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

SAVING THE LAST GREAT PLACES ON EARTH

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**Introduction to Vegetation Modeling**

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**Semi-Desert Grassland**

Schussman, Heather. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Semi-Desert Grassland of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 53 pp.

**Madrean Encinal**

Schussman, Heather. 2006. Historical Range of Variation for Madrean Encinal of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 16 pp.

**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**

Smith, Ed. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Ponderosa Pine of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 43 pp.

**Spruce-Fir**

Smith, Ed. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Spruce-Fir of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 37 pp.

**Aspen**

Smith, Ed. 2006. Historical Range of Variation for Aspen of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 21 pp.

**Alpine Tundra**

Smith, Ed. 2006. Historical Range of Variation for Alpine Tundra of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 15 pp.

**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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## Table of Contents

## List of Tables

## List of Figures

**Chapter 1 - Historical Range of Variation for Potential Natural Vegetation Types of the Southwest**

*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.

*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.

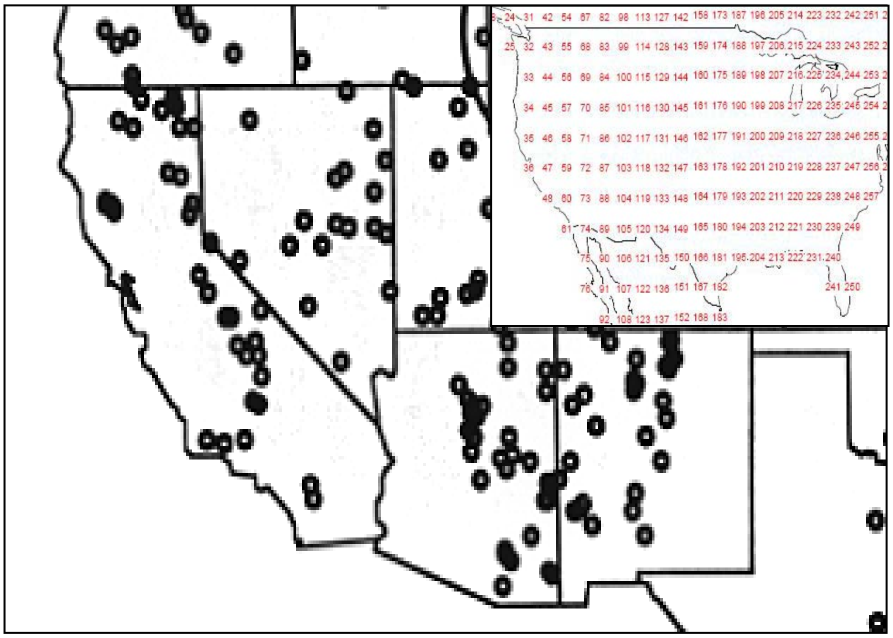
| | **88** | **89** | **104** | **105** | **119** | **120** | **133** | **134** |
|---|---|---|---|---|---|---|---|---|
| **# of Tree Chronologies** | 8-9 | 5-9 | 8-9 | 5-9 | 9 | 6-9 | 8-9 | 5-9 |

**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.

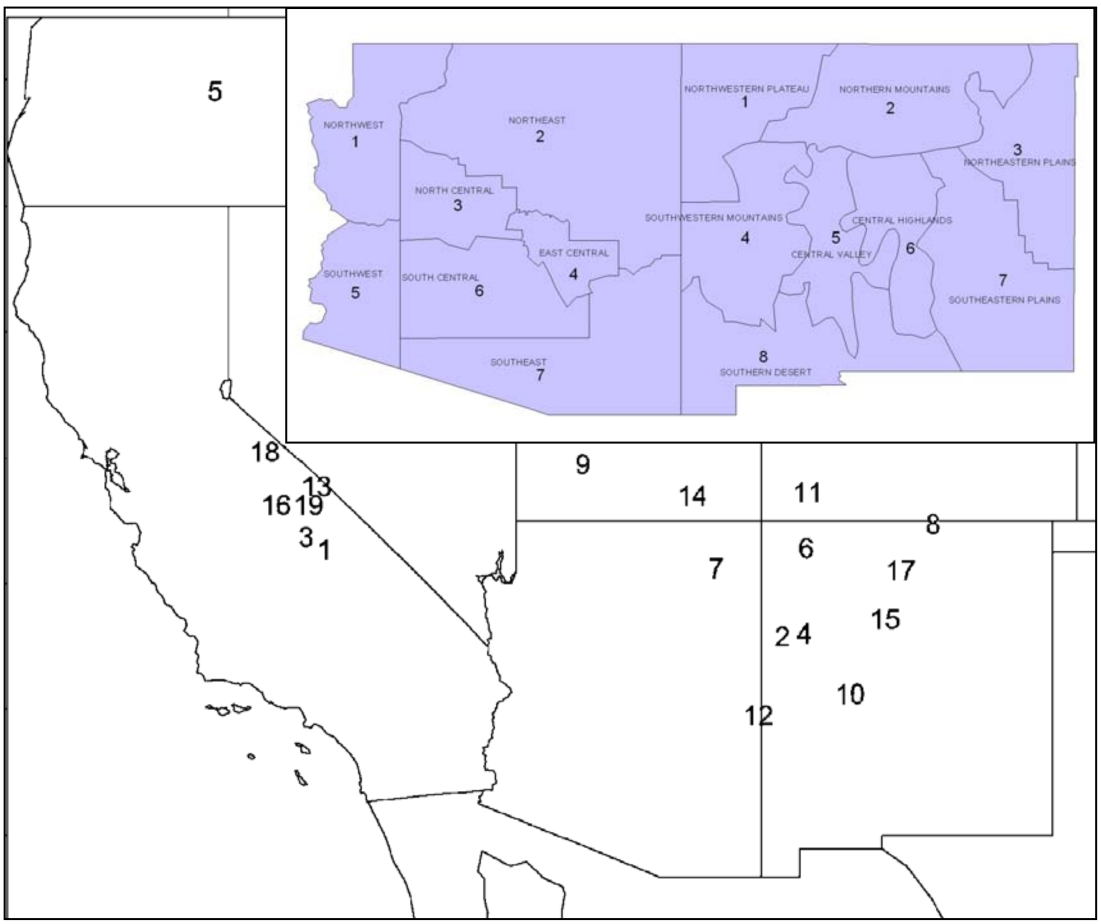



**Figure 1-1.** Identification of tree chronology locations for both the PDSI (1a taken from Cook and others 1999) and winter precipitation (1b taken from Ni and others 2002) data sets, as well as PDSI grid point locations and climate division boundaries.

