Development of Vegetation Dynamics Pathways

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INTRODUCTION

Forests change over time, sometimes slowly and sometimes rapidly. Species composition changes over time as some trees die or are killed faster than others. Structure changes when forests grow into larger size classes, when large trees are killed and replaced by regeneration, or when some overstory trees are killed and regeneration fills openings creating a multi-story condition. These changes in composition and structure of vegetation over time are described as forest succession.

The concept of succession is no longer assumed to be an orderly and unidirectional progression from regeneration to old growth climax forests (Pickett and McDonnell 1989). Such a progression can occur, but the process is typically more dynamic, and can be accelerated or reversed by various "disturbances" acting at different intensities. Some fire, pathogen, insect, wildlife, grazing, and other agents can accelerate succession to climax forest types when they kill seral species, or can retard succession by affecting climax species (Baker 1992, Edmonds and Sollins 1974, Haack and Byler 1993, Hagle and others 1995, Habeck and Mutch 1973, Harvey 1994, Harvey and others 1993b, Sampson and others 1996). Understanding the combined effects of succession and disturbance, including management actions, provides the basis for predicting future vegetation conditions.

The Interior Columbia Basin (ICB) broad-scale scientific assessment required a comprehensive description of the past, present, and future vegetation conditions across the 210 million acres comprising this watershed. It was decided that future vegetation conditions be simulated using a spatially-explicit succession model, so that the effects of various land management strategies could be compared and evaluated. Unfortunately, there were no vegetation dynamics simulation models available that would include the wide ecological and geographical scope of the ICB (Keane and others 1996). 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 using a pathway approach, and simulates disturbances stochastically. However, many succession pathways and disturbance parameters were not quantified for the myriad of forests, shrublands, herblands, riparian, and alpine ecosystems present in the ICB.

This project was initiated in July of 1994 to develop and quantify important successional pathways for all ecosystems in the ICB. These pathways would then be integrated into the model CRBSUM so the effects of management could be predicted across the entire basin. The objectives of this project were to:

1. Describe pathways of succession and disturbance in various vegetation types of the ICB.
2. Develop a user-friendly computer tool, Vegetation Dynamics Development Tool (VDDT), that provides efficient examination of the effects of management activities, natural disturbances and base successional processes on future forest and range conditions.
3. Test VDDT behavior and calibrate it for use in CRBSUM to model succession dynamics across the entire ICB.

METHODS

Succession Modeling Fundamentals

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 are linked along succession pathways converging to a somewhat stable community type or Potential Vegetation Type (PVT). Various disturbance pathways exist that may 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.

A key assumption behind these models is that PVTs occur as discrete units of land, and 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 scale at which they occur on the landscape relative to the scale of available data and the time frame allotted for the project. We felt that a more broad scale approach was justifiable on the basis that forest and rangelands are managed and primarily affected by human and natural disturbances, which occur on a scale broader than these fine scale classifications.

PVTs were selected to represent groups of vegetation that: a) were potentially identifiable with use of remotely sensed and other digital data (Menakis and others 1996) b) have a similar response to factors influencing vegetation composition and structure, such as temperature and precipitation variation and disturbance, and c) occur as the dominant vegetation type in contiguous communities larger than approximately 200 hectares. These criteria eliminated many communities that occur on limited specialized sites and those, such as many riparian vegetation types, that occur primarily as linear patches on the landscape.

In application, the 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 occur within the PVT (Appendix A). Twenty nine non-forested PVTs were defined based on typical mixes of grassland and shrub species (Appendix A).

Seral stages within a PVT were developed under a similar assumption that the change in composition and structure must be sufficient to be potentially recognizable with remotely sensed data. They were further constructed in a fashion for which additional seral stages could readily be added. Twenty two forest cover types (CTs), 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 (1994) from earlier work by Oliver and Larson (1990), six woodland structural stages, and eight non-forest structural stages were defined (Appendix C). Specific management regions were defined based on land ownership and use designations and included "Wilderness and National Parks", "USFS and BLM Lands" (U.S. Forest Service and Bureau of Land Management), and 'Private, State and Tribal lands".

Succession Workshops

The project was accomplished through a series of seven facilitated workshops to develop the approach, to capture information and expert opinion, and to test model behavior. These workshops were facilitated by the U.S.Department of Agriculture, Forest Service. ESSA Technologies Ltd. managed the process, facilitated the workshops, and produced the computer model (Kurz and others 1994, Beukema and Kurz 1995).

Succession and disturbance parameters were quantified using the Adaptive Environmental Assessment and Management (AEAM) process (Holling 1978). AEAM is a systems approach that requires an explicit causal structure, and restricts detail to a minimum. This approach was selected because of its previous effectiveness for developing insect and disease models using conceptual understanding in addition to scientific data (McNamee and others 1985). Published data on the effects of pathogens and insects on succession are not plentiful, but there was considerable agreement among specialists conceptually.

An insect and disease working group held initial workshops from July to October 1994 (Kurz and others 1994). Workshop objectives were to: a) develop an approach to modeling changes in forest 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.

Subsequent workshops with up 150 forest, range, and fire ecologists from throughout the ICB area were held in January and February 1995 to: 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, interdisciplinary groups of specialists from the earlier workshops met to test and calibrate the models, and to document assumptions and findings.

VDDT Model

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 requires that all parameters be entered at once and its lengthy output would have been too large to readily interpret. What was needed was a computer program 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 resulted in the construction of VDDT, the Vegetation Dynamics Development Tool.

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), and use is described in Beukema and Kurz (1995). VDDT simulates changes in cover types or structural stages based on successional pathways. Changes in successional classes can be due to disturbance (e.g., fire, insects, pathogens, management, etc.), or because growth dynamics have changed the cover type, structural stage, or both. Time required for movement from one successional class to another defines change in the absence of disturbance. All succession and disturbance parameters are defined and input by the user.

VDDT predicts dominant tree, shrub, or herb vegetation (cover type) and age structure (structural or successional stage) through time as a function of both base succession over time and disturbance processes. In forested vegetation, for example, it models the successional function of pathogen and insect disturbance processes described by Hagle and others (1995) and Hagle and Williams (1995). By selectively killing certain tree species or size classes, for example, pathogens or insects cause transitions from one forest type and successional stage to another. Only the effects of major agents, i.e., those that have significant, large-scale effects on cover type or structural stage, are modeled explicitly. Effects of low impact agents, such as minor pathogen or insect infestation, are included as successional transitions "without disturbance".

Fire, pathogens, insects and other disturbance agents cause transitions to different successional classes or retard such changes. The probability of these transitions define the likelihood of disturbance for each successional class over time and heavily influence 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.

During the workshops, interdisciplinary teams, experienced with 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. However, in order to evaluate combined effects of many disturbances acting in concert on the succession classes, teams members generally relied more upon the predicted distributions of succession classes at various points in time during the model run to determine whether the outcomes were reasonable.

Management Futures

Four contrasting scenarios, called management futures, were developed for the Interior Columbia Basin project. Management actions and associated probabilities of disturbances were developed within the context of these four management futures.

The Historical management future (HI) predicts disturbance and successional dynamics prior to the extensive influence of Euro-American settlement. Disturbance types, probabilities, and effects are consistent with vegetation structure and dynamics prior to 1900. The Passive management future (PM) is where no commodities are produced and lands are used for recreation, education, and research. Fire suppression is continued at current levels, but no timber harvesting or grazing occurs, and insects and disease functions without human interference. In the Consumptive Demand management future (CD), the goal is to maximize commodity production through grazing, timber harvest, and other management practices. The effects of disease, insects, and fire are prevented or suppressed where economical. The Active management future (AM) focuses on the maintenance of natural ecosystem functions and processes. Timber harvest, grazing, prescribed fire, fire suppression, and other forest and rangeland management activities are designed to achieve vegetation structure consistent with ecosystem function and process. Historic fire, disease and insect functions are maintained where feasible, generally through vegetation manipulation. The effects of introduced agents are mitigated.

Model Evaluation

The workshop teams evaluated 10, 50, and 300 year model projections, and other time intervals as necessary. In forested PVTs, insect and disease effects were evaluated first, to isolate them from effects of fire and management. Much of the recent insect and disease data and the experience of workshop participants has been based on forests altered by fire suppression and other management activities (Baker 1988, Fellin 1979, Gara and others 1985, Gast and others 1991, Hessburg and others 1993, Martin 1988, Monnig and Byler 1992, Thies 1990), and the projected outcomes of insect and disease activities were evaluated against these data and experiences. Subsequent work groups explored model behavior with all forms of disturbances, separately and in combination, and disturbance probabilities were adjusted accordingly. Testing generally followed the same sequential steps.

Evaluate natural succession with historical disturbances. Estimated historical forest types and successional stages were used to initialize the model, and runs were made with historical disturbance probabilities. Adjustments were made to get "steady state" behavior over 300 years or longer. The assumption was that the relative proportions of each type and stage were maintained across the Columbia Basin over time, within a "historical range of variability" (Morgan and others 1994), even though the cover type and structural stage constantly changed on any particular location within the Basin. This "steady state" behavior was useful for projecting departures from expected, due to increased human activities of the past and future centuries.

Evaluate current disturbances under the passive management future. Here, the models were designed to approximate current conditions, and run with current insect, pathogen, and other disturbances with fire probabilities that reflected current suppression capabilities. This allowed evaluation of the outcomes of insect and disease activities, several of which have been intensified by current conditions and activities (Byler and others 1994, Hagle and Byler 1993, Wickman 1992, Harvey and others 1995). This also allowed for testing of the outcomes of wildfire events, given current assumptions about the effectiveness of wildfire suppression. This management future provided a way to explore change trajectories for vegetation types that were outside of presumed historical ranges of variability, to determine if these vegetation types were returning to, or moving further from, historical conditions.

Evaluate effects under the consumptive demand management future. This evaluation included effects of management actions undertaken to maximize commodity production, plus the effects of disturbances and assumptions similar to those under the passive management future. In forest PVTs, the probabilities used for insects, pathogens and fire were the same for both consumptive demand and passive management, but management activities were added. For example, blister rust resistant stock was planted for white pine blister rust (Cronartium ribicola) management, root disease probabilities were increased with partial cuts that left susceptible species, thinning of bark beetle susceptible stands reduced beetle disturbance probabilities, and wildfire probabilities were adjusted to reflect probabilities for managed stands.

The consumptive demand management future actions were not the same as past management actions on public lands. Here we assumed maximum commodity production, while public lands have been managed for multiple use since 1974, and major areas had little management except for the suppression of wildfire.

Evaluate the effects of management under the active management future. This scenario also included active management of vegetation. However, the management actions under this management future were designed to approximate the effects of historical disturbances, and maintain or restore cover types and structural stages to historical conditions. Treatments included regeneration harvesting, with natural or planted seral species, to mimic the effects of historical stand replacement fires; precommercial and commercial thinning, to simulate the effects of mixed severity fires, insects and pathogens; use of fire as a management tool, alone or in combination with other treatments; and specific restoration activities, such as planting of rust-resistant white pine.

RESULTS AND DISCUSSION

The Modeling Process

The AEAM process was a good way to refine the modeling approach, to parameterize succession parameters, to develop the supporting rules, and to test VDDT following development. Use of interdisciplinary workshops enabled us to capture unpublished information and judgements of knowledgeable scientists. Nearly all successional and disturbance parameters were quantified by these teams of "experts" from various resource fields in a workshop format. Iterative workshops allowed each workshop to build on progress made in previous ones. Additionally, the AEAM process provided the focus for work groups to systematically address key modeling considerations, such as: questions of temporal and spatial scale, end point indicators of values, and interactions of ecosystem components.

