Calochortiana

Research Journal of the Utah Native Plant Society

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Calochortus nuttallii (Sego lily), state flower of Utah. By Kaye Thorne.

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Calochortiana, a New Publication of the Utah Native Plant Society

Hundreds of scientific journals already exist for the dissemination of research on botany and ecology (including several fine publications based in Utah and the west). Nonetheless, space and financial constraints prevent many useful papers from being published in first and second-tier journals, relegating such work to the gray literature. In June 2012, the board of the Utah Native Plant Society (UNPS) recognized the need for a peer-reviewed, electronic journal for unpublished gray-literature reports that pertain to Utah botany and vegetation. The board voted to establish an annual, technical journal that would complement its bimonthly member's magazine, the *Sego Lily*. The objective of the new publication, named *Calochortiana* ("of or relating to *Calochortus* or Sego Lily", the state floral emblem of Utah), is to provide a forum for professional and amateur scientists to share their findings on Utah botany and ecology with their colleagues. *Calochortiana* will focus primarily on monitoring or status surveys of rare species, seed propagation protocols, floristic checklists, genetic studies, vegetation mapping, natural history research, or other topics that might not otherwise be accepted in existing journals. All submissions will be peer-reviewed and the journal made available for free on the UNPS website. The journal is put together by an all-volunteer editorial board, though supported by UNPS. Readers, of course, are encouraged to show their appreciation by becoming members of UNPS!

This first issue of *Calochortiana* contains papers presented at the 5th Southwestern Rare and Endangered Plant Conference, hosted by UNPS in March 2009. These papers were originally intended for publication by the US Forest Service as part of a proceedings volume. Unfortunately, staff changes, budget shortfalls, and new policy review requirements greatly delayed publication of the proceedings by the Forest Service. In October 2012, UNPS assumed responsibility for disseminating the conference papers to help launch its new journal. The second issue of *Calochortiana* will be published on the UNPS website (www.unps.org) in the fall of 2013. Submissions for that issue will be accepted through 30 April 2013. For more information, please contact me (walt@kanab.net). - *Walter Fertig*

The Fifth Southwestern Rare and Endangered Plant Conference
Salt Lake City, Utah, March 2009

In late 2007, botanists in the southwestern United States began discussions about holding a region-wide rare plant conference modeled after the Fourth Southwestern Rare and Endangered Plants meeting held in Las Cruces, New Mexico in 2004. It was widely acknowledged through the botanical grapevine that it ought to be Utah's turn to host the event. Mindy Wheeler, who was chair of the Utah Native Plant Society (UNPS) at the time, proposed that the Society take the lead in organizing a conference, slated for early spring 2009. UNPS already had experience with co-hosting the annual state rare plant meeting with Red Butte Garden, so how hard could a regional conference be?

Without going into the gory details, the months of developing an agenda, finding a venue, creating a website, signing up sponsors, sending out invitations to speakers and attendees, organizing field trips, hiring caterers, and completing hundreds of other tasks all just seemed to whisk by. On the evening of March 16, 2009, UNPS was proud to host the first event of the Fifth Southwestern Rare and Endangered Plant Conference - an informal mixer at historic Fort Douglas on the campus of the University of Utah in Salt Lake City. Fortified by good food, fine spirits, and excellent company, the organizers and participants of the conference were off to a good start.

The conference officially began the following morning. Noel Holmgren, curator emeritus of the New York Botanical Garden, gave the keynote address in which he briefly outlined the history of the Garden's *Intermountain Flora* project and described patterns of species richness and endemism in the Great Basin, Colorado Plateau, and the rest of the Southwest. UNPS presented Noel and Pat Holmgren with hand-crafted lanyards (for their hand lenses) in appreciation of their decades of work on the *Intermountain Flora*.

Over the next three days, 36 additional speakers gave presentations or workshops and an additional 20 posters were displayed at an evening reception. Presentations covered a variety of topics, ranging from seedling ecology and rare plant biology to distributional modeling, impacts of climate change, plant biogeography, and fire ecology.

The conference concluded with a Friday field trip to Stansbury Island along the south side of the Great Salt Lake. Despite the unusually warm temperatures of mid-March, relatively few plants were flowering, though attendees were treated to a display of violet buttercup (*Ranunculus andersonii* var. *andersonii*) in bloom.

All told, over 150 botanists attended the week-long conference. Much of the success of the conference could be attributed to the hard work of the planning and program committees, both chaired by Mindy Wheeler with the able assistance of Bill Gray, Ann Kelsey, Bill King, Therese and Larry Meyer, Robert and Susan Fitts, Loreen Allphin, Rita (Dodge) Reisor, and Leila Shultz. A number of volunteers from UNPS and Red Butte Garden helped with registration, food, and behind the scenes work, including Elise Erler, Tony Frates, Celeste Kennard, Kipp Lee, Bill Nelsen, Kody Wallace, Sue Budden, Pamela and Robert Hilbert, Allene Keller, Jena Lewinsohn, Marilyn Mead, and Bev Sudbury. Artist Laura Call Gastinger provided a beautiful painting of Dwarf bearclaw poppy (*Arctomecon humilis*) for the conference program and souvenir mug. The following corporate and institutional sponsors assisted financially or by other means: The Nature Conservancy of Utah, US Forest Service Rocky Mountain Research Station, University of Utah Department of Biology, the Flora of North America project, Providia, Utah Natural History Museum, Utah Botanical Center, Red Butte Garden and Arboretum, the state of Utah Department of Natural Resources, and Bio-West, Inc.

Twenty presenters at the conference kindly prepared manuscripts for this inaugural issue of *Calochortiana*, which will serve as the official proceedings document for the conference. Thanks to all the contributors for their willingness to share, and for their patience. - *Walter Fertig*

Abstracts of Presentations and Posters not Submitted for the Proceedings

Biogeography of the Intermountain Region and Connections to the Southwestern USA

Noel H. Holmgren, Curator Emeritus, New York Botanical Garden.

Abstract: The Intermountain Region lies between the east base of the Sierra-Cascade mountain chain and the west side of the Rocky Mountains. Its southern boundary overlooks the warm deserts of the Southwest and the northern boundary lies along the base of the Oregon and Idaho batholiths. The Great Basin occupies nearly two-thirds of the Region, and the Wasatch and Uinta Mountains and the Utah segment of the Colorado Plateau occupy the eastern third. In combination, the plant associations, vegetation zones, and plant species distinguish the region as a reasonably natural floristic unit, but there are many geologic-historical relationships with the Southwest. With the changing climate, even greater similarities may be anticipated in the future. The basin and range topography of the Great Basin offers a perfect place to monitor possible species migration from south to north and from valley to mountain.

Flora of the Arizona Strip

Duane Atwood, Brigham Young University, retired

Abstract: The "Arizona Strip" is a unique botanical area isolated from the rest of Arizona by the Colorado River. Our knowledge of its flora has been slow and incremental with a few collections from the early botanists who visited southern Utah such as Edward Palmer (1870) C.C. Parry (1874-1875); and later by A.L. Siler and Marcus E. Jones. Generally speaking, most Arizona botanists have given little attention to this area. The first concentrated effort of collecting on the Strip was by Ralph K. Gierisch, a retired Forest Service employee, who worked primarily as a volunteer for the BLM Arizona Strip District located in St. George, Utah. Ralph made hundreds of collections, which are deposited at that office with many duplicates at BYU and NAU. My interest and first collection from the Strip was made 27 May 1968 1 mile north of Fredonia to secure the type for *Phacelia constancei*, while working on a revision of the crenulatae group of *Phacelia* (Hydrophyllaceae). Then later in 1970 while living in Fredonia and working on the Kaiparowits Environmental Impact Studies with BYU, thru 1975; and as the first botanist for BLM and the second one nationally for the Cedar City BLM District (1975-1977). Collection trips to this unique area continued through to the present, often with Larry C. Higgins. An annotated list of vascular plants has been generated for the entire Strip and the National Parks and Monuments within its borders. Six new endemic taxa have been described from the area: *Phacelia higginsii, P. furnisii, P. hughesii, Camissonia dominguez-escalantorum, Physaria arizonica* var. *andrusensis* and *Tetradymia canescens* var. *thorneae*.

Biogeography and the Evolution of Rare, Endemic Species: Insights from two Mustard Genera in the Southwest (*Draba* and *Boechera,* Brassicaceae).

Loreen Allphin, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT and Michael D. Windham, Duke University, Durham, NC.

Abstract: With a growing number of plant species in danger of extinction due to human induced threats, species-by-species approaches to management are becoming unrealistic. Conservation of rare plants would be improved by a clearer understanding of the evolutionary forces that give rise to rare, endemic species. These data might facilitate the development of management strategies applicable to a wide range of rare species. For this study we conducted a detailed survey of species within the genera *Draba* and *Boechera* from the Southwest United States (genera and a region with the high concentrations of endemic species). We collected data on geographic distribution, degree of endemism, chromosome number, ploidy level, breeding system, reproductive fitness and presumed mode of speciation. The study revealed some interesting evolutionary and biogeographic patterns. Some rare endemic species in these genera were primarily diploid, outcrossing, paleoendemic species with relatively low fecundity. Conversely, other endemic species in these groups were primarily polyploid, autogamous or apomictic, neoendemics with relatively high fecundity. These patterns appear to reflect both the type of speciation that occurred and the geologic/biogeographic history of the region. The geography of rarity and endemism in these genera appears to be an expression of primary divergence, reticulate evolution, and evolutionary time.

Physical and Chemical Characteristics of Xeric Soils in Eastern Great Basin Determines the Natural Plant Associations, but Recently Ruderal Species have Become an Important Factor.

Rodd Hardy, Bureau of Land Management, Salt Lake City, UT

Abstract: What are major physical and chemical properties of the soil profiles that are key factors for different plant associations? What are the major natural plant associations based on these soil properties? What particular ruderal species, to what degree, and when did these invaders become a major role within plant associations today? What recommendations are needed to mitigate the impacts of ruderal species to natural plant communities? This paper will note the ecotone sharpness in which plant communities in dry climates change from one type to another for major plant species and the chemical properties of the soil which determine specific plant communities. Winterfat and gray molly sites have particularly been vulnerable to annual grass and goosefoot forbs, but invasive species effects upon endemic species such as Pohl's milkvetch and Small spring parsley has also been notable.

Predictive Habitat Models for *Arctomecon californica* Torrey & Frémont and *Eriogonum corymbosum* Bentham var. *nilesii* Reveal for the Upper Las Vegas Wash Conservation Transfer Area, Nevada.

Amy A. Croft, Thomas C. Edwards, Jr., Janis L. Boettinger, Glen Busch, James A. MacMahon, US Geological Survey and the Ecology Center, Utah State University

Abstract: The Upper Las Vegas Wash Conservation Transfer Area (ULVWCTA), situated northwest of Las Vegas, Nevada provides habitat for two of the state's special status species, *Arctomecon californica* Torrey and Frémont and *Eriogonum corymbosum* Bentham var. *nilesii* Reveal. In an effort to aid the Bureau of Land Management Las Vegas Field Office in conservation based decision making, we built a family of statistical models capable of predicting likely locations of each species in the ULVWCTA. To predict locations of the plant species, emphasis was placed on sensitivity, the ability of the models to predict where the species were located. *A. californica* sites were characterized by soils with low shear and compressive strength values, a low percentage of rock, and a physical soil crust. The most common soil type and vegetation association occupied by *A. californica* was the Las Vegas type (spring deposits) and the *Ambosia dumosa-Atriplex confertifolia* vegetation association. Models for *A. californica* had moderate to excellent predictive capabilities, with accuracies as reflected by sensitivity ranging from 75% to 95%. Small sample sizes precluded construction of any models for *E. corymbosum* var. *nilesii*. Instead, we were able to successfully predict likely locations of *E. corymbosum* var. *nilesii* with the *A. californica* models. Overall, the models had predictive capabilities of sufficient accuracy to be used in conservation decisions for the ULVWCTA.

Comprehensive Interactive Plant Keys for the Southwest

Bruce S. Barnes, Flora ID Northwest, Pendleton, OR

Abstract: Plant conservation and management for any given locality is a complex process which depends on reliable and continually updated information regarding what species are found and where. These critical data

often require time-consuming initial and ongoing plant surveys. Computerized interactive keys produced over the past 14 years by the author greatly facilitate plant surveys by reducing the time to key unknown species by 90% or more. This presentation will demonstrate the use of the plant identification software, to provide the audience with an understanding of the potential applications of this resource. The keys include all known vascular plants, both native and introduced, which grow outside of cultivation in 16 states and 4 Canadian provinces, including California, Nevada and Utah, with Arizona and New Mexico to be added in 2010. Plant characteristics may be selected in any order, with no forced choices. Terms are defined and illustrated, extensive references are included, and color photos are provided for over 99% of species. Synonyms and menus of genera and families are provided to reduce problems of changing nomenclature. The software is continuously updated with name changes, new plant finds, and new photos, with free annual updates available for purchasers. The keys are available by state or larger region. In most cases descriptive information is provided for separating subtaxa when present. These keys are a powerful, innovative tool to assist in providing timely plant survey data for plant conservation and management.

The Climate Puzzle of Global Warming: It is not just about Chilies!

Robert R. Gillies, Director/State Climatologist, Utah Climate Center at Utah State University

Abstract: In arid and semi-arid Western North America, observations of climate change point to an increase in average temperature that is greater than the rest of the world's average. In line with such a warming trend in climate, several studies of the precipitation regime for the region have documented less snowfall as evidenced by decreases in snowpack as well as earlier snow melt, increased winter rain events and reduced summer flows. An ensemble of global climate model (GCM) projections for Western North America reflect just such conditions in that they suggest intensifying drying conditions to be the norm for the Southwest region due primarily to Hadley Cell intensification. Regions that lie to the Northwest, the GCMs have as benefiting from increased precipitation but in transitional zones, i.e., between the wetter and drier zones, any gains in projected precipitation are offset by the likelihood of an increased frequency of above normal temperatures during the summer months; such results suggest that an overall deficit in water resources is on the cards for much of the Intermountain West.

Long-Term Perspectives on Vegetation: Paleoecology as a Tool for Conservation and Ecosystem Management

Mitchell J. Power, Utah Museum of Natural History, Department of Geography, University of Utah

Abstract: Long-term studies on vegetation history have demonstrated the role of climate in controlling the composition and distribution of species through time. Paleoecological studies that use fossil plant and pollen offer many lessons from the past, including: 1) plant species respond individualistically to climate change, 2) vegetation composition during the last Ice Age, 21,000 years ago, was very different than today, and 3) plants have "migrated" across hundreds to thousands of kilometers since the last Ice Age in response to changing climate and disturbance regimes. These lessons from paleoecology can be used to inform conservation efforts towards the protection of plant species that face unprecedented climate change. Traditionally, most "long-term" conservation studies span less than 50 years and therefore characterize historical variations in plant communities within a limited temporal domain. Conservation efforts aim to restore natural habitats and protect landscapes, but the question remains; what to restore things to? Through merging paleoecological knowledge with conservation objectives, land managers and conservationists are better positioned to make informed decisions to protect plant species as we experience the rapidly changing climate of the 21st century.

The Southwest Region 'GAP' Program for Mapping Vegetation and Species

Doug Ramsey, Department of Geography and Earth Resources, Utah State University, Logan, UT

Abstract: The Southwest Regional Gap Analysis Project (SWReGAP) is an update of the Gap Analysis Program's mapping and assessment of biodiversity for the five-state region encompassing Arizona, Colorado, Nevada, New Mexico, and Utah. It is a multi-institutional cooperative effort coordinated by the U.S. Geological Survey Gap Analysis Program. The primary objective of the update is to use a coordinated mapping approach to create detailed, seamless GIS maps of land cover, all native terrestrial vertebrate species, land stewardship, and management status, and to analyze this information to identify those biotic elements that are underrepresented on lands managed for their long term conservation or are 'gaps.'

Responses of Colorado Plateau Drylands to Climate Change: Variability due to Land Use and Soil-Geomorphic Heterogeneity

Mark E. Miller and Jayne Belnap, U.S. Geological Survey, Southwest Biological Science Center, Moab, UT

Abstract: Dryland ecosystems comprise well over 50 percent of the Colorado Plateau province and are subjected to land uses such as livestock grazing, recreation, and energy development. Low and variable amounts of precipitation constrain dryland resilience to land-use activities, making drylands particularly susceptible to persistent changes in structure, function, and capacity for providing key ecosystem services such as soil stabilization. Through multiple effects on soil and vegetation attributes, land use also mediates ecosystem responses to climate. Ecosystem responses to interactive effects of land use and climate vary spatially in relation to soil geomorphic properties such as texture, depth, horizonation, and topographic setting due to effects of these properties on water and nutrient availability, soil erodibility, and site susceptibility to hydrologic alteration by soil-surface disturbances. We use existing data from Colorado Plateau drylands to illustrate these concepts and to develop a set of testable hypotheses about climate-land-use interactions (i.e., how climate and land use each affect ecosystem resilience to the other) in relation to soil-geomorphic properties. For example, we predict that climate-land-use interactions in Colorado Plateau drylands will be greater on deep soils than on shallow, rocky soils because the former support grasslands and shrub steppe ecosystems that have been most extensively used and modified by livestock grazing. We also predict that climate-land-use interactions will be greater on relatively fine-textured soils than on coarse-textured soils because the former tend to be more susceptible to exotic plant invasions and hydrologic alteration following disturbance, and because they exhibit greater fluctuations in resource availability in response to precipitation variability. Variable ecosystem responses to climate due to land use and soil have implications for scientists' efforts to predict ecological consequences of climate change with sufficient detail to inform management decisions, and for decision makers' efforts to prioritize and evaluate risks of different management strategies.

Colorado Rare Plant Conservation Initiative, Saving Colorado's Wildflowers

Brian Kurzel, Colorado Natural Areas Program

Abstract: The Colorado Rare Plant Conservation Initiative is a diverse partnership of public and private organizations dedicated to conserving our state's natural heritage by improving the stewardship of Colorado's most imperiled plants. One hundred thirteen native plant species in Colorado are considered imperiled or critically imperiled by the Colorado Natural Heritage Program, meaning they are at significant risk of extinction. Of these species, 63 are endemic, growing only in Colorado and no place else in the world. Nearly 50% of our state's imperiled native plants are considered poorly or weakly conserved. Unlike animals, Colorado has no state-level recognition or protection for plants. Impacts to Colorado's rare plants are at an all-time high due to our rapidly expanding human population. Primary threats include habitat loss and fragmentation associated with resource extraction, motorized recreation, housing and urban development, and roads. Many rare plants are also at risk due to a simple lack of awareness regarding their precarious status. Despite the size and scale of these threats, we still have a chance to make a difference through strategic conservation actions, since healthy populations of many imperiled plants still exist. The goal of the Rare Plant Conservation Initiative is to conserve Colorado's most imperiled native plants and their habitats through collaborative partnerships for the preservation of our natural heritage and the benefit of future generations.

Rare Plant Management and BLM Policy

Carol Spurrier, Bureau of Land Management, Washington, DC.

Abstract: Rare plant conservation continues to be part of the multiple use mission of the Bureau of Land Management (BLM) in the United States. With continuing increases in the demand for all types of energy and other goods provided by the public lands, as well as landscape scale changes in natural vegetation due to increased wildfire and climate change, we wondered if the public lands that have been designated as part of the Natural Landscape Conservation System (NLCS) hold significance for protection of rare plant resources in BLM. We examined 2006 occurrence data on BLM lands from NatureServe within NLCS unit boundaries to determine rare plant species occurring in each unit. In this paper we discuss our findings for the different types of designations (wilderness, wilderness study areas, National Monuments and National Conservation Areas) within the System.

Thinking and Acting Together to Preserve Uinta Basin Rare Plants

Joan Degiorgio, Northern Mountains Regional Director, The Nature Conservancy, Salt Lake City, UT

Abstract: Utah's Uinta Basin is home to dozens of endemic plant species. Nine of those species are at risk due to increased levels of energy development. Representatives from state, federal and local agencies, the Ute Tribe, private consultants, conservation groups, researchers, industry and others have come together as the Uinta Basin Rare Plant Forum to collectively address threats to these plants. Through a transparent, open planning process key ecological attributes of each plant were identified and rated for viability, stresses identified and specific strategies developed. This planning effort has been an excellent tool to "capture" the collective wisdom of local experts; and, with this knowledge, develop comprehensive strategies for the nine species simultaneously. With an agreed upon strategy, the Forum will work together implementing the highest leverage strategies and engaging more partners and dollars because of the solid foundation built through this planning process.

Interagency Management Agreement for TES Species in Central Utah

David Tait, botanist, Fishlake National Forest, Richfield, UT.

Abstract: The Bureau of Land Management Richfield Field Office, Fishlake National Forest, and Capitol Reef National Park share management responsibilities for many of the same Threatened, Endangered & Sensitive plant species (TES). To enable each of these agencies to better manage their shared TES species, they developed an interagency agreement in 1999 that enables them to pool their funding. This funding, which has been minimal at times, has been used to employ an interagency botanist and hire seasonals to survey and monitor these TES species throughout their ranges, regardless of agency boundaries. The BLM Price Field Office and the US Fish and Wildlife Service were added in 2007. This project has allowed us to: (1) conduct intensive surveys for target species on potential habitat within the project area, (2) determine potential for impact by visitor, recreational or livestock use on long-term viability of these rare plants, and (3) conduct long-term monitoring on several of the rare species. Between 1999 and 2008 approximately 100,580 acres were surveyed for some 30 TES plants species by the IA team. approximately 27,500 acres on BLM, 37,920 acres on Capitol Reef, and 35,160 acres on lands administered by the Fishlake.

Conservation Success for a Rare Idaho Endemic: Conservation Agreement and Botanical Special Interest Area for Christ's Paintbrush

Kim Pierson-Motychak, Sawtooth National Forest, Twin Falls, ID and Jeffrey E. Motychak, Motychak Environmental Consulting, Twin Falls, ID.

Abstract: Christ's Indian Paintbrush (*Castilleja christii*) is a rare species known from only one population in Southwestern Idaho, Cassia County. Due to its restricted distribution and vulnerability to threats, *C. christii* is designated as a Candidate species for Federal listing under the Endangered Species Act (ESA). Conservation Strategies were completed in 1995 and 2002 for the establishment of long-term monitoring protocols. These have been implemented from 1995 to present. In 2003, the portion of the population not included in the Mount Harrison Research Natural Area (RNA) was designated as the Mount Harrison Botanical Special Interest Area (BSIA). In 2005, a ten year Candidate Conservation Agreement (CCA) was signed between the US Fish and Wildlife Service and the USDA Forest Service. This CCA identified the key threats to the population which included: 1) non-native plant introduction and establishment, 2) recreational impacts, 3) hybridization, 4) unauthorized livestock impacts, 5) road construction, maintenance, and facilities, and 6) natural threats. A total of 42 conservation action items were committed to in the CCA. Results from the implementation of these conservation action items include aggressive non-native plant treatment, increased interpretive education, agency and public interaction, long-term demographic and reproductive monitoring, host-specificity determination, and preliminary pollination ecology. Population trends indicate that while plant densities within the communities have declined over the 13-year period, individual reproductive output (flowering stems/plant) has increased.

Modeling Distributions of Rare Plants in the Southern Great Basin of Utah

Marti Aitken, Utah State University and US Forest Service Pacific Northwest Research Station, Portland, OR; Leila M. Shultz, College of Natural Resources, Utah State University, Logan, UT; and David W. Roberts, Department of Ecology, Montana State University, Bozeman, MT.

Abstract: Field-validated landscape level predictive models identify potential plant habitat for rare plants in the Great Basin of western North America. Four rare species (*Jamesia tetrapetala, Penstemon nanus, Primula domensis,* and *Sphaeralcea caespitosa*) endemic to the southern portion of the eastern Great Basin (SW Utah)

were chosen to include a range of environmental variability, growth form, and plant communities. Herbarium records of known occurrences were used to identify initial sample sites. We established multiple field sites to determine the geographic coordinates, environmental attributes (slope, aspect, soils, parent material) and vegetation data (associated species) in order to develop two predictive models for each species: a field key and a probability-of-occurrence or predictor map. The field key was developed from environmental attributes and associated species data collected at the sites and used only field data. Predictive maps were developed with a geographic information system (GIS) containing slope, elevation, aspect, soils, and geologic data – then randomly tested. Classification-tree (CT) software was used to generate dichotomous field keys and the maps of occurrence probabilities. Predictions from both models were randomly field-validated during the second phase of the study, and final models were developed through an iterative process. Data collected during the field validation were then incorporated into subsequent predictive models. The models identified potential habitat by combining elevation, slope, aspect, rock type, and geologic process into habitat models for each species. The cross-validated models were >96% accurate and generally predicted presence with accuracy >60%.

Ute Ladies'-Tresses in the Diamond Fork Watershed: An Update

Bridget M. Atkin and Steve R. Ripple, BIO-WEST, Logan, Utah

Abstract: Ute ladies'-tresses (*Spiranthes diluvialis*) (ULT) was listed as threatened in 1992. The largest known population is in the watershed of Diamond Fork Creek and its tributary, Sixth Water Creek. Between 1916 and 2004, these streams were used as canals, and they conveyed irrigation water diverted from Strawberry Reservoir to the Wasatch Front. Increased peak flows altered the stream channel and aquatic ecosystem, creating unique conditions that allowed the rare orchid to thrive. In 2004 a system of pipes was installed to divert water directly into the Spanish Fork River, thereby reducing the flows in Diamond Fork and Sixth Water Creeks. Studies of ULT populations have been conducted since 1992 under the direction of Utah Reclamation Mitigation and Conservation Commission. Results show that ULT colonies are still maintaining large numbers. However, monitoring of ULT has been difficult. The unique life-cycle characteristics of ULT, along with its dynamic habitat, create many challenges. Highly variable yearly ULT counts are very difficult to interpret or correlate with environmental parameters. In 2005 other studies were initiated and more associated plant species data are now being systematically collected to track changes that may indicate whether the decreased flows are impacting ULT habitat. During 2007 ULT numbers showed at least two flushes, in early August with tiny individual plants. Conversely, in 2008 ULT numbers were highest in mid-September and plants were large. These observations have wide reaching implications pertinent to many species, indicating that unless a population is observed carefully, data could easily be misinterpreted.

Arizona Cliffrose (*Purshia subintegra*), An Arizona Endemic

Debra Crisp, Coconino National Forest, Flagstaff, AZ, and Barbara G. Phillips, Zone Botanist, Coconino, Kaibab and Prescott National Forests

Abstract: The Arizona cliffrose is a long-lived shrub, endemic to white Tertiary (Miocene and Pliocene) limestone lakebed deposits that are high in lithium, nitrates, and magnesium and is an Endangered species. It occurs in four disjunct populations spread across an area of approximately 200 miles in central Arizona. Threats to Arizona cliffrose include livestock grazing, mineral exploration, road and utility corridor development, off-highway vehicle use, urban development and drought. In this poster we summarize the results of some long-term monitoring transects initiated in 1987. These transects are in the Cottonwood population, which is thought to be the healthiest and contains the most diverse age structure of the four known populations. Data on these transects were collected three times, in 1987, 1996 and in 2008.

Demography and Pollination Biology of Graham's Penstemon (*Penstemon grahamii*), a Uinta Basin Endemic; 5-year results.

Rita [Dodge] Reisor and Wendy Yates, Red Butte Garden and Arboretum, University of Utah, Salt Lake City, Utah

Abstract*:* *Penstemon grahamii* is a Uinta Basin endemic which grows on oil-shale outcrops of the Green River Formation. Long-term monitoring plots were established for *P. grahamii* to collect basic life history data, study pollination biology, and survey critical habitat. Research was conducted over 5 years (2004 to 2008) during May – June, at the Blue Knoll/Seep Ridge and Buck Canyon population sites located on BLM land. Data gathered includes rosette diameter, number of inflorescences, inflorescence height, flowers per inflorescence, number of fruiting individuals, and herbivory. The breeding systems study used the following treatments: autogamy, geitonogamy, xenogamy, and vector pollination as a control group. Surveys were based on historic Element Occurrence (EO) reports and surrounding habitat. Demographic data suggest that *P. grahamii* population size has remained fairly stable over the study period. Annual survivorship rates range from 47 – 82%, and mortality ranging from 6 – 36%. Flowering events are highly variable annually, ranging from zero flowering plants in 2006, up to 44% in 2004. As expected for the breeding systems results, the vector (control) produced the most fruits, then xenogamy, geitonogamy, and autogamy with the least fruits produced. Survey results found existing populations at each historic EO visited, and expanded the range and size for some occurrences. Current threats include high rates of herbivory, habitat loss, and fragmentation due to oil and gas development. It is unknown how the reproductive success of *P. grahamii* may be influenced by other development related impacts such as dust production and pollinator disturbance.

Micropropagation Studies in *Astragalus holmgreniorum*

Aaron R. Fry, Brett A. McGowan, and Julianne Babaoka, Ally Bench, Renée Van Buren and Olga R. Kopp, Department of Biology, Utah Valley University, Orem, Utah, 84058

Abstract: *Astragalus holmgreniorum*, a species endemic to the northern areas of the Mojave Desert is listed as a federally Endangered species. Threats to the species stem from habitat destruction arising primarily from commercial and residential development, overgrazing by livestock, recreational vehicles, and mining operations. In an attempt to develop a micropropagation technique aimed at aiding in recovery efforts for the species, we report successful induction of shoots from callus tissue. Explants were taken from leaves (abaxial and adaxial surfaces) and from petioles. These were incubated in MS medium amended with 2,-4 D and BA to induce callus formation. Murashige and Skoog medium amended with 7 mg/L of 2,-4 D and 2 mg/L of BA induced the formation of embryos and plantlets. Current work focuses on the effects of varying concentrations of NAA, IBA, and IAA on root formation. Following root induction, we plan to acclimatize plantlets by incubating them in potting soil. Ultimately, we hope that this research may be used to aid in recovery efforts of this species.

Geochemical Analysis of Tuffaceous Outcrops Associated with the Narrow Endemic, *Penstemon idahoensis* Welsh & Atwood

Paul R. Grossl, William A. Varga, and Richard M. Anderson, Utah State University, Plant, Soils, and Climate Department and Utah Botanical Center, Utah State University.

Abstract: Idaho penstemon (*Penstemon idahoensis* Welsh & Atwood) is a Sawtooth National Forest Sensitive plant species narrowly endemic to the Goose Creek drainage in northern Box Elder County, Utah, and adjacent southern Cassia County, Idaho. Idaho penstemon is a short, glandular, perennial forb comprised of several stems which emerge from a semi-woody caudex and topped with showy, blue flowers. Its distribution is restricted to dry, light-colored, sparsely vegetated, tuffaceous outcrops of Tertiary Salt Lake Formation sediments. Botanists have long recognized the association of endemic, often rare, plant species with unusual soils. Edaphic endemism is prominent among those plant associations which include ultramafic bedrock, such as serpentine, or calcareous bedrock such as limestone, chalk, dolomite, or gypsum. Edaphic endemic species frequently arouse conservation concern due to their restricted distributions or small plant population sizes. The focus of this investigation considered the question whether *Penstemon idahoensis* utilizes unusual soil conditions that exclude other taxa and thus provide low competition environments. To answer this question we attempted to ascertain via geochemical analysis any selective or restrictive constituents or composition including the presence or absence of gypsum, unusual soil pH levels, soil texture, salinity (EC), organic matter, or atypical element distributions associated with common soil components.

What's Happened to Siler Pincushion Cactus?

Lee E Hughes, Ecologist, Arizona Strip Field Office, St. George, UT, retired

Abstract: The Siler Pincushion Cactus has, like all vegetation in the southwest, been under the influence of a ten year drought. The effects of this drought are evident in the data gathered on the cactus. The poster will show the data from the six demographic plots on the cactus. The data starts in 1986 and goes through to 2008. It summarizes the mortality data. The size structure for each plot is shown graphically to demonstrate the affect of the drought on the size composition of the cactus. In summary the drought has reduced the small cactus significantly. Also shown, is the effect (or no effect) from livestock and ATVs being present in the

plots. The plot data shows a cactus with drought problems, but in some areas is doing well also.