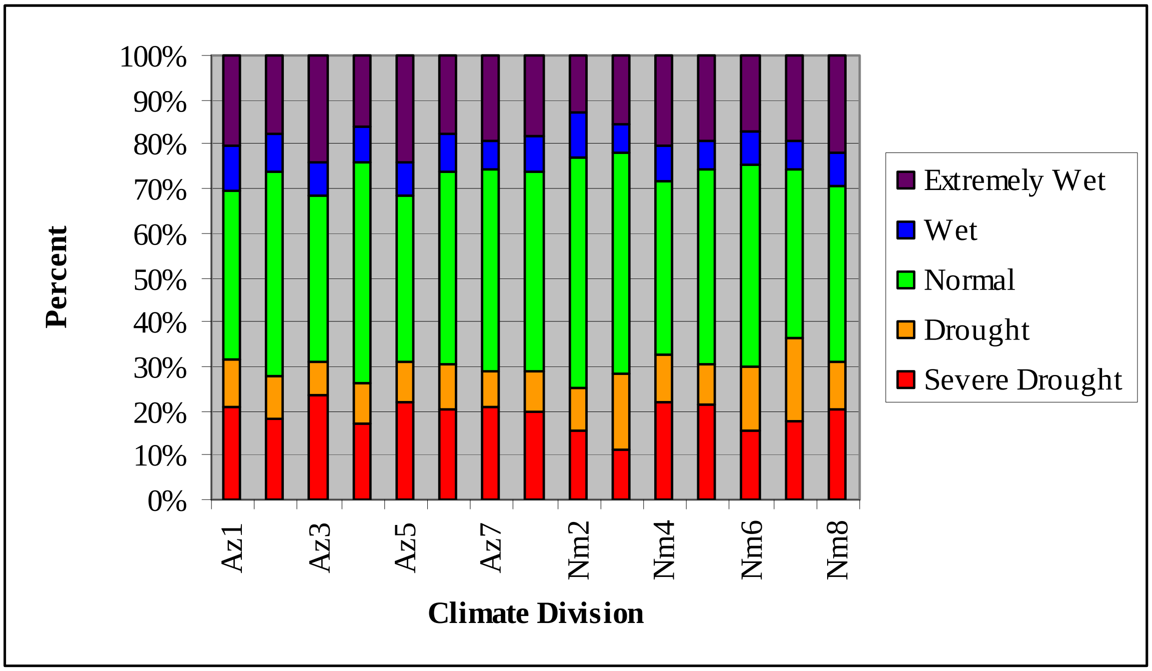



**Figure 1-2.** Comparison of the percent of years in all year types for all climate divisions in the Southwest.

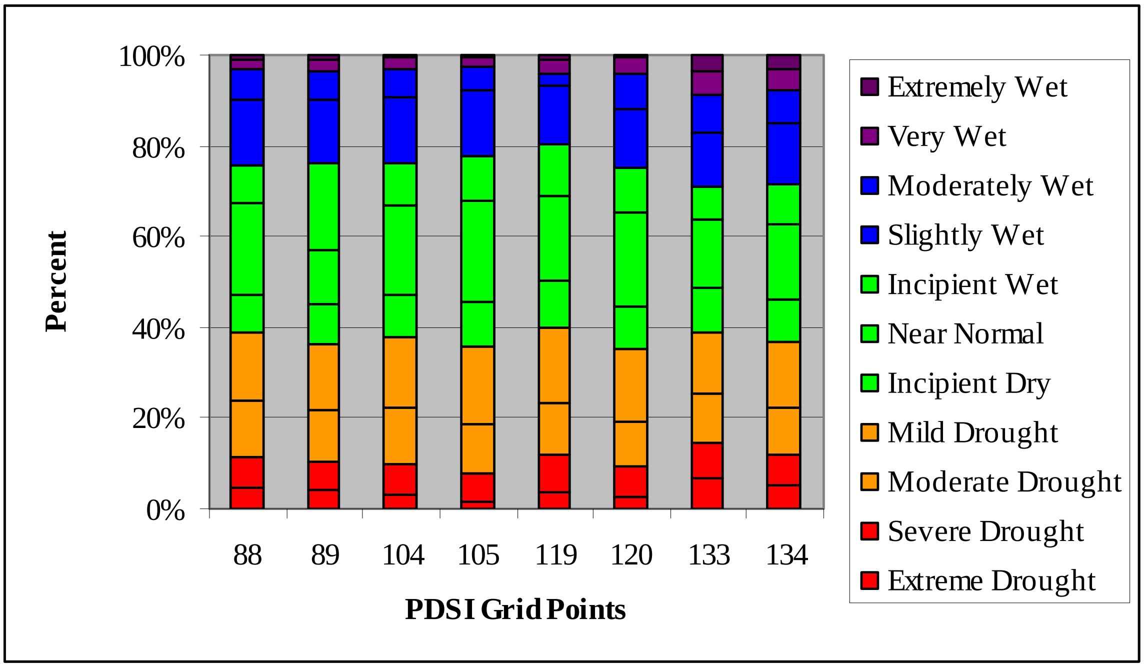



**Figure 1-3.** Comparison of the percent of years in all year types for all PDSI grid locations in the Southwest.

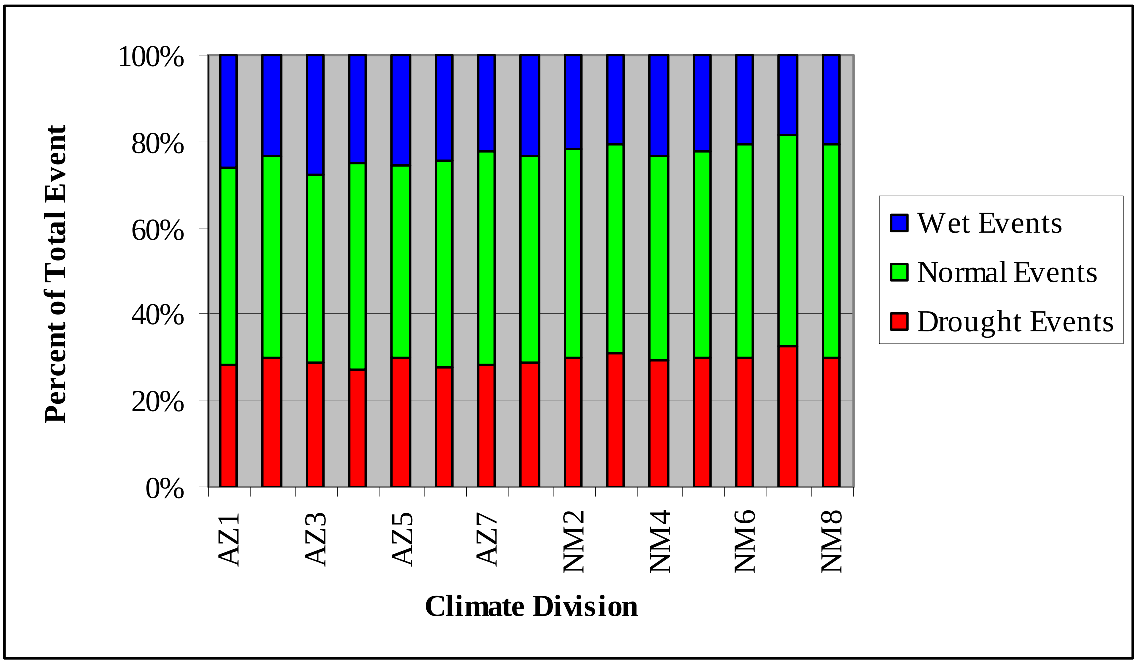



**Figure 1-4.** Comparison of the percent of events classified as drought, normal, and wet events for all climate divisions in the Southwest.

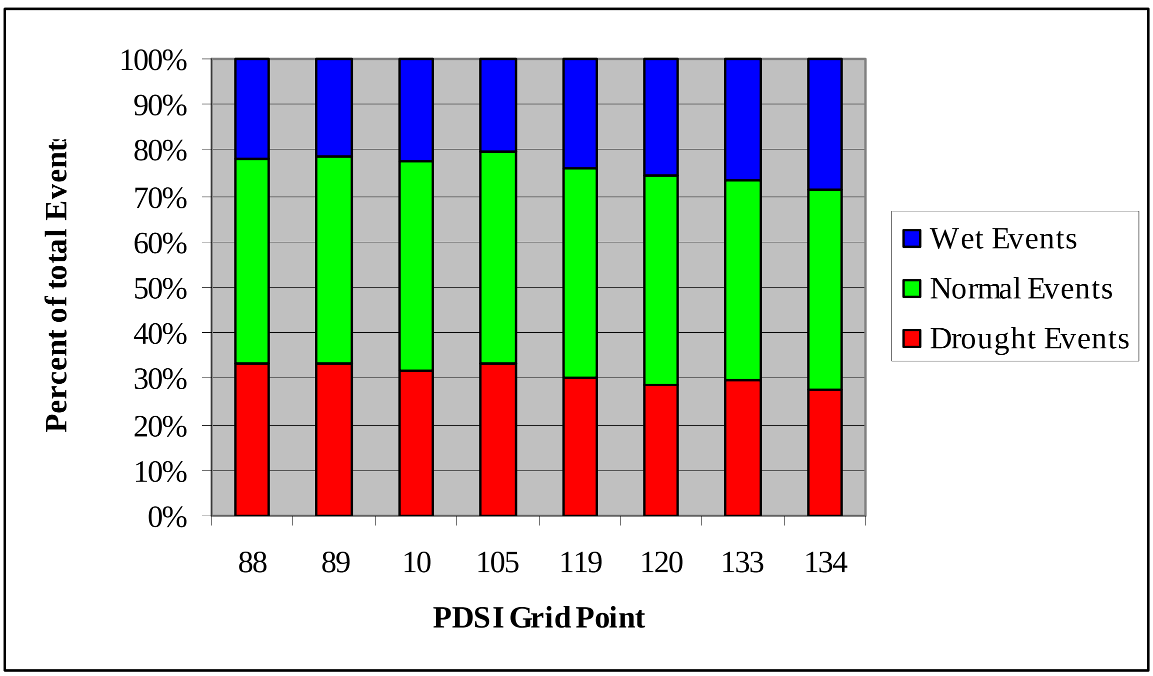



**Figure 1-5.** Comparison of the percent of events classified as drought, normal, and wet events for all PDSI grid locations in the Southwest.

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 16$^{th}$ 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 4 - Interior Chaparral

## *4.1 General Description*

Arizona chaparral occurs throughout central Arizona, southwestern New Mexico, and northern parts of Mexico as a discontinuous band of vegetation. The majority of this vegetation type exists at mid elevations (3,002 ft to 6,004 ft) below the mogollon rim in Arizona and in extreme eastern Chihuahua and western Coahuila, average precipitation varies from 15 to 25 inches per year (Carmichael and others 1978; Pase and Brown 1982). It is bordered by ponderosa pine or pinyon juniper at the upper elevations, and semi-desert grassland or sonoran/mojave desert at the lower elevations (Carmichael and others 1978). Species composition and dominance varies greatly across the broad range of soils and topography that occur throughout its range. In fact, multiple researchers (Brown and Lowe 1974; Carmichael and others 1978; Darrow 1944; Swank 1958) have attempted to detail out chaparral's complex structure by grouping vegetation based on plant associations. The latest of these classifications was that carried out by Carmichael and others (1978) who broke out Arizona chaparral into 8 communities based on major plant associations within central Arizona (Table 4-1). As evidenced by Carmichael and others' (1978) classification, shrub live oak is the most common, dominant shrub within Arizona chaparral, however, a wide range of other shrubs and trees (45 species) were also found within the chaparral associations.

