

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



**Southwest Forest Assessment Project  
2006**

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## Table of Contents

|  |       |
|--|-------|
| Acknowledgments.....   | i     |
| List of Tables .....   | iv    |
| List of Figures.....   | v     |
| Chapter 1 - Historical Range of Variation for Potential Natural Vegetation Types of the Southwest..... | 1-1   |
| 1.1 Introduction.....  | 1-1   |
| Definition of HRV .....  | 1-1   |
| HRV's Application in Land Management Decision-Making.....  | 1-2   |
| Influence of Temporal and Spatial Scale on Reported Values .....                                       | 1-3   |
| Urgency, Limitations, Assumptions, and Misuse of HRV .....   | 1-7   |
| Use of Reference Sites .....   | 1-7   |
| 1.2 Methods Used in Determining HRV.....   | 1-7   |
| Introduction.....  | 1-7   |
| Dendroecology .....  | 1-7   |
| Paleoecology.....  | 1-8   |
| Narrative Descriptions .....   | 1-8   |
| Historic Photographs.....  | 1-8   |
| Climate Analysis.....  | 1-11  |
| Expert Opinion.....  | 1-18  |
| Negative Data or Missing Information .....   | 1-18  |
| 1.3 Introductory References.....   | 1-19  |
| Chapter 10 - Alpine Tundra .....   | 10-1  |
| 10.1 General Description .....   | 10-1  |
| 10.2 Historical Range of Variation of Ecological Processes .....                                       | 10-5  |
| Vegetation Dynamics.....   | 10-5  |
| Disturbance Processes and Regimes.....   | 10-6  |
| 10.3 Historical Range of Variation of Vegetation Composition and Structure .....                       | 10-7  |
| Patch Composition of Vegetation .....  | 10-7  |
| Patch or Stand Structure of Vegetation.....  | 10-7  |
| Synthesis .....  | 10-8  |
| 10.4 Anthropogenic Disturbance (or Disturbance Exclusion).....   | 10-8  |
| Herbivory .....  | 10-8  |
| Silviculture.....  | 10-8  |
| Fragmentation .....  | 10-8  |
| Mining.....  | 10-9  |
| Fire Management .....  | 10-9  |
| Exotic Introductions (Plant & Animal).....   | 10-9  |
| Synthesis .....  | 10-9  |
| 10.5 Effects of Anthropogenic Disturbance.....   | 10-10 |
| Patch Composition of Vegetation .....  | 10-10 |
| Patch or Stand Structure of Vegetation.....  | 10-10 |
| Synthesis .....  | 10-11 |
| 10.6 Bibliography .....  | 10-13 |

## List of Tables

- 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..... 1-1
- 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..... 1-5
- 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..... 1-8
- Table 1-4. Percent of variation in the known cool season precipitation record explained (R<sup>2</sup> 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>)..... 1-12
- Table 1-5. Number of tree chronologies used in climate reconstructions for each PDSI grid point location for the Southwest..... 1-12

## List of Figures

|   |      |
|---|------|
| 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... | 1-14 |
| Figure 1-2. Comparison of the percent of years in all year types for all climate divisions in the Southwest.....  | 1-15 |
| Figure 1-3. Comparison of the percent of years in all year types for all PDSI grid locations in the Southwest. ....   | 1-15 |
| Figure 1-4. Comparison of the percent of events classified as drought, normal, and wet events for all climate divisions in the Southwest.....   | 1-16 |
| Figure 1-5. Comparison of the percent of events classified as drought, normal, and wet events for all PDSI grid locations in the Southwest. ....  | 1-16 |
| Figure 10-1. 1946—At timberline on the Blue Lake Trail [on the Carson National Forest, New Mexico. The trees are Englemann Spruce.....  | 10-2 |
| Figure 10-2. Habitat types for Alpine Tundra based on topographic position and snow deposition.....   | 10-3 |
| Figure 10-3. 1941—A Molybdenum mine near Red River [on the Carson National Forest, New Mexico]. About 75 men worked at this mine.....   | 10-9 |

# 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       | <b>7,700</b>      |
| Aspen Forest and Woodland                         | 335,900           | 500                       | 0                     | 3,400                 | 93,200     | 2,200       | 75,900     | 0                            | 11,600  | <b>522,700</b>    |
| Barren  | 0                 | 26,900                    | 13,000                | 100                   | 35,900     | 14,900      | 196,400    | 2,100                        | 300     | <b>289,600</b>    |
| Cottonwood Willow Riparian Forest                 | 19,500            | 74,800                    | 14,900                | 7,100                 | 219,500    | 55,600      | 389,000    | 28,500                       | 11,000  | <b>819,900</b>    |
| 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 | <b>26,494,600</b> |
| Disturbed/Altered                                 | 83,300            | 9,200                     | 600                   | 6,000                 | 218,200    | 37,200      | 47,800     | 5,600                        | 400     | <b>408,300</b>    |
| Gallery Coniferous Riparian Forest                | 100               | 0                         | 0                     | 0                     | 1,100      | 0           | 100        | 0                            | 0       | <b>1,300</b>      |
| 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  | <b>24,665,100</b> |
| Great Plains Grassland                            | 316,800           | 1,270,300                 | 29,000                | 10,000                | 16,055,000 | 3,158,400   | 181,000    | 14,100                       | 11,400  | <b>21,046,000</b> |
| Interior Chaparral                                | 1,345,900         | 414,600                   | 33,800                | 31,300                | 590,500    | 350,800     | 333,100    | 6,400                        | 11,000  | <b>3,117,400</b>  |
| Madrean Encinal Woodland                          | 2,736,200         | 518,800                   | 151,400               | 34,400                | 1,259,800  | 609,300     | 1,165,200  | 14,800                       | 2,200   | <b>6,492,100</b>  |
| Madrean Pine-Oak Woodland                         | 831,900           | 20,200                    | 1,700                 | 5,000                 | 89,200     | 30,100      | 438,400    | 100                          | 200     | <b>1,416,800</b>  |
| Mixed Broadleaf Deciduous Riparian Forest         | 42,600            | 36,200                    | 5,000                 | 4,200                 | 115,800    | 17,300      | 65,500     | 7,900                        | 4,300   | <b>298,800</b>    |
| Mixed Conifer Forest                              | 1,216,300         | 33,900                    | 2,700                 | 43,500                | 225,900    | 13,800      | 191,000    | 1,000                        | 52,000  | <b>1,780,100</b>  |
| Montane Grassland                                 | 17,200            | 0                         | 0                     | 0                     | 16,900     | 0           | 2,300      | 0                            | 0       | <b>36,400</b>     |
| Montane Willow                                    | 17,300            | 14,400                    | 800                   | 600                   | 42,800     | 11,500      | 12,100     | 100                          | 4,100   | <b>103,700</b>    |

