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Development of Management Scenarios for Modeling Disturbance Regimes and Succession in the Interior Columbia River Basin

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PREFACE

The following report was prepared by either University scientists through cooperative agreement, project science staff, or contractors as part of the ongoing efforts of the Interior Columbia Basin Ecosystem Management Project, co-managed by the U.S. Forest Service and the Bureau of Land Management. It was prepared for the express purpose of compiling information, reviewing available literature, researching topics related to ecosystems within the Interior Columbia Basin, or exploring relationships among biophysical and economic/social resources.

This report has been reviewed by agency scientists as part of the ongoing ecosystem project. The report may be cited within the primary products produced by the project or it may have served its purposes by furthering our understanding of complex resource issues within the Basin. This report may become the basis for scientific journal articles or technical reports by the USDA Forest Service or USDI Bureau of Land Management. The attached report has not been through all the steps appropriate to final publishing as either a scientific journal article or a technical report.

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INTRODUCTION

Changes in the structure and composition of forest and rangeland vegetation are caused by succession and disturbance. These changes affect ecosystem function, as well as the value humans place upon ecosystems for commodity production and amenities. Vegetation changes through succession in the absence of disturbance, as well as in response to both planned (for example, timber harvest, livestock grazing, or prescribed fire) and unplanned disturbances (for example, insect/disease, wild ungulate grazing, or wildfire). People alter vegetation through planned management activities, such as by harvesting timber, grazing domestic livestock, using prescribed fires, suppressing wildfires, and introducing exotic species. Unplanned disturbances include many different effects that are often not expected. Understanding the combined effects of succession and disturbance, including both planned and unplanned effects, provides the basis for understanding how systems evolved and developed (historical), where we are today (current) and options for the future.

The Interior Columbia Basin and Portions of the Klamath and Great Basins (ICB) broad-scale scientific assessment required a comprehensive description of the past, present, and future vegetation conditions across approximately 58 million hectares (144 million acres). Historical and future vegetation conditions were simulated using a spatially-explicit succession model, so that the effects of various land management strategies could be compared and evaluated. The Columbia River Basin SUccession Model (CRBSUM) was specifically developed to perform this task (Keane and others 1996). CRBSUM is a computer program that models successional development deterministically, but provides for multiple pathways, and simulates disturbances stochastically.

Successional dynamics for vegetation types in the ICB were modeled using the multiple pathway approach of Kessell and Fischer (1981). Cover type-structural stage classes were linked along succession pathways converging to a somewhat stable community type or Potential Vegetation Type (PVT). Various disturbance pathways existed that could redirect the cover type-structural stage classes in a way different from the succession pathways. See Keane and others (1996) for a detailed description of the modeling process.

Prior to the ICB assessment, most succession pathways and disturbance parameters had not been quantified for the myriad of forest, shrubland, herbland, riparian, and alpine ecosystems present in the ICB. In this document we describe the general approach and assumptions for the development of the successional pathway diagrams, disturbance effects, and disturbance probabilities, all of which were developed through intensive workshops and work group sessions[1]

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[1]The formal workshops were recorded in notes, summary documents, and inputs to the vegetation dynamics development tool (VDDT) model. That information is available in the administrative record and data record for landscape ecology (Hann and others 1997). There were too many group and individual working sessions to keep track of so there are no hard copy records of notes from those sessions. However, the information, logic, and testing from those sessions was recorded in the VDDT model files for the ICB scenarios (see metadata Theme

to capture the available information and expert opinion of forest and range ecologists and managers. It was acknowledged in these workshops that a tool was needed to quickly test and validate the succession and disturbance parameter estimations. The CRBSUM model could not be used because it required that all parameters be entered at once and its lengthy output would have been too large to readily interpret. A computer program was needed that contained the same modeling algorithms as CRBSUM, but with an easy and efficient user interface that allowed for quick parameter modification and model evaluation. This need resulted in the construction of VDDT, the Vegetation Dynamics Development Tool (Beukema and Kurz 1995). VDDT is a relatively simple, user-friendly model that allows users to create and test time and disturbance effects on vegetation dynamics. Development is described in Kurz and others (1994).

Fire, pathogens, insects and other disturbance agents cause transitions to different successional classes or retard such changes. The probability of these transitions defined the likelihood of disturbance for each successional class over time and heavily influenced the predicted distribution of succession classes. In VDDT, the user first defines disturbance agents that commonly act upon the various successional classes for a PVT, inputs the transition probabilities, and then runs VDDT for a specified modeling period. The predicted proportions of succession classes at any given time during the model "run" are used as indicators of the net effects of the disturbance transition probabilities and successional pathways. These proportions are displayed graphically in VDDT and help the user evaluate model behavior and outcome.

The succession and disturbance modeling was initiated in 1994 to develop and quantify important successional pathways for the ecosystems that were identified in the broad-scale historical and current mapping of the ICB (Byler and others 1996). These pathways were then integrated into the model CRBSUM so the effects of management could be predicted across the entire ICB. The VDDT succession and disturbance modeling was accomplished through a series of seven facilitated workshops and numerous informal work groups to develop the approach, to capture information and expert opinion, and to test model behavior. These workshops were facilitated by the ICB Ecosystem Management Project (ICBEMP). ESSA Technologies Ltd. assisted in coordinating the process and facilitating the workshops, and also produced the VDDT computer model (Kurz and others 1994, Beukema and Kurz 1995).

An insect and disease working group held initial workshops and working sessions at various periods from July to October 1994. The working groups had four major objectives: a) develop an approach to model changes in vegetation cover types and structural stages, including the development of preliminary potential vegetation classes and successional pathways, b) develop supporting rules for the model, c) assess insect and pathogen effects on vegetation at the landscape scale, and d) assess the impacts of changes in vegetation on insects and pathogens. These initial working groups provided experience for development of the first VDDT model and

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in managing the modeling process. Based on this experience, we expanded the scope of modeling to all vegetation and disturbance types. Subsequent workshops and working sessions were held between January and February 1995 involving about 150 ecologists and managers from throughout the ICB. These subsequent workshops and working sessions had three primary goals: 1) refine and supplement forested potential vegetation types and successional pathways, 2) develop pathways and disturbance probabilities for rangeland vegetation types, and 3) develop management actions and associated disturbance probabilities under four management futures (or scenarios) (Keane and others 1996).

In February, March, and April 1995, following the development of the VDDT, smaller groups of ecologists and managers from the earlier workshops and working sessions met to test and calibrate the models and to document assumptions and findings. During the subsequent workshops and working sessions, ecologists and managers who were experienced with the vegetation successional dynamics defined in the models also calculated individual transition probabilities prior to the model run. These transition probabilities were based on factors such as disturbance frequency, extent, and severity. Workshop and working group participants generally relied upon the predicted distributions of succession classes at various points in time during the model run to determine whether the outcomes were reasonable. This provided a logic-check to evaluate combined effects of many disturbances acting in concert on the succession classes.

This document is a companion to the VDDT successional models (metadata Theme 882-Vegetation Dynamics Development Tool), which include all the scenario successional pathways and disturbance probabilities for each PVT (metadata Theme 883-Management Scenario Data Files for VDDT). The user may view the various scenario successional pathway diagrams or the individual disturbance probabilities by running the VDDT model. This paper only provides an overview with examples and does not deal with every PVT with associated multiple pathways and types of disturbances.

POTENTIAL VEGETATION TYPES (PVTs)

Successional models of ICB vegetation were based on unique potential vegetation types or PVTs, which were assumed to occur as discrete units of land and to define areas of relatively similar successional dynamics. It was recognized that fine-scale classifications of habitat types or ecological sites could not be modeled, due to the fine scale at which they occur on the landscape relative to the broad-scale of available data. The objective of the ICB assessment was to identify broad-scale spatial and temporal trends that would aid in answering major policy questions about the condition of various land uses, ecosystem health, and native species habitats. The scale for summary of these conditions was at the Basin, Environmental Impact Statement[2]

[2]There were two EIS areas: the Eastside EIS area which included eastern Oregon and Washington; and the Upper Columbia EIS area which included western Montana, Idaho, northwestern Wyoming, and small portions of northern Nevada and Utah.

(EIS), and various other subregional[3] stratifications. This level of broad-scale data and understanding of succession and disturbance was considered adequate and appropriate for answering the major policy questions at the scale of subregional stratification.

The PVTs were selected to represent groups of vegetation: a) that were potentially identifiable with use of remotely sensed and other digital data; b) that had a similar response to factors influencing vegetation composition and structure, such as temperature and precipitation variation and disturbance; and c) that produced the dominant vegetation type in contiguous communities larger than approximately 200 hectares (500 acres or about 2-1x1 km pixels). These criteria eliminated many communities that occur on fine-scale environments, such as small patches of riparian or wetland vegetation types, or linear features, such as streams, roads, or utility corridors.

We chose a limited number of potential vegetation types to represent the vegetation within the ICB. For forested vegetation types, PVTs were developed on a scale roughly equivalent to the series level of the habitat type classification. Twenty five forested PVTs were defined based on a classification system described by MacDonald (1990), and named after typical mixes of climax tree species that occurred within the PVT. Twenty nine non-forested PVTs were defined based on typical mixes of grassland and shrub species (Table 1). During model development and for purposes of documentation, these were grouped into potential vegetation type groups (Table 1) (Harvey and others 1994). Write-ups follow for each of the PVT groups, in which the representative habitat types and plant associations included in each group are listed.

A number of discussions were held during the workshops and working sessions to define what a PVT represented in relation to the temporal consideration of the ICB analysis. Most discussions were centered on non-forest vegetation that was undergoing encroachment by such conifers as junipers (*Juniperus* spp.), ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*) in response to fire exclusion. The question was whether these situations should be included within the forested and woodland PVTs or the non-forested vegetation PVTs. Given the widespread nature and the importance to non-forested vegetation of this process, it was decided to include the encroachment process within the models where appropriate. In some cases the conifer encroachment process was added to a non-forested PVT model. For example, the basic successional model for Mountain Big Sagebrush Steppe was similar over the entire ICB and stabilized with sagebrush as the dominant species. Additional models were developed for areas where encroachment by juniper or Douglas-fir could potentially occur. Model users will need to determine whether the steppe or encroachment model is the most appropriate for their particular region. For the ICB assessment, the mid 19th century was the baseline date for the beginning of encroachment due to fire exclusion. If the area functioned primarily as a non-forest or woodland PVT prior the mid 19th century, the appropriate non-forest PVT model was used. If

[3] There were 13 Ecological Reporting Units (ERUs) that were large contiguous groups of subwatersheds with similar biophysical conditions. There were also groupings of subbasins and physiographic units.

the area had functioned primarily as a forested PVT with non-forested successional stages present, an appropriate forest PVT model was used. In many cases historical excessive livestock grazing also influenced encroachment rates, but at this broad a scale was determined not as influential as fire exclusion.

Table 1. Potential vegetation type (PVT) groups and group members. The designations used in the CRBSUM and VDDT models are also shown for all models and their geographic variants.

PVT Group and Group Members	Designations in CRBSUM and VDDT
ALPINE	
Alpine Shrub Herbaceous	ALSHR*
COLD FORESTS	
Edaphic Lodgepole Pine	LPPA (Yellowstone) and LPPB (Oregon)
Dry Spruce-fir	SFDWA (with aspen) and SFDNA (without aspen)
Harsh Spruce-fir	SFWBP (WBP>LPP) and SFLPP (LPP>WBP)
Whitebark Pine/Alpine Larch	WBALN (North) and WBALS (South)
MOIST FORESTS	
Wet Grand Fir/White Fir	GFWFE (East Cascades) and GFWFI (Inland)
Western Redcedar-Western Hemlock	CDHME (East Cascades) and CDHMI (Inland)
Pacific Silver Fir	PSLFR
Wet Spruce-fir	SFWET
Mountain Hemlock	MTHMI (Inland), MTHME (East Cascades) and MHSRF (Shasta red fir)
TRANSITIONAL FORESTS	
Moist Douglas-fir	MSDF
Dry Grand Fir/White Fir	DGFWF
Pacific Ponderosa Pine-Sierra Mixed Conifer	PPSMC
WARM, DRY FORESTS	
Ponderosa Pine	INTPP

Dry Douglas-fir	DRDFA (without ponderosa pine) and DRDFB (with ponderosa pine)
WOODLANDS	
Limber Pine	LIMP
White oak	WOAK
Juniper	JUOC*
Mountain Mahogany	CEW1 (with sagebrush) and CEW2 (without sagebrush)
Low Sage w/Juniper	LSXJ (xeric) and LSMJ (mesic)
Mountain Big Sagebrush w/Junper	BSMJ
Mountain Big Sagebrush w/Conifer	BSMC
Fescue/Conifer	FESC2
Aspen	ASPEN
SHRUBLANDS	
Salt Desert Shrub	SDSH
Basin Big Sagebrush/Wildrye	BSBW
Low Sagebrush	LSME (mesic) and LSXE (xeric)
Wyoming Big Sagebrush	WBSA (hot) and WBSC (cold)
Threetip Sagebrush	TTSA
Mountain Big Sagebrush	BSML (mesic), BSMW (west)
Antelope Bitterbrush	PUTR
Mountain Shrub	MTSH
GRASSLANDS	
Bluebunch Wheatgrass	AGST
Fescue Grassland	FESC
RIPARIAN	
Big Greasewood/Ryegrass	SARP
Riparian Graminoid	RIGR and RPSED*(Sedge)

Salix/Carex	SALX and MRLS*(Mountain riparian low shrub)
Cottonwood Riverine	CTRV

*Not applicable at the broad-scale; information was compiled by workshops for modeling at a finer scale.

SUCCESSION CLASSES

Seral stages within a PVT were developed under a similar assumption that the change in composition and structure must have been sufficient to be potentially recognizable with remotely sensed data. They were further constructed in a fashion that allowed additional seral stages to be readily added. Twenty two forest cover types (CT), based on Society of American Foresters forest cover types (Eyre 1980), and fourteen range cover types, based on Society for Rangeland Management grasslands cover types (Shiflet 1994), were the primary seral components used for modeling (Appendix B). Other CTs were added to define types that these 36 classifications did not address. Seven forested structural stages were adapted by O'Hara and others (1996) from earlier work by Oliver and Larson (1990) for forested PVTs, while six woodland structural stages and eight shrub and herbland structural stages were defined for non-forest PVTs.

In forested vegetation, composition changes with succession, typically toward dominance by the most shade-tolerant tree species that can occur. In the absence of subsequent disturbance events, succession after a stand-replacing disturbance generally follows a sequence of structural stages: 1) a non-forested condition dominated by shrubs or grasses and herbaceous or exotic plants; 2) stand initiation (SI); 3) stem-exclusion stage with closed canopy (SECC); 4) understory reinitiation (UR); and 5) old forest, multi-strata stands (OMS) (O'Hara and others 1996). In the absence of disturbance in OMS, succession perpetuates OMS. Where exotics dominate, it takes longer for the transition to SI. In SI, tree seedlings and saplings reach more than 50 percent canopy cover, usually distributed in clumps. In the SECC structural stage, tree saplings and poles are dense and the understory shrubs, grasses, and forbs are the least abundant compared to other stages. Once some of the trees die, others regenerate to create the UR structural stage. In UR stands, there is a wide separation between the overstory trees and the establishing understory trees, which are often establishing in gaps created when individual trees or groups of trees die. Eventually, in the absence of disturbance, an old, multi-strata stand (OMS) develops. The young forest, multi-strata (YFMS) only develops following disturbance that kills old trees (for example, following an overstory removal tree harvest, or some insects and diseases) in the OMS or UR structural stages. In the absence of disturbance, YFMS stands become OMS stands. Old forest single-strata (OSS) develops when disturbance in the OMS results in the death of most or all of the small trees, as could occur with frequent surface fires. In the absence of disturbance, OSS stands become OMS stands as young trees regenerate episodically over time under an old overstory.

These patterns occurred in all PVT groups, but the rates of transition (represented as successional age in the model), the probabilities of disturbance, and the types of disturbance differed. The probabilities of disturbance were high in all of the management scenarios in the PVT groups, so that the climax forests (OMS dominated by the most shade-tolerant species that can grow on the site) were seldom very abundant, even in the historical scenario. Furthermore, some PVT groups, such as the warm, dry, old growth forests, were more typically the disturbance-maintained OSS than the relatively undisturbed OMS.

Non-forested PVTs follow a somewhat different pattern, depending on the PVT. Grassland types generally do not change structure unless they are highly productive, in which case they can change in size, or they encounter encroachment by woodland or conifer structures. Shrubland types typically change from herb to shrub structures and also can undergo encroachment from woodland or conifer structures. Invasion by exotic perennial and annual species can substantially change the structural development patterns of both grassland and shrubland types. In particular, invasion by exotic annual grasses, that are both highly flammable and more competitive than the native perennials, can alter pathways in grasslands and shrublands.

DISTURBANCE AND DISTURBANCE PROBABILITIES

Disturbances refer to those events that are relatively discrete in time and that influence vegetation composition and/or structure (Pickett and White 1985). In this application, a disturbance was any event that altered the structural stage, cover type, and/or successional age (the time that vegetation remained within a cover type-structural stage combination in the absence of disturbance). Disturbances were assigned probabilities for occurrence. Probabilities can be interpreted as the likelihood that a disturbance would occur in any given year for any given pixel. In general, disturbance probabilities were the inverse of the frequency of occurrence of a particular type and severity of disturbance for a given combination of cover type and structural stage.

Certain assumptions were made to simplify the successional pathway diagrams and to accommodate the model structure. In any given year in the model, a single pixel could only be of one structural stage, cover type, and successional age. The number of possible changes for a given pixel was limited to succession or disturbance. The potential vegetation type for a given pixel remained constant through time and under all management scenarios – it did not change with succession or disturbance. When disturbance occurred, there was only one result or pathway for each given disturbance (however, we did accommodate different outcomes in some cases by designating disturbances as, for instance, mixed severity fire 1, 2, and 3 in the moist forest PVT group). A disturbance could change either or both the structural stage or dominant cover type.

If the structural stage and cover type remained the same, successional age could be advanced (+, accelerating the time in which a given pixel would develop into the next stage of succession) or delayed (-, effectively extending the time that the pixel remained in the current structural stage and cover type). In the model, all impacts of disturbance were immediate. When a disturbance occurred, one or more of the structural stage, cover type, and successional age would change. If the disturbance changed successional age only, the disturbance effect was shown as a circle beginning and ending at the same "box" in the successional pathway diagram. The disturbance probabilities did not change with time within a given management scenario.