**Table 4-1.** Community associations, with scientific name of dominant shrubs, and mean elevation for each association identified by Carmichael and others (1978) for central Arizona chaparral.

| Community Association | Scientific Name | Mean Elevation (ft) |
|---|---|---|
| Shrub live oak – birchleaf mountain mahogany | *Quercus turbinella – Cercocarpus betuloides* | 3,773 |
| Shrub live oak – mixed shrub | *Quercus turbinella* – mixed shrub | 3,937 |
| Pointleaf manzanita | *Arctostaphylos pungens* | 4,265 |
| Arizona cypress – shrub live oak | *Cupressus arizonica* - *Quercus turbinella* | 4,429 |
| Shrub live oak – datil yucca – yellowleaf silktassel | *Quercus turbinell – Yucca baccata – Garrya flavescens* | 4,921 |
| Yerbasanta – desert ceanothus | *Eriodictyon augustifolium – Ceanothus greggii* | 4,4921 |
| Pringle manzanita | *Archtostaphylos pringlei* | 5,249 |
| Arizona oak – yellow leaf silktassel – Emory oak | *Quercus arizonica – Garrya flavescens – Quercus emoryi* | 5,577 |

*4.2 Historic Range of Variation of Ecological Processes*

*Vegetation Dynamics* – Interior chaparral appears to be a fairly stable vegetation type due to the majority of its species having the ability to quickly re-sprouting following disturbance events, such as fire and mechanical or chemical removal (Cable 1975; Lillie and others 1964; Pase and Ingebo 1965; Pond and Cable 1960). Additionally, the few species that regenerate from seed require fire to prepare the seedbed (Carmichael and others 1978). Historically, this led to quick recovery of chaparral following the dominant natural disturbance, fire. In current times, these same mechanisms have allowed chaparral to maintain its dense canopy cover character regardless of human disturbance.

*Disturbance Processes and Regimes*

Below is a discussion of the frequency, intensity, severity, seasonality, and spatial and temporal scale of disturbances that occur within the interior chaparral vegetation type.

**Climate –** See Chapter 1, climate analysis section.

**Fire -** Frequent fires, covering hundreds of square miles at a time and occurring primarily between April and June, have been well documented through direct (fire scar analysis) and indirect (ecology of dominant species) lines of evidence for the semi-desert grasslands and ponderosa pine forests that border chaparral shrublands in Arizona (Bahre 1985; Cooper 1960; Covington and Moore 1994; Dieterich 1980; Kaib and others 1996; McPherson 1995; Swetnam and Baisan 1996; Weaver 1951). Documentation regarding fire occurrence within the chaparral PNVT, however, relies most heavily on indirect information such as fire adaptation of chaparral species as well the general ecology of the system.

In particular, Carmichael and others (1978) identify chaparral as fire adapted because its deep, well developed root system allows most chaparral species to sprout rapidly following fire. Like wise, they note that non-sprouting species (desert ceanothus and manzanita) "do not germinate in the absence of heat scarification". Based on ecological evidence, Pase and Brown (1982) and Wright and Bailey (1982) identify possible fire return interval ranges of 50 to 100 years and 20 to 80 years respectively. A quantitative study conducted by Sneede and others (2002) for the Prescott Basin within the Prescott National Forest identified an average burn interval of 30 to 40 years. In addition to knowing fires occurred somewhere on the order of every 20 to 100 years, ecologically speaking, chaparral fires are known to be high intensity stand replacing fires (Overby and Perry 1996). However, we don't have good information regarding the size of fires that swept across this PNVT.

**Hydrology –** We found no studies, in addition to those cited in the *conversion to chaparral section,* that documented hydrological processes, such as flooding, as important ecological determinants for the interior chaparral vegetation type.

**Herbivory** - Mule deer, white-tailed deer, and black bears are key herbivores in interior chaparral. Deer eat a variety of forbs, shrubs and browse, as well as mast and other fruits (Baker 1999; Cable 1975). Conversion treatments of chaparral to grassland, were shown to increase forage for deer, elk, and cattle. However, the decrease in protective cover following conversion was also shown to negatively affect deer, especially when treatments occurred on large landscape scales (Baker 1999; Cable 1975). Additionally, cover and food for black bear is best when there are shrubs and low trees due to presence of numerous mast and fruit producing species (Baker 1999).

**Predator/Prey Extinction and Introductions** - We found no studies that implicated predator/prey extinctions and/or introductions as important ecological determinants for the interior chaparral woodland vegetation type.

**Insects and Pathogens** - We found no studies that implicated insects and/or pathogens as important ecological determinants for the interior chaparral vegetation type.

**Nutrient Cycling** - We found no studies, in addition to those cited in the *conversion to chaparral* section, that documented nutrient cycling for the interior chaparral vegetation type.

**Windthrow –** Not an applicable category for interior chaparral

**Avalanche** - Not an applicable category for interior chaparral

**Erosion –** We found no studies, in addition to those cited in the *conversion to chaparral section,* that documented erosion within the interior chaparral vegetation type.

*4.3 Historical Range of Variation of Vegetation Composition and Structure*

*Patch Composition of Vegetation* **–** We found 5 early 1900s (1917 to 1957) photographs taken on the Apache, Gila, and Tonto National Forests (Figures 4-1 and 4-2). It is difficult to identify vegetation characteristics, other than moderate density shrub cover, from the photographs. other than the moderate cover depicting interior chaparral vegetation. We found no pre-1900 photographs or peer reviewed documentation that identified historic conditions for the interior chaparral vegetation type.

**Overstory –** *We found no studies that documented historic overstory conditions for the interior chaparral vegetation type.*

**Understory –** We found no studies that documented historic understory conditions for the interior chaparral vegetation type.

**Herbaceous Layer –** We found no studies that documented historic herbaceous layer conditions for the interior chaparral vegetation type.

*Patch or Stand Structure of Vegetation*

**Canopy Cover Class (%) or Canopy Closure** - We found no studies that documented historic canopy cover for the interior chaparral vegetation type.

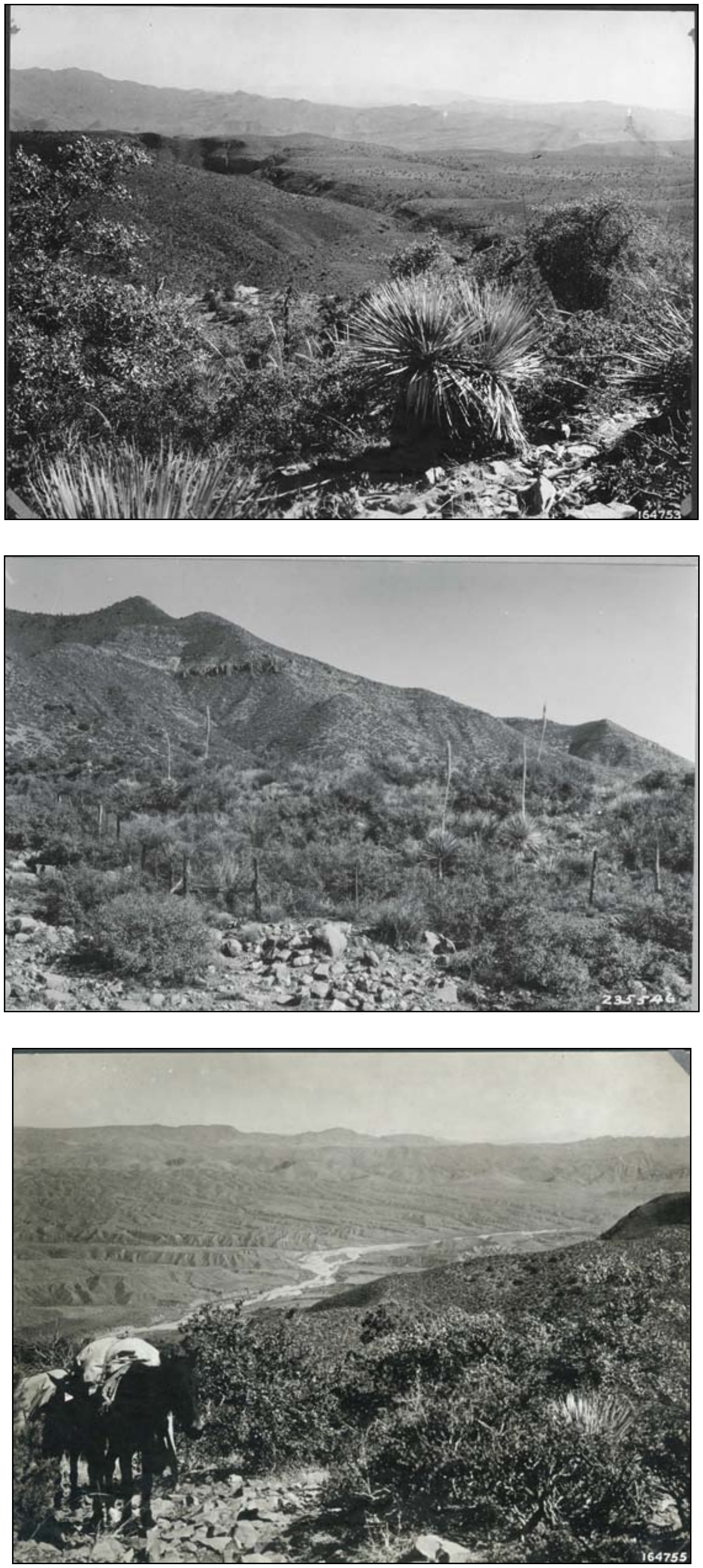


**Figure 4-1.** Photographs of interior chaparral taken in 1917 (top), 192? (middle), and 1957 (bottom) in the Sierra Ancha experimental range on the Tonto National Forest. Top photograph is looking at the Pinal Mountains from Mt. Baker, middle photograph is of an experimental plot, and the bottom photograph is overlooking Cherry Creek from near the summit of Sierra Ancha. Photographs courtesy of the USFS.