| 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  | <b>18,493,100</b> |
| Ponderosa Pine Forest             | 5,835,300         | 112,500                   | 16,400                | 94,200                | 1,408,400 | 147,000     | 1,588,900 | 900                          | 44,100  | <b>9,247,700</b>  |
| Sagebrush Shrubland               | 134,500           | 685,200                   | 1,600                 | 66,300                | 642,100   | 184,700     | 977,200   | 21,200                       | 11,700  | <b>2,724,500</b>  |
| 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 | <b>26,586,700</b> |
| Spruce-fir Forest                 | 355,200           | 35,000                    | 1,000                 | 7,000                 | 128,200   | 2,300       | 72,000    | 300                          | 10,000  | <b>611,000</b>    |
| Sub-alpine Grasslands             | 311,700           | 13,900                    | 200                   | 2,500                 | 183,400   | 10,700      | 55,700    | 0                            | 27,000  | <b>605,100</b>    |
| Urban/Agriculture                 | 20,800            | 35,100                    | 49,200                | 2,300                 | 4,119,500 | 219,000     | 334,900   | 5,600                        | 23,900  | <b>4,810,300</b>  |
| Water                             | 25,300            | 25,000                    | 2,300                 | 79,100                | 122,000   | 900         | 38,100    | 15,600                       | 55,500  | <b>363,800</b>    |
| Wetland/Cienega                   | 8,900             | 9,500                     | 200                   | 400                   | 35,000    | 7,100       | 6,800     | 2,900                        | 1,100   | <b>71,900</b>     |

*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 PNV 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  |   |
| <i>'Historic increases in woody vegetation in Lincoln County, New Mexico'</i> 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<br>includes mostly photographs from the Ft. Valley Research Station archive, but also from the RMRS on-line photographs |
| Rocky Mountain Research Station  | Flagstaff, AZ               | Susan Olberding            | No   | interior chaparral (on-line resource only), ponderosa pine, riparian   | Photographs from several field season that investigated the effects of fire over several years  |
| Saguaro National Park  | Tucson, AZ                  | James Leckie               | No   | Madrean encinal, Madrean pine-oak  |   |
| 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   |   |
| <i>The changing mile revisited</i> 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<br>unpublished report<br>"Wood plenty, grass<br>good, water none"<br>by Harley Shaw | n/a | Harley<br>Shaw | Yes | pinyon-juniper, semi-<br>desert grasslands | Photographs taken<br>from Harley's<br>manuscript that will be<br>published in the near<br>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 PNVNT 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 PNVNTs 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 PNVNTs that we thought were good examples of various model states within a PNVNT (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 Kipfmüller 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 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 (R<sup>2</sup> 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 (R<sup>2</sup> 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 |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <b>R<sup>2</sup><br/>(%)</b> | 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 |
|-----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| <b># of Tree<br/>Chronologies</b> | 8-9 | 5-9 | 8-9 | 5-9 | 9   | 6-9 | 8-9 | 5-9 |

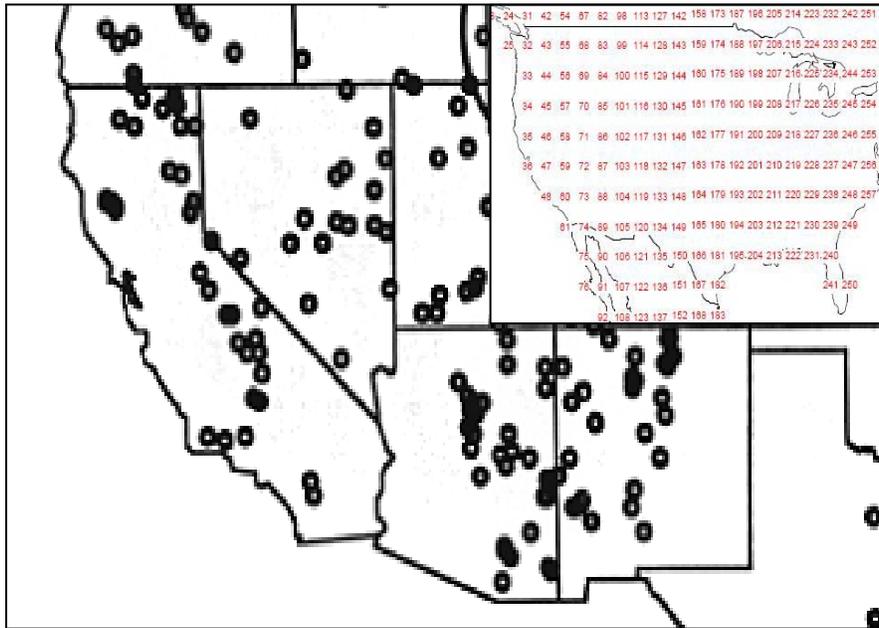
**Methods-** For a detailed discussion of the methodology used to identify 1) year to year variability, 2) range, frequency, and length of extreme and non-extreme events, and 3) spatial and temporal comparison, see Schussman 2006 (Assessing Low, Moderate, and High Severity Dry and Wet Events Across the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

