Historical Range of Variation
and
State and Transition Modeling of Historic and Current Landscape Conditions for Potential Natural Vegetation Types of the Southwest

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SAVING THE LAST GREAT PLACES ON EARTH

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Introduction to Vegetation Modeling

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Semi-Desert Grassland

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Madrean Encinal

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Interior Chaparral

Schussman, Heather. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Interior Chaparral of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 24 pp.

Madrean Pine-Oak

Schussman, Heather and Dave Gori. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Madrean Pine-Oak of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 35 pp.

Mixed Conifer

Smith, Ed. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Mixed Conifer of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 31 pp.

Ponderosa Pine

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Aspen

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Alpine Tundra

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Montane Grassland

Smith, Ed. 2007. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Montane Grassland of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 43 pp.

Pinyon-Juniper

Gori, Dave and Joanna Bate. 2007. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Pinyon-Juniper of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 141 pp.

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1.1 Introduction

Definition of HRV-

The Historical Range of Variation or Variability (HRV) is a description of the change over time and space in the ecological condition of potential natural vegetation types and the ecological processes that shape those types. Potential natural vegetation types (PNVT) represent the vegetation type and characteristics that would occur when natural disturbance regimes and biological processes prevail (Table 1 – 1). We base HRV descriptions on the best available empirical information that has been documented, peer-reviewed, and published in journals, reports and books (more in Methods, 1.2). For the purposes of this document, HRV descriptions focus on characteristics important for managing PNVTs found on National Forests in Arizona and New Mexico, including: vegetation composition and structure and how this attribute varies across the region within a PNVT; patch or stand characteristics such as size and spatial distribution; patch dynamics such as succession; the dominant disturbance processes and frequency of disturbance that shape ecological conditions within a PNVT over time; anthropogenic disturbances or exclusion of natural disturbance regimes; and the effects of climatic fluctuations.

Table 1-1. List of potential natural vegetation types that exist on Region III forests, for which historical range of variation is investigated. Potential Natural Vegetation Types are coarse scale groupings of ecosystem types that share similar geography, vegetation, and historic disturbance processes such as fire, drought, and native herbivory.

Alpine Tundra	Mixed Conifer forest
Aspen forest and woodland	Montane grassland
Cottonwood willow riparian forest	Montane willow riparian forest
Deserts	Pinyon Juniper woodland
Gallery coniferous riparian forest	Plains grassland
Great Basin grassland	Ponderosa Pine forest
Great Plains Grassland	Sagebrush shrubland
Interior chaparral	Semi-desert grassland
Juniper woodland	Shinnery Oak
Madrean encinal	Spruce-fir forest
Madrean pine oak woodland	Sub-alpine grassland
Mixed broadleaf deciduous riparian forest	Wetlands/cienega

Descriptions of HRV also focus on quantifying the rate of change in PNVT characteristics and the influence of humans on changes in PNVT characteristics. Several authors have noted that contemporary patterns of vegetation and their dynamic processes developed in the Southwest during the early Holocene, around 11,000 to 8,000 years ago (Allen 2002, Anderson 1993, Weng and Jackson 1999). However, due to limitations on the availability of recorded data from tree rings, pollen, and charcoal discussed in the

Methods section (1.2), unless otherwise noted, the time period that we consider to frame the "**Pre-settlement**" portion of the HRV descriptions is between the years 1000 to 1880. Large-scale expansion and westward movement and settlement by United States citizens and European (and other ethnic) immigrants following the Civil War mark the onset of major anthropogenic disturbances in the Southwest: extensive, commercial livestock grazing, river damming and canal construction, railroad logging, and widespread fire regime alteration, all of which have had significant impacts on vegetation and ecological processes (Carlson 1969, deBuys 1985, Allen 1989, Covington and Moore 1994, Touchan and others 1996). Thus we refer to that portion of the HRV that resulted from conditions after 1880 as the "**Post-settlement**" or anthropogenic disturbance period. There is ample evidence to suggest that while aboriginal or Native American influences on the landscape prior to 1800 were detectable in some locations, the magnitude of anthropogenic disturbance after 1880 was much greater (Allen 2002).

We include post-settlement or anthropogenic disturbances as an important part of the HRV for PNVTs because in many cases the pre-settlement vegetation patterns and processes have been significantly altered by humans, not only in magnitude but also in rates of change. When empirical data are available, we document the processes, such as altered herbivory, silvicultural activities, habitat fragmentation, altered hydrology, mining, fire management, and introduction of exotic species of plants and animals. We then describe the effects of these processes on the characteristics, natural processes, and vegetation dynamics observed for PNVTs.

HRV's Application in Land Management Decision-Making – Understanding the response of PNVTs to disturbance processes (or the absence of disturbance processes) and the characteristics of PNVTs over time enables land managers to better characterize components of ecosystem diversity. In the context of land management planning, HRV enables managers to identify desired future conditions and the need for change by comparing current conditions with the range of historical conditions. HRV also describes the evolutionary context for PNVTs present today by identifying the disturbance processes (and variability) that serve as major determinants of PNVT characteristics (Morgan and others 1994). Understanding the relationship among disturbance processes, the responses of organisms to these processes, and current conditions enables managers to evaluate the potential for proposed management actions to meet ecological sustainability goals. Moreover, since the form and function of PNVTs are shaped by these processes, HRV characterizations can assist land managers in evaluating how and where appropriate disturbance regimes may be integrated into management actions.

HRVs characterize a range of *reference conditions* against which ecosystem change, anthropogenic or stochastic, can be measured (White and Walker 1997) and the landscape-scale effects of succession and disturbance on vegetation characteristics over time (Landres and others 1999). Identifying reference conditions and the range of variation is important for identifying land management goals and land-use allocations. Historical Range of Variation descriptions also enable land managers to better predict where management actions are likely to have the greatest effect on restoring some of the patterns and processes identified in the HRV. However, the current biophysical conditions under which land management is practiced are different from the evolutionary environment under which ecological systems developed. For example, climate continues to change, which affects vegetation mortality, reproduction, and disturbance processes. Anthropogenic effects of landscape fragmentation through road construction, exotic species introductions, and fire suppression also contribute to what has been called the "no analogue" condition: the current evolutionary environment may be different from the historic evolutionary environment, and some historical conditions may be neither attainable nor desirable as management goals (Swetnam and others 1999).

The Historic Range of Variation identifies the scope, magnitude, variability and probability of occurrence for processes that govern the form and function of PNVTs. Complete understanding of PNVTs is unattainable, but cataloguing and organizing what is known about systems can give managers easy access to that information and facilitate its incorporation into planning processes and documents. Some aspects of HRV have not been documented in the literature, and some pre-settlement patterns that are documented may not be desirable or attainable given the dynamic nature of climate and ecological systems. However, management actions can be adapted as information gaps are filled, and well designed land management hypotheses can be tested with rigor. HRV does not absolutely define an acceptable range of conditions, but can help with setting meaningful, empirically based boundaries. If the explicit goals of management actions aspire toward conditions that are outside of the HRV (departure), then the rationale used in developing such goals can be evaluated, assumptions documented, and results of pertinent management actions can be monitored closely (Morgan and others 1994). The vegetation characteristics and process probabilities described in an HRV can form the basis for quantitative models of vegetative change by providing the variables that populate the models. Several models have been developed to incorporate a combination of deterministic, stochastic, and probabilistic events into predictive models of ecosystem change (Morgan and others 1994). Models can be used to test the effects of various management scenarios on ecological systems.

In summary, a well researched and organized HRV description enables managers of that system to:

- Understand reference conditions and reference variability for ecological systems;
- Understand the effects of natural disturbance processes in the absence of anthropogenic activities;
- Understand likely direction of ecological systems under various management scenarios and thus help identify and understand the need for change;
- Evaluate and predict management outcomes;
- Understand the relationship between natural disturbance processes and anthropogenic activities in the development of short- and long-term management goals.

Influence of Temporal and Spatial Scale on Reported Values - The effect of scale, both spatial and temporal is well recognized for its importance in HRV descriptions (Morgan and others 1994). Reported values of ecosystem characteristics and processes are dependent upon the scale at which they are measured, and the amount of variability of measured values also varies at different scales (Wiens 1985, Turner and Gardner 1991). For example, species richness (total number of species) increases in many ecosystem types with increasing plot size (Darlington 1957), a tenet that is basic to biogeography. Similarly, the reported values of ecological processes such as fire are dependent upon the temporal and spatial scales at which they are measured, due to differences in topography and aspect (spatial) and climatic changes (temporal). However, spatial variability of topography and aspect can be viewed at multiple scales, from microsite differences operating at the smallest scale of a few feet to the landscape scale of millions of acres. Similarly, climatic differences can operate at multiple scales from short-term drought of a few years, to decadal to century scale trends of long-term drought. Also, size of the sampling area (spatial), and length of the sampling period (temporal) both affect the reported values for ecological processes, resulting in variation in the estimated parameter due to sampling. The selection of the appropriate scales of time and space for HRVs should be based upon the analytical objectives (Bourgeron and Jensen 1993). For this project, the focus of the analysis is in understanding vegetation dynamics for a variety of PNVTs in the Southwest Region of the United States. For this reason, we have chosen to report values for the full extent of each PNVT across the two-state Region III of the United States Forest Service. The spatial scale thus falls into the range of hundreds of thousands to millions of acres, depending on the PNVT, and with the exception of Alpine/Tundra, Gallery Coniferous Riparian Forest, Montane Grassland, and Wetland/Cienega (Table 1-2). Similarly, since the time period of inquiry for establishing HRV focuses on pre- and post-settlement times for these PNVTs, and time scale should encompass multiple generations of vegetation (Morgan and other 1994), the time scale of inquiry is over hundreds of years, from approximately 1000 until the present. Ultimately, we have allowed the availability of published empirical data to be our guide in determining and reporting relevant information regarding the magnitude and variability of ecosystem characteristics and processes for these HRVs.

Table 1-2. Approximate area (in acres) of potential natural vegetation types (PNVTs) in Arizona and New Mexico across major landowners. The Other landowner category in this table includes: Bureau of Reclamation, non-federal parks, Valles Caldera National Preserve, county lands, Department of Energy, USDA Research, State Game and Fish, and unnamed lands. USFS Region 3 National Grasslands in New Mexico, Oklahoma and Texas were not included in this analysis. Data used to generate this table came from The Southwest Regional Gap Analysis Program (SWReGAP) and the landownership GIS-based layer. Note that accuracy testing has not been conducted for SWReGAP data. Total acres in bold indicate the scale for which HRVs were developed.

Potential Natural Vegetation Type	US Forest Service	Bureau of Land Management	Department of Defense	National Park Service	Private	State Trust	Tribal	US Fish and Wildlife Service	Other	Total
Alpine Tundra	1,600	0	0	0	6,100	0	0	0	0	**7,700**
Aspen Forest and Woodland	335,900	500	0	3,400	93,200	2,200	75,900	0	11,600	**522,700**
Barren	0	26,900	13,000	100	35,900	14,900	196,400	2,100	300	**289,600**
Cottonwood Willow Riparian Forest	19,500	74,800	14,900	7,100	219,500	55,600	389,000	28,500	11,000	**819,900**
Deserts	1,018,300	8,593,300	3,537,800	1,321,000	3,418,000	3,340,700	3,429,500	1,583,200	252,800	**26,494,600**
Disturbed/Altered	83,300	9,200	600	6,000	218,200	37,200	47,800	5,600	400	**408,300**
Gallery Coniferous Riparian Forest	100	0	0	0	1,100	0	100	0	0	**1,300**
Great Basin/ Colorado Plateau Grassland and Steppe	684,400	2,853,400	23,000	572,300	5,695,500	2,599,300	12,175,500	43,200	18,500	**24,665,100**
Great Plains Grassland	316,800	1,270,300	29,000	10,000	16,055,000	3,158,400	181,000	14,100	11,400	**21,046,000**
Interior Chaparral	1,345,900	414,600	33,800	31,300	590,500	350,800	333,100	6,400	11,000	**3,117,400**
Madrean Encinal Woodland	2,736,200	518,800	151,400	34,400	1,259,800	609,300	1,165,200	14,800	2,200	**6,492,100**
Madrean Pine-Oak Woodland	831,900	20,200	1,700	5,000	89,200	30,100	438,400	100	200	**1,416,800**
Mixed Broadleaf Deciduous Riparian Forest	42,600	36,200	5,000	4,200	115,800	17,300	65,500	7,900	4,300	**298,800**
Mixed Conifer Forest	1,216,300	33,900	2,700	43,500	225,900	13,800	191,000	1,000	52,000	**1,780,100**
Montane Grassland	17,200	0	0	0	16,900	0	2,300	0	0	**36,400**
Montane Willow	17,300	14,400	800	600	42,800	11,500	12,100	100	4,100	**103,700**

Potential Natural Vegetation Type	US Forest Service	Bureau of Land Management	Department of Defense	National Park Service	Private	State Trust	Tribal	US Fish and Wildlife Service	Other	Total
Riparian Forest										
Pinyon-Juniper Woodland	3,375,200	2,872,700	22,300	556,700	4,442,500	1,505,300	5,647,800	19,000	51,600	**18,493,100**
Ponderosa Pine Forest	5,835,300	112,500	16,400	94,200	1,408,400	147,000	1,588,900	900	44,100	**9,247,700**
Sagebrush Shrubland	134,500	685,200	1,600	66,300	642,100	184,700	977,200	21,200	11,700	**2,724,500**
Semi-desert Grassland	1,642,300	8,013,000	1,463,300	99,000	7,996,600	5,914,600	951,900	321,000	185,000	**26,586,700**
Spruce-fir Forest	355,200	35,000	1,000	7,000	128,200	2,300	72,000	300	10,000	**611,000**
Sub-alpine Grasslands	311,700	13,900	200	2,500	183,400	10,700	55,700	0	27,000	**605,100**
Urban/Agriculture	20,800	35,100	49,200	2,300	4,119,500	219,000	334,900	5,600	23,900	**4,810,300**
Water	25,300	25,000	2,300	79,100	122,000	900	38,100	15,600	55,500	**363,800**
Wetland/Cienega	8,900	9,500	200	400	35,000	7,100	6,800	2,900	1,100	**71,900**

Urgency, Limitations, Assumptions, and Misuse of HRV – As time passes, fewer records of HRV are available to help fill in gaps in our knowledge; old trees, snags, stumps and logs burn or decay, and records from professionals who have witnessed change are lost or not archived making it difficult to assess some important sources of information before they are gone. It is important to prioritize data gaps and to encourage efforts to fill gaps, although in many cases, pre-settlement information may never be available. Historical data must be interpreted with caution, as it is not always possible to assign causation to observed phenomena, as confounding factors may not always be discernible, and their relative contribution to observed records may not be accountable (Morgan and others 1994).

Use of Reference Sites - When historical data are lacking, especially for pre-settlement conditions, it has been suggested that areas with relatively unaltered disturbance regimes can be used to assess and describe the HRV for an area of similar biophysical setting (Morgan and others 1994). Hence, wilderness areas with intact fire regimes, or research natural areas where livestock grazing has been excluded, and riverine systems with intact flow regimes for example may provide valuable information on ecosystems where these disturbance regimes have been altered in a majority of sites or areas. However, the degree to which even large wildernesses have been affected by humans, and the lack of breadth of biophysical settings represented by preserved areas limit the availability of reference sites. Within each PNVT description, we have identified reference sites that were used for developing its HRV.

1.2 Methods Used in Determining HRV

Introduction - We utilized extensive library searches of Northern Arizona University, University of Arizona, and University of New Mexico, and published reports from Rocky Mountain Research Station. We used published, peer-reviewed journal articles, as well as published conference proceedings, reports, theses and dissertations, and book chapters as sources of information. We limited our search to relevant literature that came from studies of Southwest ecosystems, with a geographical emphasis on Arizona, New Mexico, and northern Mexico to ensure compatibility and relevance to Southwest ecosystems. Sometimes, results from studies in Utah, Colorado, California and other states were reported to show similarities or differences among geographic areas.

Dendroecology - Annual growth rings left by trees in living tissue, stumps, snags, logs, and even archeological artifacts such as vigas and latillas of pueblo construction have been analyzed to estimate past and present age classes, seral stages, or community composition (Morgan and others 1994, Cooper 1960, White 1985). Growth rings that have been scarred by fire (fire rings) along with analysis of existing or past age structure have been used to estimate past patterns and processes of several vegetation types (e.g., Romme 1982, Arno and others 1993, Morgan and others 1994). Forest tree rings can also be analyzed to discern climatic variation, forest structure, insect outbreaks, patch dynamics or successional pathways, frequency and severity of fire regimes, and other processes (e.g., Fritts and Swetnam 1989). In most cases, the size of plots used in Southwest studies we cite ranged in size from 25 to 250 acres. In some cases, it may be difficult to parse out and differentiate between confounding factors such as climatic fluctuation, competition, and insect outbreak. Every year, fire, silvicultural practices, and decomposition remove more of the available record.

fluctuation, competition, and insect outbreak. Every year, fire, silvicultural practices, and decomposition remove more of the available record.

Paleoecology - Deposits of plant pollen and charcoal in wetland soils and stream sediments, and in packrat middens can be analyzed to estimate even longer records of vegetation presence on the landscape (e.g., Anderson 1993, Allen 2002).

Narrative Descriptions - Several early explorers and historical writers left narrative descriptions of the ecological condition of the landscape as they found it. We chose not to incorporate this information into our HRVs except on rare occasion when general trends were observed by multiple observers and reported in the literature (e.g., Muldavin and others 2002).

Historic Photographs - We conducted an exhaustive search of available historic photographs in order to create the SWFAP photographic database. The goal of compiling this database was to identify photographs that would be useful for describing the HRV of vegetative characteristics and VDDT model states for each PNVT. The details regarding the creation of this database are outlined below.

In order to compile the SWFAP photographic database, archives that stored historical and present day landscape scale photographs of the Southwest were researched (Table 1-3).

Table 1-3. Photographic archive, location of archive, persons contacted, identification of the types of photographs (potential natural vegetation types = PNVTs) obtained from each archive, and additional information regarding the photographs collected. Note that not all photographs researched and collected were incorporated into the final SWFAP photographic database.