The major vegetation management activities included in the forest models were fire, timber harvest, and thinning. Fire severity classes followed definitions by Morgan and others (1996). Stand-replacing fires (SRF) resulted in mortality of more than 70 percent of the overstory trees (or shrubs if there were no trees, or grasses if there were no shrubs or trees). Typically, these were crown fires, but they could also be severe surface fires that killed stems and roots. In contrast, more than 70 percent of the overstory trees survived underburns (UB, called nonlethal fires by Morgan and others 1996). Mixed fires were intermediate in their effects. These descriptions applied to the burn locations. The relative degree of mortality was judged by comparing the burned vegetation to its condition before the fire, or to adjacent unburned vegetation, within three years after the fire.

Tree harvest definitions varied somewhat among PVT groups, and not all tree harvests were used in all PVT groups or in all management scenarios (none were applied in the HI management scenario). Because of shortage of time to do a literature review, the terminology used for the active management scenario tree harvest and thinning definitions were the same as for consumptive demand and passive management. This was an unfortunate component of the process because the same codes were used to mean very different treatments between active management and the other scenarios. We hope to summarize a subsequent document describing the differences in assumptions about type of treatment for the different scenarios. This problem emerged primarily in the tree harvest and thinning, but also occurred with terminology in prescribed fire and livestock management. Terminology used for forest thinning included commercial and precommercial, high or low, although these were sometimes identified more specifically. Partial cuts included overstory removal, small patch clearcuts, individual and group selection, and preparatory cuts of shelterwoods. However, these were often identified more specifically. Clearcuts included even-aged regeneration cuts, whether or not green trees were retained.

The major vegetation management activities included in the non-forest models were prescribed fire, livestock grazing, seeding with native and/or exotic species, and herbicides. Herbicide use was primarily limited to control of exotic species and not included as a general vegetation treatment method. For the woodlands, tree harvest methods were also included to achieve various management objectives. Emphasis of the use of these activities varied greatly between land ownership and management scenarios. Management activities were minimized for the wilderness land classification and ecosystem function scenario and emphasized more for assumptions on management of private lands and the restoration scenario.

In most instances for non-forested PVTs, wildfire was included as a lethal fire which removed the overstory, at least temporarily, and initiated secondary succession. Most of the shrub communities within the ICB cannot be burned under any intensity without loosing most of the existing shrub overstory. The primary exceptions are for the grassland PVTs, juniper savannas, and herbaceous seral stages within shrub dominated or woodland vegetation where nonlethal fires may occur. Both historical and recent human-caused occurrence of fire was generalized across a given PVT. Literature was drawn upon as much as possible, but for many regions and PVTs expert opinion of the development team was the primary data source. It was also realized that fire occurrence varied due to factors such as topography, adjacent fuels, adjacent vegetation types, and human activity, but this variation was not included within most models.

Herbivory by domestic and wild animals was considered to be a widespread influence on most non-forest and woodland PVTs within the ICB. Domestic livestock use was modeled as having one of the following influences depending upon the PVT and season, frequency, and severity of herbivory. Herbivory may: 1) cause retrogression of vegetation composition (directional change away from the stable composition), 2) retard the rate or stop successional development, and 3) accelerate secondary successional development. It was recognized that some levels of herbivory have little influence on vegetation composition or successional pathways but these were not included in the models since by definition successional development is not affected. However, this caused considerable problems in using the model to estimate or sensitivity-test response of vegetation against levels of livestock use. Many current and future management strategies for livestock result in no effect on vegetation composition or successional rates. Consequently, we could not use the model as a bookkeeping system for amount of livestock use. The model was only useful as a bookkeeping system for types of vegetation and disturbance. The same was true for wildlife grazing.

The effects of wild herbivores other than ungulates were included primarily as part of the successional process and not included as a disturbance factor in the models. We could not find an adequate information base to define the specific influences of low levels of chronic herbivory by small mammals and insects on the overall succession of non-forested and woodland vegetation. The effects of large wild ungulates on succession were considered similar to domestic livestock effects. However, the probabilities were lower because the populations were considered to be lower, and the animals are not geographically confined. We also recognized that the wild ungulates often utilize different sites and different species within a community. The only other wild herbivore included as a successional factor within the models was the beaver because of its importance in the successional development of some riparian vegetation types.

Invasion by exotic species since the historical period presents a major change in the ICB environment. The list of exotic species is extensive and growing rapidly. It was recognized that specific species may have different influences on vegetation development and the influence is dependent upon PVT, successional stage, and management. However, the list of species was too extensive to include all species separately. Annual grasses were separated in the model for some PVTs because of their influence on fuel loads, fire occurrence, and interspecific competition.

Other exotic species that primarily influence competition were included under the exotic herb category. For more local applications, the models may need refinement in terms of exotic species effects.

MANAGEMENT SCENARIOS

Four contrasting scenarios were developed for the Interior Columbia Basin project (Table 2). Management actions and associated probabilities of disturbances were developed within the context of these four management scenarios.

Table 2—Four management scenarios are represented in the model simulations.

Management scenario	Description	Code
Historical	Designed to mimic pre-Euro-American settlement systems with the influence of Native Americans. No exotics and no livestock grazing.	HI
Consumptive Demand	Designed to respond to social demands of consumptive use of all resources. Maximize harvests, livestock grazing, mining, and include exotics. Fire suppression to protect resources.	CD
Passive Management	Designed to emphasize amenity uses on Federal lands. Minimal harvests, livestock, mining, hunting and road-building. Assumes same level fire suppression resources as CD, but protect lives & property.	PM
Active Management	Designed to mimic ecosystem functions and restore various ecosystems. Harvest, livestock management, and prescribed fires are used to mimic ecosystem processes. Fire suppression is included as a part of active management to protect lives and property and restore ecosystems.	AM

The Historical management scenario (HI) was used to predict disturbance and successional dynamics prior to the extensive influence of Euro-American settlement. Disturbance types, probabilities, and effects were consistent with our data on vegetation structure and dynamics prior to 1900. The Passive Management scenario (PM) emphasized management of Bureau of Land Management- and Forest Service-administered lands (BLM/FS) for recreation, education, and research with minimal emphasis on commodity production. Fire suppression efforts were assumed to continue at current levels but with an emphasis on protection of lives and property rather than the standing crop of commodity resources. In the Consumptive Demand management scenario (CD), the emphasis was assumed to maximize commodity production through grazing, timber harvest, and other management practices. The effects of disease, insects, and fire were prevented or suppressed where economical. The Active Management scenario (AM) focused on the maintenance of functioning ecosystems within their inherent succession/disturbance regime as constrained by their biophysical capability. The AM objective was to simulate management for a properly functioning system as described in the Assessment of Landscape Dynamics (Hann and others 1997). Timber harvest, grazing, prescribed fire, fire suppression, and other forest and rangeland management activities were designed to achieve vegetation structure consistent with ecosystem function and process. Fire, disease, insect, and other disturbance functions were maintained where feasible, generally through vegetation manipulation. The effects of introduced agents were assumed to be mitigated.

Specific management regions were defined based on land ownership and use designations. They included "Wilderness and National Parks," "USFS and BLM Lands" (U.S. Forest Service- and Bureau of Land Management-administered), and "Private, State, and Tribal Lands." Disturbance probabilities were assessed for each scenario by management region. In some cases there were no substantial differences between management regions or scenarios, but in most cases differences occurred. The management regions reflected the general intensity of management (1=wilderness, 2=actively managed federal land, and 3=intensively managed, including private and tribal lands).

MODEL BUILDING STRATEGY

We followed a sequence of steps in developing the disturbance effects and probabilities for each PVT group. First, we developed the successional pathway diagrams through a series of interactive workshops and working sessions. These diagrams reflected the successional changes expected in the absence of disturbance, and the effects of disturbance in changing cover type, structural stage and/or successional age.

Then, we focused on developing the HI management scenarios. We used the interactive VDDT model (Beukema and Kurz 1995) to input and run probabilities, and then to change probabilities as necessary to result in the relative abundance of cover types, structural stages, and cover types-structural stage combinations that were consistent with both the documented information available and the opinions of experts involved. We usually started with the historical fire probabilities and then added insect and pathogen probabilities, effects of grazing, and other appropriate disturbances for the given environment, cover type/structure class, and successional pathway. The process was iterative, for we often revised the successional pathway diagram or adjusted disturbance probabilities. We were careful in modifying transition times for succession, and in modifying disturbance probabilities to keep the changes consistent with historical information and with the expert opinion of those involved. We also ensured that the models were sensitive to those disturbances that were most prevalent and most important in a given PVT group.

Once we were satisfied with the HI management scenario, we did not alter the successional pathway diagram in building the other management scenarios. There were, of course, disturbances (for example, logging or prescribed fire) present in other management scenarios that had not occurred under the HI management scenario. However, the successional transitions in the absence of disturbance and the effects of disturbances remained the same under all management scenarios – they just occurred at different probabilities under the different management scenarios. For example, the probability of logging under the HI scenario was zero. Furthermore, the relative abundance of cover types and structural stages also differed. For the HI management scenario, the probabilities of disturbance were the same for all management regions. Using the VDDT required some assumption of the initial conditions – the relative abundance of different structural stage and cover type combinations. We started with them all equal and ran the model under the probabilities until the relative abundance of cover type, structural stage, or the combination of cover type and structural stage did not change. The final result of the HI runs was used to initialize all other management scenarios in the VDDT model during the model development process. Similarly, historical (circa mid-1800 to 1900) vegetation composition and structure was used to initialize the model runs for CRBSUM (Keane and others 1996). We developed two historical management scenarios in PVTs with white pine blister rust, an exotic disease. The two scenarios were developed based on effects where white pine blister rust has been active and where its effects have been negligible.

The CD management scenario for a given PVT group was developed from the HI management scenario by altering the fire probabilities to reflect fire suppression, roads, and other fire exclusion effects. Then we added the disturbances and probabilities for management activities to produce commodities (for example, logging and grazing). Again, we used the VDDT model (Beukema and Kurz 1995) as an interactive tool to help adjust the disturbance probabilities. The ability to run the VDDT model quickly was invaluable, for it gave a readily interpretable picture of the effects of different assumptions, even though it did not show the spatial distribution of cover types and the contagion of disturbances. The fire probabilities differed for the three management regions (we reduced the historical fire probabilities by factors reflecting efficacy of fire suppression as described for each of the PVT groups, and these factors differed for PVT groups). Generally, fire suppression was more effective for the private and tribal lands and least effective in the larger roadless and wilderness areas. No commodity production occurred in the wilderness, but the insect and pathogen probabilities were often adjusted, depending on the vegetation and disturbance characteristics, to reflect the differences in fire suppression effects on advancing succession and on allowing fuel accumulation.

The PM management scenario was developed directly from the CD management scenario by eliminating all consumptive management treatments from management region 2, the federal lands open to multiple use. Probabilities of fire, insects, and pathogen disturbances for management region 3, the private/tribal lands, remained the same as in the CD management scenario. Probabilities of insect and pathogen disturbances in management region 1, the wilderness, remained the same as in the CD management scenario as well. Fire probabilities increased in management region 1, however, to reflect the reduced efficacy of fire suppression where road access was not maintained and fine grass fuels were not reduced by livestock grazing. In dry forests, the probabilities of mixed and stand-replacing fires increased, sometimes dramatically, in response to the increased stand density and the more abundant and vertically and horizontally continuous fuels (see discussion of fire probabilities by management scenario for each PVT group). We assumed that fire suppression efforts were designed to protect people, their property, and soil, water, and air resources, but would be most focused on the private, state, and tribal lands, moderately focused on BLM/FS lands, and least focused on BLM/FS wilderness. Under PM, the probabilities for insects and pathogens were those from wilderness (management region 1) under the CD management scenario, changed as necessary to reflect differences in risks and hazards. Then the models were run, and minor adjustments were made if warranted by model behavior.

The AM management scenario was both the most challenging and the scenario for which we had the least time available for development. Also, a smaller group of the many ecologists involved in the overall project were directly involved with developing the AM management scenarios, due to time constraints. However, those developing this management scenario for all PVT groups were actively involved at every step of the process from the development of the successional pathway diagrams to the setting of disturbance probabilities for the other management scenarios. We used the results of the HI, PM, and CD management scenarios for comparison. We sought to approximate through management (that is, by the types and probabilities of disturbance, including tree harvest, prescribed burning, and grazing) the relative abundance of cover types, structural stages, and cover types-structural stage combinations that resulted from the HI management scenario. The relative abundances from the HI scenario were used as a reference and not necessarily as a goal. For in some PVT groups where exotics are now abundant, or where "boom and bust" cycles are extreme, a more sustainable outcome was referenced. The VDDT model runs for the AM scenario for a given PVT were initiated with previous results from the CD scenario. This action recognized that management had not started with a clean slate approximating historical conditions. Then we eliminated all disturbances that were inconsistent with the historical disturbance regimes, and created "fixes" where feasible for the disturbances added to the systems by people, such as introduction of exotic species. We altered seed probabilities where appropriate to reflect the emphasis on regenerating species that commonly dominated in pre-Euro-American settlement conditions. Then we designed management actions (for example, extensive use of prescribed fire) that would both approximate the effects of historical (where feasible and sustainable) disturbances and create historical abundance of different cover type-structural stage combinations. Wherever it was consistent with the goal of restoring ecosystem structure and function, we used treatments that produced commodities for human use (for example, prescribed fire in combination with tree harvest to accomplish thinning or to create uneven-aged stands or to regenerate desired species). The insect and disease probabilities were altered if appropriate. For example, probabilities were altered to reflect the development of an intensive effort to increase blister rust resistance in forest stands containing western white pine (*Pinus monticola*), limber pine (*Pinus flexilis*), or whitebark pine (*Pinus albicaulis*). Fire probabilities reflected fire suppression efforts (see description under each PVT group). We assumed that the insect, pathogen, fire, and timber harvest probabilities for private/tribal lands would be the same as under the CD management scenario (that is, commodity production would still be the major goal, as opposed to the non-wilderness federal lands where restoration of ecosystem function was the goal with commodities produced as a side effect where feasible). The disturbance types and probabilities in management region 1, the wilderness, were adjusted less than those that occurred under the CD and PM management scenarios – typically we assumed that prescribed fires (both natural and management-ignited) would be more desirable under the AM than under the CD and PM management scenarios.

WARM, DRY FORESTS

The warm, dry forest potential vegetation type groups all support ponderosa pine or Douglas-fir as the most shade-tolerant tree species that can grow on the site. Many different ponderosa pine and Douglas-fir habitat types and plant associations were represented (Table 3). These warm, dry forests are the driest of the forested potential vegetation types considered capable of supporting moderate timber production. Ponderosa pine is the most common tree species, for it is the only conifer that occurs widely on ponderosa pine habitat types and plant associations. Those sites where ponderosa pine is the climax tree species were modeled as INTPP. We did not separately model the sites where ponderosa pine forests are climax but closed canopy forests do not develop because of harsh site conditions.

Ponderosa pine is a major seral species on many Douglas-fir potential vegetation types (DRDFB). In some parts of the ICB, ponderosa pine does not occur as a seral species on dry Douglas-fir habitat types or plant associations (DRDFA). The climate is typically warm and dry, particularly in the summer. Droughts are common. Fires were historically frequent. The site conditions and soils are highly variable, but often the soils are well-drained and poorly developed.

Table 3. Representative habitat types and plant associations for the potential vegetation type groups included in the warm, dry forests.

PVT Group	Representative Habitat Types and Plant Associations	Name in Model
Interior ponderosa pine	PIPO/AGSP, PIPO/FEID, PIPO/PUTR, PIPO/PRVI, PIPO/SYAL, PIPO/PHMA, PIPO/CARU, PIPO/CELE, PIPO/SYOR, PIPO/ARTRV, PIPO/CAGE	INTPP
Dry Douglas-fir without ponderosa pine	PSME/CARU, PSME/AGSP, PSME/FEID, PSME/FESC, PSME/SYAL, PSME/PHMA, PSME/SYOR, PSME/BERE, PSME/OSCH, PSME/SPBE, PSME/CAGE, PSME/JUCO, PSME/CELE, PSME/ARCO	DRDFA

Dry Douglas-fir with ponderosa pine	PSME/CARU, PSME/AGSP, PSME/FEID, PSME/FESC, PSME/SYAL, PSME/PHMA, PSME/SYOR, PSME/BERE, PSME/OSCH, PSME/SPBE, PSME/CAGE, PSME/JUCO, PSME/CELE, PSME/ARCO	DRDFB

These PVT groups are widely distributed and heavily used by people for many different commodities. These sites are currently grazed and many sites were very heavily grazed in the late 1800s and early 1900s. Trees have been extensively harvested, although regeneration is often difficult due to the frequency of drought. Recreational and watershed values are also important. A tremendous diversity of animals use these forests throughout the year. We did not represent the important, but less widely distributed conditions found on open, rocky sites.

Successional pathways

The successional pathway diagram for dry Douglas-fir forests with ponderosa pine was typical of warm, dry forests. A relatively simple composition of tree species existed. Most of the changes through time were structural; this was all the more evident on the other PVTs within the PVT group, for they all supported only one conifer species. The frequency of disturbance and the range of environmental conditions contributed to the structural diversity common on sites dominated by these PVTs.

Following stand-replacing disturbances, sites are often dominated by exotic species, shrubs or perennial bunch grasses, depending on site conditions and past disturbances. Exotic species dominate under current conditions on many sites, whereas historically, native species of shrubs or grasses dominated. Our seed probabilities reflected this difference for the historical and other scenarios (see scenario descriptions). Where exotics dominate, it takes longer for the transition to the stand initiation stage (SI). The probabilities of disturbance were high under any of the management scenarios in these PVT groups.

Disturbance effects

Fire was and continues to be one of the most important disturbances in ponderosa pine and Douglas-fir stands. We assumed a single fire probability historically for each PVT within the group (Table 4) based on published literature (Agee 1993, Arno 1980, and references cited therein). Although fire probabilities varied over space, there was remarkable similarity in the historical mean fire return intervals documented for a given PVT. Probabilities were simply the inverse of the mean interval between fires (Table 4).

Table 4. Historical fire frequency and associated probability used in the historical scenario and as the basis for calculating fire probabilities for all scenarios (see text).

Potential Vegetation Type	Model Name	Fire Interval	Probability
Interior ponderosa pine	INTPP	18.5	0.054
Dry Douglas-fir without ponderosa pine	DRDFA	25	0.04
Dry Douglas-fir with ponderosa pine	DRDFB	22	0.045

To derive the probabilities for fires of different severity in the CD, PM, and AM scenarios, the fire probabilities for the HI scenario (Table 4) were multiplied by the numbers shown in Table 5. The multipliers were determined by expert opinion. In the HI scenario, fire probabilities were the same for all management regions. In the CD, PM, and AM scenarios, fire probabilities differed by management region.

