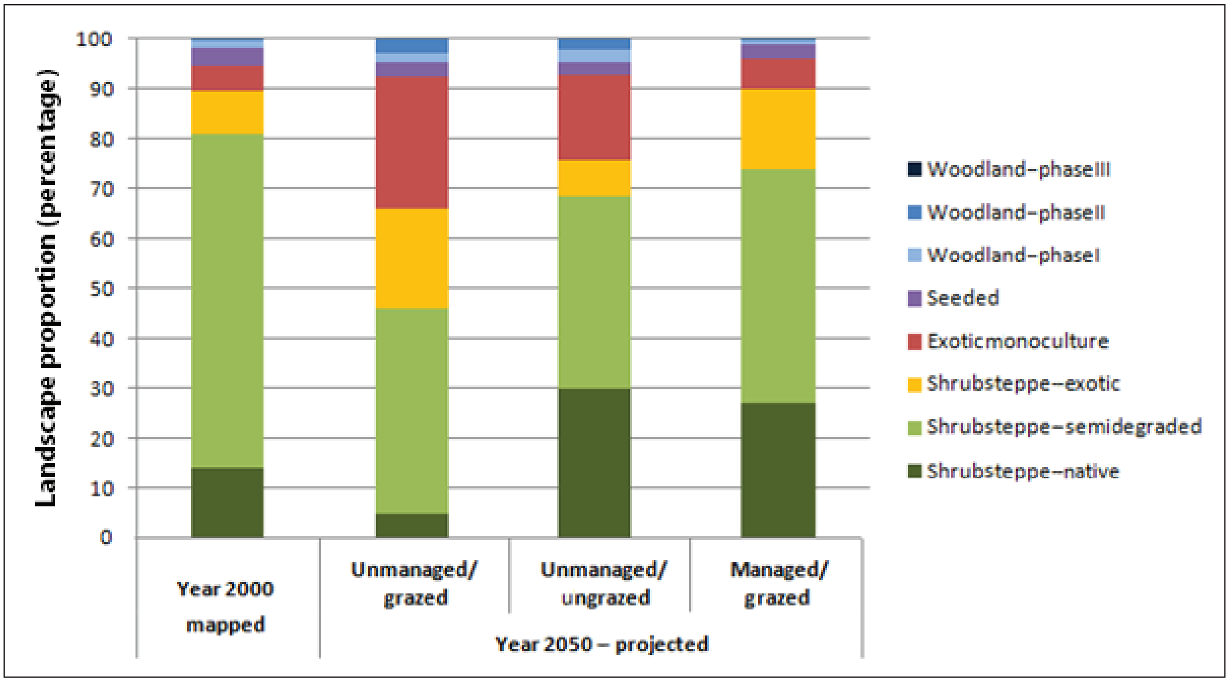

Figure 2.11—Generalized state class composition in Wyoming big sagebrush across three management scenarios in the Oregon southeast modeling zone. Columns show mapped landscape proportion in 2000 (left) and projected landscape proportion in year 2050 under three management scenarios (middle and right).

advantage for exotic grasses. A comparison of initial to future conditions across all scenarios suggested invasion by exotic grasses is likely to continue across all three management options, but the rate of invasion might vary depending on the amount of active management and grazing (fig. 2.11). By time step 50, about half of the landscape was projected to be dominated by exotic grasses (shrub steppe-exotic and exotic grass monocultures) under the unmanaged/grazed scenario. With the removal of grazing (unmanaged/ungrazed), vegetation condition still declined over time owing to conversion of already semidegraded shrub steppe to exotic grass state classes. Through active seeding of exotic grass encroached state classes, the managed/grazed scenario resulted in relatively constant levels of exotic grass monocultures over time, with slightly more area in exotic shrub steppe and native state classes, but less area in semidegraded shrub steppe by 2050. The model outcomes suggested that removal of grazing alone will not likely improve range condition in these warm, dry sagebrush systems, and that active management is required to restore already degraded systems.

Maps of model results by modeling stratum show the variability in invasion risk across the landscape (fig. 2.12) and may help managers identify locations likely to have high levels of invasion by exotic grasses and other conservation targets. Projected exotic grass invasion levels at year 2050 were highly heterogeneous across the warm, dry Wyoming sagebrush of southeastern Oregon. These maps can be useful to prioritize areas for treatment across large landscapes when budgetary constraints limit the ability to implement restoration treatments widely.