Photographic Archive	Location of Archive	Contact Person	Repeat Photographs Collected	PNVTs for which photographs were obtained for	Additional Comments
Apache-Sitgreaves National Forest	Springerville, AZ	Bob Dyson	No	aspen, interior chaparral, mixed conifer, montane grasslands, pinyon-juniper, riparian, spruce-fir	The photographs came from the A-S historic archives, and were sent on a CD. The CD included about 500 photographs, although none of the photographs have information regarding dates taken or the specific locations of the photographs.
Carson National Forest	Taos, NM	Bill Westbury and Dave Johnson	No	aspen, mixed conifer, montane grassland, riparian, spruce-fir	

Coronado National Forest	Tucson, AZ	Bill Gillespie and Geoff Soroka	No	aspen, interior chaparral, Madrean encinal, Madrean pin-oak, mixed conifer, pinyon-juniper, semi-desert grasslands	Two sources were used. One was from Bill Gillespie, and included only historical photos. The other source was from Geoff Soroka, where most photos were taken in part to ground-truth the mid-scale vegetation mapping effort.
Ecological Restoration Institute	Northern Arizona University	Dennis Lund	No	aspen, mixed conifer, pinyon-juniper, ponderosa pine	photos from Dennis's collection from national and local USFS archives
Gila National Forest	Silver City, NM	Reese Lolly	No	interior chaparral, mixed conifer, pinyon-juniper, ponderosa pine	
'*Historic increases in woody vegetation in Lincoln County, New Mexico*' by E. Hollis Fuchs	n/a	E. Hollis Fuchs	Yes	mixed conifer, montane grasslands, ponderosa pine, pinyon-juniper, riparian, semi-desert grasslands	Photographs taken directly from Hollis' book.
Jornada Experimental Range	Las Cruces, NM	n/a	Yes	semi-desert grasslands	photos from on-line archive
Rocky Mountain Research Station	Flagstaff, AZ	Susan Olberding	No	interior chaparral (on-line resource only), ponderosa pine, riparian	includes mostly photographs from the Ft. Valley Research Station archive, but also from the RMRS on-line photographs
Saguaro National Park	Tucson, AZ	James Leckie	No	Madrean encinal, Madrean pine-oak	Photographs from several field season that investigated the effects of fire over several years
Santa Fe National Forest	Santa Fe, NM	Mike Bremer	No	mixed conifer, pinyon-juniper, riparian, spruce-fir	
Santa Rita Experimental Range	southeastern AZ	n/a	Yes	semi-desert grasslands	photos from on-line archive
Sharlot Hall Museum	Prescott, AZ	Ryan Flahive	No	aspen, interior chaparral, mixed conifer, pine-oak, pinyon-juniper, riparian	
The changing mile revisited' by Turner, Webb, Bowers, and Hastings.	Tucson, AZ	Ray Turner and Diane Boyer	Yes	Madrean encinal, riparian, semi-desert grasslands	These photographs were taken directly from this book.
United States Geological Survey	Tucson, AZ	Diane Boyer and Ray Turner	Yes	Madrean encinal, riparian, semi-desert grasslands	From the Desert Laboratory Repeat Photography Collection

United States Geological Survey	Los Alamos, NM	Craig Allen	Yes	pinyon-juniper, ponderosa pine, mixed conifer, spruce-fir	Photographs taken from an unpublished paper by Hogan and Allen (2000).
US Forest Service Region 3	Albuquerque, NM	Sheila Poole	Some	alpine-tundra, aspen, interior chaparral, Madrean encinal, Madrean pine-oak, mixed conifer, montane grasslands, pinyon-juniper, riparian, semi-desert grasslands, spruce-fir	
US Forest Service unpublished report "*Wood plenty, grass good, water none*" by Harley Shaw	n/a	Harley Shaw	Yes	pinyon-juniper, semi-desert grasslands	Photographs taken from Harley's manuscript that will be published in the near future by the RMRS.

Many of these photographic archives included museums and federal agencies like the US Geological Survey, the National Park Service, individual National Forests, USFS Research Stations, and the USFS Regional Office. In addition to traditional photograph archives, other sources of photographs came from published books of repeat photography, unpublished manuscripts of repeat photography, and photographs taken in the field for vegetation mapping purposes or other reasons. Several historical societies and Arizona and New Mexico state agencies were contacted about potential photographs, however, none proved to have photographs that would meet the needs of this project. Our goal was to obtain photographs of each PNVT from a variety of locations, so that one area (or state) was not over-represented, showing a variety of conditions with an emphasis on repeat photography sequences.

When viewing photographic archives, or photographs from the field, we viewed all of the photographs available, and then selected those photographs that we deemed potentially appropriate photographs for this project. The criteria used to make the initial selection of photographs from the archives are outlined below:

- We discarded all photographs where buildings and/or people were the main subject, and one could not see the vegetation well
- We discarded all photographs where the quality of the photo was poor
- We discarded photographs if they were repeating the same subject matter (i.e. two photographs taken at the same time of the same landscape, we would hold on to the 'best' one and discard the other)
- We discarded many photographs that repeated the same subject matter and model state (i.e. if there were 30 photographs of park-like ponderosa pine from roughly the same location and roughly the same dates, we kept approximately the 'top' 5)
- We retained any photographs that were repeats over time
- We retained any photographs of PNVTs that we had a limited number of, or that we had limited numbers for that location (i.e. if we had hundreds of ponderosa pine forest photographs in Arizona but few for New Mexico, we would select

the best photographs for Arizona and keep all the ones that were taken in New Mexico)

- We retained any photographs of PNVTs that we thought were good examples of various model states within a PNVT (i.e., open canopy, closed canopy, early seral, late seral)
- We attempted to get as many historical photographs (vs. current day) as possible, although we were limited by availability

After the initial selection of photographs was made, Nature Conservancy ecologists evaluated all photographs for their inclusion into the final SWFAP Photographic Database. Any photograph incorporated into the HRV and state-and-transition model documents were incorporated into the final SWFAP Photographic Database.

The SWFAP Photographic Database uses Extensis Portfolio 7.0 software for Windows to organize and display the selected photographs. Information regarding each photo, including: file name, title, location, date, photographer, if it is linked to a model state in the state-and-transition documents, if it is a repeat of another photograph taken at the same location but different time, copyrights, and source of photograph are included in the database.

Climate Analysis - In Arizona and New Mexico, precipitation is primarily bimodal, highly variable from year to year and from location to location, and has a large impact on vegetation. Extended wet or dry periods can cause changes in vegetation at the life form (grass, shrub, or tree) and/or species composition level (McPherson and Weltzin 1998; Swetnam and Betancourt 1998; Turner and others 2003). The wet period of the late 1970's early 1980's in the southwest has been documented to coincide with the expansion of multiple tree species; wet winters in general tend to coincide with increases in shrub cover, while extended dry periods have coincided with grass, shrub, and tree mortality (Barton and others 2001; Crimmins and Comrie 2004; Grissino-Mayer and Swetnam 2000; Miller and Rose 1999; Savage 1991; Swetnam and Betancourt 1998).

While there is an understanding that climate and, precipitation in particular, play an important role in Southwest vegetation dynamics, little information regarding historical patterns of dry and wet events exists for the Southwest despite multiple regional climate reconstructions (Cook and others 1999; Ni and others 2002). Additionally, the focus of most long-term climate studies, at any scale, is to identify extreme conditions (Cook and others 1999; Cleaveland and Duvick; Laird and others 1996; Meko and others 1995; Ni and others 2002; Salzer and Kipfmueller 2005; Stahle and others 1985; Stahl and Cleaveland 1988). This focus yields little information regarding lower impact events and relies heavily on statistical thresholds, which makes identifying connections with ecological impacts difficult to assess.

Given that there is ecological data to support the idea that both extreme and lower impact (or non-extreme) events can effect Southwest vegetation; the goal of this analysis is to 1) describe historic year to year climate variability, 2) identify the range, frequency, and length of extreme and non-extreme climate events, 3) compare the occurrence of these events spatially throughout the Southwest and temporally across the last 1000 years.

Data - There are two publicly available climate reconstruction data sets that cover the Southwest region for the last 1000 years; a summer (June to August) Palmer Drought Severity Index (PDSI) reconstruction and a winter (November to April) precipitation reconstruction (Cook and others 1999; Ni and others 2002). Both reconstructions correlate tree ring information with climatic information (PDSI or winter precipitation) in order to model past climate values. The nation-wide summer PDSI information covers years 0 to 2003, and is available for 8 grid locations (4 in Arizona and 4 in New Mexico) across the Southwest (Figure 1-1a). We limited our use of this data set to years 1000 to 1988 in order to be able to make comparisons with the winter precipitation data set. The subset of the summer PDSI data utilizes between and 5 and 9 tree chronologies per grid location. The Southwest winter precipitation data covers from years 1000 to 1988, is available for 15 climate divisions (7 in Arizona and 8 in New Mexico) throughout the Southwest, and utilizes 19 tree chronologies (Figure 1-1b). While there are some differences in the two data sets, they both utilize many of the same tree chronologies and, since summer PDSI is partly a measure of the lack of precipitation in late winter/early spring, identify roughly the same climate feature – winter precipitation.

It is important to note some key caveats regarding the data sets. The percent of variation in the cool season precipitation record explained (R2 value) by Ni and others (2002) reconstruction varies for each climate division and should be considered when evaluating results (Table 1-4) (CLIMAS 2005 http://www.ispe.arizona.edu /climas/research / paleoclimate/product.html). Similarly, the Cook and others (1999) reconstructions are based on anywhere from 5 to 9 tree chronologies with less certainty in the reconstruction occurring with fewer chronologies (Table 1-5). Additionally, information used to build both reconstruction models comes from upper elevation pine species which should be considered when extrapolating these data to lower elevation warm season dominated vegetation types or areas. Even with the above mentioned constraints, these climate data give an unprecedented regional look at historic climate conditions throughout the Southwest.

Table 1-4. Percent of variation in the known cool season precipitation record explained (R2 value) by Ni and others (2002) for all 15 climate divisions in Arizona and New Mexico (CLIMAS 2005 http://www.ispe.arizona.edu/climas/ research/paleoclimate/ product.html).

	Az1	**Az2**	**Az3**	**Az4**	**Az5**	**Az6**	**Az7**	**Nm1**	**Nm2**	**Nm3**	**Nm4**	**Nm5**	**Nm6**	**Nm7**	**Nm8**
R^2 (%)	49	62	48	50	42	51	44	65	59	44	44	41	40	42	36

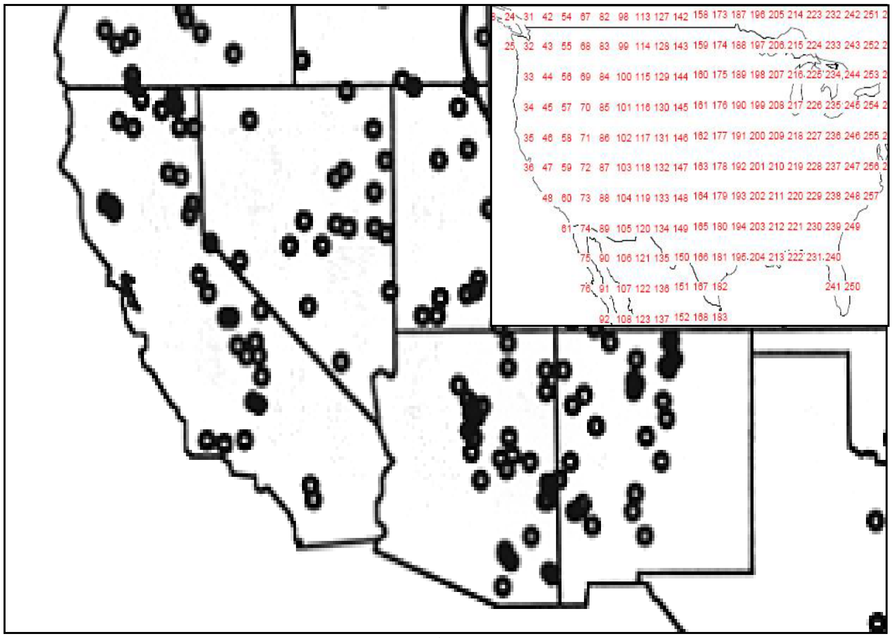
Table 1-5. Number of tree chronologies used in climate reconstructions for each PDSI grid point location for the Southwest.

	88	**89**	**104**	**105**	**119**	**120**	**133**	**134**
# of Tree Chronologies	8-9	5-9	8-9	5-9	9	6-9	8-9	5-9

Methods- For a detailed discussion of the methodology used to identify 1) year to year variability, 2) range, frequency, and length of extreme and non-extreme events, and 3) spatial and temporal comparison, see Schussman 2006 (Assessing Low, Moderate, and High Severity Dry and Wet Events Across the Southwestern United States from Year 1000 to 1988).

Results - A comparison of the percent of dry and wet winter precipitation years, for the 15 climate divisions that span Arizona and New Mexico, showed a pattern of 19% of the years, between year 1000 and 1988, classified as severe drought or extremely wet years, 11% classified as drought years, 8% classified as wet years, and 43% classified as normal years (Figure 1-2 and Appendix 1- Table 1.1 and Figures 1.1 to 1.15). The long-term winter precipitation averages for each climate division range from 2.4 to 9.8 inches/yr. Comparisons of the 8 summer PDSI locations showed the pattern of 11% of the years classified as severe and extreme drought, 27 % classified as moderate and mild drought, 38% classified as near normal and incipient wet and dry spells, 20% classified as slightly or moderately wet, and 5% classified as very and extremely wet years (Table 1-5, Figure 1-3, and Appendix 1 - Table 1.2 and Figures 1.16 to 1.23). Overall there is little regional variability in the percent of dry and wet years for either the winter precipitation or summer PDSI data sets. Of the regional variability that is present, the majority of the variation occurs within the winter precipitation data set between severe drought and drought years. For example, New Mexico climate divisions 2, 3, and 6 had fewer severe drought years than the average, but had higher drought years.

There is also little regional variability in the total number of drought, normal, and wet events that occurred in either the winter precipitation of summer PDSI data sets (Figure 1-4, Figure 1-5, Appendix 2 - Tables 2.1 and 2.2 and Figures 2.1 to 2.23). Specifically, there were on average 52 drought events, 41 wet events, and 85 normal events identified for the winter precipitation data and 71 drought events, 54 wet events, and 104 normal events identified for the summer PDSI data set. In contrast, the range of the length of events does exhibit some regional variability with winter precipitation events ranging between 9 and 26 years for the longest drought events, between 14 and 23 years for the longest wet events, and between 19 and 40 years for the longest normal events. This level of variability is also seen in the summer PDSI data set with between 19 and 25 years for the longest drought event, between 8 and 17 years for the longest wet events, and between 14 and 23 years for the longest normal events (Appendix 2 - Table 2.1 and Figures 2.1 – 2.23). The timing of the events identified is fairly consistent across the entire Southwest (ie all climate divisions and PDSI grid point locations document drought and wet events occurring in roughly the same years even though the magnitude of those events varies regionally).



1a.

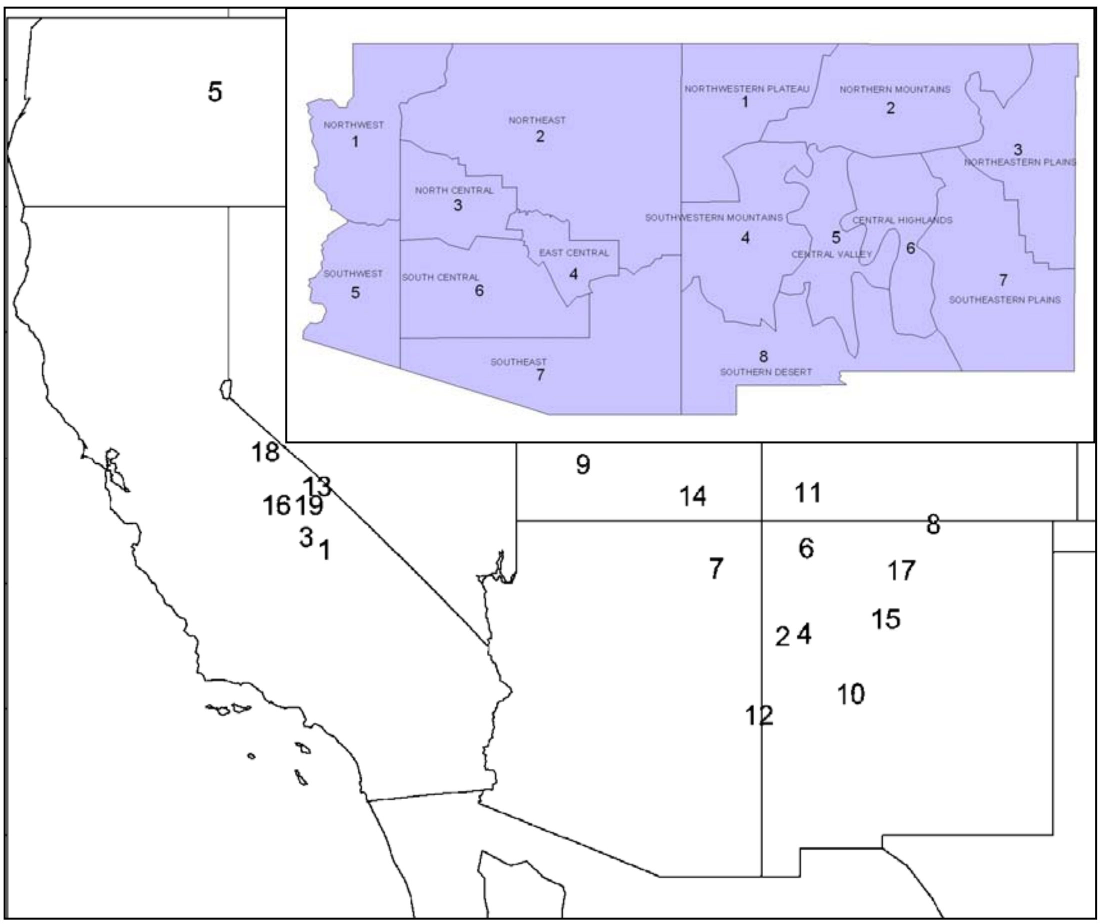


Figure 1-1. Identification of tree chronology locations for both the PDSI (1a taken from Cook and others 1999) and winter precipitation (1b taken from Ni and others 2002) data sets, as well as PDSI grid point locations and climate division boundaries.

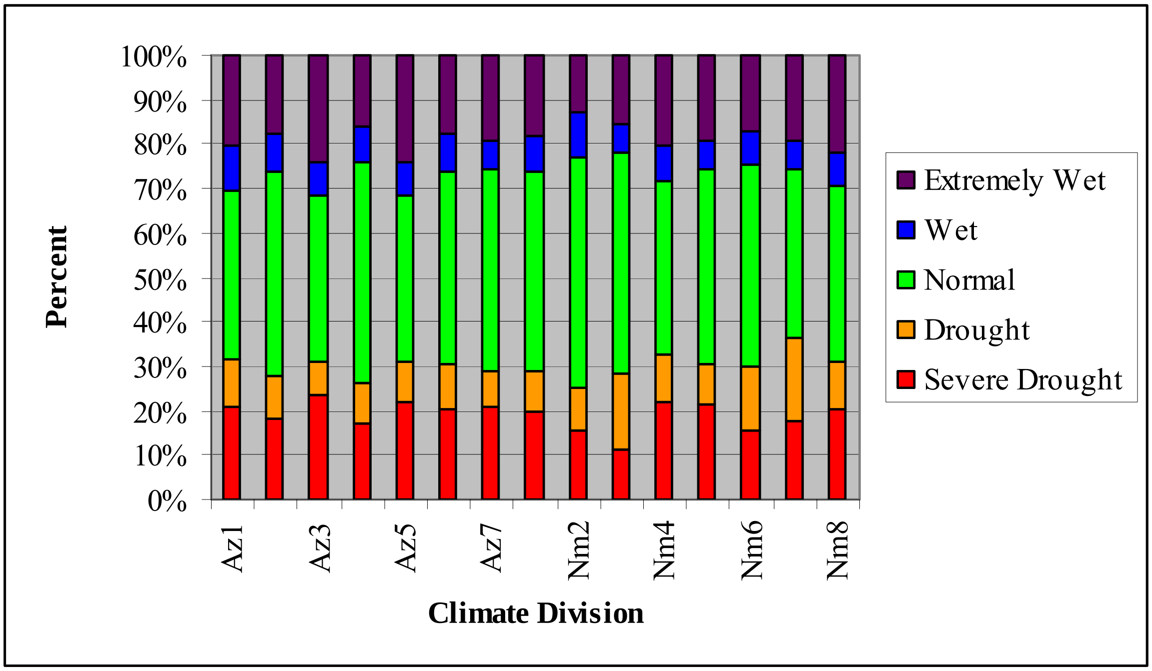


Figure 1-2. Comparison of the percent of years in all year types for all climate divisions in the Southwest.