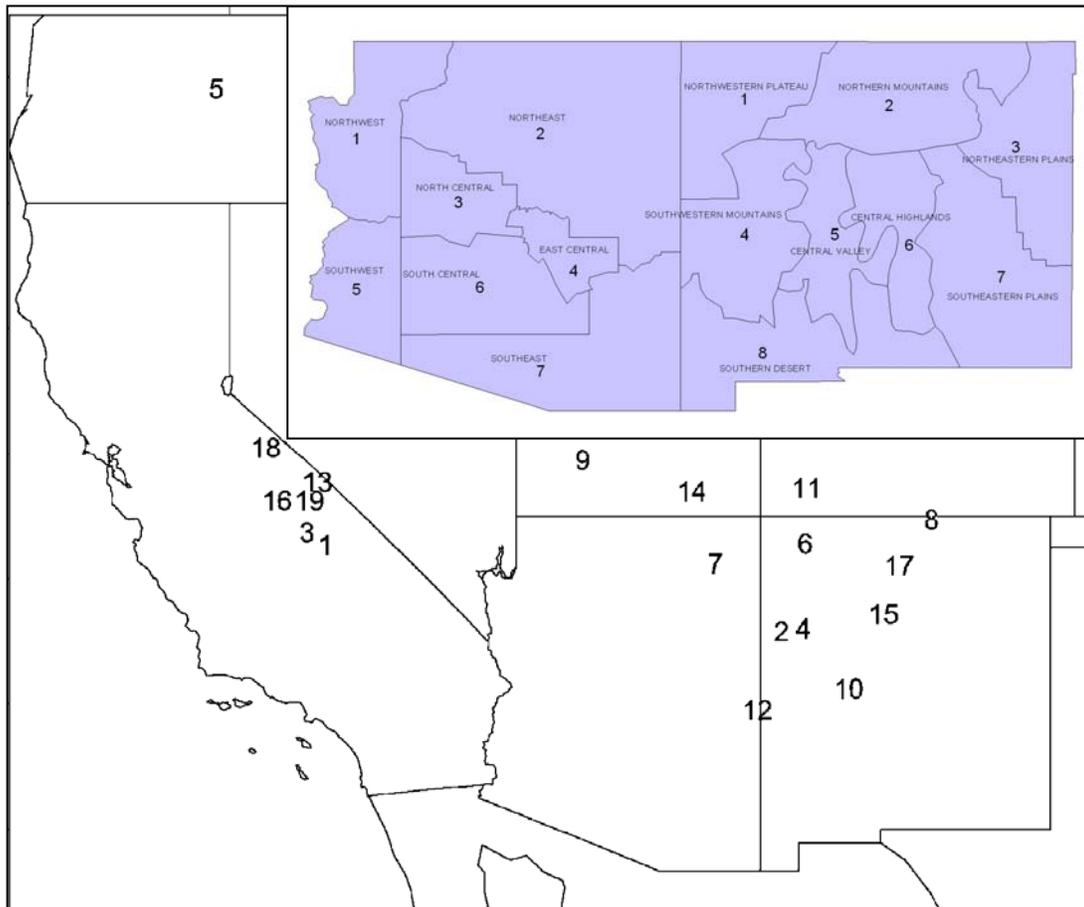
classified as severe and extreme drought, 27 % classified as moderate and mild drought, 38% classified as near normal and incipient wet and dry spells, 20% classified as slightly or moderately wet, and 5% classified as very and extremely wet years (

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 or 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).

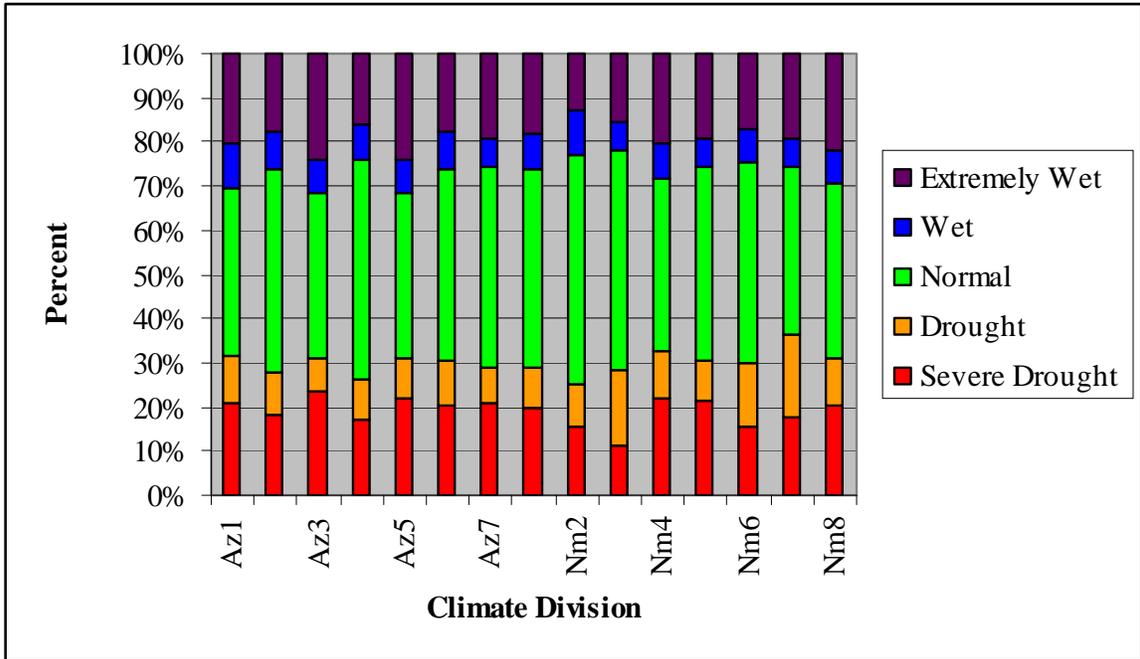


1a.