Several difficulties were encountered in the process, however. One was due to the order of the modeling process. We would have been more efficient had we begun with development of the main model components by a broader interdisciplinary group, rather than beginning with development of the forest vegetation insect and disease components by pathologists and entomologists. This would have been more consistent with the AEAM processes, and would have helped avoid problems that occurred when development of some models lagged behind others.

The same people rarely attended all workshops. This resulted in a lack of consistency in parameter estimation across all workshops. Often, workshop groups ignored past workshop products, so there was a tendency for one group to re-do or change what a previous group had done. This was exacerbated when the workshop leadership roles were filled by different individuals. However, involving the same contractors (ESSA Ltd.) for facilitation of the meetings and tracking progress between meetings helped lessen potential problems between workshops.

The same level of expertise was not available for all PVTs and for all disturbance types. Consequently, the PVTs that were rarely studied or addressed, often had the least accurate successional parameters and the fewest experts to describe them. Knowledge of each disturbance process was seldom constant across all vegetation types. Some experts had vast knowledge of ponderosa pine (*Pinus ponderosa*) forests and their fire regimes, but had little knowledge of fire in whitebark pine (*Pinus albicaulus*) cover types. Consequently, disturbances such as fire were often modeled in great detail in some pathways and received only minor attention in other pathways. In addition, some management futures were developed with more time and input from experts than others.

Some successional pathways lack disturbance processes that were specified in other pathways. These inconsistencies are especially prevalent in rangeland types. Additionally, some workshop groups provided more detailed successional pathways for certain PVTs, while different groups simplified successional dynamics in other PVTs by reducing detail and not including many important disturbances or succession classes.

Caution should be used in interpreting results of model runs for any given specific geographic area. The model shows the proportion of change that is likely to occur from disturbances, not the exact time and place of occurrence. Time and place is difficult to predict, especially for outbreaks of insects and wildfires, even though the long-term average changes they cause may be accurate. We expect that probabilities and time frames will change as more information is accumulated. Successional effects of some persistent agents, such as root diseases or white pine blister rust, are more predictable than fire or outbreak of insects. Yet the rates of change they cause are not well quantified, a situation that will improve as more data become available. Nevertheless, the successional dynamics defined in these workshops provide realistic long-term projections of vegetative change as influenced by various natural and human disturbances, and allows for comparison of the effects of different management activities. In summary, we feel we have a good first approximation of the effects of broad scale disturbance effects, based on the current state of our understanding of forest and nonforest vegetation succession.

VDDT Model

Testing indicates that VDDT realistically represents major changes in proportions of cover types and structural stages at the scales and time frames for which it was intended. The VDDT model simulates the effects of major natural disturbances under the historic management future, and generally creates current cover types and structural stages when initiated with historical conditions. It also realistically projects the effects of introduced white pine blister rust and several rangeland undesirable exotic species. We consider VDDT an adequate tool for the purpose for which it was intended. It gives realistic long-term projections of vegetative change as influenced by various natural and human-related disturbances, and allows comparison of the effects of different management activities.

Model Results

A large number of model runs were made for each PVT. Some conclusions are possible from these runs, which are presented below for three of the major forest PVTs and three of the major non-forest PVTs. We give assumptions and findings for the different management futures to represent a range of conditions and trends.

Dry Forests--Dry Douglas-fir (Psuedotsuga menziesii) with ponderosa pine was evaluated as an example of ICB Dry Forests. Historically, low intensity fires maintained ponderosa pine cover types, mainly as older single-story structures. Regeneration occurred mainly in small patches. Large stand replacement fires were rare. Figures 1 and 2 show results of 300 year simulations of natural succession with historical disturbances. The predominant cover type is ponderosa pine; the predominant structural stage is old forest single story.

The Douglas-fir cover type has increased in abundance today. Multi-story stands are currently common, both in the pine and Douglas-fir cover types, and densities are generally much higher than historical conditions. The changes are mainly due to effective suppression of surface and mixed severity wildfires, and selective harvesting of the higher value pines. The multi-story Douglas-fir forests are susceptible to defoliating insects, root disease, Douglas-fir beetle (Dendroctonus pseudotsugae), and Douglas-fir dwarf mistletoe (Arceuthobium douglasii). Dense, multi-story pine forests are susceptible to pine bark beetles (Dendroctonus spp.) and pine dwarf mistletoe (Arceuthobium species). Modeling results show that these agents continue to alter cover type and structural stage, as indicated by others (Gast and others 1991, Hessburg and others 1993, Wickman 1992).

Under the passive management future, model projections show a continuing loss of single-story pine cover types and an increase in multi-story structural stages for the next 50 years. Remaining old-growth pines in dense pine and Douglas-fir forest types will be killed by pine bark beetles, particularly during periods of drought. Insects and pathogens will continue to reduce productivity, increase stored biomass, and increase risks of severe wildfires.

We assumed that increasing fuel loadings and periodic droughts would eventually limit our ability to prevent stand replacement fires in these types, so some return to pine forests is observed at 300 years. This will likely come at the expense of soil productivity (Harvey and others 1992, 1993a).

Under the consumptive demand management future, ponderosa pine cover types will be increased by planting, but Douglas-fir types will be retained in many areas by partial cutting for economic reasons. Prescribed fire will be used only where it is economical. Short rotations will be emphasized, so old pine forests will not be restored. There will be little change to increasing fire risks and other undesirable changes in the urban interfaces and on other lands that are not managed for resource production.

Under the active management future, reforestation using group selection, and other methods that mimic the effects of mixed severity fire, will eventually restore and maintain pine cover types. Thinning and prescribed fire will be used to control densities and favor pine, mimicking the effects of historical surface and mixed severity fires. Rotations of 150 to 300 years might be achieved in some areas. The negative effects of severe wildfires and insect and disease activities will be reduced by altering forest susceptibility. Using approximately equal amounts of cover types in ponderosa pine and Douglas-fir as "current conditions" (Figure 3), a 50 year simulation of active management resulted in an increase in ponderosa pine type (Figure 4).

Moist Forest--Inland Western Redcedar/Western Hemlock PVT (*Thuja plicata*/*Tsuga* heterophylla) was selected to represent ICB Moist forests. A large number of cover types were historically possible in complex systems such as the Inland Western Redcedar/Western Hemlock PVT. Old growth stands of cedar persisted in river valleys, but were logged early. Western white pine (Pinus monticola) was the dominant cover type on lower slopes in northern Idaho, and was a major stand component elsewhere. A 300 year simulation of natural succession with historical disturbance resulted in a predominance of western white pine cover type (Figure 5), and old forest multi-story (Figure 6).

The introduced white pine blister rust disease has greatly reduced the amount of white pine. The combined effects of the rust, mountain pine beetle (Dendroctonus ponderosae), and harvesting virtually eliminated forests of the white pine cover type (Byler and others 1994, Byler and Zimmer-Grove 1990, Moeur 1992, Monnig and Byler 1992, Harvey and others 1995). Historically, stand replacement fires of tens of thousands of acres occurred at average intervals of 150 to 200 years (Heinselman 1978, Zack and Morgan 1994), and resulted in repetitive regeneration to white pine and other seral species (Monnig and Byler 1992). Mixed severity fires reduced densities and favored western larch (Larix occidentalis), and possibly white pine that would have otherwise been lost to competition. Native root diseases removed Douglas-fir, subalpine fir, and grand fir from various cover types at the stem exclusion and understory reinitiation stages, favoring pines and larch (Byler and others 1990, Byler and others 1994). Lodgepole pine (Pinus contorta), cedar, hemlock, and sometimes larch components were reduced by competition. The last major stand replacement fires occurred in the 1880s and 1910s. Since then, most regeneration of seral species has been brought about by harvesting relatively small patches. Significant amounts of rust-resistant white pine have been planted in recent decades (Bingham 1983, McDonald and Hoff 1991).

White pine blister rust arrived in the west about 1910, spread throughout the white pine cover type, and caused a transition from young stages of white pine cover types to Douglas-fir, grand fir (Abies grandis), subalpine fir (Abies lasiocarpa), and others (Byler and others 1994, McDonald and Hoff 1991, Moeur 1992). Selective harvesting of the high-value old growth white pine, outbreaks of mountain pine beetle, and the blister rust eliminated older stages. The rust continues to prevent natural reestablishment of the white pine cover type by killing regeneration. The combination of root diseases and white pine blister rust in Douglas-fir and grand fir cover types has affected productivity (Hagle and others 1994, Matthews 1995).

Model projections under the passive management future show continued loss of the white pine cover type. Root disease and associated bark beetles of Douglas-fir, grand fir, and subalpine fir are the major agents of change for the 50 year projection, continuing the current trends of transition of fir stands to cedar and hemlock on the Cedar/Hemlock PVTs, and to young multistory stands of grand fir and subalpine fir where those species are climax. It was assumed that large-scale stand replacement wildfires will occur in the future due to our inability to control them. The forests that result will be mixed, but white pine and western larch cover types will be poorly represented due to the activity of white pine blister rust and a reduction of natural seed sources.

The consumptive demand management future assumes that white pine cover types will be increased where economic through aggressive regeneration harvesting and planting of rust resistant stock (Hagle and others 1989), and older age classes will be poorly represented. Selective harvesting will continue for economic reasons in other stands, which will perpetuate young, multi-story forests of Douglas-fir, true firs, cedar and hemlock. We assume cedar and hemlock forests on dry, upland sites will be of reduced productivity, primarily due to root disease and drought.

Under the active management future, it is assumed that reforestation with rust resistant white pine will be successful in achieving rotations of that type for as long as 150 to 300 years, although achieving this may be dependent on continuing long-term monitoring, research, and development. Model results show that considerable reforestation for many decades will be required if western white pine is to be a significant forest type. Results of a 100 year simulation produced a several-fold increase in white pine cover type (Figure 8) from "current" (Figure 7), although the white pine was restored to only approximately sixty percent of the historical abundance (Figure 5). Reforestation will be complemented by integrated management of western white pine, including intermediate stand treatments (Hagle and others 1989).

Cold Forest--Subalpine Fir / Whitebark Pine PVT was selected to represent the Cold forest dynamics of the ICB. Cold forests have generally been less affected by human caused disturbances than other PVGs. Most cold forests occur at high-elevations and in roadless or wilderness areas. Figure 9 and 10 show results of a 300 year simulation of natural succession with historical disturbance.

Nevertheless, these forests have been affected by fire suppression policies, and those with a whitebark pine component have been significantly affected by the blister rust disease (Keane and Arno 1993, Hoff and Hagle 1990). Historically, mixed severity and stand replacement fires provided suitable areas for Clark's nutcracker (Nucifraga columbiána) to bury whitebark pine seed. Whitebark pine forests developed slowly, but tended to be long-lived. White pine blister rust caused extensive mortality of whitebark pine throughout northern Idaho and western Montana, and to a lesser-degree, elsewhere in the Columbia Basin. Unlike western white pine, old forest structural stages of the whitebark pine cover type remain in many locations, but their extent has been greatly reduced (Keane and Arno 1993). Mountain pine beetle hastened the reduction of older stages in some areas, and wildfire suppression has reduced opportunities for regeneration.

These trends will continue under passive management, and whitebark pine cover types will be largely gone from extensive areas within about 50 years. Ecological effects of losing this key cover type may be severe. For example, the species serves as an important food source for grizzly bear (Ursus arctos) and other vertebrates. Also, fuels and fire risks will increase.

The consumptive demand management future is generally not appropriate, because these forests are not well suited for timber production, and many are excluded from active management by law.

It was assumed for the active management future that the rust resistance present in whitebark pine could be enhanced through artificial selection (Hoff and Hagle 1990), or by natural selection using tree cutting and prescribed fire. It was also assumed that some degree of management in these forests would be acceptable to the public and economically viable. A combination of tree cutting, prescribed fire, and planting was used to regenerate rust resistant pine forests and reduce competition from subalpine fir. Model projections show that current trends of losing whitebark pine cover types can be reversed within about 50 years (Figure 12 compared with Figure 11)), but the reversal will likely require significant investments in research, development, and management.