In all scenarios, where more than one fire severity was considered likely to occur, the probabilities for fires of all severity classes totaled the overall fire probability. These probabilities were the beginning point. Where necessary, they were adjusted during the workshops based upon model performance and expert opinion.

The multipliers were designed to account for fire suppression, roads, and altered fuel abundance through human influence. The probability of stand-replacing fires increased greatly (by a factor of 4 to 10) under the influence of fire suppression and management practices that increased the total amount and vertical continuity of fuels (Agee 1993, Morgan 1994). The effects of fire exclusion are numerous in these types – typically stand density increases, there are more canopy layers, and Douglas-fir increases in abundance (except on ponderosa pine PVTs). The probability of stand-replacing fires increases under fire exclusion policies, which reflects the change in stand structure and the accumulation of fuels, but the degree of increase was not the same under all scenarios. The probability of nonlethal and mixed severity fires was reduced under all scenarios relative to historical fire probabilities. Note that in these warm, dry forests, we assumed that prescribed fires would be used as an active part of management under the CD and AM scenarios.

In general, the effects of fire suppression were greatest for private and tribal lands (management region 3), least for wilderness (management region 1), and intermediate for federal lands open to active management (management region 2). Thus, the multipliers (Table 5) differed by management region under the CD, AM, and PM scenarios. We assumed the same level of fire suppression on private and tribal lands under the CD, AM, and PM scenarios, so multipliers were the same. For the AM scenario, underburn and mixed severity fires occurred at probabilities midway between CD and PM scenarios, except for management region 3, which was the same as under the CD scenario. For the INTPP and the DRDFA in the AM scenario, we assumed that there was a 5 and 10 percent mitigation effect due to tree harvest and prescribed burning for the stand-replacing fires in management regions 1 and 2. The latter assumption did not apply to the DRDFB type because the historical fire probability was essentially zero, so it was assumed to be 0.002 for stand-replacing fires under all scenarios and management regions (Table 5).

Table 5. Multipliers for fire probabilities to reflect influence of degree of fire suppression activity and relative success by fire severity class.

	CD Management Region[1]			PM Management Region			AM Management Region		
	1	2	3	1	2	3	1	2	3
Interior Ponderosa Pine (INTPP)									
Stand-replacing fires	--[2]	--	--	--	--	--	--	--	--
Mixed Severity fires	5	4	4	6.5	6	4	5.8	5	4
Nonlethal fires	0.15	0.13	0.13	0.18	0.15	0.13	0.17	0.14	0.13
Dry Douglas-fir without Ponderosa pine (DRDFA)									
Stand-replacing fires	8	8	8	10	10	8	7.5	7	8
Mixed Severity fires	0.45	0.35	0.35	0.48	0.45	0.35	0.47	0.4	0.35
Nonlethal fires	0.5	0.4	0.4	0.6	0.5	0.4	0.55	0.45	0.4
Dry Douglas-fir with Ponderosa pine (DRDFB)									
Stand-replacing fires	--	--	--	--	--	--	--	--	--
Mixed Severity fires	5	4	4	6.5	6	4	5.8	5	4
Nonlethal fires	0.15	0.13	0.13	0.18	0.15	0.13	0.17	0.14	0.13

[1] Management region reflects general intensity of management: 1 = wilderness, 2 = actively managed federal land, and 3 = intensively managed, including private and tribal lands.
[2] Probability was assumed to be 0.002 for all cases where stand-replacing fires did not historically occur.

In all scenarios subject to fire suppression, the probability of insects and pathogens, such as dwarf mistletoe that increase in dense and multi-layered stands, was increased to reflect the development of such stand characteristics in stands that burned less often than historically.

Tree harvest was also a very common disturbance that greatly altered the successional pathways.

We assumed that clearcuts would be seldom used on these sites, even under consumptive demand, because of the difficulties obtaining reliable regeneration success.

The introduction of exotic species, such as knapweed (*Centaurea* spp.), has had a dramatic effect on the rates of succession and the values of many of these dry forests. We assumed that there would be some attempts to mitigate the effects of exotics under the AM scenario. Land managers are often unable to eliminate exotic species even when that is the management objective.

Management scenarios

We developed probabilities for the maximal application of the scenario for all lands within legal constraints. We assumed that these probabilities reflected the limits of feasibility, but all were sustainable. The probabilities reflected enlightened management based upon the best current knowledge about ecosystem function. For instance, we assumed that although under consumptive demand the goal was maximizing commodity production and return on investment, that investment must have considered the long-term sustainability of the practices applied, so that short-term gain could not occur at the expense of long-term sustainability.

Historical (HI)
Prior to extensive and intensive use by people, there were many old, single-storied stands that were maintained by frequent fires. Insects and pathogens were present at endemic levels, but the effects of bark beetles were typically not dramatic. Outbreaks occurred, but were seldom synchronous across large areas because the stand structures were heterogeneous. Fires were frequent, and were predominately nonlethal in their effect on either the trees or the associated shrub, grass, and forb vegetation.

We estimated, based upon professional experience, that in the ponderosa pine PVT groups, bunch-grasses would dominate following stand-replacing disturbances 80 percent of the time, otherwise shrubs would dominate. These probabilities were indicated in the model with the seed probabilities of 0.8 and 0.2, respectively. In the process of succession, trees also established and eventually dominated the site, resulting in the transition to the SI structural stage with a ponderosa pine cover type.

Consumptive Demand (CD)
We assumed that management under the CD scenario would result in few old single- and multi-storied stands. Some would be maintained on lands managed for commodity production because of the very high commercial value for large-diameter trees that have few knots and that grow slowly. The value of the clear wood and veneer from such trees is high now and likely to increase as such trees become increasingly rare. Grazing by domestic livestock was extensive, particularly in the SI, OMS, and OSS structural stages. Grazing did not reduce tree survival greatly, except in the SI structural stage where some trees were damaged and grazing prolonged the time necessary for trees to dominate the site. Although grazing can reduce the fine

herbaceous biomass that fuels fire, ponderosa pine needles can often be abundant enough to support fires if weather conditions are favorable.

Fires were actively suppressed, but prescribed fires were used actively to promote nutrient cycling, and to maintain vigorous and productive understory plants for grazing domestic livestock and as habitat for game species, and to encourage hunting and recreational use. Probabilities were the same for management regions 2 and 3 (non-wilderness).

In the ponderosa pine PVT groups, exotic plant species occur. In wilderness areas, we estimated the probability as 0.75 that exotic species would dominate following stand-replacing disturbances, and the probabilities that bunch grasses or shrubs would dominate following stand-replacing disturbances were 0.15 and 0.15 respectively. We assumed that exotic species were more likely in the non-wilderness areas because of the more intensive activity of humans and their domestic livestock. We estimated the probability as 0.8 that exotic species would dominate following stand-replacing disturbance in actively managed areas (that is, management regions 2 and 3); the probabilities that bunch-grasses or shrubs would dominate following stand-replacing disturbances were 0.1 and 0.1, respectively. These probabilities imply that exotics will dominate sites following stand-replacing disturbances either 10 or 15 percent of the time, based on management history.

Passive management (PM)

Fires were actively suppressed. There was no active tree harvest, prescribed fire, or other active management to alter the occurrence, severity, or extent of insect and pathogen activities. Similarly, there was no attempt to limit the spread or the invasion of exotic plant species, even if these had negative consequences for the native animal diversity or had negative watershed impacts following fires. No grazing of domestic livestock occurred.

We expected abundant P-group annosum (*Heterobasidion annosum*) root disease. Few of the many stumps created by current tree harvests are treated and none of them would be treated under this scenario (although no more trees would be cut). The resulting root disease would affect the composition and structure on many sites. The probabilities that exotics, shrubs, or grasses would dominate following stand-replacing disturbances were the same as in the CD scenario.

Active management (AM)

Fires were actively suppressed. Prescribed fires were widely used, often in combination with tree harvest, to approximate the proportion of structural stages and relative abundance of cover types found under the historical scenario.

The probabilities that exotics, shrubs, or grasses would dominate following stand-replacing disturbances were the same as in the CD scenario. Timber harvest focused on density management through thinning from below and prescribed surface fires in the mid- and late-seral successional stages. Old forests were promoted, and the OSS structural stage was relatively more abundant than under the CD and PM scenarios as the result of restoration efforts that combined fuels management, thinning from below, and extensive use of prescribed fire. There was individual tree harvest in the old multi- and single-storied stands. Stumps would be treated to reduce P-group annosum root disease.

Limitations

We represented all ponderosa pine potential vegetation types as one potential vegetation type group, with one set of disturbance effects and probabilities for each management scenario and management region. Thus, we had to generalize across a tremendous range of environmental conditions, disturbance histories, species composition, and genetic makeup of the plant communities represented. Furthermore, we could not reflect the differences in succession that occur with different understory plant species composition and structure. For these reasons, the groups were too broad to represent many management issues. Given the variety of conditions represented by these models, the model projections were useful in assessing general and relative trends only. We necessarily had to generalize by aggregating the information for many different sites and types of stands.

We urge those who use, interpret, apply, and adapt these models not to substitute model output for local site and stand information when formulating stand management decisions.

Not all disturbances that will or have occurred were included in these models. We estimated disturbance probabilities only for those disturbances that would change cover type, structural stage, and/or successional age. In the warm, dry forest PVT groups, grazing by domestic livestock is not only possible but highly probable in all structural stages and cover types, yet we only represented it in the earliest structural stages because we felt that only in those stages would grazing by domestic livestock alter the rate of succession. Even in those stages, the probability that grazing would affect succession was less than the probability that sites would be grazed, which meant that our probabilities were an underestimate of the frequency of grazing by domestic livestock.

We excluded disturbances, such as dwarf mistletoe, that do not alter the pattern of vegetation at the 1-km^2 pixel size. Dwarf mistletoe slows growth, stresses trees, increases their susceptibility to bark beetles and fire-induced mortality, and directly causes significant mortality in ponderosa pine and Douglas-fir trees. Yet most such effects are on individual trees or small groups of trees and are not detected on maps with a minimum mapping unit of 1-km^2 or larger.

Fire probabilities reflected the average influences of fire occurrence and fire suppression, and could not reflect the probabilities for each unique spatial location. Our fire probabilities also included general and pervasive effects, such as road construction and valley settlement, that jointly contribute to reduced fire frequency under fire exclusion policies. Certainly, the relative influence of these effects differs between and within land use categories, as has been indicated in general terms by the probabilities assigned. However, we could not reflect the differences in fire probabilities that existed for some areas based upon either relative isolation from roads and access for fire suppression, use of prescribed fire, or management objectives for different landowners.

No contagion was represented. For an individual stand of trees, the probability of insects, pathogens, fire, grazing, and tree harvest is affected by the degree to which these disturbances affect surrounding stands, as well as the topography and road access. We were unable to represent these effects in this model.

The scenarios are not what is likely to be applied on the ground. Few people would suggest that we manage all warm, dry forests in all places according to the probabilities reflected in any single one of these management scenarios. We hope that the comparison of results under the four contrasting management scenarios will be useful in exploring the implications of different management assumptions, and in formulating management alternatives, each of which will probably look quite different than any one of the management scenarios.

The dynamics of vegetation at the ecotone between PVT groups was not well represented in these models. For instance, we assumed that we accurately represented the types and rates of succession where Douglas-fir can invade mountain big sagebrush. However, the long-term dynamics of Douglas-fir invasions depends on climatic conditions that were not well represented in this model, and upon represented factors (such as fire and grazing) with important interactions that are not yet well understood. This problem was made worse by the difficulties in accurately mapping PVT groups, particularly for the warm, dry forests where they border shrubland and woodland types.

The conversion of forest vegetation dominated by exotic species was not well represented, yet these changes are ecologically and socially significant. We named only one exotic-dominated ponderosa pine community type, but there are great differences in fire probabilities, wildlife use, grazing potential, tree regeneration, and sediment production among ponderosa pine communities dominated by cheatgrass (*Bromus tectorum*), knapweed, and leafy spurge (*Euphorbia esula*).

The overall results and individual probabilities for disturbances under the different scenarios will greatly benefit from use and review of these models. Note that in general, the AM and PM scenarios were developed by a smaller group of experts working for a shorter time than the HI and CD scenarios. This was a constraint imposed by the modeling process.

Discussion

A great deal of disturbance by fire, insects, and pathogens was necessary to create and maintain vegetation in conditions consistent with the earliest historical documents. Pristine vegetation, that vegetation that the first Euro-Americans would have encountered when they came to North America, was by no means undisturbed. Human activity has altered the type of disturbance in current vegetation to such an extent, even in wilderness areas, that the type and degree of other disturbances, and the resulting forest composition and structure, have changed greatly. Under all management scenarios that included active and extensive fire suppression (the CD, PM, and AM scenarios), this trend would continue to a greater or lesser degree.

Future disturbances, such as fires, are likely to be more extensive and more severe (they will cause different and greater changes in structure and composition than historically occurred). Bark beetle and pathogen probabilities will often increase. To a limited degree, human-caused disturbance, such as timber harvest, prescribed burning, and grazing can substitute for natural disturbance, such as fire or insect action, but only if human use is conservative and creative. Intensive timber harvest as most commonly implemented over the last 30 years in the warm, dry forests will not substitute for the extent and effects of historical fire and other disturbances. Thus, the location, timing, and effects of human action should be carefully chosen to be consistent with the overall environmental constraints. Historical conditions are one reference for these choices (Swanson and others 1993, Morgan and others 1994).

Under historical conditions, low-intensity surface fires occurred often, maintaining open, often single-storied stands of trees with diverse understory species. Tree regeneration occurred episodically, and often in small patches. Large stand-replacing fires were relatively rare. Insects and pathogens were active, contributing to the high rate of disturbance, and the often resilient nature of the forests.

Under the PM scenario, single-storied structures dominated by ponderosa pine were less abundant than historically, and less abundant than exists under current management. Multi-storied stands increased. The remaining old trees in dense pine and Douglas-fir stands were likely to be killed by bark beetles. Surface fires (represented as underburns in the models) were less common because of fire suppression and the subsequent accumulation of fuels and increased stand densities, which would result in increased likelihood of mixed severity and stand-replacing fires. The increased fuel loading, high stand density, high rates of tree mortality caused by insects and pathogens, in combination with the droughts that characterize these types all would make it increasingly difficult to prevent stand-replacing fires.

Under the CD scenario, ponderosa pine cover types on Douglas-fir PVTs were more abundant than in the PM scenario, but less than in the HI scenario. Ponderosa pine cover types were increased by planting and by use of prescribed fire. Prescribed fire would be used only where economical, which is much more extensive than under current practices, even though the resulting nonlethal fires would occur with lower probability than historically. Single-storied stands dominated by old trees would not be restored to their historical abundance, although some would be found where producing high-value wood from large-diameter trees was a goal and grazing provided high income. Some OMS stands would also be found where tree harvest was not economically feasible. Little was done to change increasing fire risks in the urban-wildland interface and on other lands not managed for commodity production.

Under the AM scenario, the relative abundance of structural stages approached historical proportions, but only after considerable time. This was accomplished through prescribed burning in combination with thinning from below and other harvest practices to manage both structure and composition of the warm, dry forests. The susceptibility of forests to severe wildfires and to extensive disease and insect outbreaks was reduced relative to the PM and CD scenarios. Some commodities were produced as an outcome of actively managing forest structure and composition to ensure healthy ecosystems. However, the restoration process would take time.

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TRANSITIONAL FORESTS

These forests are considered transitional between the more mesic moist forests and the warm, dry forests dominated by ponderosa pine and Douglas-fir. The precipitation and temperatures are intermediate between the warmer and drier conditions at lower elevations, and less conducive to plant growth than found in the moist forests. Droughts are common.

These forests are less widely distributed than either the moist forests or the warm, dry PVT groups, but they are very important locally for timber, grazing, wildlife habitat, and watershed protection. In periods of drought, trees growing on transitional forest PVTs are stressed, especially if the stands are dense; there are multiple canopy layers and/or the stands are dominated by late-seral species. Stressed trees are more susceptible to insects and pathogens. These forests have been greatly influenced and greatly changed by human influence. Because fire suppression and other human activities, such as preferential harvest of big trees and early-seral species, have often resulted in dense stands with multiple canopy layers dominated by true firs, they have also altered the type, severity, and extent of disturbances, such as fires, bark beetles and other insects, and root disease. Representative habitat types and plant associations are shown in Table 6.

Table 6. Representative habitat types and plant associations for the transitional forests.

PVT Group	Representative Habitat Types and Plant Associations	Name(s) in Model

Moist Douglas-fir	PSME/LIBO, PSME/VAGL, PSME/PHMA, PSME/VACA, PSME/ACGL, PSME/HODI, PSME/VAME, PSME/PAMY	MSDF
Dry grand fir/white fir	ABGR or ABCO: /CAGE, /CARU, /VASC, /ARCO, ABGR/HODI, ABGR/SPBE, ABGR/TRLA, ABGR/SYMPH	DGFWF
Pacific ponderosa pine-Sierra mixed conifer	(no specific plant associations)	PPSMC

Successional pathways

The successional pathway diagrams for the transitional forest PVTs were much simpler than most of the adjacent moist forest PVTs, for fewer tree species occur on these relatively drier sites. Each PVT supports at least three major tree species, each of which can dominate many structural stages. Many different disturbances can and do occur. The resulting dynamics are thus complex when the disturbances interact, and are likely to differ greatly under the different management scenarios.

Disturbance effects

Fire was and continues to be one of the most important disturbances in the transitional forests, for the sites are productive enough to yield abundant fuels and droughts are common enough that fires often occur. Table 7 shows historical fire intervals for moist Douglas-fir, dry grand fir/white fir, and Pacific ponderosa pine-sierra mixed conifer types and the corresponding probabilities. These values were drawn from published literature (Agee 1993, Arno 1980, and references cited therein).