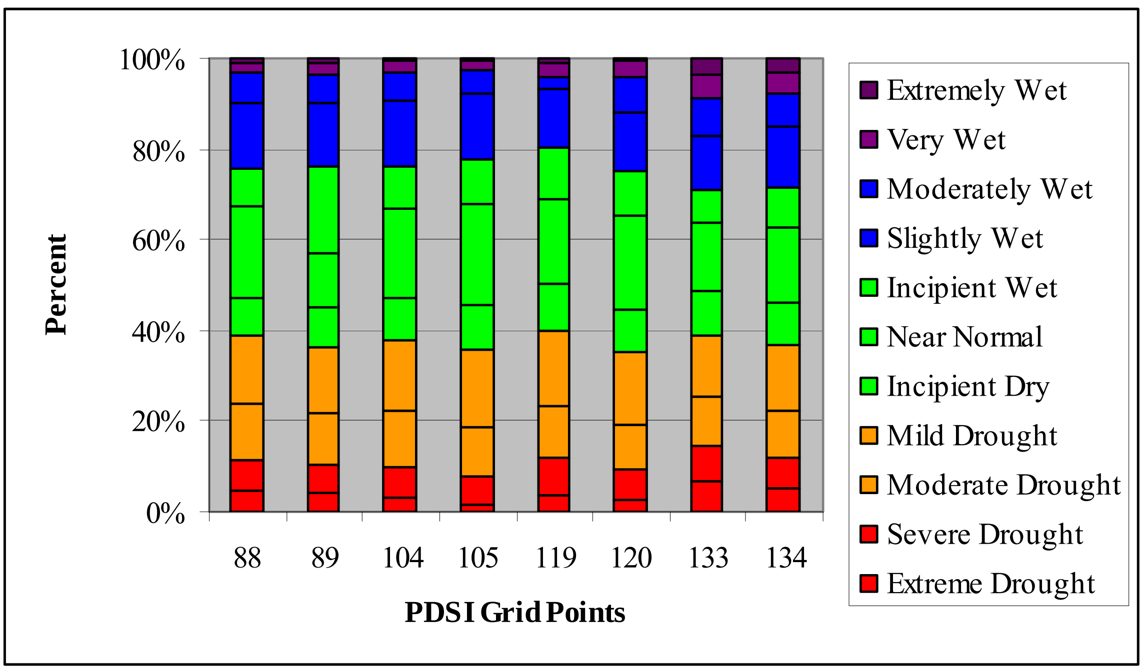


Figure 1-3. Comparison of the percent of years in all year types for all PDSI grid locations in the Southwest.

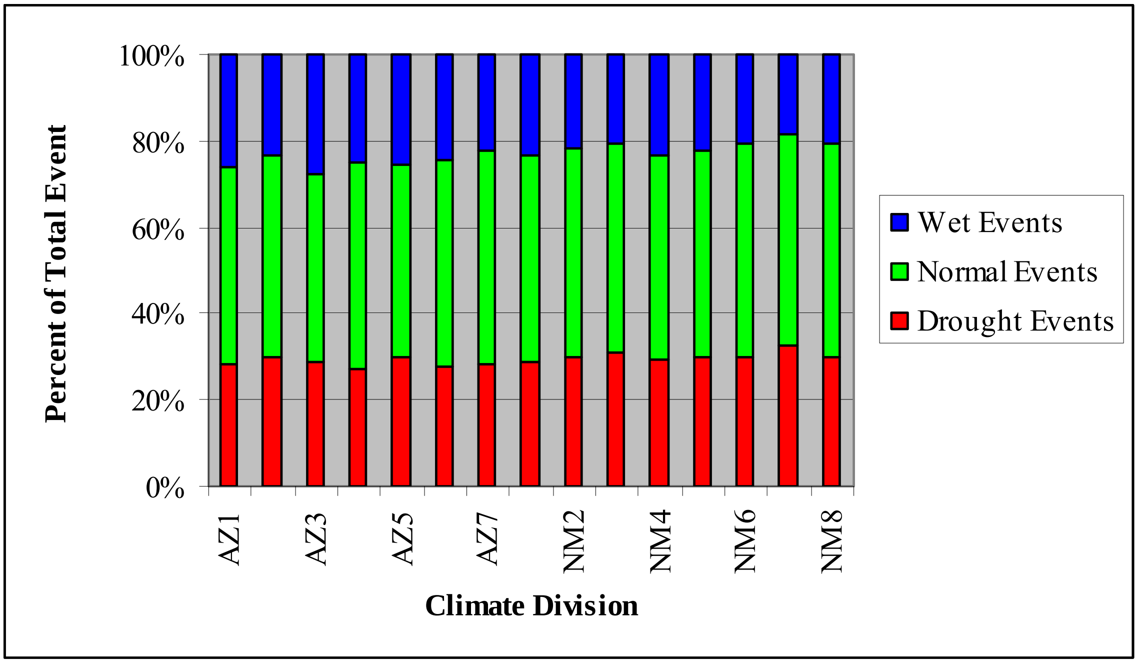


Figure 1-4. Comparison of the percent of events classified as drought, normal, and wet events for all climate divisions in the Southwest.

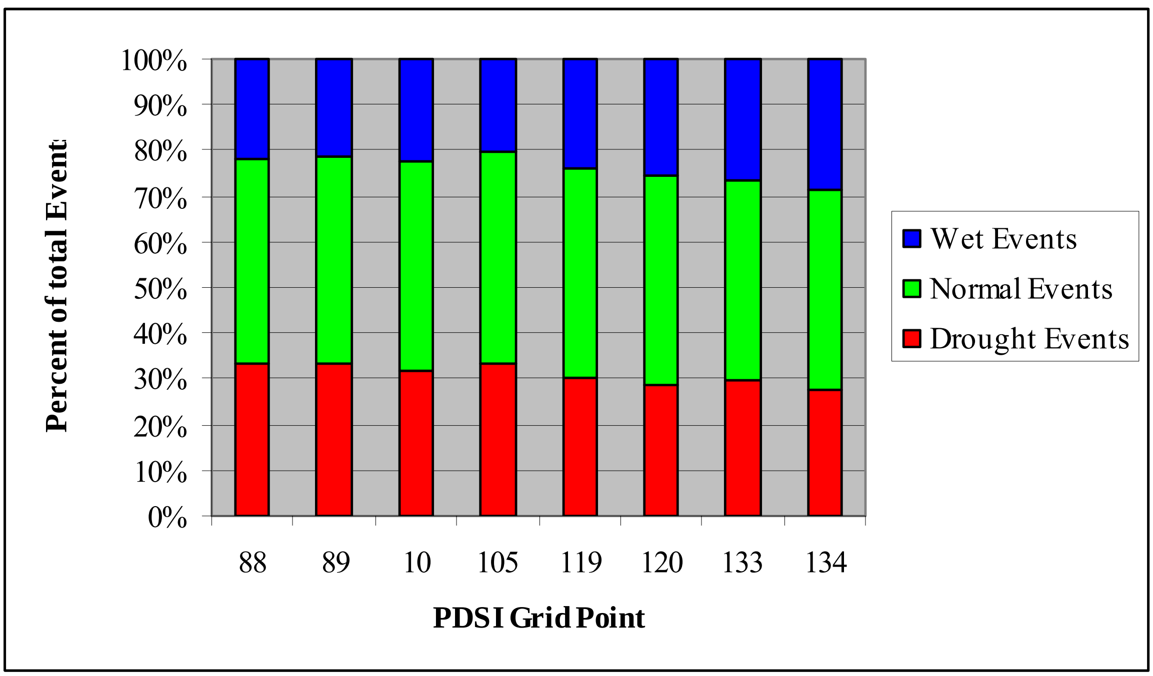


Figure 1-5. Comparison of the percent of events classified as drought, normal, and wet events for all PDSI grid locations in the Southwest.

The high end of the relative drought and wet magnitude ranges varies somewhat throughout the region (Appendix 2 - Table 2.1). Most strikingly, 5 climate divisions (AZ3, AZ6, AZ7, NM7, and NM8) and all PDSI grid points experienced droughts of greater magnitude than the regional 1950's range while 11 climate divisions (AZ2, AZ3, AZ4, AZ6, AZ7, NM3, NM4, NM5, NM6, NM7, and NM8) and all PDSI grid points experienced wet events of greater magnitude than the regional 1980's wet period. Relative drought magnitudes for the winter precipitation data set ranged between -866.5 and -25.4%, wet magnitudes ranged between 1,397.4 and -6.7%, and normal magnitudes ranged between 198.5 and -283.0% of **cumulative deviation from average** with the regional range of the 1950's drought and 1980's wet period having relative magnitudes between -629.0 and -102% and 139 and 634% respectively for all climate divisions. Ranges for summer PDSI relative magnitudes (**cumulative PDSI value**) ranged between -55.7 and -1.9 for drought events, between 28.9 and 2.1 for wet events, and between 10.0 and 6.2 for normal events with the regional range of the 1950's drought and 1980's wet period having relative magnitudes between -34.5 and -9.1 and 6.3 and 11.7 respectively. The amount of variability in the relative magnitude of events throughout the region was quite impressive. For example, for climate division AZ3, the 1950's drought was a fairly low intensity (-102) event for which 29 other drought events were of greater magnitude. However, for climate division NM3, the 1950's drought was the most severe event (-629%) recorded for the last 989 years.

Evaluation of the average years between drought and wet events of all severity levels (high, moderate, and low) showed a consistent pattern of lower severity events occurring more frequently than higher severity events (Appendix 2 - Table 2.2). Specifically, for the winter precipitation data set, low severity drought events occurred on average every 23 to 51 years, moderate events occurred every 18 to 69 years, and high severity events occurred greater than every 100 years (Appendix 2 - Table 2.2). Similarly, the summer PDSI data set showed low severity droughts events occurring every 18 to 26 years, moderate events every 19 to 37 years, and high severity events every 74 to 296 years. For wet events identified in the winter precipitation data low severity events occurred every 26 to 58 years, moderate events occurred every 34 to 65 years, and high severity events occurred every 220 to 838 years. Again summer PDSI events were similar with low severity events occurring every 24 to 47 years, moderate events occurring every 26 to 79 years, and high severity events occurring every 68 to 273 years. In contrast to this pattern, low and high severity normal events occurred less frequently than moderate events with low severity events occurring every 44 to 153 years, high severity events occurring every 50 to 149 years, and moderate events occurring every 7 to 12 years.

Discussion - For both Arizona and New Mexico, most areas have experienced drought and wet events of greater magnitude than the regional range of magnitudes experienced in the 1950's and 1980's. The magnitude and pattern of events in this analysis are in agreement with other climate assessments for the Southwest (Cook and others 1999. Ni and others 2002; Meko and others 1995; Salzer and Kipfmueller 2005; Stahl and others 2000). Specifically, high magnitude and/or persistent drought (1128 to 11160, 1584 to 1592, and 1776 to 1792) or wet conditions (1304 to 1360 and 1904 to 1920) identified in this analysis coincided with warm/dry or cool/wet periods documented for the southern Colorado Plateau, by Salzer and Kipfmueller's (2005). Additionally, the 16th century megadrought has been documented to have coincided with the abandonment of “a dozen” pueblos in New Mexico (Stahle and others 2000).

Comparison of the pattern of dry and wet events for specific climate division with PNVT shows that climate divisions AZ3, AZ6, AZ7, NM7, and NM8 all experienced drought events greater than the regional 1950’s drought range. This pattern of higher severity events occurring within southeastern Arizona and southern New Mexico suggests that PNVTS predominantly located within this area (ie the semi-desert grasslands, Madrean pine oak woodland, Madrean encinal, and interior chaparral) historically have a pattern of the highest severity events. This regional pattern is also seen in the PDSI data set where grid point locations 105, 120, and 134 had the lowest magnitude of wet events along with drought magnitudes greater than the regional 1950’s range.

The results of both the year to year climate variability (percent of years in a given year type; Figures 1-2 and 1-3) and event variability analysis (Figures 1-4 and 1-5) reveal that dry, wet, and normal years and events, of all magnitudes, are all common historically in the Southwest. For example, a drought event of any magnitude historically occurred on average every 14.5 years while wet events, of any magnitude, occurred on average every 19.4 years. This suggests that managing for an “average” year or period is less advantageous than management practices that are variable and responsive to the continually changing climate conditions that typify the Southwest. Additionally, the knowledge that extreme events, of greater magnitude than we have an ecological understanding of, have occurred in the past suggests that land managers need to be aware of and plan for the possibility of a recurrence of such events.

Finally, while having an understanding of historic climate patterns is helpful, recent research on global climate change suggests that future events may be nothing like those seen historically (Nielson and Drapek 1998; IPPC 2001). Research by Breshears and others (2005) begins to demonstrate the need to look at the change in effect of events given changing climate factors. Given the possible discrepancies between the pattern and/or magnitude of events as well as the effect of future events on vegetation, it is important to use historic climate information as a starting point for understanding trends in vegetation dynamics with the understanding that changing climatic factors as well as variability within the historic record, such as the Little Ice Age, also need to be evaluated (Millar and Woolfenden 1999).

Expert Opinion - We did not utilize expert opinion in developing our HRVs but instead relied on published empirical data. Limitations to expert opinion include lack of rigor, inclusion of bias, lack of repeatability, and limitation of spatial or temporal record (Morgan and others 1994). We did consult with subject experts extensively, however, in helping to identify data sources and reports not available in standard periodicals or journals.

Negative Data or Missing Information - Many pieces of historical information are lacking from the historical record (White and Walker 1997). When information is lacking, rather than not include this information in the HRV, we explicitly state that there is no information on the topic to indicate that we searched for, and were unable to find any relevant studies.

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Chapter 7 - Ponderosa Pine Forest & Woodland

7.1 General Description

Southwestern ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws. *Var. scopulorum*) occurs in large contiguous patches throughout Arizona and New Mexico, at elevations ranging from 5500 feet to 8500 feet. These relatively warm and dry forests are dominated by ponderosa pine, pinyon pine (*Pinus edulis*, *P. discolor*), junipers, (*Juniperus spp.*), and several oaks (*Quercus spp.*). Ponderosa pine forest occupies 9,247,700 acres (or 6.12%) of the total combined land area of Arizona and New Mexico, of which 5,835,400 acres (or 63.10%) are under US Forest Service management on 11 National Forests, which comprises 28.64% of Region 3 National Forest land area (USGS 2004). The number of acres of ponderosa pine forest on each National Forest is found in Table 7-1:

Apache-Sitgreaves	**Carson**	**Cibola**	**Coconino**	**Coronado**	**Gila**
926,400	408,000	508,900	814, 600	65,400	1,754,600
Kaibab	**Lincoln**	**Prescott**	**Santa Fe**	**Tonto**	**Total**
555,100	68,500	98,400	505,400	130,100	5,835,400

Table 7-1. Approximate area (in acres) of potential natural vegetation types (PNVTs) across 11 Region 3 National Forests in Arizona and New Mexico. Region 3 National Grasslands in New Mexico, Oklahoma and Texas were not included in this analysis. Data used to generate this table included The Southwest Regional Gap Analysis Program (SWReGAP) and the landownership GIS-based layer. Note that SWReGAP data have not been tested for accuracy and are derived from remote sensing; therefore, analyses at the individual National Forest scale may be inaccurate.

Ponderosa pine forest is typically bounded at the upper elevation by mixed conifer forest, and at the lower elevation by grassland, pinyon-juniper forest, or chaparral, although extensive intergrading of species may occur at ecotone boundaries along gradients of slope, elevation, aspect, and moisture (Moir 1993). Climatological data indicate that ponderosa pine forests occupy a wide moisture and temperature gradient, with annual precipitation ranging from 20 to 35 inches, and mean annual air temperatures ranging from 41 to 52 °F, which allow for a growing season of approximately 180 days (Moir 1993). Figure 7-1 is a 1906 photograph of ponderosa pine forest in the Coconino National Forest, and Figure 7-2 is a 1903 photograph from the Kaibab National Forest showing a typical ponderosa pine-bunchgrass community.

Figure 7-1. 1906 Photograph of ponderosa pine forest in the Coconino National Forest. Note mixed sizes/ages - large trees in the foreground, and smaller trees including regeneration in the background. Photograph from Northern Arizona University's Ecological Restoration Institute.

Figure 7-2. 1903 photograph of ponderosa pine bunchgrass forest (or savannah) near Tusayan, AZ on the Kaibab National Forest. Note the wide expanse of grass between clumps of large trees, but also a mixture of age and size classes is present. Photograph from Northern Arizona University's Ecological Restoration Institute.

The Southwest Region of the United States Forest Service (1997) delineates 19 plant associations or habitat types for the ponderosa pine series. Below we provide the relevant, verbatim excerpted names of those habitat types, their "key criteria" for identification, and their location within Region 3. Other details of plant association composition, structure, TES climate class, fire ecology, reforestation and revegetation considerations, adjacent plant associations, and references can be found in the original text.

1. Ponderosa pine/rockland. KEY CRITERIA: Exposed rock outcroppings or very shallow (<4" deep) soil comprises 50 to 90% of the surface. Understory species are scarce and trees include ponderosa pine, pinyon and/or junipers. LOCATION: Scattered throughout the southwest where large rock outcroppings occur in the ponderosa pine region. Elevation: 7,500' - 8,500'.
2. Ponderosa pine/Indian ricegrass (*Oryzopsis hymenoides*). KEY CRITERIA: Must have hoary rosemarymint (*Poliomintha incana*), which is a shrub. An open forest that occurs on sandy soils. LOCATION: Very local in northern New Mexico (on stabilized sand dunes near Espanola) and southern Colorado (on the eastern edge of the Great Sand Dunes). Occurs on deep, sandy soils. Elevation: 5,900' to 6,300'.
3. Ponderosa pine/blue grama (Bouteloua gracilis). KEY CRITERIA: Blue grama is well represented, or if poorly represented, alligator juniper or pinyon are common. Arizona fescue is scarce or absent. Ponderosa pine overstory is often open; shrubs are poorly represented although big sagebrush may be well represented on some sites. LOCATION: Widespread in New Mexico, Arizona, Colorado and Utah. Lower elevations (6,250' to 8,550') of the ponderosa pine series.
4. Ponderosa pine/Arizona walnut. KEY CRITERIA: Arizona walnut or canyon grape are common, but riparian trees like Arizona alder (*Alnus oblongifolia*), boxelder (*Acer negundo*), sycamore (*Platanus wrightii*), or species of cottonwood (*Populus* spp.) are limited to microsites. Twoneedle pinyon (*Pinus edulis*), Arizona pinyon (*Pinus fallax*) are absent or accidental. LOCATION: Occasionally found on alluvial terraces of intermittent washes or stream sides south of the Mogollon Rim and in southwestern New Mexico. Elevation: 5,500 to 6,400'.
5. Ponderosa pine/Gambel oak. KEY CRITERIA: Must have at least 5% canopy cover of Gambel oak. Overstory regeneration is ponderosa pine. Douglas-fir (*Pseudotsuga menziesii*) is absent or accidental. Widespread and common throughout New Mexico, Arizona, Colorado, and Utah. Elevations range from 6,000' to 9,200' on a wide variety of slopes, landforms, and soils. Mean annual precipitation is 20-22" per year.
6. Ponderosa pine/pointleaf manazanita (*Arctostaphylos pungens*). KEY CRITERIA: Pointleaf manzanita, a large shrub, is abundant (> 25% canopy cover). This community type is interpreted (Muldavin and others 1996) as a fire-derived expression of various ponderosa pine/evergreen oak habitat types. Douglas-fir and silverleaf oak are absent or accidental. LOCATION: Central Arizona, south of the Mogollon Rim, particularly on the Tonto National Forest and San Carlos Reservation, and north of the rim in the Pinedale/Showlow area and vicinity. On steep upper slopes, ridgetops, or elevated plains. Elevation: 5,600' to 6,800'.