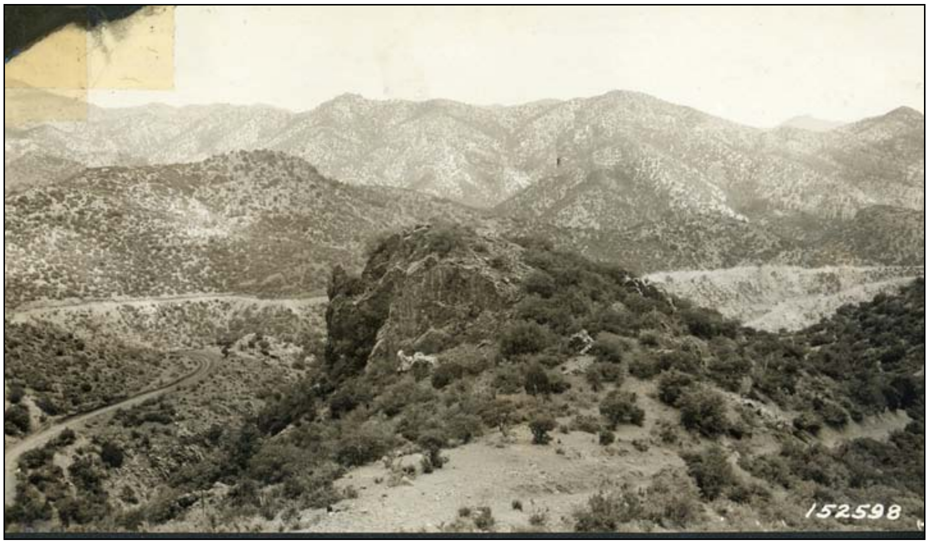



**Figure 4-2.** Photographs of interior chaparral taken in 1920 (top) and 1928 (bottom) on the Apache and Gila National Forests respectively. Top photograph is of the Clifton-Springerville road looking south while the bottom photograph is of the “Kneeling Nun at Santa Rita”. Photographs courtesy of the USFS.

**Structure Class (Size Class)** - We found no studies that documented the historic structure class of trees for the interior chaparral vegetation type.

**Life Form –** We found no studies that documented historic life forms for the interior chaparral vegetation type.

**Density** - We found no studies that documented historic tree density for the interior chaparral vegetation type.

**Age Structure** - We found no studies that documented historic tree age structure for the interior chaparral vegetation type.

**Patch Dispersion –** We found no studies that documented historic patch dispersion for the interior chaparral vegetation type.

*Reference Sites Used*

**Limitations –** There is currently little information regarding chaparral vegetation near the turn of the century or for sites free from human disturbance. This definitely presents a large limitation to the extent to which historic conditions can be described.

**Characteristics of Applicable Sites –** Ideally, reference sites for chaparral would exist and would have intact fire regimes, be free from mechanical, chemical, or prescribed fire treatments and would include photographic documentation. Given the dense character of chaparral and the steep terrain on which it is located, identifying reference sites free from human disturbance is possible, however, finding historic site condition information for such sites is much less likely.

*4.4 Anthropogenic Disturbance (or Disturbance Exclusion)*

*Herbivory* - Due to the steep slopes and high shrub cover (around 80 %) associated with chaparral shrubland, livestock grazing impacts have been restricted to those lower elevation sites that have both gentle slopes and relatively low shrub cover (Pase and Brown 1982). These livestock accessible sites were heavily grazed, between 1880 and 1920, and up until the 1940s they were the locations of a flourishing mohair goat industry (Pase and Brown 1982). For a more detailed discussion of the impacts of goat browsing, see Chaparral to grassland Conversion section.

*Chaparral to Grassland Conversion* - Around the 1950's there became a growing concern in Arizona that chaparral vegetation was taking water away from streams that could be used for agriculture and other human uses and that its' dense vegetation offered little forage value or access to wildlife or livestock (Pase and Granfelt 1977; Cable 1975).

> Chaparral in Arizona is used far below its potential. Conversions to grass can greatly increase water and grass production, and improve wildlife habitat. Management options include conversion to grass, maintaining shrubs in sprout stage, changing shrub composition, reseeding, and using goats to harvest shrub forage (Cable 1975).

These concerns resulted in 30 years of experimentation in the conversion of chaparral shrubland to a more open grassland shrub type that would use less water, be less of a fire hazard, and provide more forage for wildlife and livestock. These many experiments investigated the effectiveness of fire, herbicide, clipping, and seeding of non-native perennial grasses (Boers, Weeping, and Lehmanns lovegrasses) individually as well as in combination with each other, to eradicate chaparral vegetation. While the underlying assumption of many of these experiments, that chaparral needed to be changed in order to be beneficial to humans, is not the most ecological in nature, the results of many of these studies yielded important information regarding the ecology of this PNVT and its' dominant species.

From these studies, the most well documented characteristic of chaparral vegetation is its ability to quickly recover shrub cover to pre-disturbance levels. Multiple studies within Arizona showed that shrub cover on converted areas increased rapidly, pushing out grasses and forbs (Cable 1975; Lillie and others 1964; Pase and Ingebo 1965; Pond and Cable 1960). Studies by Pond and Cable (1960) and Lillie and others (1964) documented shrub cover to be back to pre-treatment levels within 7 years. Specifically, Pond and Cable (1960) showed that shrub live oak was very difficult to kill due to its ability to re-sprout, even 5 annual treatments of fire could not kill shrub live oak. In fact, burning, in general, increased the stem number of shrub live oak (Pond and Cable 1960). Lillie and others (1964) found that clipping of shrub live oak followed by fire lead to a slight increase in the number of stems produced, while clipping followed by chemical application of herbicide decreased stem weight, with spring time herbicide application yielding larger decreases in stem weight when compared to fall application.

Pond and Cable's work (1960) also investigated repeated fire effects on other chaparral species, they found skunkbush sumac to re-sprout erratically and suggested repeated burning appeared to be an unlikely means of eradicating this shrub species, Wrights silktassel and hollyleaf buckthorn were found to be easily killed by two years of repeat burning while desert ceanothus, manzanita, and larchleaf goldenweed were killed by just one fire, due to their inability to re-sprout (Pond and Cable 1960). Overall, Pond and Cable's work (1960) suggests that repeated burning will not get rid of the dominant shrub, shrub live oak, but can eliminate valuable forage species (Wrights silktassel and hollyleaf buckthorn) or species that do not re-sprout following disturbance. Similarly, Carmichael and others (1978) concluded that chaparral plants that reproduce through prolific production of seeds and require heat scarification to germinate (manzanita and desert ceanothus) may be lost from chaparral communities under both frequent and infrequent fire regimes. Frequent fire regimes that eliminate plants before they have a chance to produce seeds may result in the loss of seed reproducers over time, however, infrequent fire regimes may also result in loss of seed reproducers, as they are not as long lived as re-sprouting species and require fire to prepare the seed bed for reproduction (Carmichael and others 1978).

Given the tenacity of chaparral vegetation, and shrub live oak in particular, the use of repeated treatments, or a combination of treatments was experimented with in order to convert chaparral to grassland. For example, chaparral conversion on the Tonto National Forest utilized several approaches. On the Three Bar Experimental watershed, aerial application of granular karbutilate herbicide was followed by non-native seeding, while other studies used plant desiccating chemicals, followed by prescribe fire, then non-native seeding, followed by 3 years of annual herbicide application to try and keep shrub cover low and perennial grass cover high (Baldwin 1968; Pase and Ingebo 1965).

While these conversion attempts did not lead to long lasting “chaparral grasslands” in Arizona, they did result in studies of these temporary changes that generated valuable information regarding changes in water and sediment yield. Specifically, attempted conversions on the Tonto National Forest showed increased water yields ranging from 1 ½ area inches per year up to 6 area inches per year with increases in perennial flow of streams in treated watersheds (Baldwin 1969; Davis 1989; Hibbert and others 1974; Pase and Ingebo 1965). A detailed analysis of chaparral conversion on three hydrograph components for the Natural Drainages experimental watershed in central Arizona, showed increases in quick flow (30 %), peak flow (26 %), and delayed flow(32 %) (Alberhasky 1983). Additionally, in the Three Bar watershed, nitrate levels on treated watersheds fluctuated with rainfall events increasing from normal levels of 0.2 p/m to 24 p/m and 36 p/m, following storm events of 2.1 and 3.3 inches (Hibbert and others 1974). Davis (1989) found 10 times greater nitrate concentrations in streams associated with a 13 year old herbicide treated watersheds, however, prescribed fire did not cause further increases in nitrate nor did it increase sulfate, bicarbonate, or chloride anions nor calcium, magnesium, sodium, or potassium cations. The increase in nitrate was attributed to the decomposition and mineralization of a huge quantity of dead biomass followed by precipitation driven leaching (Davis 1989).