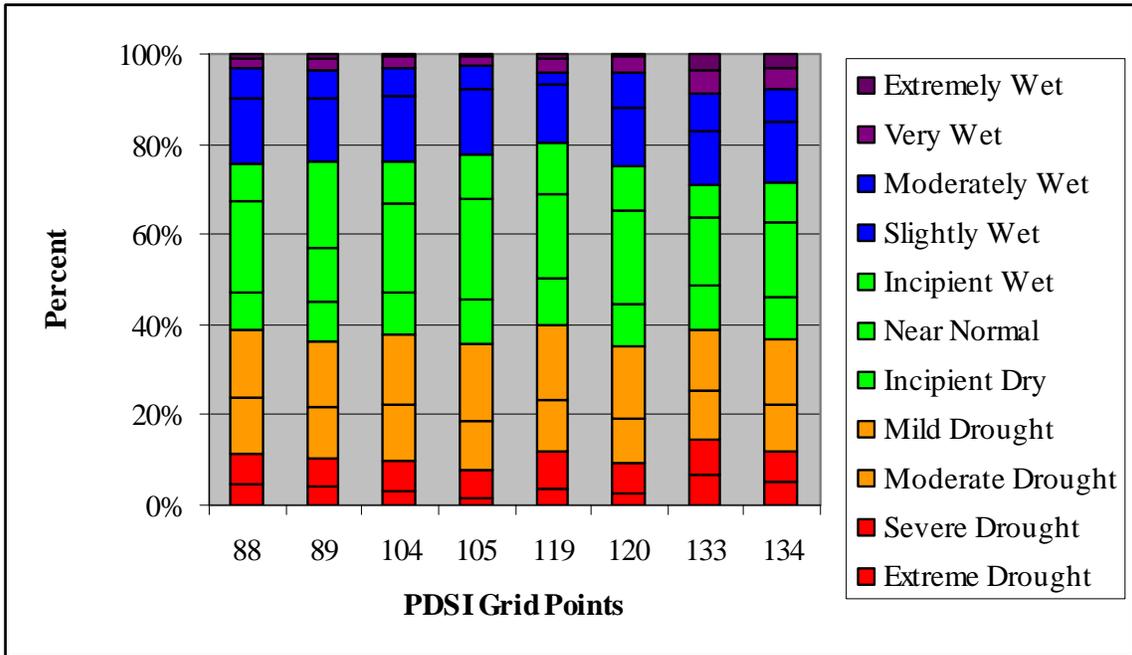


1b.

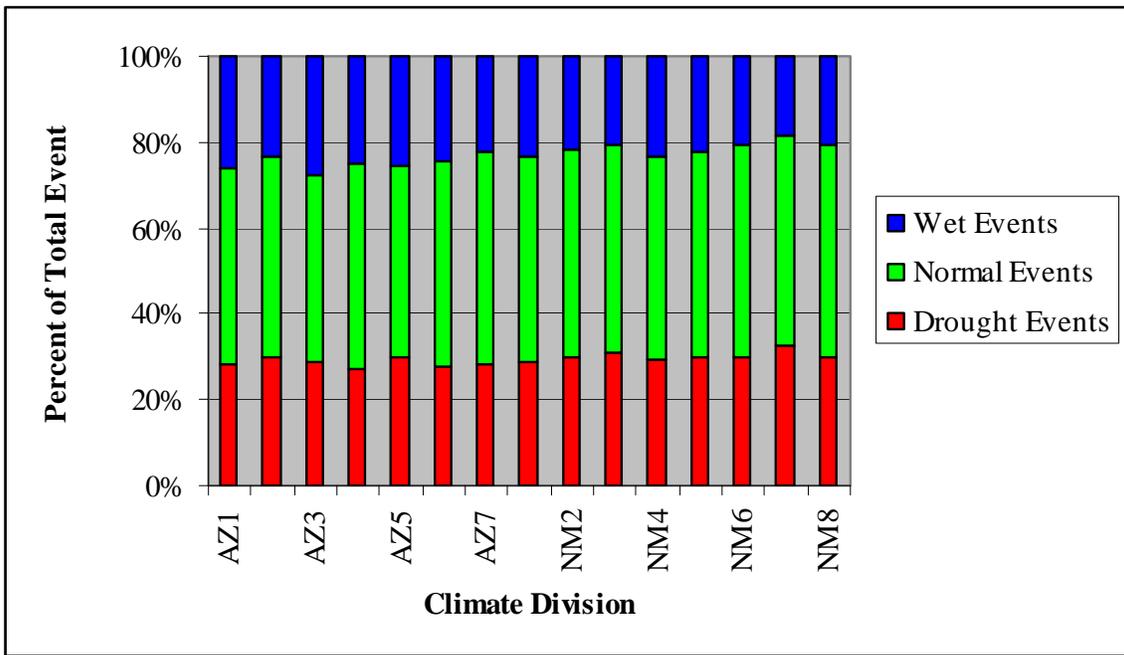
**Figure 1-1.** Identification of tree chronology locations for both the PDSI (1a taken from Cook and others 1999) and winter precipitation (1b taken from Ni and others 2002) data sets, as well as PDSI grid point locations and climate division boundaries.



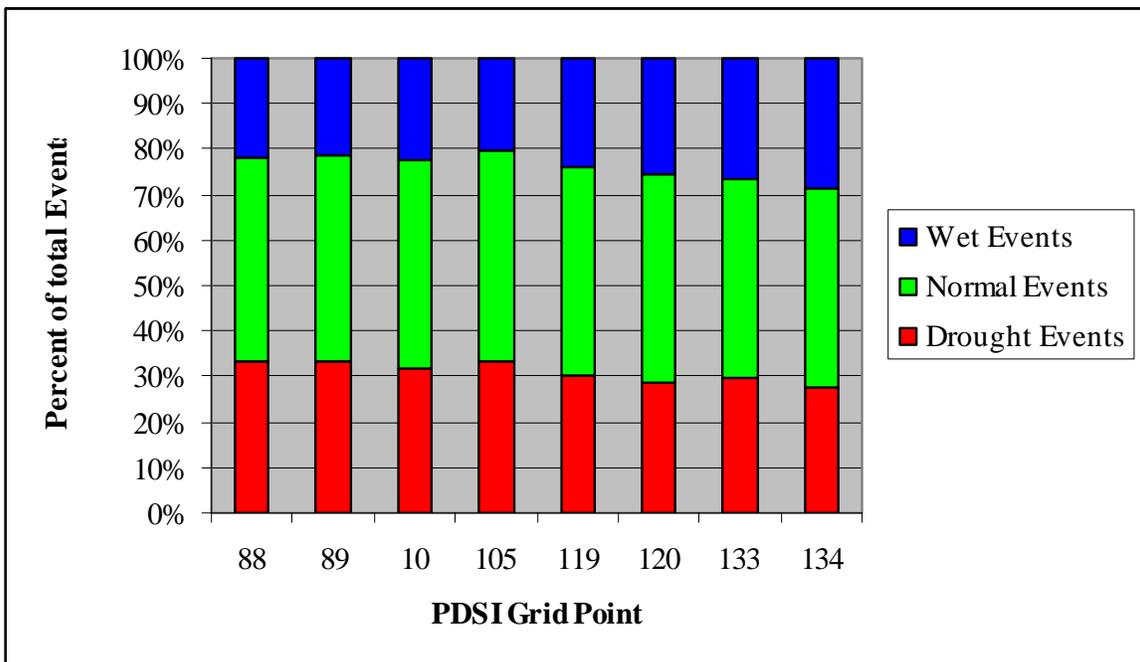
**Figure 1-2.** Comparison of the percent of years in all year types for all climate divisions in the Southwest.