Clark County (Nevada) Rare Plant Modeling and Inventory

Sonja R. Kokos, Clark County Desert Conservation Program, Las Vegas, NV; David W. Brickey and Larry R. Tinney, TerraSpectra Geomatics, Las Vegas, NV; and Analie R. Barnett and Robert D. Sutter, The Nature Conservancy, Southeastern Region, Durham, NC

Abstract: To understand the distribution of rare plants covered under the Clark County Multiple Species Habitat Conservation Plan, Clark County and Terra-Spectra Geomatics developed two predictive GIS models. The models used ASTER Imagery and Landsat ETM+ Imagery, soils data (NRCS SSURGO), geologic data, and presence/absence data for eight rare and endemic plant species. The first model was used to predict the distribution of three gypsum loving species, the Las Vegas bearpoppy (*Arctomecon californica*), Sticky ringstem (*Anulocaulis leiosolenus* var. *leiosolenus*), and Las Vegas buckwheat (*Eriogonum corymbosum* var. *nilesii*). The second model was used to predict the distribution of five sand or potentially sand loving species, the Three-corner milkvetch (*Astragalus geyeri* var. *triquetrus*), Pahrump Valley buckwheat (*Eriogonom bifurcatum*), Sticky buckwheat (*Eriogonum viscidulum*), Beaver Dam breadroot (*Pediomelum castoreum*), and White-margined beardtongue (*Penstemon albomarginatus*). Using these models, Clark County can now describe the occurrence of all eight species in terms of high, medium and low probabilities. During the 2009 and 2010 field seasons, the county will test both models using a sampling protocol developed jointly by Clark County and The Nature Conservancy. Intuitively, we expect these models to predict the distribution of some species better than others, and further model refinement will be needed. However, the results to date have produced some interesting hypotheses regarding the life history and biology of these species. We expect the results will be valuable to Clark County and the federal land management agencies charged with managing these species.

Post-Fire Monitoring of Erosion Resistance and Dust Emission on the Milford Flat Fire, West-Central Utah

Mark E. Miller, National Park Service, Moab, UT (formerly U.S. Geological Survey, Southwest Biological Science Center, Kanab, UT)

Abstract: Soil stabilization is a major objective of post-fire emergency stabilization and rehabilitation (ES&R) projects, yet monitoring data are rarely sufficient to determine whether treatments effectively achieve this objective. To address this information need, the U.S. Geological Survey and Bureau of Land Management are collaboratively monitoring effects of ES&R treatments on soil-surface stability and rates of dust emission in low-elevation portions of the 147,000-ha Milford Flat Fire that occurred in west-central Utah in July 2007. In August 2008, monitoring plots were established to evaluate the effectiveness of three types of ES&R treatments (aerial seeding and chaining, seeding with a rangeland drill, and seeding with a rangeland drill after herbicide application) in areas where field observations and satellite imagery indicated high rates of dust emission during spring 2008. Monitoring attributes include indicators of erosion resistance (soil stability, ground cover, and sizes of gaps between plant canopies) in addition to measures of plant cover and community composition. Seasonal rates of dust emission are currently monitored with BSNE dust samplers. Sampling in August 2008 indicated that average soil-surface stability was highest in unburned control plots and in burned plots that were not treated. Average soil stability was lowest in burned plots that were seeded with a rangeland drill following herbicide application. During the August-October 2008 period, rates of wind-driven soil movement varied over three orders of magnitude and were greatest in plots that received ESR treatments, were in exposed landscape settings, and had soils that were most susceptible to wind erosion.

Using GIS and Remote Sensing to Predict Dominant Plant Species Distributions in Rich County, Utah

Kate Peterson, Doug Ramsey, Leila Shultz, John Lowry, Alexander Hernandez, and Lisa Langs-Stoner, Remote Sensing/GIS Laboratory and Floristics Lab, Dept. of Wildland Resources, Utah State University, Logan, UT

Abstract: This research shows models of the potential spatial distribution of key upland plant species in Rich County, Utah. We used geospatial data layers of abiotic factors and remotely sensed (RS) imagery in conjunction with field-collected vegetation data. Plant species distribution maps are used to objectively and cost-effectively correlate soil maps units with GIS data in the production of Ecological Site Descriptions (ESD's). These were produced for Rich County in accordance with NRCS (Natural Resources Conservation Service) standards. Inasmuch as abiotic factors and vegetation associations can be used to predict the potential distribution of rare plants, we believe these analyses can be used to guide field searches for populations of endemic species.

A Newly Discovered *Gutierrezia* on the Colorado Plateau

Al Schneider, www.swcoloradowildflowers.com and Peggy Lyon, Colorado Natural Heritage Program

Abstract: The authors will present information on the newly discovered species, *Gutierrezia elegans* or Lone Mesa Snakeweed. They discovered *G. elegans* August 4, 2008 while doing a plant survey in the new Lone Mesa State Park, 30 miles north of Dolores, Colorado. See http://www.swcoloradowildflowers.com/Yellow%20Enlarged%20Photo%20Pages/gutierrezia%20elegans.htm for details, including the full description published in the December, 2008 issue of the *Journal of the Botanical Research Institute of Texas*.

Incorporating Demography, Genetics, and Cytology into Long-Term Management Plans for a Rare, Endemic Alpine Species: *Draba asterophora*

Emily Smith and Loreen Allphin, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT.

Abstract: *Draba asterophora* (Brassicaceae), a rare and endemic mustard, is known from three population clusters (North, Southeast, and south) occupying a narrow range of alpine habitats surrounding Lake Tahoe. The southern population cluster has been segregated as variety *macrocarpa*, whereas the other two clusters have been assigned to variety *asterophora*. Because this small, matted, perennial occurs at alpine sites, the species faces impending threats to its habitat through ski run expansion and development as well as from global climate change. With funding from the USDA Forest Service and local ski resorts, we are conducting morphological, ecological, chromosomal, and genetic studies of both varieties of *D. asterophora* to provide a framework upon which future management plans and mitigation can be developed. Preliminary results suggest that there are significant differences between the three population clusters. These include differences in soil composition, soil chemistry, plant density, demographics reproductive success, and genetics. Chromosome counts from the northern populations (Mt. Rose, Nevada) are tetraploid (n=20). Allozyme banding patterns support the hypothesis that these have arisen through autopolyploidy. The southeastern population has shown both diploid and triploid counts. Because the species includes more than one ploidy level, it should not be treated as a single panmictic taxon for purposes of conservation.

Endangered Milkvetches of Washington County, Utah

Wendy Yates, Red Butte Garden and Arboretum, University of Utah, Salt Lake City, UT; and Ally Bench Searle and Renee Van Buren, Utah Valley State University, Orem, UT.

Abstract: *Astragalus ampullarioides* (Welsh) Welsh and *A. holmgreniorum* Barneby are two federally listed Endangered species endemic to Washington County, Utah. *A. ampullarioides* is known from only four known populations, and *A. holmgreniorum* from only three populations. Prior research conducted on these species by Van Buren and Harper (2003) focused on vegetative and demographic characteristics. There have been no prior studies on the soil seed bank or seed viability. This study focused on determining the density of the soil seed bank and the percent seed viability for both species. For *Astragalus ampullarioides* soil was removed from two of the four known populations. For *Astragalus holmgreniorum* soil was removed from ten densely populated areas. Seeds were sifted from the soil and collected. The seeds extracted were then tested for viability by allowing them to germinate. Those seeds that did not germinate were further tested using the Tetrazolium test. This study found *Astragalus ampullarioides* had a soil seed bank density of 50 seeds/m^2 soil and viability was 68.2%. *Astragalus holmgreniorum* had a soil seed bank density of 1.8 seeds/m^2 soil and viability was 87.7%.

Collaborative Conservation for Washington County, Utah's Federally-Listed Plants

Elaine York and Gen Green, The Nature Conservancy, Salt Lake City, UT.

Abstract: Washington County, Utah is home to four-federally listed plants: the Dwarf bear poppy (*Arctomecon humilis*), Siler pincushion cactus (*Pediocactus sileri*), Holmgren milkvetch (*Astragalus holmgreniorum*) and Shivwits milkvetch (*Astragalus ampullarioides*). Each faces pressing threats, especially habitat loss and degradation from urban development, invasive plants, and off-road vehicle use. Through U.S. Fish and Wildlife (USFWS) coordination and the efforts of partners, many conservation actions have been completed including land acquisition, habitat fencing, habitat restoration, the establishment of Areas of Critical Environmental Concern, seed germination and pollinator research, community education efforts, a habitat management endowment and more. Conservation actions have been implemented by USFWS, Bureau of Land Management, Dr. Renée Van Buren, Dr. Kimball Harper, Dr. Susan Meyer, U.S. Geological Survey,

Washington County, Red Cliffs Desert Reserve, the Shivwits Band of the Paiute Tribe, Zion National Park, Utah Native Plant Society, Utah Natural Heritage Program, School and Institutional Trust Lands Administration, The Nature Conservancy, and more.

Spatial Landscape Modeling: The Land Manager's Tool Box

Elaine York and Louis Provencher, The Nature Conservancy, Salt Lake City, UT.

Abstract: Facilitated by The Nature Conservancy, the Spatial Landscape Modeling Project quantitatively modeled the reference and current conditions for seventeen major vegetation types in the Grouse Creek Mountains and Raft River Mountains, a 1.1 million acre landscape in northwest Utah. Partners – including Utah Partners for Conservation and Development, Bureau of Land Management, Sawtooth National Forest, Utah Division of Wildlife Resources, National Resources Conservation Service, Quality Resource Management, and private landowners – shared management data to explore effectiveness of current management and developed computer-generated alternative management scenarios to consider options for optimal land health. Cutting-edge technology from remote sensing, GIS analysis and partner-informed computer models produced a number of tools to assist land managers in their understanding of large-scale vegetation dynamics, long-term management options and the importance of management cooperation across land-ownership borders.

An Update on Ecological Investigations of the Shivwits Milk-Vetch (*Astragalus ampullarioides*), Washington County, Utah

Mark E. Miller and Rebecca K. Mann, formerly US Geological Survey, Southwest Biological Science Center, Kanab, UT; Rebecca Lieberg, Cheryl Decker and, Kathy Davidson, Zion National Park, and Harland Goldstein and James D. Yount, U.S. Geological Survey, Earth Surface Processes Team, Denver, CO

Abstract: The Shivwits milk-vetch (*Astragalus ampullarioides*) is one of four federally protected plant species restricted to particular geologic substrates at the edge of the Colorado Plateau and Mojave Desert in Washington County, Utah. Since 2006, the U.S. Geological Survey and National Park Service (Zion National Park, ZNP) have been studying this species in relation to geology and soils, herbivory, exotic plants, and mycorrhizal fungi. Habitat studies in 2006 documented the species on a new geologic substrate and across a broad range of soils, expanding the concept of potential habitat. Consumption of inflorescences by native herbivores reduced reproductive output in a ZNP subpopulation by 90% in 2006 (low production year) and 75% in 2008 (high production year). Preliminary analyses indicate no significant effects of exotic red brome (*Bromus rubens*) biomass on growth or reproductive output of established milk-vetch plants in the same subpopulation during spring 2008. Effects of brome biomass on seedling recruitment remain unclear because low precipitation in 2006 and 2007 prevented seed collection required for experimental studies. In 2007, median soil seed bank density in plots at ZNP was 45.7 seeds m^2, with an extremely high density (2741 seeds m^2) in the plot with the sandiest soil. Coarse textured soils in this plot may reduce germination frequency, thereby resulting in long-term seed accumulation. Overall, results to date indicate that caging to exclude native herbivores may be the least expensive way to improve the viability of extant populations by enhancing reproductive output.

Population Genetic Structure of an Endangered Utah Endemic *Astragalus ampullarioides* (Welsh) Welsh (Fabaceae)

Jesse W. Breinholt, Utah Valley University, Orem, UT and Brigham Young University, Provo, UT; and Renee Van Buren, Olga R. Kopp, and Catherine L. Stephen, Utah Valley University, Orem, UT

Abstract: The Shivwits milkvetch, *Astragalus ampullarioides* (Welsh) Welsh, is a perennial herbaceous plant in the family Fabaceae. This Utah edaphic endemic was federally listed as Endangered in 2001 because of high habitat specificity and low numbers of individuals and populations. All known occupied habitat for *A. ampullarioides* was designated as critical habitat by the US Fish and Wildlife Service in 2006. We used AFLP markers to assess genetic differentiation among the seven extant populations and quantify genetic diversity in each. Six different AFLP markers resulted in 217 unambiguous polymorphic loci. We used multiple methods to examine how population genetic structure in this species has changed over time. The genetic data indicate that, relatively recently, *A. ampullarioides* consisted of a single large contiguous genetic unit that fragmented over time into 3 genetic regions. These regions further fragmented and extant populations have differentiated through genetic drift. Populations exhibit low levels of gene flow, even between geographically close populations. We suggest plans for population establishment or augmentation carefully consider the genetic makeup of each of the extant populations.

Summary of *Sclerocactus* Monitoring in the Uinta Basin

Maria Ulloa, formerly Bureau of Land Management, Richfield, UT

Abstract: *Sclerocactus brevispinus* is a small barrel cactus endemic to the Pariette Draw and *S. wetlandicus* is a larger barrel cactus endemic to the Green River benches. Both geographic locations are in the Uinta Basin. These species were listed as Threatened with *Sclerocactus glaucus.* Currently the species are under review by USDI-FWS; the agency is working on its final ruling to make the taxonomic changes to separate these 3 species. In May of 1997, 37 monitoring plots of *S. brevispinus* and *S. wetlandicus* were established in the Uinta Basin, including 9 plots with transplanted individuals. Ecosphere Environmental Service (Ecosphere) entered a Cooperative Agreement with the Vernal Field Office of the Bureau of Land Management (BLM) to study the genus *Sclerocactus* in the Pariette Drainage. All cacti within a 15m-radius of the plot center point were mapped and tagged. In 1998, the plots were read by Ecosphere. Funding to continue the monitoring was not allocated. During the winter of 2004, BLM decided to relocate the plots for the 2005 field season to see if the tagged cacti could be found. The BLM was successful at relocating the plots and the tagged cacti and decided to continue the monitoring for 4 years. In addition to finding the fate of the tagged cacti, all new individuals have been mapped and tagged. Other information collected has been number of flowers, number of capsules, and a small sampling of how many seeds per capsule. During the field season of 2008, a random sampling of the distance of cacti from the center of ant's nests was measured to determine if ants influenced distribution and dispersal of seeds.

Demographics of *Sclerocactus* Species in the Uintah Basin

Lynda Sperry, SWCA Inc., Salt Lake City, UT

Abstract: Botanical surveys associated with oil and gas development in the Uintah Basin provide large databases for listed plant species in compliance with the Endangered Species Act. We have extensively surveyed two threatened cacti species over the past three years. A total of 8,793 individuals were identified in 2008, 4,780 were *Sclerocactus wetlandicus*, 3,663 were *S. brevispinus*, and 350 were identified as possible hybrids. We found the greatest concentration of *S. brevispinus* on north facing slopes (20%), followed by flat surfaces (15%), and the least amount on east facing slopes (6%). The aspect was not as significant for *S. wetlandicus* with 18%, 17%, and 16% on north, south, and flat surfaces respectively. The aspect with the least number of *S. wetlandicus* was northwest-facing with 6% of the individuals surveyed. Both species were found more often in communities dominated by *Atriplex*, including *A. confertifolia*, *A. canescens*, or *A. corrugata*. Using the SSURGO data layer, *S. wetlandicus* was found more frequently on Motto-Rock outcrop complex, whereas *S. brevispinus* was more frequently found on Badland-Rock outcrop complex. Both soil types are dominated by clay and have high salinity ratings. Utilizing survey data collected as part of the permitting process for oil and gas development provides a unique opportunity to gain basic ecological and demographic information for federally listed species.

Breeding System Characterization of a Threatened, Cliff Dwelling, Narrow Endemic *Primula*

Jacob B. Davidson and Paul G. Wolf, Biology Department, Utah State University, Logan, UT.

Abstract: The maguire primrose (*Primula cusickiana* var. *maguirei* or *Primula maguirei*) is a Threatened cliff dwelling endemic plant found only in northern Utah's Logan Canyon. Although a small number of populations are close to one another, these populations have highly differentiated genetic structure. Maguire primrose, like most species in the genus *Primula*, exhibits reciprocal herkogamy in its morphology. Pin morphs have stigmas that extend to the opening of the corolla tube and anthers found near the bottom of the tube. Thrum morphs have stigmas found near the bottom of the corolla tube and anthers that are near the mouth of the corolla tube. Despite the spatial separation of anthers and stigmas, self fertilization has been observed for a number of *Primula* species. In the spring of 2008, I made hand pollinations using intramorph illegitimate outcrossings, legitimate intermorph outcrossings, and various autogamy and geitonogamy tests, while excluding pollinators. Resulting seed set was examined from each treatment. Several temperature and relative humidity monitors were placed near the plants, to see if environmental conditions affected hand pollination success. Temperature fluctuations at each study site ranged widely between freezing temperatures and 20ºC. We share our preliminary results from this initial field season here.

The Taxonomic Distinctness of *Eriogonum corymbosum* var. *nilesii*

Mark Ellis, Biology Department, Utah State University, Logan, UT.

Abstract: We examined populations of perennial, shrubby buckwheats in the *Eriogonum corymbosum* complex and related *Eriogonum* species in the subgenus *Eucycla*, to assess genetic affiliations of the recently named variety *E. corymbosum* var. *nilesii*. We compared AFLP profiles and chloroplast DNA sequences of plants sampled from Colorado, Utah, Nevada, northern Arizona, and northern New Mexico. We found evidence of genetic cohesion among Nevada's Clark County populations as well as their genetic divergence from populations of other *E. corymbosum* varieties and *Eriogonum* species. The genetic component uncovered in this study supports the morphological findings upon which the nomenclatural change was based, attesting to the taxonomic distinctness of this biological entity.

Drymocallis and Other Generic Segregates from *Potentilla* (Rosaceae)

Barbara Ertter, UC Berkeley, Curator of Western North American Flora

Abstract: Generic delimitation in tribe Potentilleae (Rosaceae) has historically vacillated between a broadly circumscribed *Potentilla* and recognition of various segregate genera. Recent convergence of morphological and molecular studies has shown that several segregates are in fact more closely related to *Fragaria* than to core *Potentilla*. These are accordingly treated as *Comarum palustre*, *Dasiphora fruticosa, Sibbaldia procumbens, Sibbaldiopsis tridentata,* and multiple species of *Drymocallis* in a pending volume of *Flora of North America* (FNA). The last genus includes *Potentilla arguta, P. fissa,* and *P. glandulosa* in North America, as well as 10-20 Eurasian species (e.g., *D. rupestris*). However, rather than simply transferring the existing subspecies or varieties of *P. glandulosa* into *Drymocallis,* a provisional revision was undertaken to more closely approximate the natural variation that occurs in western North America. As a result, 15 species of *Drymocallis* are recognized in FNA, some with additional varieties: *D. arguta, D. arizonica, D. ashlandica, D. campanulata, D. convallaria, D. cuneifolia, D. deserertica, D. fissa, D. glabrata, D. glandulosa, D. hansenii, D. lactea, D. micropetala, D. pseudorupestris,* and *D. rhomboidea.* Some species and varieties are newly described, and additional variation was noted as potentially deserving taxonomic recognition or conservation attention. This revision of *Drymocallis* acknowledges the existence of wide zones of intergradation and ambiguous populations, countered by the philosophy that conservation and other needs are poorly served by too broad taxonomic circumscriptions that gloss over valid components of biodiversity in an ecogeographic setting.

Doing Adaptive Management: Improving the Application of Science to the Restoration of a Rare Tahoe Plant

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Abstract: Tahoe yellow cress (*Rorippa subumbellata*), a plant endemic to the shores of Lake Tahoe, has been a candidate for protection under the Endangered Species Act since 1999. In 2002, a conservation strategy that described an adaptive management process for directing research, management, and restoration of the species was adopted by 13 signatory stakeholders. Although the implementation phase is at least four years from completion, we believe it provides an operative example of science-driven decision making. Specifically, we have found that implementation of adaptive management can be successful if: 1) the conceptual model of the adaptive management process is modified to include benefits to biological resources *in situ*, 2) all stakeholders are included upfront in the adaptive management working group to participate in the strategy and design of the whole program, 3) key management questions are used to focus data collection and identify essential management actions, and 4) information flow and the sequence of project stages (actions) are designed to facilitate stakeholder responses. In addition, the chance of success is greatly increased when agencies carefully choose target resources that meet several corollary requirements. A program of experimental reintroductions of Tahoe yellow cress from 2003 to 2006 not only produced a wealth of knowledge useful to managers, it also released 1.5 million new seeds and 10,000 new plantlets into appropriate habitats around Lake Tahoe. Such tangible benefit to the species prompted the U.S. Fish and Wildlife Service to downgrade the priority status of the species under ESA.

An Annotated List of the Endemic Species of Arizona

Andrew Salywon, Wendy Hodgson, Desert Botanical Garden, Phoenix, AZ; Todd Ontl, Desert Botanical Garden and Department of Ecology and Evolutionary Biology, Iowa State University, Ames, IA; and Martin Wojciechowski, School of Life Sciences, Arizona State University, Tempe, AZ

Abstract: In the *Flora of Arizona*, Kearney and Peebles (1964) estimated that roughly 5% (ca.164 spp.) of the flora is endemic to the state, and identified southern Arizona as harboring nearly double the number of endemic species compared to other parts of the state. However, no list of endemic taxa was provided. Therefore, in order to make meaningful comparisons of the endemic diversity with other states and to identify "hotspots" of endemicity within Arizona, we are compiling and annotating a list of the endemic plant taxa in Arizona. The annotations include taxonomic synonomy, publication and typification information in addition to distributional, ecological and evolutionary relationship data. Our working list is composed of ca. 250 taxa from 43 families and identifies the northern portion of the state (namely the Arizona Strip and the Grand Canyon) as harboring the highest percentage of endemics, in contrast to Kearney and Peebles analyses. It is hoped that insights into the relationships between geographical patterns and biological processes that can be gained from the list, including comparisons of the timing and mode of evolution of different groups. For example, *Astragalus*, *Perityle*, *Agave*, *Eriogonum* and *Penstemon* have been identified as the genera with the most endemic species. Not surprisingly these genera are composed of mostly annuals to short-lived perennials, with the exception of *Agave,* and are in groups that have undergone rapid and recent diversification in the Quaternary. In contrast, the woody endemics *Berberis harrisoniana*, *Rhus kearneyi* ssp. *kearneyi*, *Sophora arizonica* (= *Calia*) & *Purshia subintegra* are most likely of Tertiary origin and relictual.

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Southwestern Ciénegas: Rare Habitats for Endangered Wetland Plants

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Abstract. Ciénega refugia for rare plants are medium to low elevation wet meadows characterized by stable springs and seeps in arid regions. Ciénega soils are usually alkaline and highly organic. Several southwestern plant species are confined to these habitats, making ciénega biotic communities distinct from other riverine or lentic wetlands in the region. A comprehensive inventory of southwestern ciénegas has not been completed; however, these habitats are clearly rare and diminishing in extent. Groundwater depletion, erosion, conversion to agriculture or aquaculture, abusive grazing, and exotic weeds threaten most remaining ciénega habitats and the rare species confined to them. Government and non-profit conservation agencies are attempting to restore and preserve a few remnant pieces of previously large ciénegas in Arizona, New Mexico, and Texas. Healthy ciénega habitats require active and continuous management at great effort and expense, especially for weed control.

DEFINITION AND DESCRIPTION

'Ciénega' is Spanish for a swamp, bog, or marsh. It is also spelled 'ciénaga' throughout much of the Spanish-speaking world – especially South America and the Caribbean. The 'ciénega' spelling is prevalent in the American southwest and often used in northern México. The origin of the word 'ciénega' is thought to be a contraction of the Spanish words 'cien aguas' meaning 'a hundred waters or fountains' (Crosswhite 1985). This is an allusion to springs, seeps and wet ground over a large area instead of a single pool, slough, or stream channel.

Ciénegas gained acceptance as distinct climax communities of ecological significance when Hendrickson and Minckley (1985) made a thorough assessment of the ciénegas of southeastern Arizona. They defined the ciénega climax community as mid-elevation (1,000-2,000 m) freshwater wetlands with permanently saturated, highly organic, reducing soils occupied by a low-growing herbaceous cover of mostly sedges and rushes. Few woody plants occur in the ciénega flora and often only as riparian tree species around the drier margins. Ciénegas occur in arid landscapes with high rates of evaporation, so the soils at the drying wetland margins usually have surface crusts of alkali or salts that are the deposited dissolved solids of evaporated or transpired soil solutions.

Ciénega biotic communities of the southwestern United States and northern México are almost always features of springs and spring seeps (Brown 1982, Hendrickson and Minckley 1985, Dinerstein et al. 2000). Not all springs support ciénegas, but almost all ciénegas are supported by springs. These arid-land springs arise where stable aquifers intercept the ground surface in artesian basins or along geologic faults and fractures. They are generally not associated with fluctuating alluvial aquifers in channels that are flood-scoured, so are more likely to be found in the upper reaches of small drainages near geologic faults and igneous extrusions, in karst topography, and on gentle slopes where water-bearing strata have been exposed by river erosion or scarps. Size of individual ciénegas varies greatly from less than one acre to several hundred acres and is an expression of spring flow and topography.

Ciénega vegetation is usually highly productive and dense. A list of plant species for southeastern Arizona ciénegas was assembled by Hendrickson and Minckley (1985). Milford and others (2001) and Sivinski and Bleakly (2004) produced lists of ciénega plants for the Rio Pecos Basin of eastern New Mexico. Most individual ciénegas have relatively low plant species diversity, but contribute a productive and rare subset of wetland species and habitats to an otherwise arid landscape. The most common ciénega plants of the southwestern region are the open water (when present) emergents of bulrush (*Schoenoplectus* spp.) and cattail (*Typha* spp.); sedges and rushes of water-saturated soils (*Eleocharis* spp., *Carex* spp., *Bolboschoenus maritimus* (L.) Palla, *Fimbristylis* spp.); salt- and alkali-tolerant inland saltgrass (*Distichlis spicata* (L.) Greene), scratchgrass (*Muhlenbergia aperifolia* (Nees & Meyer) Parodi), and Mexican or Baltic rush (*Juncus arcticus* Willdenow vars. *mexicanus* (Willdenow) Balslev or *balticus* (Willdenow) Trautvetter) on seasonally saturated and sub-irrigated soils; and alkali sacaton (*Sporobolus airoides* (Torrey) Torrey) on the drier ciénega margins. Woody plants are usually not a significant part of ciénega vegetation cover (Figure 1), but patches of shrubby willows (*Salix* spp.) or willow-baccharis (*Baccharis salicina* Torrey & Gray) may occur and the drier ciénega margins will often have riparian trees such as cottonwood (*Populus* spp.), Arizona ash (*Fraxinus velutina* Torrey), and tree willows.

Figure 1. Blue Hole Ciénega in Guadalupe County, New Mexico (September 2008) with Wright's marsh thistle (right-center) and Pecos sunflower (distant yellow background).

As climax communities associated with aridland springs of the southwest, ciénega-types of vegetation associations should be expanded to include more floristic regions and physical conditions than just the southeastern Arizona ciénegas described by Hendrickson and Minckley (1985). Ciénega synonyms in the Great Basin deserts, Sonoran and Chihuahuan deserts can sometimes include 'vega', 'wet meadow', 'saltgrass meadow', 'alkali meadow' and even 'oasis'. They are not necessarily confined to medium elevations and can also occur around desert springs at low elevations. Water coming from ciénega springs may be fresh or somewhat salty. In short, most ciénega-type habitats are the wet meadows that form around aridland springs and seeps.

It is the relative permanence of the spring features that make many ciénega habitats biologically distinct from other types of wetland communities. Ciénegas are typically positioned in the upper reaches of small drainages or above river channels where they are protected from the scouring floods that frequently modify river marshes and floodplains. Ciénega spring flows may vary, but are less susceptible to the flooding and drying than playa basin wetlands during moist and arid cycles of the climate. Sediment cores from San Bernardino Ciénega in southeastern Arizona show wetland conditions for most of the last 7,000 years (Minckley and Brunelle 2007) and at Cuatro Ciénegas in Coahuila the fossil pollen in sediments indicate nearly identical ecological conditions for more than 30,000 years (Meyer 1973). Such springs are refugia for species that may have been more widespread and common during wetter periods of the Quaternary. Several fish and invertebrate species are now confined to only one or a few aridland springs and the ciénegas they support are small remnants of stable habitat for some rare and endangered plants.

LOSING (WET) GROUND

The interaction of humans with aridland springs and ciénegas is a prehistoric tale of early and prolonged dependence (Hanes 2008; Rhea 2008) with a more recent history of almost universal destruction or diminution during the last two centuries (Unmack and Minckley 2008). Hendrickson and Minckley (1985) documented the history and demise of many southeastern Arizona ciénegas – mostly by arroyo cutting that dropped spring aquifers below the ground surface. The tragic loss of most large springs and ciénegas by water withdrawals and aquifer depletion in the Chihuahuan desert of Trans-Pecos Texas is also well documented by Brune (1981), El-Hage and Moulton (1998), and Poole and Diamond (1993). Of all the southwestern states, the ciénegas of

New Mexico are the least studied and documented in published literature. The following are a few examples of some historic and extant New Mexico ciénegas that I have personally studied.

San Simon Ciénega was one of the wetland jewels in the crown of the southwest. It was a wet valley bottom about five miles long and a half mile broad that straddled the New Mexico/Arizona border in the upper-most reach of the San Simon Valley of Hidalgo County. The perennial spring-run creek had emergent marsh vegetation surrounded by wet meadow bordered with riparian woodland in sharp contrast to the adjacent Chihuahuan Desert scrub. When I first visited in 1994, San Simon Ciénega was dead and being covered with mesquite (*Prosopis glandulosa* Torrey). Many decadent cottonwood and willows trees still survived as reminders of the former wetland. The situation is the same today, but a little grimmer as these senescent tree remnants continue to decline.

The lower part of San Simon Ciénega in Arizona was destroyed just before the turn of the twentieth century by regional overgrazing of cattle and an arroyo erosion cut that lowered the water table (Hendrickson and Minckley 1985). The arroyo headcut was arrested by a dam at the New Mexico border and seemed to spare the New Mexican part of the ciénega. Then irrigated cotton farming moved into the Arizona side of the valley and intercepted the spring aquifer emanating from the Chiricahua Mountains. An anonymous and undated report at the New Mexico Energy, Minerals and Natural Resources Department, Forestry Division documents most of the following events. The spring-run creek stopped flowing in 1952, shortly after irrigated agriculture started. When the Mexican duck was listed as an Endangered species, the New Mexico Game and Fish Department and federal Bureau of Land Management attempted to create some open-water nesting habitat in the still wet valley bottom by detonating powerful explosives. The resulting crater pools were not suitable nesting habitat, created habitat for weedy plants, and the valley bottom continued to dry from irrigated farming in the adjacent uplands. A nesting pond was excavated and frequently pumped full of water, but was eventually abandoned after the Mexican duck was removed from the list of Endangered species for taxonomic reasons. All permanent wetlands quickly disappeared from the valley.

Another loss of desert springs and ciénegas occurred at a cluster of large springs near the dry mouth of the Rio Mimbres in Grant County. The fates of Apache Tejo Spring, Cold Spring, Kennecott Warm Spring, and Kennecott Cold Spring were to be completely captured by wells to supply water to the copper mill at Hurley in the early twentieth century. Walking from creosote desert into these former wetlands to find dusty gray organic soil supporting only clumpy alkali sacaton and surrounded by the decades-old carcasses of big cottonwood trees can only be described as shocking and depressing (Figure 2). Only two springs in the area remain wet to this day – Faywood Hotspring on its travertine

Figure 2. Dead riparian woodland surrounding dry ciénega at former Cold Spring in Grant County, New Mexico (April 1993).

hill with much reduced flow and no ciénega, and nearby Faywood Ciénega, which is supplemented and maintained by piped-in water from a distant upland spring. And what might we have lost from these wetlands? The type collection of *Cleome sonorae* A. Gray (= *Cleome multicaulis* A.P. de Candolle) was made "near the Mimbres" in 1851 and not seen again in the state. Perhaps one of these dead spring ciénegas was the habitat for this rare wetland species that is now likely extirpated from New Mexico.

Most New Mexicans think of Lake Valley as an abandoned mining town in Sierra County, but the original Lake Valley is three miles north of the town at Berrenda Creek. An igneous extrusion across the broad Lake Valley segment backed-up a series of seasonal marshes and a permanent spring and seeps with ciénega vegetation. Berrenda Creek has only intermittent flow during wet seasons and storm events, but the runoff captured in Lake Valley sediments slowly discharged into a perennial spring run at the base of the valley. A diversion levee around Lake Valley was constructed about a century ago that dried the wetlands, which were converted to irrigated agriculture. The diversion outlet caused the lower spring run to erode into a deeply incised channel that still supports riparian woodland, but has lost its ciénega habitats.