Dry Shrub--The Big Sage-Warm PVT was selected to illustrate the dynamics of ICB Dry Shrub PVTs. While it is generally assumed that fire's influence has diminished from historical periods for most PVTs, a notable exception is the Big Sage-Warm PVT. The ecology of this PVT has been extensively altered by the introduction of exotic grasses. These grasses are primarily cheatgrass (Bromus tectorum) and medusahead (Elymus caput-medusae) within the ICB, although other annual grass species may be locally important. Annual grasses have altered two important processes within this PVT: 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 to be irreversible.

Historically, fire was the major disturbance factor that altered composition on a large scale. Fire was only moderately common in the Big Sage-Warm PVT, due to low levels of fine fuel production. Occasional epidemic levels of Aroga websteri occurred, but these normally affected limited areas. As a consequence, this PVT in the HI management future was dominated by community types with a mature sagebrush overstory and a perennial grass understory (Figure 13). The remainder was composed of other early and mid successional stages.

Exotic grasses are the major influence on natural processes that shape this PVT in the PM, CD, and AM management futures. These model projections predict the continual increase in exotic-dominated communities with a corresponding decrease in native community types. Exotics are predicted to dominate 85 percent of the PVT land area under the CD management future in the 300 year projection (Figure 14). With active management, native-dominated CTs were maintained on about 50 percent of the PVT area (Figure 15). This reduction was achieved primarily through the seeding of native grasses and increased fire suppression activity.

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

Cool Shrub--Mountain Big Sagebrush-Mesic with Juniper PVT was selected to represent the Cool shrub component of the ICB. This PVT includes those areas within the mountain big sagebrush (Artemisia tridentata vaseyana) zone that potentially may develop juniper woodland vegetation. Currently it 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 (Juniperus occidentalis). However, it may also include Utah juniper (J. osteosperma) in the southeastern portion of the ICB or Rocky Mountain juniper (J. scopulorum) in portions of western Montana. Fire was the primary limiting factor for the dominance of juniper in the HI management future. Juniper woodlands have a number of biological controls, but 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 (Figure 16). Probabilities decline rapidly as the juniper stands develop dominance. Once fully mature woodland develops, it becomes resistant to low and moderate intensity fires. Woodland structural stages account for about 25 percent of the PVT in the HI management future (Figure 17).

Active fire suppression and consumption of fine fuels by domestic livestock reduces the probability of fire and often accelerates the rate of juniper woodland development. Woodland development further reduces herbaceous (fine fuel) production, which in turn additionally decreases fire probabilities. The CD management future assumes 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 accounts for 10 percent of the PVT, and other woodland stages compromise five percent of the CD management future land area, for a total juniper woodlands area of only 15 percent. (Figure 18).

Exotic annual grasses may occur in the more arid portions of this PVT. The presence of these species increase fire probabilities and reduce natural regeneration of native herbaceous plant species. This results in a landscape dominated by CTs with overstories of sagebrush or juniper and understories dominated by exotic forbs and grasses as characterized by the CD and AM management futures. Fires in the annual grass-dominated understories result in cheatgrass-dominated communities for the case of sagebrush/cheatgrass CTs, and open juniper woodland with cheatgrass understories for juniper/cheatgrass and juniper/sagebrush/cheatgrass CTs. Without successional mechanisms available to lead out of these stages, seeding of native perennial grasses is commonly employed to re-establish the native species on the sites. Exotic grasses may also be used in place of natives for the CD and AM management futures to re-establish perennial grasses on the site.

Dry Grass--The Conifer / Fescue PVT represents 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 boundary between forest and non-forest, but the boundary was dynamic. The most common forested types adjacent to the herblands were those dominated by ponderosa pine, Douglas-fir, or both. Other conifers may have been 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 present. Sagebrush was not a component of the vegetation in general during any successional stage. As fire became more frequent locally, herbland stages became more prevalent. Localities or periods of time where fire was less frequent allowed forests to expand into the adjacent herb communities. The model predicts that on average, spatially or temporally, conifer communities accounted for roughly 45 percent and herb- dominated communities about 55 percent of the PVT area in the HI management future (Figure 19).

In the CD management future, the conifer-dominated stages increase greatly as a response to the decreased fire occurrence. In addition, much of the original grassland area is subject to invasion by exotic herbs, primarily knapweeds and starthistles (Centauria spp.). These species may also occupy the understory of the open conifer types. The model predicts that nearly 10 percent of the former herb-dominated area will have an exotic herb-dominated community. An additional 20 percent of the area will become open conifer stages with exotics as the dominant understory (Figure 20). 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 management futures are predicted to have greater areas dominated by conifers (80 and 70 percent respectively) as compared to the HI management future (Figure 20 and 21 compared to figure 19). Under the AM management future, exotic herbs will dominate much of the former grassland and open conifer communities, but to a lesser extent than the CD management future. Exotic-dominated communities are less flammable than the native grass-dominated types. This will 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 (Centaurea spp.), yellow starthistle (Centaurea solstitialis), whitetop (Cardaria draba), skeletonweed (Chondrilla juncea) , and leafy spurge (Euphorbia esula). Many others 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 occur at chronic levels, and was included in the "normal" factors influencing vegetation succession. Herbivory by domestic livestock remains as a dominant land use of non-forested vegetation within the ICB. Its occurrence continues 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 are not accounted for in the models.

The Historic management future 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 is 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 futures.

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

The Consumptive Demand management future 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.

The Active Management future included active management of vegetation with emphasis on natural processes. This scenario included commodity production, but vegetation management activities that tended to include historical disturbances and maintain historical proportions of structural stages were given emphasis. 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 done using native species if possible. Herbicides were used only to control designated noxious weeds, not as a general vegetation management technique.

SUMMARY

The historic management future provides a reference of how systems operated prior to European settlement and points to the effects of European settlement on ICB vegetation. The models indicate that high levels of natural disturbance maintained historical proportions of forest and range cover types and successional stages. In forested PVTs, wildfire, insects, and pathogens historically maintained seral forests, slowing or reversing the progression to climax cover types. Today, the proportion of seral forests has been greatly reduced by wildfire suppression, timber harvest practices, and in the case of white pine forests, the introduction of blister rust. In non-forested areas of the ICB, the frequency and importance of historical fire increased with increasing precipitation and higher production of fine fuels. The frequency of fire has been reduced due to active fire suppression, reduction of fine fuel levels from livestock grazing, and breakage of fuel continuity via agriculture, roads and other types of development. The effects of the reduction of fire occurrence is most evident in the ecotone between rangeland and forested PVTs, and rangeland and woodland PVTs. Historically, fire was the major factor determining these boundaries. The primary PVTs affected by reduced fire frequency are those associated with mountain big sagebrush and canyon grasslands. This has resulted in the expansion of ponderosa pine, Douglas-fir, and juniper.

The Passive management future produces vegetation structures different from historical vegetation structures over the long term. Given currently altered vegetation conditions, new disturbance agents, and continued fire suppression, trajectories for seral cover types will continue to depart from historical conditions under a passive management future in forested PVTs. Several under-represented cover types and structural stages, mainly older age classes of potentially long-lived seral tree species, will continue to decrease in abundance. The major agents of change for the next 50+ years are insects and pathogens. Over longer time frames, given assumptions about our eventual failure to control wildfire, fire will greatly affect succession class distributions and fire risk will intensify.

In forested PVTs, a Consumptive Demand management future invokes a mix of management actions that restore and maintain young, single-story stands of seral species and actions that, for short-term economic reasons, maintain multi story forests of climax cover types. Focus on short term economics can lead to actions that maintain types and stages with reduced productivity resulting from insect and disease activities.

The Active management future best maintains, and in part restores, vegetative structures that occurred historically. Predictions indicate that trajectories of unhealthy cover types can be changed. We can realign our management to be more in harmony with historical processes, and this can result in cover types and structural stages that more nearly represent those that occurred historically. Active management differs considerably from past management actions, of both lands managed for maximum production, and lands managed for other purposes. Longer rotations will be prescribed for forests of potentially long-lived seral species such as western white pine, western larch, and ponderosa pine. Thinning from below will mimic the effects of mixed severity wildfire and native pathogens and insects by removing those species and sizes that are most susceptible. Fire will be widely applied. Harvesting will remove a large proportion of climax species and a small proportion of seral species. Active management will also leave much residual structure, both living and dead.

Model projections show that considerable management will be required to maintain or restore representative cover types and structural stages, given the need to suppress wildfires on some lands, the altered conditions of some current vegetation, and new disturbances such as introduced plant species and diseases. However, it may not be technically feasible to restore all conditions, even if it would be desirable to do so. Increased active management from the recent past may be required where maintenance and restoration are goals. However, achieving these goals will require better aligning of management treatments with natural processes.

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Figure Captions

Figure 1--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Dry Douglas-fir with Ponderosa pine PVT.

Figure 2--Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Dry Douglas-fir with Ponderosa pine PVT.

Figure 3--Current distribution of cover types in Dry Douglas-fir with Ponderosa pine PVT.

Figure 4--Results of 50 year simulation of active management on distribution of cover types in Dry Douglas-fir with Ponderosa pine PVT.

Figure 5--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Inland Western Red Cedar/ Western Hemlock PVT.

Figure 6--Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Inland Western Red Cedar/ Western Hemlock PVT.

Figure 7--Current distribution of cover types in Inland Western Red Cedar/ Western Hemlock PVT.

Figure 8--Results of 100 year simulation of active management on distribution of cover types in Inland Western Red Cedar/Western Hemlock PVT.

Figure 9--Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Subalpine Fir/Whitebark Pine PVT.

Figure 10--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Subalpine Fir/ Whitebark Pine PVT.

Figure 11--Current distribution of cover types in Subalpine Fir/Whitebark Pine PVT.

Figure 12--Results of 50 year simulation of active management on distribution of cover types in Subalpine Fir/Whitebark Pine PVT.

Figure 13--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Big Sage Warm PVT.

Figure 14--Results of 300 year simulation of consumptive demand management future on distribution of cover types in Big Sage Warm PVT.

Figure 15--Results of 300 year simulation of active management on distribution of cover types in Big Sage Warm PVT.

Figure 16--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Mountain Big Sage w/ Juniper PVT.

Figure 17--Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Mountain Big Sage w/ Juniper PVT.

Figure 18--Results of 300 year simulation of consumptive demand management future on distribution of cover types in Mountain Big Sage w/ Juniper PVT.

Figure 19--Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Conifer - Fescue PVT.

Figure 20--Results of 300 year simulation of consumptive demand management future on distribution of cover types in Conifer - Fescue PVT.

Figure 21--Results of 300 year simulation of active management on distribution of cover types in Conifer - Fescue PVT.