7. Ponderosa pine/Silverleaf oak. KEY CRITERIA: Silverleaf oak (*Quercus hypoleucoides*) is well represented (>5% canopy cover). Ponderosa pine is the dominant overstory species, and Douglas-fir and white fir (*Abies concolor*) are absent or accidental. LOCATION: A major plant association in southeastem Arizona, including the following geographic areas- Chiricahua, Pinaleno, Santa Rita, Santa Catalina, Huachuca and the Galiuro Mountains with outliers to San Carlos and Ft. Apache Reservation, and in New Mexico, to the Brushy Mountains on the Glenwood Ranger District (Gila NF). Elevations generally 5,700' - 8,000', but can be outside this range on special topographic sites.
8. Ponderosa pine/Emory oak (*Quercus emoryi*). KEY CRITERIA: Emory oak is well represented (>5% canopy cover). Located primarily in drainages and lower slopes. Gambel oak and silverleaf oak are absent or poorly represented. Rocky Mountain juniper (*J. scopulorum*) is absent or accidental. LOCATION: This plant association occurs south of the Mogollon Rim, in southwestern New Mexico, and southern Arizona. It is more likely found in the Central Highlands, along the base of the Mogollon Rim and the Nantanes Plateau, and it is uncommon in the basin ranges and plateau regions of southern Arizona. Found most commonly on mid to lower slopes and ravine bottoms, PIPO/QUEM is most differentiated along drainages with granitic soils (Udic Ustochrepts). Elevation: 5300' -6900'. Mean annual precipitation is 20-22" per year.
9. Ponderosa pine/netleaf oak (*Quercus rugosa*). KEY CRITERIA: Netleaf oak is well represented, or if poorly represented, oaks are well represented and netleaf oak is the dominant species of oak. This association deviates from the typical silverleaf oak series rule as Douglas-fir and southwestern white pine (*Pinus strobiformis*) can be minor in the stand at climax. Ponderosa pine is still the dominant overstory species. White fir is absent or accidental. LOCATION: Mostly found in southeastern Arizona and southwestern New Mexico (Animas Mountains, with outliers in the Mogollon Mountains near Glenwood). This is the highest elevational type of the ponderosa pine plant associations with an evergreen oak understory. Generally [found] on steep, upper slopes or ridge-tops with shallow rocky soils with rocky outcrops. Elevation: 5,200' - 8,800'.
10. Ponderosa pine/mountain muhly (*Muhlenbergia montana*). KEY CRITERIA: Although mountain muhly is often present to well represented, it does not have to be present to be called this plant association. Gambel oak, if present, is <5% canopy cover. Douglas-fir and quaking aspen (*Populus tremuloides*) are absent or accidental and then usually in microsites, or if present, may represent an ecotone between PIPO/MUMO and an adjacent plant association. LOCATION: Southwest and central New Mexico up through southern Colorado, southern Arizona to southern Utah. Elevation: 7100' to 9400' on south facing slopes. Elevated and valley plains, piedmont hillslopes, mountain slopes, mesas and benches. Soils are varied. Mean annual precipitation is 20-25" per year.
11. Ponderosa pine/Arizona white oak (*Quercus arizonica*). KEY CRITERIA: Arizona white oak is well represented (>5% canopy cover). This is one of the warmest, driest ponderosa pine environments. Gambel oak, silverleaf oak, and Emory oak are poorly represented or absent. Douglas-fir, white fir, southwestern white pine and Rocky Mountain juniper are absent or accidental. LOCATION: South of the Mogollon Rim, in southwestern New Mexico and southern Arizona. More likely found in the Central Highlands, along the base of the Mogollon Rim and the Nantanes Plateau. Uncommon in the basin ranges and plateau regions of

southern Arizona. On a wide range of soils and parent materials. Elevation: 5,380' to 7,750'.

12. Ponderosa pine/Gray oak (*Quercus grisea*). KEY CRITERIA: Oaks must be well represented (>5% canopy cover). Must have at least 1% canopy cover of gray oak, but gray oak must be the dominant oak. Gambel oak, if present, is clearly minor in abundance to gray oak. Southwestern white pine and Douglas-fir are absent or accidental. These grasses are absent or accidental: Arizona fescue, pine muhly, bullgrass, and pinyon ricegrass. LOCATION: In central New Mexico and and east-central Arizona: on Apache-Sitgreaves National Forests. (Clifton and Alpine ranger districts)-Big Blue, Blue Mtns., AZ; on the Gila National Forest (Luna, Reserve, Mimbres, and Quemado ranger districts)-Blue Mtns., NM, Saliz Mtns., San Francisco Mtns., Mogollon Mtns., Black Range, NM, Tularosa Mtns., NM; on the Cibola National Forest (Magdalena and Mountainair ranger districts) - San Mateo, Gallinas Mtns., NM, also in Organ Mtns., NM. Frequently on slopes and ridgetops, often on shallow soils and rocky outcrops. Also found on deep soils of alluvial terraces and valley plains. Elevation: 6,100-8,800', at upper elevations on south or west slopes). Mean annual precipitation is 19-21" per year.
13. Ponderosa pine/wavyleaf oak (*Quercus x pauciloba*). KEY CRITERIA: This ponderosa pine dominated plant association must have at least 5% canopy cover of oak, with at least 1% cover of wavyleaf oak. Gray oak is scarce or absent, and Gambel oak, if present, is less dominant than wavyleaf oak. LOCATION: Widespread in southern (Sacramento Mtns., Lincoln NF and Mescalero Apache Reservation) and central to northeastern New Mexico. Found locally in other reaches of northern New Mexico. Elevation: 6,500'-8,200' on hot, dry sites. Surface rock cover can be high [averaging 27% in one study (DeVelice, 1986)]. Mean annual precipitation is 20-21" per year, with hot and dry weather in May and June.
14. Ponderosa pine/screwleaf muhly (*Muhlenbergia virescens*). KEY CRITERIA: A mesic ponderosa pine site, must have screwleaf muhly. This is the wettest type in the ponderosa pine series in northern Arizona. Douglas-fir, white fir, and pinyon are absent or accidental. LOCATION: Southwest and central New Mexico, southern Arizona to central Arizona (up to San Francisco Peaks area). Elevation: 6,700' to 8,800' to 9,400' (2,879 m) on south-facing slopes. Mean annual precipitation is 23"-25" per year. Found on many slopes and aspects.
15. Ponderosa pine/screwleaf muhly-Arizona fescue (*Festuca arizonica*). KEY CRITERIA: A mesic ponderosa pine site, must have screwleaf muhly and Arizona fescue. Douglas-fir, southwestern white pine, and Utah juniper (*Juniperus osteosperma*) are absent or accidental. LOCATION: Central Arizona (generally north of the Mogollon Rim up to the San Francisco Peaks area), and southwestern New Mexico (Gila NF). Elevation: 6,900'-9,200'. Found on many slopes and aspects.
16. Ponderosa pine/Arizona fescue. KEY CRITERIA: Must have Arizona fescue, or if grazing history includes persistent use which can explain the absence of Arizona fescue, then Kentucky bluegrass (*Poa pratensis*) is present. Douglas-fir, white fir, pinyon, and juniper are generally absent or accidental. The DAPA2 phase may contain Douglas-fir, usually in microsites, and the BOGR2 phase may contain some pinyon and junipers. LOCATION: Widespread in New Mexico, central Arizona, and southern Colorado, infrequent south of the Mogollon Rim.

Elevated and valley plains, piedmont hillslopes and mountain slopes, Elevation: 6,800' - 8,800' to 9,400' on south-facing slopes. Mean annual precipitation is 20-25" per year.

17. Ponderosa pine/kinnikinnik (*Arctostaphylos uva-ursi*). KEY CRITERIA: Kinnikinnic (*Arctostaphylos uva-ursi*), a low-growing shrub, ranges from 25-70% canopy cover and generally is the sole dominant understory species. Douglas-fir, twoneedle pinyon, and white fir are absent or accidental. LOCATION: Northern New Mexico (Jemez, Sangre de Cristos, and San Juan mountains) and southern Colorado. Elevation: 7,700' to 9,200'. Shallow soils of ridgetops, stony or excessively well drained soils on other slopes.
18. Ponderosa pine/Stansbury cliffrose (*Purshia stansburiana*). KEY CRITERIA: Must have Stansbury cliffrose in the understory. White fir is absent or accidental, but occasional Douglas-fir may be present in the late successional overstory. LOCATION: Central and northern Arizona, local in central and northern New Mexico (Zuni Mtns., Jicarilla Apache Reservation); also in Utah, Colorado, Wyoming, and Idaho. Rough, rocky topography at warmer limits of ponderosa pine forests. Elevations: 6,700' to 7,400'. Usually on soils with sandstone-limestone parent materials. Mean annual precipitation is19-20" per year.
19. Ponderosa pine/black sagebrush (*Artemisia nova*). KEY CRITERIA: Must have black sagebrush, which is a short sagebrush shrub found from northwestern New Mexico and northern Arizona (Kaibab Plateau and Grand Canyon) north to Oregon and Idaho. The open stand structure of ponderosa pine combines with a denser structure in woodland species, and greater than 5% canopy cover of shrubs. LOCATION: Local in northern New Mexico, northern Arizona, and southern Colorado. Widespread in southern Utah. This plant association has a minor distribution in New Mexico and Arizona. Elevation: around 8,200'. Occurs primarily on flat, basaltic mesa tops and elevated plains. In southern Utah, often occurs on flat benches. Rooting depths are often shallow due to restrictive subsurface horizons. Youngblood and Mauk (1985) state that in southern Utah, "sites may potentially have seasonal high water tables and even ponding."

Moir and others (1997) have combined these 19 plant associations of the Southwest into three major groups, based on similarities in structure, composition, and fire response.

> "The **fringe pine forest types** are at dry, warm, lower elevations where ponderosa pine occurs with woody species that are common in the adjoining pinyon/juniper and pinyon/oak/juniper woodlands. Depending on geographic location, typical associated species are *P. edulis*, *P. discolor*, *P. californiarum*, *Juniperus* spp., *Quercus grisea*, *Q. arizonica*, *Q. emoryi*, *Arctostaphylos pungens*, *Artemisia tridentata*, and *Chrysothamnus nauseosus*. Associated trees form a mid-level canopy layer below the ponderosa pine overstory (Marshall 1957). These additional species provide resources for a wide variety of animals. Blue grama (*Bouteloua gracilis*) is a diagnostic species, and ponderosa pine/blue grama has widespread forest association throughout the Southwest (USFS 1986).
>
> Where precipitation is greater than about 480 mm [20 inches], blue grama is absent or minor and ponderosa pine occurs with **understory bunchgrass** species, mainly *Festuca arizonica*, *Muhlenbergia montana*, and/or *M. virescens*. There may be a mid-level canopy of shrubs, copses of oaks, or even an occasional oak

tree (Kruse 1992), but these are minor vegetation components. Fires, either lightning- or human-caused, are frequent in these dry forests. Southwestern pine forests can be grouped with ponderosa pine forests in other areas in the Western United States that share a similar fire ecology. Southwestern ponderosa pine/bunchgrass forests are similar to warm, dry forests in Idaho, Montana, and Utah (Davis et al. 1980; Crane and Fischer 1986; Fischer and Bradley 1987; Bradley et al. 1992). Numerous descriptions of presettlement forests in the Southwest (Woolsey 1911; reviews Cooper 1960; Covington and Moore 1994; Moir and Dieterich 1988) apply to this group of forests.

The third group has **understories dominated by shrubs and midlevel trees**. Bunchgrasses may still be abundant, especially as patches in open areas. Common woody associates include *Quercus gambelii*, *Q. undulata*, *Robinia neomexicana*, *Cercocarpus montana*, and *Symphoricarpos oreophilus*. These forests are similar in structure and fire responses to the warm, moist ponderosa forests of central Idaho and Utah (Crane and Fischer 1986; Bradley and others 1992)."

Another grouping of the nineteen habitat types could be delineated as follows, based on the similarities of surface fire regimes (USFS 1997):

1) Bunchgrass types, including 3, 10, 14, 15, 16, and possibly 5;

2) Shrub understory types, including 6, 7, 8, 9, 11, 12, 13, and possibly 5;

3) Fringe types, which includes 1, 2, 4, 17, 18, and 19. These include mesic areas or rocky areas where fire is either less frequent or less important in maintaining the vegetation type.

7.2 Historical Range of Variation of Ecological Processes

Vegetation Dynamics – Ponderosa pine regeneration by seed has been suggested to be episodic, occurring only with the unique combination of heavy seed production, very moist springs and summers, and a period of several years without fire (Pearson 1950, Savage and others 1996). The results of a series of successful, historical regeneration events have been quantified from the Gus Pearson Natural Area prior to 1876 to be approximately 0.4 to 1.57 trees per acre per decade for the past 300 years (Mast and others 1999). Figure 7-3 shows a 1933 photograph of ponderosa pine regeneration and the notes by early forester Gus A. Pearson on the photograph, indicating that there are three age classes, and the approximate years of regeneration events: pre-1890, 1890, 1910, 1914, 1919, and 1929.

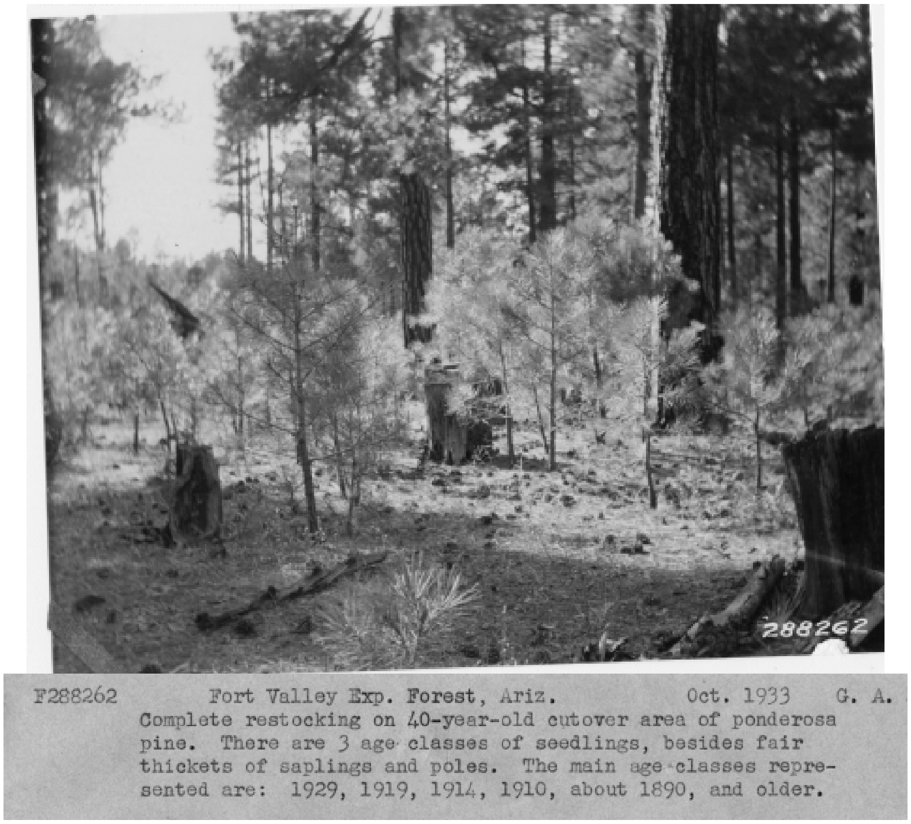

Figure 7-3. 1933 photograph and annotation by Gus A. Pearson of regeneration in ponderosa pine from the Ft Valley Experimental Forest on the Coconino National Forest. Photograph from Northern Arizona University's Ecological Restoration Institute.

Six vegetative structural stages (VSS) have been identified for ponderosa pine (Moir and Dieterich 1988), VSS1-VSS6, corresponding to different ages, densities, and sizes of trees within a forest. Ponderosa pine forest dynamics are affected by fire, insects, diseases, and windfall (Moir and others 1997). Canopy cover classes for each stage are delimited as A (0 to 40%), B (40 to 60%), and C (>60%). The VSSs and their descriptions are as follows:

1. VSS1 -- Openings occur following major disturbance such as fire or gap processes. These openings may be maintained as open parks or meadows in pine savannahs where frequent surface fires occur and may also include a snag stage following a stand replacing fire.
2. VSS2 – This forest is composed of seedlings and saplings with dbh<5 in growing in an herbaceous or shrubby environment. As seedlings grow into saplings the canopy begins to close.
3. VSS3 – Young stands are composed of small trees (5 in<dbh<11.9 in), and usually clumped and dense, with canopy cover often exceeding 70% without recurring fire. Stands have a sparse herbaceous understory, few snags, and single-storied structure.
4. VSS4 -- Mid-aged stands have larger trees (14 in<dbh<17.9 in) that are sexually mature, tend to be multi-storied, and contain some snags.
5. VSS5 – Mature stands have large trees (dbh>17.9 in) in single or multi-storied stands, with more litter and dead and downed debris in fire-suppressed stands.

These stands may contain larger snags than mid-aged stands, and produce a good seed crop.

6. VSS6 – Old-growth forests are single and multi-storied, have many mature trees and dense canopies (>40% canopy cover) in stands that have not experienced ground fires in their VSS1 and VSS2 stages. Prior to 1890, these forests were extensive and more open (0 to 40% canopy cover), had very little coarse woody debris on the forest floor, but required at least 300 years beyond the VSS1 or burned snag stage to attain old-growth characteristics.