Some of the best remaining examples in New Mexico of ciénega habitats around aridland springs occur in the Rio Pecos valley on karst topographies near Santa Rosa (Guadalupe County) and Roswell (Chaves County). Even these are degraded and shrinking in size. Hundreds of acres of seeping ground with spring runs and sinkhole lakes have become surrounded by the City of Santa Rosa. About half of the original ciénega habitats have been damaged or destroyed by excavations for fish hatchery ponds or public fishing ponds; filling for sport fields, buildings, roads and parking lots; and dense infestation by Russian olive (*Elaeagnus angustifolia* L.) and salt cedar (*Tamarix chinensis* Loureiro) forests.

A 25-mile stretch of Rio Pecos valley from Roswell south to Dexter has sinkhole lakes, resurgent creeks, spring runs, and seeps – sometimes with extensive ciénegas. Some of these have also been damaged by fish hatchery operations (Dexter National Fish Hatchery) and recreational development (Bottomless Lakes State Park and Roswell Country Club). Aquifer depletion below a municipal well completely dried a mile-long ciénega north of Dexter and other springs and seeps are likely impaired by the irrigated agriculture that dominates the landscape on the west side of the river. Fortunately, large seeps and spring runs from the highly alkaline Salt Creek aquifer support some ciénega habitats on Bitter Lake National Wildlife Refuge near Roswell. Unfortunately, the wildlife focus on this refuge has caused extensive damage to ciénega habitats with the numerous dikes, diversions and drains constructed to enhance fish and waterfowl habitats – although this is recently changing with more attention being paid to rare wetland plants.

RARE PLANTS OF SOUTHWESTERN CIÉNEGAS

While several animal species are endemic to particular aridland springs or areas of spring features, very few ciénega plants are so narrowly endemic. Some notable exceptions include Amargosa niterwort (*Nitrophila mohavensis* Munz & Roos), Ash Meadows mousetails (*Ivesia kingii* S. Watson var. *eremica* (Coville) Ertter), Ash Meadows gumplant (*Grindelia fraxinopratensis* Reveal & Beatley), and spring-loving centaury (*Centaurium namophilum* Reveal, Broome & Beatley), which are endemic to Mohave Desert springs around the Ash Meadows region of southwestern Nevada and adjacent California. Another very rare ciénega plant with a very small geographic distribution is reclusive lady's tresses orchid (*Spiranthes delitescens* Sheviak). This Endangered orchid is presently known from only four ciénegas in close proximity near the international border of southern Arizona (Coleman 2000).

Most rare ciénega plants have very broad distributions of several hundred, or sometimes more than a thousand, miles in length. They are rare species because their ciénega habitats are very rare. Widespread wetland species usually do not get much attention from rare plant botanists because of multiple-state (or country) distributions and the difficulties of accessing a class of habitat that is predominantly on private property. A few widespread ciénega species, however, are starting to get some much needed scrutiny by botanists and land managers in southwestern states.

Only three extant populations of Parish's alkali grass (*Puccinellia parishii* A.S. Hitchcock) were known at the time this species was proposed for inclusion on the Endangered Species list in 1994. This annual grass occupies the highly alkaline soils of aridland springs and ciénegas. The proposal to list gave southwestern field botanists the incentive (funding) to search for new populations, which located or confirmed a total of 30 sites at seeps and ciénegas – 17 in New Mexico, 11 in Arizona, 1 in eastern California, and 1 in southwestern Colorado (FR Vol. 63, No. 186, 51329-51332, 9/25/98). USDI-Fish and Wildlife Service withdrew the proposal to list in 1998, but New Mexico still lists this plant as state endangered because it is a wetland species with less than 100 acres of total known occupied habitat (New Mexico Rare Plant Technical Council 1999).

The Pecos sunflower (*Helianthus paradoxus* Heiser) is another good example of a widespread ciénega plant that is a threatened species. It occupies only alkaline spring ciénegas from western Texas to west-central New

Mexico. The dramatic and almost complete demise of aridland ciénegas from aquifer depletion in the Chihuahuan Desert of Texas left only two populations of Pecos sunflower in a region that probably contained several. Some of the New Mexico populations are also damaged or threatened by aquifer depletion and nearly all are degraded by exotic tree infestations (USDI-Fish & Wildlife 2008). Pecos sunflower was listed as a federally threatened species in 1999 and its ciénega habitats are finally receiving some management attention specific to the needs of this plant.

Wright's marsh thistle (*Cirsium wrightii* A. Gray) sometimes occurs in the same New Mexican ciénegas occupied by Pecos sunflower, but there appear to be fewer thistle populations in the United States. It ranges from southeastern New Mexico to southeastern Arizona and northern Chihuahua and Sonora. The type locality and single Arizona location at San Bernardino Ciénega has not been seen again since that ciénega was dried by down-cutting of the adjacent Black Draw. Some New Mexico populations at Lake Valley, Sacramento Mountain springs, and the City of Roswell (Country Club) have also been extirpated (New Mexico Rare Plant Technical Council 1999, Sivinski 1995, 2005). This is clearly a threatened ciénega species in the United States; however, the status of this plant in México is unknown. A dismal trend of aridland spring loss in México (Contreras and Lozano 2002, Unmack and Minckley 2008) offers little hope that this species is faring better south of the border. *Cirsium mohavense* (Greene) Petrak (synonym = *Cirsium virginense* Welsh) is a related wetland thistle that may be occupying the same sinking ship in the Mojave Desert except that the Mojave thistle is not exclusively a ciénega plant and also occurs in some hanging garden and riparian habitats (Utah Native Plant Society 2008).

Leoncita false foxglove (*Agalinus calycina* Pennell) also co-occurs with Pecos sunflower and Wright's marsh thistle in a ciénega at Bitter Lake National Wildlife Refuge in southeastern New Mexico. It is otherwise only known from an extant population at the Diamond Y Spring ciénega in western Texas, another historic and ambiguous collection in western Texas, and an historic collection in Coahuila (Poole et al. 2007). This is another species with almost no data available on its status in México. It seems to be exceedingly rare, but much additional research must be accomplished to support the initial appearance of rarity.

Additional botanical surveys of all ciénegas in the southwestern United States and northern México will be needed to fully understand ciénega plant distributions and the threats to their habitats. Botanists should consult southwestern ichthyologists, herpetologists and aquatic invertebrate biologists who have been much more aggressive in locating and gaining access to aridland springs. They can help determine which springs support ciénega habitats and may already know many of the landowners.

MANAGEMENT CHALLENGES

Some remnant southwestern ciénegas have been acquired by federal and state governments and The Nature Conservancy as natural preserves or wildlife refuges. These have usually been protected because of the rare or endangered animals inhabiting the actual spring features, but the rare ciénega plants also need to be considered in preserve management. Ciénegas are productive and dynamic biotic communities that have attracted use by large herbivores for millions of years. A protective fence and hands-off approach for preserve management may only yield a ciénega that is overgrown, thatchy, drying, and pest-ridden (Kodric-Brown and Brown 2007, Unmack and Minckley 2008). Needs for grazing or fire prescriptions, aquifer protection or restoration, and weed control calls for active management.

Restoration and management of ciénegas affected by arroyo cuts that have lowered the potentiometric surface of adjacent springs and seeps will require the very difficult task of aggrading incised channels (Minckley and Brunelle 2007, Turner and Fonseca 2008). The ground water of a dead or damaged ciénega may still be close to the surface, but requires significant sedimentation and restoration of sheet flow to bring the potentiometric surface back to ground level and re-establish a "living" ciénega. On the other hand, former ciénegas supported by spring aquifers that have been depleted by groundwater pumping are unlikely to resume surface flow and become "living" again for the foreseeable future.

Blue Hole Ciénega in Santa Rosa, New Mexico was purchased by the State Forestry Division's Endangered Plant Program in 2005 to preserve critical habitat for the endangered Pecos sunflower and Wright's marsh thistle. This 116-acre ciénega was about one-third infested with Russian olive trees (plus salt cedar to a lesser extent), suddenly ungrazed by livestock, and illustrative of some vegetation management challenges in a ciénega preserve (Figures 3 and 4).

Weed tree control was an immediate concern because the entire ciénega was rapidly trending towards Russian olive woodland. Inmate work crews with chainsaws and backpack herbicide sprayers spent a total of 3,600 man-hours cutting trees, spraying stumps, and broadcasting slash during the late summer and autumn months when the soil surface was dry over much of the ciénega. Winter to summer was an unsuitable period for weed control because effective herbicides could not be used while the soil surface was constantly wet or pooling water. The initial percent kill for tree stumps was about 80%.

Figure 3. Work crew felling Russian olive trees at Blue Hole Ciénega (September 2007).

When the slash had dried for three to five months, the entire ciénega was burned in December. Winter is the only feasible burn period because Pecos sunflowers set seed and die in October and the seeds begin to germinate in late February. The burn and mop-up took two days and was conducted by three State Forestry wildland fire crews, one USDA-Forest Service wildland fire crew and a pumper crew from the Santa Rosa Municipal Fire Department. The fire carried very well through the thick fine fuel of the grass and rush cover, but was generally not hot enough to consume tree slash more than one-inch in diameter.

The bare, open ground of the burned ciénega created optimum habitat for germination and growth of annual ciénega plants such as Pecos sunflower and seepweed (*Suaeda calceoliformis* (Hooker) Moquin-Tandon) (Figures 5 and 6). Perennial ciénega plants quickly developed a lush growth that covered the charred one- to twelve-inch diameter tree slash lying on the ground. Most of the Wright's marsh thistle rosettes that had been burned made new rosettes and many bolted flower stalks the following autumn. Unfortunately, about 20% of the weed tree stumps resprouted, and the still living roots around each dead stump sprouted one or more new weed tree saplings. These were three to four feet tall and wide by October when a work crew spent another 1,000 man-hours treating the resprouts with herbicide.

After almost three years of weed tree control, controlled fire, and expenditure of $80,000, Blue Hole Ciénega might be restored to a point where a small crew can annually destroy new weed tree seedlings within a few days. The Albuquerque Chapter of the Native Plant Society of New Mexico has volunteered to annually inspect the ciénega for other weed species that could arrive and become established, if not quickly detected. Accumulations of dead, thatchy, native vegetation will still have to be managed. Since high densities of Pecos sunflower are desirable at this preserve, intensive livestock grazing during the growing season is not an option. Therefore, controlled fires at suitable frequency (yet to be determined) will be needed for the foreseeable future.

Most southwestern ciénegas are in private ownership because the spring features associated with them are valuable assets in an arid region. Restoration, protection and management of these rare and unique habitats are costly and require perpetual effort. Government programs that acquire ciénegas or assist landowners with their management are greatly needed in the southwestern states.

Figure 4. Controlled burn of Blue Hole Ciénega (December 2007).

Figure 5. Photo reference point at Blue Hole Ciénega before treatment (August 2006).

Figure 6. Photo reference point at Blue Hole Ciénega after treatment (September 2008).

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A New Look at Ranking Plant Rarity for Conservation Purposes, With an Emphasis on the Flora of the American Southwest

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Abstract. A new rarity ranking system for prioritizing vascular plants for conservation and research is developed. This new system, termed the "At-Risk System" (ARS), ranks species using six variables, with each variable scored from 0-3; rarity type, biology (life-from, breeding system, pollination ecology, and dispersal ecology), population trend, anthropogenic threats, climate change vulnerability, and number of populations. Scores can range from 0 to 18, with higher numbers indicating greater potential at-risk status. Selected species from the American Southwest are scored using the new system. Scores range from 2 for *Pinus ponderosa* to 18 for the critically endangered *Arctomecon humilis*. We know little about the biology and status of many rare species in the Southwest. This lack of knowledge was incorporated by using an automatic 3 score for the variables for which data are not available, which highlights uncertainty. For many species, the ARS score is not always strongly correlated with other ranking systems such as its ESA status or NatureServe G rank.

The American Southwest supports one of the richest floras in North America, with perhaps as many as 6,000 indigenous species distributed among the deserts and mountains of the region. The area includes six major arid and semi-arid biomes: the Chihuahuan, Colorado Plateau, Great Basin, Mohave, and Sonoran Deserts, and the Madrean region that extends from Mexico into southern New Mexico and Arizona. A recent compilation of rare species (Spence unpublished) has put the number of G1 and G2-ranked species at ca. 700. This preliminary list does not include the numerous local varieties of more common and widespread species, nor those species restricted to the Mexican portions of the biomes. With scarce resources, relatively few field botanists, and impending major climate change there is an urgent need to prioritize these species for conservation purposes. Unfortunately, very little is known about the basic ecological and biological characteristics of many of them. Thus, although there are ca. 260 G1 species in the American Southwest, we know relatively little about how to prioritize this list based on the likelihood of near-term extinction. Any attempt to rank large numbers of species for conservation funding must thus use a "triage" approach, based on general biological characteristics when more detailed quantitative data are not available. Rarity is also an elusive characteristic that may not be well reflected in its G rank, as it can change through time and space, and is not easily defined or quantified. Thus what defines rarity can vary across different scales (Harper 1981).

There are three principal ranking systems that exist for rare plants, two of which have been applied locally. The California Native Plant Society ranking system has been developed for the flora of California (California Native Plant Society 2001). Their system includes four lists indicating general status inside and outside of California, combined with a subjective 3-number code indicating local distribution, rarity and risks. These values are based on fairly detailed information, which is often not available for rare plants elsewhere in the Southwest. The California 1B list of rare endemic species includes over 1,000 taxa. The Nature Conservancy developed the G ranking system, which was then applied to state-level species lists throughout the West. However, the G ranking is a rather coarse-scale tool given the large number of species with either a G1 or G2 rank regionally. The third system, the IUCN threat categorization (Mace 1994; Mace and Lande 1991), has not been applied to southwestern rare plants. Other more detailed systems have been developed (e.g., Bond 1994; Kwak and Bekker 2006) but often require detailed information on genetics and estimates of pollen flow and fecundity. There remains a need among field biologists, land managers and conservation planners for a general system that can quickly rank and prioritize species within the G1-G2-G3 levels.

A significant amount of research has been done in attempting to correlate species extinction and rarity with biological traits (see reviews in Brigham and Schwartz 2003; Krupnick and Kress 2005; Kunin and Gaston 1997). In a seminal paper, Rabinowitz (1981) developed a rarity matrix that was based on geography, habitat specialization, and local population abundance. This was further discussed and applied by Kruckeberg and Rabinowitz (1985). However, this matrix approach to rarity has been little utilized in rare plant conservation planning. Kruckeberg and Rabinowitz suggested several avenues of research to pursue that may provide insight into rarity, including molecular/genetic, habitat, demographic and breeding system characteristics. More recently, Bevill and Louda (1999) examined the literature and documented 71 plant variables that had been used in the study of rarity and extinction. Many of these require detailed demographic or lab-based genetics research, and are thus impractical at a scale of the American Southwest in the near-term. Also, many reviews and studies have failed to find a strong link between specific variables and rarity (e.g., Aizen et al. 2002; Lavergne et al. 2004), although other studies have found such links (e.g., Sjöström and Gross. 2006). The general consensus is that demographic and breeding system data and molecular investigations overlaid with climate envelope analyses provide the best research approaches to understanding rarity (Brigham and Schwartz 2003; Gitzendanner and Soltis1999; Kunin and Schmida 1997). Beyond these more detailed techniques, some regional surveys have found traits that are correlated with rarity, including life-form and longevity (Harper 1979; Sjöström and Gross 2006;), breeding system (Sakai et al. 2002; Sjöström and Gross 2006; Sodhi et al. 2008;), pollination ecology (Robertson et al. 1999; Sakai et al. 2002; Sodhi et al. 2008) and dispersal ecology (Bond 1994).

Any ranking system should be general enough to be widely applicable, but also provide the ability to rank species from potentially low to potentially high "at-risk" status. It should also be based on what is known about the biology of rarity. I have developed a preliminary ranking system, with an emphasis on the arid and semi-arid flora of the American Southwest, based on six elements. This system should be viewed as a draft attempt to provide an early warning ranking for those species that potentially may be most at-risk in the Southwest. The time-frame is the next 50 years, when anthropogenic threats and climate change are likely to push many rare plants towards extinction. The elements are rarity type, biology, population trends, number of populations (TNC element occurrences), direct anthropogenic threats, and climate change vulnerability. Each of these is discussed below, with examples and ranking criteria in tabular form.

ELEMENTS OF THE RANKING SYSTEM

Each element is scored from 0 (low risk) to 3 (high risk). The six elements are rarity, biology, population trends, anthropogenic threats, climate change vulnerability, and G rank (here called the N rank, see below in Table 3). The final score is called the at-risk score (ARS) for each species. Each of the elements is described below.

1. Rarity Type

Table 1 lists the seven forms of rarity as defined by Rabinowitz (1981), scored either 0 or 1 for each level of the three categories. Each of the eight types is also coded from RI-RVIII. Since the three variables used in the system are subjective, they need to be defined in the local context of the American Southwest. Widespread species are defined as those that are typically found across one or more provinces (more than one subprovince) as defined by McLaughlin (2007). Thus a widespread species could occur in the Southwestern Region, Sonoran Province, and both the Sonoran and Mohavian subprovinces. Geographically local species are defined as those endemic to a single subprovince, such as the Colorado Plateau or Great Basin. Habitat specialists are defined as species that are generally restricted to one or a very few similar soils or substrates, while habitat generalists occur across a variety of substrates and soil types. Wetland species are also typically characterized as habitat specialists. Abundance at local sites (population or element occurrences) is more difficult to define, and remains subjective in my system. Many endemic species can be quite abundant locally (cf. Lesica et al. 2006; Spence unpublished data), while other species always seem to be uncommon or sparse where they are found. A species can have a final score of 0 for widespread common habitat generalists, to 3 for local sparse habitat specialists.

2. Biology

Detailed studies have shown that traits most closely related to rarity include low population size, demo-

Table 1. The Rabinowitz rarity matrix (Rabinowitz 1981) scored from 0-3 for the ranking system.

	Geographic Range	Widespread (0)		Local (1)	
	Habitat Specificity	Generalist (0)	Specialist (1)	Generalist (0)	Specialist (1)
Abundance at Sites	Common (0)	RI 0	RII 1	RIII 1	RIV 2
	Sparse (1)	RV 1	RVI 2	RVII 2	RVIII 3

graphic factors, competitive abilities, inbreeding depression, low pollen/ovule ratios and pollen limitation, or highly specialized breeding, pollination and dispersal systems (Brigham and Schwartz 2003; Byers and Meagher 1997; Cole 2003; Gitzendanner and Soltis 2000; Purdy et al. 1994; Schemske et al. 1994; Walck et al. 1999). In some cases rarity may also occur due to extreme and rapid habitat loss in formerly common species (eg., Ge et al. 1999). In the absence of data on these variables, proxies are needed that can be linked to the biological characteristics of rare species. Although the literature is somewhat ambivalent (e.g., Aizen et al. 2002; Bevill and Louda 1999; Sakai et al 2002), some studies have suggested that a variety of basic plant characteristics may be used to provide preliminary indications of possible vulnerability and general extinction probabilities.

Thus self-incompatible breeders, species with highly specialized and rare pollinators, and species that depend on highly specialized dispersers are often considered to be more at risk than species with more generalized biology (Aizen et al. 2002; Bond 1994; Buchmann and Nabhan 1996; Kwak and Bekker 2006). I have developed a set of four proxy variables based on the literature, with the caveat that these are only general indicators of potential at-risk status. Detailed studies are clearly needed for most species in the Southwest in order to determine the exact causes of rarity, which are likely to be taxon (genus, species) specific (Bevill and Louda 1999). The four proxy variables (traits) are life-form, breeding system, pollination ecology, and dispersal ecology. Each of these is discussed with examples in Table 2. This element is scored for a species by selecting the single highest score among the four biological traits, rather than averaging them.

Table 2. The biology element scored using four principal biological traits to characterize the vulnerability of a species to extinction.

Biological Traits Ranked	**Explanation**	**Score**	**Examples**
	Life-form and longevity		
Long-lived woody species	Long life buffers against environmental change (>100 yrs)	0	Conifers, *Coleogyne*
Short-lived woody species or long-lived herbaceous species	Some vulnerability, but generation times tend to buffer against short-term changes (>25 yrs)	1	*Atriplex*, *Ericameria*, *Pediocactus*
Short-lived perennial herbaceous species	Vulnerable, short generation time may not be able to track environmental changes (3-25 yrs)	2	*Astragalus*, *Eriogonum* *Penstemon*
Annual or biennial	Extremely vulnerable, with seed bank longevity a critical factor in persistence of populations	3	*Cryptantha*, *Ipomopsis*, *Phacelia*
	Breeding System		
Autogamous	Can set seed despite small numbers of individuals through selfing	0	Many annuals
Mixed mating	Flexible system that allows for reproduction with or without pollinators, selfing occurs	1	Many generalized insect pollinated taxa
Facultative outcrossing; some autogamy	Generally requires pollen transfer between individuals, with low selfing rates often associated with reduced fitness	2	Many insect pollinated taxa
Obligate outcrossing; xenogamy, dioecy, loss of sexual reproduction, or breeding system unknown	Requires more than one individual, specialized pollen transfer	3	Orchidaceae, dioecious species

Table 2. continued

Biological Traits Ranked	Explanation	Score	Examples
	Pollination Ecology		
Wind, water, self-pollination	No requirements for animal vectors, can pollinate and set seed regularly	0	Betulaceae, Conifers, *Populus*, aquatic species, many annuals
Generalized insects and vertebrates	Generally can pollinate and set seed through visitation of many different animal groups	1	Asteraceae, other open "dinner-plate" flowers
Generalized vertebrates	Generally can pollinate and set seed as long as hummingbirds, or other bird or bat species are present	2	Bat and hummingbird-pollinated species
Specialized animal pollination, or pollination system unknown	Requires a specialized, and often rare, insect or vertebrate species for pollination and seed set	3	Agavaceae, *Asclepias*, Orchidaceae
	Dispersal Ecology		
Wind, water	Can be transported easily by wind or water	0	Spores, dust seeds, wind dispersed species
Generalized animal dispersal	Many bird and mammal species can disperse fruits	1	Berry-producing species, sticktights, etc.
No structural or specialized features	No requirements for animal-mediated dispersal	2	Smooth seeds, short-distance dispersal only
Specialized animal dispersal	Requires a particular specialized animal vector to disperse seeds, such as Clark's nutcracker, Red crossbill, some ant-dispersed species	3	Fruits/seeds designed for specialized dispersal; *Pinus albicaulis*, *Viola* sp.

3. Population Trends

Mace (1994) suggested that population declines or loss of populations could be used to rank rare species. When data are available, this element can provide an accurate and straight-forward determination of the at-risk status of a species, but detailed information on population size and demographic data are difficult to collect and such data sets remain rare. General anecdotal information can be of some use in scoring a species in this element, however, such as loss of populations or general observational data showing declining numbers in populations. It is recommended that if time series, demographic, or abundance data are not available, that a species should be scored conservatively (higher), including a 3 when relevant as "unknown trends" (Table 3).

4. Direct Anthropogenic Threats

Anthropogenic threats can include direct and indirect threats through climate change. I have separated out climate change from other more direct anthropogenic threats as the specific characteristics used to score them are different. Direct threats include water diversion or ground water pumping, recreational activity (e.g., OHV use), domestic livestock grazing, mining, agricultural development, introduction of invasive exotics, or urbanization. Threat levels can vary from minimal such as is found in many protected areas, to severe on lands around rapidly growing urban centers. This element is scored based on approximate values for impacts to habitat, ranging from generally minimal to >90% of a species habitat impacted. GIS analysis with ground surveys are often necessary to quantify the extent of impacts, but generally a rough first approximation can be made based on the knowledge of researchers familiar with the species and its habitat and associated threats. Thus the species scores remain somewhat subjective, based primarily on levels of degradation or impacts to the species overall habitat. Often this is not well known or is difficult to categorize. Especially difficult to quantify is the magnitude and imminence of these threats, and more work is needed to develop a more objective set of criteria. For now, the element is scored based on the presence of impacts regardless of intensity and timing. Generally, when threats are poorly known and hard to quantify given available information, it is recommended that a conservative (higher) score be used. This element is scored range wide in this preliminary analysis (Table 3).

5. Climate Change Vulnerability

The climate envelope of a species can be modeled to predict distributional changes with global warming (e.g., Miles et al. 2004). Although we lack data for many species, a proxy variable that can provide a first approximation to the vulnerability of a species to climate change is its elevation range. If a species has a relatively broad elevation range, populations along the gradient will be adapted to local climates, and the species genetic ability to adapt will likely be greater than in a species with a very small elevation range exposed to a much smaller range of climate variability. Elevation ranges from <100 meters to >1000 meters are used to score each species for climate change vulnerability (Table 3).

6. Number of Known Populations

This element in the ranking system is based on the general concept of element occurrences developed by the Nature Conservancy and further refined by NatureServe (Faber-Langendoen et al. 2009). The five categories are the same as the G and S ranks on the various state and state natural heritage databases, although I have provided more explicit criteria for the G4 and G5 levels. Species with widespread continuous populations, such as many conifers, are ranked G4 if found within a single subprovince, and G5 if they are in more subprovinces. Thus a widespread species such as Saguaro (*Carnegiea gigantea*) is ranked as a G4, despite its large population size, because of its restriction to the Sonoran Desert. Since there are slight differences between this ranking element and the G scale, I have given this element the letter N for number of known populations. The scores are inverted from the N rank, thus a N1 is scored a three, an N2 a two, a N3 a one, and N4N5 a zero.

Table 3. Four additional elements of the scoring system for ranking at-risk species, with scores from 0-3, and explanations for how each is scored.

Ranking Elements 3-6	**Score**	**Explanation**
3. Population Trend		Historical trends (if known) since approximately 1900, or when the species was first discovered.
Stable or increasing	0	Populations are secure for the foreseeable future, with trends exhibiting natural short and long-term variability
Minor declines	1	Data are available to indicate that some declines have occurred, (<1% of total population), but overall most populations appear to be stable
Moderate declines	2	Data indicate moderate declines, with few populations stable and others showing declines from 1% to 10% of total numbers per year
Major declines	3	No data available, or data indicate that major and rapid declines in most populations are occurring throughout range of species; >10% decline in total numbers per year
4. Direct Anthropogenic Threats		Scores are typically applied range-wide, although they could be used in a more narrowly defined region if needed.
No direct threats	0	Few if any impacts from recreation or domestic livestock grazing, no invasive exotics present, no mining activity, recreational impacts largely absent, etc.; <1% of habitat impacted.
Minor threats	1	Minor recreational or domestic grazing impacts, few if any invasive exotic species present; <10% of habitat impacted
Moderate threats	2	Recreational impacts obvious due to development, OHV activity; intensive livestock grazing, some agricultural conversion, water developments or minor urbanization, invasive exotics present but not dominant; 10-50% of habitat impacted
Severe threats	3	Impacts obvious and immediate, major habitat degradation or conversion, extensive OHV activity, development of water sources, urbanization, invasive exotics dominant, etc.; >50% of habitat impacted; or habitat impacts unknown

Table 3. continued.

Ranking Elements 3-6	Score	Explanation
5. Climate Change Vulnerability		Estimate the elevational range based on population locality information.
Low	0	Climate envelope and/or elevation range wide (>1000 m), apparently secure from climate change for the next 50 yrs
Moderate	1	Climate envelope and/or elevation range moderate (>500 m), some vulnerability to climate change with moderate declines expected in next 50 yrs, secure for next 10 yrs
High	2	Climate envelope and/or elevation range small (100-500 m), vulnerable to climate change in the next 10 yrs, long-term (>50 yrs) probability of survival moderately low, with major population declines
Severe	3	Climate envelope/elevation range very small (<100 m), highly vulnerable to climate change, probability of survival in long-term (>50 yrs) very low to none, declines or local extirpation expected within 10 yrs; or elevation range unknown; or an obligate wetland species in American Southwest
6. Number of known populations		
N0	--	Extinct, at least in wild
N1	3	1-5 known populations, endangered (=G1)
N2	2	6-20 known populations, threatened (=G2)
N3	1	21-100 known populations, vulnerable (=G3)
N4	0	101-300 known populations, or relatively widespread and in more or less continuous stands, apparently secure (=G4)
N5	0	>300 known populations or widespread and continuous, secure (=G5)

For many species the definition of what constitutes a discrete population is difficult. In the case of widespread common species that occur in large continuous stands, the need to define discrete populations is of less importance than for rare species with localized scattered distributions In most cases, G1, G2, and G3 species tend to occur in scattered populations with gaps, where they are absent even in suitable habitat. For many of these species, gene flow and dispersal are likely to be relatively low, thus isolated populations, even if only a few hundreds of meters apart, can be effectively considered discrete and non-interacting populations. In Table 3, those species with larger more continuous species (G4 or G5) can be scored without reference to the number of discrete populations.

SCORING SPECIES USING THE SYSTEM

For each species, the at-risk score is the sum of the scores for each of the six elements: rarity, biology, declines, anthropogenic threats, climate change vulnerability and N populations (see Tables 1-3), thus:

At-risk Score (ARS) = rarity type + biology+ declines + threats + climate change + N score

A local sparse habitat specialist with only 1-5 known occurrences would be scored very high. The larger the score, the more potentially at-risk the species should be considered as a first approximation. The overall conservation score can vary from 0 to 18. Examples for selected species are given in Tables 4 and 5 and are discussed below.

General information on the status of a species should always be included for conservation planning (see Table 5). Species should be characterized as part of the ranking system by at least some basic characteristics such as life-form, nativity, geographic distribution and protection status. Nativity would include three categories: indigenous (native, widespread), endemic (native, restricted to a subprovince), and paleoendemic (local, may be in one or more subprovinces, phylogenetically and geographically isolated; *sensu* Stebbins and Major 1965). Geographic distribution is best characterized by the classification of McLaughlin (2007), who has developed the most current and detailed analysis of species distributions and floristic regionalization for the American Southwest. Protection status (land management categories) range from highly protected NGO preserves, many national parks, etc., through general public lands including wilderness, to state lands, and finally private lands. The categorization of Scott et al. (1993) provides a useful approach to categorize species. The percentage of the total number of populations in each of the land management categories should be determined, as it will provide useful additional information to make informed decisions about which species to prioritize for conservation funding.

RESULTS

If the system is to be useful, it must accurately reflect the status of known at-risk species. Results of scoring and ranking for 20 selected species using the system can be found in Tables 4 and 5. These scores are based primarily on species I have some familiarity with, and in some cases the ranking should be considered tentative. A variety of species were used as examples, ranging from critically endangered endemics such as *Artomecon humilis* and *Ranunculus aestivalis*, sparse widespread specialists such as *Epipactis gigantea*, and common endemics such as *Chrysothamnus stylosa*, to widespread

Table 4. Selected species of the American Southwest tentatively scored with the ranking system. The final at-risk score (ARS) is listed. Scores in parentheses reflect uncertainty or lack of data about some aspect of the scoring. The ARS can vary from 0 (low at-risk) to 18 (critically endangered).

Species	Rarity	Biology	Trend	Threats	Climate Change	N	ARS
Arctomecon humilis	3	3	3	3	3	3	18
Ranunculus aestivalis	3	2	3	3	3	3	17
Ipomopsis sancti-spiritus	3	2	(3)	2	3	3	(16)
Astragalus ampullarioides	3	3	2	2	3	3	16
Pediocactus bradyi	3	3	2	2	3	2	15
Puccinellia parishii	2	(3)	2	3	3	2	(15)
Actaea arizonica	3	3	2	2	3	2	15
Penstemon albomarginatus	3	2	2	2	2	2	13
Camissonia atwoodii	3	3	1	1	3	1	12
Ostrya knowltonii	2	(3)	(3)	1	2	1	(12)
Spiranthes diluvialis	2	2	2	1	3	1	11
Cycladenia humilis	2	2	1	1	3	1	10
Epipactus gigantea	2	3	1	2	2	0	10
Carnegiea gigantea	1	3	1	2	2	0	9
Cirsium rydbergii	2	2	1	1	2	1	9
Salix gooddingii	1	2	1	2	3	0	9
Erigeron maguirei	3	2	1	0	1	1	8
Chrysothamnus stylosa	1	1	1	2	1	0	6
Quercus gambelii	0	3	0	1	1	0	5
Pinus ponderosa	0	2	0	0	0	0	2

common species like *Pinus ponderosa*. The conservation scores range from 18 for *A. humilis,* 17 for *R. aestivalis*, and 9 for *E. gigantea*, 6 for *C. stylosa*, and 2 for *P. ponderosa*. If the score is in parentheses, this means that some aspect of its threat status, biology, distribution, etc., is unknown. Uncertainty resulting from a lack of data or understanding of the species status and biology should be included in the ranking system (W. Fertig, pers. comm. 2009). When an element cannot be scored due to a lack of data, that element is automatically scored a 3, thus tending to elevate the species in the ranking list.