Table 7. Historical fire frequency and associated probability used in historical scenario and as basis for calculating fire probabilities for all scenarios

Potential Vegetation Type	Name in Model	Mixed-severity Fires		Stand-replacing Fires		Underburn	
		Fire interv al	Proba-bility	Fire interv al	Proba-bility	Fire interv al	Proba-bility
Moist Douglas-fir	MSDF	100	0.010	112	0.009	67	0.015

Dry Grand fir/White fir	DGFWF	85	0.012	250	0.004	67	0.015
Pacific Ponderosa pine-sierra mixed conifer	PPSMC	125	0.008	145	0.007	67	0.015

To derive the probabilities for fires of different severity in the CD, PM, and AM scenarios, the fire probabilities for the HI scenario were multiplied by the numbers shown in Table 7. The multipliers were determined by expert opinion. Where more than one fire severity was considered likely to occur, the probabilities for fires of all severity classes totaled the overall fire probability. These probabilities were the beginning point. Where necessary, they were adjusted during the workshops based upon model performance and expert opinion.

The multipliers were designed to account for fire suppression, roads, and alteration of fuel abundance through human influence. The probability of stand-replacing fires was reduced less than the mixed severity or nonlethal fires under fire suppression policies (Table 7) (the CD, PM, and AM scenarios) because fire suppression is less effective for high intensity fires. As well, fire suppression and other management practices often result in increased tree density, a greater accumulation of fuel, and increased vertical and horizontal continuity of fuels (Agee 1993, Morgan 1994).

In general, the effects of fire suppression are greatest for private and tribal lands (management region 3), least for wilderness (management region 1), and intermediate for federal lands open to active management (management region 2). Thus, the multipliers (Table 8) differed by management region under the CD, AM, and PM scenarios. We assumed the same level of fire suppression on private and tribal lands under the CD, AM, and PM scenarios, so multipliers were the same.

The multipliers differed depending on whether ponderosa pine or Douglas-fir was the dominant cover type in the dry grand fir/white fir (DGFWF) PVT. These differences were because of the dissimilarity in type and amount of fuel produced and because ponderosa pine is more resistant to and was more historically prone to surface fires. Where Douglas-fir dominated the DGFWF PVT under the CD scenario, the proportion of fires by severity class shifted to 20 percent, 70 percent, 10 percent from historical proportions of 47 percent, 47 percent, 6 percent for underburns, mixed severity, and stand-replacing fires, respectively (Table 7). Under the PM scenario, all fire probabilities were 20 percent higher than CD, except for in management region 3 where they were the same as in the CD scenario. For the AM scenario, underburn and mixed severity fires occurred at probabilities midway between CD and PM scenarios, except for management region 3, which was the same as under the CD scenario.

Table 8. Multipliers for fire probabilities to reflect influence of degree of fire suppression activity and relative success by fire severity class.

	CD Management Region[1]			PM Management Region			AM Management Region		
	1	2	3	1	2	3	1	2	3
Moist Douglas-fir									
Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9
Mixed severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Nonlethal fires	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.1	0.1
DGFWF in Ponderosa pine cover types									
Stand-replacing fires	2	2	2	3	2.5	2	2.5	2.3	2
Mixed severity fires	1.5	1.4	1.4	1.8	1.6	1.4	1.65	1.5	1.4
Non-lethal fires	0.1	0.1	0.1	0.15	0.13	0.1	0.13	0.12	0.1
DGFWF in Douglas-fir cover types									
Stand-replacing fires	1	0.9	0.9	1.2	1.1	0.9	1.1	1.0	0.9
Mixed severity fires	0.86	0.8	0.8	1.03	0.93	0.8	0.95	0.87	0.8
Non-lethal fires	0.26	0.24	0.24	0.31	0.28	0.24	0.29	0.26	0.24
Ponderosa pine-Sierra mixed conifer									
Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9
Mixed severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Non-lethal fires	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.1	0.1

[1] Management region reflects general intensity of management: 1 = wilderness, 2 = actively managed federal land, and 3 = intensively managed, including private and tribal lands

Management Scenarios

We developed probabilities for the maximal application of the scenario for all lands within legal constraints. We assumed that these probabilities reflected the limits of feasibility, but all were sustainable. The probabilities reflected enlightened management based upon the best current knowledge about ecosystem function. For instance, we assumed that although under consumptive demand the goal was maximizing commodity production and return on investment, that investment must have considered the long-term sustainability of the practices applied, so that short-term gain could not have occurred at the expense of long-term sustainability.

Historical (HI)
In the historical scenario, prior to extensive and intensive use by people, many stands were dominated by early-seral species, and there were many old, single-storied stands that were maintained by frequent fires. Insects and pathogens were present at endemic levels. Outbreaks occurred, especially during extended droughts, but they were seldom synchronous across large areas because the stand structures were heterogeneous. At any given time, most forest stands were not susceptible to insect, pathogen, and fire disturbances. Such disturbances were important in maintaining a mixture of structural stages and cover types.

Consumptive Demand (CD)
Management under the CD scenario resulted in few old single- and multi-storied stands, although some would be found in areas where tree harvest was limited legally, by access, or other factors. Grazing by domestic livestock was extensive, but grazing did not alter the rates of succession. In part, this was because we assumed that grazing, like other management under the CD scenario, was managed to minimize the impact on production of other commodities.

Fires were actively suppressed, but prescribed fires were used actively to promote nutrient cycling, and to maintain vigorous and productive understory plants for grazing domestic livestock and as habitat for game species, and to encourage hunting and recreational use. Probabilities of fire occurrence were the same for management regions 2 and 3 (non-wilderness).

Passive management (PM)
For the moist Douglas-fir PVT, we assumed that clearcutting followed by planting would result in dominance by western larch (*Larix occidentalis*) in SI. In contrast, we assumed natural regeneration following clearcutting would result in SI dominated by Douglas-fir. Fires were suppressed, but there was no other active management. Thus, there was no tree harvest, prescribed fire, or other management to alter the occurrence, severity, or extent of insect and pathogen activities. Similarly, there was no attempt to limit the spread or the invasion of exotic plant species, even if these had negative consequences for the native animal diversity or had negative watershed impacts following fires. No grazing of domestic livestock occurred.

We expected abundant P-group annosum root disease infections. Few of the many stumps created by current tree harvests are treated and none would be treated under this scenario (although timber harvest would cease). The resulting root disease would affect the composition and structure on many sites.

Under this scenario, all disturbances in management region 3 (private and tribal lands) occurred at the same probabilities as under the CD scenario, because management on those lands was designed to produce commodities.

Active management (AM)
In the active management scenario, fires were actively suppressed. Tree harvest and prescribed fires were widely used, often together, to approximate the proportion of structural stages and relative abundance of cover types found under the historical scenario. The probabilities that exotics, shrubs, or grasses would dominate following stand-replacing disturbances were the same as in the CD scenario.

Timber harvest focused on density management through thinning from below and prescribed surface fires in the mid- and late-seral successional stages. Old forests were promoted, and the OSS structural stage was relatively more abundant than under the CD and PM scenarios as the result of restoration efforts that combined fuels management, thinning from below, and extensive use of prescribed fire. There was individual tree harvest in the old multi- and old single-storied stands. Stumps would be treated to reduce P-group annosum root disease.

In addition, timber harvests were assumed to have the following characteristics: shelterwoods left 20 to 40 ft^2 basal area per acre while both commercial thinning or underburning in combination with thinning left 80 to 100 ft^2 basal area per acre. High thinning was designed to remove dominant and codominant trees to release those in the lower crown classes. The group selection cuts were done with openings of one to one and a half acres in combination with thinning to leave 80 to 100 ft^2 basal area per acre in between the openings.

Limitations

Again, the models were necessarily general. We represented all transitional forests with just three PVTs and three management regions. For each PVT, there was only one set of disturbance effects and probabilities for each management scenario. Thus, we had to generalize across a tremendous range of environmental conditions, disturbance histories, species composition, and management objectives that differed among different land owners and managers. Nor could we reflect the differences in succession that occur with different understory plant species composition and structure. We necessarily had to generalize by aggregating the information for many different sites and types of stands.

We urge those who use, interpret, apply, and adapt these models not to substitute model output for local site and stand information when formulating stand management decisions.

Not all disturbances that will or have occurred have been included in these models. We estimated disturbance probabilities only for those disturbances that would change cover type, structural stage, and/or successional age at the 1-km^2 pixel size. Generally, we did not include those disturbances that would affect individual or small groups of trees where detection on maps with a minimum mapping unit of 1-km^2 or larger would be unlikely.

Fire probabilities reflected the average influences of fire occurrence and fire suppression, and could not reflect the probabilities for each unique spatial location. Although our fire probabilities included general and pervasive effects, such as road construction and valley settlement, we could not reflect the differences in fire probabilities that surely exist for some areas based upon relative isolation from roads and access for fire suppression, use of prescribed fire, or management objectives for different landowners. Furthermore, no contagion was represented for fire, insects, tree harvest, or any other disturbance.

For these and other reasons, the model results were most useful for exploring the implications of different management assumptions under the four scenarios. They may also be helpful in formulating management alternatives.

Discussion

In the historical scenario, disturbances by fire, insects (including bark beetles and defoliating insects), and pathogens (including root diseases) were frequent. Nonlethal, stand-replacing, and mixed severity fires all occurred and largely governed the relative abundance of cover types and structural stages. There was a diverse mixture of cover types and structural stages on the landscape. In general, forests were more heterogeneous historically than they are currently. In comparison to current conditions, there were historically fewer dense multi-storied stands dominated by Douglas-fir and grand fir (*Abies grandis*), and more of the single-storied ponderosa pine and western larch forests. Dense, uneven-aged forests of climax tree species are very susceptible to and perpetuated by native insects and pathogens, but the relative abundance of these types was less historically than currently.

Under the PM scenario, fires were suppressed and there was no other active management. However, not all fires can be suppressed, especially the high-intensity crown fires that are stand-replacing. As a result, current trends in forest composition and structure would intensify, driven by insects, pathogens, and fire. Fuels would continue to accumulate and multi-storied stands dominated by shade-tolerant, late-seral species would become increasingly common with time. High-intensity crown fires would become increasingly common. When large, stand-replacing fires occur, early seral stands establish. It is probable (though this is not explicitly modeled because the model does not include contagious spread of fire and insects) that forest watersheds would become more homogeneous. As a result, disturbances would more likely be synchronous over large areas, which could adversely affect wildlife populations and water quality.

Under the CD scenario, tree harvest would increase the proportion of stands dominated by pine and larch. Density would be controlled by thinning. The OMS and OSS structural stages would continue to be less abundant than they were historically. Extensive areas dominated by late-seral tree species would be found on lands not managed for commodity production, and on lands where timber production could not be sustained economically. In such stands, insect and pathogen disturbances would occur often.

Under the AM scenario, the relative abundance of structural stages approached historical proportions, but only after some time under this scenario. This was accomplished through prescribed burning in combination with thinning from below and other tree cutting to manage both structure and composition of the transitional forests. The susceptibility of forests to severe wildfires and to extensive disease and insect outbreaks was reduced relative to the PM and CD scenarios. Some commodities were produced as an outcome of actively managing forest structure and composition to ensure healthy ecosystems. As stated for the warm, dry forests, the restoration process takes time.

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MOIST FORESTS

The moist forests are diverse and productive. They support rich mixtures of tree, shrub, grass, and associated animal and plant species. Those that occur at low elevations are some of the most timber productive of all forests in the interior Columbia River basin. Many of these forests have been actively managed since the turn of the century; parts of the forests have been mined, logged, and roaded intensively. All of the forests are moist, with abundant winter rain or snow, and frequent summer, fall, and spring precipitation, so droughts are not common but they do occur.

The moist forests were described together for a variety of reasons. They occur on moist sites and are therefore productive and subject to a wide variety of management actions depending on the objectives. Furthermore, they were grouped together because of the common logic used to develop complicated successional pathway diagrams and disturbance probabilities. The moist forests represented some of the most complex successional pathway diagrams because of the diverse number of tree species that can dominate and also because of the many different natural and human-induced disturbances that can occur.

There were major stand-replacing and mixed-severity fire events in these types in the late 1800s through the early 1900s. Stand-replacing and mixed-severity fire events still occur, but they are not as large. Now, the regeneration of early-seral species more often occurs through timber harvesting, which typically occurs in relatively small patches compared to the size of patches created by the stand-replacing and mixed-severity fires. Tree harvest occurs on all the moist forest PVTs, but is most common on those at lower elevations.

Several of the PVT groups support western white pine, which is subject to the introduced white pine blister rust that has caused extensive white pine mortality. White pine blister rust arrived in the western United States in about 1910 and spread throughout the range of western white pine. In the mid-seral structural stages, blister rust resulted in the rapid transition to Douglas-fir, grand fir, subalpine fir (*Abies lasiocarpa*) and other cover types in areas once dominated by western white pine. Selective cutting of high-value white pine and outbreaks of mountain pine beetle have further reduced the abundance of white pine in the late-seral structural stages. At lower elevations and on sites managed for timber production, significant amounts of rust-resistant white pine have been planted in the last several decades.

Potential vegetation types

There were five potential vegetation types included in moist forests (Table 9). They included western redcedar-western hemlock, wet grand fir/white fir, Pacific silver fir, mountain hemlock, and wet spruce-fir. The plant associations represented were diverse. We created variants for many of the PVT groups to address major geographical differences, such as between the eastern Cascade mountains and the Inland West (Table 9). Shasta red fir as a cover type was found on that variant of the inland mountain hemlock PVT.

Grand fir and white fir are considered ecological equivalents. They do interbreed where they occur together, and the two play similar successional roles. Therefore, we referred to the grand fir-white fir PVT and the grand fir-white fir cover type.

Table 9. Representative habitat types and plant associations for the moist forests, which include five major PVT groups.

PVT	Representative Habitat Types and Plant Associations	Name(s) in Model
Wet grand fir/white fir	ABGR series and ABCO series, such as ABGR/PHMA, ABGR/XETE, ABGR/VAGL, ABGR/ACGL, ABGR/CLUN, ABGR/ASCA, ABGR/GYDR, ABGR/STAM, ABGR/TRCA, ABGR/TABR, ABGR/ACCI, ABGR/LIBO	GFWFE: East Cascades GFWFI: Inland
Western redcedar-western hemlock	TSHE series and THPL series: /OPHO, /CLUN, /VAME, /GYDR, /ATFI, /ASCA, /MEFE, /BENE, /XETE, /RUPE, /ADPE, /ARNE, /ARNU	CDHME: East Cascades CDHMI: Inland

Pacific silver fir	ABAM/OPHO, ABAM/ACGL, ABAM/ACTR, ABAM/MEFE, ABAM/RHAL, ABAM/VAAL, ABAM/VAME, ABAM/ACCI	PSLFR
Wet spruce-fir	SFWET	
Mountain hemlock	MTHME: East Cascades MHSRF Shasta red fir	MTHMI: Inland

Variants

We created geographical variants for some PVT groups from the models already developed. Our strategy in developing the successional pathway diagrams and the disturbance probabilities was to make as few changes to the original model as was consistent with the geographical differences. The variants reflected geographic differences in composition, succession, and disturbances. Note that these variants were very crude approximations, and will need more work in order to adapt them to local conditions.

We derived the Pacific silver fir PVT models from the Inland cedar/hemlock model simply by substituting cover types according to their successional roles. Mountain hemlock (*Tsuga mertensiana*) was substituted for western white pine, Pacific silver fir (*Abies amabilis*) for grand fir-white fir, and subalpine fir-Engelmann spruce (*Picea engelmannii*) for lodgepole pine (*Pinus contorta*). We added a YMS structural stage with the subalpine fir-Engelmann spruce cover type. We altered disturbances as follows: we eliminated all white pine blister rust and mountain pine beetle effects, and we used the successional pathways and disturbances from the wet spruce-fir for the subalpine fir-Engelmann spruce cover type. The seed probabilities, which were used in all of the successional pathway diagrams to govern the relative proportion of cover types that establish following stand-replacing disturbance, were adjusted to alter the relative abundance of cover types to fit local conditions. Other minor adjustments were made as needed to fit local experience. Given that this PVT is relatively rare within the ICB and because the model behavior was acceptable, we decided this would be sufficient.

The East Cascades variants of the grand fir-white fir and the western redcedar-western hemlock PVTs were created by adjusting the seed probabilities to greatly reduce the abundance of western white pine and western larch. All disturbances occurred with the same probabilities.

Successional Pathways

The successional pathway diagram for the western redcedar/western hemlock PVT group demonstrated the complexity of the moist forests (although this PVT had more different tree species able to dominate compared to other PVTs in the moist forests). On the western redcedar/western hemlock PVT group, we modeled six different cover types, and each of the 29 different cover type-structural stage combinations had as many as fifteen different disturbances that could occur. With four management scenarios and three management regions, the number of disturbance probabilities to be estimated was extensive. Given the variety of combinations of structural stages, cover types, and disturbances that could occur, vegetation composition was complex as it changed through time. Other moist forest PVTs were modeled with fewer cover types, but all were complex. Thus, a systematic approach was needed. Where possible, we used similar approaches to all of the PVT groups included in moist forests. For instance, the approach to fire probabilities was consistent, as described below.

Disturbance effects

The many disturbances that could occur are discussed in groups. First, we describe the approach to fire probabilities. The effects of insects and pathogens are discussed after that. Both the types and the probabilities of timber harvest are covered under descriptions of the different scenarios.

Wildfire probabilities in moist forest PVT groups (western redcedar/western hemlock, Pacific silver fir, moist grand fir/white fir) were developed based on research by Antos and Habeck (1981), Arno and Davis (1980), Barrett (1991, 1993), Barrett and Arno (1991), Fischer and Bradley (1987), and Zack and Morgan (1994). Based on professional experience, annual wildfire probabilities and effects were allocated among different structural stages and cover types.

For historical wildfire regimes, the overall probability for wildfires was modeled as shown in Table 10. For all PVT groups, all fires were assumed to be either mixed or stand-replacing at the spatial scale of one square kilometer pixels. Because the structural stages differed with respect to fuel accumulation, flammability, fuelbed structure, and presence of ladder fuels, the average wildfire probability was allocated differently among the various forest structural stages. All wild stand-replacing fires were modeled to return the pixel to the shrub structural stage. From the shrub stage, succession directed pixels to the various conifer cover types in the SI structural stage based on relative tree species regeneration success probabilities assigned in the various scenarios. The shrub stage was modeled with a fire probability of zero, based on the low flammability of the moist shrubs that dominate and the short duration of this earliest seral stage. The rare fire that could occur in this structural stage was indirectly accounted for by the fact that a small percentage of the shrub stage would cycle back on itself through the default successional pathway.