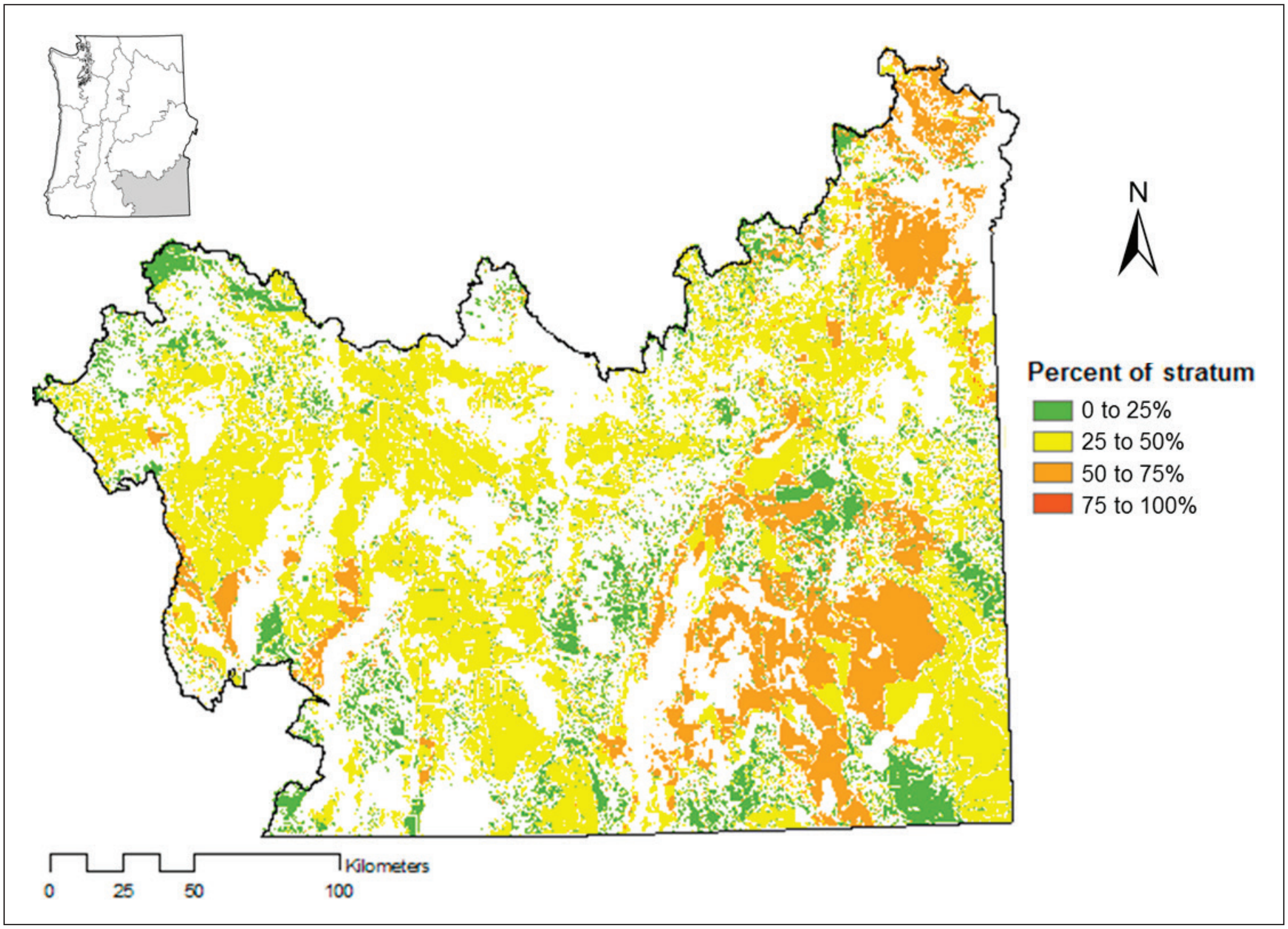

Figure 2.12—Exotic grass invasion risk map under the grazed/unmanaged scenario for Wyoming big sagebrush. The map identifies the percentage of each modeling stratum comprised of exotic grass at year 2050 in the Oregon southeast modeling zone.

Limitations

Although our STMs, model projections, and other products are useful tools for answering a variety of land management questions, they have several limitations. We identified three major types of constraints and limitations to our approach: spatial, logistical, and thematic.

Spatial Representation Constraints

The spatial resolution of our modeling outputs was limited by several interacting factors. First, our approach did not model interpixel or among-stand processes. Instead, our framework applied STM results to mapped modeling strata (intersection of potential vegetation, ownership-management, and watershed) to yield mapped stratum-scale output. Although maps of model projections appear to have a value for every modeled pixel on the landscape, our results are only applicable at the modeling stratum scale and larger aggregations. Thus, the spatial resolution of our modeling strata was constrained to a minimum modeling stratum size of 405 ha. In addition, constraints on modeling unit size reflected limitations in the spatial accuracy of the base data sets (especially potential and current vegetation, and their input data sets) that were available, but were not inherent limitations on our approach and process. Fine-scale analyses could be performed by substituting data with higher spatial resolution and accuracy.