DISCUSSION AND FUTURE WORK

The first aspect of this approach to ranking that needs to be understood better is how the at-risk score (ARS) is distributed across a large number of rare taxa. Are there distinct breaks in the score that reflect underlying causes of rarity, or are the scores more likely to exhibit a continuous distribution? If breaks occur, can they be related to other ranking systems, such as the IUCN categories of critically endangered, endangered, and threatened? The significance of a high score is probably clear in this system as in others, as those species with high scores are likely to be already endangered. But we still need to know what kind of vulnerability to human-caused threats and climate change intermediate scores might reflect. Ultimately, the system may need to be refined and altered as ranking of species is completed and patterns begin to emerge.

Since the ARS reflects a preliminary triage approach to “potential” vulnerability to near and mid-term threats (the next 10-50 years), a first use of the system would be to seek funding for research focused on medium to high-ranked species to see if in fact they are endangered or are likely to become endangered. Some previous work shows that species that initially were considered rare and in some cases listed under the Endangered

Table 5. General ranking, rarity type, nativity and geographic range for selected species of the American Southwest. The geographic ranges are derived from McLaughlin (2007; Figure 3).

Species	Rarity	ARS Score	Nativity	Geographic Range
Arctomecon humilis	RVIII	18	Endemic	Mohave Desert
Ranunculus aestivalis	RVIII	17	Endemic	Colorado Plateau
Ipomopsis sancti-spiritus	RVIII	(16)	Endemic	S. Rocky Mountains
Astragalus ampullarioides	RVIII	16	Endemic	Mohave Desert
Pediocactus bradyi	RVIII	15	Endemic	Colorado Plateau
Puccinellia parishii	RVI	(15)	Indigenous	Southwestern Region
Actaea arizonica	RVIII	15	Paleoendemic	Colorado Plateau + Madrean
Penstemon albomarginatus	RVIII	13	Endemic	Mohave Desert
Camissonia atwoodii	RVIII	12	Endemic	Colorado Plateau
Ostrya knowltonii	RVIII	(12)	Paleoendemic	Colorado Plateau + s NM
Spiranthes diluvialis	RVI	11	Indigenous	Colorado Plateau + Great Plains
Cycladenia humilis	RIV	10	Paleoendemic	Northern and Southwestern Regions
Epipactis gigantea	RVI	10	Indigenous	Widespread North American
Carnegiea gigantea	RIII	9	Endemic	Sonoran Desert
Cirsium rydbergii	RIV	9	Endemic	Colorado Plateau
Salix gooddingii	RII	9	Indigenous	Eastern and Southwestern Regions
Erigeron maguirei	RVIII	8	Endemic	Colorado Plateau
Chrysothamnus stylosa	RIII	6	Endemic	Colorado Plateau
Quercus gambelii	R1	5	Indigenous	Southwestern Region
Pinus ponderosa	RI	2	Indigenous	Northern and Southwestern Regions

Species Act have after further surveys been found to be relatively common. A good example of this is the Maguire Daisy, *Erigeron maguirei*, which was federally listed as threatened prior to comprehensive surveys of potential habitat. It has since been found to be fairly common and is recommended to be upgraded to G3 status (Clark and Tait 2007). Its ARS score (8) is lower some other widespread species such as *Epipactus gigantea* and *Salix goodingii*.

There are several future directions that can be taken with this plant rarity ranking system. First, a workshop needs to be held where botanists with knowledge of various rare species get together and test the ranking system with a species list. Such a workshop is tentatively planned for 2011 to examine and finalize the G1G2 list of 700 species in the American Southwest. A second direction is for individual researchers to use the ranking system in their own area of expertise and determine how well it can be applied, how relevant it may be, and what refinements may be needed. It is hoped that readers of this paper will be interested in doing this. I encourage those of you who attempt to use the system to contact me with comments, criticisms, and suggestions. Finally, if in the future this ranking system, or some version of it, is deemed to be useful for conservation planning, it then needs to be incorporated into future action plans, regional planning efforts, conservation documents, and heritage databases.

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The Contribution of Cedar Breaks National Monument to the Conservation of Vascular Plant Diversity in Utah

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Abstract. Like most national parks in Utah, Cedar Breaks National Monument was initially established to protect its spectacular scenery rather than to preserve biological diversity. At less than 2500 ha, the monument is one of the smallest in the region and has a relatively small vascular flora of 354 documented species. Based on conventional measures of species richness (alpha diversity), Cedar Breaks might not seem like an important component of the protected area network of Utah. However, nearly 10% of the flora of Cedar Breaks is comprised of local or regional endemics that are mostly restricted to the Claron Formation or volcanic substrates. Many of these are rare species of high management interest. Our surveys in 2007-2008 documented nearly 1200 point locations for 17 of the monument's rarest plants, including first records for *Aster welshii* and *Jamesia americana* var. *rosea*. The monument is especially significant in terms of beta diversity or complementarity, as it protects 63 plant species that are not otherwise found in NPS units in the state. As measured by an averaged Jaccard's Coefficient of Similarity, Cedar Breaks National Monument has the second most unique flora among the parks in Utah.

The Cedar Breaks Amphitheater is a large bowl-shaped valley carved from orange and white limey sandstone layers of the Eocene Claron Formation on the west face of Cedar Mountain, about 18 miles east of Cedar City in southwestern Utah (Figure 1). Local Indian tribes called the area "the circle of painted cliffs" or the "place where the rocks are sliding down all the time". Early Mormon settlers named it Cedar Breaks for the abundance of juniper (known locally as 'cedar') and the precipitous badland cliffs or breaks. President Franklin Roosevelt acknowledged the area's "spectacular cliffs, canyons, and features of scenic, scientific, and educational interest" in designating Cedar Breaks as a national monument under the Antiquities Act in 1933 (Evenden et al. 2002, Fertig 2009b). Administration of the monument was transferred from Dixie National Forest to the National Park Service (NPS), to be managed to "conserve unimpaired" the area's natural and cultural resources and values "for the enjoyment of this and future generations" (NPS 2000).

Protection of native biological diversity was not one of the rationales for creating Cedar Breaks National Monument, though this would eventually become an important part of NPS's mandate to conserve natural resources. The botanical significance of the Cedar Breaks area was just beginning to be discovered in the early 1930s. Botanists George Goodman and C. Leo Hitchcock collected the holotypes of Breaks draba (*Draba subalpina*) and Cedar Breaks wild buckwheat (*Eriogonum panguicense* var. *alpestre*) from the rim of the Cedar Breaks Amphitheater in 1930 and Bassett Maguire added the holotype of Cedar Breaks daisy (*Erigeron proselyticus,* or *Erigeron sionis* var. *trilobatus*) in 1934 (Fertig 2009b). These species are among a suite of nearly two dozen Claron formation endemics restricted to the Cedar Breaks area and the vicinity of Bryce Canyon in south-central Utah (Madsen 2001).

Today Cedar Breaks National Monument is part of a network of highly protected areas that conserve biological diversity. This network includes other NPS units (national parks, monuments, recreation areas, and historic sites), designated wilderness areas, research natural areas, BLM-managed national monuments, and private nature preserves such as those managed by The Nature Conservancy. In Utah, these lands cover nearly 14% of the state (Prior-Magee et al. 2007). Though extensive, the Utah network does not yet capture a representative sample of the full array of the state's biological diversity. Protection remains biased towards common and widespread species and vegetation types of low economic use (Fertig 2010a, Prior-Magee et al. 2007).

The purpose of this paper is to examine the contribution of Cedar Breaks National Monument to the state's preserve network by comparing the monument's floristic composition, species richness (alpha diversity), degree of endemism, and number of rare species with that of other parklands. We hope to demonstrate that despite the monument's small size, low alpha diversity, and relatively homogeneous vegetation, Cedar Breaks is significant because of its large number of plant species that are not protected elsewhere (i.e., the monument has high complementarity or beta diversity). We also hope to show how comparing annotated species checklists can be useful for identifying and prioritizing specific taxa that are missing or under-represented in the preserve network.

METHODS

From 2005-2008 we developed a revised checklist of the vascular plant flora of Cedar Breaks National Monument (Fertig 2009b, Fertig et al. 2009c). This entailed re-examination of over 700 specimens from the Cedar Breaks herbarium, as well as relevant collections housed at Brigham Young University, the University of Wyoming, and the New York Botanical Garden's Virtual Herbarium. Additional species records were obtained through a review of previous park checklists, weed surveys, and vegetation studies (Buchanan 1992, Dewey and Andersen 2005, Jean and Palmer 1987, Roberts and Jean 1989, Springer et al. 2006). Field surveys were also conducted to corroborate unvouchered reports and in conjunction with a systematic rare plant inventory (Fertig and Reynolds 2009). The final checklist was annotated with information on synonyms, taxonomic problems, population size, growth form, global distribution, nativity, flowering period, and habitat.

Eighteen rare local or regionally endemic plant species from Cedar Breaks National Monument and adjacent portions of the Ashdown Gorge Wilderness Area of Dixie National Forest were surveyed in 2007-2008 (Fertig and Reynolds 2009). Populations of target species were mapped using a Global Positioning System (GPS) device and data were collected on population size, associated species, habitat conditions, and potential threats. Most species were mapped as individual points representing the centrum of relevé-like plots of approximately 25-30 square meters. Populations of Arizona willow (*Salix arizonica*) occurred in sufficiently dense patches to be mapped as polygons.

We assembled additional species checklists for other NPS units and the BLM's Grand Staircase-Escalante National Monument (Figure 2, see Table 3 for citations). These checklists and our data for Cedar Breaks National Monument were compiled into a master statewide checklist in Microsoft excel format. The checklist followed the taxonomy and nomenclature of Welsh and others (2008). Only Utah-specific data were entered for those parks that crossed state lines (Dinosaur and Hovenweep National Monuments and Glen Canyon National Recreation Area). Unfortunately, complete species lists are not available for most wilderness areas, research natural areas, TNC preserves, and other highly protected areas, so these were excluded from the analysis. Simple queries were run in excel to compare overall species richness between parks. Jaccard's index of similarity[1] was calculated across pairs of parks to quantify beta diversity.

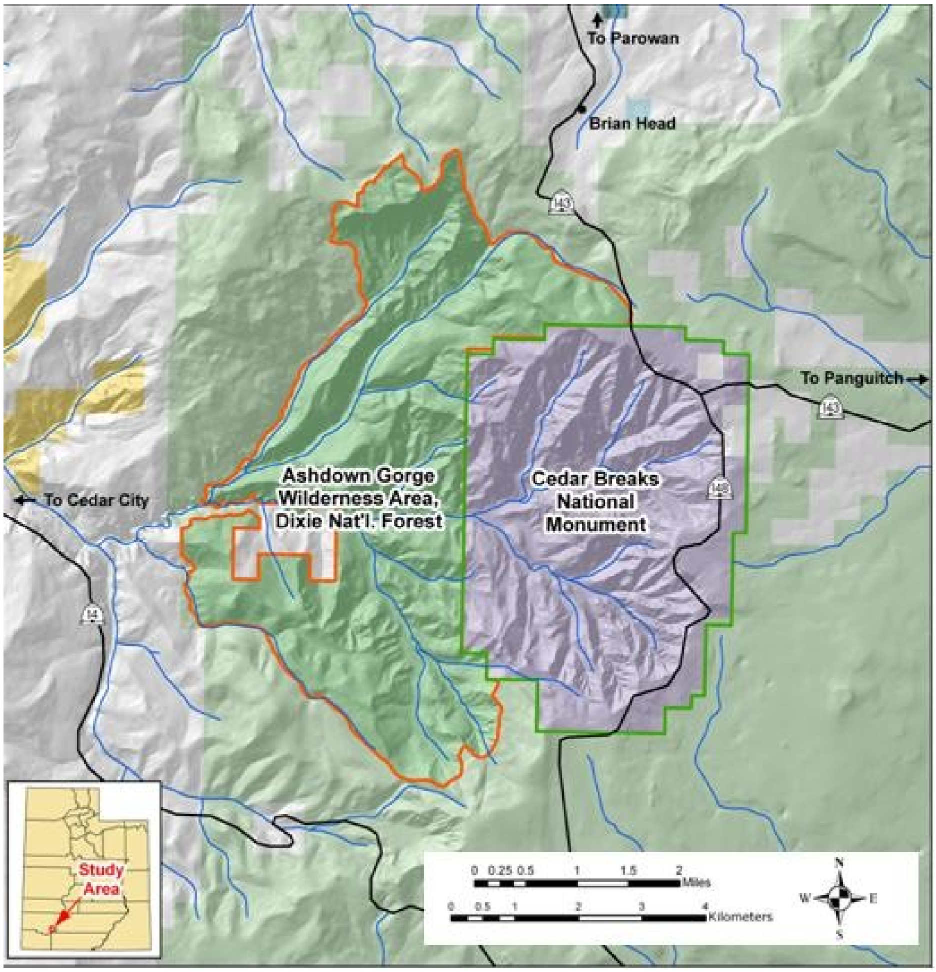

Figure 1. Cedar Breaks National Monument and Ashdown Gorge Wilderness Area, Iron County, Utah. Map courtesy of Zion National Park Resource Management & Research GIS.

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[1] Jaccard's Coefficient of Similarity is calculated by the formula $C/(N_1 + N_2 - C)$, where C = the number of taxa shared between two samples, N_1 = the number of taxa in sample one, and N_2 = the number of taxa in sample two.

RESULTS

Species Richness

Based on our re-examination of herbarium specimens, review of literature, and new field work, 354 species and varieties of vascular plants (Table 1) are currently known from Cedar Breaks National Monument (Fertig 2009b, Fertig et al. 2009c). At least 74 of these taxa have been discovered since 2005. Overall, the monument's flora has increased by 21% since Roberts and Jean (1989) reported 277 species for the area. The flora of Cedar Breaks contains 9.7% of the 3659 native and naturalized plant species documented in Utah by Welsh and others (2008) and 36% of the 156 reported families.

Figure 2. National Park Service units and BLM-managed national monuments in Utah. Park acronyms: ARCH (Arches National Park), BRCA (Bryce Canyon National Park), CANY (Canyonlands National Park), CARE (Capitol Reef National Park), CEBR (Cedar Breaks National Monument), DINO (Dinosaur National Monument), GCNRA (Glen Canyon National Recreation Area), GOSP (Golden Spike National Historic Site), GSENM (Grand Staircase-Escalante National Monument), HOVE (Hovenweep National Monument), NABR (Natural Bridges National Monument), RABR (Rainbow Bridge National Monument), TICA (Timpanogos Cave National Monument), ZION (Zion National Park). Map courtesy of Zion National Park Resource Management & Research GIS.

Native species account for 94.9% of the flora of Cedar Breaks National Monument (336 species). Nearly 82% of the species range widely across western North America and are common in Utah (Table 1). Eighteen taxa are categorized as local endemics that occupy a total area of less than 16,500 square kilometers and are restricted to the immediate vicinity of Cedar Breaks or adjacent high plateaus of south-central Utah (mostly the Tushar Range and Paunsaugunt Plateau) (Fertig 2009b). An additional 20 taxa are found only in the Colorado Plateau area of southern Utah, northeastern Arizona, northwestern New Mexico, and southwestern Colorado. Together these 38 local and regional endemics account for 10.7% of the monument's flora. Just over 2% of the flora consists of species that occur sporadically across Utah (sparse taxa) or have populations in Cedar Breaks that are widely isolated from their main, contiguous range (disjunct) (Table 1).

Only 18 introduced species (those not historically native to Utah or North America) have become established in the monument, representing 5.1% of the total flora (Table 1). The percentage of introduced species at Cedar Breaks is less than half that reported for the entire flora of Utah (13.5%) (Fertig 2007, Welsh et al. 2008). None of the introduced plant taxa in the monument are listed by the state of Utah as official noxious weeds.

Rare Species

The Conservation Data Center (CDC) of the Utah Division of Wildlife Resources (1998) recognizes 22 species from Cedar Breaks National Monument as species of concern (Table 2). Most of these are local or regional endemics restricted to the Claron Formation or species that are widespread outside of Utah but have 10 or fewer extant populations in the state. We consider two additional species from the monument to be deserving of recognition by the CDC. Madsen's daisy (*Erigeron vagus* var. *madsenii*) is a southern Utah endemic that was only described as a new taxon in 2008 (Welsh et al. 2008). Rosy cliff jamesia (*Jamesia americana* var. *rosea*) was not recognized as occurring in the state of Utah until we verified populations in Cedar Breaks and the Ashdown Gorge Wilderness Area in 2008. Previously, populations of this taxon were thought to represent var. *zionis*, a local endemic of southern Utah listed by the CDC as a species of concern and by the US Forest Service and BLM as sensitive. Var. *rosea* was formerly known only from California and Nevada (Fertig and Reynolds 2009, Holmgren and Holmgren 1989). In all, seven species from Cedar

Table 1. Statistical Summary of the Flora of Cedar Breaks National Monument*

Category	No. of Taxa Confirmed Present	No. of Taxa Reported (not confirmed)	Total
Taxonomic Diversity			
Species & Varieties	347	7	354
Full Species Only	335	5	340
Families	56	0	56
Biogeographic Diversity			
Introduced	17	1	18
Native	330	6	336
Locally Endemic	18	0	18
Regionally Endemic	20	0	20
Disjunct	2	0	2
Peripheral	0	0	0
Sparse	6	0	6
Widespread	284	6	290

The number of taxa and plant families is based on Welsh and others (2008). Biogeographic diversity categories refer to the distribution of a species within Utah and the state's contribution to its overall global range (Fertig 2009b). Introduced taxa are not native to Utah or North America but have become naturalized (breeding on their own without human assistance). Local Endemics have their entire global range restricted to an area of less than 16,500 square km (ca 6370 sq miles, or 1 degree of latitude x 2 degrees of longitude). Regional Endemics have global ranges of 16,500-250,000 square km (an area about the size of Wyoming). Disjuncts are isolated from the contiguous portion of their range by a gap of more than 800 km (ca 500 miles). Peripherals are widespread globally but occur at the margin of their contiguous range in Utah and occupy less than 5% of the state's area (usually only within a few miles of the state border). Sparse taxa occur widely across Utah or North America but their range within Utah is small and patchy, with populations restricted to specialized or uncommon habitats. Widespread taxa have global ranges exceeding 250,000 square km and occur over at least 10% of the state.

* See Addendum for additional species documented since 2009.

Breaks National Monument are presently listed as sensitive by the US Forest Service or BLM and 14 were once candidates for listing as Threatened or Endangered under the US Endangered Species Act (Table 2).

During 2007-2008 we targeted 16 of Cedar Breaks' rarest local endemics and CDC species of concern (Table 2) for survey. The number of target species increased to 18 with the discovery of extant populations of Madsen's daisy and the first records of Welsh's aster (*Aster welshii*) for the monument. We recorded at least one population of 16 of the target species at 546 different sampling points within Cedar Breaks National Monument or the Ashdown Gorge Wilderness Area. Since more than one target species was often present at each location, we actually documented 1181 different sample points for these species. For the clonal species *Salix arizonica* we delineated 16 discrete polygons in three main population clusters that cover a total area of just over one hectare (Fertig and Reynolds 2009).

Ten of our target species occurred in over 10% of our samples. These species were found mostly on the red or white limey-sandstone layers of the Claron Formation along the rim and slopes of the Cedar Breaks Amphitheater. Cedar Breaks wild buckwheat (*Eriogonum panguicense* var. *alpestre*) was the most widespread and abundant of the rare species, being found in 36% of all samples and having a population estimated at 35,200-100,000 individuals (Fertig and Reynolds 2009). This plant also has the smallest geographic range of any taxon in our study, being known only from the Cedar Breaks area within the monument and the adjacent Dixie National Forest and Ashdown Gorge Wilderness. Only three other species were estimated to have populations of over 10,000 plants: Least lomatium (*Lomatium minimum*), Markagunt aster (*Aster wasatchensis* var. *wasatchensis*), and Least spring-parsley (*Cymopterus minimus*). The least abundant and most restricted species in the study area were Rosy cliff jamesia (known from only about 100 plants in two main areas; Madsen's daisy (approximately 400 plants in three main areas), Reveal's paintbrush (*Castilleja parvula* var. *revealii* with 500 plants in two main populations), Podunk groundsel (*Senecio malmstenii* with about 1500 individuals in five sites), and Welsh's aster (with an estimated 1700 plants scattered along Ashdown and Rattle creeks in the bottom of the amphitheater).

We were unsuccessful in relocating just one of the 18 target species, the Zion draba (*Draba asprella* var. *zionensis*). This species is known from a single herbarium specimen (*Dickman s.n.* CEBR) collected from "Cedar Breaks National Monument" in 1977. Unfortunately, nothing more precise is known about the original collection site. Zion draba occurs commonly in Zion National Park on Navajo Sandstone cliffs and canyons. Comparable Navajo Sandstone outcrops are not exposed at Cedar

Table 2. Vascular Plant Species of Concern of Cedar Breaks National Monument

Family	Species/ Common Name	TNC Rank	Legal & UTCDC Status	Abundance in CEBR
Apiaceae (Umbelliferae)	*Cymopterus minimus* Least spring-parsley	G1G2Q/ S1S2	USFS: Sensitive USFWS: former C2 UTCDC: Rare	Ca 12,500 plants, in 35% of sample plots
Apiaceae (Umbelliferae)	*Lomatium minimum* Least lomatium	G3/S3	USFWS: former 3C UTCDC: Watch	Ca 33,600 plants, in 13.2% of sample plots
Asteraceae (Compositae)	*Agoseris glauca* var. *agrestis** Field agoseris	G5T5/S1S2	UTCDC: Taxonomic Problems	Not known
Asteraceae (Compositae)	*Antennaria pulcherrima** Showy pussytoes	G5?/S1	UTCDC: Peripheral	Not known
Asteraceae (Compositae)	*Aster wasatchensis* var. *wasatchensis* Markagunt aster	G2/S2	UTCDC: Watch	Ca 15,100 plants in 17.8% of sample plots
Asteraceae (Compositae)	*Aster welshii* Welsh's aster	G2/S2	UTCDC: Watch	Ca 1700 plants in 4.6% of sample plots
Asteraceae (Compositae)	*Erigeron sionis* var. *trilobatus* Cedar Breaks daisy	G2/S2	USFWS: former C2 UTCDC: Watch	Ca 4200 plants in 13.6% of sample plots
Asteraceae (Compositae)	*Erigeron vagus* var. *madsenii* Madsen's daisy	G4T?/SNR		Ca 4000 plants in 2% of sample plots
Asteraceae (Compositae)	*Haplopappus zionis* Cedar Breaks goldenbush	G2/S2	UT BLM: Sensitive USFWS: former C2 UTCDC: Watch	Ca 4100 plants in 14.3% of sample plots
Asteraceae (Compositae)	*Machaeranthera commixta** Bigelow's aster	G4G5T3?/ S3?	UTCDC: Watch	Not known
Asteraceae (Compositae)	*Senecio malmstenii* Podunk groundsel	G1/S1?	USFS: Sensitive USFWS: former C2 UTCDC: Rare	Ca 1500 plants in 4% of sample plots
Asteraceae (Compositae)	*Townsendia montana* var. *minima* Bryce Canyon townsendia	G4T3/S3	USFWS: former C2 UTCDC: Watch	Ca 4100 plants in 11% of sample plots
Brassicaceae (Cruciferae)	*Draba asprella* var. *zionensis* Zion draba	G4T3?/S3?	USFWS: former 3C UTCDC: Watch	Not known, may be falsely reported
Brassicaceae (Cruciferae)	*Draba subalpina* Breaks draba	G3/S3	USFWS: former 3C UTCDC: Watch	Ca 8700 plants in 22% of sample plots
Brassicaceae (Cruciferae)	*Physaria rubicundula* var. *rubicundula** Breaks bladderpod	G3//S3	USFWS: former 3C UTCDC: Watch	Not known
Caryophyllaceae	*Silene petersonii* Peterson's campion	G2G3/S2S3	USFS: Sensitive; USFWS: former C2 UTCDC: Watch	Ca 2900 plants in 12.1% of plots
Equisetaceae	*Equisetum variegatum** Northern scouring-rush	G5/S1	UTCDC: Peripheral	Not known

Table 2. continued

Family	Species/ Common Name	TNC Rank	Legal & UTCDC Status	Abundance in CEBR
Fabaceae (Leguminosae)	*Astragalus limnocharis* var. *limnocharis* Navajo Lake milkvetch	G2T1/S1	USFS: Sensitive USFWS: former C2	Ca 4100 plants in 15.9% of sample plots
Hydrangeaceae (Saxifragaceae)	*Jamesia americana* var. *rosea* Rosy jamesia	G5T3/SNR		Ca 100 plants in 1.1% of sample plots
Polemoniaceae	*Ipomopsis tridactyla* Tushar gilia	G5T2/S2	UTCDC: Rare	Ca 2800 plants in 9.3% of sample plots
Polygonaceae	*Eriogonum panguicense* var. *alpestre* Cedar Breaks wild buckwheat	G3T2T3Q/ SSYN	USFWS: former 3C UTCDC: Taxonomic Problems	35,200-100,000 plants estimated, in 36% of sample plots
Pyrolaceae (Ericaceae)	*Pyrola picta** White-veined wintergreen	G4G5/S1	UTCDC: Infrequent	Not known
Salicaceae	*Salix arizonica* Arizona willow	G2G3/S2	USFS: Sensitive USFWS: former Candidate UTCDC: Rare	16 small to medium sized clones in 3 main population clusters covering 1.06 ha
Scrophulariaceae (Orobanchaceae)	*Castilleja parvula* var. *revealii* Reveal's paintbrush	G2/S2	USFS: Sensitive USFWS: former C2	Ca 500 plants, in 4.8% of sample plots

*Species not surveyed in 2007-2008.
Derived from Utah Department of Wildlife Resources (1998), Fertig (2009b), Fertig and Reynolds (2009), and Fertig and others (2009c). Codes: TNC rank assesses abundance and conservation priority on a scale of 1-5 (1 being extremely vulnerable and 5 being secure) for full species (G) and varieties or subspecies (T) across their entire range and within each state (S). A "?" indicates uncertainty in the rank, Q = taxonomic questions, NR = not ranked, and SYN = species is considered a synonym and not ranked under the given name. Under legal status, USFWS = US Fish and Wildlife Service. C2 = category 2 candidate (a former category used for taxa that might warrant being proposed for Threatened or Endangered status following additional research). 3C = category 3 candidates (species dropped from consideration for listing). USFS = US Forest Service. BLM = Bureau of Land Management. UTCDC status includes conservation categories adopted by the state natural heritage program to prioritize endemic and rare plant taxa (Utah Division of Wildlife Resources 1998). These categories include: Rare (plants with rangewide viability concerns), Watch (regional endemics without rangewide viability concerns), Peripheral (rare or uncommon in Utah, but more common rangewide), Infrequent (plants occur infrequently over western US), and Taxonomic Problems (validity of species, subspecies, or variety has been questioned).

Breaks National Monument, though similar sandstone cliffs of the Straight Cliffs or Wahweap formations are present in the bottom of Ashdown Canyon. These areas were searched in 2008, but no populations were found. It is possible that the label of the specimen is erroneous and the collection was actually made in Zion National Park (Fertig and Reynolds 2009).

Similarity to Other Park Floras

Cedar Breaks National Monument ranks tenth out of the 14 NPS and BLM managed parklands considered in this study in both area and species richness (Table 3). As of 2008, Grand Staircase-Escalante National Monument is the largest protected area at over 761,000 ha and has the highest number of vascular plant species with 999[2]. In general, vascular plant species richness is positively correlated with total area, with the main exception being Zion National Park with the second highest number of species (991) but ranking sixth in total area. When park

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[2] More than 10 new species were documented in Zion National Park in 2009, allowing it to pass Grand Staircase-Escalante National Monument as the Utah parkland with the highest vascular plant species richness. See Fertig and others (2012) for updates on the flora of each NPS unit assessed in this study.

Table 3. Number of Vascular Plant Taxa in National Park Service and Bureau of Land Management Parks, Monuments, Historic Sites, and Recreation Areas in Utah

Management Area	Size (ha)	Total # of Taxa	# of Rare Taxa[a]	# of Endemic Taxa	# of Unique Taxa[b]	# of Taxa per log (area)	Source
Arches NP	30,966	524	32	82	12	50.7	Fertig et al. 2009a, 2009c
Bryce Canyon NP	14,502	587	51	71	28	61.3	Fertig and Topp 2009
Canyonlands NP	136,610	600	55	107	16	50.8	Fertig et al. 2009b, 2009c
Capitol Reef NP	97,895	888	62	142	90	77.3	Fertig 2009a
Cedar Breaks NM	2,491	354	24	38	63	45.3	Fertig 2009b, Fertig et al. 2009c
Dinosaur NM	85,096	757 (485 in UT)	80	76	69 (UT)	66.7	Fertig 2009c, Fertig et al. 2009c
Glen Canyon NRA	505,868	889 (863 in UT)	60	176	73 (UT)	67.7	Hill 2005, Spence 2005
Golden Spike NHS	1,107	149	6	6	20	21.3	Fertig 2009d, Fertig et al. 2009c
Grand Staircase-Escalante NM	761,070	999	142	193	68	73.8	Fertig 2005 & unpublished data
Hovenweep NM	318	340 (240 in UT)[c]	17	31	6	59.0	Fertig 2009e
Natural Bridges NM	3,009	428	21	72	6	53.4	Fertig 2009f
Rainbow Bridge NM	65	224	12	33	4	53.7	Fertig 2010b
Timpanogos Cave NM	101	235	8	15	39	50.9	Fertig and Atwood 2009
Zion NM	59,900	991	189	133	199	90.1	Fertig and Alexander 2009

[a] Derived from Utah Division of Wildlife Resources (1998)

[B] Defined as species found in only one of the 14 parklands considered here

[c] Erroneously reported as 214 taxa in Utah in Fertig (2009e)

size is normalized by taking the natural log of area, Zion National Park emerges as the largest flora in the study area at 90.1 species/ln(area), followed by Capitol Reef National Park and Grand Staircase-Escalante National Monument (Table 3). Cedar Breaks National Monument drops to thirteenth in alpha diversity at 45.3 species/ln(area) when area is normalized, exceeding only Golden Spike National Historic Site.

In our sample, Cedar Breaks National Monument shares the most vascular plant taxa in common with Bryce Canyon National Park (227 species), Zion National Park (202 species), and Grand Staircase-Escalante National Monument (172 species) (Table 4). Not surprisingly, these are the three parklands closest in proximity to Cedar Breaks (Figure 2). The monument shares the fewest species in common with Golden Spike National Historic Site (29 species), Rainbow Bridge National Monument (32 species), and the Utah sections of Hovenweep National Monument (37 species). Factoring in discrepancies in the relative sizes of different park floras using Jaccard's Coefficient of Similarity (JCS), Cedar Breaks National Monument is still most similar to Bryce Canyon National Park (JCS = 0.318), but is significantly less similar to Zion National Park and Grand Staircase-Escalante National Monument (JCS = 0.177 and 0.146, respectively). Timpanogos Cave National Monument, which shared only 75 species in common with Cedar Breaks, has a Jaccard's coefficient equal to that of Grand Staircase, despite being much farther distant. Based on the Jaccard's Coefficient, Cedar Breaks National Monument is least similar to Rainbow Bridge National Monument and Golden Spike National Historic Site (Table 4). Cedar Break's average coefficient of similarity among the other thirteen parklands in the study is 0.128. This is the second lowest value among all the parks analyzed, and is bested only by Golden Spike National Historic Site (average JCS = 0.121). By comparison, Canyonlands National Park (average JCS = 0.326) and Grand Staircase-Escalante National Monument (average JCS = 0.312) share the most species on average with other Utah parklands.