Multiple studies also showed that sediment loads also increased following shrub removal. Specifically, Pase and Ingebo (1965) found sediment transport to be 0.02 acre feet before a fire and between 5.9 and 13.74 acre feet following a fire in a conversion watershed, with sediment transport returning to pre-treatment levels within 4 years. Heede and others (1988) also found that large amounts of sediment are moved into stream channels within chaparral watersheds following fire, due to the complete denuding of vegetation within a steeply sloping environment. However, rapid recovery of vegetation created buffer strips was found to greatly reduce sediment loss from slopes. In particular, they found that following a 1959 fire erosion pavements had the highest sediment delivery (average of 1470 kg/ha/yr) to stream channels while buffer strips experienced low sediment delivery (average 5 kg/ha/yr) (Heede and others 1988). Sediment movement to the channels caused an aggradation event followed by degradation within the channels that continued through 1985. Ultimately, Heede and others (1988) suggested that to avoid severe erosion following fires that work should focus on establishing vegetation buffers along channel banks.

More recent studies have looked at the effects of fire on water repellency and nutrient cycling within chaparral. In regards to water repellency, Brock and DeBano (1988) found that water repellency in chaparral soils varies both horizontally and vertically within the soil profile and exists both before and after burning; however, fire greatly increases overall water repellency in the soil. Changes in repellency can result in increased soil erosion and can prevent the wetting of microsites which are necessary for seed germination (Brock and DeBano 1988). Prescribed fires were also found to have an effect on nutrient cycling within chaparral soils. Overby and Perry (1996) found that nitrogen and phosphorus concentrations increased following prescribed fires, with birchleaf mountain mahogany dominated sites having greater increases over shrub live oak dominated sites due to higher liter accumulation and higher nutrient concentrations within birchleaf mountain mahogany tissues. Specifically, exchangeable $NH_4^+$-N increased from 5.39 to 71.62 mg/kg on birchleaf mountain mahogany sites and from 5.23 to 36.10 mg/kg on shrub live oak sites; extractable P increased from 5.8 to 22.62 mg/kg on birchleaf mountain mahogany sites and from 5.46 to 14.58 mg/kg on shrub live oak sites. This release of nutrients increases soil fertility for seedlings, re-sprouting species, and soil micro-organisms.

In an effort to find a more "natural" solution to the use of chemicals to convert chaparral to grassland, multiple studies were conducted on the effectiveness of goats as shrub cover decreasers. While studies by Severson and DeBano (1991) and Knipe (1983) both found goats to be effective at decreasing shrub cover, they also noted some detrimental impacts of goat browsing. Specifically, Knipe (1983) noted that due to the penning of goats, overuse of browse in what he referred to as "sacrifice zones" was high and impacted forage most palatable to wildlife (mountain mahogany and Wright's silktassel). Similarly, Severson and DeBano (1991) showed that forage most heavily grazed by goats was also the most palatable deer forage and noted that this pattern of use could result in the loss of these species which would "reduced forage diversity and [cause] nutritional stress" to livestock and wildlife. Additionally, they noticed that litter levels were statistically decreased under desert ceanothus plants due to goat browsing and this, in combination with trampling of the nitrogen fixing plants by goats, decreased nutrients under the shrub canopy which they hypothesized could have long term impacts on nutrient cycling within chaparral (Severson and DeBano 1991).

*Fragmentation* – We found no studies that documented the effects of fragmentation on the interior chaparral vegetation type.

*Mining* - We found no studies that documented the effects of mining in the interior chaparral vegetation type.

*Fire Management* – Given the relatively less frequent and broad fire return interval (20 to 100) that chaparral shrublands are adapted to, the last 120 years of fire suppression has had less effect on chaparral than frequent fire regime adapted vegetation types. In general, structural changes, such as changes from a grass dominated structure to a shrub dominated one, have not occurred within chaparral. The only change that has been documented within this PNVT is an increase in shrub cover densities within already existing chaparral stands (Huebner and others 1999; Huebner and Vankat 2003). For a detailed discussion of their studies see section 4.5, **Overstory.**

*Exotic Introductions (Plant & Animal)* - We found no studies that documented the effects of exotic introductions on the interior chaparral vegetation type. However, there is documentation of the seeding of non-native perennial grasses, such as Lehmann and Boer's lovegrasses, in an effort to convert chaparral to grassland (Hibbert and others 1974). While seeding was effective in some areas, grasses only remained until shrub cover had returned to pre-disturbance levels, hence while non-native perennial grasses may be present, they do not dominate areas or effectively change chaparral vegetation (Hibbert and others 1974).

### *4.5 Effects of Anthropogenic Disturbance*

*Patch Composition of Vegetation*

**Overstory -** On a landscape scale, there has been little change in chaparral shrublands since 1880, even with the unsuccessful 1950's to 1980's era attempts to convert these shrublands to grasslands. Studies by Huebner and Vankat (2003) and Huebner and others (1999) in central Arizona have investigated vegetation change within the chaparral shrublands and its associated grasslands and found that little change has occurred within this vegetation type. Huebner and others (1999) study investigated changes within 3 chaparral classes (chap 75 = ≥ 75 % cover, chap 50 = ≥ 50 % and < 75% cover, and chap 25 = ≥ 25 % and < 50 % cover), chaparral associated grasslands (≥ 75 % cover) and 2 juniper woodland classes (jun 50 = ≥ 50 % and < 75% cover, and jun 25 = ≥ 25 % and < 50 % cover). The results for the chaparral and chaparral associated grasslands showed that 93% of dense chaparral (≥ 75 % cover) and 75 % of chaparral associated grasslands (≥ 75 % cover) were unchanged between the years 1940 and 1989 (Huebner and others 1999). They also noted a change in the density of chaparral with a decline in the least dense class, chap 25, and an increase in the densest chaparral, chap 75, with moderately dense, chap 50, showing no change (Huebner and others 1999). Additionally, in Huebner and Vankat's (2003) investigation of environmental and disturbance factors associated with vegetation change in chaparral, they show environmental factors to be the most important determinants in creating chaparral, chaparral associated grassland, juniper woodland, and juniper woodland grassland with disturbances such as fire and livestock grazing not playing a role in differentiating the chaparral types. Additionally, they note that the changes seen in chaparral associated grasslands are the result of non-chaparral trees (junipers, mesquite, and acacia) suggesting that chaparral is a stable vegetation type (Huebner and Vankat 2003).

On a species level, it is quite possible that changes have occurred within chaparral shrublands. A repeat photography study, by Pond (1971), of individual chaparral plants between 1920 and 1967 showed that longevity of individual chaparral species varied. Shrub live oak, skunkbush (*Rhus trilobata*), manzanita (*Archtostaphylos pungens*), and wait-a-bit bush (*Mimosa biuncifera*) all survived the 47 year study, through vegetative growth; however, sacahuista (*Nolina microcarpa*) and desert ceanothus (*Ceanothus greggii*) died sometime between 1935 and 1967 (Pond 1971). It is important to note that other sacahuista and desert ceanothus plants were found near the dead photographed plants and were presumed to be the offspring of original plants (Pond 1971). Given that all of the plants, except manzanita, that survived the 47 year study are sprouters following disturbance and the two plants that did not survive reproduced via seed, it seems likely that species composition and cover change little over time without disturbance. Cable (1975) documented a change in chaparral species composition from a pre-burn dense manzanita community, with minor amounts of shrub live oak and desert ceanothus, to a post-burn community consisting of narrow leaf yerbasanta, Pringle manzanita, desert ceanothus, deerbrush, true mountain mahogany, yellowleaf silktassel, emory oak, and shrub live oak seedlings. This suggests that while chaparral vegetation is relatively stable, disturbance events can change the species composition of an area.

The lack of structural changes in chaparral vegetation is likely due to three main factors: 1) Chaparral vegetation quickly regenerates shrub cover following disturbances (fire, clipping, and herbicide), hence conversion attempts have proven to be unsuccessful at eliminating these shrublands; 2) Chaparral is little effected by livestock grazing as the density of chaparral and steep slopes make the majority of this vegetation type unusable by livestock; 3) Due to its adaptation to a less frequent and broad fire return interval (20 to 100), 120 years of fire suppression has not greatly changed its historic fire regime.

**Understory –** We found no studies, in addition to those cited in the **Overstory** and **Density** sections, that documented changes within the interior chaparral understory.

**Herbaceous Layer** - We found no studies that documented changes within the interior chaparral herbaceous layer.

*Patch or Stand Structure of Vegetation*

**Canopy Cover Class (%) or Canopy Closure** - We found no studies, in addition to those cited in the **Overstory** section, that documented canopy cover changes within the interior chaparral vegetation type.

**Structure Class (Size Class)** - We found no studies that documented changes in tree size classes within the interior chaparral vegetation type.

**Life Form** - We found no studies, in addition to those cited in the **Overstory** section, that documented changes in life form within the interior chaparral vegetation type.

**Density –** We found no studies, in addition to those cited in the **Overstory** section, that documented changes in tree density within the interior chaparral vegetation type.

**Age Structure –** We found no studies, in addition to those cited in the **Overstory** section, that documented changes in age structure within the interior chaparral vegetation type.

**Patch Dispersion –** We found no studies, in addition to those cited in the **Overstory** section, that documented changes in patch dispersion within the interior chaparral vegetation type.

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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.