In this and subsequent paragraphs, we describe how fire probabilities were applied in the western redcedar/western hemlock PVT group. This serves as an example of how the fire probabilities were systematically assigned to the different structural stages based upon historical fire probabilities. We assumed that historically, mixed-severity fires occurred approximately once in 80 years in the western redcedar/western hemlock PVT group. Stand-replacing fires historically occurred once every 200 years on average (Table 10). These probabilities were partitioned among the structural stages. The SI structural stage for all cover types was modeled as having a higher probability of wildfire than average, based on fuel structures in this stage and the historical records of reburns 15 to 40 years after an initial wildfire. An annual fire probability of 0.0067 was used in SI, which approximated a fire return interval of 150 years. Given the 15- to 25-year residence time in the SI structural stage, approximately 10 to 17 percent of SI stands would experience a wildfire. This was probably a conservative estimate of double burn probabilities. All wildfires in this structural stage were modeled as stand-replacing fires based on fuelbed characteristics and the small size, high flammability, and low fire resistance of the seedling and sapling trees.

In contrast, the SECC structural stage has a dense canopy with moist understory surface conditions. It also has no understory canopy layer, which means no ladder fuels. Professional experience in this structural stage also reflected low fire risk. For these reasons, the SECC structural stage was modeled with a low annual fire probability. For shade-tolerant cover types with dense and more flammable foliage, stand-replacing and mixed-severity fires were considered equally likely when wildfires occurred. Western larch, Douglas-fir, western white pine, and lodgepole pine either have more fire resistant bark and/or more open foliage, and the probability of a mixed-severity fire in these cover types was modeled as twice as likely as a stand-replacing fire. Following a mixed-severity fire in the SECC structural stage, a pixel was generally modeled as staying in the same cover type, but progressing more rapidly to the UR structural stage due to the canopy opening, and subsequent rapid development of understory canopy on these moist forests.

In the UR, YFMS, OMS, and OSS structural stages, trees differ more in fire resistance. Because of relative physical, structural, and growth characteristics, probable post-fire cover types vary by pre-fire cover type. For these reasons, and based on professional experience, mixed-severity fires in each cover type were allocated to various post-fire cover type pathways. The cover type allocations for the cedar hemlock/western hemlock PVT group were representative of how these transitions were handled in other PVT groups:

From white pine: 0.25 to WP (white pine); 0.25 to DF (Douglas-fir); 0.4 to WL (western larch); and 0.1 to GF/WF (grand fir/white fir).
From grand fir/white fir: 0.6 to GF/WF; 0.2 to WL; 0.2 to DF.
From cedar/hemlock: 0.6 to C/H (cedar/hemlock); 0.2 to WL; 0.1 to GF/WF; 0.1 to DF.
From Douglas-fir: 0.8 to DF; 0.2 to WL.
From western larch: 0.1 to WL.
From lodgepole pine: 0.8 to LP (lodgepole pine); 0.2 to DF.

Because of changes resulting from selective harvest practices of large larch trees during the last century and from the loss of the thinning effects of mixed-severity fires, the white pine and cedar/hemlock cover type allocations were altered for the three management scenarios:

From white pine: 0.3 to WP (white pine); 0.25 to DF (Douglas-fir); 0.35 to WL (western

larch); and 0.1 to GF/WF (grand fir/white fir).
From cedar/hemlock: 0.8 to C/H (cedar/hemlock); 0.1 to GF/WF; 0.1 to DF.

Based on fuel structures and understory moisture conditions, the UR structural stage was modeled as being closest to the mean wildfire probability across all structural stages. In general, a mixed-severity fire in the UR structural stage results in a transition to OMS structural stage. This occurs because mixed-severity fires cause patchy mortality and, characteristically, a rapid understory regeneration in the moist forest PVT groups. Thinning from the fire, and the subsequent nutrient flush lead to faster growth in surviving medium-sized trees, resulting in enough large trees to classify as OMS. Stands in the UR structural stage progress to OMS after a mixed-severity fire, rather than YFMS, because larger trees are more likely to survive mixed-severity burns.

The YFMS and OMS structural stages were modeled as having higher probabilities of burning than average due to their high volume of both dead fuels and ladder fuels. Because of these fuel structures, wildfires were modeled as twice as likely to be stand-replacing rather than mixed-severity. Because of the thinning effect, patchy understory mortality, higher probability of large tree survival, and rapid understory regeneration, the pathways after mixed-severity fire in YFMS and OMS all led to the OMS structural stage. If the stand was already in OMS, the time was reset by minus 30 years.

The OSS structural stage has moist understory conditions, few ladder fuels, and less fine and medium sized dead fuel overall than in the YFMS and OMS structural stages. Overall probability of wildfire was modeled as somewhat less than average across all structural stages.

Fire probabilities

For the three management scenarios, the probabilities listed in Table 10 and distributed among cover types and structural stages as just described were adjusted based on Table 11. The adjusted probabilities reflected wildfire control objectives, effectiveness of control under various weather conditions, effects of varying access due to road density under different management regimes, and accumulation of ground and ladder fuels under the various scenarios. Based on fire control experience and the literature, we modeled a relatively high rate of success in controlling the underburns and mixed-severity fires, because they burn at lower intensity than stand-replacing fires. We modeled a much lower rate of success at controlling potentially stand-replacing fires because they usually occur under more severe weather conditions when control technology is relatively ineffective. Reduced probability of mixed-severity fires will lead to increased ground and ladder fuels in almost all structural stages, which also means reduced long-run effectiveness in controlling potentially stand-replacing fires occurring during severe fire weather. In some of the scenarios, the fire control effectiveness was modeled higher than in others, based on the fuel complexes expected to develop under various management and insect and disease regimes.

Table 10. Historical fire probabilities used as the basis for calculating fire probabilities under the

different scenarios. We assumed that all fires were either mixed-severity or stand-replacing.

Potential Vegetation Type	Name in Model	Mixed-severity Fires		Stand-replacing Fires	
		Fire interval	Probability	Fire interval	Probability
Wet grand fir/white fir	GFWFE / GFWFI	133	0.0075	150	0.0068
Western redcedar-western hemlock	CDHME / CDHMI	80	0.0125	200	0.0050
Pacific silver fir	PSLFR	175	0.0057	150	0.0069
Mountain hemlock	MTHME / MHSRF	160	0.0062	175	0.0057
Wet spruce-fir	SFWET	170	0.0059	165	0.0061

Table 11. Multipliers for fire probabilities to reflect influence of degree of fire suppression activity and relative success by fire-severity class. These were applied to the historical fire probabilities listed in Table 10 to determine overall fire probabilities for the different management regions under the consumptive demand (CD), passive management (PM), and active management (AM) scenarios.

	CD Management Region[1]			PM Management Region			AM Management Region		
	1	2	3	1	2	3	1	2	3
Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9
Mixed-severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Nonlethal fires[2]	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.1	0.1

[1] Management region reflects general intensity of management: 1 = wilderness, 2 = actively managed federal land, and 3 = intensively managed, including private and tribal lands

[2] Historically, all fires were assumed to be mixed and stand-replacing

For the CD and PM scenarios, wildfire probabilities were reduced the greatest due to heavy emphasis on fire suppression, relatively good access, and high investments in managed lands. In the PM scenario, we assumed less effective fire suppression due to less access and lower rates of investment on federally managed lands. For the AM scenarios with moderately good access, emphasis on managing stand structures and fuels, and high investments in managed lands, fire probabilities were intermediate between HI and CD depending on the management intensity.

Management scenarios

The management scenarios were all built starting from the historical with blister rust (HIB) scenario, since blister rust is now a feature of these ecosystems.

Consumptive Demand (CD)
The CD scenario was built from the HIB scenario by adding tree harvest regimes that emphasized economic values and timber volume production. Thinnings, various sorts of partial cuts, and clearcuts were used where opportunities were available. Stands with larger trees had relatively high rates of tree harvest since maintenance of particular forest structures (such as old growth) was not an objective. Insect and disease probabilities were then adjusted to account for the effects of timber harvest. For example, partial cutting in Douglas-fir cover types has been documented to raise the amount of root rot mortality and to both accelerate the development of cedar/hemlock cover types and perpetuate YFMS. After clearcutting, the most commercially valuable species were planted (DF, WL, & WP), and clearcut stands were rapidly established as SI. Grazing by domestic livestock occurs in moist forests, but seldom alters rates and directions of succession. This is in part due to the low grazing potential in some moist forest PVT groups, including cedar-hemlock, mountain hemlock, and Pacific silver fir. In the grand fir type, grazing can reduce Douglas-fir regeneration success and favor ponderosa pine.

Passive Management (PM)
The PM was essentially a reserve approach. This was modeled by beginning with the CD scenario. Then wildfire probabilities were adjusted as shown in table 11. All harvest and thinning activities were removed. Insect and pathogen levels were adjusted for managed federal lands to generally those levels found in the wilderness regime. However, in the Douglas-fir cover type, root diseases were assumed to be intermediate between wilderness and intensively managed private lands to approximate the elevated pathogen levels due to past management.

Active Management (AM)
The AM scenario was based on using treatments that produced goods and services for humans while sustaining the relative abundance found under historical conditions for ecosystem composition, structure, and function. We focused on three modeling objectives: (1) maintain a mix of structural stages similar to the historical landscape structures; (2) maintain a composition with a mix of cover types similar to historical levels and with a good representation of long-lived seral species capable of producing large wood necessary for numerous ecosystem functions; and (3) maintain overall disturbance rates somewhat similar to historical levels. Within the time horizons of this planning and modeling effort, we felt it was unrealistic to expect to restore white pine to its full historic role (note that both the historical abundance and our ability to increase white pine differ with PVT group and their variants). However, the white pine genetics program and various silvicultural techniques provide opportunities to partially recover white pine.

Plantings and treatments assumed that all planted white pine would be blister rust resistant and that silvicultural techniques would favor a mix of long-lived seral species, such as western larch and western white pine, that historically occurred and that best emulated natural structures and supported natural processes while providing value for humans.

The AM scenario was built starting from the CD scenario. Then appropriate adjustments were made in order to meet the above objectives. All clearcut harvests were eliminated; all regeneration harvests were modeled as shelterwoods with reserves. Some of these harvest treatments could be group shelterwoods with reserves and others could leave individual reserve trees scattered throughout the harvest areas, but overstory density would be managed in all these regeneration areas so that the early seral, light-demanding species would be capable of dominating on 75 percent or more of the area. Regeneration harvests were modeled as returning to the SI structural stage based on the assumption that planting and stocking control would be actively used to produce species mixes able to meet the scenario objectives. Note that the result would be many standing dead, dying, and live trees (patchy and less than 30 percent canopy cover in large trees) following stand-replacing tree harvest, just as there would be following historical stand-replacing fires. In general, regeneration harvests were only used in OMS and OSS structural stages to recycle approximately two thirds of the stands through this pathway rather than stand-replacing wildfires. We assumed that regeneration efforts on managed stands would be successful in establishing early-seral commercial species suited to the site. For example, in the western redcedar/western hemlock PVT group, in the LP cover type UR structural stage and in DF cover type UR and YFMS structural stages, shelterwood with reserves was used at a rate equivalent to wild stand-replacing fires to recycle stands heavily impacted by root diseases. As a default value, after regeneration harvest, pre-treatment cover types were allocated to new cover types in the following ratios: 50 percent to WP, 40 percent to WL, and 10 percent to DF. However, the pre-harvest LP cover type went 10 percent to LP instead of DF, and the pre-harvest C/H cover type went to 10 percent C/H rather than DF. The DF cover type went to 60 percent WP and 40 percent WL. The WL cover type went to 50 percent WL and 50 percent WP. Generally, no harvest-regeneration cuts were applied until the structural stage that represented the average age of stand-replacing fire in the historical scenario (for example, YFMS, OMS, and OSS in cedar-hemlock PVT group), except where excessive mortality of western white pine in the UR structural stage triggered harvest and regeneration. Clearcut and plant in the AM scenario included residual medium and large live trees.

Because the AM scenario incorporated natural process as a part of management objectives and methods, we assumed that prescribed unplanned mixed-severity fire was used when it was likely to meet management objectives for landscape structures and disturbance rates. Thinning and prescribed burning were actively used to emulate natural disturbances where appropriate, to avoid excessive fuel buildups and to manage stand structures. However, prescribed mixed-severity fires were also used at the probabilities listed in Table 10 for all except the SI structural stage. In general, prescribed mixed-severity fire moved the pixel to the subsequent structural stage, and was often used to accelerate the stand development through the SECC, UR and YFMS structural stages. In the SECC structural stage, following prescribed mixed-severity fire, most pixels stayed in their pre-fire cover type but went to the UR structural stage. However, in the WP cover type, because young WP are so fire sensitive and WL is often a stand component, only one-third of the pixels stayed in the WP cover type and two-thirds went to WL. Likewise, the LP cover types went one-half to LP and one-half to DF. For the UR, YFMS, OMS, and OSS structural stages, prescribed mixed-severity fire generally kept one-third of the pixels in the pre-fire cover types and two-thirds went to WL. However, the C/H cover type in the UR, YFMS, OMS, and OSS structural stages went to GF/WF rather than WL. The LP cover types went to DF YFMS rather than WL OFMS. In the C/H cover type with OSS structural stage (most of which are cedar-dominated), the prescribed mixed-severity fire went to C/H OMS. The net result of prescribed fire and judicious tree harvest was reduction in the probability of stand-replacing fire over the CD scenario.

High thinnings and partial cuts in the CD scenario were not used in the AM scenario because they would not meet stand structural objectives. Low thinnings (assumed to include both commercial and precommercial) were heavily used in the AM scenario because they met the objectives of restoring large tree and large wood components, and emulated the structure-altering effects of wildfires. In the SECC structural stage, low thinnings were used at a rate sufficient to thin approximately 90 percent of the pixels during their residence time in this stage. After low thinning, pixels generally stayed in the same cover type, but were accelerated by 30 years through the SECC structural stage. However, in DF cover types low thinnings were used at a rate to thin only 50 percent of pixels during their residence time.

In the UR and YFMS structural stages low thinnings were generally used at a rate that would thin 75 percent of the pixels during their residence time in this structural stage and were advanced directly to the OMS structural stage in the pre-treatment cover type. However, in the DF cover type, due to root diseases, only 25 percent were thinned and these progressed to C/H YFMS; in the WP and C/H cover types two-thirds of the thinned pixels progressed to the OSS structural stage and only one-third went to the OFMS structural stage. Low thinnings were not used in the OMS and OSS structural stages. Thus, low thinning was used to accelerate the development of stands with large trees.

Overall, we assumed that silvicultural treatments that mimic natural processes affect 75 percent of the pixels, except in the OMS and OSS structural stages which cycle after 300 years. We assumed that there would be active management (for example, tree harvest) in all age classes, including areas that regenerated following large stand-replacing fires in the late 1800s and early 1900s, even though the latter areas are often currently unroaded.

Limitations

In addition to the general limitations and uncertainties described for all of the models, there were many particular to the moist forest models. These are very complex systems with a large number of cover types, cover type-structural stage combinations, and disturbances. Given the complexities and the many ways in which the disturbances interact with one another and with the cover type, structural stage, and successional age, this model was simply a first approximation of the effects of management on succession and disturbance. However, the results are reasonable and represent expert knowledge of the ecologists and forest managers with extensive local experience in both managed and unmanaged stands.

The variants, particularly those for the East Cascades, were created by simply altering cover types. Few other alterations were made (as described above), and we had less overall expertise among the ecologists working on those models. Thus the approximations were more crude and it is very important that the models be carefully examined when adapted to local conditions.

Contagion of disturbance is probably important in moist forests, where the probability that any given point burns in a stand-replacing fire or is logged depends greatly on its location relative to both roads and other burning or logged sites. Yet, we were unable to incorporate that into this model. As a result, the models were more useful for contrasting general trends and relative abundance of cover types and structural stages over relatively large areas, than for predicting either forest characteristics or the occurrence and spatial extent of a given type or severity of disturbance.

Discussion

One of the contrasts between the CD and AM scenarios was in the effects of partial cuts. In the CD scenario, partial cuts favored shade-tolerant tree species. While in the AM scenario, partial cuts left more of the shade-intolerant and often more disease resistant tree species. In contrast to current conditions, western white pine and other early seral tree species, such as western larch, occupied extensive areas under historical conditions. Now, western white pine is much less common, both as a cover type and as a component in mixed stands, due to the introduction of white pine blister rust, logging that often selectively removed white pine, and suppression of the natural fires which often encouraged abundant regeneration of western white pine. Historically, old forests dominated by western larch or white pine were relatively common, depending on the potential vegetation type group, but now these old forests are relatively rare. Under the historical scenario, both stand-replacing and mixed-severity fires burned over relatively large areas at long intervals (150 years or more depending on the PVT, as documented above). Mixed-severity fires reduced tree densities and favored western larch, and possibly white pine, that would have otherwise been lost through advancing succession. Native root diseases removed many Douglas-fir, subalpine fir, and grand fir trees in the SECC and UR structural stages, thus favoring pines and larch.

Under the PM scenario, white pine, western larch, and other early-seral cover types continued to decline in abundance from current conditions, and were much less abundant than in the HI scenario. Root diseases, bark beetles, and fires were the major agents of change. Blister rust continued to remove white pine from stands where they occurred. Jointly with cessation of logging, these disturbances resulted in progressively more dominance by late-seral cover types such as subalpine fir, grand fir, western redcedar (*Thuja plicata*), and western hemlock (*Tsuga* *heterophylla*) – these are the most shade-tolerant of the conifer species that can grow on a given PVT. We assumed that large, stand-replacing fires would occur in the future under the right conditions, and that many of them would be uncontrollable. Therefore, the resulting forests would be of mixed composition with little white pine even on sites where it historically occurred in abundance.

Under the CD scenario, white pine increased over current conditions through aggressive regeneration harvesting and planting of rust-resistant white pine seedlings. However, white pine did not approach historical abundance under this scenario. Partial cutting continued for economic reasons, resulting in continued dominance by late-seral cover types and young, multi-storied forests. Root disease was very abundant, killing many trees and resulting in lost productivity of wood fiber, particularly on drier sites where true firs and other shade-tolerant species now dominate. Not all fires were successfully suppressed, which increased the likelihood that those fires able to burn would be more severe as fuels accumulated and fewer fire-resistant tree species increased in relative abundance.

Under the AM scenario, we assumed a substantial, long-term investment in programs to breed and plant white pine resistant to white pine blister rust. Intermediate stand treatments, such as thinning, were used to manage tree density, growth, and susceptibility to insects and pathogens. Both regeneration and intermediate stand treatments were designed to favor early-seral tree species, such as white pine and western larch. Even with this effort, however, western larch and white pine did not recover to historical abundance levels, especially in old forests. We assumed that stands of Douglas-fir and true firs would be harvested where economical, before root diseases made such harvests difficult to justify economically.