The low Jaccard's Coefficient value for Cedar Breaks is a consequence of the area's low overall species richness and the relatively high number of plant taxa that are unique to the monument. Of the 354 taxa documented for Cedar Breaks National Monument, 63 species (17.8% of the local flora) are not found in any of the other protected areas in this study (Table 3). Only Zion National Park has a higher percentage (19.9%) of its flora that is protected nowhere else in the state. Ten of the 24 rare species of Cedar Breaks are protected only in the monument and another ten occur just in Cedar Breaks and Bryce Canyon National Park.

DISCUSSION

Creating a protected area network that contains full representation of the entire array of native biological diversity is one of the core principles of contemporary conservation biology (Groves et al. 2002, Margules and Pressey 2000, Margules and Sarkar 2007, Scott et al. 1993, Stein et al. 2000). The foundation of such a network already exists in Utah, consisting of national parks, monuments, recreation areas, historic sites, designated wilderness, research natural areas, national wildlife refuges, and Nature Conservancy preserves. Unfortunately, many of the best protected sites in the state were originally created for their scenic and historic values or recreation potential rather than the preservation of biological diversity. Significant gaps remain in the state's protected area network, especially for many rare and endemic species and plants from lowland habitats that have been largely converted to agriculture or residential use (Fertig 2010a, Prior-Magee et al. 2007).

Building a modern preserve network is expensive and difficult, requiring costly land acquisition, changes in economic or regulatory policy, and expenditure of political capital. Because of these costs, it is critical that conservation strategies be both effective and efficient (Margules and Sarkar 2007, Stein et al. 2000). To maximize efficiency, conservation biologists often focus their efforts on preserving hotspots of unusually high species richness, representative examples of major vegetation types (that serve as surrogates for all biodiversity), and areas with high complementarity. Hotspots and vegetation types are especially useful for capturing broad swaths of diversity when building networks from scratch, but can become less efficient as preserve systems grow and gaps become more obvious (Williams et al. 1996). With its emphasis on species that tend to be rare and localized, complementarity can be an effective alternative to hotspots and vegetation types when filling specific holes in the network (Margules and Sarkar 2007, Williams et a. 1996).

Cedar Breaks National Monument has been part of the Utah protected area network for over 75 years. But if Cedar Breaks were not already protected, would it be a worthy addition to the network? In terms of overall species richness, the answer at first glance appears to be no. The monument contains only 354 vascular plant species, compared to the average of 558 taxa for the other parklands considered in this study. The area's low alpha diversity can be attributed to the monument's small size and relatively homogeneous vegetation (especially compared to larger parks in the Colorado Plateau portion of the state). Relative to other parks, Cedar Breaks also has a fairly low number of endemic and rare species.

It is in terms of complementarity that Cedar Breaks makes its primary contribution to the state's protected area network. Jaccard's Coefficient of Similarity is a useful formula for measuring complementarity as it weights similarities in floristic composition between areas by discrepancies in total species richness. With an average JCS of 0.128, Cedar Breaks National Monument has the most dissimilar flora of any parkland considered in this study other than Golden Spike National Historic Site. The monument's low JCS score is a consequence of its relatively high number of unique plant species (63 taxa or nearly 18% of the local flora) that are not protected elsewhere in the state. While many of these unique species are Claron endemics, the majority are taxa restricted to elevations above 3000 meters. The average elevation of Cedar Breaks is 2800 meters, a figure that exceeds the highest elevation of all other parks in the Utah reserve network. The 14 parklands in the preserve network analyzed here protect 2007 of Utah's 3659 native and naturalized vascular plant species (54.8% of the total state flora). Cedar Breaks' unique contributions account for 3.1% of the total. Ten of the 24 rare plant species recognized for Cedar Breaks and 9 of the 38 local or regional endemics are among the species protected nowhere else.

The flora of Cedar Breaks is most similar to that of Bryce Canyon National Park, with the two parks sharing 227 plant taxa. This degree of similarity is not surprising given the proximity of the areas and their similar elevation, vegetation, and geology (both parks have extensive outcrops of reddish-orange Claron Formation badlands). Although there is redundancy in the protection of some species in both parks, this is not necessarily disadvantageous, as having multiple populations in the protected area network can reduce the risk of catastrophic loss and enhance the preservation of multiple genotypes (Noss and Cooperrider 1994, Margules and Sarkar 2007). Similar redundancy occurs among common montane forest and meadow species found in both Cedar Breaks and Timpanogos Cave national monuments, which despite their great distance from each other share similar vegetation types and a relatively high Jaccard's Coefficient of Similarity.

Based on our analysis of vascular plant checklists from selected parklands, nearly 45% of the native and naturalized flora of Utah is not represented in the state's existing preserve network. Some of the omissions may be an artifact of incomplete sampling or data synthesis, especially of wilderness areas, research natural areas, national wildlife refuges, private nature preserves, and other protected areas that could not be included in this analysis for lack of data. Other holes will only be filled by targeting specific plant taxa identified by analyzing system-wide complementarity. Fortunately, many of the missing species occur in specific geographic areas or habitat types which are, themselves, poorly represented in the current network. Fertig (2010a) identified just 12 geographic areas that, if protected, would capture 70% of the missing plant species in the preserve network on Utah's Colorado Plateau. These are mostly "hotspots" of unprotected endemism and include the La Sal, Abajo, Henry, Tushar, Boulder, and Pine Valley mountains, Book Cliffs, Tavaputs, and Fish Lake plateaus, Uinta Basin, Sevier Valley, and San Rafael Swell. Statewide, important gaps also exist in the Great Basin, lowland riparian areas, and the foothills and montane zones of northern mountains. Future additions to the network may well be sites like Cedar Breaks that are of relatively small size or modest species richness but which have significant beta diversity.

For any reserve network to function, it will be increasingly important to keep score of what species are represented, how many populations are captured, and whether these populations are of sufficient size or quality to persist. Annotated species lists and databases of distributions are critical tools for identifying gaps in the reserve network. Efficient planning and implementation of a complete reserve system requires that intelligent choices be made in selecting geographic areas and species to target for inclusion. Measuring complementarity, as we have done for Cedar Breaks and other parklands, is a key step in the prioritization process.

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Addendum

Since this paper was written in the summer of 2009, 31 new vascular plant taxa have been collected or reported for Cedar Breaks National Monument, increasing the flora to 385 species and varieties (Fertig et al. 2012). Among the more uncommon or noteworthy additions to the monument's flora are *Botrychium lunaria* (sparse in Utah and the first species of Ophioglossaceae for Cedar Breaks), *Cirsium clavatum* var. *clavatum* (a regional endemic, first collected in 1982 and located in a search of specimens at the Brigham Young University herbarium), and *Penstemon caespitosus* var. *suffruticosus* (a local endemic of southern Utah).

In recent years, local political leaders in Iron County, Utah, have proposed changing Cedar Breaks from a national monument to a national park and having the park annex the Ashdown Gorge Wilderness on its western boundary. I conducted a floristic survey of the Ashdown Gorge Wilderness in the summer of 2009 (Fertig 2009g) and documented 308 vascular plant taxa. Of these species 247 were previously known from Cedar Breaks National Monument, while 61 were new species for the local area. If the Ashdown Gorge Wilderness Area were added to Cedar Breaks National Monument the total flora would increase to 426 taxa (Fertig 2009g).

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Studying the Seed Bank Dynamics of Rare Plants

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Abstract. Seed bank studies are important for understanding the population biology of rare plants, especially short-lived species from unpredictable environments. Seed retrieval studies are used to determine how long seeds persist in the soil and how seed dormancy changes through time. Even short-term studies (three to five years) can help determine whether the seed bank is transient or persistent and characterize the shape of the seed depletion trajectory. Laboratory germination studies can provide clues about seed bank persistence, and in situ seed bank studies can quantify seed bank size, but only retrieval studies provide the information needed to inform population viability analysis.

In order to assess the status of a rare plant population, botanists need some way to measure and quantify demographic (life history) variables. This can be as straightforward as quantifying the number of plants present in an area using a simple monitoring protocol, or it can involve classifying the individuals present by age, size or stage (for example, seedling, juvenile, vegetative adult, reproductive adult). It can also include an evaluation of the potential contribution of an individual to the next generation, that is, its reproductive output in terms of numbers of seeds or vegetative ramets produced and the quality of those seeds or ramets. If the plants are permanently marked and their attributes quantified on multiple occasions, it becomes possible to perform quantitative life history analysis (Brigham and Schwartz 2003). One of the goals of life history analysis for plants of conservation concern is the formal inclusion of life history information into mathematical models that predict the probability of population persistence under different scenarios. The term used for the creation, execution, and interpretation of such models is population viability analysis (PVA; Beissinger and McCullough 2002).

Population viability analysis for plants is a relatively new area of research (Doak et al. 2002). One feature of plant life history that makes PVA difficult is the presence of a largely invisible life cycle stage, namely seeds in the soil seed bank. This paper deals both with assessing the need for including soil seed bank data in life history analysis for a particular plant species and tackling the problem of obtaining seed bank data when necessary.

WHEN ARE SOIL SEED BANKS IMPORTANT?

Doak and others (2002) provide an excellent discussion of problems associated with assumptions about seed banks in the context of PVA for plants. They first present the two extremes for plant life history strategy. At one extreme is a life history much like that of the vertebrates for which PVA was first developed. In these organisms, for example, giant sequoias, newborns are subject to high and variable mortality, the juvenile phase lasts a long time and is characterized by slow growth and increasing annual survival, and adults are long-lived. Plants with this life history usually produce seeds that have a very short tenure in the seed bank, less than a year. At the other extreme are plants that have short and risky juvenile stages and short life spans as adults, but whose seeds have high dormancy and high survivorship in the soil, resulting in a large, persistent seed bank. For plants in the former category, the seed bank can safely be ignored in PVA, because the transition from seed production to seedling takes place within a single year. But for plants that produce long-lived seeds, the dynamics of the seed bank can play a very important role in population biology, and false assumptions based on inadequate data can lead to major problems with the resulting PVA.

Doak and others (2002) identify two plant life history attributes most critical for deciding how important accurate measurement of seed bank dynamics is likely to be. The first, as implied above, is plant longevity, and the second is the effect of a variable environment on adult survival and reproduction. A long and stable mature stage with multiple opportunities for reproduction is likely to minimize the importance of a persistent seed bank. On the other hand, short-lived plants which are at variable risk of mortality and/or reproductive failure as adults are likely to be associated with long-lived seeds and persistent seed banks. Different combinations of positions along these two gradients (life span and environmental risk to adults) result in different assessments of the importance of seed banks. Even relatively long-lived shrubs may have persistent seed banks if there is a risk of catastrophic mortality to adult plants, for example through fire or epidemic disease. And even annuals may have relatively short-lived seeds if the chances of adult survival to seed production are high.

Another source of clues about the importance of the persistent seed bank is in the germination behavior of the seeds in a laboratory setting. If the seeds are nondormant at dispersal and cannot readily be induced into dormancy, it is unlikely that they will be able to form a persistent seed bank under field conditions. Similarly, if the seeds are dormant at dispersal but lose dormancy in response to an environmental cue likely to be encountered before the optimum germination time within the year, they are also unlikely to form a persistent seed bank. This type of dormancy is called cue-responsive or predictive dormancy. It functions to time germination optimally within the year following production by allowing the seeds to sense their environment and respond appropriately. Many spring-germinating species in the temperate zone have this type of seed dormancy, with moist-chilling or cold stratification that simulates winter conditions as the cue. This prevents precocious germination the autumn following production but allows complete germination the following spring.

Not all cue-responsive dormancy is associated with short-lived seed banks, however. Sometimes the cue is associated with an episodic event such as fire (Keeley 1987), or tillage that exposes weed seeds to light (Baskin and Baskin 1985). Such seeds may persist in the soil for many years, but will germinate synchronously when the cue is received. These seeds germinate readily in response to a laboratory-administered cue. The trick is in recognizing that such a cue is unlikely to be encountered under field conditions within any particular year, so that seeds with this kind of cue-responsive dormancy form a persistent seed bank.

The best laboratory clue that seeds of a species are likely to form a persistent seed bank under field conditions is the presence of cue-non-responsive dormancy. These seeds will germinate to only small percentages no matter what dormancy-breaking treatment is applied. Sometimes it is possible to determine what pretreatment is needed to make the seeds become responsive to a particular cue, but more often even this is very difficult. The individual seeds are programmed to come out of dormancy at different times over a protracted period, and there seems to be no way to speed or circumvent this process. Often the only way to break cue-non-responsive dormancy is to resort to unnatural treatments like injuring the seed, and sometimes even these draconian measures fail to trigger germination.

METHODOLOGIES FOR STUDYING SEED BANKS

For many people, the most obvious way to begin a study of seed bank dynamics is to attempt to quantify the in situ seed bank. This involves taking seed bank samples from the field and somehow measuring the number of seeds these samples contain. A common measuring method involves spreading the soil samples out in shallow pans, applying water, and counting and removing germinants as they emerge. Usually the soil sample is turned multiple times to encourage subsequent flushes of germination and emergence, and the seed bank is considered depleted when no further emergence occurs. Obviously, this methodology involves numerous assumptions about the dormancy status of the seeds, because seeds that do not germinate and emerge as seedlings are not included in the quantification. Sometimes the seedling emergence methodology includes multiple cycles of application of dormancy-breaking cues, for example, moist-chilling, which increases the chances of complete germination. But for truly cue-non-responsive species, these methodologies are clearly inadequate.

Another commonly applied method for quantifying the in situ seed bank involves flotation, usually using a chemical such as potassium carbonate at high molarity. This method has been shown to yield more seeds on average than the emergence (germination) methodology (Ishikawa-Goto and Tsuyuzaki 2004), but the extracted seeds are no longer viable. This inability to distinguish between viable and nonviable seeds and to evaluate seed dormancy status represents a major disadvantage to this method.

A third method for quantifying in situ seed banks is rather labor-intensive, but avoids some of the problems associated with the previous two methods (Meyer et al. 2007). The samples are dry-screened (or wet-screened, depending on the soil type) using sieve sizes that eliminate fine soil and large particles such as gravel and root chunks. The remaining fraction, which contains the seeds of interest, is hand-processed to remove the seeds, which can then be subjected to germination testing and/ or viability evaluation. This method works best for medium to large seeds. Its accuracy is increased by inclusion of numerous small samples rather than fewer large samples, given an equal volume of sampled material.

Sampling regime is a critical aspect of in situ seed bank evaluation, because the lateral distribution of seeds in soil is usually extremely heterogeneous. This means that stratified sampling regimes and often very large sample sizes are needed to get replicable data. It is highly advisable before launching into such a study to make sure that it is well-designed and will yield the desired information. In order to quantify the persistent seed bank, it is important to sample after germination is complete for the year but before any input of seed rain from current-year production, so that only seeds at least a year old will be sampled.

Sampling the in situ seed bank cannot provide any information about seed bank persistence beyond a single year, because there is no way to know the age of seeds removed from the samples. Seeds from the previous production year could be the only ones present prior to dispersal of current-year seeds, or there could be an accumulation of seeds from an unknown number of prior production years. In situ sampling provides a quantification of the seed bank at a given point in time, but does not directly address seed bank dynamics.

The method of choice for determining how long seeds can persist in the seed bank is the seed retrieval (seed burial or artificial seed bank) experiment. In this method, seeds of known age are introduced into the seed bank in a form that makes their subsequent retrieval and evaluation possible. This usually involves placing them in some sort of mesh bag that allows free passage of water and air, but not seeds. We usually use nylon mesh bags made from mosquito netting, which has a fine enough mesh size to contain even very small seeds. For larger seeds, fiberglass window screening works well. The nylon lasts for many years as long as it is covered with soil so that it cannot photo-degrade, and fiberglass screening can be placed directly on the surface.

Some have criticized seed retrieval experiments because they place the seeds in an environment somewhat different from that experienced by seeds in the natural seed bank. An alternative method, or one that can be used in conjunction with a retrieval experiment, is an emergence experiment, where seeds of known age are planted in precise locations using a template or field marking system and monitored for emergence. For both retrieval and emergence experiments, it is important to include adequate replication and to use block designs to avoid localized effects that generate large experimental error.

The retrieval method involves destructive sampling, so that it is necessary to include a different set of retrieval bags for each evaluation date. For rare plants, this can involve a prohibitively large number of seeds. But even yearly retrievals for three years, using a few hundred seeds, can provide valuable information that is difficult to obtain in any other way.

Processing retrieval bags can be a zen experience, not suitable for those inclined to attention deficit. Particularly when the samples are wet after a germination event, it can take some time to untangle and quantify the germinants. Remaining ungerminated seeds are then incubated under controlled conditions and classified as germinable, dormant, or nonviable. With frequent sampling and adequate replication, it is possible to get a very good picture of the phenology of dormancy loss and germination, and also secondary dormancy induction, if it occurs.

It is important to distinguish if possible between seeds that are lost from the seed bank through germination and those that are lost through pre-germination mortality. These two processes have potentially very different demographic consequences. Getting accurate information on field-germinated seeds requires retrieval soon after the germination event, and it can be difficult to anticipate the correct retrieval timing. Laboratory data can be helpful here. For example, if you know the seeds can germinate at near-freezing temperatures, it is reasonable to expect them to germinate during winter in places where the snow cover is deep enough to insulate the seed bed from freezing. This is a common strategy in environments where the soil dries quickly in the spring.

PATTERNS OF SEED BANK DEPLETION

Seed retrieval data can be examined graphically by plotting the percentage of initially viable seeds still present as viable seeds in the seed bank (actually, in the artificial seed bank) as a function of time in the field. For any given seed population, this will yield a characteristic seed depletion trajectory through time (fig. 1). For species that do not form persistent seed banks, this trajectory will essentially be a line that goes to a value of zero within a year of the initiation of the retrieval experiment (Figure 1a). Species with this type of seed depletion trajectory are said to have transient seed banks. In situ seed bank sampling after germination is complete but before current-year seed rain for species with transient seed banks is expected to yield no viable seeds.

Basin wildrye (*Leymus cinereus*) is an example of a species with nondormant seeds and a transient seed bank (Meyer et al. 1995; Figure 2). Seed collections from three populations were placed in retrieval experiments in early fall at salt desert shrubland, sagebrush steppe, and mountain meadow sites. Germination did not take place in autumn, even though seeds were nondormant, because of their relatively long germination time. All the seeds germinated by the end of the following spring, regardless of population of origin or habitat at the seed retrieval site.

Blackbrush (*Coleogyne ramosissima*) is another example of a species with a transient seed bank (Meyer and Pendleton 2004; Figure 3). Its seeds are dormant at dispersal in mid-summer but have cue-responsive dormancy, losing dormancy both in the dry state at high summer temperatures and during moist chilling. As a consequence, if winter rainfall is adequate, seeds germinate to high percentages during early spring. A few seeds may carry for a year over if the winter is unusually dry, but this is the exception rather than the rule.

Seeds with cue-responsive dormancy that responds to a disturbance-associated cue show a similar pattern to those that form transient seed banks, except that there is an extended time delay prior to the seed bank-depleting germination event (Figure 1 b). These species are difficult to study in retrieval experiments, because the cue, such as fire or soil disturbance, is not only unpredictable but also would tend to destroy a retrieval experiment. Information on this type of seed bank depletion trajectory generally comes either from emergence experiments or from in situ seed bank studies that show abrupt

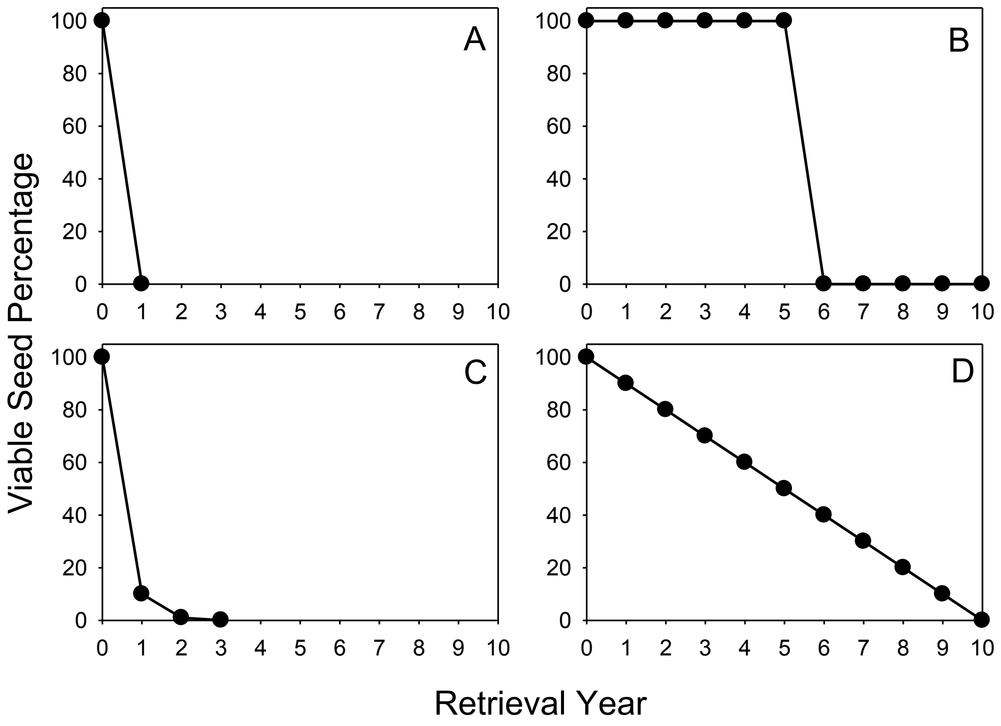

Figure 1. Schematic seed bank depletion trajectories for: (A) a species with a transient seed bank and a depletion trajectory that reaches zero within one year, (B) a species with cue-responsive dormancy and a seed bank that persists until a specific dormancy-breaking cue is received, (C) a species with a short-persistent seed bank, a constant loss rate, and a negatively exponential depletion trajectory, and (D) a species with cue-non-responsive seeds and a linear seed bank depletion trajectory.

decreases in seed density following receipt of the germination cue.

In many herbaceous perennial species, most of the seeds are programmed to germinate during the first year following production, but some possess a mechanism permitting carryover for at least a year, even when conditions for dormancy release and germination the first year are optimal. These species are said to have short-persistent seed banks. This germination response pattern results in a seed depletion trajectory that is essentially negatively exponential (Figure 1c). If rate of loss of a cohort of seeds in the seed bank is constant across years, this is the type of seed depletion trajectory that will be generated. For example, if 80% of the seeds are lost the first year, 80% of the remaining 20% are lost the second year, and 80% of the remaining 4% are lost the third year, this would generate a negatively exponential loss trajectory.

Lewis flax (*Linum lewisii*) is an example of a species that may exhibit a negatively exponential loss trajectory (Meyer and Kitchen 1994; Figure 4). Seed dormancy loss and germination phenology in this species and its close relative *L. perenne* (Euopean blue flax) also vary as a function of both population of origin and habitat at the seed retrieval site. In a two-year retrieval experiment at three sites, the "Appar" release of European blue flax had nondormant seeds that formed only a transient seed bank, regardless of retrieval site habitat. In contrast, the montane Strawberry seed collection of Lewis flax was largely dormant at the initiation of the retrieval experiment and required chilling to become nondormant (Figure 4). It lost dormancy and germinated completely by the end of the first spring at its site of origin in the mountains, exhibiting the transient seed bank pattern. It carried over a substantial fraction through the end of the second year at the foothill and especially the salt desert site. Seeds placed outside of their environmental context can show very different germination patterns than those placed in the habitat of origin. These seeds did not receive sufficient chilling to break dormancy at the drier sites and tended to form a persistent seed bank under those conditions.

The foothill Provo Overlook seed collection of Lewis flax was nondormant at the initiation of the retrieval experiment, but contained a fraction that could be induced into secondary dormancy early during chilling the first year (Figure 4). This resulted in a divergence of seed sub-populations, so that a sizeable fraction germi-

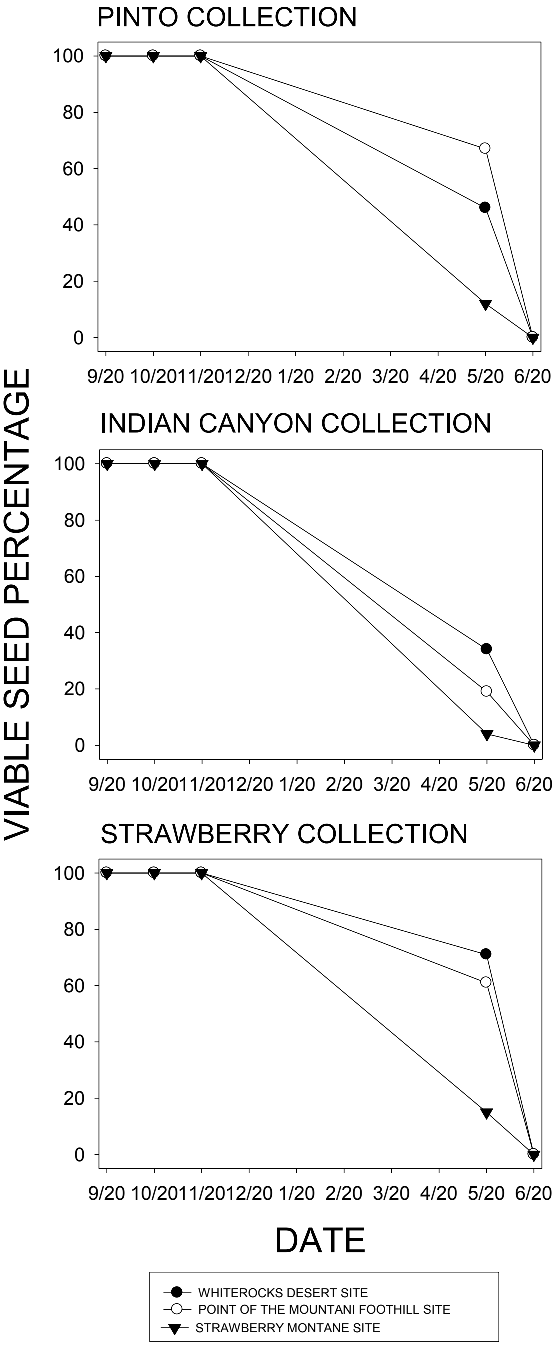

Figure 2. Seed bank depletion trajectories for three collections of basin wildrye (*Leymus cinereus*) placed in retrieval experiments at montane, foothill, and salt desert sites. All seeds germinated within a year of initiation of retrieval experiments. Adapted from Meyer and others (1995).

nated the first year in all three habitats, but 20-30% remained in dormancy through the spring and carried over to the second year, generating the characteristic negatively exponential pattern. Three additional years of retrieval data for the Provo Overlook collection at these sites showed continued gradual decline in viable seed numbers each year (Meyer unpublished data).

Seed bank depletion for shadscale (*Atriplex confertifolia*) exhibited a pattern somewhat similar to that of Lewis flax, but in this case the pattern resulted in a more persistent seed bank (Figure 5). There was no germination at all during the first year in the field, but a sizeable germination pulse occurred the second spring after retrieval initiation. During eight subsequent years in the field, the size of the remaining viable seed fraction slowly diminished until it was at or near zero for most collections (Figure 5; Meyer unpublished data). Laboratory germination experiments help to explain this pattern. Shadscale seeds are dormant at dispersal and tend to be nonresponsive to the chilling cue that triggers them to emerge at the correct time for establishment in early spring (Meyer et al. 1998). They must after-ripen in the dry state to become responsive to the chilling cue, and the rate of increase in the chilling-responsive fraction is an exponential function of temperature during dry storage (Garvin and Meyer 2003). This delays germination for at least a year, because the high summer temperatures needed for after-ripening are first experienced only after the first winter in this autumn-ripening species. Each summer another fraction becomes chilling-responsive, and this fraction is able to germinate the following spring if its chilling requirement is met. The resulting depletion trajectory is like a slow-motion version of the negative exponential pattern for species with short-lived seed banks. Once the first pulse of germination is complete, the trajectory becomes essentially linear through time.

In contrast to the slow-exponential depletion trajectory seen for shadscale, species with truly cue nonresponsive dormancy tend to exhibit a linear depletion trajectory, with no large germination pulse in any one year and certainly not in the early years (Figure 1d). Hard-seeded legumes like Utah ladyfinger milkvetch (*Astragalus utahensis*) are typical of this group. Hard-seededness refers to the inability of a seed to imbibe water because of physical barriers imposed by the seed coat or endocarp. It is often possible to trigger synchronous germination in hard-seeded species by injuring the seed coat, and it has been thought that such scarification must be a part of the natural dormancy-breaking regimen. Under field conditions, however, hard-seededness seems to be very gradually lost through time without any specific scarification mechanism. Because the seeds lose hard-seededness at different rates, this functions to spread germination over many years.

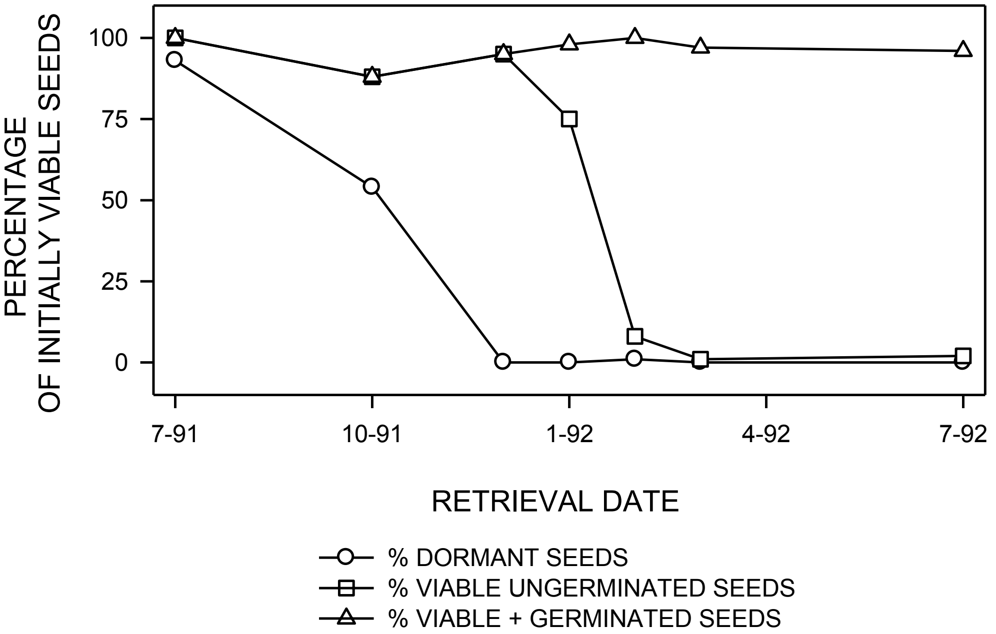

Figure 3. Change through time in the dormant seed fraction, the viable seed fraction, and the viable plus germinated seed fraction for blackbrush (*Coleogyne ramosissima*) seeds placed in a retrieval experiment in the habitat of origin at Arches National Park. All seeds germinated within a year of initiation of the experiment soon after dispersal. Adapted from Meyer and Pendleton (2004).