**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 1160, 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<sup>th</sup> 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 PNVTS 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; IPCC 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 10 - Alpine Tundra

*10.1 General Description* – Tundra refers to a cold climate landscape or vegetation type that is above tree-line and is dominated by herbaceous or shrubby vegetation. The word tundra derives etymologically either from the Russian tundra, which means “land of no trees,” or from the Finnish tunturi which means “arctic or barren hill” (Zwinger and Willard 1972) or “treeless plain” (Smith 1990). It is generally recognized that four distinct types of tundra exist on Earth, including Arctic Tundra, Alpine Tundra, Sub-arctic or Sub-alpine Tundra, and Maritime and Sub-antarctic Tundra (Rosswall and Heal 1974). In the Southwest, only Alpine Tundra is represented by several occurrences in the San Juan, Sangre de Cristo and Sacramento Mountains of New Mexico, and in the White Mountains and San Francisco Mountains of Arizona (Figure 10-1). Alpine tundra has the second lowest representation of all Potential Natural Vegetation Types by land area for the two-state region, comprising only about 7,700 acres, with about 1,600 acres falling under USFS management and the remaining 6,100 acres in private land ownership (USGS 2004). However, alpine tundra occurs in very small patches, and not every patch was detectable in the SWReGAP analysis (e.g., acreage is not listed for known areas in the Carson, Cibola, and Lincoln National Forests). Thus, the total land area of alpine tundra may be underestimated.

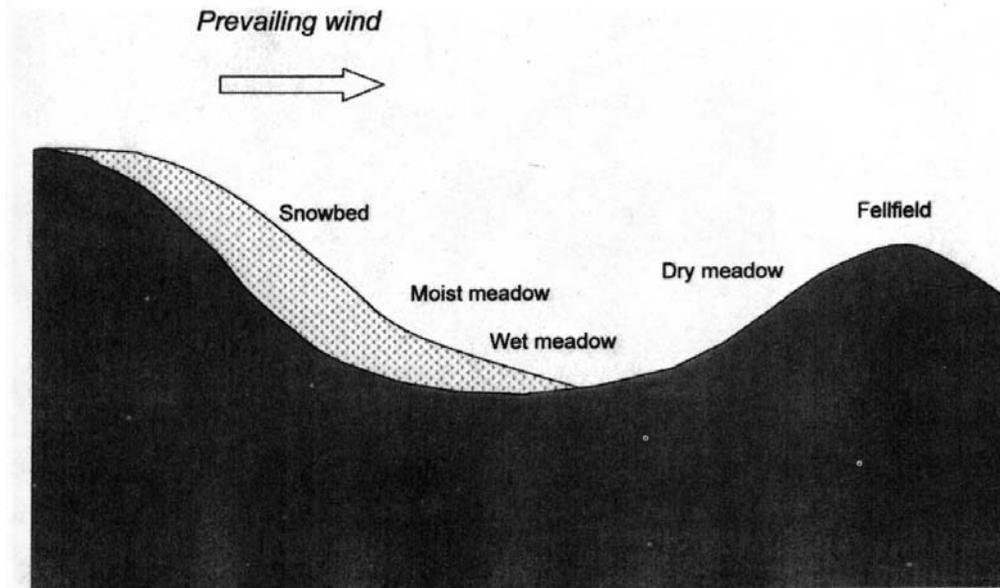
Alpine tundra occurs in the Southwest at elevations over 11,500 feet, and because of its relative inaccessibility and limited distribution, very few scientific studies have been published on its classification, structure, composition, and function (Moir 1993). A National Science Foundation funded Long-Term Ecological Research (LTER) site exists at Niwot Ridge, Colorado that encompasses alpine tundra vegetation (NW of Boulder in the Roosevelt National Forest, see <http://culter.colorado.edu/NWT/index.html>). Most of the research cited in this HRV description comes from published scientific work that was conducted at the Niwot Ridge site, unless noted from Arizona or New Mexico.



**Figure 10-1. 1946—At timberline on the Blue Lake Trail [on the Carson National Forest, New Mexico. The trees are Englemann Spruce. Photo by R. King, FS #440702. <http://www.fs.fed.us/r3/about/history/carson/pages/car024.jpg.htm>**

Alpine tundra in the Southwest has not been adequately studied or described from an autecological standpoint. Consequently, all alpine tundras in Arizona and New Mexico have been lumped into one single series, the *Acomastylus rossii* (formerly *Geum rossii*) series (Moir 1983), although Baker (1983) delineated ten community types on Wheeler Peak in New Mexico. At Niwot Ridge LTER, several systems have been proposed for delineating plant alliances, noda, or habitat types (Komarkova 1980, May and Webber 1982, Walker and others 2001).

Figure 10-2 depicts the currently accepted delineation of habitat types in alpine tundra based on snow distribution and topographic features (Walker and others 2001, after Billings 1973), for alpine tundra present in Colorado.



**Figure 10-2.** Habitat types for Alpine Tundra based on topographic position and snow deposition. (Figure from Walker and others 2001, after Billings 1973).

**Fellfields** occur on windblown slopes and ridge crests, have 10-50% of the ground surface covered with cobbles and exposed gravels, and have an open canopy and high diversity of cushion plants. Crustose lichens are very diverse in these sites, but bryophytes are uncommon. Fellfields remain snow-free throughout the year, although they may be covered with a thin crust of snow in depressions. **Dry Meadows** are dominated by bog sedge (*Kobresia*) and sedge (*Carex*) turfs. These areas typically have thin snow cover in winter that melts early in the season, providing for a relatively long growing season (150 to 200 days). **Moist Meadows** receive a modest snow cover that melts later in the spring, providing a shorter growing season of 100-150 days. These are in relatively rich and productive sites dominated by a lush cover of forbs and grasses, predominantly Ross' avens (*Acomastylis rossii*) and tufted hairgrass (*Deschampsia caespitosa*). **Late-melting Snowbank or Snowbed** communities as the name implies, experience harsh conditions due to the longer persistence of deeper snow, and have a growing season <100 days. These areas may be dominated by various willow species (*Salix spp.*) and sibbaldia (*Sibbaldia procumbens*) and sedges (*Carex spp.*). Due to the longer duration of snowmelt, these sites often have saturated soils and plants that are adapted to standing water. **Wet Meadows** are often downslope of snowbeds, and have plants adapted to subhygric conditions, such as sedges, bistort (*Polygonum bistortoides*), ledge stonecrop (*Rhodiola integrifolia*), and white marsh marigold (*Caltha leptosepala*). **Shrub Tundra** areas are dominated by willow species, but also have bistort and stonecrop present, and line the edges of ponds and streams in lower alpine tundra areas.