Ponderosa pine stand dynamics have been estimated for a generalized southwestern ponderosa pine forest in the "Management Recommendations for the Northern Goshawk in the Southwestern United States" (Reynolds and others 1992). The authors utilized Vegetative Structural Stage (VSS) classes in this document, and based their findings on published data for the time required for trees to become established following disturbance and on data for tree diameter growth rates for several species, and they defined the pathological age of trees as the age beyond which growth slows, decay develops significantly, and mortality becomes high (Reynolds and others 1992). The authors acknowledged that a successful seedling establishment period in time depends upon a combination factors determined by ponderosa pine characteristics, individual tree genetics, and climate:

- ◊ Cone crop frequencies
- ◊ Successful cone development
- ◊ Seed production and development
- ◊ Proper germination conditions in the soil
- ◊ Root system establishment
- ◊ Climatic conditions.

They also identified factors that influence tree diameter growth rates:

- ◊ Initial diameter
- ◊ Site productivity
- ◊ Climatic conditions
- ◊ Level of management

Reynolds and others (1992) provided estimates of diameter growth rates, age in VSS, accumulated age, and proportion of landscape in each VSS for a typical ponderosa pine forest with Basal Area (BA) of 60 ft^2/ac and a site index of 70 (trees at this site attain height of 70 feet in 100 years), shown here in Table 7-2:

Vegetative Structural Stage and dbh (inches)	VSS1 0-1	VSS2 1-5	VSS3 5-12	VSS4 12-18	VSS5 18-24	VSS6 24+
MINIMAL MANAGEMENT						
Diameter growth/decade (inches)	0	1.33	1.52	1.48	1.3	1
Years (acc-yrs)	20 (20)	30 (50)	46 (96)	41 (137)	46 (183)	50 (233)

Landscape in SS (%)	9	13	20	17	20	21
MODERATE MANAGEMENT						
Diameter growth/decade (in)	0	1.91	1.76	1.64	1.4	1.10
Years (acc-yrs)	20 (20)	21 (41)	40 (81)	37 (117)	43 (160)	45 (204)
Landscape in SS (%)	10	10	19	17	20	24
INTENSIVE MANAGEMENT						
Diameter growth/decade (inches)	0	2.5	2	1.8	1.5	1.2
Years (acc-yrs)*	20 (20)	16 (36)	35 (71)	33 (104)	40 (144)	50 (194)
Landscape in SS (%)	10	8	18	17	21	26

Table 7-2. Estimates of diameter growth rates, age in Vegetative Structural Stage (VSS), accumulated age, and proportion of landscape in each VSS for a typical ponderosa pine forest with Basal Area (BA) of 60 ft^2/ac and a site index of 70. *Years (acc-yrs) = Number of years in that VSS (and total accumulated years in tree age). Data are from Reynolds and other (1992).

This information is generalized for all types of ponderosa pine forests, and no other information on stand dynamics could be located. With the variety of plant associations or habitat types that exist for ponderosa pine in the Southwest, one could expect variations in response to disturbance by different habitat types as well as variations in the frequency of disturbance.

Disturbance Processes and Regimes

Climate- See Introduction Chapter on Climate. Swetnam and Baisan (1996) determined that fuel production and fuel moisture, both dependent upon climate, were important factors in ponderosa pine fire regimes. Fire years are tightly correlated with drought, especially when preceded by one to three years of high precipitation which builds fine fuels in grasses and herbaceous cover. Years with few fires are correlated with high precipitation. Swetnam and Betancourt (1990, 1998) described climate-fire linkages.

Fire- Ponderosa pine forests throughout the Southwest formerly experienced widespread, low-intensity surface fires of frequent return intervals (Weaver 1951, 1952, Cooper 1960, Dieterich 1980, Covington and Moore 1994, Swetnam and Baisan 1996). Analysis of a comprehensive network of fire scar sites and their fire chronologies indicates that for 53 sites in Arizona and New Mexico where ponderosa pine dominates or co-dominates, mean fire return intervals were 2 to 17 years for fires scarring one or more trees, and 4 to 36 years for fires scarring between 10% and 25% of trees between the years of 1700 and 1900 (Swetnam and Baisan 1996). For the same network of sites, Swetnam and Baisan (1996) reported a range of Weibull Median Probability Interval (WMPI) values of 1.74 to 13.83 years. For a smaller subset of 31 pure ponderosa pine sites, the FRI ranged from

5.4 to 36.3 years for fires scarring more than 25% of trees, with an average of 15.6 years. With such a wide range of fire return intervals, it would be instructive to parse the data from the 53 sites into the three broad categories of xerophytic ponderosa pine forest delineated by Moir and others (1997): **fringe ponderosa pine forest**, **ponderosa pine-bunchgrass**, and **ponderosa pine-shrub**. Due to the presence of multiple moisture, temperature, and soil gradients, it is unclear at this time how to group similar forest communities within similar disturbance groups, although Touchan and others (1994) identified the major factors controlling differences in fire intervals among sites as topography, grazing history, and climatic variability, and not habitat type.

Other fire regime studies include Sneed and others (2002) finding of a WMPI of 1.79 to 3.93 years, with a minimum fire interval (FI) of 1 year and a maximum of 24 years for the period of 1615 to 1996 for ponderosa pine forest in the Prescott National Forest in Arizona. They also found through analysis of early, middle, and late- early-wood that 8.1% of fires occurred in May or early June, 24.4% of fires occurred in mid-June, and peaked at 63.9% in late June and July with the onset of "monsoon" rains and lightning storms, and 3.8% of fires occurred in August and early September as fuels became wetter. They reported no evidence of fires occurring from late September to early May (Sneed and others 2002). Fule and others (2003) also analyzed rings for seasonality at Grand Canyon National Park, and noted that they were able to discern differences on 54% of samples. They found that 12% of fires occurred during the dormant season, spring fires accounted for 54% of fires, and 46% of fires occurred during the summer. They also noted that because narrow rings were the most common reason for not being able to detect fire season, their seasonal distribution may be biased toward wetter years, which might not reflect the entire range of variation for ponderosa pine forests (Fule and others 2003).

Fule and others (2003) analyzed fire scars from ponderosa pine forests on the north and south rims of Grand Canyon National Park, and compared "mainland" sites further from the rim of the canyon with "island" sites that were closer to the rim on plateaus or points. They found that prior to 1880, fires burned most frequently on lower elevation "islands" at a WMPI of 3.0 to 3.9 for all fires, 6.3 to 8.6 for large fires scarring 25% or more of the sampled trees. Fires on the higher elevation "mainland" site on the interior of the North Rim were less frequent, with a WMPI of 5.1 years for all fires and 8.7 years for large fires. The "mainland" site on the South Rim had the least frequent fire, with WMPI of 6.5 years for all fires, and 8.9 years for large fires (Fule and others 2003). In this same study, Fule and others (2003) were able to compare their tree-ring fire scar analysis with known extent of recent historical fires, to calibrate the accuracy of the chronology. This was in response to a criticism raised by Baker and Ehle (2001) that fire scar analysis provided estimates that were sufficiently uncertain as to require bracketing of mean fire interval estimates by as much as 1100 to 1200%. The analysis by Fule and others (2003) showed that for known fire events recorded by direct observation over the period 1924 to 1999, the tree-ring fire scar analysis correctly identified 100% of those fires down to a 20-acre size. Fule and others (2003) did offer that rather than bracket their fire return intervals, they needed to be explicit with the assumptions that the fire-scar analysis techniques probably missed some additional, smaller fires, and that all fires studied, including historic as well as current, "burn with a mosaic of intensities and include unburned areas within the overall fire perimeter." Figure 7-4 is a 1909 photograph from near Grand Canyon indicating patches of different ages and sizes, with a grassy understory.

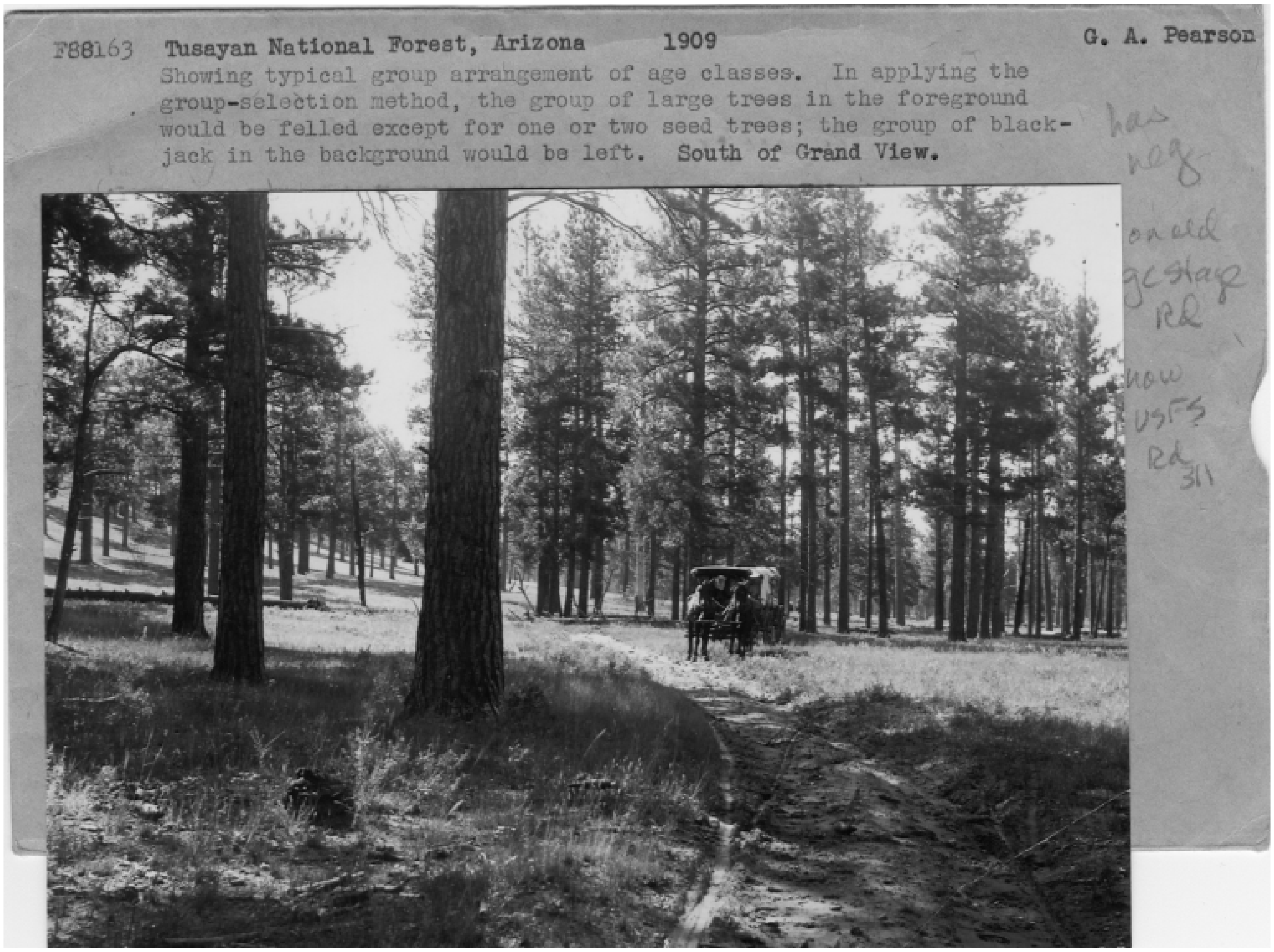

Figure 7-4. Photograph from 1909 from the Kaibab (formerly Tusayan) National Forest near Grand Canyon's s South Rim showing interspersion of patches of different ages and presumably, fire intensities. Photograph by Gus Pearson. Photograph from Northern Arizona University's Ecological Restoration Institute.

The size of historic fires has been estimated from several studies (Bahre 1985, Swetnam and Dieterich 1985, Swetnam 1990, Swetnam and Baisan 1996, Fule and others 2003), but has not been definitively determined for all years nor all areas. Bahre (1985) refers to early historic accounts of millions of acres burning during certain years in the mountains of southeastern Arizona, and Fule and others' (2003) data from Grand Canyon National Park indicate that in certain years bracketed by their study (1873, 1879), fires likely would have covered most of the study area, if not more (22 square miles = 14,000 acres). Swetnam and Dieterich (1985) analyzed fire scars and reported an average fire size of approximately 3,000 acres. Swetnam and Baisan (1996) indicate that large fires in ponderosa pine were synchronized in certain years, and may have covered large areas burning for months, but indicated that further spatial analysis of their regional datasets were underway to give more precise estimates of the spatial extent of historic fires.

Hydrology- We found no studies that documented hydrological processes such as flooding as important historical ecological determinants for the ponderosa pine vegetation type.

Herbivory- We found no studies that documented herbivory as an important historical ecological determinant for the ponderosa pine vegetation type.

Predator/Prey Extinction and Introductions - We found no studies that implicated predator/prey extinctions and introductions as important historical ecological determinants for the ponderosa pine vegetation type.

Insects and Pathogens – For thousands of years, Southwestern forest trees have been host to several species of insects, pathogenic fungi, and parasitic plants (Dahms and Geils 1997). Unfortunately, the earliest reports of bark beetles on ponderosa pine date from the early 1900s, after settlement (Dahms and Geils 1997), so there are no accounts of historic insect outbreak periodicity.

Nutrient Cycling – We found no studies that documented historic nutrient cycling processes or rates for the ponderosa pine vegetation type, although several studies have shown short-term increases in litter decomposition and nutrient cycling rates as a result of restoration efforts (thinning and burning) compared to un-restored controls (Covington and Sackett 1984, Covington and Sackett 1986, Kaye and Hart 1998, review in Selmants and others 2003, Kaye and others 2005).

Windthrow - We found no studies that documented windthrow as an important historical ecological determinant for the ponderosa pine vegetation type.

Avalanche - We found no studies that documented avalanche as an important historical ecological determinant for the ponderosa pine vegetation type.

Erosion - We found no studies that documented erosion as an important historical ecological determinant for the ponderosa pine vegetation type.

Synthesis –Many of the studies of stand dynamics of ponderosa pine forests have focused on ponderosa pine-bunchgrass communities, with general trends in size and age of stands inferred from existing stands, and remnants of past stands. Ponderosa pine forests in the Southwest generally experienced a high frequency, low intensity surface fire regime, although on a small scale, individual trees occasionally may have torched via fuel ladders carrying surface fire into the crowns over small areas (Swetnam and Baisan 1996, Vankat 2006). Beyond fire studies, little is known about historic disturbance factors that shaped ponderosa pine forests in historic times, because settlement and disturbance disruption occurred simultaneously.

7.3 Historical Range of Variation of Vegetation Composition and Structure

Patch Composition of Vegetation - We found no studies that documented historical patch composition of ponderosa pine forests.

Overstory – Several studies have documented age and size structure, as well as tree density and basal area for pre-settlement ponderosa pine forests (Covington and Moore 1994, Fule and others 1997, Mast and others 1999, Moore and others 1999, Huffman and others 2001, Fule and others 2002, Sneed and others 2002, Fule and others 2003, Gildar and others 2004, Moore and others 2004, Cocke and others 2005). Fule and others (2003) reconstructed 1880 forest structure for ponderosa pine forests at Grand Canyon National Park's north rim, and Cocke and others (2005) reconstructed 1876 forest structure for ponderosa pine forests on the San Francisco Peaks. Table 5-3 displays reported values for the following ponderosa pine forest structure data by trees per acre, basal area, and percentage of basal area by tree species or group of species:

GCNP	**ABCO**	**ABLA**	**PIEN**	**PIPO**	**POTR**	**PSME**	**RONE**	**Total**
Trees/ac	12.3	0	0	64.4	57.5	2.0	N/A	136.2
BA(ft^2/ac)	8.3	0	0	41.8	6.1	1.7	0	57.9
% BA	14.3	0	0	72.2	10.5	3.0	0	100.0
SFPA	**ABIES**	**PIAR**	**PIEN**	**PIPO**	**POTR**	**PSME**	**PIFL**	**Total**
Trees/ac	0	0	0	23.4	0.9	0.4	0	24.9
BA(ft^2/ac)	0	0	0	31.4	0.3	1.4	0	33.1
% BA	0	0	0	95.1	0.8	4.1	0	100.0

Table 7-3. Historic forest structure reconstructed for two sites (GCNP=Grand Canyon National Park in 1880, SFPA=San Francisco Peaks in 1876) in Arizona. Basal area (BA) is expressed both in square feet per acre (ft^2/ac) and as percent of total. Species or groups across column labels are as follows: ABCO=white fir (*Abies concolor*), ABLA=corkbark fir (*Abies bifolia* formerly *A. lasiocarpa*), PIEN=Engelmann spruce (*Picea engelmanii*)+blue spruce (*Picea pungens*), PIPO=ponderosa pine (*Pinus ponderosa*), POTR=aspen (*Populus tremuloides*), PSME=Douglas-fir (*Pseudotsuga menziesii*), RONE=New Mexican locust (*Robinia neomexicana*), ABIES=white fir+corkbark fir, PIAR=bristlecone pine (*Pinus aristata*), PIFL=limber pine (*Pinus flexilis*). Data are from Fule and others (2003) and Cocke and others (2005).

In a similar study, Fule and others (1997) determined 1883 forest stand density and basal area for 62 plots at Camp Navajo near Flagstaff, AZ. They reported a mean tree density of 59.9 trees/acre (s.d.=45.6), and mean total basal area of 56.2 ft^2/acre (s.d.=6.1) for ponderosa pine forest as pre-settlement conditions.

In another study that compared historic data from early forest inventories, Moore and others (2004) reported values from the "Woolsey plots" that were established in high timber productivity sites across Arizona and New Mexico in ponderosa pine forests over the period 1909 to 1913 to track potential productivity of SW forests through time through periodic resampling. They reported the following values for tree density and basal area.

Tree Species								Total	
		PIPO		PSME		PIST/PIFL		BA	Trees/ac
Plot	Location	BA	TPA	BA	TPA	BA	TPA	BA	TPA
CIBS1A	Cibola NF	19.2	32.8	3.0	2.4	4.8	7.3	27.0	42.5
CIBS2A	Cibola NF	38.8	50.6	0.00	0.00	0.00	0.00	38.8	50.6
GILAS1A	Gila NF	14.8	19.4	6.5	4.1	0.3	0.4	21.6	23.9
JEMS2A	Jemez	38.8	36.0	0.00	0.00	0.00	0.00	38.8	36.0
JEMS3A	Jemez	60.6	88.7	1.3	1.2	0.00	0.00	61.9	89.9

Table 7-4. Basal area (BA in ft^2/ac) and trees per acre (TPA) for trees with dbh>3.6 inches for five sites in New Mexico by trees species within ponderosa pine forest. Tree codes are PIPO=ponderosa pine, PSME=Douglas-fir, PIST/PIFL=southwestern white pine (*Pinus strobiformis)*/limber pine. Data are from Moore and others (2004).

Understory - We found no studies that documented the historical understory composition of ponderosa pine forests.

Herbaceous Layer- We found no studies that documented the historical herbaceous layer composition of ponderosa pine forests. Before European settlement, ponderosa pine forests were generally open stands with well-developed herbaceous understories (Cooper 1960).