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COLD FORESTS

The cold, harsh climate of the cold forests limits the biomass production and tree growth rates. Winters are harsh, summers are cold, and the growing season is short. Habitat types and plant associations included in the cold forest PVT groups were those that occur in upper subalpine forest environments (Table 12). Productivity on these sites is limited by cold temperatures and frequent frosts, the short growing season, and the poor soils. The soils are variable, but are typically coarse-textured, well-drained, and poorly developed. Most of the organic matter is in the soil surface and the organic layers are on top of the soil.

This PVT group is located in high elevation, montane environments. It is important for watershed protection, scenery, and wildlife habitat. Where whitebark pine is abundant, the stands are important to a wide variety of animal species, especially grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), squirrels, and Clark's nutcracker (*Nucifraga columbiana*). Past tree harvest is relatively rare. On some sites, grazing by domestic sheep and other livestock was intense early in this century and although these forests are still grazed by sheep in some locations, the animal density is much reduced.

In general, the cold forests have been less influenced by human activity than either the moist or warm, dry forests. This is because they are generally less productive of wood fiber and less accessible, since most occur at higher elevations than the moist and warm, dry forests. There are substantial areas of cold forests in wilderness areas and national parks where active management cannot legally occur, even under the CD scenario. Nevertheless, all cold forests, even those in remote wilderness areas and large national parks, have been affected by fire suppression.

Table 12. Representative habitat types and plant associations for the potential vegetation type (PVT) groups included in the successional models for cold forests.

PVT Group	Representative Habitat Types and Plant Associations	Name(s) in Model
Edaphic lodgepole pine	Any in the PICO series, including PICO/VAME, PICO/LIBO, PICO/VACA, PICO/XETE, PICO/CARU, PICO/VASC	LPPA: Yellowstone variant LPPB: Oregon variant
Dry spruce/fir	ABLA/VASC, ABLA/ACGL, ABLA/XETE, ABLA/THOC, ABLA/CARU, ABLA/CAGE, ABLA/ARLA, ABLA/OSCH, ABLA/LUHI	SFDWA: With aspen SFDNA: Without aspen
Harsh spruce/fir	ABLA/ARCO, ABLA/CAGE, ABLA/STOC, ABLA/CACA, ABLA/JUCO, ABLA/CARO, and all in the ABLA-PIAL series	SFWBP: WBP>LPP[1] SFLPP: LPP>WBP[2]
Whitebark pine/alpine larch	Any in the PIAL and LALY series: /VASC, /FEID, /CAGE, /CARU, /JUCO	WBALN (North) WBALS (South)

[1] Whitebark pine more abundant than Lodgepole pine.

[2] Lodgepole pine more abundant than Whitebark pine.

Where whitebark pine occurs, the introduced white pine blister rust has caused extensive mortality and reduced abundance of the whitebark pine cover type relative to historical conditions. Whitebark occurs on the dry spruce/fir, harsh spruce/fir and whitebark pine/alpine larch PVTs.

Successional pathways

The successional pathway diagrams were all relatively simple. Few tree species can dominate on these sites. Subalpine fir and Engelmann spruce were treated as a single cover type. Depending on the individual PVT, one or the other or both dominate in late-seral forest stands. In the edaphic lodgepole pine PVT group, there was no OSS.

Variants were created to represent the major differences in tree composition within PVT groups. Our strategy in developing variants was to use the same successional pathway diagram for all variants and to alter as few disturbance probabilities as possible to create reasonable vegetation dynamics. Variants for the dry spruce/fir, harsh spruce/fir, and whitebark pine/alpine larch were created by altering the seed probabilities. The probabilities governed the proportion of dominant cover types that followed stand-replacing disturbances – in the model, they governed the transition from the shrub- or herb-dominated nonforest community to the tree dominated SI structural stage. As a result, they also governed the relative abundance of cover types in all structural stages. For instance, the principal difference between SFWBP and SFLPP was in the seed probabilities. For SFWBP we set these as 0.9 for WBP and 0.1 for LPP; in SFLPP the seed probabilities were 0.1 for WBP and 0.9 for LPP. Similarly, the two variants of dry spruce/fir, SFASP and SFDNA, differed primarily in the seed probabilities. Ecologically, these are very similar in the successional roles played by tree species, and the effects of insects, pathogens, fire, and tree harvest. The presence or absence of aspen (*Populus* spp.) affects the scenic and wildlife habitat values found in these forests. There are geographical areas within the ICB where aspen is relatively rare in these forests.

In contrast, the variants of edaphic lodgepole pine shared the same successional pathway diagram, but they differed in the probabilities of disturbance (such as fire) and the rates of transition from one structural stage to another. This reflected the lower productivity of the lodgepole pine forests that are found in and around Yellowstone.

Disturbance effects

Fire was and continues to be the major disturbance agent in cold forests, but mountain pine beetle is also important. Tree harvest occurs in some PVT groups, such as the edaphic lodgepole pine and the dry spruce/fir. The cold forests are far less productive for wood fiber than the moist forests and warm, dry forests. However, the wood produced is locally important.

We assumed a constant fire probability historically for each PVT within the group. The fire probabilities were based on published literature (Agee 1993, Arno 1980). Although fire probabilities varied over space, there was remarkable similarity in the mean fire return intervals for a given PVT. Probabilities were simply the inverse of the frequency (Table 14).

Stand-replacing and mixed severity fires are relatively more common than nonlethal fires in the cold forests. Note that while most stand-replacing fires were crown fires, surface fires sometimes replaced stands of fire-sensitive species like subalpine fir.

Table 13. Historical fire intervals and equivalent probabilities used as the basis for adjusting fire probabilities under management scenarios.

Potential Vegetation Type	Name in Model	Fire Interval	Probability
Edaphic Lodgepole pine			
Yellowstone variant	LPPA	200	0.0050
Oregon variant	LPPB	80	0.0125
Dry spruce/fir			
With aspen	SFDWA	185	0.0058
Without aspen	SFDNA	185	0.0058
Harsh spruce/fir			
WBP>LPP[1]	SFWBP	75	0.0130
LPP>WBP[2]	SFLPP	75	0.0130
Whitebark pine/alpine larch			
North variant	WBALN	300	0.0033
South variant	WBALS	300	0.0033

[1] Whitebark pine more abundant than Lodgepole pine.
[2] Lodgepole pine more abundant than Whitebark pine.

The corresponding probabilities were systematically reduced for the different scenarios by multiplying the base fire probability by the numbers listed in Table 14. The reduction accounted for the influence of fire suppression and other effects that reduced overall fire probability. The multipliers were determined by expert opinion. Fire suppression is relatively less effective for stand-replacing than for mixed-severity fires. Where more than one fire severity was considered likely to occur, the probabilities for fires of all severity classes totaled to the overall fire probability. Individual probabilities were adjusted during the workshops based upon model performance and expert opinion.

Mountain pine beetle effects are important in these forests, for they can kill many lodgepole pine and whitebark pine trees, particularly during outbreaks. We did not model their effects until stands reached the SECC, because only stands with relatively large trees support outbreaks. Dwarf mistletoe was modeled as occurring in YFMS and OMS stands, where it acted to prolong the transition times between structural stages on edaphic lodgepole pine and dry spruce/fir PVT groups.

Table 14. Multipliers for fire probabilities to reflect influence of degree of fire suppression activity and relative success by fire severity class. Multipliers differ for each management region under each management scenario. Scenarios are consumptive demand (CD), passive management (PM), and active management (AM).

	CD Management Region[1]			PM Management Region			AM Management Region		
	1	2	3	1	2	3	1	2	3
Harsh spruce/fir (SFWBP & SFLPP)									
Stand-replacing fires	0.8	0.7	0.7	0.8	0.7	0.7	0.8	0.8	0.8
Mixed severity fires	0.8	0.4	0.4	0.8	0.4	0.4	0.6	0.6	0.6
Nonlethal fires	0.8	0.08	0.08	0.8	0.08	0.08	0.2	0.2	0.2
Whitebark pine/alpine larch (WBALN & WBALS)									
Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Mixed severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Non-lethal fires	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.1	0.1
Edaphic lodgepole pine (LPPA & LPPB)									
Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Mixed severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Non-lethal fires	did not occur			did not occur			did not occur		
Dry spruce/fir (SFDWA & SFDNA)									

Stand-replacing fires	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9
Mixed severity fires	0.8	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.5
Non-lethal fires	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.1	0.1

[1] Management region reflects general intensity of management: 1=wilderness, 2=actively managed federal land, and 3=intensively managed, including private and tribal lands.

Management scenarios

In all scenarios, disturbances included fire and mountain pine beetle, with some dwarf mistletoe in the lodgepole pine. Mountain pine beetle kills lodgepole pine, and whitebark pine to a lesser degree. Disturbance by mountain pine beetle in YFMS perpetuated YFMS because the beetles predominantly kill larger trees. When mountain pine beetles disturbed OMS, the result was conversion to UR twice as often as conversion to SI. Mountain pine beetles in UR accelerated the successional transition to OMS. Where stands were actively managed (management regions 2 and 3 under CD and AM scenarios), mountain pine beetle still occurred but at reduced probabilities. Tree harvest was included for the CD and AM scenarios.

Historical (HI)
In the historical scenario, insects, pathogens, and fire occurred at historical levels. We estimated probabilities based upon known levels, such as for fire. However, more often, we used expert judgment and interactive modeling with VDDT (Beukema and others 1996) to develop probabilities that produced the relative abundance of cover types and structural stages that were reasonable and consistent with historical information. Fire, mountain pine beetle, and to a limited degree dwarf mistletoe, were the disturbances affecting vegetation composition and structure.

Consumptive Demand (CD)
In the consumptive demand scenario, commodities were produced by timber harvesting, but only on sites where sustainable. Clearcutting was used where regeneration could be obtained successfully. We assumed that much of the harvesting would be accomplished through thinning and partial cutting that left standing green trees to provide seed and site protection. In the Yellowstone variant of the edaphic lodgepole pine PVT, we assumed that clearcuts would occur without site preparation, and that partial cuts, commercial thinning, and thinning from below would be the common tree harvest techniques. There was no tree harvest in whitebark pine-alpine larch PVT because the sites are poor, resulting in both slow growth and low success with regeneration. The sites are also generally inaccessible by road and often located where roads are expensive to build. Grazing occurred on all of the sites, but with low forage production did not alter successional patterns at the coarse resolution of the model.

Passive Management (PM)
Fires were suppressed in the passive management scenario. There was no tree harvest,

prescribed fire, or other active management to alter the occurrence, severity, or extent of insect and pathogen activities. Similarly, there was no attempt to limit the spread or the invasion of exotic plant species, even if these had negative consequences for the native animal diversity or had negative watershed impacts following fires. No grazing of domestic livestock occurred.

Active Management (AM)
In the active management scenario, fires were actively suppressed for all sites. Prescribed fires were used on some sites. Timber harvest was used where it would be useful in creating stand structures and compositions in the approximate relative abundance found historically in these cold forests. Wood fiber and other commodities were produced where consistent with enhancing and maintaining ecosystem function. Tree harvest focused on density management. Relative to the CD and PM scenarios, old forests were promoted to approximate their relative abundance under the HI scenario. Clearcutting without site preparation was not used in management region 2. Instead, partial cutting, high thinning, and commercial thinning were used to manage stand structure. For instance, commercial thinning in the SECC was designed to accelerate the successional development to UR and eventually to OMS.

In the SFWBP and SFLPP PVTs, we adjusted the fire probabilities as described above and then partitioned those into wildfires and prescribed fires. In wilderness and parks (management region 1), 30 percent of all fires were planned prescribed fires, 60 percent of all fires were prescribed fires with unplanned ignitions, and the remainder were wildfires. Within both actively managed areas (management regions 2 and 3), we assumed that 10 percent of all fires were wildfires, 10 percent were prescribed fires ignited by managers, 10 percent were prescribed fires with unplanned ignitions, and 70 percent of all fires were mimicked through tree cutting.

Tree cutting treatments in the SFWBP and SFLPP PVTs are defined as follows. The CC+Reserve mimicked stand-replacing fires by cutting 70 percent of the standing trees and burning the remaining 30 percent in order to kill them, allowing for 50 percent consumption of the woody debris less than 3 inches in diameter. This action was then followed by planting seedlings resistant to white pine blister rust. Group selection approximated the effects of mixed severity fires by removing all shade-tolerant trees, removing fire-intolerant trees, burning, and (in whitebark pine cover types) planting seedlings resistant to white pine blister rust. Thin2 treatments approximated surface fires by removing small tress and then igniting prescribed fires. CC+ResPlant mimicked stand-replacing fires by clearcutting 70 percent of the standing tree basal area, burning in order to kill the remaining 30 percent, and planting seedlings resistant to white pine blister rust. GRPSelPlant approximated the effects of mixed severity fires by cutting all shade-tolerant trees, removing some whitebark pine, underburning, and (in whitebark pine cover types) planting white pine blister rust-resistant seedlings.

For those PVT groups that supported whitebark pine (dry spruce/fir, harsh spruce/fir, and whitebark pine/alpine larch), there were intensive efforts to reduce the mortality due to blister rust. We assumed that there would be the necessary investment in research and application to reduce the probability of mortality due to blister rust by 50 percent in all structural stages.

In the whitebark pine/alpine larch PVT, we assumed that no tree harvest was possible. All active management involved prescribed fires with both unplanned (lightning) and planned (manager-ignited) fires. For both the wilderness and the multiple-use federal lands, we assumed that 0.3 of the wildfires were planned, 0.6 were unplanned, and 0.1 were wildfires.

Limitations

There are few fire history data available for cold forests. Such information is limited to a few geographical areas. We included only those disturbances that would change cover type, structural stage, or successional age at the coarse scale (1 km^2 or 250 ac). Thus, disturbances that would affect individual or small groups of trees were not included.

No contagion of fire, tree harvest, insects, and pathogens were included in the models. We know that the likelihood of any place being affected by disturbance depends, in part, on whether adjacent stands are affected. We were unable to represent this in the models, but this could be incorporated as models are adapted in the future.

That there will be sufficient investment in research and development to reduce blister rust-caused mortality by 50 percent in whitebark pine forests is a big solution that is potentially unfounded. Significant efforts have been made over the last 60 years to develop and plant rust-resistant western white pine on the moist forest PVTs, but those efforts have focused on a species that is commercially important. This is an expensive program. However, the ecological integrity of the forests where whitebark pine and western white pine were historically abundant depends upon active management of the rust and its impacts.

Discussion

Although the cold forests have been less affected by humans than forests at lower elevations, human actions have advanced succession, primarily through fire suppression. Where whitebark pine occurs, it has declined greatly in abundance from historical to current times due to the introduction of white pine blister rust, less frequent fires, and the effects of mountain pine beetle.

In the historical scenario, disturbances by fire, insects, and pathogens were frequent, though they occurred less often than in forests at lower elevations. Nonlethal, stand-replacing, and mixed severity fires largely governed the relative abundance of cover types and structural stages. There was a diverse mixture of cover types and structural stages on the landscape. In general, forests were more heterogeneous historically than they are currently. Dense, uneven-aged forests of climax tree species are very susceptible to native insects and pathogens, especially during droughts, but the relative abundance of these types is less historically than currently.

Under the PM scenario, fires were suppressed and there was no other active management. However, not all fires can be suppressed. As a result, current trends would intensify, driven by insects, pathogens, and fire. Fuels would continue to accumulate and multi-storied stands dominated by shade-tolerant, late seral species would become increasingly common with time. Stand-replacing fires would continue to be common.

Under the CD scenario, there were fewer old forests than historically, but the contrast between HI and CD was less than for forests at lower elevations. Although fires were suppressed, stand-replacing and mixed severity fires would occur because of the difficulties in suppressing these fires.

In the AM scenario, management was designed to address the current conditions found in these forests, including reduced productivity and increased dead and live biomass which could fuel severe wildfires. More old forests were found on the landscape, but they were less abundant than in the HI scenario. Some commodities were produced, but fewer trees were harvested than in the CD scenario.

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SHRUBLANDS

Shrubland PVTs included nine sagebrush steppe types and one each of salt desert shrub, mountain shrub, and antelope bitterbrush types (Table 15). The sagebrush steppe was represented by PVTs dominated by basin big sagebrush (*Artemisia tridentata tridentata*), Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), mountain big sagebrush (*Artemisia tridentata vaseyana*), three-tip sagebrush (*Artemisia tripartita*), and low sagebrush (*Artemisia arbuscula*). While many communities dominated by other species of sagebrush occur in the ICB, they seldom occur in large patches. Nor can they be readily differentiated with remotely sensed data. The low sagebrush PVT models were based on low sagebrush, but also included many other of the dwarf species of sagebrush such as stiff (*Artemisia rigida*), black (*Artemisia arbuscula nova*), and early low sagebrush (*Artemisia longiloba*). Communities of these other dwarf species may be locally common.

The Wyoming big sagebrush communities were divided into two broad groups - hot and cold. This division was made to separate out the influence of medusahead (*Elymus caput-medusae*), cheatgrass, and other annual grasses on fire occurrence and succession of these communities.

The hot Wyoming big sagebrush sites, primarily associated with Sections 342C, 342I, and 341E, are more heavily affected by exotics and these changes were considered to be irreversible. With current technology, the only feasible method to replace the exotics is through a seeding program which may necessarily include herbicides. In many instances exotic species such as crested wheatgrass (*Agropyron cristatum*) or varieties such as fairway crested wheatgrass may have to be utilized due to low native seed availability and poor seedling establishment. The lower Snake River Plain and basin of central Washington (sections 342C, 342I, and 341E) are most affected but the occurrence of cheatgrass is throughout the ICB. Succession of Wyoming big sagebrush communities in other portions are best modeled by WBSC unless the user has other information upon which to base the decision. Succession of the mountain big sagebrush communities was represented by 3 models (BSMW, BSML, and BSME). The models were very similar in pattern but were adjusted for regional differences in successional rates and susceptibility to invasion by exotic species.

Basin Big Sagebrush has not been adequately described in the literature. It is a moderately common habitat type that occurs on relatively wide alluvial valley bottoms at lower elevations throughout the Great and Columbia Basins. Most of this habitat type has been altered by human management through agriculture, severe grazing, and lowering of the water table. Those areas currently in natural vegetation are frequently dominated by basin big sagebrush and annual grasses. Although this habitat type has not been adequately described, it has been referred to in several publications including Bunting and others, 1985 and Bunting and others, 1987. Most of this vegetation is probably seral to coniferous communities dominated by ponderosa pine, Douglas-fir, and other species.