Other habitat delineations have been described for all (Moir 1993) or part (Baker 1983) of New Mexico's alpine tundra vegetation. Moir (1993) described nine different New Mexican communities that suggest strong floristic and structural affinities with alpine tundra in Colorado. His delineation included a **Krummholz** community that is found at the lower elevation alpine tundra edge, and is dominated by Engelmann spruce

(*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) of low stature (<3 feet). There is a strong shrub component in these low thickets. Moir also describes a **Fellfield** or **Rock Field** community that is similar in composition to Colorado fellfield described above. The **Kobresia Turf** is similar to the Colorado dry meadow, but in New Mexico kobresia shares dominance with Ross' avens, which is included in Colorado's wet meadows.

Moir (1993) asserts that the most common type of alpine tundra in New Mexico is what Baker (1983) described as the *Carex rupestris*/**Cushion** type. This type falls intermediate to the fellfield and kobresia communities, with many cushion plants dominating, but kobresia is minor or absent and Drummond's sedge (*Carex rupestris* var. *drummondiana*) is common and forms a sod. The wettest and most limited alpine tundras in New Mexico are the **Snowbank** and **Rivulet** communities, which border either melting snowbanks or small rivulets formed downslope of melting snowbanks and are both dominated by different shrub communities. Snowbanks are dominated by dwarf willows (*S. arctica* and *S. reticulata*) in low mats along with several species of lichens and herbaceous plants, while rivulet communities are dominated by showy forbs such as groundsels (*Senecio* spp.), ledge stonecrop, rose crown (*Clementsia rhodantha*), and Parry's primrose (*Primula parryi*). These two wet communities resemble Colorado's wet meadow and shrub alpine tundras. Moir (1993) and Baker (1983) describe two other wet alpine communities that are either dominated by Drummond's rush (*Juncus drummondii*), found near melting snowbanks, or tufted hairgrass, or found on sites that have late-melting snowbanks with high insulation.

The last community type described by Moir (1993) is the **Rock Outcrop** or **Rubbleland** found at high elevation, which supports specialized plant communities such as talus or scree slope dependent plant species like the San Francisco Peaks groundsel (*Senecio franciscanus*), a federally listed Threatened species. Other species found in this habitat include (*Senecio atratus*), (*Ligularia soldanella*), (*Saxifraga chrysantha*), and (*S. flagellaris*). However, the most abundant vegetation in this habitat type is crustose and foliose lichens, whose abundance reflects whether the rock substrate is geomorphically active or inactive, with less lichen coverage correlated with more disturbance or snow coverage (Moir 1993).

The alpine tundra vegetation in Arizona is not as well studied as that in New Mexico. Zwinger and Willard (1972) assert that the alpine tundra on the San Francisco Peaks and the White Mountains of eastern Arizona is more closely related to that of the Great Basin, while New Mexico's alpine tundra is included with that of the southern Rocky Mountains. However, Moore's report (1965) indicates that, based on floristic analysis, alpine tundra community on the San Francisco Peaks is "definitely related to the alpine flora of the main Rocky Mountain peaks." However, Moore (1965) also indicated that the plant community of the San Francisco Peaks is "extremely poorly developed and floristically impoverished" in comparison with northern locations of alpine tundra in the more northern Rocky Mountains, indicating that it was isolated about 10,000 years ago. This finding led him to hypothesize that adverse conditions of drying and warming are diminishing the character of alpine tundra on the San Francisco Peaks, leading to retrogression of community diversity to a simpler flora (Moore 1965).

## *10.2 Historical Range of Variation of Ecological Processes*

*Vegetation Dynamics* – Very little is known about the current condition and ecological processes, let alone the historic condition and processes of alpine tundra (Baker 1983, Moir 1993, Bowman and Seastedt 2001). Here we present a brief review of some of the physical and biological factors that are known to influence the patterns of alpine tundra vegetation.

Because of the location of alpine tundra in exposed, cold, and windy sites, physical factors such as topography, wind, snow drifts, and snow melt runoff are the major determinants of species and community distribution. Growing season length is determined by the amount of snow on a site, and snow depth is determined by aspect, slope, wind speed and direction. Snow cover can provide protection from extremely cold temperatures, frost damage, dehydration, and physical damage from snow and wind-blown particles, and snow cover of soil reduces intensive and deep soil freezing and subsequent frost heaving and soil weathering. Conversely, snow cover can reduce growing season length through soil cooling (Walker and others 2001). Wind is a major determinant of cushion-plant and tussock graminoid dominance in fellfields and exposed tundra turfs. These compact life forms reduce wind effects in winter and drought stress in summer, whereas plants that are protected by snow drifts in winter tend to have erect growth forms, soft leaves, and are not as drought tolerant (Walker and others 2001). The temperature of an alpine tundra community is determined by microtopography and slope position, and exhibits wide variation (Walker and others 2001). Soil moisture is a strong determinant of alpine tundra community type, and is dependent upon spatial and temporal patterns of precipitation and snow melt. Soil moisture also influences soil nutrient availability to plants (Walker and others 2001).

Biotic factors that affect alpine tundra plant communities include interspecific competition, facilitation, complex herbivore-plant interactions, and soil micro-flora and fauna. Interspecific competition has been documented for a few alpine tundra species, indicating that competition is important in structuring this vegetation type. Facilitation, or positive interactions among plants has been less studied, although in environments where physical stress levels are high, such as alpine tundra, it has been hypothesized that facilitation may be more important than competition through mechanisms of nurse plants that provide seed protection, seedling protection, and the decreased formation of needle ice detrimental to seedlings (Bertness and Calloway 1994, Walker and others 2001). Several herbivore species have been studied in alpine tundra, but little research has been focused on direct effects of herbivory on alpine tundra plant species or community composition. Below-ground herbivory by gophers has an indirect effect on vegetation through increased nutrient availability (especially nitrogen), and its direct effects on community composition through preferential grazing and disturbance: gophers prefer to graze on forbs over grasses, thus increasing the abundance of graminoids (Dearing 2001).