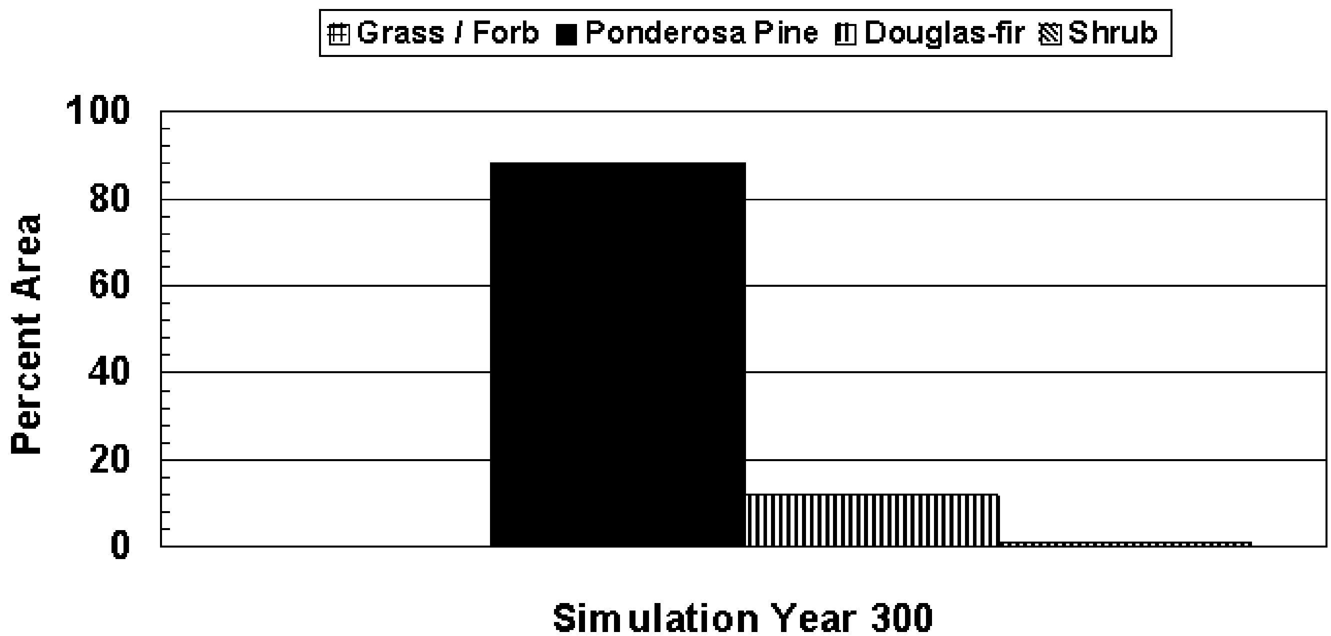
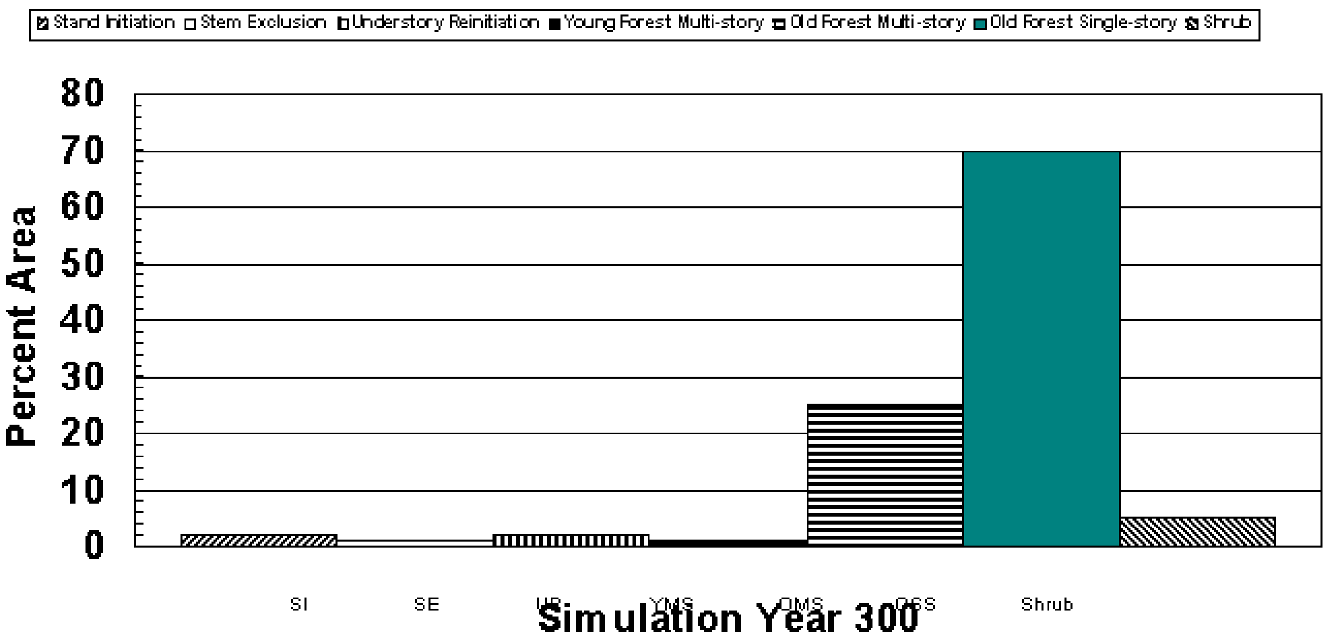


Figure 1–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Dry Douglas-fir with Ponderosa Pine PVT.



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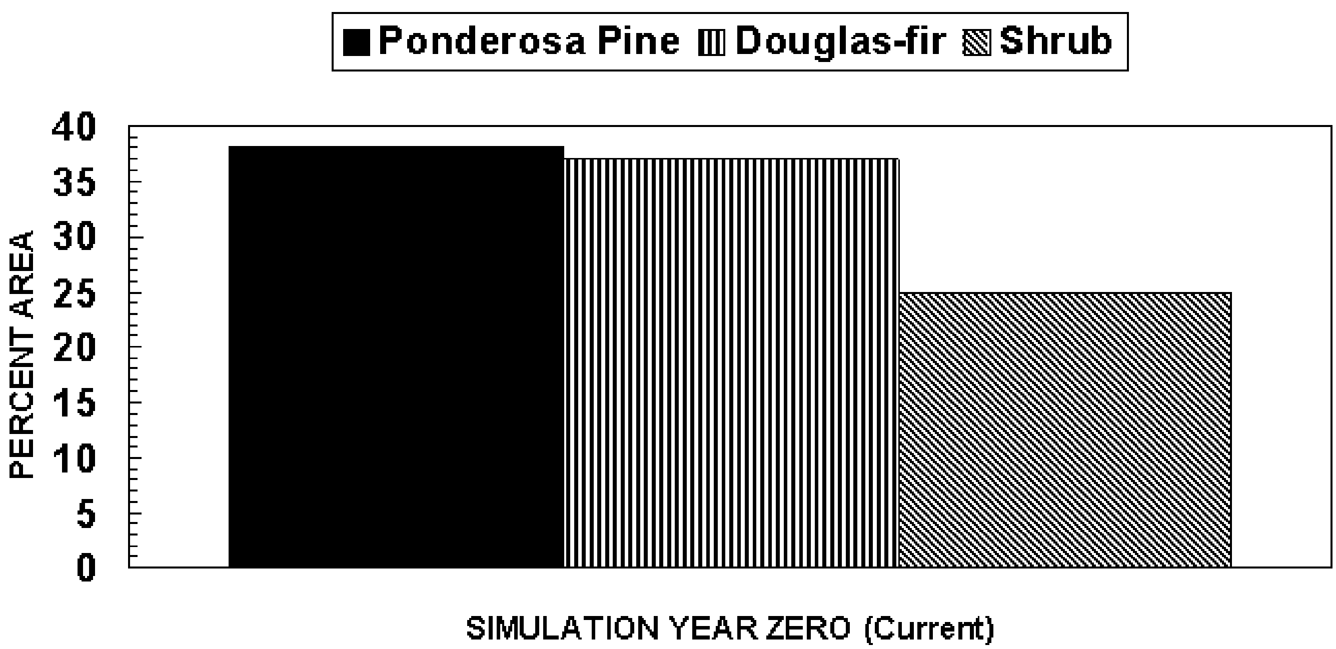

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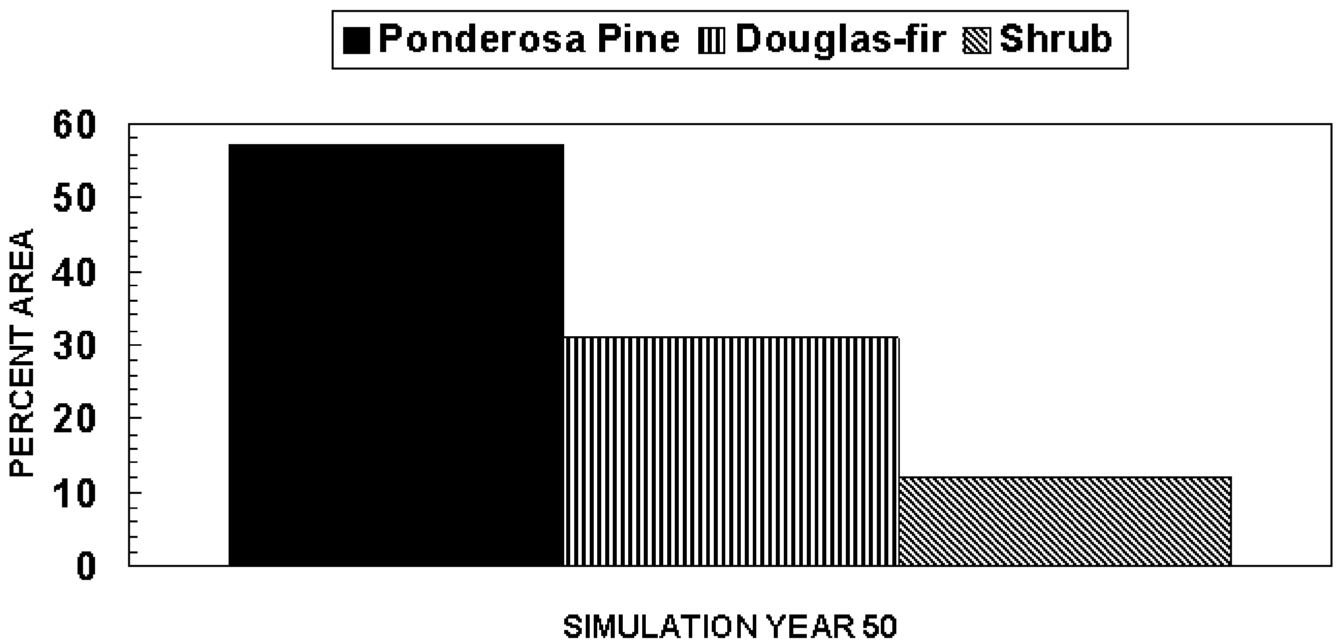

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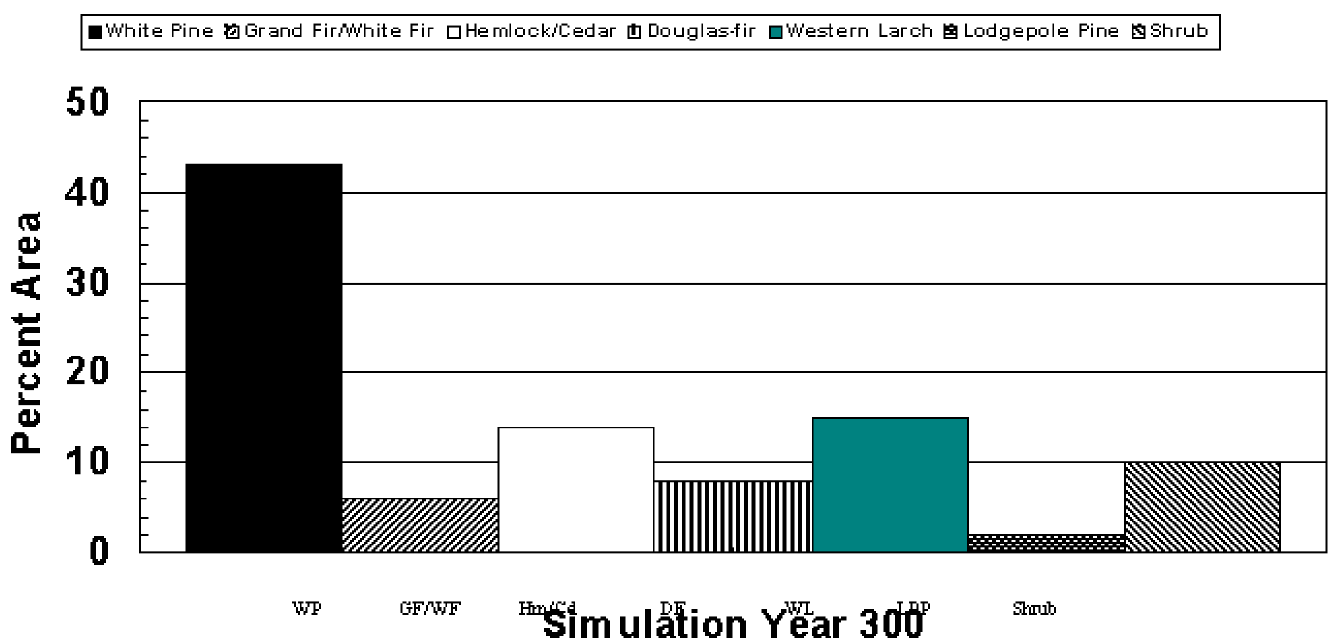

Figure 5–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Inland Western Red Cedar / Western Hemlock PVT.