Patch or Stand Structure of Vegetation – Cooper (1960) used a contiguous quadrat analysis of two study areas in the White Mountains of eastern Arizona to determine that trees were clumped in distribution, with clumps ranging in size from 0.16 to 0.32 acre (Covington and Moore 1994). White (1985) used the nearest neighbor technique to determine clumpiness in the Gus Pearson Natural Area, and reported that most clumps were composed of 3 to 44 trees, and each group varied in size from 0.05 to 0.70 acre in size. Moore and others (1993) studied the same area and determined clumps to average around 0.16 acre, with a range of 0.08 to 0.64 acre. Biondi and others (1994) used spatial statistics to describe spatial patterning at GPNA, and reported that stem size was spatially auto-correlated over patches with diameter of 98.43 feet, or 0.17 acre.

Canopy Cover Class (%) or Canopy Closure –White (1985) determined a pre-settlement canopy cover value of 22%, while Covington and Sackett (1986) determined a value of 17%. Covington and Moore (1994) cite a description by Pearson (1923) of how, "rarely does ponderosa pine crown cover reach more than 30%, and usually not over 25%." These values were determined for the ponderosa pine-bunchgrass habitat type on basaltic soils (Covington and Moore 1994).

Structure Class (Size Class)- Historically, there was a larger proportion of older, larger trees and a smaller proportion of younger smaller trees compared to contemporary forests (Dieterich 1983, Covington and Moore 1994, Fule and others 1997). Moore and others (2004) compared historical versus current size class structure of ponderosa pine forests from the 15 Woolsey plots in Arizona and New Mexico, and found that forest surveys conducted from 1909 to 1913 had stand density (of trees >= 3.6 inches DBH) of 34.9 ft^2/ac. They also determined that the Quadratic Mean Diameter, a measure of central tendency in tree diameter within a stand weighted by number of trees was 15.2 inches over the same time period, and that on average, each 1.1 hectare (2.8 ac) plot had 61.5 "young" trees, and 13.3 "old" trees [old and young based on morphology of tree bark] (Moore and others 2004).

Life Form - We found no studies that documented the historical life form composition of ponderosa pine forests.

Density – See *Overstory*, above, for reported values of tree density by species expressed in trees/acre (TPA) and basal area (BA – ft^2/acre).

Age Structure – White (1985) determined that pre-settlement stands were of uneven aged or mixed age composition (Covington and Moore 1994). Moore and others (2004) determined that the Quadratic Mean Diameter, a measure of central tendency in tree diameter within a stand weighted by number of trees was 15.2 inches over the 1909 to 1913 time period, and that on average, each 1.1 hectare (2.8 ac) plot had 61.5 "young" trees, and 13.3 "old" trees [old and young based on morphology of tree bark].

Patch Dispersion – We found no studies that documented the historical patch dispersion of ponderosa pine forests, although the Woolsey plots (Woolsey 1911, Moore and others 2004) could be analyzed for spatial distribution of patches.

Recruitment Dynamics - Ponderosa pine regeneration by seed has been suggested to be episodic (Cooper 1960, Covington and Moore 1994, Savage 1996), and has been quantified from the Gus Pearson Natural Area prior to 1876 to be approximately 0.4 to 1.57 trees per acre per decade for the past 300 years (Mast and others 1999).

Reference Sites Used – Reference sites are the Gus Pearson Natural Area and Camp Navajo (Moore and others 1999), the Woolsey Plots (Moore and others 2004), Kaibab National Forest (Fule and others 2002), Grand Canyon National Park (2003), and the San Francisco Peaks (Cocke and others 2005).

Synthesis –Historic forest structure, patch size, basal area and density of trees are well quantified for portions of northern Arizona, but may not reflect the entire distribution of ponderosa pine forests in Arizona and New Mexico, and may not be sufficient to reflect the historic range of variation for the two-state region. Other measures of forest structure such as patchiness, canopy cover, and age or size-class distribution are not as well quantified, and the values reported are not representative of the entire geographic distribution of ponderosa pine in the Southwest.

7.4 Anthropogenic Disturbance (or Disturbance Exclusion)

Herbivory – The disruption of historic fire regimes by introduced grazing animals has been well documented in southwestern ecosystems, and ponderosa pine forests were utilized as summer range for large numbers of sheep and cattle (Allen 1989, Covington & Moore 1994, Swetnam et al 1999). Herbivory by cattle also reduces competition by grasses with conifer seedlings, allowing them to expand or encroach into grasslands (Dahm and Geils 1997).

Silviculture – The practice of silviculture has a long history in the Southwest, and ponderosa pine was the most economically important species because of its use in many applications such as fuel wood, mining timbers, home building, and other commercial uses for lumber. Initially, most hand felling was very selective, as only the most desirable, large trees were removed. Around 1880, with the influx of more Anglo-Americans and others to the region, along with railroads, large-scale logging became more feasible (Schubert 1974). A variety of harvest techniques including clearcutting, selective logging, and group selection were employed, which have left harvested areas with a mosaic of even-aged and uneven-aged stands, a deficit in the oldest trees (Dahms and Geils 1997), as well as some bare areas more prone to erosion (Bahre 1998).

Fragmentation – Construction of logging roads has occurred in many ponderosa pine forests of the Southwest, although we could find no studies that documented the impacts of fragmentation on ponderosa pine forests.

Mining – We found no studies that documented mining as an important ecological determinant for the ponderosa pine vegetation type.

Fire Management –
The disruption of historic fire regimes by introduced grazing animals has been well documented in southwestern ecosystems, and ponderosa pine forests were well utilized as summer range for large numbers of sheep and cattle (Allen 1989, Covington & Moore 1994, Swetnam et al 1999). In a study of ponderosa pine fire scars in the Chuska Mountains bordering northern Arizona and New Mexico, Savage and Swetnam (1990) reported a MFI of 2.8 years for the period 1660 to 1830, when early introduction of sheep disrupted this frequent fire regime. Subsequently, from 1830 to 1930, the MFI increased to 6.1 years, and for the period 1930 to 1986, when fire suppression activities were more organized and effective, the MFI jumped to 13 years, meaning fires were almost five times less frequent in modern times than in pre-settlement times. In the early 1900s, active fire suppression through the construction of fire lines and roads, and later concerted efforts with fire brigades and air tankers, began to function as the primary mechanism for excluding fire from Southwestern forests (Covington and Moore 1994, Swetnam and Baisan 1996). Fire exclusion was very successful initially, but subsequent accumulation of fuels, through litter-fall and logging debris accumulation, and development of fuel “ladders” of live and dead trees that are capable of conveying surface fires in to the crowns and canopies of forests (Covington and others 1994) made fire suppression more difficult. As the number and size of fires has increased over the last century (Dahms and Geils 1997), the emphasis on use of prescribed or “fire-use” fire has increased within land management agencies, with varying levels of success due to complex social, economic, and climatic factors (Zimmerman 2003).

There is an increase in fire intensity and severity in recent years, with large, stand replacing fires such as the La Mesa fire of 1977, Cerro Grande of 2000, and Rodeo-Chediski of 2002 serving as examples. Figure 7-5 portrays the dense growth of ponderosa pine along the Mogollon Rim (AZ) in 1923 following about 40 years of fire suppression.

Figure 7-5. 1923 photograph showing large number of ponderosa pine stems of small size along the Mogollon Rim, presumably as a result of fire suppression. Original photo caption: Remarkable growth of Ponderosa pine. Much of this growth was since the military abandoned its use of the Verde Rim Road. Photo by E. W. Kelley. FS #175776

Exotic Introductions (Plant & Animal) – See Herbivory, above. Several exotic plant species are beginning to colonize areas that have experienced high intensity wildfires (Crawford and others 2001).

Synthesis –
The most important anthropogenic disturbances for ponderosa pine forests include grazing, which removed fine fuels needed for carrying frequent, low intensity surface fires; silvicultural practices, which have changed forest age class distribution, composition, density, and cover values, and the cessation of frequent fire regimes, which prior to about 1900 ranged in frequency between 2 and 17 years. There are interactions between human-caused disturbance and climate, which may intensify or confound their effects.

7.5 Effects of Anthropogenic Disturbance

Patch Composition of Vegetation

Overstory – Fule and others (2003) described current forest structure for ponderosa pine at Grand Canyon National Park's north rim, and Cocke and others (2005) described current forest structure for ponderosa pine forests on the San Francisco Peaks. Table 7-5 displays reported values for the following ponderosa pine forest structure data by trees per acre, basal area, and percentage of basal area by tree species or group of species:

GCNP	ABCO	ABLA	PIEN	PIPO	POTR	PSME	RONE	Total
Trees/ac	80.7	44.0	1.1	92.4	90.1	8.3	0	316.7
Regeneration	672.9	20.2	0	429.9	932.8	20.2	0	2076.1
BA(ft^2/ac)	35.7	6.5	0.3	82.3	26.1	2.6	0	153.8
% BA	23.2	4.3	0.2	53.5	17.0	1.7	0	100
SFPA	**ABIES**	**PIAR**	**PIEN**	**PIPO**	**POTR**	**PSME**	**PIFL**	**Total**
Trees/ac	0	0.1	0.1	253.6	7.3	19.9	12.1	293.2
Regeneration	0	0	0	216.1	89.7	16.5	13.6	335.9
BA(ft^2/ac)	0	0	0.1	132.4	2.3	8.7	6.6	150.0
% BA	0	0	0	88.3	1.5	5.8	4.4	100

Table 7-5. Current forest structure determined for two ponderosa pine sites (GCNP=Grand Canyon National Park in 1880, SFPA=San Francisco Peaks in 1876) in Arizona. Basal area (BA) is expressed both in square feet per acre (ft^2/ac) and as percent of total. Species or groups across column labels are as follows: ABCO=white fir (*Abies concolor*), ABLA=corkbark fir (*Abies bifolia* formerly *A. lasiocarpa*), PIEN=Engelmann spruce (*Picea engelmanii*)+blue spruce (*Picea pungens*), PIPO=ponderosa pine (*Pinus ponderosa*), POTR=aspen (*Populus tremuloides*), PSME=Douglas-fir (*Pseudotsuga menziesii*), RONE=New Mexican locust (*Robinia neomexicana*), ABIES=white fir+corkbark fir, PIAR=bristlecone pine (*Pinus aristata*), PIFL=limber pine (*Pinus flexilis*). Trees are defined as stems having dbh > 1 inch, and regeneration as stems having dbh <= 1 inch. Data for GCNP are from Fule and others (2003), and for SFPA are from Cocke and others (2005).

For the GCNP north rim site, the ponderosa pine forest has increased from 136.2 (se=20.1) trees/acre to 316.7 (se=47.5) trees/acre, not counting current regeneration, which is a 132% increase in tree density from pre-settlement times to present. Similarly, the basal area increased from 57.9 (se=23.1) ft^2/ac to 153.8 (se=20.0) ft^2/ac, representing a 165% increase in tree density (Fule and others 2003). For the San Francisco Peaks study, Cocke and others (2005) reported an increase in tree density from 24.9 (se=2.6) trees/ac to 293.1 (se=47.2) trees/ac, for a 1,079% increase, and basal area increased from 33.0 (se=4.9) ft^2/ac to 150.0 (se=13.1) ft^2/ac, for a 355% increase in current forest density over pre-settlement ponderosa pine forest density.

Understory- See *Herbaceous Layer*, below.

Herbaceous Layer – The effects of fire suppression and livestock grazing on understory and herbaceous vegetation is reviewed by Korb and Springer (2003), and effects of tree thinning and prescribed burning by Abella (2004). Generally, as the overstory density has increased, both total cover and species richness have decreased (Korb and Springer 2004). Also, thinning and burning generally increase ground flora (understory and herbaceous) biomass, but composition and populations processes (such as recruitment) have been little studied in ponderosa pine forests (Abella 2004).

Patch or Stand Structure of Vegetation – We found no studies that documented the effects of human disturbance on the patch or stand structure of ponderosa pine forests.

Canopy Cover Class (%) or Canopy Closure – Fule and others (2003) reported a value of 53% +/- 10.8% (se) for ponderosa pine at Grand Canyon National Park's North Rim.

Structure Class (Size Class) - Moore and others (2004) compared historical (1909-1913) versus current (1997-1999) size class structure of ponderosa pine forests from the 15 Woolsey plots in Arizona and New Mexico. They reported average current forest stand density (of trees >= 3.6 inches DBH) of 124.2 ft^2/ac. They also determined that the Quadratic Mean Diameter, a measure of central tendency in tree diameter within a stand weighted by number of trees, was 11.3 inches over the same time period, and that on average, each 1.1 hectare (2.8 ac) plot had 416 "young" trees, and 57.2 "old" trees [old and young based on morphology of tree bark] (Moore and others 2004).

Life Form – We found no studies that documented the effects of human disturbance on the current life form of ponderosa pine forests.

Density – The density of Southwest ponderosa pine forests has been reported to be 124.2 ft^2/ac for the Woolsey plots throughout Arizona and New Mexico (Moore and others 2004). More site specific studies have reported values of 153.8 ft^2/ac for the Grand Canyon National Park (GCNP) (Fule and others 2003), and 150.0 ft^2/ac for the San Francisco Peaks (Cocke and others 2005). Density expressed in trees per acre has been reported as 316.7 for stems > 1 inch DBH and 2076 for stems < 1 inch for the GCNP, for a total of 2392.7 trees/acre (Fule and others 2003). For the SFPA, Cocke and others (2005) reported 293.2 trees/acre for stems > 1 inch DBH and 335.9 for stems < 1 inch, for a total of 629.1 trees/acre.

Age Structure – Generally, ponderosa pine forests have been shown to have more young trees in the understory (Fule and others 2003, Moore and others 2004, Cocke and others 2005). Moore and others (2004) determined that the Quadratic Mean Diameter, a measure of central tendency in tree diameter within a stand weighted by number of trees was 11.3 inches over the 1997 to 1999 time period, and that on average, each 1.1 hectare (2.8 ac) plot had 416 "young" trees, and 57.2 "old" trees [old and young based on morphology of tree bark].

Patch Dispersion - We found no studies that quantified the effects of human disturbance on the patch dispersion of ponderosa pine forests.

Recruitment Dynamics – Several authors have reported regeneration rates for the post-settlement period to be on the order of tens to hundreds of stems per acre (Covington and Moore 1994, Savage and others 1996, Moore and others 1999).

Synthesis – Anthropogenic disturbance has led to major changes in ponderosa pine forest structure and function. With the introduction of grazing animals at various times during the 19th century, low intensity and frequent surface fires have been replaced with high intensity and infrequent crown fires. Although the effects of these large, stand-replacing fires are variable, several fires have led to long-term changes from forested systems to grasslands, shrublands, and areas of dense pine regeneration (Savage and Mast unpublished data, Dahms and Geils 1997). Areas that have not burned yet have higher density of trees, especially of the smaller size class and younger age class, changing the quality of habitat for wildlife and humans (Covington and Moore 1994, Dahms and Geils

1997, Allen and others 2002). While good information exists for some areas that have the benefit of intensive study, many areas remain unstudied, and many data gaps remain that will help to ascertain reference conditions (Moore and others 1999, Allen and others 2002). Figure 7-6 is a photographic comparison 128 years apart in the Coconino National Forest, showing the change in density, spacing or clumpiness, and age class distribution.

1875

2003

Figure 7-6. Paired photographs from Walker Lake (Coconino NF) between 1875 and 2003 after approximately 128 years of fire suppression. Note the number, size and spacing of ponderosa pine in the upper photo, and the density increase by smaller trees in the lower photograph. Photos courtesy of Northern Arizona University's Ecological Restoration Institute.

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Chapter 13 - Vegetation Models for Southwest Vegetation

13.1 Introduction

In response to the USDA Forest Service Southwest Region's need for landscape scale planning tools, we developed broad-scale state and transition models for 8 Potential Natural Vegetation Types (PNVTs) in the Southwest based on a comprehensive literature review. We utilized this information to describe vegetation model states, identify parameter values for these models and to run quantitative scenario analysis, using Vegetation Dynamics Development Tool (VDDT) software, to determine the relative proportion of model states on the landscape. Vegetation Dynamics Development Tool software is a non-spatial model that allows the user to model vegetation change over time as a series of vegetation states that differ in structure, composition, and cover and to specify the amount of time it takes to move from one vegetation state to another in the absence of disturbance. Various disturbance agents affecting the movement of vegetation between states (or transitions) are incorporated (e.g., surface fires, stand-replacing fires, grazing, insect outbreaks, and drought events). By varying the types and rates of disturbance across the landscape, the effects of different disturbance regimes, such as historic and current fire regimes, or different management treatments, such as wildland fire use, fire suppression, prescribed burning, grazing practices, and mechanical fuel treatments, on vegetation can be investigated. These models will summarize and synthesize the current state of scientific knowledge of vegetation dynamics. Additionally, they will provide forest planners and managers with powerful tools for understanding, investigating, and demonstrating the effects of alternative scenarios for the management of vegetation on national forests at scales ranging from the Ranger District to the Southwest Region.

The region-wide scale at which the models were constructed, as well as the sole reliance on published scientific information to build and parameterize the models, necessarily limits the level of detail in a model as well as the applicability of the model to a given site. Given these constraint, it is important to utilize information from these models to understand general trends in vegetation change and dynamics at large scales while utilizing finer scale models (such as those found in Ecological Site Descriptions developed by the Natural Resources Conservation Service) and/or expert information to model and evaluate land management at the site level.

13.2 Methodology

State and Transition Models - We defined all model states, transitions between states, and transition probabilities using information from published, peer-reviewed journal articles, as well as published conference proceedings, reports, theses and dissertations, and book chapters. We limited our search to relevant literature that came from studies of Southwest ecosystems, with a geographical emphasis on Arizona, New Mexico, and northern Mexico to ensure compatibility and relevance to Southwest ecosystems. This information is synthesized in narrative form for each PNVT in a companion document entitled

"Historic Range of Variation for Potential Natural Vegetation Types of the Southwest" (Schussman and Smith 2006).

We described each model state by 1) its dominant vegetation and/or life form, 2) percent canopy cover or density of one vegetation component (ie grass, shrubs or trees), and 3) the number of years that can be spent in that state (without a disturbance) before it transitions to another state. Dominant vegetation and life form definitions followed the USFS's guidelines which break down or identify dominance types in terms of a single dominant species or genera when either accounts for ≥ 60% canopy cover, or in terms of co-dominant species or genera when 2 or more species or genera account for ≥ 80% canopy cover together with each individually having ≥ 20% canopy cover. Life forms are classified as tree if tree canopy cover is ≥ 10%, shrub if shrub canopy cover is ≥ 10%, and herbaceous if herbaceous canopy cover is ≥ 10% herbaceous canopy cover (Brohman and Bryant 2005). We utilized USFS guidelines in the model building process in order to make the models directly comparable to Region 3's mid-scale mapping of current vegetation. Parity of this nature will allow modeled estimates of historic vegetation to be compared with current vegetation in order to determine departure from historic and too help identify desired future conditions.

We identified nineteen types of transitions that are likely under historical (pre-1880) and/or current (post-1880) conditions: stand replacing fire, mixed severity fire, surface fire, in-growth, drought event, wet event, large droughts followed immediately by erosion events such as large wet events or wind events(Drought/Wet/Wind), windthrow, avalanche, insect outbreak, disease outbreak, herbivory (native and non-native), use by Native people, plant growth, pre-scribed fire or wildland fire use, spread of non-native species, and mechanical or chemical treatments. This is not an exhaustive list of possible transitions but rather represents a list for which there was information available to determine the effect and/or frequency of the transition.