In contrast to the size of our modeling strata, our input data were generally raster data with a 30-m pixel resolution. This difference in scale between inputs and outputs was a consequence of base data accuracy, our selection of modeling zone size, and logistical considerations. In general, our potential and current vegetation maps were reasonably robust at intermediate to broad scales, but limited in accuracy when examined on a pixel-by-pixel basis. Because of these spatial uncertainties at fine scales, our modeling framework is best adapted to addressing management-related questions at mid to broad scales (e.g., across multiple watersheds).

In addition, our projections incorporated error from each spatial layer used to define our modeling strata and initialize our models, in addition to error inherent in the STMs themselves. Although all of these maps were distributed as rasters with 30-m ground pixel resolution, they are all best used at broader scales. A more formal analysis on the relationship between summary scale and potential and current vegetation map accuracy performed by the LEMMA team showed that GNN maps of an old-growth structure index are quite robust when summarized over 8660-ha hexagons, and that accuracy increases with larger summary units (Gregory et al. 2011). Similarly, the ILAP variables are also likely to improve with coarser scales of summary. Map error was particularly prevalent at the forest/arid land margin, where low tree cover values were particularly challenging to map. Note that these errors were carried through the modeling process and contribute to modeling uncertainty, particularly at the boundaries between features within the spatial layers. For broad-scale analyses, the ramifications of boundary errors were likely minimal, but for analyses at intermediate and fine scales, additional assessments to quantify the error would be useful, and data developed for finer scale use should be substituted.

Logistical Constraints

Our approach had some practical limitations inherent to working with large data sets. To create, analyze, and display data from our models, users need a fairly high level of technical proficiency with databases and GIS software. The capacity to use and modify scripted procedures is also helpful if users plan to build new analyses to compare management options. We have packaged and documented our procedures to make them as user-friendly as possible, but there would still be a significant learning curve for anyone wishing to run the models and conduct further analyses. Improvements to the Path software are likely, and we hope that workflow and data management procedures will continue to improve.

An additional challenge stems from our models not being optimization models. Our process facilitated a gaming approach rather than producing "best" or "optimal" answers. The ILAP decision support tools currently being developed will help to fill some of this need.

Thematic Constraints

The simple structure of STMs is a strength of the modeling approach. The models are well-suited for both communication of results to nontechnical audiences, and for honing or building new models in collaboration with land managers, who may have deep ecological understanding but limited technical skills. However, this simplicity comes with some inherent limitations. These limitations are primarily thematic and relate to the definitions of the state classes and the transitions that are incorporated in each model. Definitions for state classes and transitions for vegetation were not standardized across STMs (Stringham et al. 2003), and the models adapted and developed for our project have important differences among the major vegetation types within the project and as compared to other projects.

The STMs do not explicitly model ecosystem processes, such as nutrient cycling, net primary productivity (NPP), seed dispersal, and interspecific competition. Vegetation dynamics may affect numerous ecosystem processes, and vice versa (Chapin et al. 1997). Although vegetation-ecosystem process interactions were not explicitly defined within ILAP STMs, they were implicit within the potential vegetation definitions, and the associated STM structures. For example, in the alpine STM, succession and growth-related transition rates were slow, reflecting low NPP common at high elevations where cold weather constrains nutrient cycling and the growing season. Because ecosystem processes were implicit within our models and not explicitly defined, they cannot be explored in and of themselves within the basic ILAP framework without additional efforts to link model state classes, transitions, and outputs to ecological processes. The data and information available to inform transition pathways and transition rates varies widely among STMs. Some transitions are based largely on empirical data (e.g., MTBS fire frequencies), some on models (e.g., FVS succession rates), and others almost entirely on expert judgment. Most STMs use a variety of information sources to parameterize transitions and use expert judgment to fill in the knowledge gaps. The STMs compiled and developed for ILAP can be easily updated and changed as new data and information become available.

The types of questions that can be addressed by our STMs were constrained to those that relate directly to the state classes and transitions contained within each model.

The types of questions that can be addressed by our STMs were constrained to those that relate directly to the state classes and transitions contained within each model. For example, the vegetation units within the forested potential vegetation state classes for OR/WA represented classified vegetation types that were labeled only with a dominant tree species. Subdominants were not explicitly labeled, although they were implicitly associated with each cover type, and understory species were not considered. Because of this setup, the behavior of individual species through time could only be extracted from a limited set of our ILAP potential vegetation types. However, arid land vegetation cover types usually contained more compositional detail than the forest cover types, including functional groups (perennial grass, annual grass) or individual species (e.g., Wyoming big sagebrush, western juniper). Still, the thematic resolution of the models was generally constrained to vegetation communities or groups of species, rather than individual species.