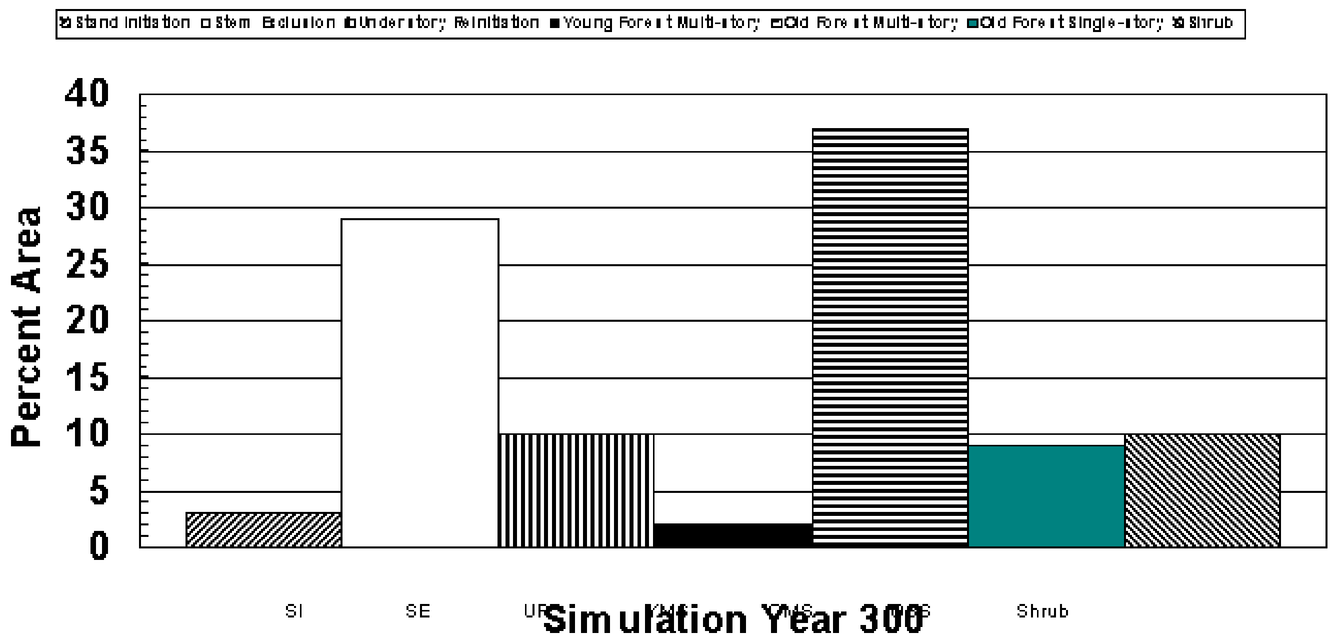

Figure 6–Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Inland Western Red Cedar / Western Hemlock PVT.

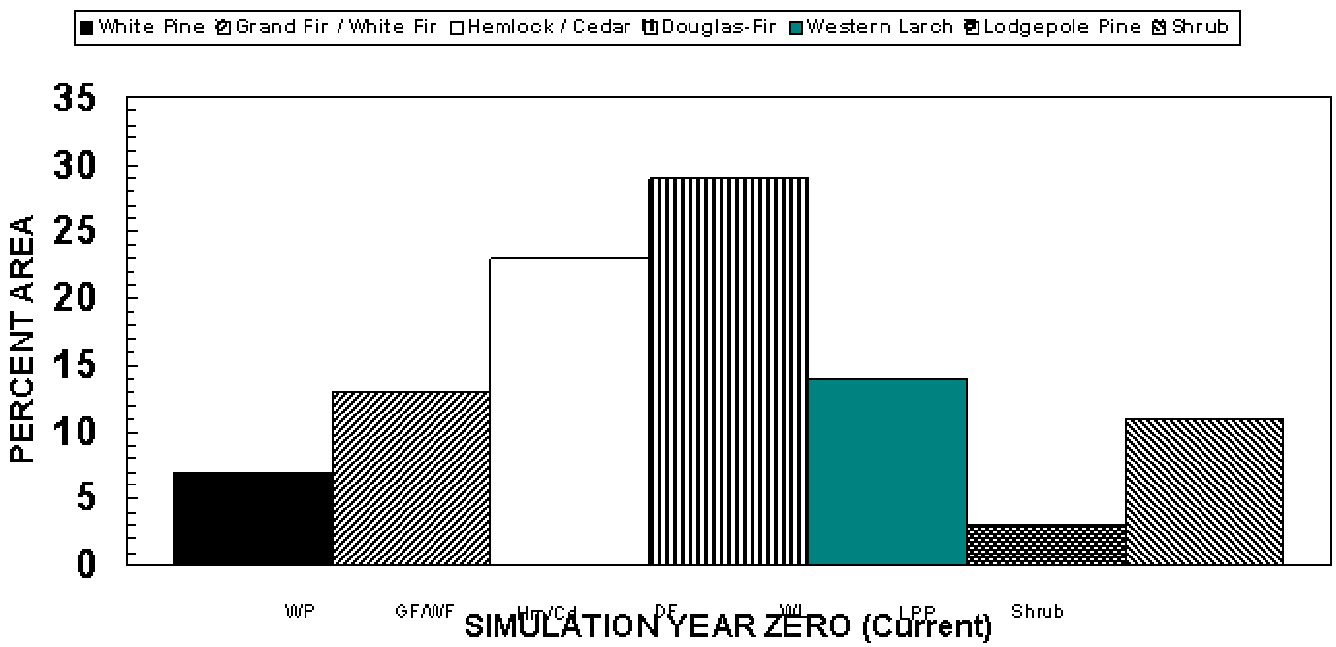

Figure 7–Current distribution of cover types in Inland Western Red Cedar / Western Hemlock PVT.

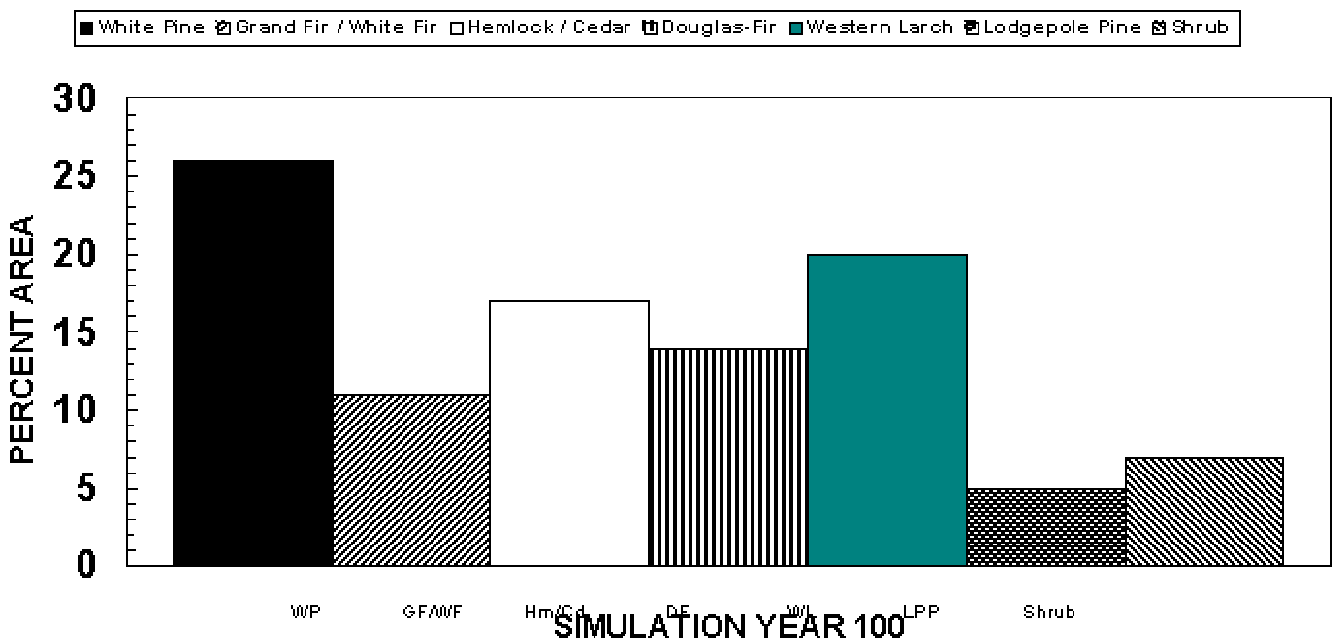

Figure 8—Results of 100 year simulation of active management on distribution of cover types in Inland Western Red Cedar / Western Hemlock PVT.

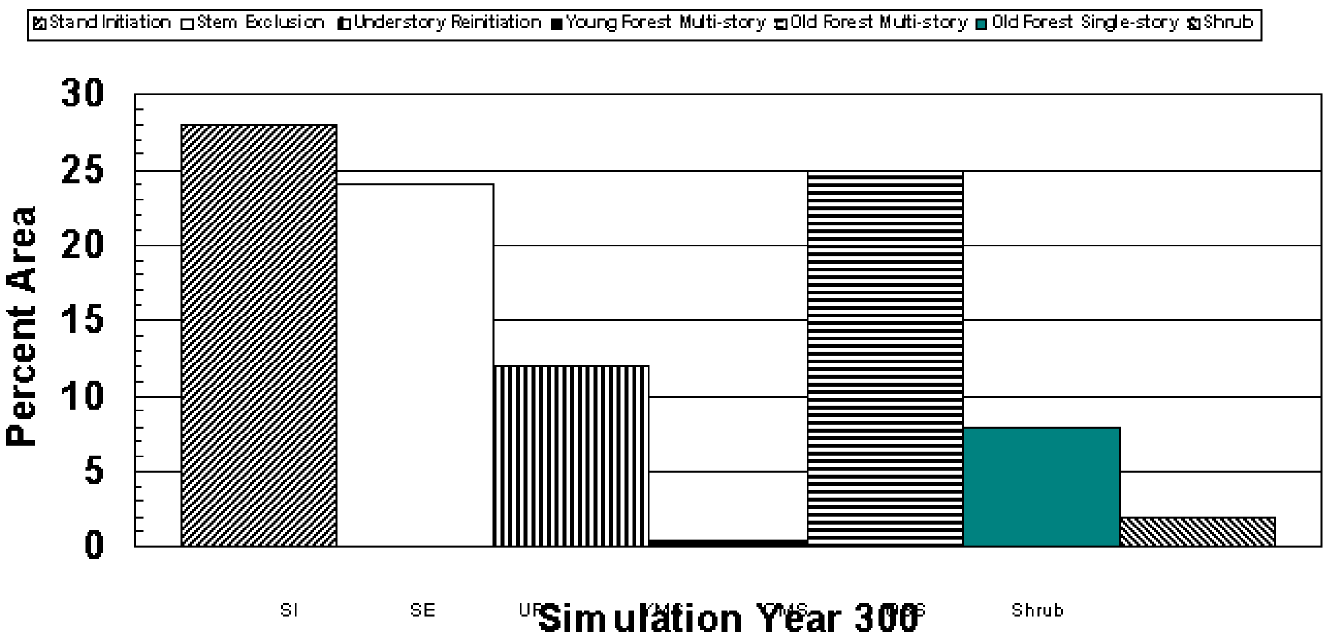

Figure 9–Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Subalpine Fir / Whitebark Pine PVT.