The level of model complexity (number of model states and transitions) varies by PNVT based on the amount of available information. For example, there is a great deal of disturbance, cover, and post-disturbance regeneration information available for the ponderosa pine PNVT, hence a 10 state model with 5 transitions was created. In contrast, there is little to nothing known about these same factors for the Madrean encinal PNVT, hence no model was not created.

Vegetation Dynamics Development Tool - We used VDDT software to model historic and current proportions of the landscape in all model states. We included transitions in the models only if 1) there was documentation that consistently identified the frequency and effect of that transition on vegetation composition and structure; and 2) if that transition was applicable to a majority of the vegetation within the regional PNVT being modeled. For example, we know that mechanical and chemical treatments of interior chaparral occurred at varying frequencies and intensities throughout small portions of Arizona's interior chaparral between 1950 and 1980, however, these treatments were variable across the landscape and applicable to only a small portion of interior chaparral vegetation in Arizona and New Mexico. Given the variability in treatments and the low applicability of these transitions to the regional description of the PNVT, these transitions were not modeled. However, if some or all of these treatments are being considered for future management they can easily be incorporated into the model at a later date.

Model Parameters – Vegetation Dynamics Development Tool models are non-spatial models with between 0 and 50,000 sample units (pixels) for all states that can be simulated over 1 to 1000 year time horizons. Sample units are assigned to a state at the start of the model and change from one state to another based on the probability of transition occurrence. The proportion of the modeled landscape (number of pixels) in any given state is identified for all years modeled.

In order to minimize the variability in model output that arises from variation in sample size (i.e., the number of pixels modeled) and to standardize models for all PNVTs, we conducted a sensitivity analysis of a "simple" grassland model to determine the appropriate number of sampling units (pixels) and model runs (simulations) to use in scenario analysis. The "simple" grassland model is a 4 box model that includes 3 transitions (fire, drought, and plant growth) (Figure 13-1). Results of the sensitivity analysis showed that variation due to sample size was minimized when 1,000 or more sample units were used (Table 13-1). Based on this result we set the modeled landscape at 1000 pixels and ran each scenario for a total of 10 runs (simulations) in order to calculate a mean and standard deviation value for each modeled state. This analysis also highlighted the need to perform a sensitivity test on the range of values identified for the probability of a transition in each model, as seemingly small differences in the probability of a transition had large impacts on model output when the transitions are very **frequent** yet had little impact on model output when transitions are very **infrequent** (Tables 13-2 and 13-3). Given these results and the fact that information from different studies of the same PNVT yielded a range of values for the frequency of transitions, we decided to use sensitivity analysis to determine the impact of imprecise information on all models for which a range of values was identified in the literature. Specifically, when a range of values was given for a transition, we ran the model using the average value, as well as the high and low ends of the value range and reported the results from all three model runs.

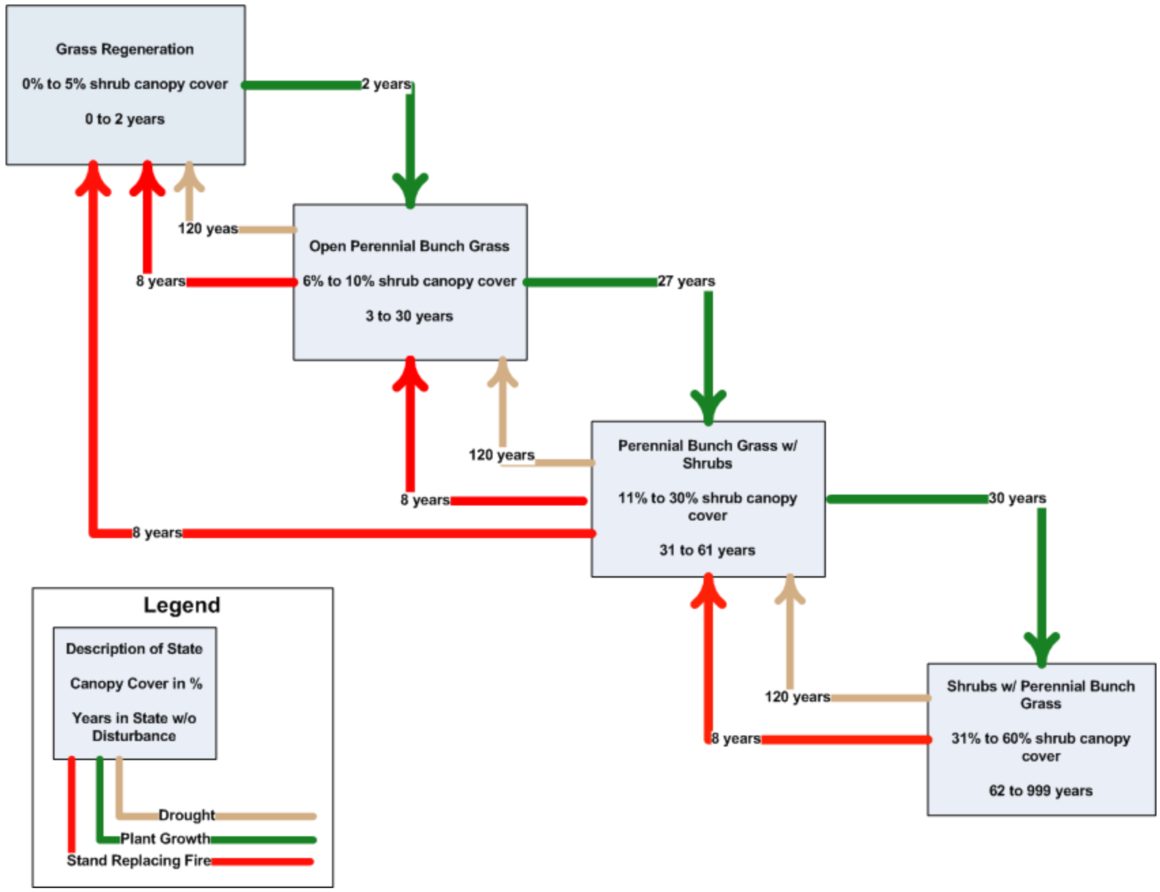

Figure 13-1. Simple grassland model used in sensitivity testing of VDDT software

Table 13-1. Sensitivity analysis showing the stabilization of model output, as indicated by average percent of the modeled landscape in each vegetation state and average standard deviation, when model is run at or above 1,000 sample units.

Sample Number	State A (%)	Standard Deviation (%)	State B (%)	Standard Deviation (%)	State C (%)	Standard Deviation (%)	State D (%)	Standard Deviation (%)
10	14.0	10.6	54.2	16.1	17.8	11.0	14.0	11.8
100	15.1	3.8	56.6	5.3	17.2	3.3	13.1	3.0
1000	13.5	1.0	57.4	1.4	16.5	1.0	12.5	1.1
10000	13.7	0.4	57.3	0.6	16.4	0.4	12.6	0.4

Table 13-2. Sensitivity analysis showing dramatic changes in the average percent of the landscape in each state when the frequency of the fire transition (every 8 years) is multiplied by a range of values between 0 and 2. Increasing the frequency of fire by a factor of 2 drastically changed the average percent of states A, C, and D. Similarly, decreasing the frequency by roughly a half (Every 20 years) also drastically changed the average percent of most of the states.

Fire Frequency Multiplier	Fire Frequency	State A (%)	State B (%)	State C (%)	State D (%)
0.0	none	0.0	0.0	0.0	100
0.4	Every 20 years	1.1	18.1	22.2	58.6
0.8	Every 10 years	8.6	48.5	20.1	22.8
1.0	Every 8 years	13.7	57.6	16.2	12.5
1.2	Every 7 years	15.7	66.3	11.8	6.2
1.6	Every 5 years	26.9	66.0	5.2	1.9
2.0	Every 4 years	31.5	65.9	1.9	0.0

Table 13-3. Sensitivity analysis showing little change in the average percent of the landscape in each state when the frequency of the drought transition (every 120 years) is multiplied by 0, 1, and 2. Increasing the frequency of drought by a factor of 2 increased the average percent of state A by only 5%, while state B saw a change of 6%. Decreasing the probability to 0 decreased A by about 4% and B by 2.5%, increased D by 5% and had little effect on state C.

Drought Frequency Multiplier	Drought Frequency	State A (%)	State B (%)	State C (%)	State D (%)
0.0	None	16.3	56.4	14.5	12.8
1.0	Every 120 years	20.4	59.0	13.2	7.4
2.0	Every 60 years	15.9	65.3	13.0	5.8

We ran the historic models for 1000 years, as this temporal span corresponds with the widest frame of reference offered by the scientific literature. Additionally, 1000 year long runs allowed for infrequent transitions, such as stand replacing fires in the spruce fir PNVT and extreme drought events in all PNVTs, to occur several times within each simulation. Ultimately, this level of temporal depth makes for a robust historic model that allows for multiple replicates of infrequent events while not over reaching the bounds of our historic knowledge. Current models were run for 120 years as this corresponds to the post-European settlement era when large scale changes to historic fire, flooding and grazing regimes in the Southwest were first documented.

We began all historic model runs with equal proportions of the modeled landscape in each state. For example if the model had 4 states then the historic model would start the 1000-year simulation with each state making up 25% of the landscape. However, for the current models, we began the 120-year simulations with the proportions of each state equal to the output values (900-year averages) from the historic model runs. This allowed us to simulate how the last 120 years of management has changed the historic proportions of the vegetative states.

Variability - One of the main concerns with vegetation models is the use of mean values to model the frequency of events that are variable in space and time. This is a valid concern and criticism as the mean value is not a metric for describing variability. For example, in the Madrean pine oak woodland, mean fire return interval (MFRI) for all fires, at 15 sites located in Arizona and northern Mexico, ranged between 3 and 7 years, while the MFRI for fires that scarred 25% of the trees ranged between 5 and 13.2 years (Fulé and Covington 1998; Fulé and others 2005; Kaib and other 1996; Swetnam and Baisan 1996; Swetnam and others 1992). Additionally, the minimum and maximum number of years between any given fire was between 1 and 38 years (Fulé and others 2005; Kaib and other 1996; Swetnam and Baisan 1996; Swetnam and others 1992).

Given concern over the use of mean values and the variability in the frequency of Southwest transitions we investigated the ability of VDDT to model variability in vegetation dynamics. Specifically, we analyzed year to year variability in our simple grassland model. Results of this analysis showed there to be little variability from year 10 to 1000 (13- 2). This was due to the consistency with which the probability of the transitions occurred (i.e., every year, each sample unit in which fire could occur had a probability of 0.12 of having that fire) as well as the large number of sampling units.

Climatic factors are known to be important drivers for many of the transitions we modeled, such as fire occurrence and insect outbreaks. Given this connection, we investigated the incorporation of climate variation on these transitions within the models. This was accomplished through the use of VDDT's "annual multiplier" function. This function allows the user to identify the frequency of year types that are known to increase or decrease the frequency of a transition, and then apply a multiplier value to the mean probability based on the occurrence of the year types. As year types vary, so too does the probability of a transition occurring. The result of the inclusion of hypothetical multipliers into the simple grassland model was year to year variability in the probability of a transition resulting in year to year variability in the proportion of the landscape in any given state (Figure 13-2 and Table 13-4). The inclusion of annual variability into the models allowed us to estimate not only the mean proportion of the landscape in a given state, but also the minimum, maximum, and standard deviation values for a state.

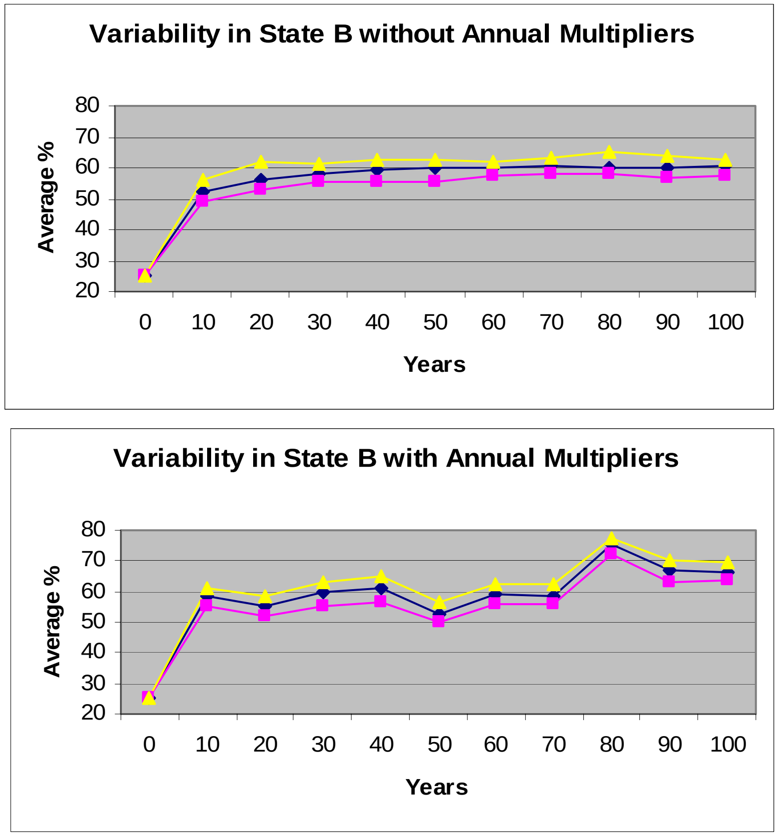

Figure 13-2. Comparison of year to year variability in state B of the simple grassland VDDT model with and without the use of annual multipliers. Maximum values in yellow, average values in blue, and minimum values in pink.

Table 13-4. Sensitivity analysis showing differences in annual variability with and without the use of the annual multiplier function.

Model State	Average Percent (No Multiplier)	Average Standard Deviation	Average Percent (Multiplier)	Average Standard Deviation
A	15.5	1	13.5	9.6
B	59.8	3.6	57.6	11.5
C	14.6	1.1	16.8	6.1
D	10.1	1.8	14.4	5.9

Fire Variability – The connection between fire occurrence and climate in the Southwest has been well established (Crimmins and Comrie 2004; Swetnam and Betancourt 1998). Based on this knowledge and our understanding of modeling year to year variability with VDDT, we modeled climate-mediated fire transitions using the annual multiplier function. To run the annual multiplier function we needed to identify the frequency of year types that increased and/or decreased fire occurrence as well as identify the magnitude of the effect. We obtained this information by analyzing the percent of regional fires that occurred in each year type using contingency table analysis (for an example see (Table 13-5). The regional fires were identified by Swetnam and Betancourt (1998) on the basis of having been recorded at two thirds of all sites, 41 of 63 sites, with fire history reconstructions in the Southwest; these fires occurred between1709 and 1879. The year types (severe drought, drought, normal, wet, and extremely wet) were identified from an in-depth analysis of Ni and others' (2002) 989-year winter precipitation reconstruction. Details of this analysis are described in a companion document entitled "Assessing Low, Moderate, and High Severity Drought and Wet Events Across the Southwestern United States from Year 1000 to 1988" (Schussman 2006).

Table 13-5. Example of contingency table analysis used to identify the magnitude of connection between regional fires and year type with a significant ($p < 0.001$) difference.

Year Types	Regional Fire No % of years (total count)	Regional Fire Yes % of years (total count)
Severe Drought	74.8 (238)	25.2 (80)
Drought	81.4 (131)	18.6 (30)
Normal	89.2 (538)	10.8 (65)
Wet	96.6 (113)	3.4 (4)
Extremely Wet	99.7 (339)	0.3 (1)

We identified the frequency of year types by simply totaling the percent of years, out of 989, for each individual year type. Finally, we derived the annual multiplier from the contingency table analysis by dividing the frequency of fire occurrence in a given year type by the mean probability of fire occurrence within the model. For example, if the frequency of regional fire occurrence in the severe drought year type was 0.252 (or regional fires occurred 25.2% of the time in severe drought years) and the mean probability of fire occurrence in the model was 0.12, then we applied a multiplier of 2.1 to the fire transition for all severe drought years. This change increases fire probability from 0.12 to 0.252 in severe drought years but maintains the mean fire frequency across all year types.

Finally, in order to make this information specific to a PNVT model, we selected data for inclusion in each PNVT fire/climate analysis based on the geographical overlap of winter precipitation climate data, which are identified for the 15 climate divisions within Arizona and New Mexico, with a PNVT boundary.

Model Reporting –We developed a descriptive state and transition diagram for historic and current conditions as well as a current photographic diagram for each PNVT. For all historic transitions, the historic frequency, or range of frequencies, of each transition is identified. Additionally, all possible transitions for which there was some level of information are included in the state and transition model. However, only those transitions for which the transition impacted the majority of the vegetation within a

PNVT and for which information regarding the frequency and effect of the transition on the vegetation was consistently identified were included into the quantitative VDDT models. Identification of the frequency of transitions, source(s) used to identify transitions, and assumptions made in identifying the frequency or effect of transitions are detailed in tabular form for both historic and current models, for each PNVT separately in the following chapters.

For the historic models, we report the 900-year average, minimum, maximum, and average standard deviation for each state. We report results from the last 900 of the 1000 years because it takes the model 50-100 years to come to equilibrium from initial conditions. For the current models, we report the average, minimum, maximum, and standard deviation of the final year of the 120-year model run. The summary statistics were calculated based on 10 model runs (simulations) for both the historic and current models.

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Chapter 18 - Ponderosa Pine–Bunchgrass Forest Model

18.1 Ponderosa Pine Vegetation Dynamics – Ponderosa pine-bunchgrass forests dominate the mid-elevation forests of Arizona and New Mexico, occurring in a diverse mixture of age-, size-, and canopy cover classes within an uneven-aged forest system. Prior to about 1880, these forests were much more open, with canopy cover rarely exceeding 30% (Pearson 1923, White 1985). Surface fires maintained these open forests with low intensity, widespread fires occurring at a frequency of about 5 to 36 years when the >25% trees scarred filter, or fire rotation values are used (Swetnam and Baisan 1996). Native Americans used fire and were a source of ignition in some places at varying times and seasons, but their contribution to the overall fire frequency is vastly overshadowed by lightning-caused fires (Allen 2002). Propagation of these lightning-initiated fires was supported by a contiguous bed of dense bunchgrasses, forbs and litter in the herbaceous layer. Following fire, and in conjunction with periods of high precipitation, ponderosa pine seedlings established in great numbers, but regeneration has been sporadic and patchy across space and through time (Mast and others 1999). Natural surface fires have been suppressed since about 1880, allowing for the accumulation of large quantities of surface fuels and fuel ladders, facilitating an increase in the frequency, size, and intensity of stand replacing fires (to about once every 100 years -- Savage and Mast 2005).

Grazing animals have been implicated for the removal of surface fuels and the subsequent decrease in surface fire frequency (Savage and Swetnam 1996), but the extent of influence of grazing animals has not been quantified systematically across the Southwest Region. Swetnam and Baisan (1996) determined that climate has influenced fuel production and fuel moisture, thereby affecting the fire regime of ponderosa pine, with large fire years correlated with drought years, especially when preceded by one to three years of higher than average precipitation. Years with fewer fires are correlated with higher precipitation (Swetnam and Betancourt 1990). Various species of bark-beetle insects are endemic to the Southwest, and while historic outbreaks are not well understood, current forests have experienced large-scale irruptions of bark beetles with a frequency of 1-2 outbreaks per century since disruption of the surface fire regime and the resulting increase in density of SW forests (Dahms and Geils 1997, Negron and others 2000).