## *Disturbance Processes and Regimes*

***Climate***- See *Introduction* for climate information.

***Fire***- We found no studies that documented fire as an important historical ecological determinant for the alpine tundra vegetation type.

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

***Herbivory***- Marmots, pikas, voles, and gophers are the primary herbivores that have had an impact on alpine tundra vegetation. Bighorn sheep once lived on the upper slopes of the San Francisco Peaks in Arizona and Wheeler Peak in New Mexico until about 1900, and bighorn sheep were successfully reintroduced to Wheeler Peak in 1993. Little is known about historic impacts of these herbivores, although current research at the Niwot Ridge site in Colorado has documented herbivory effects on vegetation. Marmots consume 2.6 to 6.4% of the available primary production in their foraging areas, with the majority of early forage consisting of grasses in the early part of the season, gradually being replaced by forbs and then seeds later in the season (Dearing 2001). Marmot burrows and adjoining areas are typically devoid of vegetation due to foraging and burrowing activities (Dearing 2001).

Pikas tend to forage out and away from their central rock and talus refuges, maintaining cushion plant communities (fellfield) in close proximity. They preferentially graze on forbs in adjacent moist and dry meadows (especially *A. rossii*) giving selective advantage to graminoids (Dearing 2001). Pathways created by these herbivores also alter the landscape through soil compaction and vegetation removal. Burrowing activities can cover and kill plants (Huntly and Inouye 1988), and accelerate decomposition; this type of chronic disturbance lowers carbon storage in the upper soil horizon, reducing long-term soil fertility (Cortinas and Seastedt 1996, Dearing 2001). However, small herbivores also concentrate soil nutrients and aid nutrient transport and mineralization through plant consumption and subsequent deposition of about 50% of consumed biomass in urine and feces, but typically in localized areas near burrows (Dearing 2001). With most herbivory pressure exerted by small mammals on forbs, graminoids should be more dominant on the alpine tundra landscape. However, forbs may competitively exclude graminoids through faster growth rates, or other herbivores that preferentially consume graminoids (such as grasshoppers and elk) may counteract the effects that have been quantified for gophers, pika and marmots, through complex interactions that have yet to be quantified (Dearing 2001).

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

***Insects and Pathogens*** – We found no studies that documented insects and pathogens as important historical ecological determinants for the alpine tundra vegetation type.

***Nutrient Cycling*** - We found no studies that documented nutrient cycling as an important historical ecological determinant for the alpine tundra vegetation type.

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

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

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

***Synthesis*** – There have been very few studies on the HRV of alpine tundra ecological patterns and processes, although some work has been conducted in Colorado. The factors that influence the spatial distribution of different alpine tundra types have been well defined for the southern and central Rocky Mountains. Some of the mechanisms of native herbivore influence on alpine tundra have been studied, but most ecological processes have not yet been studied.

### *10.3 Historical Range of Variation of Vegetation Composition and Structure*

***Patch Composition of Vegetation*** - We found no studies that documented historical patch composition of the alpine tundra vegetation type.

***Overstory*** – Not applicable.

***Understory*** - We found no studies that documented the historical understory composition of the alpine tundra vegetation type.

***Herbaceous Layer***- We found no studies that documented the historical herbaceous layer composition of the alpine tundra vegetation type.

***Patch or Stand Structure of Vegetation*** – We found no studies that documented the historical stand structure of the alpine tundra vegetation type.

***Canopy Cover Class (%) or Canopy Closure*** – Not applicable.

***Structure Class (Size Class)*** - We found no studies that documented the historical structure class of the alpine tundra vegetation type.

***Life Form*** - We found no studies that documented the historical life form of the alpine tundra vegetation type.

*Density* - We found no studies that documented the historical density of the alpine tundra vegetation type.

*Age Structure* - We found no studies that documented the historical age structure of the alpine tundra vegetation type.

*Patch Dispersion* – We found no studies that documented the historical patch dispersion of the alpine tundra vegetation type.

*Recruitment Dynamics* - We found no studies that documented the historical recruitment dynamics of the alpine tundra vegetation type.

*Reference Sites Used* – All current alpine tundra sites are potential reference sites, however, since there are no historical data from the pre-settlement period, no reference sites were identified.

*Synthesis* – Because alpine tundra is primarily herbaceous vegetation consisting of forbs and graminoids, there remains little evidence of historical vegetation patterns. Due to the limited distribution of alpine tundra at high elevation and in inaccessible areas, there are few historic photographs documenting the appearance of historic vegetation.

#### *10.4 Anthropogenic Disturbance (or Disturbance Exclusion)*

*Herbivory* – Domestic sheep and cattle have grazed many areas of alpine tundra in the Rocky Mountains since Euro-American settlement, although cattle are susceptible to a high-altitude induced disease affecting survivorship that has precluded widespread grazing (Bowman and others 2002). Sheep have caused trampling, trail-cutting, and erosion when the animals were allowed to congregate (Bowman and others 2002). The extirpation of grizzly bears in the southern Rocky Mountains may have contributed to decreased vegetation and surface disturbance through elimination of bears' excavation of roots and tubers in alpine meadows, reducing creation of early successional states in small patches (Bowman and others 2002). Also, Rocky Mountain elk may have increased in abundance due to lower predation pressures, and higher elk populations have had detrimental effects on willow communities in Rocky Mountain Park, CO (Bowman and others 2002).

*Silviculture* – Not Applicable.

*Fragmentation* – Recreation impacts have been noted but not quantified for alpine tundra. Backpacking, alpine skiing, climbing, and sightseeing are all activities that occur in alpine tundra ecosystems, and have the potential to fragment the alpine landscape primarily from trampling of vegetation and erosion (Bowman and others 2002). Hartley (1976) studied the effects of trampling on alpine and sub-alpine vegetation in Glacier National Park, Montana, and found that 35 alpine species decreased as the trail system grew, and seven species increased. Some of the plants that increased were “semi-weedy” invasive native plants from lower elevation. Hartley (1976) also determined that stored

carbohydrates decreased 20 to 50% within 0.5m of the trail, compared to >2m away from the trail, suggesting that trampling or trail proximity reduced plants' ability to make and store reserves, thereby reducing vigor.