Table 15. Representative habitat types and plant associations for the potential vegetation type groups included in shrublands vegetation.

PVT	Representative Habitat Types and Plant Associations	Name
Salt desert shrub [SRM 414]	Daubenmire 1970: Grayia spinosa-P. secunda, Eurotia lanata-P. secunda (Does not fit model well but doesn't fit into other models either)	SDSH
Basin big sagebrush/wildrye steppe [SRM 401]	N/A	BSBW

Low sagebrush steppe (mesic) [SRM 320, 321, 405, 406]	Mueggler and Stewart 1980: Artemisia arbuscula/A. spicatum, A. arbuscula/F. idahoensis Hironaka and Fosberg 1983: Artemisia nova/A. spicatum, A. nova/F. idahoensis, A. arbuscula/P. sandbergii, A. arbuscula/A. spicatum, A. arbuscula/F. idahoensis, Artemisia longiloba/F. idahoensis	LSME
Low sagebrush steppe (xeric) [SRM 407]	Daubenmire 1970: Artemisia rigida Hironaka et al. 1983: A. rigida/P. sandbergii	LSXE
Wyoming big sagebrush steppe (hot)	Daubenmire 1970: A. tridentata/A. spicatum Mueggler and Stewart 1980: A. tridentata/A. spicatum (Mont) Hironaka et al. 1983: A. tridentata subsp. wyomingensis/P. sandbergii, A. wyomingensis/Sitanion hystrix, A. wyomingensis/Stipa thurberiana, A. wyomingensis/A. spicatum, A. wyomingensis/Stipa comata, A. tridentata subsp. tridentata/A. spicatum	WBSW
Wyoming big sagebrush steppe (cold), primarily ARTRWY in sections not listed above [SRM 403]	Daubenmire 1970: A. tridentata/A. spicatum Mueggler and Stewart 1980: A. tridentata/A. spicatum Hironaka et al. 1983: A. tridentata subsp. wyomingensis/P. sandbergii, A. wyomingensis/Sitanion hystrix, A. wyomingensis/Stipa thurberiana, A. wyomingensis/A. spicatum, A. wyomingensis/Stipa comata, A. tridentata subsp. tridentata/Agropyron spicatum, A. tridentata subsp. tridentata/F. idahoensis	WBSC
Threetip sagebrush steppe [SRM 324, 404]	Daubenmire 1970: Artemisia tripartita/A. spicatum Mueggler and Stewart 1980: A. tripartita/F. idahoensis Hironaka et al. 1983: A. tripartita/A. spicatum, A. tripartita/F. idahoensis	TTSA

Mountain big sagebrush (WEST) primarily ARTRVA in sections 342 & 341 [SRM 402]	Daubenmire 1970: A. tridentata/F. idahoensis Hironaka et al. 1983: A. tridentata subsp. vaseyana/A. spicatum, A. vaseyana/F. idahoensis, A. vaseyana/S. comata, A. vaseyana-Symphoricarpos oreophilus/A. spicatum, A. vaseyana-Symphoricarpos oreophilus/F. idahoensis, A. vaseyana- Symphoricarpos oreophilus/Carex geyeri Johnson and Simon 1983: A.vaseyana/F. idahoensis, A. vaseyana/Carex geyeri, A. vaseyana-Purshia tridentata/F. idahoensis, A. vaseyana-Symphoricarpos oreophilus/Bromus carinatus	BSMW
Mountain big sagebrush (EAST), primarily ARTRVA in sections 331, 332 & 333 [SRM 314, 315, 316]	Daubenmire 1970: A. tridentata/F. idahoensis Mueggler and Stewart 1980: A. tridentata/F. idahoensis, A. tridentata/F. scabrella Hironaka et al. 1983: A. tridentata subsp. vaseyana/A. spicatum, A.vaseyana/F. idahoensis, A. vaseyana/S. comata, A. vaseyana-Symphoricarpos oreophilus/A. spicatum, A. vaseyana-Symphoricarpos oreophilus/F. idahoensis, A. vaseyana- Symphoricarpos oreophilus/Carex geyeri	BSME
Antelope bitterbrush steppe [SRM 101, 302]	Daubenmire 1970: Purshia tridentata/F. idahoensis Mueggler and Stewart 1980: Purshia tridentata/F. idahoensis, Purshia tridentata/F. scabrella Hironaka et al. 1983: Purshia tridentata/A. spicatum, P. tridentata/Stipa comata Johnson and Simon 1987: Purshia tridentata/F. idahoensis, P. tridentata/	PUTR
Mountain shrub [SRM 419, 420, 421]	Johnson and Simon 1987: Symphoricarpos albus-Rosa spp., Physocarpus malvaceus/S. albus	MTSH

Disturbance effects

While it is generally assumed that fire's influence has diminished from historical periods for most Shrubland PVTs, a notable exception is the Wyoming Big Sage-Warm PVT. The ecology of this PVT has been extensively altered by the introduction of exotic grasses. These grasses are primarily cheatgrass and medusahead within the ICB, although other annual grass species may be locally important. Within this PVT, annual grasses have altered two important processes: herbaceous plant recruitment and fire frequency. This change has resulted in a landscape dominated by annual grasses with ecological processes largely determined by frequent fires. The changes are considered irreversible.

Historically, fire was the major disturbance factor that altered composition on a large scale. Fire was only moderately common in the Wyoming Big Sage-Warm PVT, due to low levels of fine fuel production. Occasional epidemic levels of the Aroga moth *(Aroga websteri)* occurred, but these normally affected limited areas. As a consequence, this PVT in the HI management scenario was dominated by community types with a mature sagebrush overstory and a perennial grass understory. The remainder was composed of other early- and mid-successional stages.

Exotic grasses were the major influence on natural processes that shaped this PVT in the PM, CD, and AM management scenarios. The model projections predicted a continual increase in exotic-dominated communities with a corresponding decrease in native community types. Exotics were predicted to dominate 85 percent of the PVT land area under the CD management scenario in the 300 year projection. With active management, native-dominated cover types were maintained on about 50 percent of the PVT area. This reduction was achieved primarily through the seeding of native grasses and increased fire suppression activity.

In response to vegetation depletion from livestock use early this century, and conversion to annual grasses in the later half, considerable area of the Wyoming Big Sage Warm PVT has been seeded to exotic perennials of wheatgrasses. These seeded areas were also considered a permanent stage, but sagebrush may re-establish. The establishment of the perennial wheatgrasses has significantly reduced fire potential as compared to the native- or annual-dominated condition.

Management Scenarios

Historical (HI)

The historical scenario was used to evaluate the Big Sage Warm PVT. The relationships within the model were considered reasonable if the stable proportion of structural stages within a PVT approximated the historical condition. However, it must be emphasized that the structural stage proportions are not known precisely, and that wide variation in the proportion of structural stages undoubtedly occurred through time. It was assumed that the ecological changes due to Euro-American development and the introduction of exotic species are irreversible. The HI conditions cannot be reproduced under any management scenario.

Consumptive Demand (CD)

The Consumptive Demand scenario assumed that the primary commodity produced by the non-forested lands would be livestock forage. All decisions were made to maximize the amount of forage available. Management practices that were emphasized (those with high probability) to meet this objective included prescribed fire, seeding of depleted lands (particularly those dominated with noxious weeds or annual grasses), and herbicide application to control noxious and other weeds. Other multiple uses were accommodated where they were compatible with livestock forage production.

Passive Management (PM)
The PM scenario assumed that there would be no commodity production from federally managed lands. Fire suppression would continue at current levels. Exotic plants would continue to expand in many PVTs and those species placed into a state noxious weed category would need to be controlled. Due to the changes initiated by fire suppression and weed introduction, the proportion of structural stages would not approximate the historical steady state condition.

Active Management (AM)
The AM scenario included active management of vegetation with emphasis on natural processes. This scenario included commodity production, but emphasis was placed on vegetation management activities that tended to include historical disturbances and maintain historical proportions of structural stages. However, it was assumed that historical levels of structural stages or disturbance could not be reproduced due to a number of irreversible alterations to this PVT. The use of prescribed fire was the primary vegetation management activity. Fire was used to re-establish former extents of forest, woodland, and rangeland vegetation types. Livestock grazing was included in the scenario, but primarily as a vegetation management technique rather than a means to achieve economic production. Reclamation of land dominated by exotics was emphasized, and seeding of depleted land was practiced using native species if possible. Herbicides were used only to control designated noxious weeds, not as a general vegetation management technique.

GRASSLANDS

Two grassland PVTs were modeled, the Agropyron Steppe (AGST) and Fescue Grassland (FESC) represent the xeric and mesic grasslands of the ICB, respectively. Typical vegetation is located in the Palouse and canyons below the conifer zone. Most of the AGST PVT area has been altered by human use and exotic species invasion. For many of the exotics, the changes were considered to be irreversible and tended to stabilize in exotic dominated communities without major management intervention. Most of the AGST area has annual grasses as a dominant or co-dominant species. Currently, the area is undergoing another transformation to dominance by one of several knapweeds, crupina (*Crupina* spp.), or other exotic forbs.

Examples of near pristine FESC are more easily found but are also subject to exotic species invasion, particularly by the knapweed group. AGST and FESC sites dominated by exotics were considered to be stable. Re-establishment of native vegetation species would require management activities such as herbicide and seeding treatments.

Table 16. Habitat types associated with Interior Columbia Basin grasslands.

PVT	Representative Habitat Types and Plant Associations	Name
Bluebunch wheatgrass steppe [SRM 317, 318, 319, 104, 105]	Daubenmire 1970: Agropyron spicatum/Poa secunda, Sporobolus cryptandrus-P. secunda, Aristida longiseta-P. secunda	
	Tisdale 1979: A. spicatum/Poa sandbergia, A. spicatum/Opuntia polyacantha	
	Mueggler and Stewart 1980: A. spicatum/P. sandbergia, A. spicatum/A. smithii	
	Johnson and Simon 1983: A. spicatum/Eriogonum hieracleoides, A. spicatum-P. sandbergii (basalt), A. spicatum-P. sandbergii/ Scutellaria angustifolia, A. spicatum-P. sandbergii/ Astragalus cusickii, A. spicatum-P. sandbergii/Erigeron pumilis, A. spicatum-P. sandbergii (granite), A. spicatum-P. sandbergii (scabland), A. spicatum-P. sandbergii/Phlox colubrina, A. spicatum-P. sandbergii/O. polyacantha, A. spicatum-Sporobolus cryptandrus-Aristida longiseta	

Fescue grassland [SRM 102, 103, 108, 304, 307, 311, 312]	Daubenmire 1970: A spicatum-Festuca idahoensis, F. idahoensis-Hieracium cynoglossoides, F. idahoensis /Symphoricarpos albus, Stipa comata-P. secunda Tisdale 1979: F. idahoensis/Koeleria cristata, F. idahoensis/S. albus, F. idahoensis/A. spicatum Mueggler and Stewart 1980: Festuca scabrella/A. spicatum, F. scabrella/F. idahoensis, F. idahoensis/A. smithii, F. idahoensis/A. spicatum, F. idahoensis/Carex filifolia, F. idahoensis/Stipa richardsonii Johnson and Simon 1983: Festuca virdula-Carex hoodii, F. viridula/Lupinus laxiflorus, F. idahoensis-K. cristata (ridgetops), F. idahoensis-K. cristata (mounds), F. idahoensis-K. cristata (high elevation), F. idahoensis-K. cristata (low elevation), F. idahoensis-A. spicatum (ridgetops), F. idahoensis-A. spicatum/Lupinus sericeus, F. idahoensis-A. spicatum/Balsamorhiza sagittata, F. idahoensis-A. spicatum/P. colubrina, F. idahoensis-Danthonia intermedia, F. idahoensis-Carex hoodii, F. idahoensis- Carex geyeri

WOODLANDS

Overall, the climate of the woodland PVT groups is warmer and drier than the forests, but milder than the adjacent shrublands and grasslands. The habitat types and plant associations are diverse (Table 17). Tree regeneration and growth are slow. It takes several centuries for climax stand conditions to develop in the absence of disturbance.

Woodlands are seldom included in the managed timber base, but they are a source of fuelwood. Woodlands are often used for livestock grazing, which does not affect the successional patterns substantially. Many wildlife species use limber pine forests for forage and protection, particularly in the winter. Due to the low productivity, trees in woodlands are not typically cut for lumber. However, in areas adjacent to mines and small communities where few other tree species were available, trees were cut for mine timbers, charcoal kilns, and fuelwood. Scenery and watershed protection are important values of woodlands.

The structure and composition of vegetation in woodlands is largely determined by the dry, harsh climate, fire, and past human influence. Many different shrub, herb, and grass species are found within woodland communities, particularly where tree canopies are sparse. Species composition can vary greatly from site to site. As many woodlands have become more dense within the last century due to fire exclusion, understory plants have often become less abundant. Within the last century, limber pine has expanded into communities formerly dominated by mountain big sagebrush and other shrubs or grasses. Often, the expansion has been the result of fire exclusion. In some areas, however, the expansion could be partially attributed to very heavy grazing early in this century.

Three juniper woodland models were developed (LSMJ, LSXJ, BSMJ). These were modifications of low sagebrush steppe (LSME, LSXE) and mountain big sagebrush steppe (BSMW) models since sagebrush usually occurs as a seral stage in the development of this vegetation. Western juniper (*Juniperus occidentalis*) woodlands were used as the typical type because they are the most common in the ICB. These were also applied to the Utah juniper (*Juniperus osteosperma*) woodlands found within the southeastern ICB, but some modifications may be required to make the models more representative of this vegetation's dynamics when analysis is performed at finer scales. Juniper woodlands presented the most variety of management opportunities of all the types modeled. Consequently, management activities such as woodcutting, mechanical control, prescribed burning, and seeding were included in the models. The warmer juniper woodlands, particularly Utah juniper, has been affected by annual grass invasion which has altered fire probabilities and successional rates in some localities.

Conifer encroachment into non-forest vegetation during the current period is a widespread process in the ICB. The MBSC model was developed to represent encroachment by species other than juniper. This model was extremely general considering the wide variety of vegetation affected. The encroachment process has affected fescue grasslands, mountain big sagebrush steppe, mountain shrublands, curlleaf mountain-mahogany (*Cercocarpus ledifolius)*, and aspen woodland vegetation. Users may find it more appropriate to modify these models to include the encroachment process rather than using MBSC when doing finer scale analyses. Fire was assumed to be the primary factor limiting conifer development in these communities during the historical period.

Development of the Mountain Big Sagebrush-Mesic with Juniper PVT included those areas within the mountain big sagebrush zone that may potentially develop juniper woodland vegetation. Currently this PVT is within the ecotone between the sagebrush-dominated and conifer-dominated types in the south, and parts of the eastern portions of the ICB. Within the ICB, the primary juniper species is western juniper. However, this PVT may also include Utah juniper in the southeastern portion of the ICB or Rocky Mountain juniper (*Juniperus scopulorum*) in portions of western Montana. Fire was the primary limiting factor for the dominance of juniper in the HI scenario. Although juniper woodlands have a number of biological controls, none are apparently capable of removing major portions of the stand and setting succession back to a shrub- or herb- dominated stage. Fire probabilities were relatively high for sites occupied by sagebrush or herbland stages and these cover types occupied the major portion (75 percent) of the type. Probabilities declined rapidly as the juniper stands developed dominance. Once fully mature woodlands develop, they become resistant to low and moderate intensity fires. Woodland structural stages accounted for about 25 percent of the PVT in the HI scenario.

Table 17. Representative habitat types and plant associations for the potential vegetation type (PVT) groups included in the woodland models.

PVT	Representative Habitat Types and Plant Associations	Name
Limber Pine	Any in the PIFL series, including /CELE, /FEID, /JUCO, /HEKI	LIMP
Oregon White Oak		WOAK
Curl-leaf mountain-mahogany woodland, primarily in sectiom M332 [SRM 415]	Mueggler and Stewart 1980: Cercocarpus ledifolius/A spicatum Hironaka et al. 1983: C. ledifolius/A. spicatum Johnson and Simon 1987: Cercocarpus ledifolius	CEW1
Curl-leaf mountain-mahogany woodland with sagebrush, primarily in sections M331, 341 & 342 [SRM 322]	Mueggler and Stewart 1980: Cercocarpus ledifolius/A spicatum Hironaka et al. 1983: C. ledifolius/A. spicatum Johnson and Simon 1987: Cercocarpus ledifolius	CEW2
Low sagebrush (mesic)/juniper woodland [SRM 412]	Hironaka et al. 1983: J. occidentalis added to A. arbuscula/A. spicatum, A. arbuscula/F. idahoensis	LSMJ
Low sagebrush (xeric)/juniper woodland [SRM 412]	These generally include Juniper associated with A arbuscula, A. nova and A rigida that occur on very xeric shallow sites. ie : Hironaka et al. 1983: J. occidentalis added to A. arbuscula/A. spicatum, A. arbuscula/F. idahoensis	LSXJ
Juniper Woodlands	With the exception of Johnson and Simon (1987), no habitat types for the juniper woodlands of the CRB have been described. They include vegetation dominated by J. occidentalis, J. scopulorum or J. ostreosperma-Pinus monophylla.	JUOC

Mountain big sagebrush/ juniper woodland [SRM 412]	Hironaka et al. 1983: J. occidentalis added to A.vaseyana/F. idahoensis, A. vaseyana-Symphoricarpos oreophilus/ /F. idahoensis Johnson and Simon 1987: J. occidentalis/F. idahoensis-A. spicatum	BSMJ
Mountain big sagebrush/conifer woodland [SRM 317, 324]	These are primarily mountain big sagebrush hts with conifers added. Mueggler and Stewart 1980: A. tridentata/F. idahoensis, A. tridentata/F. scabrella Hironaka et al. 1983: A. vaseyana/A. spicatum, A.vaseyana/F. idahoensis, A. vaseyana-Symphoricarpos oreophilus/A. spicatum, A. vaseyana-Symphoricarpos oreophilus/F. idahoensis, A. vaseyana-Symphoricarpos oreophilus/Carex g	
Aspen woodland	Aspen community types have been described for the southeastern portion of the CRB by Mueggler and Campbell (1982), for southwestern Montana by Hansen et al. (1988) and for western Wyoming by Youngblood and Mueggler (1981). Many are seral communities of coniferous vegetation types. Another includes Johnson and Simon 1987: Populus tremuloides.	

Successional pathways

The successional pathway diagrams for the woodland types were much simpler than those for the forest PVT groups. Although grazing, diseases, and insects occurred, they seldom altered successional pathways.