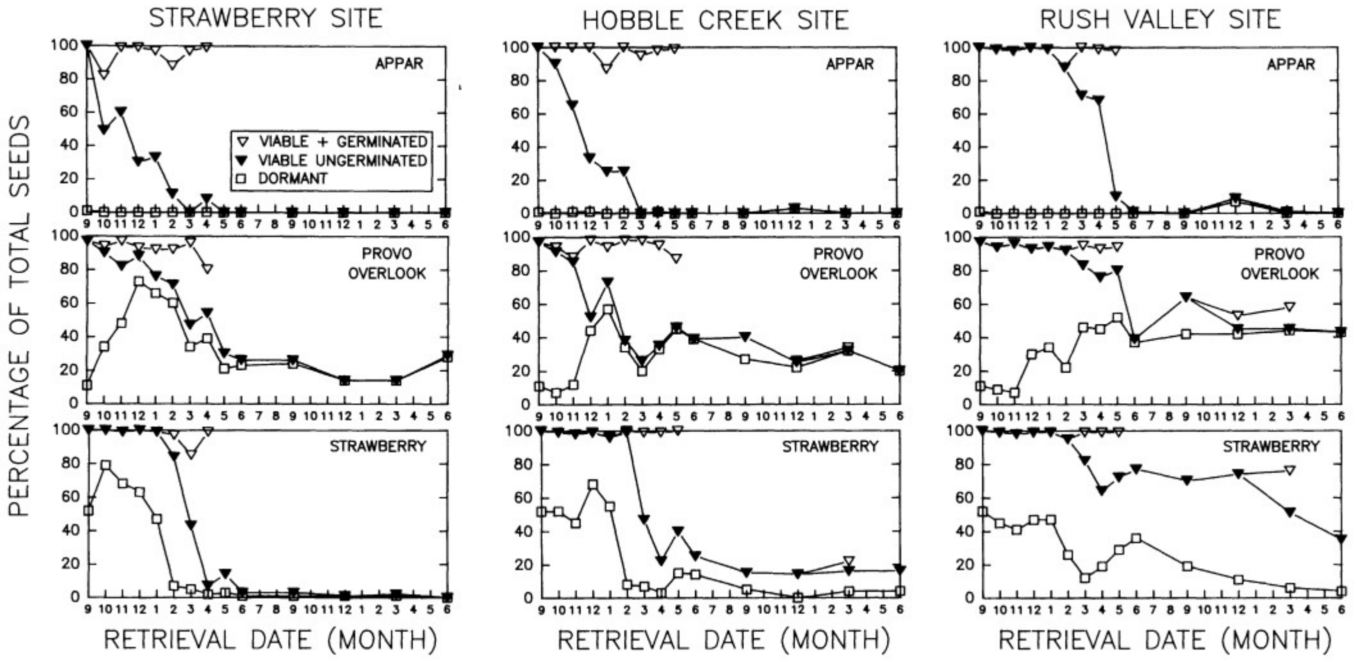

Figure 4. Change through time during a two-year period for dormant seed percentage, viable ungerminated seed percentage, and viable plus germinated seed percentage for three collections of *Linum* placed in retrieval experiments at montane (Strawberry), foothill (Hobble Creek), and salt desert (Rush Valley) study sites. Adapted from Meyer and Kitchen (1994).

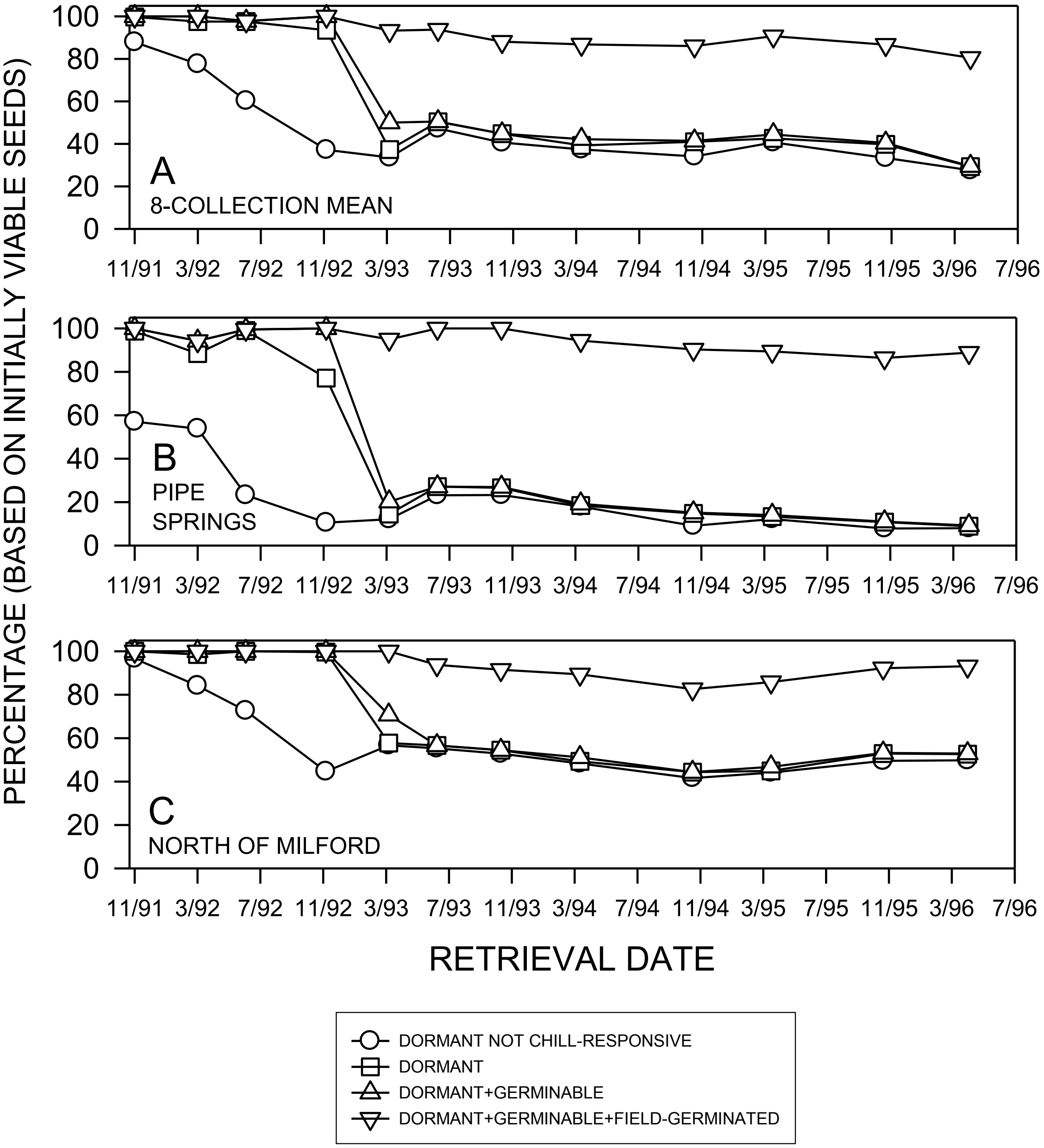

Figure 5. Patterns of change in the precentage of non-chill-responsive dormant seeds, chill-responsive dormant seeds, dormant plus germinable seeds and viable plus germinated seeds over a five-year period for: (A) The mean of eight seed collections, (B) the Pipe Springs seed collection, and (C) the north of Milford seed collection. Adapted from Meyer and others (1998).

Two or three years of retrieval data are usually sufficient to determine whether a species will show a negatively exponential or a linear depletion trajectory. When Utah ladyfinger milkvetch seeds were placed into retrieval experiments at three contrasting sites, depletion trajectories were clearly linear at all three sites (Figure 6). The slope of the depletion trajectory was quite similar across habitats and showed no clear pattern as a function of habitat, indicating that rate of loss of hard-seededness was not tightly tied to environmental conditions.

For *A. utahensis*, regression equations based on the first two years of retrieval data at each site were able to predict the approximate size of the remaining fraction in the subsequent four years. These equations were also used to estimate maximum longevity of this seed population in the seed bank, which was about 14 years at the montane site, 10 years at the foothill site, and 12 years at the salt desert site. Including the later retrievals in these regressions did not change them significantly, even though the fit of the lines for these later dates was not as good. This retrieval experiment had only two replications per retrieval date, resulting in considerable error in the estimate of hard-seededness, especially in later years, when values dropped far below 100%. The regression equation may be the best indicator of actual rate of seed bank depletion under this scenario.

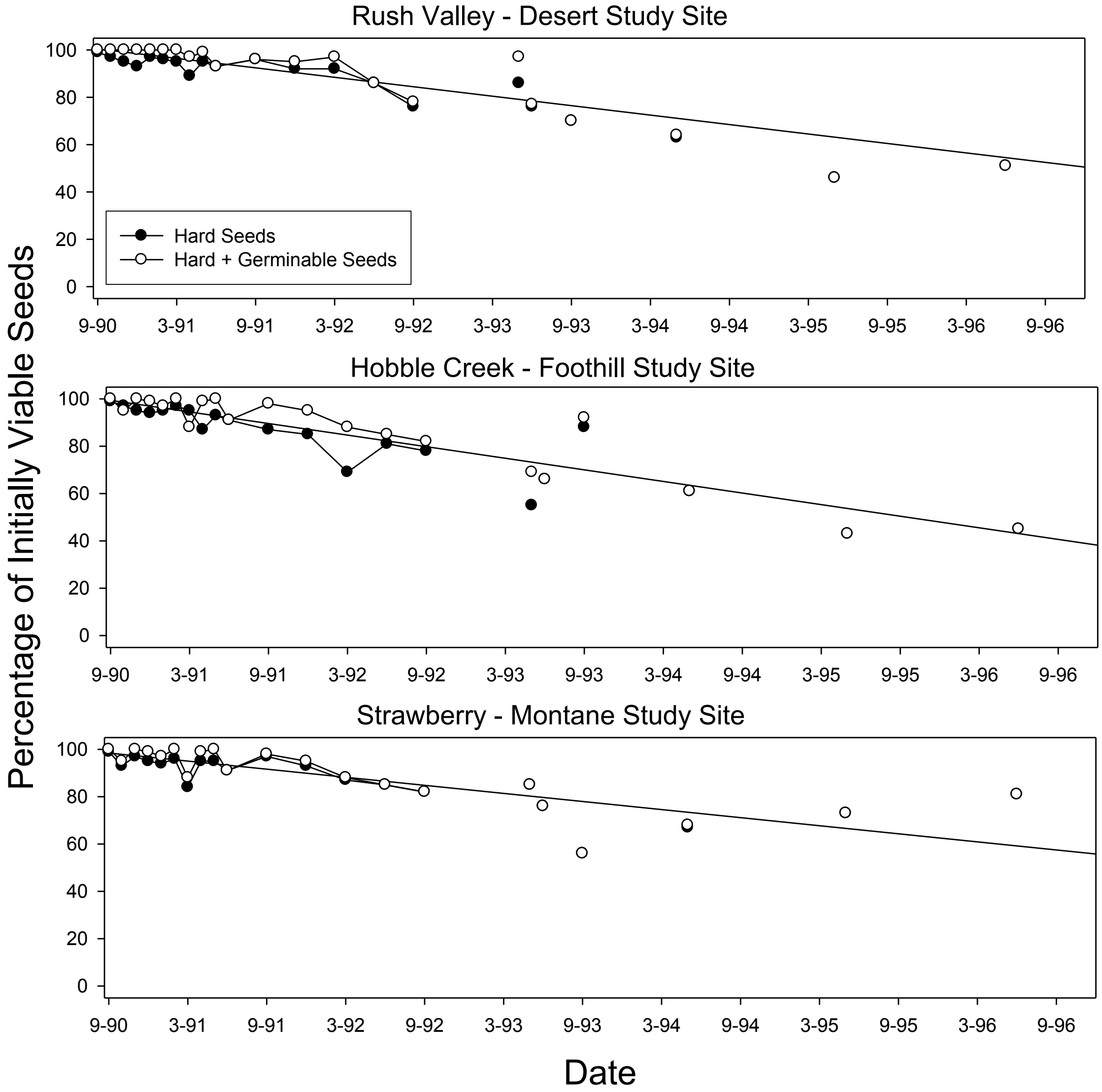

Figure 6. Patterns of change over a six-year period in the percentage of hard seeds and hard plus germinable seeds (total viable seeds) for a collection of Utah ladyfinger milkvetch (*Astragalus utahensis*) placed in seed retrieval experiments at three sites. Regression lines are fit to total viable seed percentage values at each site based on the first two years of retrieval (Rush Valley site: Percentage of viable seeds = -0.022 (days)+100.4, d.f.=13, $R^2 = 0.794$, $P<0.01$; Hobble Creek site: Percentage of viable seeds = -0.027 (days)+99.3, d.f.=13, $R^2 = 0.783$, $P<0.01$; Strawberry site: Percentage of viable seeds = -0.019 (days)+98.6, d.f.=13, $R^2 = 0.730$, $P<0.01$).

All of the species discussed so far are common plants that were included in seed bank studies in order to understand their establishment ecology, rather than to provide seed bank data to inform PVA. There are very few long-term seed retrieval studies for rare plants. The Snake River Plains endemic *Lepidium papilliferum* is one of the few rare species whose seed bank dynamics have been included in PVA (Meyer et al. 2005, 2006). This spring ephemeral species has cue non-responsive seeds that show the characteristic linear decrease as a function of time in the proportion of initially viable seeds remaining in the seed bank (Figure 7; Meyer et al. 2005). There was little or no germination during the first two years of this eleven-year retrieval study, so that at least three years of retrieval data would have been needed to estimate the slope of seed bank depletion. The maximum longevity in soil for two seed collections included in the study was estimated to be 12 years. Seeds of this species can be induced to germinate by piercing imbibed seeds and subjecting them to 2-4 weeks of moist chilling. Development of this technique has facilitated greenhouse production of seeds for reintroduction experiments, but seems to shed little light on how the seeds gradually become nondormant in the field.

Rare plants can be expected to have seeds that run the gamut of germination response patterns and associated seed bank depletion trajectories. As discussed above, it is frequently important to investigate this aspect of rare plant population biology, especially when the goal is to understand the likely future status for a population or species. The information obtained from seed bank studies can also be critical for planning management and mitigation activities.

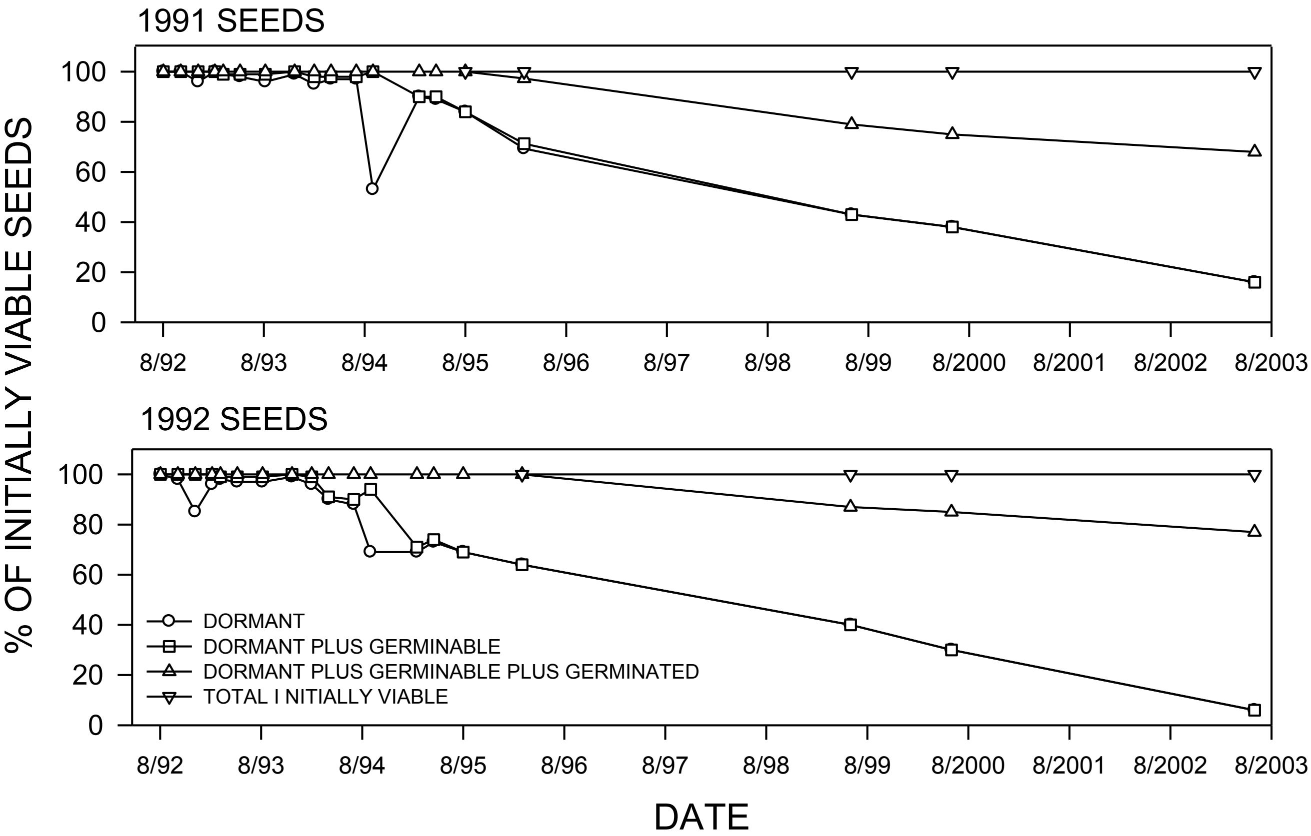

Figure 7. Patterns of change through time in dormant seed percentage, dormant plus germinable seed percentage, and viable plus germinated seed percentage over an eleven-year period in a seed retrieval experiment with two collections of *Lepidium papilliferum*. The difference between viable plus germinated seed percentage and initially viable seed percentage represents seeds that lost viability prior to germinating. Adapted from Meyer and others (2005).

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East Meets West: Rare Desert *Allium*s in Arizona

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Abstract. Two previously poorly known desert species of *Allium* in Arizona, *A. bigelovii* and *A. parishii,* were investigated to determine their actual rarity and conservation status. Each approached Arizona from different deserts and opposite directions: *Allium bigelovii* from the Chihuahuan Desert in New Mexico and *Allium parishii* from the Mohave Desert in California. The status of *Allium bigelovii* was made difficult to understand by the many misidentifications of herbarium specimens. A review of herbarium specimens and field visits determined that *Allium bigelovii* is a Chihuahuan Desert species that enters southeastern Arizona and is disjunct farther west into the Sonoran Desert on unusual lacustrine soils. *Allium parishii* was only known from historic collections in two mountain ranges in western Arizona. These historic locations were relocated. Although these two *Allium* species normally occur nearly 500 km apart and in different deserts, they approach within less than 100 km in the Sonoran Desert of western Arizona.

There are 96 species of *Allium* L. in North America north of Mexico with thirteen species in Arizona (McNeal and Jacobsen 2002). The taxonomy of *Allium* in Arizona is largely unchanged since the monograph of Ownbey (1947). Three of the species recognized there are now treated as varieties: *Allium nevadense* S. Wats. var. *cristatum* (S. Wats.) Ownbey as *A. atrorubens* S. Wats. var. *cristatum* (S. Wats.) D. McNeal; *A. palmeri* Wats. as *A. bisceptrum* S. Wats. var. *palmeri* (Wats.) Cronquist; and *A. rubrum* Osterhout as *A. geyeri* S. Wats. var. *tenerum* Jones. The thirteen Arizona species are rather equally divided through the diverse Arizona habitats of deserts and mountains, aridlands and wetlands, low and high elevations, and northern and southern floristic affinities. Two of the desert species, *Allium bigelovii* S. Wats. (Figure 1) and *A. parishii* S. Wats. (Figure 2), have been poorly known in Arizona, but for different reasons. The taxonomic identity of the former, and consequently its real range and habitat in Arizona, has been confused by the many misidentifications of herbarium specimens; and, the geographic status of the latter in Arizona was made unclear by its few historic records in the state.

The range of *Allium bigelovii* was described by Ownbey (1947) as "…southwestern New Mexico, northwestward across central Arizona to Mohave County." In Arizona he cited five historic collections: (isotype, *Palmer 532* NY 1876 (Figure 3); *Rusby 839* NY 1883; *Crooks et al* ARIZ 1939; *Crooks & Darrow* ARIZ 1938; and *Benson & Darrow* POM 1941), all from central Arizona (Figure 4). The type collection of *A. bigelovii* is from Cook's Springs (*Bigelow s.n.*) in southwestern New Mexico (Watson 1871). Several collections at RSA (*Eastwood 8276*, *Greene s.n..*, *Jones s.n.*) and at NY (*Greene s.n.*, *Rusby s.n..*, and *Holmgren 6891*) document its historic occurrence in southwestern New Mexico. Sivinski (2003) described the habitat and range of

Figure 1. *Allium bigelovii.*

Figure 2. *Allium parishii.*

Figure 3. First collection of *Allium bigelovii* in Arizona, *Palmer 532* Walnut Grove, Yavapai County.

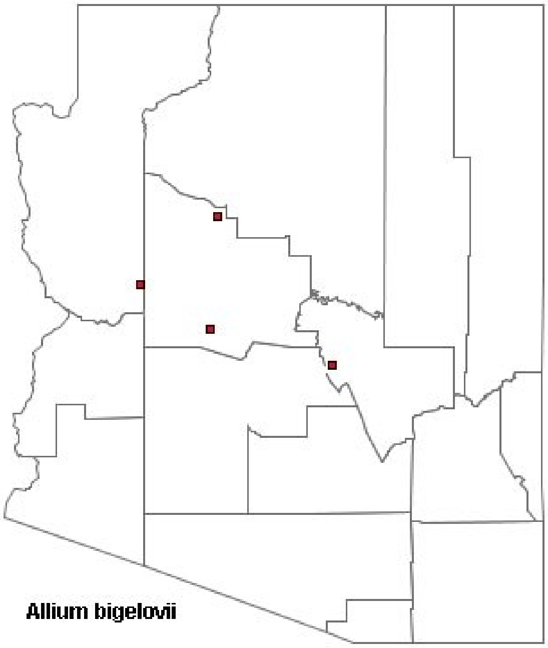

Figure 4. Map of the Arizona distribution of *Allium bigelovii* based on Ownbey (1947).

Allium bigelovii in New Mexico as "…a desert species of southwestern New Mexico", therefore, a Chihuahuan Desert species. At the start of this study twenty six collections at Arizona herbaria (ARIZ, ASU, ATC, Grand Canyon National Park (GC), Museum of Northern Arizona (MNA), and BLM Safford [BLMS]), had been identified or annotated as *A. bigelovii* (Table 1). Based upon these annotations, *A. bigelovii* was widely variable in habitat from desert to chaparral, grassland, oak woodland, pinyon-juniper woodland, and ponderosa pine and wide ranging geographically from southeastern Arizona westward beyond Wickenburg into the Sonoran Desert and northwestward to the Hopi lands and the Grand Canyon on the Colorado Plateau (Figure 5). This situation made its identity as a species and its natural habitat in Arizona puzzling.

By examining these collections, I determined that over half had been misidentified and only twelve were actually *Allium bigelovii* (Table 1). The misidentified collections were annotated by me to several other species, the majority (8) as *A. bisceptrum* var. *palmeri*, three as *A. macropetalum*, two as *A. acuminatum*, and one as *A. atrorubens* var. *cristatum* (Table 1). The large number of misidentifications of *Allium bigelovii* as *A. bisceptrum* var. *palmeri* was due to their pairing in the key in Kearney and Peebles (1960) and the vague species differentiation based on qualitative characters there. To make species determinations I used the two species' descriptions in Ownbey (1947) that included quantitative morphological characters as well as information on herbarium labels of habitat and geographic data. The basis for species definition was thus an evolutionary combination of morphology and ecology, a species' physical characters, and the niche a taxonomic entity occupies in nature. The refinement of the identity of *A. bigelovii* in Arizona combined with a knowledge of its habitat and range in New Mexico demonstrated that *A. bigelovii* is a Chihuahuan Desert species (Figure 6) that extends from southwestern New Mexico into southeastern Arizona (Figure 7) (*Gunder AZ930-8* ASU; *Lunt 6* BLMS).

The localities of the remaining Arizona collections of *Allium bigelovii* followed an interesting disjunct pattern of distribution that extended the range of *A. bigelovii* discontinuously on Mid-Late Tertiary lacustrine deposits across central Arizona. This relictual "stepping-stone" pattern had been documented by me (Anderson 1996) for many species of various floristic affinities including other Chihuahuan Desert species: *Anulocaulis leisolenus* (Torrey) Standl., *Polygala scoparioides* Chodat., and *Thamnosma texana* (A. Gray) Torrey. The lacustrine deposits (Nations et al. 1982) containing *A.*

Table 1. Author annotations of specimens at Arizona herbaria: ARIZ, AU, ATC, BLM Safford (BLMS), Grand Canyon National Park (GC), and Museum of Northern Arizona (MNA), previously identified as *Allium bigelovii* .

Allium bigelovii	*Allium acuminatum*	*Allium atrorubens* var *cristatum*	*Allium bisceptrum* var. *palmeri*	*Allium macropetalum*
ARIZ: *Crooks s.n.* 1938; *Crooks s.n.* 1939; *Darrow 10906*. ASU: *Butterwick 4504*, *6165*; *Gunder s.n.* ATC: *Kierstad 80-1*; *Morefield 1324*; *Llambreschte 30*. BLMS: *Lunt s.n.* MNA: *Haskell & Deaver 2449*; *Wetherill s.n.*	ARIZ: *Reichenbacher 1391*. ASU: *Lehto 21378.*	GC: *Stochert s.n.*	ARIZ: *Fishbein 304*; *Warren 248*. ATC: *Kasch s.n.* 1979, *s.n.* 1980; *Llamphear s.n.*; *Reese s.n.* BLMS: *Bingham 3225*. MNA: *Kewanwytewa s.n.*	ARIZ: *Wright s.n.* ASU: *Duran s.n.*; *Toleman 6-N.*

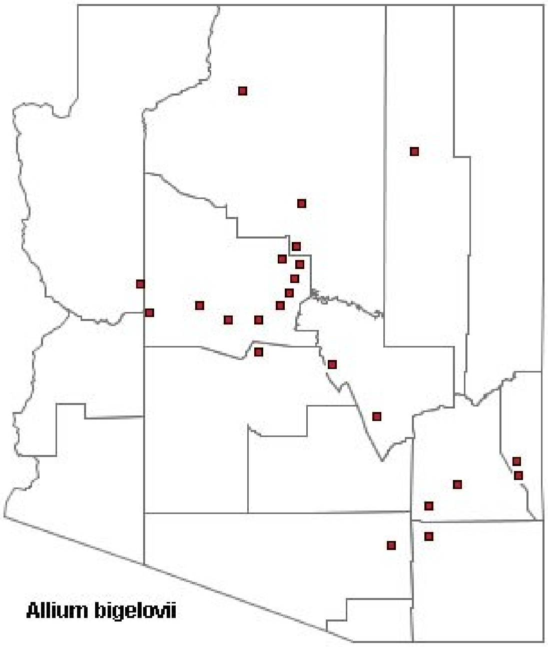

Figure 5. Map of the Arizona distribution of *Allium bigelovii* based on twenty six collections identified as *Allium bigelovii* at Arizona herbaria.

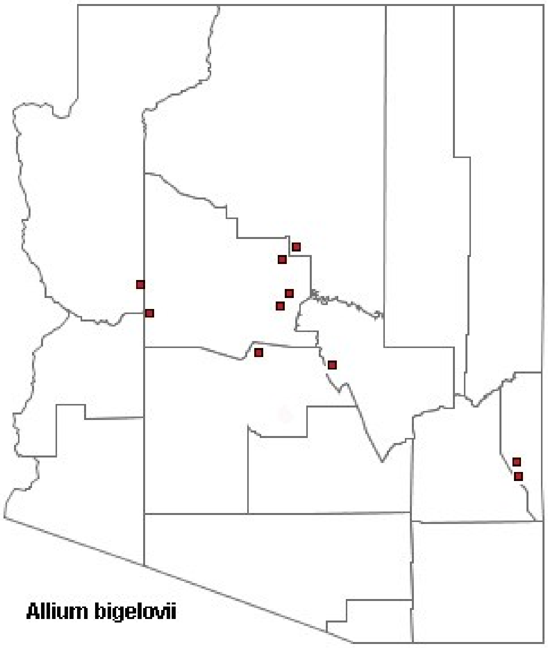

Figure 6. Revised map of Arizona distribution of *Allium bigelovii* based on author's annotations of collections at Arizona herbaria.

Figure 7. Chihuahuan Desert habitat of *Allium bigelovii* in Greenlee County, Arizona.

Figure 8. Sonoran Desert habitat of *Allium bigelovii* on lacustrine habitat at Burro Creek, Mohave County, Arizona, (westernmost occurrence).

Figure 9. Close up of *Allium bigelovii* at Burro Creek.

bigelovii include, from southeast to northwest, Tonto Basin (*Crooks s.n.* 1939 ARIZ); Verde Formation - Verde Valley (*Morefield 1324* ATC; *Lambreschte 30* ATC; *Haskell & Deaver 2449* MNA; *Wetherill s.n.* MNA); Rock Springs beds - Table Mountain (*Kierstead 80-1* ATC); Milk Creek beds - Walnut Grove (*Palmer 532* NY); Burro Creek (*Crooks s.n.* 1938 ARIZ; *Darrow 10906* ARIZ; *Butterwick 4504* ASU; *Anderson 2008-07* ASU; and Chapin Wash Formation - Anderson Mine (Otton 1981) (*Butterwick 6165* ASU; *Anderson 2008-03* ASU [Appendix 1]). These disjunct localities brought the Chihuahuan Desert species, *Allium bigelovii*, into the Sonoran Desert of west central Arizona as far west as Burro Creek, Mohave County (Figures 8, 9). *Allium bigelovii* is rarer in Arizona than previously thought. It is now known from approximately eight to ten localities (some collections from the Verde Valley have vague locality data on the herbarium labels). Because it occurs throughout southwestern New Mexico and is "…occasionally abundant…" there (Sivinski 2003), *A. bigelovii* is not a rare species overall.

Allium parishii is a rare Mohave Desert species from California with peripheral localities in western Arizona at the eastern edge of its range (Figure 10). The type collection of *A. parishii* is from Cushenbury Springs, San Bernardino County, CA (*S. B. Parish 1344* NY) (Watson 1882). A recent review of *Allium parishii* by White (2005) documented its current range and status. In California it primarily occurs in the San Bernardino Mountains (San Bernardino County), Little San Bernardino Mountains (Riverside County) and eastward into Joshua Tree National Park (JTNP). White (2005) recommends CNPS List 1B status. Its range in Joshua Tree National Park has recently been expanded by T. La Doux, botanist at JTNP (pers. comm. 2008).

In Arizona, *Allium parishii* was once known only from an historic collection by Marcus Jones in 1903 (*Jones s.n.*, POM) from the Chemehuevi Mountains (Figure 11) which are now identified as the Mohave Mountains just east of Lake Havasu City, Mohave County. In 2005, students from Northern Arizona University made *Allium* collections in the Mohave Mountains. These collections were originally labeled as *Allium atrorubens* (*Aamodt 9* ATC) and A. *nevadense* (*Dow 13* ATC), but I subsequently identified them as *A. parishii*. These collections of *Allium parishii* were thus from the same mountain range as the historic Jones collection, but they included specific GPS locality data. In 2008 I relocated *A. parishii* in this area (Figure 12) and recorded habitat data, associated species, and GPS locations (*Anderson 2008-05* ASU [Appendix 1]). Interestingly, the two sites I recorded were only a mile apart but the plants grew on soils from different geological substrates: granite at Scott's Well (Figure 13) and metamorphic gneiss near Arrastra Well (Figure 14). Also, the former site contained a diverse Sonoran/Mohave desert

Figure 10. Map of *Allium parishii* distribution in Arizona.

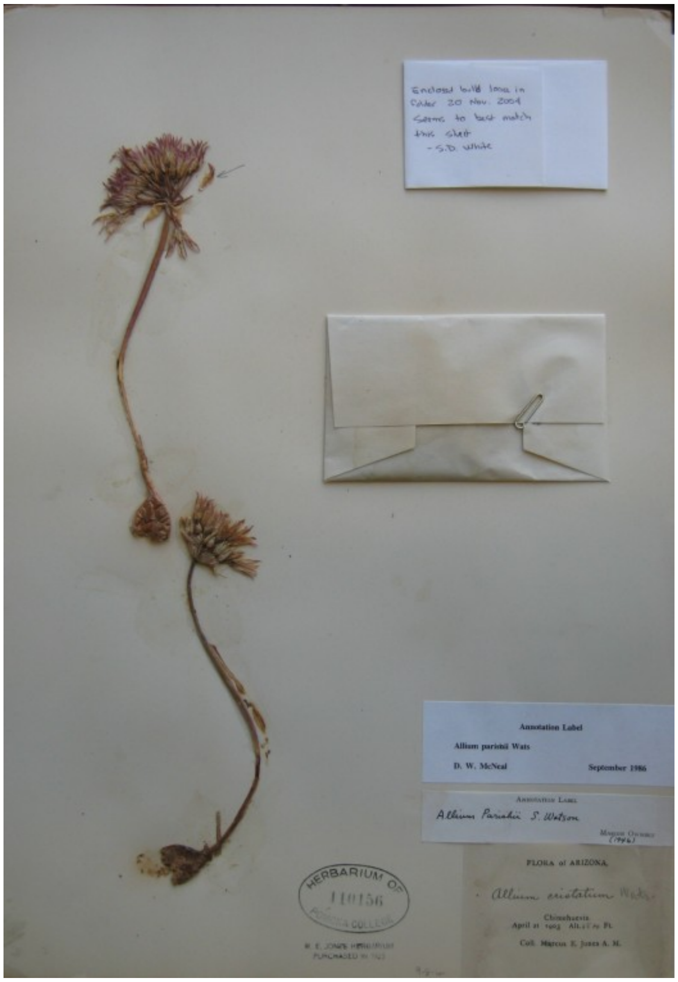

Figure 11. *Jones s.n.* 1903 collection of *Allium parishii* from the Chemehuevi Mountains.