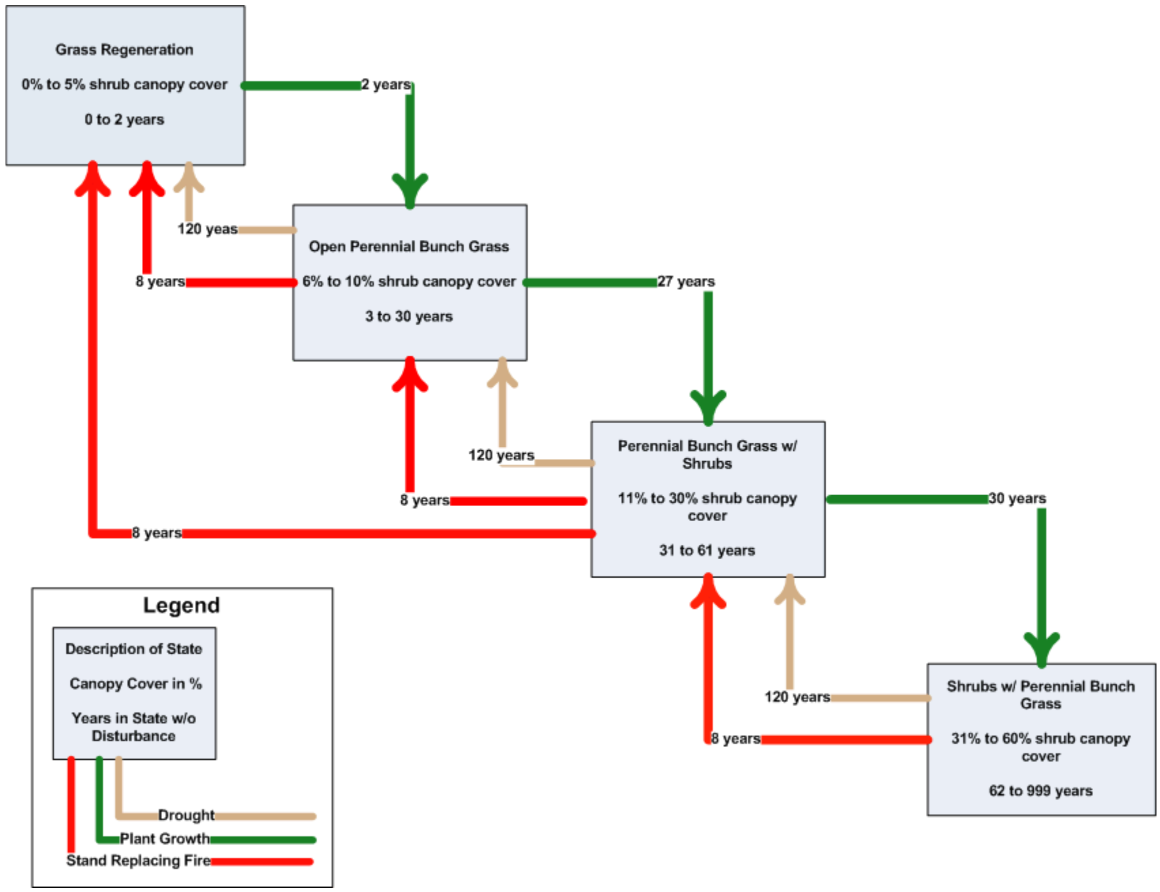



**Figure 13-3.** Simple grassland model used in sensitivity testing of VDDT software

**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 |

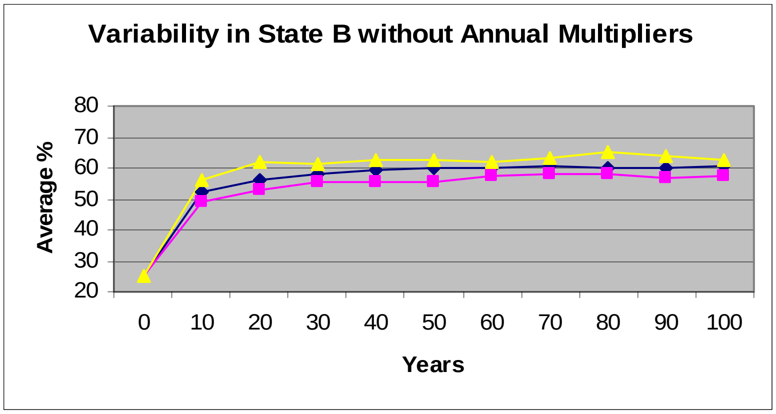
We ran the historic models for 1000 years, as this temporal span corresponds with the widest frame of reference offered by the scientific literature. Additionally, 1000 year long runs allowed for infrequent transitions, such as stand replacing fires in the spruce fir PNVT and extreme drought events in 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.



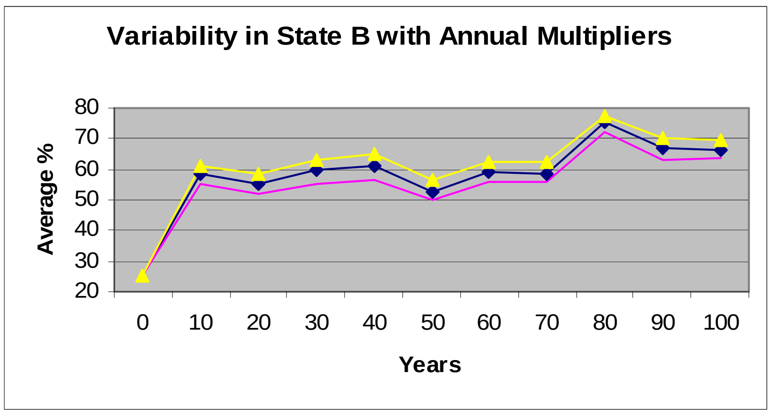




**Figure 13-4.** Comparison of year to year variability in state B of the simple grassland VDDT model with and without the use of annual multipliers. Maximum values in yellow, average values in blue, and minimum values in pink.

**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<br>% of years<br>(total count) | Regional Fire Yes<br>% of years<br>(total count) |
|---|---|---|
| **Severe Drought** | 74.8<br>(238) | 25.2<br>(80) |
| **Drought** | 81.4<br>(131) | 18.6<br>(30) |
| **Normal** | 89.2<br>(538) | 10.8<br>(65) |
| **Wet** | 96.6<br>(113) | 3.4<br>(4) |
| **Extremely Wet** | 99.7<br>(339) | 0.3<br>(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.

*13.3 Introductory References:*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# Chapter 15 - Interior Chaparral Model

## *15.1 Interior Chaparral Vegetation Dynamics*

Interior chaparral appears to be a fairly stable vegetation type due to the majority of its species having the ability to quickly re-sprouting following disturbance events, such as fire and mechanical or chemical removal (Cable 1975; Lillie and others 1964; Pase and Ingebo 1965; Pond and Cable 1960). Additionally, the few species that regenerate from seed require fire to prepare the seedbed (Carmichael and others 1978). Historically, this led to quick recovery of chaparral following the dominant natural disturbance, fire. In current times, these same mechanisms have allowed chaparral to maintain its dense canopy cover character regardless of human disturbance but have increased densities due to disturbance exclusion.

Graphical and photographic depictions of these vegetation dynamics are displayed in Figures 15-1, 15-2 and 15-3; results of the quantitative VDDT models are shown in Tables 15-1 and 15-2.