*Mining* – We found no studies that documented mining as an important ecological determinant for the alpine tundra vegetation type in the Southwest. Many alpine tundra sites in Colorado have been affected by precious metal and molybdenum mines (Bowman and others 2002), and there is a historic photograph of a molybdenum mine from the Carson National Forest historic archives, but this 1941 mine appears to be at lower elevation than alpine tundra (Figure 10-3).



**Figure 10-3.** 1941—A Molybdenum mine near Red River [on the Carson National Forest, New Mexico]. About 75 men worked at this mine. Photo by E. O. Buhler, FS #413400. [http://www.fs.fed.us/r3/about/history/carson/pages/car008\\_jpg.htm](http://www.fs.fed.us/r3/about/history/carson/pages/car008_jpg.htm)  
*Fire Management* – Not applicable.

*Exotic Introductions (Plant & Animal)* – Trout stocking of alpine lakes has occurred in Colorado and other western states, and except for mention of exotic trout stocking of alpine lakes on the Carson National Forest, no data were available for the SW ([http://www.fs.fed.us/r3/carson/recreation/wilderness/wheeler\\_peak\\_info.shtml](http://www.fs.fed.us/r3/carson/recreation/wilderness/wheeler_peak_info.shtml)). Non-native fish introductions can dramatically change native communities and extirpate amphibians, fish, invertebrates, and zooplankton (Bowman and others 2002).

*Synthesis* – Some generalized trends in grazing pressure and exotic introductions have been documented in Colorado, but no studies focused on the Southwest. Mining and recreation activities are also known to influence alpine vegetation, but no studies

mentioned any specific impacts for the Southwest. Carbon and nitrogen from anthropogenic sources are deposited in alpine tundra systems. Carbon dioxide (CO<sub>2</sub>) levels have been monitored at Niwot Ridge since 1968, the longest record of atmospheric CO<sub>2</sub> in North America, and have increased from 322 parts per million (ppm) to almost 370 ppm over thirty years (Sievering 2001). The anthropogenic contribution of total annual N deposition is estimated to be about half of the 5 lbs. N/acre that falls as wet and dry forms of N (Sievering 2001).

### *10.5 Effects of Anthropogenic Disturbance*

#### *Patch Composition of Vegetation*

*Overstory* – Not applicable.

*Understory*- We found no studies that documented the effects of human disturbance on the understory composition of alpine tundra vegetation.

*Herbaceous Layer* – Due to the extreme environment of alpine tundra systems, recovery of vegetation following disturbance is thought to be very slow, on the order of hundreds to thousands of years (Bowman and others 2002). In one of the few long-term studies of recovery by Alaskan tundra after more than 20 years following disturbance caused by fire and bulldozing, there were distinct differences between areas affected by the two disturbance types, and between disturbed areas and undisturbed areas (Vavrek and others 1999). Primary productivity, species richness, and species diversity were not different between burned and unburned plots, but depth of thaw was greater in burned plots. By contrast, depth of thaw was the only factor that was not significantly different in bulldozed versus non-bulldozed plots. Primary productivity and species richness were higher in bulldozed plots, but diversity was higher in the control plots (Vavrek and others 1999). This study indicated that the effects of the anthropogenic disturbance on the vegetation are more important than changes in the abiotic environment. Vegetative propagules remained in the soil following fire, but did not remain in the soil following bulldozing. Thus, both seeds and vegetative propagules were involved in recolonization after fire, but only seeds were involved in recovery following bulldozing (Vavrek and others 1999).

*Patch or Stand Structure of Vegetation* - We found no studies that documented the effects of human disturbance on the patch or stand structure of alpine tundra vegetation.

*Canopy Cover Class (%) or Canopy Closure* - We found no studies that documented the effects of human disturbance on the canopy cover of alpine tundra vegetation.

*Structure Class (Size Class)* - We found no studies that documented the effects of human disturbance on the structure class of alpine tundra vegetation.

*Life Form* – We found no studies that documented the effects of human disturbance on the life form of alpine tundra vegetation.

*Density* - We found no studies that documented the effects of human disturbance on the density of alpine tundra vegetation.

*Age Structure* - We found no studies that documented the effects of human disturbance on the age structure of alpine tundra vegetation.

*Patch Dispersion* - We found no studies that quantified the effects of human disturbance on the patch dispersion of alpine tundra vegetation.

*Recruitment Dynamics* - We found no studies that documented the effects of human disturbance on the recruitment dynamics of alpine tundra vegetation.

*Synthesis* – Because there is so little information on historic alpine tundra vegetation, we found no studies linking human disturbance to changes in conditions of alpine tundra from pre-settlement to current. One study that tracked recover of Alaskan tussock tundra following disturbance concluded that recovery of vegetation was most affected by the type of disturbance and its effect on the vegetation rather than the effect of the disturbance on the abiotic environment (Vavrek and others 1999).

The areas of inquiry showing the greatest potential for hypothesis testing of environmental effects of human disturbance include climate change, changes in N deposition, and changes in atmospheric ultraviolet light transmission that have been monitored during the post-settlement period. Due to its high elevation, and lack of land area upslope, alpine tundra is uniquely susceptible to changes in climate, particularly if temperatures continue to increase (Welker and others 2001). However, despite recent warming trends, repeat photography indicates tree-line elevation has been stable in both the northern Rocky Mountains of Montana and Wyoming (Butler and others 1994) and central Rocky Mountains of Colorado (Baker and others 1995) since at least the beginning of the 20<sup>th</sup> century, indicating that alpine tundra is slow to respond in spatial distribution to climate change (Bowman and others 2002). However, recent work in Switzerland alpine vegetation indicates that community composition has changed (increased species richness) over the last century, and that the rate of change has increased in the last 20 years when compared to the first 80 years of the 20<sup>th</sup> century (Walther and others 2005).

Increased atmospheric N deposition is important for several reasons, and has become the subject of intensive study recently (Welker and others 2001). Due to the cold temperature and short growing season of alpine tundra ecosystems, N cycling rates are relatively low, and primary productivity is also lower than other montane systems. Thus, increases in N supply due to elevated deposition levels have the potential to impact plant and microbial community composition through selection for N-utilizing plants and microbes, and to increase N losses to downslope aquatic and other terrestrial ecosystems (Welker and others 2001). Conceptual models have been developed to explain and predict consequences of climate change (Grant and French 1990), N-deposition (Welker and others 2001), and the interactions of climate, hydrology-geochemistry, and

geomorphology-paleoecology (French and others 1986) on Front Range alpine tundra in Colorado.

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