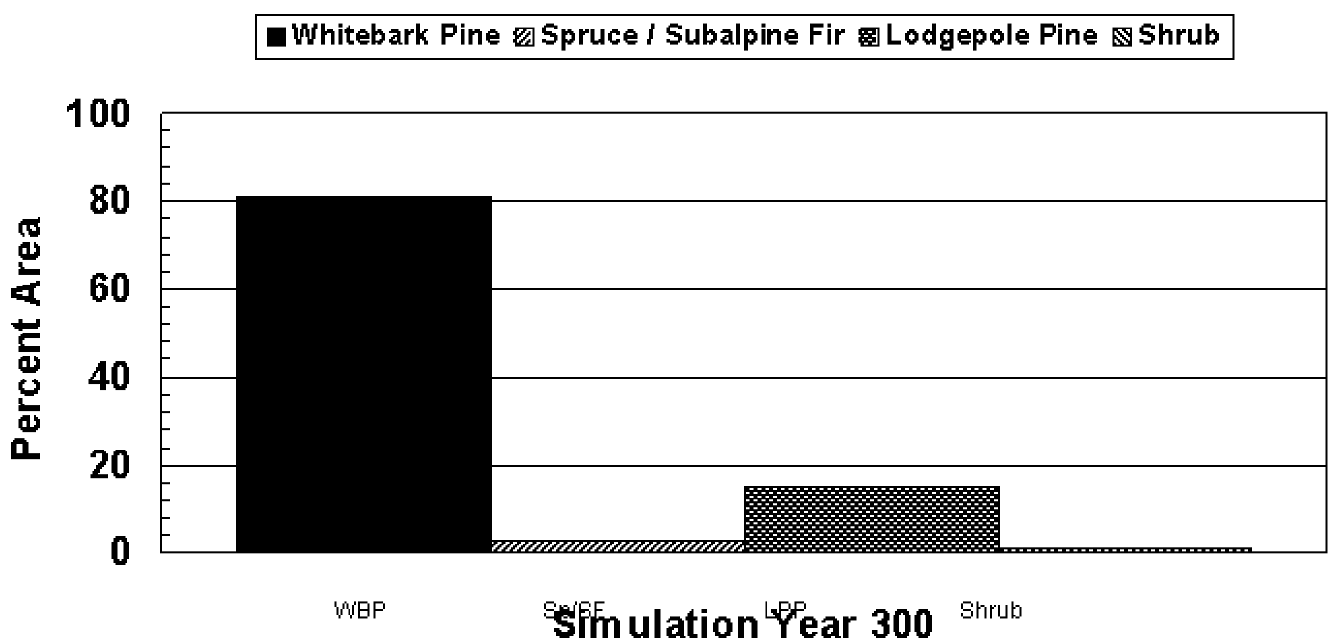

Figure 10–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Subalpine Fir / Whitebark Pine PVT.

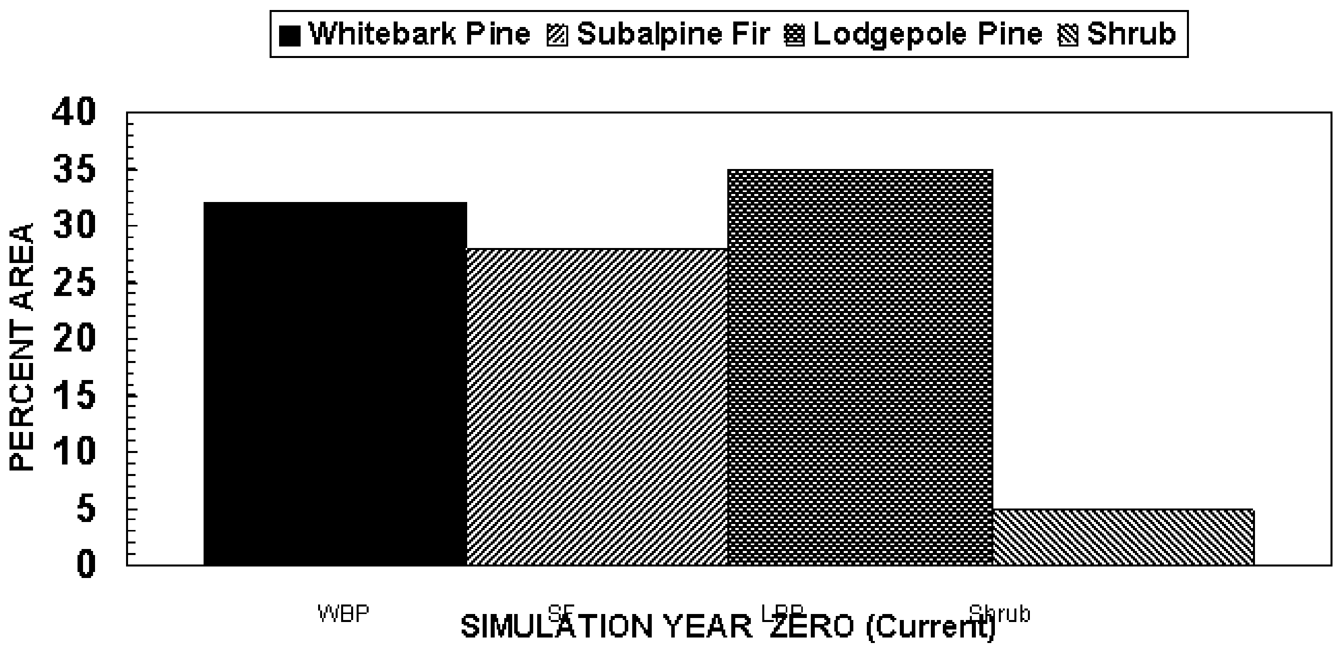

Figure 11–Current distribution of cover types in Subalpine Fir / Whitebark Pine PVT.

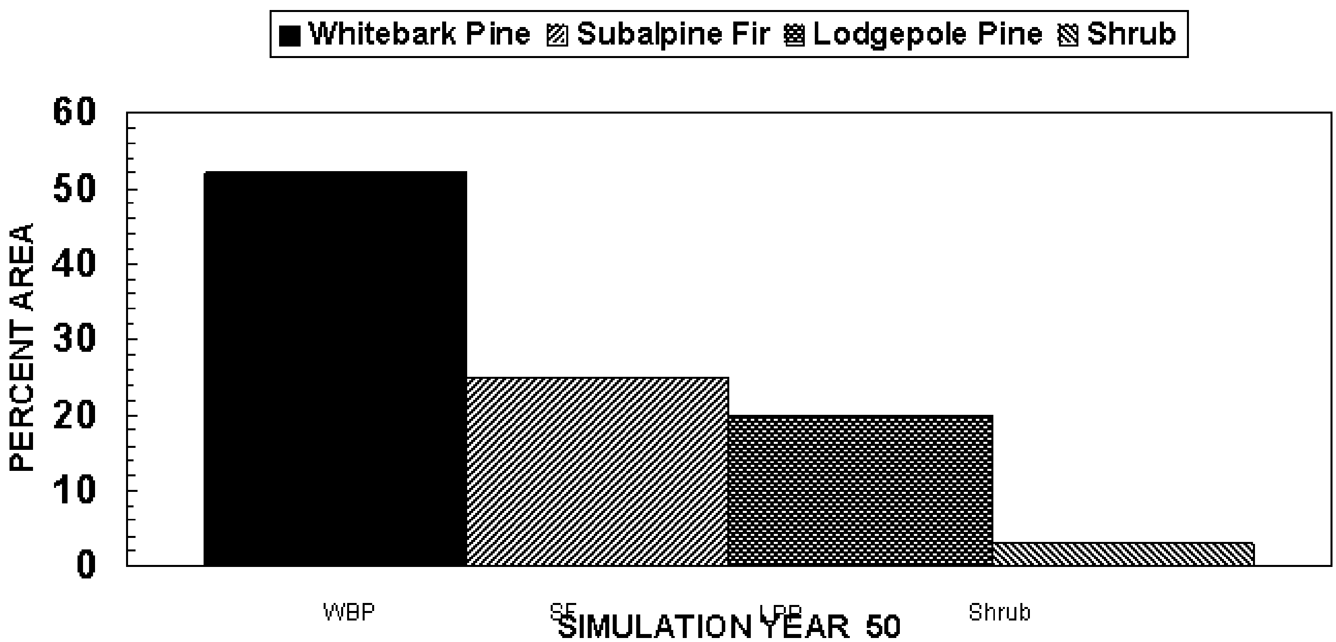

Figure 12–Results of 50 year simulation of active management on distribution of cover types in Subalpine Fir / Whitebark Pine PVT.

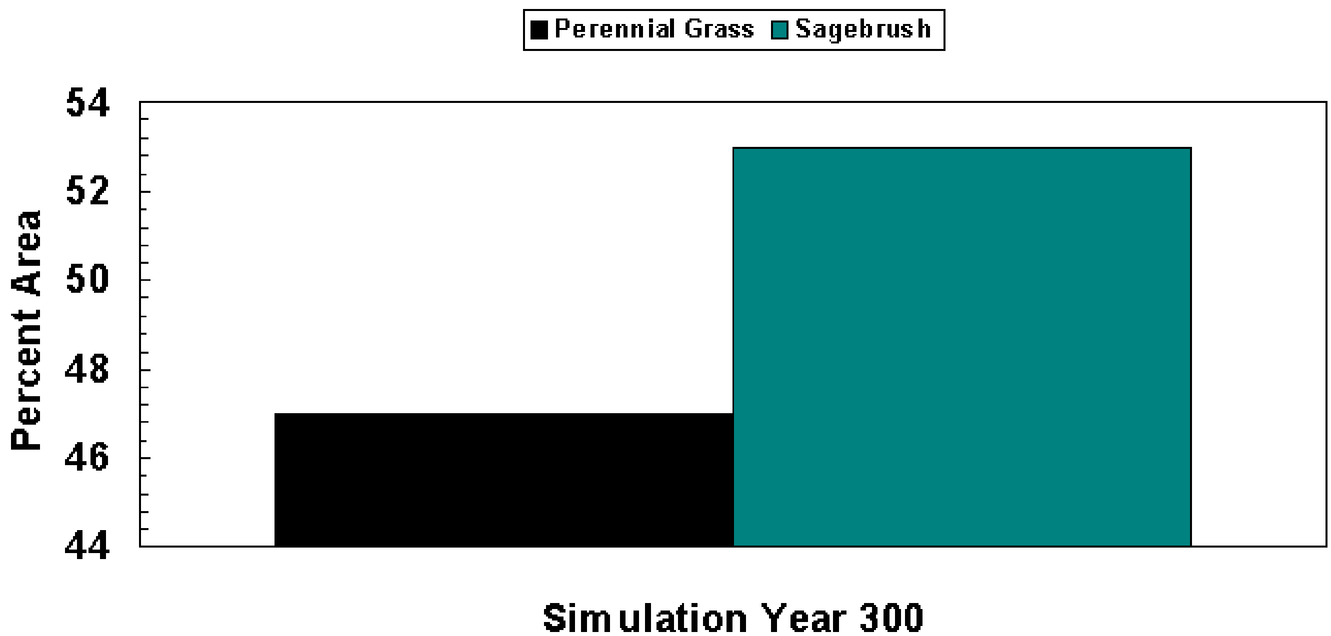

Figure 13–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Big Sage Warm PVT.