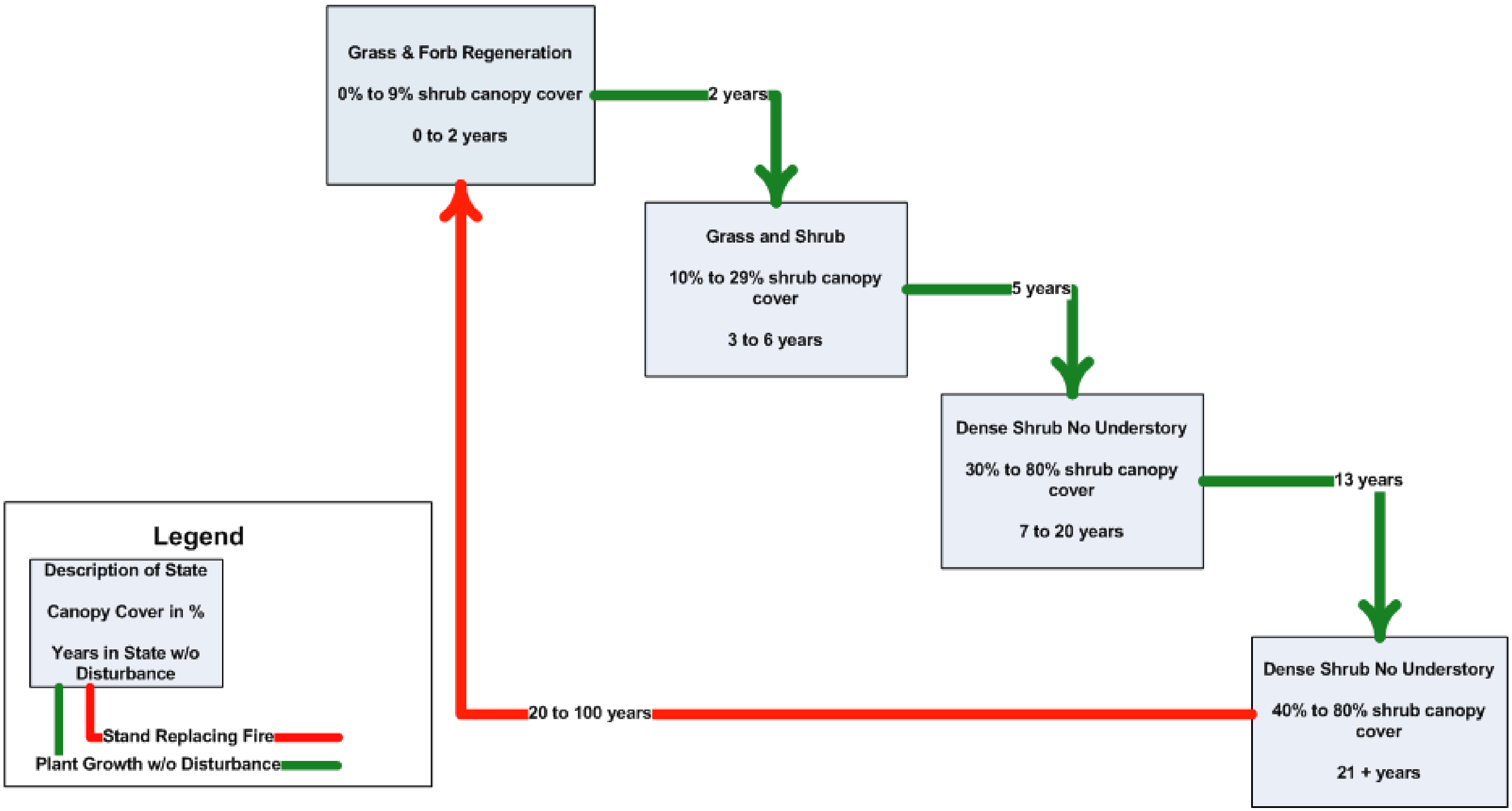


**Figure 15-1.** Conceptual historic state and transition model for the interior chaparral vegetation type. Frequency of transitions are noted when this information is supported by published sources, where no or conflicting information exists on the frequency of transitions, unknown is the notation.

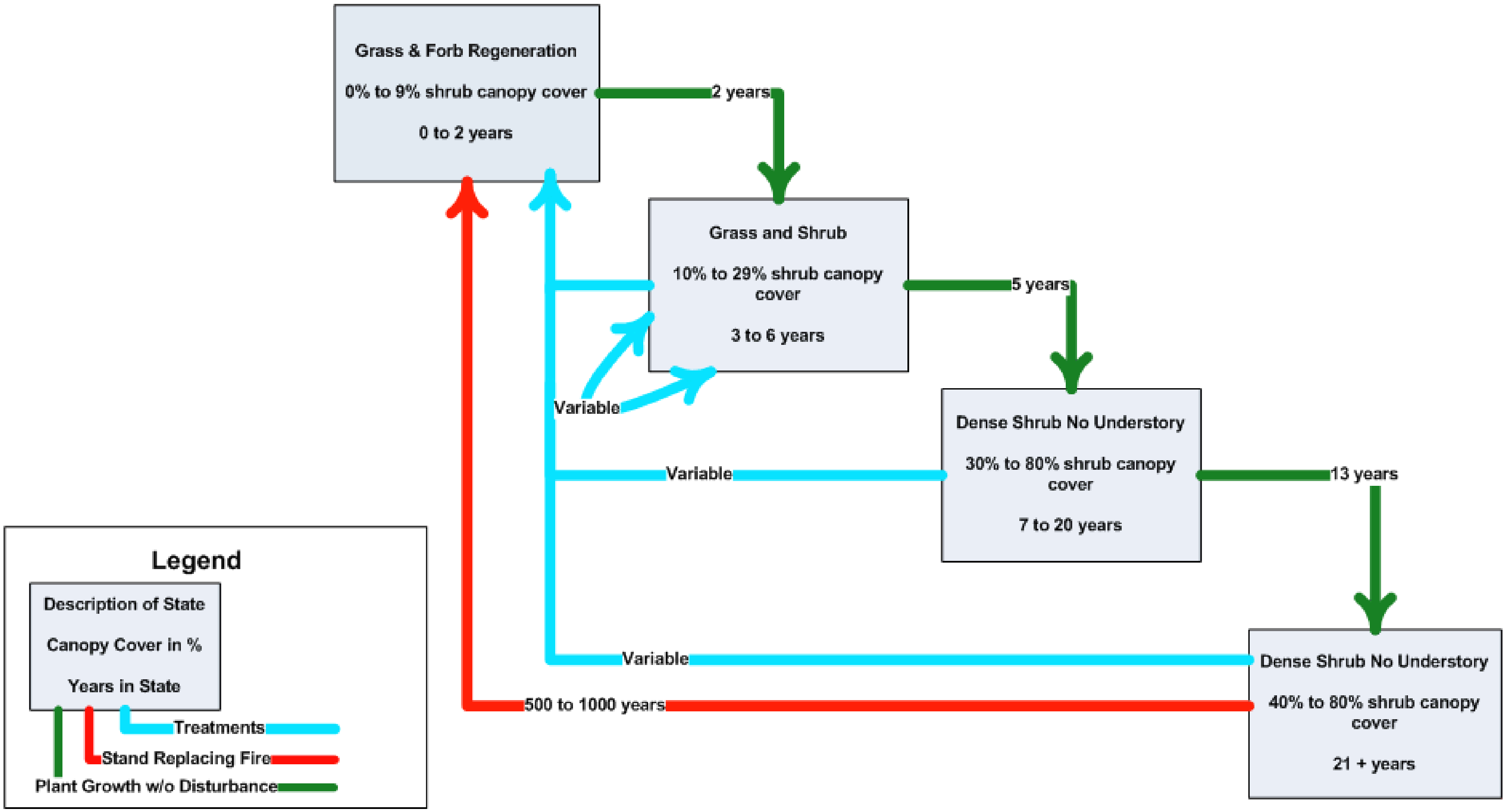


**Figure 15-2.** Conceptual current state and transition model for the interior chaparral vegetation type. Frequency of transitions are noted when this information is supported by published sources; where no or conflicting information exists on the frequency of transitions, unknown or variable, respectively, is the notation.

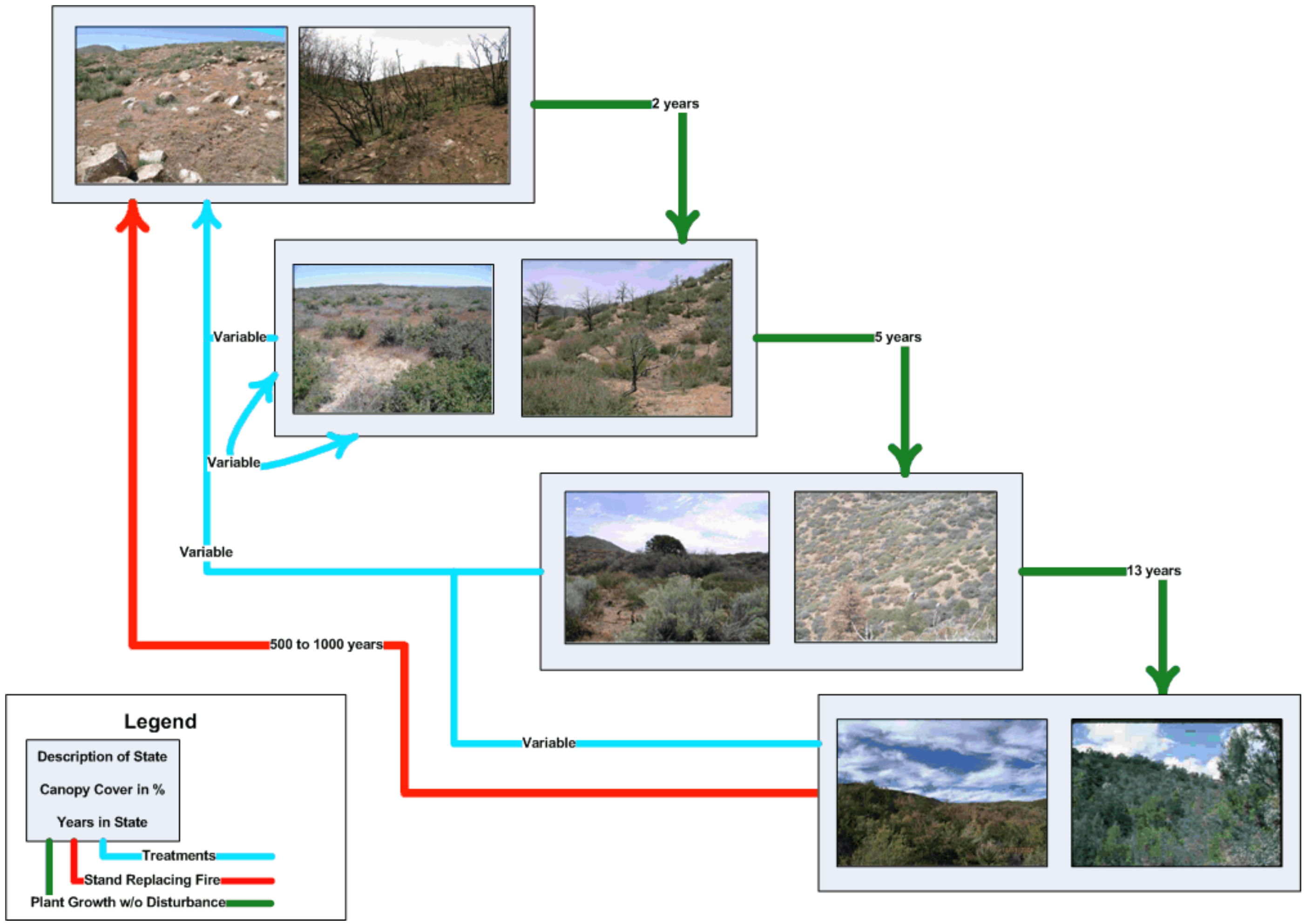


**Figure 15-3.** Photographic depiction of current conceptual state and transition model for the interior chaparral vegetation type. Frequency of transitions are noted when this information is supported by published sources; where no or conflicting information exists on the frequency of transitions, unknown or variable, respectively, is the notation. Bottom photographs courtesy of Jeff Saroka (USFS).