An additional constraint inherent to the basic ILAP framework is the implicit assumption that vegetation potential does not shift over time. Each modeling stratum was linked to a single potential vegetation type, which was linked to a single STM. This assumption may be robust enough on a short timeframe but becomes problematic in the context of climate change, which will likely shift site potential, and reorganize species assemblages. On the other hand, given the uncertainties embedded in current climate modeling, information on the historical range of variability (HRV) may be our most certain available guide as to how ecosystems will behave in the future (Keane et al. 2009) and what management actions may prevent irreversible, deleterious changes. Our potential vegetation types were based on

HRV, and our STMs were parameterized from HRV wherever data were available. This does not imply that modeling approaches that do incorporate climate change are not worth exploring, just that they do not yet necessarily yield a more reliable projection than HRV-based models. Other work as a part of ILAP explored how to extend the ILAP models to encompass shifts in site potential, linking multiple models to allow for transitions among vegetation types (chapter 7).

Another important driver of vegetation change through time is the legacy of past climate, disturbance, and land use (Chase 2003, Rhemtulla and Mladenoff 2007). Historical influences on vegetation composition operate at a variety of spatio-temporal scales. On a millennial timeframe, vegetation shifts related to historical climate change have been documented (Hotchkiss et al. 2007) and vegetation species composition and abundance is affected by past climate. On a decadal timeframe, or even over centuries, vegetation patterns can also reflect the legacy of human land use (Dupouey et al. 2002, Foster et al. 1998). Because the legacy of past climate, disturbance regime, and land use is reflected within our initial conditions (via our current vegetation layer), and also in our transition rates (via the fire regime), many important dimensions of legacy effects are accounted for implicitly within the ILAP framework. Because of this construction limitation, as with ecosystem processes, questions relating directly to legacy effects cannot be explicitly addressed with the data we have developed for our particular application.

Scenario Analysis

The baseline ILAP scenario with no management activities except for fire suppression only (FSO) is available across all lands. Within the focus areas, additional scenarios were also run to reflect timber harvesting, restoration activities, and other management. However, the range of management options is limited, and more work is needed to develop realistic management transition rates across ecological and administrative boundaries. The interpretation of model results would be greatly improved by a larger number of management scenarios, and development of alternative management scenarios will greatly improve the utility of ILAP models.

Data Products and Tools

Most of the data, models, and tools produced for ILAP are publically available on the Western Landscapes Explorer website, maintained by the Institute for Natural Resources (www.westernlandscapesexplorer.info). The STMs were run for all lands in AZ/NM and OR/WA, and input data, models, and summarized output for the default FSO scenario are available in files called rollout packages. Rollout packages each contain the Vegetation Dynamics Development Tool (VDDT) and Path modeling databases, model documentation, initial GIS data needed for the rollup process, post-rollup modeling strata and state class spatial data, and STM outputs (i.e., projected future landscape conditions). Rollout packages are separated by modeling zone, and separated between forests and arid lands in OR/WA, and forests, woodlands, and arid lands in AZ/NM.

In addition to the FSO scenario results for all lands, additional summarized results are available for focus areas to characterize alternative management actions and summarize across variables of interest (see "Example Results"). An alternative resilience scenario was run for the forested environments of eastern Washington and Oregon (called east-side forests), and two additional scenarios were run for arid lands of southeastern Oregon. In AZ/NM, results for various management scenarios are available for the Sky Islands focus area.

Conclusions

The methods, models, and data presented here provide a means to perform integrated landscape assessments in support of mid- to broad-scale planning efforts that span multiple watersheds and affect vegetation, habitat, economics, and other processes. Similar models have been employed over smaller spatial extents to address shortcomings related to integrated metrics at the landscape scale, future conditions, alternative strategies, and cost-benefit analyses in commonly used approaches to conservation planning (Low et al. 2010). The original thrust of the project was to generate information for land management planning that could be used to support prioritization of management activities at mid to broad scales, and to advance efforts to integrate daunting issues such as including climate change in the planning process in a tractable manner. It has become exceptionally clear over the course of this project that when modeling at multistate scales, a wide range of complex questions can be studied using ILAP data and models. Examples in this chapter represent a small glimpse of the potential for graphs, maps, and other reporting that can be built from the VDDT/Path output. Linking STM output to other characteristics of interest can provide information about vegetation change integrated with fuels, wildlife, economic, and other data (chapters 3 through 7). Graphs, maps, and charts of economic, ecological, and social variables can be linked to the raw output, and summarized to further increase the breadth of questions that can be addressed across a landscape, watershed, ownership, or potential vegetation type. The framework can also be linked with other modeling systems (e.g., FVS) for validation or calibration. Although there are constraints to using STMs related to scale, and logistics, the ILAP framework is a demonstrably robust and flexible tool for assessing management alternatives and prioritizing management actions at regional scales, for a diversity of ecological and social contexts.

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