Figure 12. *Allium parishii* in the Mohave Mountains.

Figure 13. Mohave Mountains habitat, Mohave County, Arizona, of *Allium parishii* with diverse Sonoran/ Mohave Desert shrubs on granitic soils.

Figure 14. Mohave Mountains habitat of *Allium parishii* in low diversity burned habitat on metamorphic gneiss soils.

shrub community whereas the latter site had much less shrub diversity and a dense growth of *Bromus rubens* L. (red brome) (Figure 15) due to a wildfire as evidenced by old burn scars on *Yucca brevifolia* stumps.

More recent collections have been made from the Kofa Mounains near Quartzite, in La Paz/Yuma Counties, 50 miles south of the Mohave Mountains, beginning in 1937 (*Nichols s.n.* ARIZ) and continuing in 1960 (*Monson s.n.* ARIZ) and 1976 (*Irwin 33* ARIZ). Also in 2005, *Allium parishii* was relocated in the Kofa Mountains by Karen Reichhardt from the BLM Yuma Field Office (*Reichhardt 2005-100* ARIZ). The Kofa Mountains are a well known locality for many relict species including *Washingtonia filifera* Wendl. and *Berberis harrisoniana* Kearney and Peebles. I visited this site and recorded the habitat, associated species, and GPS location (*Anderson 2008-04* ASU [Appendix 1]). In the Kofa Mountains *A. parishii* occurs on yet another edaphic habitat: volcanic soils derived from andesite, in a diverse Sonoran Desert shrub community (Figure 16). The Kofa Mountains site showed no evidence of wildfire and contained little *Bromus rubens* (Figure 17). *A. parishii* seems to be a resilient species due to the ecological variability in its geological and edaphic habitats and its ability to survive the increasing wildfire frequency scourging the Sonoran and Mohave Deserts due to the growing presence of *Bromus rubens*.

The biogeographical effect of past climatic and geological history on plant species migrations can result in unusual patterns of distribution. The research presented here has demonstrated the surprising geographic proximity of these two desert species of *Allium* previously known primarily from opposite sides of Arizona (Figure 18). The accurate delineation of *Allium bigelovii* as a Chihuahuan Desert species with a disjunct population as far west as Burro Creek and the rediscovery of *A. parishii*, a California Mohave Desert species, at the eastern edge of its range in the Mohave Mountains, brings these two species, usually 500 km apart, to within less than 100 km of each other in the Sonoran Desert of Mohave County, Arizona.

Figure 15. Mohave Mountains burned habitat of *Allium parishii* with thick cover of *Bromus rubens*.

Figure 16. Kofa Mountains habitat, La Paz County, Arizona, of *Allium parishii* on volcanic andesitic soil.

ACKNOWLEDGMENTS

I want to thank Edward Gilbert and Elizabeth Makings from Arizona State University for help in making maps and J. Mark Porter from Claremont College, Rancho Santa Ana Botanic Garden, for help in making

Figure 17. Kofa Mountains habitat of *Allium parishii* showing lack of *Bromus rubens*.

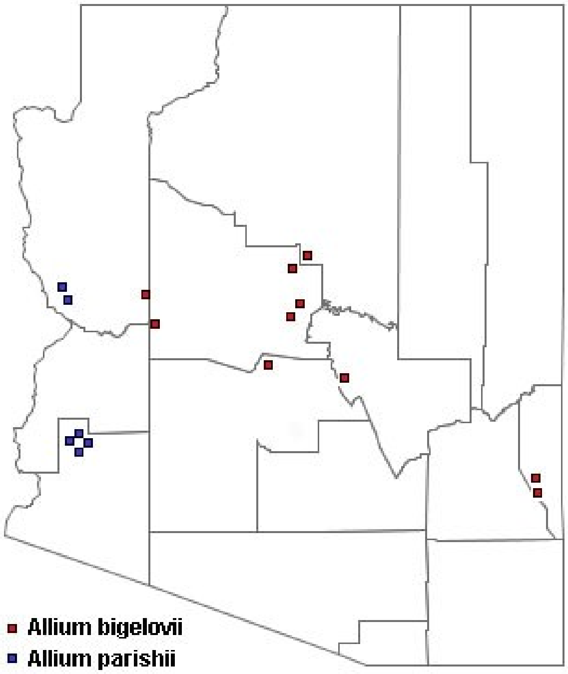

Figure 18. Map of *Allium bigelovii* and *A. parishii* showing distributional proximity in Mohave County, Arizona.

maps and figures. Christine Bates, Karen Reichhardt, and Dick Zeller provided field assistance. Dr. D. McNeal, Dr. D. Pinkava, and Mr. R. Sivinski reviewed the manuscript.

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APPENDIX 1

All voucher specimens are deposited at Arizona State University (ASU).

Allium bigelovii S. Wats.

Arizona: Yavapai Co.: Anderson Mine site, late Tertiary lacustrine outcrop; with *Canotia holocantha*, *Ambrosia dumosus*, *Fouquieria splendens*, *Nolina bigelovii*, *Yucca brevifolia*, *Pleuraphis rigida*, *Calochortus flexuosus*; *Tiquilia canescens*; Locally common; 12S 0290870 3798207 1945 ft. John L. Anderson 2008-03, Apr 7, 2008.

Arizona: Mohave Co.: Burro Creek Cliffrose site, ca 2 miles above Six Mile Crossing of Burro Creek; late Tertiary lacustrine outcrop; with *Canotia holocantha*, *Polygala acanthoclada*, *Chrysothamnus nauseosus* var. *junceus*, *Ziziphus obtusifolia*, *Calochortus flexuosus*, *Pleuraphis rigida*, *Aristida purpurea, Dichelostemma pulchra*; Locally common; 12S 0283300 3828471 2436 ft. John L. Anderson 2008-07, Apr 24, 2008.

Allium parishii S. Wats.

Arizona: La Paz Co.: Kofa Mts., High Tank Seven side canyon off of Burro Canyon; north-facing andesite hillside; with *Simmondsia chinensis*, *Bernardia incana*, *Eriogonum fasciculatum*, *Fouquieria splendens*, *Ephedra aspera*, *Canotia holocantha*, *Viguieria deltoides*, *Acacia greggii*, *Krameria grayi*, *Gallium stellatum*, *Xylorhiza tortifolia*, *Pleuraphis rigida*, *Stipa speciosa*, *Calochortus kennedyi*, *Dichelostemma pulchra*, *Opuntia chlorotica*, *Agave desertii*; uncommon (ca 50 plants on one acre surveyed); 11S 0777891 3698772 2788 ft. John L. Anderson 2008-04, Apr 17, 2008.

Arizona: Mohave Co.: Mohave Mts., side canyon with Scotts Well, ca ½ miles NE of Scotts Well; north-facing granite hillside; with *Canotia holocantha*, *Nolina bigelovii*, *Eriogonum fasciculatum*, *Encelia virginensis*, *Galium stellatum*, *Acacia greggii*, *Viguieria deltoides*, *Lotus rigida*, *Ephedra aspera*, *Opuntia acanthacarpa*, *Thamnosma montana*, *Janusia gracilis*, *Xylorhiza tortifolia*, *Pleuraphis rigida*, *Stipa speciosa*; uncommon (ca 100 plants on ten acres surveyed); 11S 758164 3829072 3220 ft; T14N R 18W S7 NENW; John L. Anderson 2008-05, Apr 23, 2008.

Spatial Patterns of Endemic Plant Species of the Colorado Plateau

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Abstract. The Colorado Plateau region supports one of the highest levels of endemism in the United States. Of the 6,800 vascular plants of the region more than 300 are endemic. Endemic species may have a higher risk of extinction due to their restricted geographic range. This risk may be increased with climate change. To better understand the risk to endemics, ecological niche modeling can provide a better understanding of the dynamics of environmental factors on a species range. For the endemics of the Colorado Plateau, a changing climate may modify species range. But underlying factors such as substrate and specialized habitat will also play a role in how a species range may change. The focus of this study is to understand spatial patterns and factors that predict endemism and then model species potential distribution.

The Colorado Plateau ecoregion supports one of the highest levels of endemism in North America, ranking in the top three ecoregions on the continent for the total number of endemics in all taxonomic groups (Ricketts et al 1999). The Colorado Plateau also has the highest rate of endemism in terms of actual numbers of species (Kartesz and Farsted 1999). The harsh, dry environment of the Colorado Plateau has historically placed intense environmental stress on the flora. Factors such as soil, climate, and water scarcity among others seem to limit the geographic range of many species. More than 300 species of vascular plants on the Colorado Plateau are endemic. Many of the endemic plant species are edaphic endemics restricted to one soil type, but larger geographic patterns of plant endemism can also be seen in the Colorado Plateau's "sky island" habitats. Other important areas are those below 2000m; these lower elevations have a greater number of endemics than higher elevations (Welsh 1978).

The Colorado Plateau contains 122,805,655 acres of land, of these 3,622,942 acres (3 percent) are protected lands in National Parks and Monuments, another 64,748,735 acres (52 percent) are federally owned (Figure 1). Land ownership is also unique for the Plateau with the third most federally controlled land per area of all other ecoregions. Protected areas of the Colorado Plateau have a pivotal role to play in enabling species and ecosystems to persist. Protected areas can remove or control many of the threatening processes such as habitat loss and fragmentation.

The distribution of endemic plants in protected areas is not fully known and very little work has been completed in modeling distribution shifts in response to climate change. To better understand the complexity and variability climate change may have on the distribution of plants and animals, ecologists have recently developed the concept of computationally based Ecological Niche Models (ENMs) (Peterson, Soberon and Samcjez-Cordero 1999; Peterson and Vieglais 2001; Stockwell and Peters 1999). ENMs integrate a wide range of environmental data (including point location data) to define potential species habitats. The output of ENMs is a set of grids of potential habitat based on the co-occurrence of known species locations and various environmental conditions. Each grid is assessed for accuracy by comparing a set of reserved species locations to the predicted habitat distributions.

The predicted ENM habitats can be projected onto past, current, and modeled future landscapes thus providing testable habitat conditions that can be compared to known conditions to assess model accuracy and improve environmental predictions (Peterson et al. 2002). Projection onto the current landscape indicates the present day geographic distribution of suitable conditions for these plant species - the species potential habitat. Comparing these projections to historical and current location data provides information on the changes that plants have made in their dispersal in response to disturbances and environmental changes in the recent past. Projecting the model onto future landscapes provides information of how climate change may affect the species distribution and dispersal ability.

METHODS

MaxEnt

Data collection is the first step in modeling a species distribution; species location point records and environmental data are needed for the model. Location point records used in this study are from herbaria and Natural Heritage Programs from the Four Corners region, National Park Service and the Bureau of Land Management. Species with occurrence points from less than 10 populations were excluded from modeling because prior studies have demonstrated that fewer than 10 populations is not meaningful without extensive habitat re-

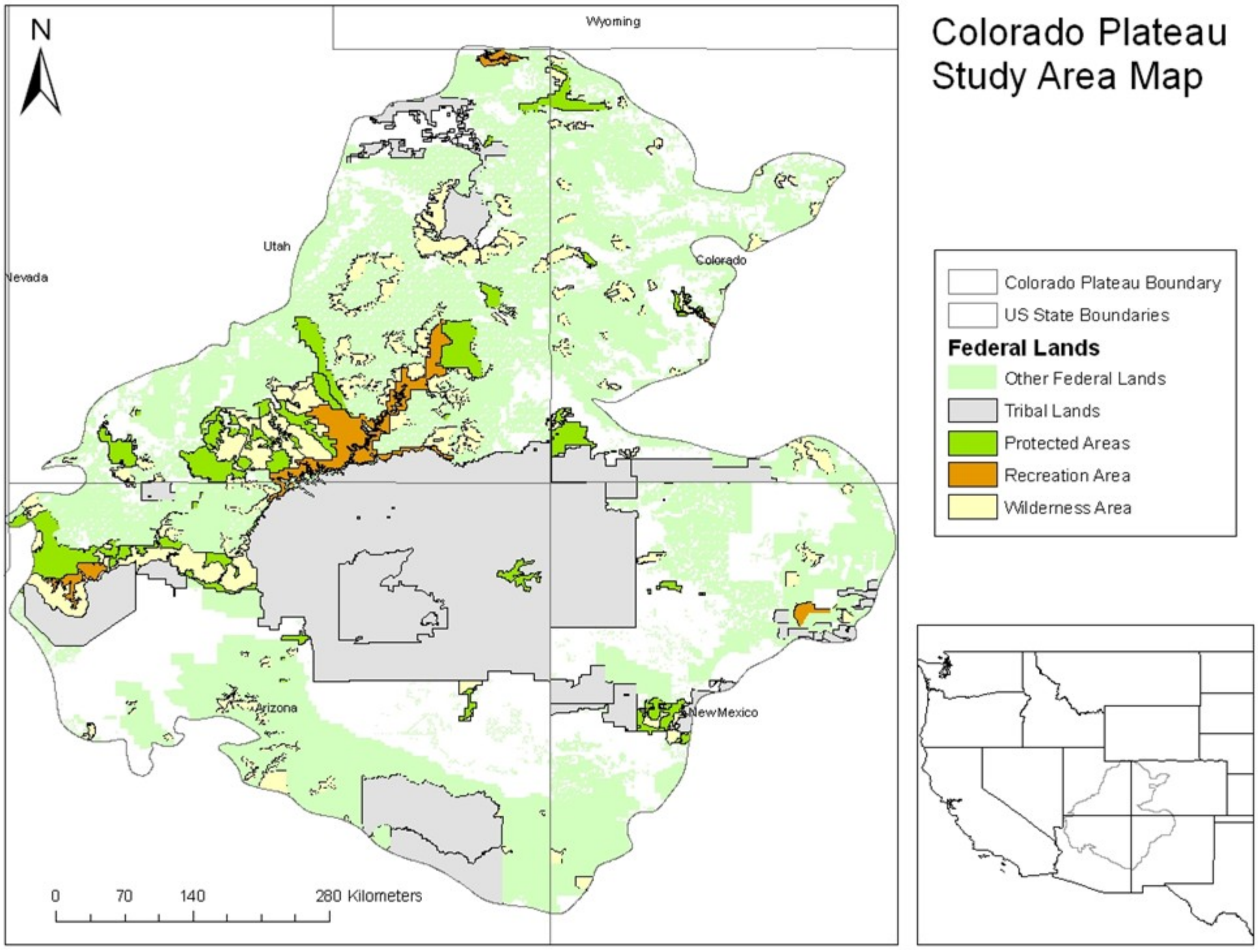

Figure 1: Colorado Plateau Study Area Map

quirement data and climate envelope constraints that may not be available (Stockwell and Peterson 2002). Environmental data listed in Table 1 are from www.worldclim.org and the USGS Hydro1K digital elevation model data. These variables include precipitation, temperature, aspect and slope. Geologic layers are from the USGS 1995 soils data. The geologic layers were converted from polygon to raster and downscaled to 1 km to match the climate and elevation layers.

The modeling technique used in this study was Maximum Entropy or MaxEnt. MaxEnt is a general-purpose machine learning method of ecological niche modeling (Phillips, Anderson and Schapire 2006). MaxEnt estimates a species probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent the information about the species distribution (Phillips, Anderson and Schapire 2006).

An important factor for choosing MaxEnt was that it allows for the use of presence-only data and categorical variables. In addition, MaxEnt has been shown to perform better than other algorithms for modeling distributions with limited data points (Elith et al 2006 and Pearson et al 2007). MaxEnt provides mechanisms to assess the relative importance of each independent variable, which provides a better understanding of range shifts due to climate change.

To calibrate the models all location points were randomly divided into training (70 percent) and testing (30 percent) datasets. To evaluate the accuracy of the model and each variable's predictive power, the Receiver Operating Characteristic (ROC) curve (Hanley and McNeil 1982) was used for both training and test data. The ROC curve represents the relationship between the percentage of presences correctly predicted (sensitivity) and one minus the percentage of the absences correctly predicted (specificity). The Area Under the Curve (AUC) measures the ability of the model to classify correctly a species as present or absent. AUC values can be interpreted as the probability that when a site with the species present and a site with the species absent are drawn at random, the former will have a higher predicted value than the latter. Following Araujo and Guisan (2006), a rough guide for classifying the model accuracy is: 0.5-0.6=insufficient, 0.6-0.7=poor, 0.7-0.8=average, 0.8-0.9=good and 0.9-1=excellent.

Table 1. Environmental Variables
BIO 1-Annual Mean Temperature
BIO 2-Mean Diurnal Range
BIO 3-Isothermality
BIO 4-Temperature Seasonality
BIO 5-Maximum Temperature of Warmest Month
BIO 6-Minimum Temperature of Coldest Month
BIO 7-Temperature Annual Range
BIO 8-Mean Temperature of Wettest Quarter
BIO 9-Mean Temperature of Driest Quarter
BIO 10-Mean Temperature of Warmest Quarter
BIO 11-Mean Temperature of Coldest Quarter
BIO 12-Annual Precipitation
BIO 13-Precipitation of Wettest Month
BIO 14-Precipitation of Driest Month
BIO 15-Precipitation Seasonality
BIO 16-Precipitation of Wettest Quarter
BIO 17-Precipitation of Driest Quarter
BIO 18-Precipitation of Warmest Quarter
BIO 19-Precipitation of Coldest Quarter
DEM-Digital Elevation Model 1km
Slope Angle-Derived from DEM
Slope Aspect-Derived from DEM
Geology-Landform Description

Alternative Suitability Models

Three final models were built for each species: 1) full model, 2) pruned model, and 3) topo model. The full model contained all variables. The pruned model was based on findings from a jackknife analysis, used to evaluate individual variable importance in model development. The jackknife method evaluates variable predictive strength by excluding each variable and creating a tentative model with the remaining variables (Phillips, Anderson and Schapire 2006). Then tentative models are created using each variable in isolation (Phillips, Anderson and Schapire 2006). Tentative models are then compared to the full model. The pruned model is then produced with only important predictive variables found during the jackknife analysis. The goal of the pruned model was to remove redundant variables and provide a better fit to the most important environmental predictors, when compared with the full model. The topo model used only elevation, slope angle and slope aspect as variables. There is a known correlation between elevation and climate (precipitation and temperature). The topo model was used to see how predictions of current species distributions based on topography alone (elevation, slope and aspect) compared to models with climate data (temperature, precipitation, slope and aspect). All three models are evaluated for accuracy with an AUC score.

Spatial Comparison of Model Output

The habitat suitability maps produced by the three models were then compared spatially to identify places of predictive agreement between models (consistently predicted present or absent), and places where predicted area of suitable habitat were in disagreement. A spatially-explicit (by pixel) comparison was performed following the methods proposed by Parolo and others (2008), which produced two output maps. The first map identifies areas of maximum agreement between the models and the second map identifies areas of minimum agreement between models.

RESULTS

Two hundred and eleven endemic plants were identified to have 10 or more representative location points for accurate modeling. The least number of points used for training data were seven with three test points, and the largest was 168 training points with 71 testing points. Model accuracy varied across species with AUC values ranging from 0.6423 to 1. The jackknife analysis demonstrated that slope aspect was the least predictive variable for the most species and Precipitation Seasonality (BIO15) was the highest predictive variable for the most species (Table 2).

Example of ENM for *Sclerocactus mesae-verdae*

One example of a rare endemic plant modeled is the Mesa Verde cactus (*Sclerocactus mesae-verdae*). Mesa Verde cactus is listed as Threatened by the US Fish and Wildlife Service and a recovery plan was written in 1984 (Heil 1984). The recovery plan suggested that populations should be monitored to determine their stability (Ladyman 2004). This cactus is restricted to populations in the Four Corners region of New Mexico and Colorado. Mesa Verde cactus occurs in salt-desert scrub communities, typically in the Fruitland and Mancos shale formations, but has also been found to grow in the Menefee Formation overlaying Mancos shale (Roth 2001). It is most frequently found on the tops of hills or benches and along slopes and at elevation ranging from 4900 to 5500 ft (Roth 2001). Annual precipitation varies from approximately 8 to 20 cm. Average temperatures

Table 2. Total number of training and test points used in the model and the overall AUC value for the model. Predictor variable with the highest AUC value when used in isolation and the variable with the least predictive power for each species.

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Abronia argillosa	28	12	0.9759	Slope Aspect	0.5681	BIO 9	0.9039
Agave utahensis ssp. *kaibabensis*	12	5	0.9933	BIO 19	0.372	BIO 15	0.9724
Aliciella haydenii	14	5	0.9903	BIO 5	0.4052	BIO 11	0.8754
Amsonia jonesii	47	20	0.9789	Slope Angle	0.6246	BIO 18	0.8829
Amsonia peeblesii	31	12	0.9979	Slope Aspect	0.7798	BIO 14	0.9554
Aquilegia grahamii	8	3	0.9955	BIO 17	0.3579	BIO 15	0.9371
Aquilegia loriae	10	4	0.9994	BIO 10	0.4245	BIO 11	0.9758
Argemone arizonica	8	3	0.9817	BIO 19	0.3105	Slope Angle	0.8387
Argemone corymbosa ssp. *arenicola*	7	2	0.9998	BIO 2	0.3846	BIO 16	0.9845
Asclepias cutleri	20	8	0.8857	Geology	0.5897	BIO 14	0.9104
Asclepias welshii	15	6	0.9802	BIO 2	0.649	BIO 11	0.9563
Astragalus ampullarius	26	10	0.9957	Slope Angle	0.5299	BIO 15	0.9392
Astragalus beathii	21	9	0.9994	Slope Angle	0.5269	Geology	0.9521
Astragalus consobrinus	11	4	0.997	Slope Aspect	0.5	BIO 11	0.9555
Astragalus cronquistii	48	20	0.9989	Slope Angle	0.6139	BIO 15	0.9437
Astragalus debequaeus	63	26	0.89	Slope Aspect	0.6442	BIO 9	0.975
Astragalus desperatus var. *conspectus*	17	6	0.9989	Slope Aspect	0.4179	BIO 11	0.9945
Astragalus desperatus var. *petrophilus*	21	8	0.9991	Slope Angle	0.3093	BIO 12	0.9643
Astragalus deterior	83	35	0.9997	Slope Aspect	0.6219	BIO 8	0.9842
Astragalus detritalis	24	10	0.9075	Slope Aspect	0.4536	BIO 11	0.9654
Astragalus duchesnensis	56	23	0.9981	Slope Angle	0.7779	BIO 7	0.9799
Astragalus eastwoodiae	14	6	0.9851	BIO 10	0.4144	BIO 11	0.906
Astragalus episcopus var. *lancearius*	8	3	0.9595	BIO 8	0.4212	BIO 16	0.836
Astragalus hamiltonii	11	4	0.759	Slope Angle	0.4996	BIO 16	0.9884
Astragalus henrimontanensis	10	4	0.9996	Slope Aspect	0.4454	Geology	0.9316
Astragalus humillimus	19	7	0.9988	Slope Aspect	0.6221	BIO 4	0.9775
Astragalus iodopetalus	33	14	0.9985	Slope Aspect	0.7224	BIO 7	0.9746
Astragalus iselyi	16	6	0.999	Slope Aspect	0.7312	BIO 8	0.9718

Table 2. Continued

Species	**# Training Samples**	**# Test Samples**	**Test AUC**	**Least Predictive Variable**	**AUC**	**Highest Predictive Variable**	**AUC**
Astragalus linifolius	14	6	0.9721	BIO 2	0.5	BIO 8	0.9492
Astragalus malacoides	16	6	0.9887	Slope Aspect	0.4433	BIO 16	0.9338
Astragalus micromerius	10	3	0.9897	BIO 5	0.5042	BIO 11	0.941
Astragalus moencoppensis	52	22	0.9854	Slope Aspect	0.6095	BIO 16	0.9076
Astragalus musiniensis	63	26	0.9868	Slope Aspect	0.4348	BIO 16	0.9137
Astragalus naturitensis	62	26	0.9953	Slope Aspect	0.5935	BIO 8	0.9406
Astragalus nutriosensis	21	8	0.9982	Slope Aspect	0.4817	Geology	0.9908
Astragalus oocalycis	8	3	0.9958	BIO 19	0.4252	BIO 16	0.9727
Astragalus perianus	20	8	0.9749	BIO 2	0.6125	Geology	0.9398
Astragalus piscator	16	6	0.9999	Slope Angle	0.6152	BIO 9	0.9976
Astragalus proximus	12	5	0.9772	BIO 12	0.4203	BIO 16	0.9341
Astragalus rafaelensis	83	35	0.9999	Slope Angle	0.707	BIO 7	0.9709
Astragalus rusbyi	21	9	0.9982	Slope Angle	0.7211	BIO 3	0.9328
Astragalus schmolliae	18	7	0.9996	Slope Angle	0.7367	BIO 11	0.9848
Astragalus serpens	19	7	0.9976	Slope Aspect	0.4439	BIO 8	0.9671
Astragalus sesquiflorus	24	10	0.9983	Slope Aspect	0.491	BIO 6	0.9368
Astragalus sophoroides	28	11	0.9994	BIO 2	0.8478	BIO 12	0.9723
Astragalus striatiflorus	24	10	0.9959	Slope Aspect	0.5023	BIO 15	0.952
Astragalus tortipes	8	3	0.988	Slope Angle	0.4142	Geology	0.9211
Astragalus troglodytus	52	22	0.9989	Slope Angle	0.6131	BIO 3	0.9536
Astragalus welshii	16	6	0.7897	Slope Aspect	0.4063	BIO 15	0.8887
Astragalus wetherillii	12	5	0.9845	BIO 19	0.4486	BIO 15	0.9848
Astragalus xiphoides	45	18	0.9912	Slope Angle	0.5483	BIO 1	0.9824
Camissonia atwoodii	50	21	1	Slope Aspect	0.6725	BIO 12	0.9868
Camissonia eastwoodiae	19	7	0.9848	BIO 17	0.5237	BIO 13	0.8891
Camissonia exilis	38	16	0.9739	Slope Aspect	0.6027	BIO 15	0.948
Carex curatorum	19	7	0.9907	Slope Aspect	0.2923	BIO 15	0.8895
Carex specuicola	77	32	0.9969	Slope Aspect	0.4858	BIO 11	0.9395
Castilleja aquariensis	168	71	0.9999	Slope Aspect	0.6332	Geology	0.9901
Castilleja kaibabensis	24	9	0.9999	Slope Aspect	0.6471	BIO 15	0.9874
Castilleja revealii	14	6	0.9782	Slope Aspect	0.5	Geology	0.9151
Chrysothamnus molestus	35	15	0.9993	Slope Aspect	0.6306	Geology	0.9756

Table 2. Continued

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Chrysothamnus viscidiflorus ssp. *planifolius*	8	3	0.9916	BIO 2	0.4925	Slope Angle	0.7825
Cirsium chellyense	11	4	0.9864	BIO 10	0.4346	BIO 11	0.9344
Cirsium murdockii	11	4	0.7394	BIO 4	0.2853	BIO 15	0.9444
Cirsium perplexans	50	21	0.9924	Slope Angle	0.6892	Geology	0.9253
Cirsium rydbergii	26	11	0.985	Slope Aspect	0.459	Geology	0.9099
Clematis hirsutissima	19	7	0.9999	Slope Aspect	0.4112	BIO 12	0.9771
Cleomella palmeriana	17	6	0.9784	Slope Angle	0.4802	BIO 13	0.889
Crataegus saligna	19	8	0.9261	Slope Aspect	0.4154	BIO 6	0.9537
Cryptantha atwoodii	22	9	0.9994	Slope Aspect	0.5488	BIO 16	0.9697
Cryptantha capitata	33	14	0.9858	Slope Aspect	0.5139	BIO 15	0.9494
Cryptantha cinerea var. *arenicola*	12	4	0.9967	Slope Angle	0.4673	BIO 15	0.9804
Cryptantha creutzfeldtii	33	14	0.9997	Slope Aspect	0.6437	BIO 6	0.9685
Cryptantha elata	10	4	0.9997	BIO 1	0.402	Slope Angle	0.9762
Cryptantha johnstonii	12	4	0.9987	Slope Aspect	0.2564	BIO 6	0.9714
Cryptantha jonesiana	20	8	0.6423	Slope Aspect	0.2748	BIO 9	0.9782
Cryptantha longiflora	17	7	0.8946	BIO 5	0.4916	BIO 15	0.8834
Cryptantha mensana	9	3	0.8785	Slope Angle	0.217	BIO 15	0.9045
Cryptantha osterhoutii	37	15	0.9886	Slope Aspect	0.5552	BIO 13	0.914
Cryptantha paradoxa	11	4	0.9657	BIO 10	0.4083	BIO 7	0.8628
Cryptantha semiglabra	21	9	1	Slope Angle	0.7076	BIO 7	0.9914
Cycladenia humilis var. *jonesii*	26	10	0.9978	Slope Aspect	0.491	BIO 13	0.9634
Cymopterus duchesnensis	39	16	0.9988	Slope Aspect	0.7142	BIO 11	0.9706
Cymopterus megacephalus	24	9	0.9492	Slope Aspect	0.5658	BIO 15	0.9087
Cymopterus minimus	34	14	0.9916	Slope Aspect	0.4755	BIO 15	0.933
Dalea flavescens	33	13	0.9489	Slope Aspect	0.5197	BIO 13	0.8887
Draba graminea	10	4	0.9983	Slope Aspect	0.4768	BIO 10	0.9948
Eremocrinum albomarginatum	10	4	0.9826	BIO 9	0.2196	BIO 7	0.9466
Ericameria zionis	8	3	0.7485	BIO 19	0.3877	Slope Aspect	0.839
Erigeron kachinensis	60	25	0.9972	Slope Aspect	0.7543	BIO 15	0.9619
Erigeron maguirei	21	8	0.9926	Slope Aspect	0.397	BIO 9	0.9714

Table 2. Continued

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Erigeron mancus	17	6	0.9998	Slope Aspect	0.6755	BIO 15	0.9914
Erigeron proselyticus	10	4	0.9798	BIO 12	0.3529	BIO 10	0.918
Erigeron religiosus	13	5	0.9252	BIO 5	0.3833	BIO 15	0.9528
Erigeron rhizomatus	23	9	0.9999	Slope Aspect	0.6843	BIO 9	0.9796
Erigeron sionis	7	3	0.7639	BIO 19	0.445	BIO 15	0.8189
Erigeron sivinskii	14	6	0.9732	Slope Angle	0.4754	BIO 8	0.9373
Eriogonum aretioides	14	5	0.9821	Slope Angle	0.5789	BIO 15	0.9153
Eriogonum bicolor	19	8	0.995	BIO 2	0.5918	BIO 4	0.9464
Eriogonum clavellatum	45	19	0.9977	Slope Angle	0.6982	BIO 7	0.9668
Eriogonum contortum	14	5	0.9996	BIO 2	0.6408	BIO 13	0.9855
Eriogonum jonesii	26	11	0.9904	Slope Angle	0.5547	Geology	0.9317
Eriogonum leptocladon var. *ramosissimum*	23	9	0.9909	Slope Aspect	0.5519	BIO 1	0.9259
Eriogonum pelinophilum	111	47	0.9999	Slope Angle	0.716	BIO 7	0.9776
Eriogonum ripleyi	31	13	0.9998	Slope Aspect	0.5704	BIO 15	0.9741
Eriogonum scabrellum	12	5	0.9896	BIO 9	0.4757	Geology	0.9042
Eriogonum subreniforme	21	9	0.8827	Slope Aspect	0.4721	BIO 12	0.9149
Eriogonum tumulosum	14	5	0.9914	BIO 5	0.4753	BIO 7	0.9641
Errazurizia rotundata	19	7	0.9991	BIO 3	0.7049	BIO 7	0.9724
Euphorbia aaron-rossii	39	16	0.9991	Slope Aspect	0.5234	BIO 12	0.9537
Euphorbia nephradenia	10	3	0.9928	Slope Aspect	0.4562	BIO 16	0.9519
Gaillardia flava	14	6	0.9975	Slope Angle	0.6717	BIO 6	0.9812
Gilia caespitosa	24	9	1	Slope Aspect	0.817	BIO 18	0.9578
Gilia stenothyrsa	13	5	0.9989	BIO 10	0.496	BIO 9	0.9748
Gilia tenuis	8	3	0.9998	Slope Aspect	0.1882	BIO 12	0.9445
Glaucocarpum suffrutescens	46	19	1	Slope Aspect	0.7096	BIO 9	0.9904
Grindelia fastigiata	10	4	0.9902	Slope Angle	0.2632	BIO 9	0.9077
Grindelia laciniata	12	5	0.9722	BIO 3	0.3623	BIO 17	0.8674
Hackelia gracilenta	21	9	0.9998	Slope Aspect	0.6853	BIO 15	0.9844
Hedeoma diffusa	53	22	0.9998	Slope Aspect	0.6175	BIO 15	0.9649
Hedysarum occidentale var. *canone*	21	9	0.9987	Slope Aspect	0.6461	BIO 15	0.9575