In the limber pine PVT group, there was only one cover type. Although juniper and Douglas-fir could be found in stands on some sites, limber pine dominated, especially in near-climax conditions. Only four structural stages were common, as there were few YMS and OSS stands.

Other Woodland PVTs included a variety of tall shrub and dry forest types. There were two curl-leaf mountain-mahogany PVTs, CEW1 and CEW2. The primary difference was the occurrence of sagebrush within the type. CEW1 was associated with grassland vegetation and generally contained little or no other subdominant shrub species. CEW2 occurred within the sagebrush steppe region. Mountain big sagebrush and many other associated shrub species, such as snowberry (*Symphoricarpus albus*), occurred as part of the community. Sagebrush steppe may also have developed as a seral dominant prior to mountain-mahogany establishment. Curl-leaf mountain-mahogany communities may also have occurred as seral vegetation types within a number of conifer types, such as Douglas-fir, white fir, and limber pine. It was assumed that these seral communities were included in the relevant models developed by the forest PVT group.

The Conifer/Fescue PVT represented the ecotone between the forested and grassland PVTs of much of the northern portion of the ICB. This PVT was often found within the major river canyons and wide valley slopes that dissect the northern portion of the region. As with the Mountain Big Sagebrush/Mesic Juniper PVT, fire historically determined much of the dynamic boundary between forest and non-forest. The most common forested types adjacent to the herblands were those dominated by ponderosa pine, Douglas-fir, or both. Other conifers may be locally important as well. In many instances, the forest community was very open and contained a well developed grass-dominated understory. Idaho fescue (*Festuca idahoensis*) and wheatgrass were the most widespread grasses. In general, sagebrush was not a component of the vegetation during any successional stage. As fire became more frequent locally, herbland stages became more prevalent. Localities or periods of time with less frequent fire allowed forests to expand into the adjacent herb communities. The model predicted that on average, spatially or temporally, conifer communities accounted for roughly 45 percent and herb-dominated communities about 55 percent of the Woodland PVT area in the HI scenario.

Management Scenarios

In the CD scenario, conifer-dominated stages increased greatly as a response to decreased fire occurrence. In addition, much of the original grassland area was subject to invasion by exotic herbs, primarily knapweed and starthistle (*Centauria* spp.). These species may also have occupied the understory of the open conifer types. The model predicted that nearly 10 percent of the former herb-dominated area would have an exotic herb-dominated community. An additional 20 percent of the area would become open conifer stages with exotics as the dominant understory. These may be conservative estimates, as these species continue to expand their range and the ecological amplitude of this group is not known. Steep dissected topography limits the use of the most successful seeding practices within the PVT, making restoration to native grassland difficult.

Both the CD and AM scenarios were predicted to have greater areas dominated by conifers (80 and 70 percent respectively) as compared to HI. Under the AM scenario, exotic herbs dominated much of the former grassland and open conifer communities, but to a lesser extent than the under CD. Exotic-dominated communities are less flammable than the native grass-dominated types. This would result in reduced fire occurrence and hasten the succession from grassland stages to conifer-dominated stages, and open conifer to closed conifer stages.

Many areas of the ICB dominated by mesic sagebrush or grassland PVTs have also been affected by the introduction of one of several exotic perennial broadleaved plants. Of particular widespread current importance within the ICB are the knapweeds, yellow starthistle *(Centaurea solstitialis*), whitetop (*Cardaria draba*), skeletonweed (*Chondrilla juncea*) , and leafy spurge (*Euphorbia esula*). Many other plant species are potentially important locally. The domination of the plant community by these plants has altered many ecological processes associated with the historical condition.

Historical wildlife herbivory was generally considered to have occurred at chronic levels, and was included in the "normal" factors influencing vegetation succession. Herbivory by domestic livestock remained as a dominant land use of non-forested vegetation within the ICB and continued to affect some of the ecological processes and vegetation patterns observed.

Insects, pathogens, rodents, and other biological factors were recognized as important determinants of vegetation pattern, but the specific effects have not been quantified for most rangeland vegetation types. Therefore, their epidemic level influences were not accounted for in the models.

Active fire suppression and consumption of fine fuels by domestic livestock reduced the probability of fire and often accelerated the rate of juniper woodland development. Woodland development further reduced herbaceous (fine fuel) production, which in turn additionally decreased fire probabilities. The CD scenario assumed more intensive management of the woodland overstory, via clearcutting, prescribed burning, and other practices, to maintain the shrub and herbaceous stages. The open woodland structural stage accounted for 10 percent and other woodland stages compromised five percent of the CD scenario land area, for a total juniper woodlands area of only 15 percent.

Exotic annual grasses occurred in the more arid portions of this PVT. The presence of these species increased fire probabilities and reduced natural regeneration of native herbaceous plant species. This resulted in a landscape dominated by cover types with overstories of sagebrush or juniper and understories dominated by exotic forbs and grasses as characterized by CD and AM. Fires in the annual grass-dominated understories resulted in cheatgrass-dominated communities in sagebrush/cheatgrass cover types, and open juniper woodland with cheatgrass understories in juniper/cheatgrass and juniper/sagebrush/cheatgrass cover types. Without successional mechanisms available to progress from these stages, seeding of native perennial grasses was commonly employed to re-establish the native species on the sites. Exotic grasses may be used instead of native grasses for the CD and AM scenarios to re-establish perennial grasses on the site.

Disturbance effects

Limber pine

No disturbances other than fire were included in the models. Although limber pine sites were grazed, we assumed that succession was not affected. Bark beetles and white pine blister rust occurred, yet their effects were localized. We assumed that there would be no tree harvest other than opportunistic cutting of relatively large trees. Removing many such trees would not be sustainable.

We assumed a constant fire probability historically for each PVT within the group. Based on published literature, we assumed that the historical fire probabilities were constant for a given PVT. Although fire probabilities varied over space, there was remarkable similarity in the mean fire return intervals for a given PVT. Probabilities were simply the inverse of the frequency (Table 18).

Table 18. Historical fire intervals and equivalent probabilities.

Potential Vegetation Type	Name in Model	Fire Interval	Probability
Limber pine	LIMP	50	0.020
White oak	WOAK	50	0.020

Limber pine PVT sites are often rugged and inaccessible, fires are typically patchy and small, and the fire suppression priority is low (Bradley and others 1992). Not much forage exists, so the sites are not grazed heavily enough to change the fire probabilities significantly. Nonlethal surface fires seldom occurred, and mixed severity fires were 8 to 10 times as common as stand-replacing fires. Fire frequency was variable (Cooper 1975) and based upon these data we used a historical fire frequency of one every 50 years for mixed severity fires, shared between understory reinitiation and old multistory stands. Cooper (1975) found 6 fire scars in 300 years on a Douglas-fir tree associated with a limber pine stand. Gruell (1983) reported a mean fire interval of 74 years in a limber pine/bluebunch wheatgrass stand in southwestern Montana. Keown (1977) reported a mean fire interval of 100 years in a Montana limber pine stand with grass and shrub understory. Mixed and stand-replacing fires have become more common under fire exclusion policies.

Fire exclusion has been quite effective in woodlands in the last century, as evidenced by the encroachment of limber pine into adjacent sagebrush-grasslands, and by the increased tree density relative to historical reports and photographs. We assumed that fire suppression was effective at reducing the probability of mixed severity fires, but not stand-replacing fires, under the CD, PM, and AM scenarios (Table 19). The multipliers were determined by expert opinion.

Table 19. Multipliers for fire probabilities to reflect influence of degree of fire suppression activity and relative success by fire severity class.

	CD Management Region[1]			PM Management Region			AM Management Region		
	1	2	3	1	2	3	1	2	3
Limber pine (LIMP)									
Stand-replacing fires	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mixed severity fires	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Nonlethal fires	did not occur			did not occur			did not occur		

Limitations

The models were necessarily generalized across a tremendous range of environmental conditions, disturbance histories, species composition, and genetic makeup of the plant communities represented. We were unable to reflect the differences in succession that occurred with different understory plant species composition and structure. We urge those who use, interpret, and apply these models not to substitute model output for local site and stand information when formulating stand management decisions.

Fire probabilities reflected the average influences of fire occurrence and fire suppression, and could not reflect the probabilities for each unique place. The general effects of roads, valley settlement, and other pervasive effects were considered in the fire probabilities, but we could not reflect their influence on fire probabilities in specific locations or under different land ownership. Furthermore, no contagious fire spread was represented in the model.

Discussion

For the limber pine PVT, there were no differences among management scenarios under the HI, CD, and PM scenarios. In the AM scenario, we used prescribed fire (both natural and management-ignited) in management region 1, the wilderness.

In all scenarios, fires maintained a mix of structural stages. The SI structural stage and shrub-dominated vegetation were the most common, but UR, SECC, and OMS were also fairly common. The differences in relative abundance of the structural stages among scenarios was subtle, but significant.

In the CD, PM, and AM scenarios, fires were actively suppressed. Relative to the historical condition, fewer old multi-story stands existed. Under these three management scenarios, stand-replacing fires were more common than they were historically, partly because of the effectiveness of fire suppression at reducing the probability of mixed severity fires. The SI structural stage and vegetation dominated by shrubs (without trees) would be more abundant under the CD, PM, and AM scenario than historically. OMS was less common than historically.

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RIPARIAN VEGETATION

Riparian vegetation within the ICB does not occur in patches of sufficient size or shape to be detected with remotely sensed data at the 1 km^2 scale. Therefore, the development team did not attempt to encompass all the variation present in riparian vegetation of the ICB. However, four riparian models were developed that represented successional patterns in the more common broadscale situations (Table 20). They included: greasewood flats (SARP), graminoid meadows (RIGR), willow dominated valley bottoms (SALX), and riverine cottonwood groves (CTRV).

Table 20. Representative habitat types and plant associations for the potential vegetation type (PVT) groups included in the riparian models.

PVT	Representative Habitat Types and Plant Associations	Name
Big greasewood/ryegrass [SRM 422]	Daubenmire 1970: Sarcobatus vermiculatus/Distichlis stricta (marginal fit)	SARP
	Mueggler and Stewart 1980: S. vermiculatus/A. smithii, S. vermiculatus/Elymus cinereus	

Riparian graminoid [SRM 308, 313]	Mueggler and Stewart 1980: F. idahoensis/Deschampsia caespitosa, D. caespitosa/Carex spp. Johnson and Simon 1987: D. caespitosa/Carex spp. (moist), D. caespitosa/Carex spp. (wet), Carex spp. (wet) Youngblood et al. 1985: Carex microptera, Carex simulata, C. rostrata, C. aquatilis, C. nebrascensis, Juncus balticus, Deschampsia caespitosa, Poa palustris, Poa pratensis and others Hansen et al. 1988: Carex rostrata site type, Carex aquatilis site type, and others	RIGR
Salix/Carex	Youngblood et al. 1985: Salix geyeriana/Carex rostrata, S. geyeriana/Poa palustris, S. geyeriana/Calamagrostis canadensis, S. geyeriana/Poa pretensis, Salix boothii/ C. rostrata, S. boothii/Calamagrostis canadensis, S. boothii/Poa pratensis, Salix wolfii/Carex aquatilis, S. wolfii/C. rostrata, S. wolfii/C. canadensis, S. wolfii/D. caespitosa, S. wolfii/P. palustris, and others Hansen et al. 1988: S. geyeriana/Carex rostrata, S. geyeriana/Calamagrostis canadensis, S. geyeriana/D. caespitosa, S. candida/C. aquatilis, S. wolfii/Deschampsia caespitosa, and others	SALX
Cottonwood riverine	Daubenmire 1970: Populus trichocarpa/Cicuta douglasii Youngblood et al. 1985: Populus angustifolia/ Cornus stoloniferous, P. angustifolia/Poa pratensis Hansen et al. 1988: P. trichocarpa/ Cornus stoloniferous, P. trichocarpa/Poa pratensis, Populus angustifolia/ Cornus stoloniferous, P. angustifolia/Poa pratensis	CTRV

USING THE MANAGEMENT SCENARIO FILES IN VDDT

Appendix A is a list of Potential Vegetation Types for the Historical (HI or HS) model and the three different management scenario models, Consumptive Demand (CD), Passive Management (PM), and Active Management (AM). All of the these models must be opened under the "Old Format" files.

Range - Because cover types that did not exist historically were added to the management scenario models, the historical (HI) models are separate from the three management scenario models (CD, PM, AM) for the range PVTs. So there are two different PVT (.pvt) files for each PVT. The naming convention for the HI models includes "_HI" following the PVT abbreviation. For example, the .pvt and .scn files for the Historical Agropyron Steppe model are labeled AGST_HI.pvt and AGST_HI.scn respectively. The .pvt file for the Agropyron Steppe PVT under the management scenario model is named AGST.pvt and the .scn files are named AGST_CD.scn, AGST_PM.scn, and AGST_AM.scn for consumptive demand, passive management and active management respectively.

After a .pvt file has been chosen (remember: under "Old Format"), VDDT defaults to a choice of the corresponding .scn files. However, care must be observed with the range models. The HI .pvt files will default to .scn files for HI, CD, PM, and AM. Only the HI .scn files will run the model with the HI .pvt file. Similarly, a HI .scn file should not be chosen to run with a management scenario .pvt file.

Forest - These models are also under the "Old Format" files. The forest models are more simple to run because the historical models (HI or HS) are not separated from the three management scenario models (CD, PM, AM) as the current cover types also existed historically. However, nine historical models exist in order to include White pine blister rust to the PVT (HB). As an example, the Grand Fir/White Fir East Cascades PVT has one .pvt file - WBALS.pvt. The same PVT has five .scn files - WBALS_HI.scn (historical), WBALS_CD.scn (consumptive demand), WBALS_PM.scn (passive management), WBALS_AM.scn (active management), and WBALS_HB.scn (historical with the addition of White pine blister rust).

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Appendix A.--Potential Vegetation Type (PVT) Listing

PVT		Description
1	AGST_HI	Historic Agropyron Steppe
2	PUTR_HI	Historic PurshiaTridentata
3	BSBW_HI	Historic Basin Big Sage/Wildrye
4	LSME_HI	Historic Low Sage-Mesic
5	LSMJ_HI	Historic Low Sage-Mesic With Juniper
6	LSXE_HI	Historic Low Sage-Xeric
7	LSXJ_HI	Historic Low Sage-Xeric With Juniper
8	WBSW_HI	Historic Wyoming Big Sage-Warm
9	WBSC_HI	Historic Wyoming Big Sage-Cool
10	CTRV_HI	Historic Cottonwood Riverine
11	FESC_HI	Historic Fescue Grassland
12	BSML_HI	Historic Mountain Big Sage-Mesic-East
13	BSMC_HI	Historic Mountain Big Sage-Mesic-East w/Conifer
14	BSMW_HI	Historic Mountain Big Sage-Mesic-West
15	BSMJ_HI	Historic Mountain Big Sage Mesic West w/Juniper
17	SDSH_HI	Historic Salt Desert Shrub
18	TTSA_HI	Historic ThreeTipp Sage

PVT		Description
19	SALX_HI	Historic Salix/Carex
20	ASPEN_HI	Historic Aspen
21	CEW1_HI	Historic CELE Woodland Without ArtRva
22	CEW2_HI	Historic CELE Woodland With ArtRva
23	MTSH_HI	Historic Mountain Shrub
24	RIGR_HI	Historic Riparian Graminoid
25	SARP_HI	Historic Saltbrush Riparian
26	RPSED_HI	Historic Riparian Sedge
27	MRLS_HI	Historic Mountain Riparian Low Shrub
29	CFESC_HI	Historic Conifer-Fescue Grassland
30	JUOC_HI	Historic Juniper
31	ALSHR_HI	Historic Alpine Shrub-Herbaceous
50	CDHME	Cedar/Hemlock East Cascades
51	CDHMI	Cedar/Hemlock Inland
52	DRDFA	Dry Douglas-fir without PPine
53	DRDFB	Dry Douglas-fir with PPine
54	DGFWF	Dry GrandFir/WhiteFir
55	LIMP	Limber Pine
56	LPPA	Lodgepole Pine-Yellowstone
57	LPPB	Lodgepole Pine-Oregon
58	MSDF	Moist Douglas-fir
59	GFWFE	Grand Fir/White Fir East Cascades
60	GFWFI	Grand Fir/White Fir Inland
61	MTHME	Mountain Hemlock East Cascades
62	MTHMI	Mountain Hemlock Inland
63	INTPP	Interior Ponderosa Pine
64	PPSMC	Pacific P-Pine/Sierra Mixed Con
65	MTHRF	Mountain Hemlock/Shasta Red Fir
66	PSF	Pacific Silver Fir
67	SFDWA	Spruce-Fir Dry with Aspen

PVT		Description
68	SFDNA	Spruce-Fir Dry without Aspen
69	SFWET	Spruce-Fir Wet
70	SFWBP	Spruce-Fir(WBP>LPP)
71	SFLPP	Spruce-Fir(LPP>WBP)
72	WBALN	White Bark Pine/Subalpine Larch North
73	WBALS	White Bark Pine/Subalpine Larch South
74	WOAK	White Oak
101	AGST	Agropyron Steppe
102	PUTR	PurshiaTridentata
103	BSBW	Basin Big Sage/Wildrye
104	LSME	Low Sage-Mesic
105	LSMJ	Low Sage-Mesic With Juniper
106	LSXE	Low Sage-Xeric
107	LSXJ	Low Sage-Xeric With Juniper
108	WBSW	Wyoming Big Sage-Warm
109	WBSC	Wyoming Big Sage-Cool
110	CTRV	Cottonwood Riverine
111	FESC	Fescue Grassland
112	BSML	Mountain Big Sage-Mesic-East
113	BSMC	Mountain Big Sage-Mesic-East w/Conifer
114	BSMW	Mountain Big Sage-Mesic-West
115	BSMJ	Mountain Big Sage Mesic West w/Juniper
117	SDSH	Salt Desert Shrub
118	TTSA	ThreeTipp Sage
119	SALX	Salix/Carex
120	ASPEN	Aspen
121	CEW1	CELE Woodland Without ArtRva
122	CEW2	CELE Woodland With ArtRva
123	MTSH	Mountain Shrub
124	RIGR	Riparian Graminoid

PVT		Description
125	SARP	Saltbrush Riparian
126	RPSED	Riparian Sedge
127	MRLS	Mountain Riparian Low Shrub
129	CFESC	Conifer-Fescue Grassland
130	JUOC	Juniper
131	ALSHR	Alpine Shrub-Herbaceous