*15.2 Model Parameters*

Below in Tables 15-1 and 15-2, we identify the transitions, and probabilities associated with those transitions, used for both historic and current VDDT model runs.

**Table 15-1.** Identification of historic transition types, probabilities, and source of information used to inform the interior chaparral VDDT model.

| Transition Type | Transition Frequency or Length | Source | Assumptions |
|---|---|---|---|
| **Stand Replacing Fire** | Every 20 to 100 | Pase and Brown 1982; Sneed and others 2002; Wright and Bailey 1982 | Based on indirect (Pase and Brown 1982; and Wright and Bailey 1982) and direct (Sneede and others 2002) lines of evidence we compiled a fire return interval of between 20 and 100 years for the interior chaparral vegetation type. |
| **Plant Growth w/o Disturbance** | 2,5, and 13 years | Carmichael and others 1978, Cable 1975; Lillie and others 1964; Pase and Brown 1982; Pase and Ingebo 1965; Pond and Cable 1960 | We identified multiple sources (with similar results) that documented the time it took chaparral vegetation to reach the canopy cover classes of each state. Specifically, multiple studies showed that by 7 years chaparral has returned to pre-burn densities and/or densities high enough to eliminate the grass understory (Cable 1975; Carmichael and others 1978; Pond and Cable 1962). Additionally, it is suggested that chaparral quickly recovers to high cover levels (30 to 80%) but may not burn until roughly 20 years have passed (Cable 1975). Based on these studies we determined how long it would take to transition from one state to the next in the absence of a disturbance. We also used this information to determine the canopy cover ranges for each state. |

**Table 15-2.** Identification of current transition types, probabilities, and source of information used to inform the interior chaparral VDDT model.

| Transition Type | Transition Frequency or Length | Source | Assumptions |
|---|---|---|---|
| **Treatments (Mechanical, herbicide, and/or prescribed fire)** | Variable, not included in model | Baldwin 1968; Cable 1975; Lillie and others 1964; Pase and Ingebo 1965; Pond and Cable 1960 | We identified multiple studies, conducted primarily within the Tonto National Forest, that documented a wide range of mechanical, chemical, and fire treatments for interior chaparral vegetation. We concluded that the type of treatment was variable and occurred on a relatively small portion of interior chaparral within Arizona and New Mexico, hence we decided not to model this parameter in the regional current model. |
| **Non-native seeding** | Variable, not included in model | Cable 1975; Hibbert and others 1974 | We found documentation of the seeding of non-native perennial grasses (*Eragrostis lehmanniana* and E*ragrostis. curvula*) following conversion treatments. However, as with the treatment parameter, we determined that seeding was variable and occurred on a relatively small portion of interior chaparral in Arizona and New Mexico, hence we decided not to model this parameter in the current model. |
| **Stand Replacing Fire** | Every 0 to 500 years | Savage and Swetnam 1990; Swetnam and Betancourt 1998; Sneede and others 2002 | We based our estimate of fire on fire scar data. Specifically, regional fire scar data, along with data more localized to southeastern Arizona and the Prescott Basin, shows drastic declines in fires from 1900 to present (Savage and Swetnam 1990; Sneede and others 2002; Swetnam and Betancourt 1998). Given this information, we estimated a fire return interval of 0 to every 500 years. |

| Transition Type | Transition Frequency or Length | Source | Assumptions |
|---|---|---|---|
| **Plant Growth w/o Disturbance** | 2,5, and 13 years | Carmichael and others 1978, Cable 1975; Lillie and others 1964; Pase and Brown 1982; Pase and Ingebo 1965; Pond and Cable 1960 | We identified multiple sources (with similar results) that documented the time it took chaparral vegetation to reach the various canopy cover classes of each state. Specifically, multiple studies suggest that by 7 years chaparral has returned to pre-burn densities and/or densities high enough to eliminate the grass understory (Cable 1975; Carmichael and others 1978; Pond and Cable 1962). Additionally, it is suggested that chaparral quickly recover to high cover levels (30 to 80%) but may not burn until roughly 20 years have passed (Cable 1975). Based on these studies we determined how long it would take to transition from one state to the next in the absence of a disturbance. We also used this information to determine the canopy cover ranges for each state. |

*15.3 Results*

Results of the interior chaparral historic VDDT model show some variability in the 900 year average percent of the modeled landscape in each state based on the fire return interval range (Table 15-3). Even with this variability, all models showed a consistent pattern of the majority of the historic vegetation occurring in the Dense Shrub (greater than 21 years olds) state (83.6 %, 76.2 % and 50.5 % +/- 2.3 %, 3.2 %, and 5.2 % for fire return intervals of 100, 60, and 20 years respectively). A comparison of simulated historic conditions and current conditions shows an increase in the amount of Dense Shrub (21+ years) present under current management (Table 15-4). Specifically, increases of between 50% and 13% are seen for the 100, 60, and 20 year historic runs compared to the 0 to 500 year current runs.

**Table 15-3.** Results of the interior chaparral historic 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 (60 years), high (100 years), and low end (20 years), of the estimated fire return interval range.

| **Fire Return Interval Modeled** | **Model Output** | **Grass & Forb** | **Grass & Shrub** | **Dense Shrub (7 to 20 years)** | **Dense Shrub (21 + years)** |
|---|---|---|---|---|---|
| **Every 100 years** | Average | 1.6 | 3.3 | 11.5 | 83.6 |
| | Minimum | 0.0 | 0.4 | 5.6 | 76.6 |
| | Maximum | 4.7 | 8.0 | 18.5 | 90.1 |
| | Standard Deviation | 0.8 | 1.1 | 2.0 | 2.3 |
| **Every 60 years** | Average | 2.4 | 4.8 | 16.7 | 76.2 |
| | Minimum | 0.0 | 0.6 | 7.2 | 66.2 |
| | Maximum | 6.7 | 11.0 | 26.3 | 88.7 |
| | Standard Deviation | 1.2 | 1.7 | 2.8 | 3.2 |
| **Every 20 years** | Average | 4.9 | 9.9 | 34.7 | 50.5 |
| | Minimum | 0 | 0.3 | 18.2 | 34.4 |
| | Maximum | 12.8 | 19.6 | 50.1 | 72.2 |
| | Standard Deviation | 2.3 | 3.1 | 4.9 | 5.2 |

**Table 15-4.** Results of the interior chaparral current VDDT model, reported as the 120 year end value for average, minimum, maximum, and standard deviation of the percent of the modeled landscape in each state.

| **Fire Return Interval Modeled** | **Model Output** | **Grass & Forb** | **Grass & Shrub** | **Dense Shrub (7 to 20 years)** | **Dense Shrub (21 + years)** |
|---|---|---|---|---|---|
| **No Fire** | | | | | |
| | **Average** | 0 | 0 | 0 | 100 |
| | **Minimum** | 0 | 0 | 0 | 100 |
| | **Maximum** | 0 | 0 | 0 | 100 |
| | **Standard Deviation** | 0 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| **Every 1000 years** | | | | | |
| | **Average** | 0.2 | 0.4 | 1.4 | 98.0 |
| | **Minimum** | 0.0 | 0.2 | 1.0 | 97.0 |
| | **Maximum** | 0.5 | 0.9 | 2.1 | 98.5 |
| | **Standard Deviation** | 0.2 | 0.2 | 0.4 | 0.4 |
| **Every 500 years** | | | | | |
| | **Average** | 0.4 | 0.8 | 2.3 | 96.5 |
| | **Minimum** | 0.0 | 0.2 | 1.3 | 95.6 |
| | **Maximum** | 1.1 | 1.2 | 3.5 | 97.5 |
| | **Standard Deviation** | 0.3 | 0.3 | 0.7 | 0.7 |

### *15.4 Discussion*

These results suggest that the last 120 years of land management, mainly fire suppression, have had some effect on historic chaparral landscape conditions. Changes primarily within stand age and density are reasonable as we wouldn't expect 120 years of fire suppression to have large effects on vegetation structure within a PNVT with a historic fire return interval of 20 to 100 years. Additionally, this is in agreement with changes within chaparral vegetation documented by Huebner and others (1999). These results suggest that current interior chaparral vegetation has lost the mosaic of less dense and younger aged states. Maintenance of the 20 to 100 year fire return interval will be important for restoring and maintaining the historic range of conditions for this landscape in the future.

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