Vegetation Models - Based on this understanding of vegetation dynamics, we created state and transition models depicting historic (pre-1880) and current (1880 to present) vegetation dynamics within this forest type (Figures 18-1 through 18-2). Additionally, we used information from the state and transition models to develop quantitative Vegetation Dynamics Development Tool (VDDT) models. The VDDT software allows the user to model succession as a series of vegetation states that differ in structure, composition, and cover and to specify the amount of time it takes to move from one vegetation state to another in the absence of disturbance. Various disturbance agents affecting the movement of vegetation between states can then be incorporated (e.g., surface fires, stand-replacing fires, grazing, insect outbreaks). By varying the types and rates of disturbance across the landscape, the effects of different management treatments, such as wildland fire use, fire suppression, prescribed burning, grazing practices, and mechanical fuel treatments, on future vegetation can be investigated. While VDDT models can be used to “game play” with different management scenarios, the models we ran in this analysis only include states and transitions for which there is published information to support their inclusion within the model. We discuss model parameters, output, and analysis below (Tables 18-1 through 18-4).

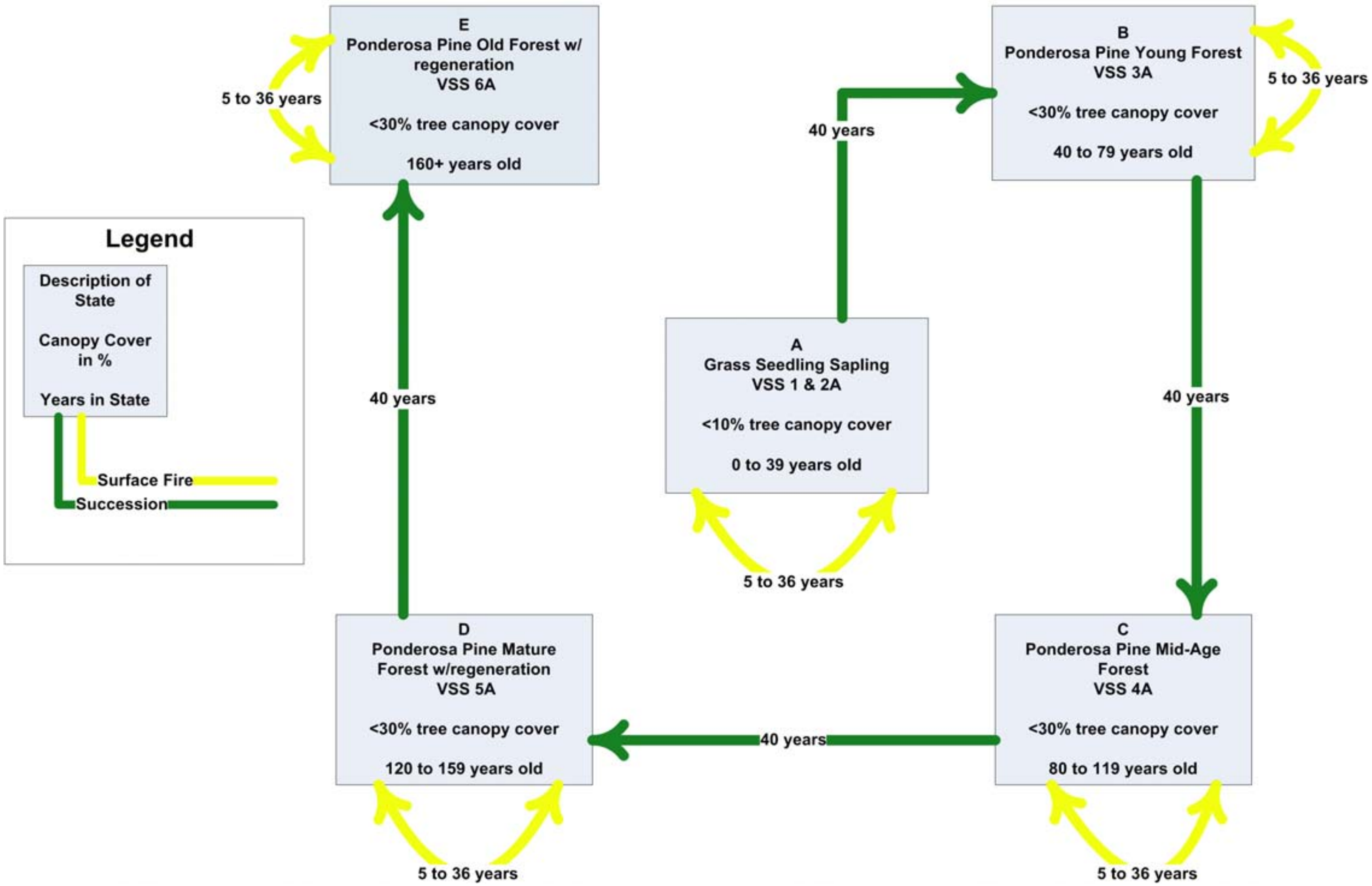

Figure 18-1. Conceptual Historic state and transition model for the ponderosa pine-bunchgrass vegetation type. Frequency of transitions are noted when this information is supported by published sources; where no or conflicting information exists on the frequency of transitions, unknown is the notation.

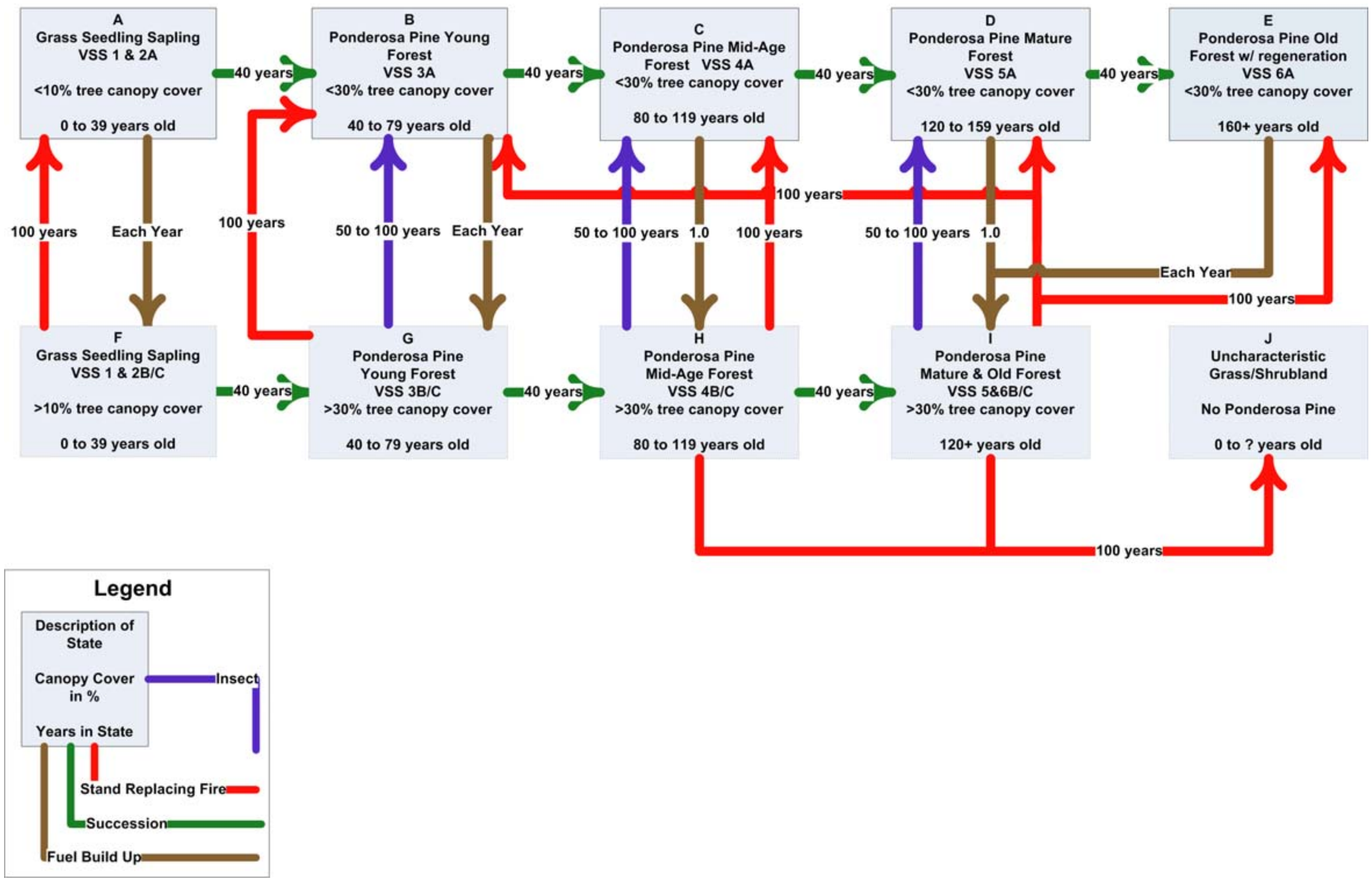

Figure 18-2. Conceptual Current state and transition model for ponderosa pine-bunchgrass native vegetation type. Frequency of transitions are noted when this information is supported by published sources, where no or conflicting information exists on the frequency of transitions, unknown is the notation. Dashed outlines represent states which may have been uncharacteristic for the historic period.

18.2 Model Parameters

In Tables 18-1 and 18-2 below, we describe the parameters included or not included within the Historic and Current VDDT models, as well as the sources of information and any assumptions used to create model parameters.

Table 18-1. Identification of Historic transitions, frequency of transitions, sources of information used, and assumptions used to develop the frequency of transitions and their effects on vegetation states included in the VDDT models.

Transition Type	Transition Frequency or Length	Sources	Assumptions
Regeneration from seed	Unknown, not used in model.	Seed production and seedling recruitment is highly variable in both space and time. Although episodic events have been documented for some areas (Mast and others 1999), there is insufficient information to assign a probability for this transition across the entire region.	Due to the lack of data on seedling recruitment, this transition is not included in the model, and hence the proportion of this seedling/sapling class of vegetation is presumed to be underestimated in the model
Surface Fire	5-36 years	Swetnam and Baisan 1996, Sneed and others 2003, Fule and others 2003.	These data are based on direct evidence (fire scar data). We modeled the endpoints of the range (5.4,36.3), and we averaged the range, using 15.6 years as the average for modeling purposes.
Stand Replacing Fire	Not used in model	Stand replacing fire was reported to be rare and small in area prior to 1880 (Moir and others 1997, Fule and others 2003, Falk 2004), and operating at the individual tree scale rather than on patches (<100 acres).	Stand replacing fire only occurred on individual trees (torching) and at very low frequency (once every 500 to 1,000 years).
Plant Growth	40 years between states	Transitions among model states were taken from silvicultural data summarized by Reynolds and others (1992).	We assume that transition from seedling/sapling to young forest takes approximately 40 years, and from young to mid-age forest, mid-age to mature forest, and mature forest to ld forest also take 40 years.

Table 18-2. Identification of Current transitions, frequency of transitions, sources of information used, and assumptions used to develop the frequency of transitions and its effect on vegetation included in the VDDT models.

Transition Type	Transition Frequency or Length	Sources	Assumptions
Fuel Build Up	Once every year after 25 years of growth.	Several authors have documented the cessation of surface fires around 1880, which has led to the accumulation of fuels (Covington and Moore 1994, Swetnam and Baisan 1996, Allen and others 2002, Fule and others 2003).	We assume that it would take approximately 25 years of growth since the last surface fire to move from an open canopy state (<30% canopy cover) to a higher canopy state (>30%).
Surface Fire	Not Used in Current model	Covington and Moore 1994, Swetnam and Baisan 1996, Sneed and others 2003, Allen and others 2002, Fule and others 2003.	Based on direct observation, we assume that surface fire has ceased at the scale of this model (9 million acres). Occasional surface fires do occur, but not at the same scale, and typically enough fuels have accumulated in most areas to quickly transition surface fires to stand replacing fires. Prescribed fire and fire use fires are occurring in some areas at some times, but not within the range of variability for this system.
Stand Replacing Fire	Once every 100 years	Cessation of surface fires and accumulation of fuels and development of fuel ladders has led to an increase in the frequency of stand replacing fires (Covington and Moore 1994, Swetnam and Baisan 1996, Covington and others 1997, Allen and others 2002). The effects of stand replacing fire on vegetation has been documented by Savage and Mast (2005).	We based our estimate of fire on fire scar data. Specifically, regional fire scar data shows drastic declines in fires from 1900 to present. Given these data, we estimated a fire occurrence of 1 in the last 100 years. Fires studied by Savage and Mast (2005) give proportions of ponderosa pine forests resulting from stand replacing fires of the 1940s to 1970s. These values were used in modeling the relative proportion of states resulting from stand replacing fire in ponderosa pine forests of the SW.
Insect Outbreak	Once every 50 to 100 years	Bark beetle insect outbreaks have occurred 1 to 2 times over the last century (Dahms and Geils 1997, Negron and others 2000).	Insect-mediated mortality of ponderosa pines is highly variable spatially and temporally, but stands seldom experience 100% mortality, and it is assumed that beetle

			outbreaks take patches from a closed to an open state of the same age.
Plant Growth	40 years	Transitions among model states were taken from silvicultural data summarized by Reynolds and others (1992).	We assume that transition from seedling/sapling to young forest takes approximately 40 years, and transitions from young to mid-age forest, mid-age to mature forest, and mature forest to old forest also take 40 years.
Silvicultural Activities	Highly variable through time and across space, thus not included in the model.	Ponderosa pine forests have been logged and thinned since the 1850s to 1880s, with silvicultural prescriptions ranging from clear-cutting to thinning of pole and smaller trees (Bahre 1985).	We assume that the model overestimates the proportion of the current landscape in the Mature to Old Forest open and closed classes due to the loss of many of the larger trees to timber harvest.

18.3 Results – Results of the Historic ponderosa pine-bunchgrass model indicate a small amount of variability in the 900-year average for each state based on the fire interval range (Table 18-3). All three FRIs predicted that a majority of the landscape (99%) would be in the open Old Forest (State E), with a very small proportion of the landscape in the Mature open forests, State D (<1%). Recall that the states represent uneven-aged stands or patches with the range of ages given representing the maximum age of the stand rather than the absolute range of ages within the patch.

The Current ponderosa pine-bunchgrass model, which was run for 120 years following the Historic conditions, had very different results from the Historic model (Table 18-4). Old forest open (State E) has been reduced 70-90%, while mature/old forest closed (State I) increased from 0% in the Historic model to a range of 53% to 57% in the Current model. The percentage of open states is very low (0 to 1%) in the current model, while there is low abundance of the closed states other than I(1-6%). Uncharacteristic grasslands (J) accumulated up to 16% of the landscape under the Current scenario, compared to 0% under the historic scenario. The minimum and average Fire Rotation values produced identical values for landscape proportion for all classes, indicating that the model is not sensitive to this variability in fire regime.

Table 18-3. Results for the Historic ponderosa pine-bunchgrass VDDT model, reported as the 900 year average, minimum, maximum, and average standard deviation for the percent of the modeled landscape in each state. Historic models simulate the average (15.6 years), maximum (36.3 years), and minimum (5.4 years) of the estimated fire return interval range.

Fire Return Interval or Rotation Modeled	Model Output	Grass/ Seedling & Sapling A Open	Young Forest B Open	Mid-Age Forest C Open	Mature Forest D Open	Old Forest E Open	Grass/ Seedling/ Sapling F Closed	Young Forest G Closed	Mid-Age Forest H Closed	Mature /Old Forest I Closed	Unchar. Grassland J Open
Every 36.3 years	Average	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Minimum	0.0	0.0	0.0	0.7	99.1	0.0	0.0	0.0	0.0	0.0
	Maximum	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Every 15.6 years	Average	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Minimum	0.0	0.0	0.0	0.7	99.1	0.0	0.0	0.0	0.0	0.0
	Maximum	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Every 5.4 years	Average	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Minimum	0.0	0.0	0.0	0.7	99.1	0.0	0.0	0.0	0.0	0.0
	Maximum	0.0	0.0	0.1	0.8	99.2	0.0	0.0	0.0	0.0	0.0
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 18-4. Results of the Current ponderosa pine-bunchgrass forest VDDT model, reported as the 120 year end value for average, minimum, maximum, and average standard deviation of the percent of the modeled landscape in each state.

Fire Return Interval or Rotation Modeled	**Model Output by Class or State**	**Grass/ Seedling & Sapling A Open**	**Young Forest B Open**	**Mid-Age Forest C Open**	**Mature Forest D Open**	**Old Forest E Open**	**Grass/ Seedling/Sapling F Closed**	**Young Forest G Closed**	**Mid-Age Forest H Closed**	**Mature /Old Forest I Closed**	**Unchar. Grassland J Open**
Every 36.3 years	Average	0.1	0.2	0.2	0.5	23.2	3.8	5.5	4.5	52.7	9.4
	Minimum	0.0	0.0	0.0	0.2	23.1	2.5	4.3	3.7	49.1	7.6
	Maximum	0.4	0.6	0.5	0.8	23.3	5.2	7.1	5.5	57.1	11.7
	Standard Deviation	0.1	0.2	0.1	0.2	0.1	0.8	0.8	0.5	2.3	1.1
Every 15.6 years	Average	0.2	0.3	0.2	0.6	7.8	5.1	8.0	6.4	57.2	14.3
	Minimum	0.0	0.0	0.0	0.2	7.7	3.8	6.5	5.4	53.6	12.3
	Maximum	0.5	0.8	0.5	1.0	8.0	6.5	9.6	7.8	61.4	15.7
	Standard Deviation	0.2	0.2	0.2	0.2	0.1	0.8	0.9	0.7	2.3	1.0
Every 5.4 years	Average	0.2	0.3	0.2	0.6	7.8	5.1	8.0	6.4	57.2	14.3
	Minimum	0.0	0.0	0.0	0.2	7.7	3.8	6.5	5.4	53.6	12.3
	Maximum	0.5	0.8	0.5	1.0	8.0	6.5	9.6	7.8	61.4	15.7
	Standard Deviation	0.2	0.2	0.2	0.2	0.1	0.8	0.9	0.7	2.3	1.0

18.4 Discussion – These modeled scenarios implicate the importance of frequent surface fire in maintaining open ponderosa pine-bunchgrass ecosystems. When comparing the Historic versus the Current models, the increase in proportion of the landscape that is closed, and susceptible to stand replacing fires that result in uncharacteristic grasslands that are not forested, and may have a low probability of becoming reforested without costly intervention, is readily apparent. When comparing the model outputs to existing conditions, it is likely that the model overestimates all classes of mature and old forest, which in reality have been reduced as a result of timber harvest (Bahre 1985), and underestimate the seedling and sapling class abundance due to the lack of a regeneration transition that would increase these class abundances (States A and F). The abundance of these model states could be refined through a careful assessment of forthcoming datasets that will quantify their current abundance in the mid-scale vegetation analysis.

18.5 Ponderosa Pine Model References

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