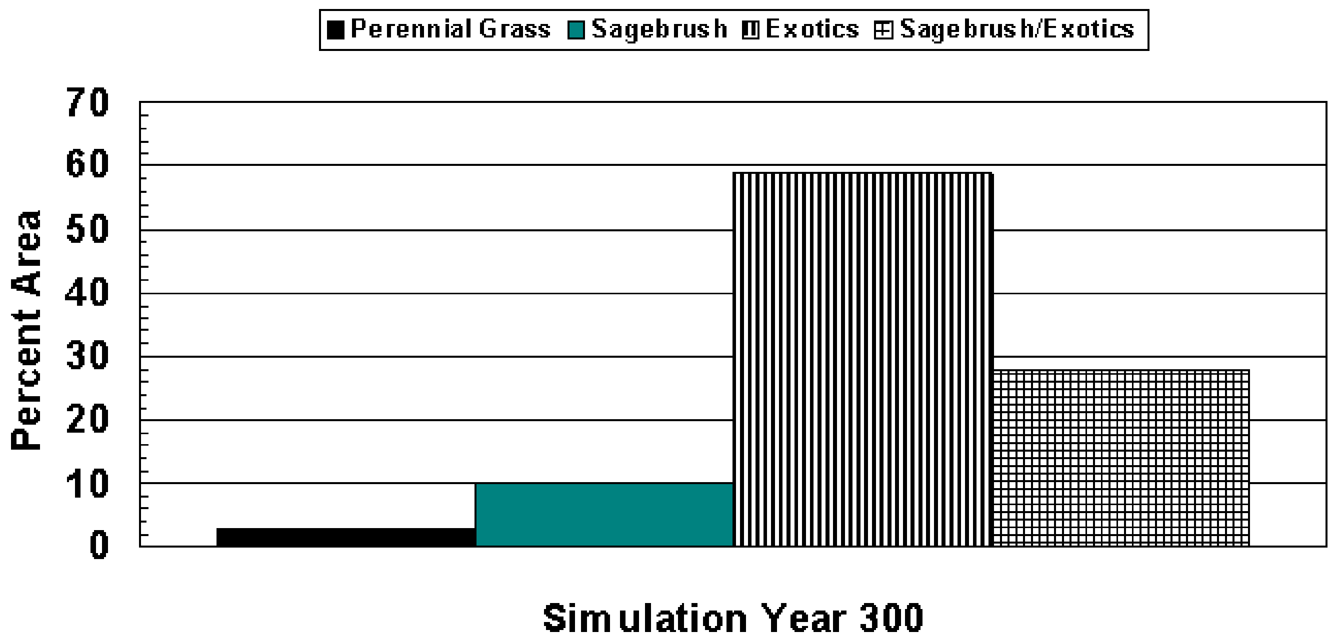

Figure 14–Results of 300 year simulation of consumptive demand management future on distribution of cover types in Big Sage Warm PVT.

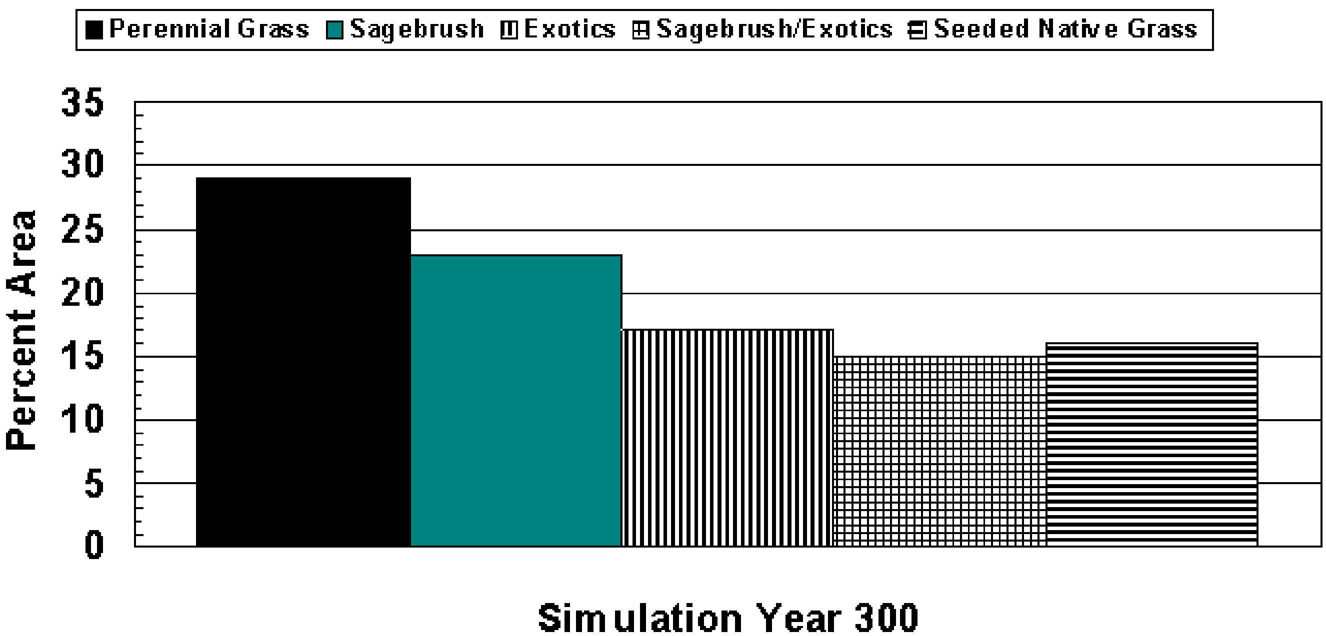

Figure 15–Results of 300 year simulation of active management on distribution of cover types in Big Sage Warm PVT.

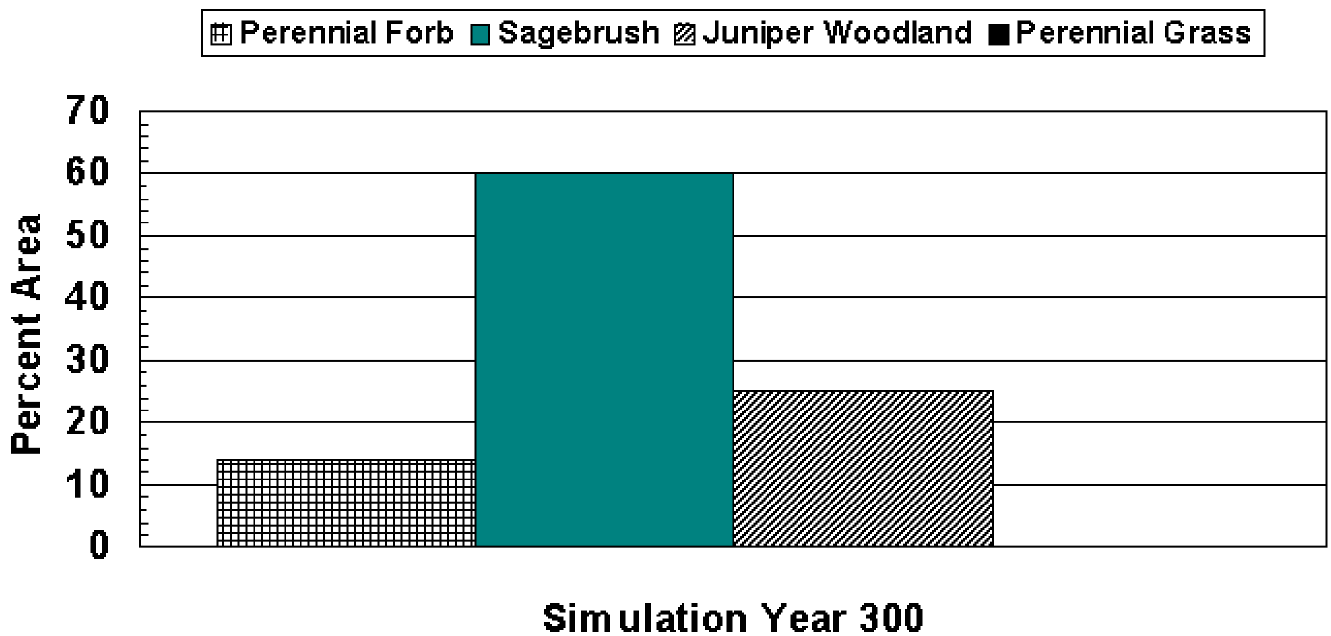

Figure 16–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Mountain Big Sage w/ Juniper PVT.

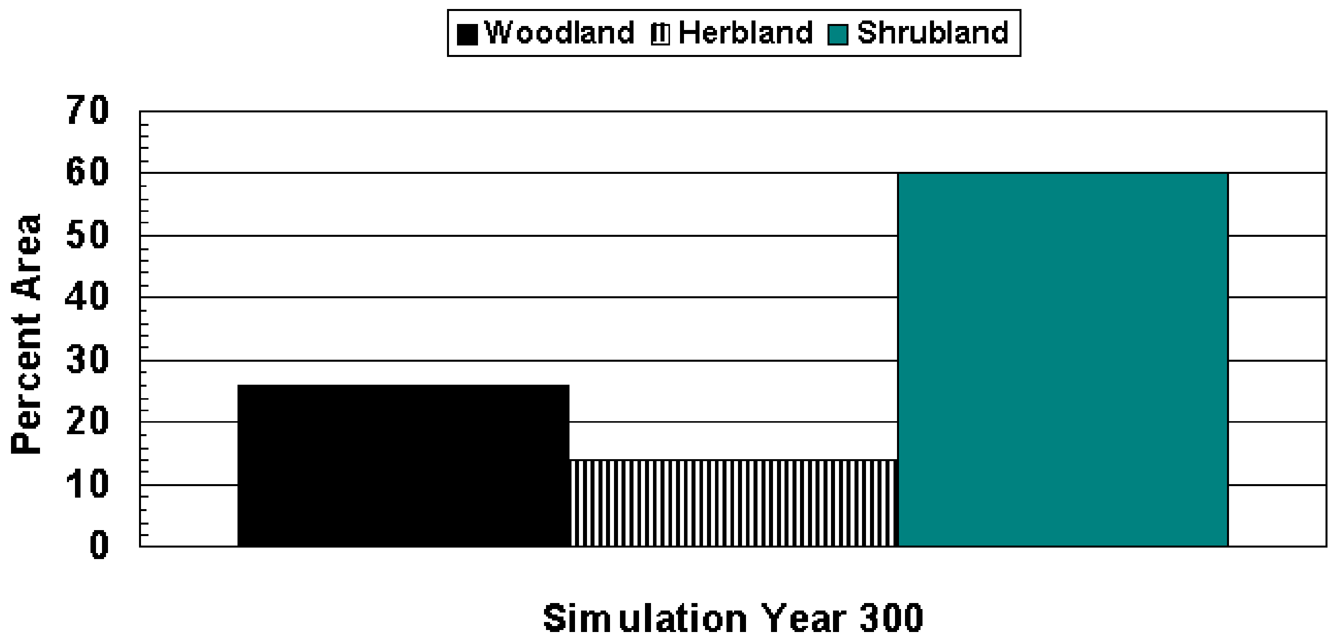

Figure 17–Results of 300 year simulation of natural succession on distribution of structural stages with historical disturbances in Mountain Big Sage w/ Juniper PVT.

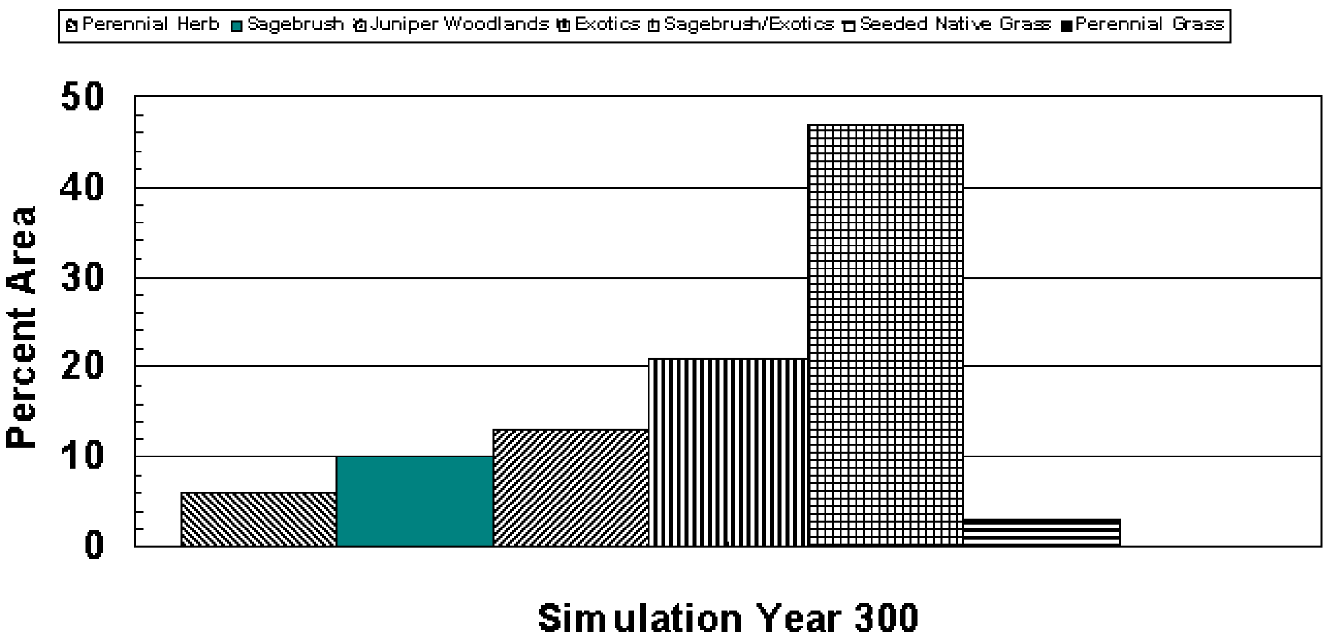

Figure 18–Results of 300 year simulation of consumptive demand management future on distribution of cover types in Mountain Big Sage w/ Juniper PVT.

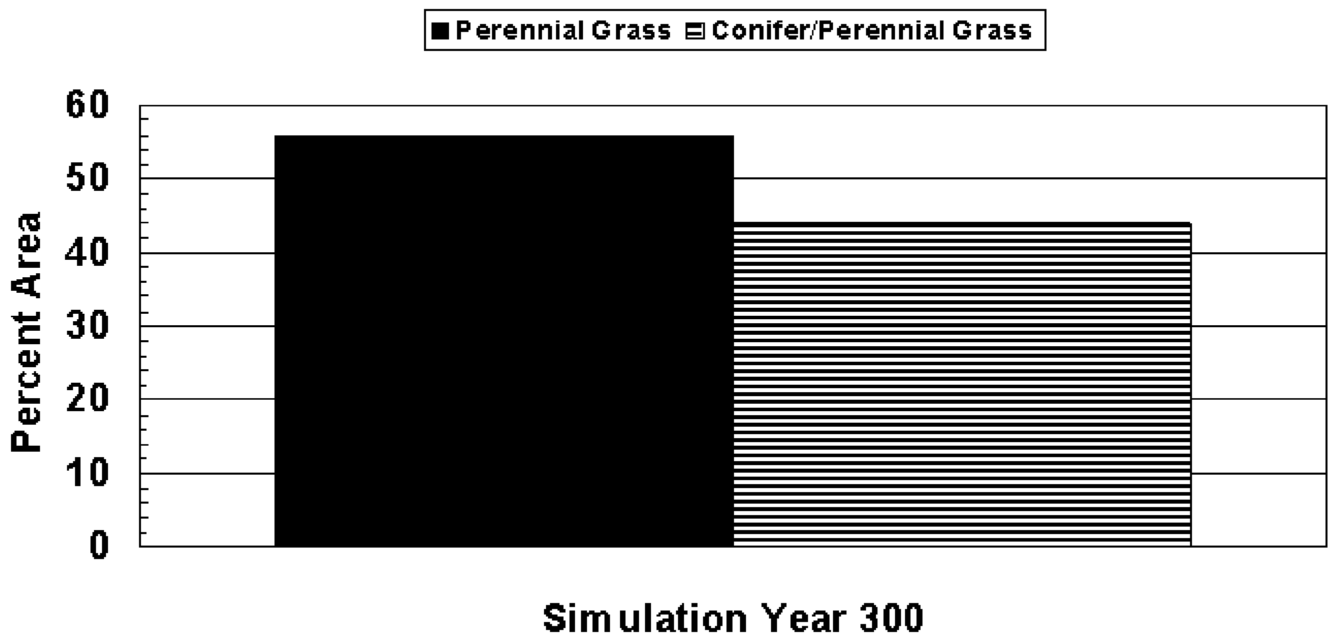

Figure 19–Results of 300 year simulation of natural succession on distribution of cover types with historical disturbances in Conifer - Fescue PVT.

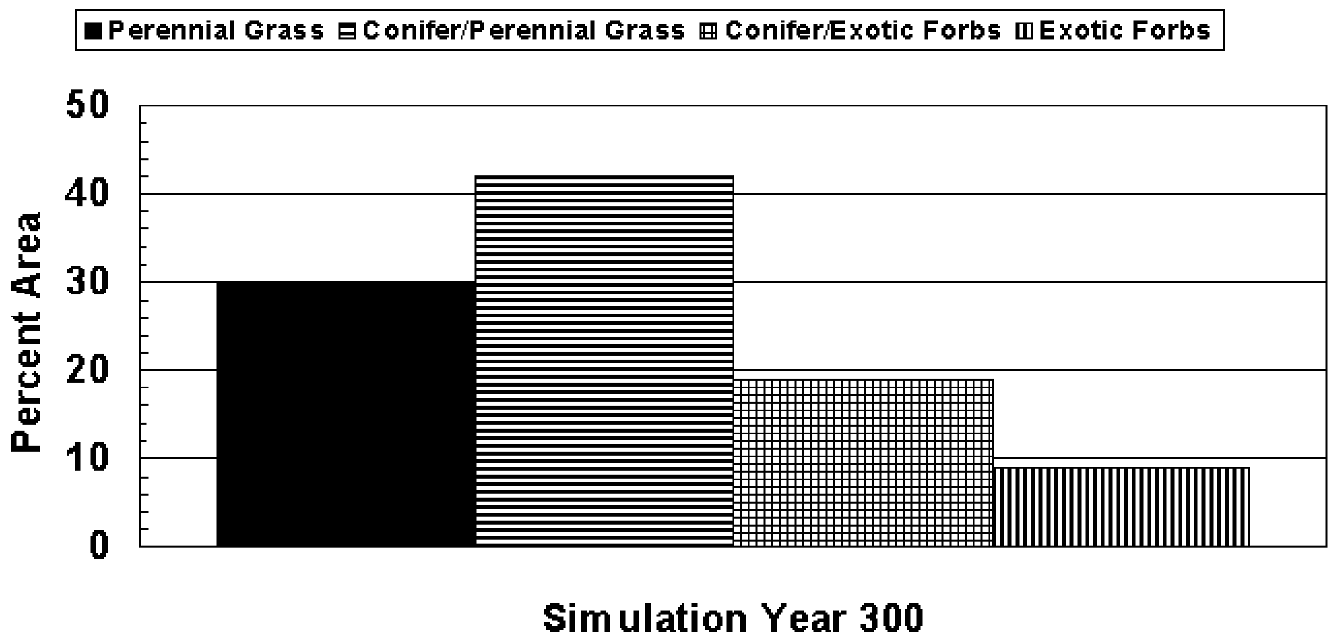

Figure 20–Results of 300 year simulation of consumptive demand management future on distribution of cover types in Conifer - Fescue PVT.

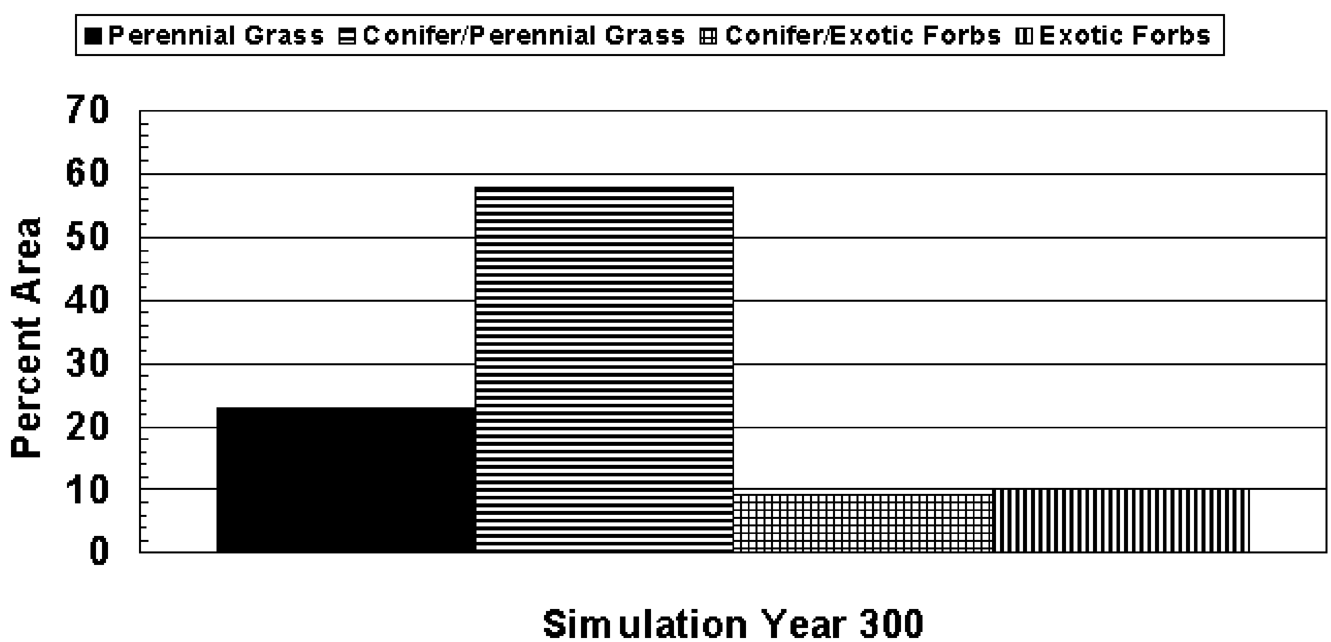

Figure 21–Results of 300 year simulation of active management on distribution of cover types in Conifer - Fescue PVT.