Table 2. Continued

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Hesperodoria salicina	28	11	0.9129	Slope Aspect	0.5241	BIO 15	0.9367
Heterotheca jonesii	12	5	0.9941	BIO 2	0.4925	Geology	0.8956
Hymenoxys jamesii	25	10	0.9953	Slope Aspect	0.5684	BIO 11	0.9456
Ipomopsis polyantha	17	6	0.9462	BIO 1	0.4734	BIO 7	0.8384
Lepidium huberi	10	3	0.9728	BIO 17	0.498	BIO 9	0.9058
Lepidium montanum var. *neeseae*	21	9	0.9541	Slope Aspect	0.7261	BIO 13	0.9437
Lesquerella congesta	23	9	1	Slope Aspect	0.6799	BIO 6	0.9971
Lesquerella kaibabensis	10	3	0.8568	Slope Aspect	0.5	Geology	0.9772
Lesquerella navajoensis	12	5	0.9999	Slope Angle	0.5	Geology	0.989
Lesquerella parviflora	86	36	0.9981	Slope Aspect	0.6236	BIO 15	0.9626
Lesquerella pruinosa	13	5	1	Slope Aspect	0.58	BIO 16	0.9931
Lesquerella vicina	24	10	0.9987	Slope Angle	0.6923	BIO 9	0.9722
Lomatium concinnum	129	54	0.9998	Slope Aspect	0.6419	BIO 4	0.9586
Lomatium latilobum	9	3	0.9962	BIO 17	0.4158	BIO 4	0.9019
Lupinus crassus	38	16	0.9863	Slope Aspect	0.5558	BIO 8	0.9477
Lygodesmia doloresensis	32	13	0.9999	Slope Aspect	0.7192	BIO 8	0.9717
Mentzelia marginata	14	5	0.942	Slope Angle	0.3475	BIO 15	0.8468
Mentzelia rhizomata	54	22	0.9999	Slope Aspect	0.716	BIO 15	0.9939
Mentzelia shultziorum	8	3	0.6819	BIO 17	0.4103	BIO 4	0.9093
Mimulus eastwoodiae	41	17	0.979	BIO 5	0.5615	Geology	0.8184
Myosurus nitidus	12	4	0.79	BIO 5	0.435	Geology	0.9316
Nama retrorsum	39	16	0.9892	Slope Aspect	0.5523	BIO 11	0.9098
Oenothera acutissima	57	24	0.9982	Slope Aspect	0.611	BIO 13	0.9686
Opuntia aurea	35	15	0.9957	Slope Aspect	0.5969	BIO 1	0.9615
Oreoxis trotteri	9	3	0.997	BIO 17	0.4995	Slope Angle	0.9762
Packera franciscana	10	4	0.9977	Slope Aspect	0.5	BIO 15	0.9707
Parthenium ligulatum	13	5	0.9637	BIO 8	0.43	BIO 15	0.8352
Pediocactus bradyi	29	12	0.9992	Slope Angle	0.7323	BIO 16	0.9645
Pediocactus despainii	17	7	0.9966	Slope Aspect	0.4568	BIO 8	0.9807
Pediocactus paradinei	28	12	0.9966	Slope Angle	0.7985	BIO 15	0.9701
Pediocactus peeblesianus var. *fickeiseniae*	40	17	0.9937	BIO 2	0.6728	BIO 11	0.9523

Table 2. Continued

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Pediocactus winkleri	10	4	0.9997	Slope Aspect	0.3578	BIO 9	0.9799
Pediomelum pariense	21	8	0.9839	Slope Aspect	0.4554	BIO 15	0.9679
Penstemon ammophilus	19	7	0.9999	Slope Aspect	0.6623	BIO 15	0.9808
Penstemon atwoodii	15	6	0.9978	Slope Aspect	0.4472	BIO 15	0.9662
Penstemon bracteatus	18	7	0.9893	Slope Aspect	0.7072	BIO 9	0.9267
Penstemon breviculus	9	3	0.6775	Slope Angle	0.2816	BIO 15	0.854
Penstemon clutei	56	24	0.9973	Slope Aspect	0.5949	BIO 15	0.9707
Penstemon distans	16	6	1	BIO 5	0.6628	BIO 1	0.9889
Penstemon flowersii	19	7	1	Slope Aspect	0.7017	BIO 7	0.9976
Penstemon gibbensii	8	3	1	Slope Angle	0.3782	Geology	0.9964
Penstemon goodrichii	17	7	0.9999	Slope Angle	0.762	BIO 16	0.9904
Penstemon grahamii	90	38	0.9996	Slope Aspect	0.69	BIO 9	0.9865
Penstemon lentus var. *albiflorus*	16	6	0.9986	BIO 5	0.625	BIO 15	0.9771
Penstemon marcusii	12	5	0.9991	Slope Angle	0.4632	BIO 18	0.9852
Penstemon nudiflorus	79	33	0.9971	Slope Aspect	0.6484	BIO 15	0.9493
Penstemon pseudoputus	39	16	0.9896	Slope Aspect	0.5151	BIO 15	0.9375
Penstemon strictiformis	9	3	0.7698	Slope Aspect	0.5716	Slope Angle	0.6493
Penstemon uintahensis	13	5	0.808	Slope Aspect	0.4688	BIO 15	0.9571
Perityle specuicola	12	5	0.9926	Slope Angle	0.4812	BIO 8	0.9507
Phacelia cephalotes	31	13	0.9851	Slope Angle	0.6395	BIO 4	0.9068
Phacelia constancei	35	15	0.991	Slope Aspect	0.6325	Geology	0.952
Phacelia crenulata var. *angustifolia*	26	10	0.9787	BIO 19	0.5829	BIO 15	0.871
Phacelia glechomifolia	46	19	0.9974	Slope Aspect	0.5353	BIO 15	0.9332
Phacelia rafaelensis	17	7	0.9748	Slope Angle	0.5166	BIO 15	0.9301
Phacelia splendens	17	6	0.9513	BIO 3	0.5761	BIO 8	0.9122
Phacelia welshii	18	7	0.9987	Slope Angle	0.724	Geology	0.9767
Phlox caryophylla	11	4	1	Slope Angle	0.4067	BIO 16	0.9953
Phlox cluteana	23	9	0.9987	Slope Aspect	0.4581	Geology	0.9465
Physaria obcordata	28	12	0.9895	Slope Aspect	0.5847	BIO 15	0.9721
Physaria repanda	11	4	0.9962	Slope Angle	0.5	BIO 15	0.9436
Platanthera zothecina	47	20	0.9555	Slope Aspect	0.6004	BIO 15	0.8757

Table 2. Continued

Species	# Training Samples	# Test Samples	Test AUC	Least Predictive Variable	AUC	Highest Predictive Variable	AUC
Potentilla angelliae	13	5	0.8715	Slope Angle	0.4887	BIO 9	0.9699
Primula specuicola	27	11	0.9925	BIO 3	0.6973	BIO 16	0.8986
Psoralidium junceum	7	3	0.9942	BIO 11	0.5	BIO 12	0.9351
Psorothamnus arborescens var. *pubescens*	10	4	0.9997	BIO 2	0.4595	BIO 16	0.9812
Psorothamnus thompsoniae var. *whitingii*	12	4	0.9996	Slope Angle	0.5391	BIO 14	0.984
Rosa stellata ssp. abyssa	15	6	0.999	Slope Aspect	0.5631	Geology	0.9772
Salix arizonica	129	54	0.9961	Slope Aspect	0.7927	Geology	0.9772
Schoenocrambe argillacea	57	24	0.9999	Slope Aspect	0.7184	BIO 9	0.9905
Sclerocactus brevispinus	45	19	1	Geology***	0.9011	BIO 7	0.9995
Sclerocactus glaucus	10	4	0.9039	BIO 10	0.3434	BIO 15	0.9249
Sclerocactus mesae-verdae	146	62	0.9997	Slope Aspect	0.648	BIO 6	0.9794
Sclerocactus parviflorus var. *intermedius*	11	4	0.9914	BIO 3	0.446	BIO 18	0.9473
Sclerocactus sileri	29	12	0.9949	Slope Aspect	0.6299	BIO 15	0.9548
Sclerocactus whipplei	35	14	0.9668	Slope Aspect	0.4761	BIO 15	0.852
Sclerocactus wrightiae	81	34	0.9869	Slope Angle	0.5928	BIO 12	0.9858
Shepherdia rotundifolia	91	38	0.9945	Slope Aspect	0.5764	BIO 15	0.924
Silene petersonii	20	8	0.9766	Slope Aspect	0.5782	BIO 6	0.9093
Silene rectiramea	11	4	1	Slope Aspect	0.5592	BIO 15	0.9866
Sphaeralcea janeae	18	7	0.9984	Slope Angle	0.7861	BIO 13	0.9927
Sphaeralcea psoraloides	40	17	0.9993	Slope Angle	0.5282	BIO 12	0.9812
Talinum thompsonii	10	4	1	Slope Aspect	0.5	BIO 6	0.9978
Thelypodiopsis juniperorum	33	13	0.9989	Slope Aspect	0.6393	BIO 7	0.9586
Townsendia aprica	52	21	0.9934	Slope Aspect	0.6216	BIO 11	0.9343
Townsendia glabella	77	33	0.9767	Slope Angle	0.5305	BIO 15	0.9328
Townsendia rothrockii	36	15	0.9902	BIO 2	0.6204	BIO 15	0.925
Trifolium neurophyllum	20	8	0.9862	Slope Aspect	0.4605	BIO 3	0.9729
Vanclevea stylosa	31	12	0.9924	Slope Aspect	0.6921	BIO 12	0.9618
Xylorhiza glabriuscula var. *linearifolia*	7	3	0.9981	BIO 11	0.4973	BIO 4	0.9204
Zigadenus vaginatus	16	6	0.995	Slope Angle	0.5341	Geology	0.9368

in the town of Shiprock near plant locations range from a high/low in January (coldest month) of 44.4°F/17°F to a high/low in July (hottest month) of 95°F/58°F (Ladyman 2004). The federal listing of Mesa Verde cactus provides detailed information on habitat, soil and climatic requirements of the plant, providing great detail to compare to model data.

Mesa Verde Cactus has 208 species location points. Models were developed using 146 for model training and 62 for model test validation points. The full, pruned and topo models were used to analyze suitable habitat for Mesa Verde cactus. The AUC score of the full model, incorporating all of the environmental variables, was 0.9977. The AUC score of the pruned model, developed from jackknife analysis, was 0.997. The pruned model showed geology as the highest predictive variable. In comparison, the topo model AUC score was 0.831. The accuracy of the three niche models measured by AUC scores, demonstrated that all three models performed better than random (AUC 0.5). The full and pruned models were nearly identical in AUC scores (0.9977, 0.997). The topo model was out performed by both the full and pruned models.

Variable isolation during jackknife analysis indicated geology, minimum temperature of coldest month, mean temperature of coldest quarter and temperature seasonality were the most predictive variables, with an AUC of 0.9 or above (Table 3). Variable inclusion during jackknife analysis did not show any significant results; the AUC scores only changed 0.001 between models. The least predictive variable was slope aspect.

Table 3: Mesa Verde Cactus model AUC scores.

Sclerocactus mesae-verdae		**Jackknife Variable Exclusion**		**Jackknife Variable Isolation**	
#Training samples	146	AUC without Geology	0.997	AUC with only Slope Aspect	0.5824
Iterations	500	AUC without BIO 4	0.9974	AUC with only BIO 2	0.6194
Training AUC	0.9977	AUC without BIO 1	0.9975	AUC with only Slope Angle	0.7073
#Test samples	62	AUC without BIO 10	0.9975	AUC with only BIO 12	0.7626
Test AUC	0.9977	AUC without BIO 11	0.9975	AUC with only BIO 19	0.7773
AUC Standard Deviation	0.0005	AUC without BIO 13	0.9975	AUC with only BIO 17	0.7802
		AUC without BIO 16	0.9975	AUC with only BIO 14	0.7907
		AUC without BIO 17	0.9975	AUC with only BIO 5	0.8222
		AUC without BIO 18	0.9975	AUC with only BIO 18	0.834
		AUC without BIO 19	0.9975	AUC with only BIO 13	0.8354
		AUC without BIO 8	0.9975	AUC with only BIO 16	0.8423
		AUC without BIO 9	0.9975	AUC with only BIO 7	0.8472
		AUC without BIO 12	0.9976	AUC with only BIO 3	0.8556
		AUC without BIO 14	0.9976	AUC with only BIO 10	0.8608
		AUC without BIO 15	0.9976	AUC with only BIO 1	0.8774
		AUC without BIO 2	0.9976	AUC with only BIO 9	0.8813
		AUC without BIO 3	0.9976	AUC with only BIO 8	0.8919
		AUC without BIO 5	0.9976	AUC with only BIO 15	0.8961
		AUC without BIO 6	0.9976	AUC with only BIO 4	0.9141
		AUC without BIO 7	0.9976	AUC with only BIO 11	0.9169
		AUC without Slope Angle	0.9976	AUC with only BIO 6	0.9655
		AUC without Slope Aspect	0.9976	AUC with only Geology	0.9888

The habitat suitability maps also varied between the models (Figure 2). The full model (Figure 2a) and the pruned model (Figure 2b) clearly show a smaller range than the topo model (Figure 2c). The area of suitable habitat for the full model was 919,973 acres, the pruned model 1,386,261 acres and the topo model 47,110,640 acres.

The spatial comparison of models found 571,307 acres of suitable habitat agreement between the models (Figure 2d). Disagreement analysis of the three models shows 47,081,482 acres (Figure 2e) and suggests that the topo model generated the most disagreement between models.

DISCUSSION

Alternative Suitability Models

The use of alternative models can offer a better understanding of how environmental variables play a role in a species distribution. The comparison of the three models may provide a deeper knowledge of species-environment relationships and lead to a more rigorous assessment of potential distributions. The alternative models may also identify needs in data to further understand species-environment relationships.

The three models used in this analysis all performed better than random. The full and pruned models performed the best (highest AUC scores) while the topo model over predicted suitable habitat. The jackknife analysis provided a way to understand variable importance for the use in the pruned model. This may help eliminate redundant variables and an overly large model.

Most pruned models showed a larger area of suitable habitat when compared with the full models. This suggests two possible interpretations: 1) the full model may be over fit, and not predicting all potential suitable habitat, or 2) the pruned model may be over predicting. Another interesting aspect of using alternative models was the use of only topographic variables in the topo model. Although this model over predicted suitable habitat for Mesa Verde cactus, other species models show a closer fit. This model may provide a way to analyze a species distribution when only elevation data are available, as Parolo and others (2008) found with *Arnica montana*.

Spatial Comparison

The spatial comparison of habitat suitability map output from the three models provides quantification of uncertainty in the model predictions of suitable habitat. Levels of uncertainty have important management implications. Areas with high model agreement that a species is present but without known occurrences of that species are target areas for field surveys. Areas of disagreement may provide insight into variables that contribute to uncertainty that could be better resolved through additional field work.

Final Habitat Maps and Use

The goal of this project was to identify potential suitable habitat for species by using alternative models evaluated with AUC scores and a spatial comparison. When comparing the three models, the AUC scores range from good to excellent for Mesa Verde cactus. The spatial comparison identified the full and pruned models as having similar predicted areas, while the area predicted by the topo model was larger. This technique provides a more rigorous analysis of the potential distribution of suitable habitat.

The methods described above provide a more straightforward ecological interpretation of how the environment affects a species' distribution. This modeling technique can also provide a better understanding of endemic plant distributions. These models can be used for future field investigations to find new populations and to identify relationships between climate, geology and topography with endemics.

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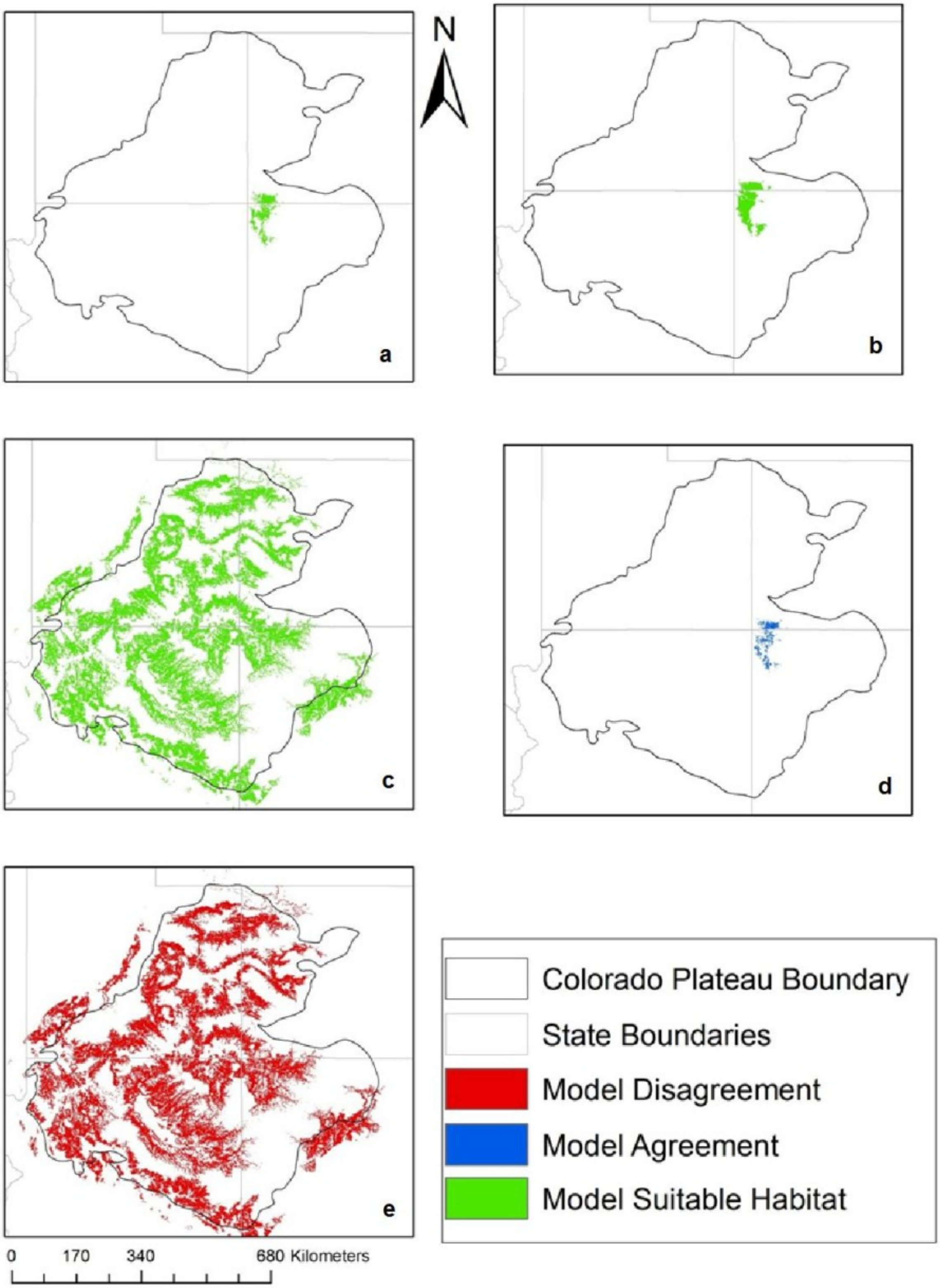

Figure 2. Mesa Verde Cactus distribution maps. Full model with all variables (a), pruned model (b), topo model (c), Suitable Habitat maps Maximum Agreement (d), Suitable Habitat maps Minimum Agreement (e).

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Biogeography of Rare Plants of the Ash Meadows National Wildlife Refuge, Nevada

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Abstract. The Ash Meadows National Wildlife Refuge encompasses more than 23,000 acres of unique desert that provides habitat for at least 25 plant and wildlife species found nowhere else in the world. Distinctive hydrology sustains high concentrations of endemic plants on the Refuge. Spring complexes, alkaline desert uplands, and velvet ash, emergent marsh and wet meadow communities known only to exist within the Refuge provide structure and habitat for several rare, endemic and endangered plants. Two studies designed to assist the Refuge with large-scale habitat restoration plans are underway. These studies include mapping all vegetation communities to a fine scale and locating and mapping the distribution of rare and listed plants on the Refuge. Mapping and classifying the vegetation communities to the alliance and association scale throughout the entire Refuge will provide a baseline of existing ecological conditions for monitoring change in the future. The rare plant surveys will also serve as a tool for monitoring the rare plants and the habitats in which they occur. Initially, vegetation classification standards were based upon community types derived from multiple earlier published sources. Due to the unique habitats and patterns of co-dominance of species occurring at the Refuge, several new alliance and association classification descriptions are being written to accurately describe plant communities.

Description of the Ash Meadows National Wildlife Refuge

The Ash Meadows National Wildlife Refuge (AMNWR) encompasses more than 23,000 acres of unique desert that provides habitat for at least 25 species found nowhere else in the world. The refuge may support the largest concentration of endemic species of any terrestrial landscape in the 48 contiguous United States. The Devil's Hole pupfish (*Cyprinodon diabolis*) and one plant species, Ash Meadows niterwort (*Nitrophila mohavenis*), are listed as federally endangered, and most of the other endemic species are either listed as threatened or are managed as sensitive species. Unfortunately, past human activities in AMNWR have resulted in the invasion of numerous non-native plant species, several of which negatively affect native populations and habitats (Otis Bay and Steven Ecological Consulting 2006). Ash Meadows is essentially a watered island amidst the vast Mojave Desert. Groundwater discharging from a regional carbonate aquifer feeds the numerous springs that exist at Ash Meadows. Spring discharge maintains soil moisture in the lowlands while uplands receive water only from rainfall that averages less than 2.75 inches annually. Annual evaporation exceeds 98.50 inches.

Ash Meadows is situated at approximately 2,200 feet elevation in the Mohave Desert, 40 miles east of Death Valley National Monument headquarters at Furnace Creek, California, and 90 miles northwest of Las Vegas, Nevada (Figure 1). It is located in the east-central portion of the Amargosa Desert. A series of Cambrian limestone and dolomite ridges form the eastern boundary of the Refuge near the center of the Amargosa Valley. The northern boundary crosses Quaternary playa deposits while the southern boundary primarily crosses Quaternary alluvial fan deposits. The pattern of sand dunes, badlands, alluvial fans, and broad meadows observed throughout Ash Meadows is the result of a history of playa deposition followed by erosion, formation of alluvial fans adjacent to surrounding ranges, and the transport of sand by both wind and infrequent flows in larger washes and drainages.

The distinctive hydrology of Ash Meadows is the result of an extensive groundwater system and surface water drainage that culminates in the Carson Slough, a tributary to the Amargosa River (Otis Bay and Stevens Ecological Consulting 2006). Carson Slough is the primary drainage in Ash Meadows and is generally considered the core of the Ash Meadows ecosystem. The Crystal Spring drainage and the Jackrabbit/Big Spring drainages are significant tributaries of Carson Slough and drain large portions of the Refuge. Two primary aquifers, a regional carbonate aquifer and a local valley-fill aquifer, are present. Water is generally retained within the wetlands and alkali flats that sustain many of the Refuge's endemic plants, as well as some endemic fish and wildlife species (BLM 2007). The persistence of this water since the late Pliocene/early Pleistocene has allowed for the continued existence of relict plants and animals which gained access to the region during pluvial climates. The isolation of these species in this harsh environment permitted their differentiation from related taxa and resulted in the distinctive character of many present-day occupants (Reveal 1980). The onset of more xeric conditions isolated Ash Meadows, thereby

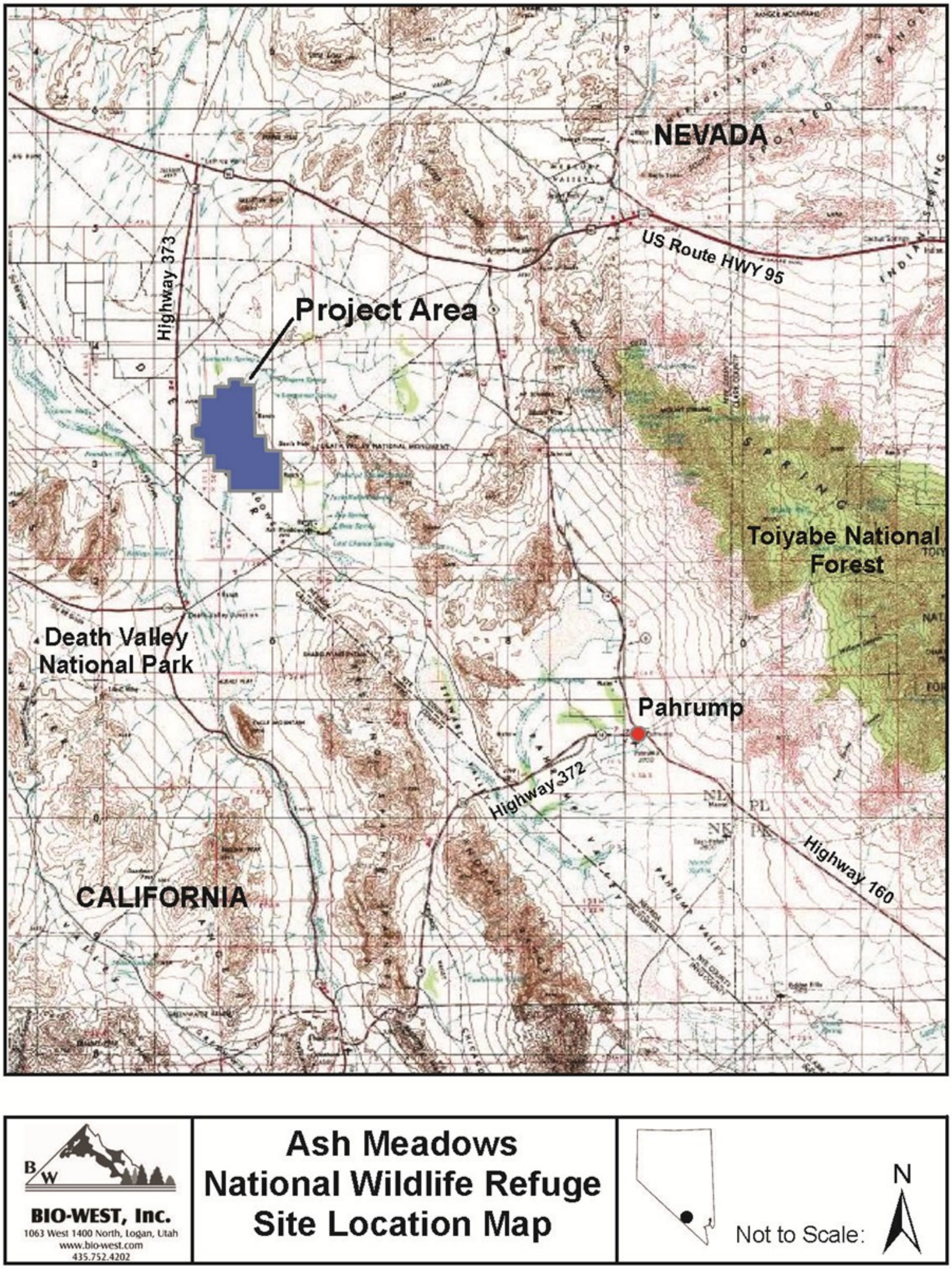

Figure 1. Location of the Ash Meadows National Wildlife Refuge.

prohibiting genetic exchange with nearby populations, leading to progressive differentiation in plant and animal species now endemic to the area (Reveal 1980). Reveal (1980) concluded that four of the endemic Ash Meadows species (*Astragalus phoenix*, *Mentzelia leucophylla*, *Grindelia fraxinopratensis* and *Centarium namophilum*) are most closely related to congeners presently found in montane portions of the Intermountain Region. Their persistence to the present day is attributed to successful adaptation to a more xeric environment, the local persistence of water, and to relatively cool temperatures created by cool air drainage from the surrounding mountains (Beatley 1977, Reveal 1980).

Current-day vegetation at AMNWR is composed of a typical Mohave creosote shrub vegetation community in addition to emergent marshes, wet meadows, distinctive spring complexes, alkaline desert uplands, and velvet ash community assemblages, several of which are known to exist only within the Refuge (Figure 2). These vegetation communities provide habitat for several rare and endangered plants, including endemic species, as well as federally-listed fish and wildlife species (Bio-West 2007).

CREATION OF THE REFUGE

Several legal and management documents led to the establishment of AMNWR in 1984. Devil's Hole National Monument was declared by presidential proclamation in 1953, and federal water rights for it were adjudicated by the Supreme Court in 1976. The 1966 National Wildlife Refuge System Administration Act provided direction on Refuge management responsibilities and guidance. The Endangered Species Act of 1973, as amended, provided authority for appropriate protection and management of federally listed species. The U.S. Fish and Wildlife Service (USFWS) prepared a Warm Springs Pupfish Recovery Plan in 1976, and a Devil's Hole Pupfish Recovery Plan in 1980. The Refuge was established on 18 June, 1984 with the purchase of 12,654 acres of land from The Nature Conservancy.

The Refuge now occupies a total of 23,488 acres in the Ash Meadows valley. Since designation, several documents have guided Refuge management. The 1987 Ash Meadows Refuge Management Plan outlined general principles for management of Refuge ecosystems and listed species. The 1990 AMNWR Recovery Plan for the Listed Species of Ash Meadows outlined recovery needs for 12 listed species, and identified tasks to be completed to recover and downlist or delist endangered species (Sada 1990). In addition to the individual threatened and endangered plants and animals of Ash Meadows, the plan recognized the need for the recovery of Ash Meadows habitats, processes and ecosystems. The plan also included specific guidance on management objectives (Sada 1990). In 2000, an Environmental Assessment was completed (Otis Bay and Stevens Ecological Consulting 2006).

ECOSYSTEM RESTORATION

Managers at AMNWR are seeking to restore impacted wetland and desert upland habitats to conditions that existed 100 years ago in an effort to promote endemic species recovery. Large-scale ecosystem restoration plans include impacted habitats in the Carson Slough and Crystal Reservoir areas. Successful restoration projects have been completed at Kings Pool in the Point of Rocks area, and at Jackrabbit Spring, where visitors can view desert pupfish (Bio-West 2008).

While the Refuge still supports a complex system of important native communities, portions have been significantly impacted by historic agricultural and mining activities. Impacts have included peat mining in marshlands surrounding Carson Slough in the 1960s and alfalfa farming and cattle grazing in the 1970s. These activities reduced discharge from all springs, and many spring outflows were channelized (Sada 1984). A complex irrigation system was constructed to support farming efforts, and resulting agricultural impacts included grading, cutting irrigation trenches, pumping spring pools, and creating water holding areas such as Crystal Reservoir (Otis Bay and Stevens Ecological Consulting 2006). Land disturbances created by farming and grazing activities, as well as severe alteration of an ecosystem's hydrology, can cause considerable change in vegetation community composition and allow for the encroachment of weedy and non-native species (Fraser and Martinez 2002).

Two of the most obvious chronic threats to AMNWR species and ecosystems involve flow modification and land conversion associated with former agricultural development and invasive species. The most severe long-term threat to the Refuge is potential future groundwater extraction from the regional carbonate aquifer (Otis Bay and Stevens Ecological Consulting 2006). Currently, the Refuge is developing large-scale habitat restoration plans for Carson Slough, Crystal Reservoir, and other springs and areas around the Refuge. The proposed plans consider the removal of the remaining irrigation system and water control structures in an effort to restore the hydrology and geomorphology of the Refuge to a natural system. The hydrologic restoration will also support vegetation community and wildlife habitat restoration attempts. However, restoring an existing water system that has supported an area for decades could have unintended consequences.

Within the Refuge, impacts resulting from the historic alterations to the landscape are evident both in the extensive monocultures of salt cedar (*Tamarix ramosis-*

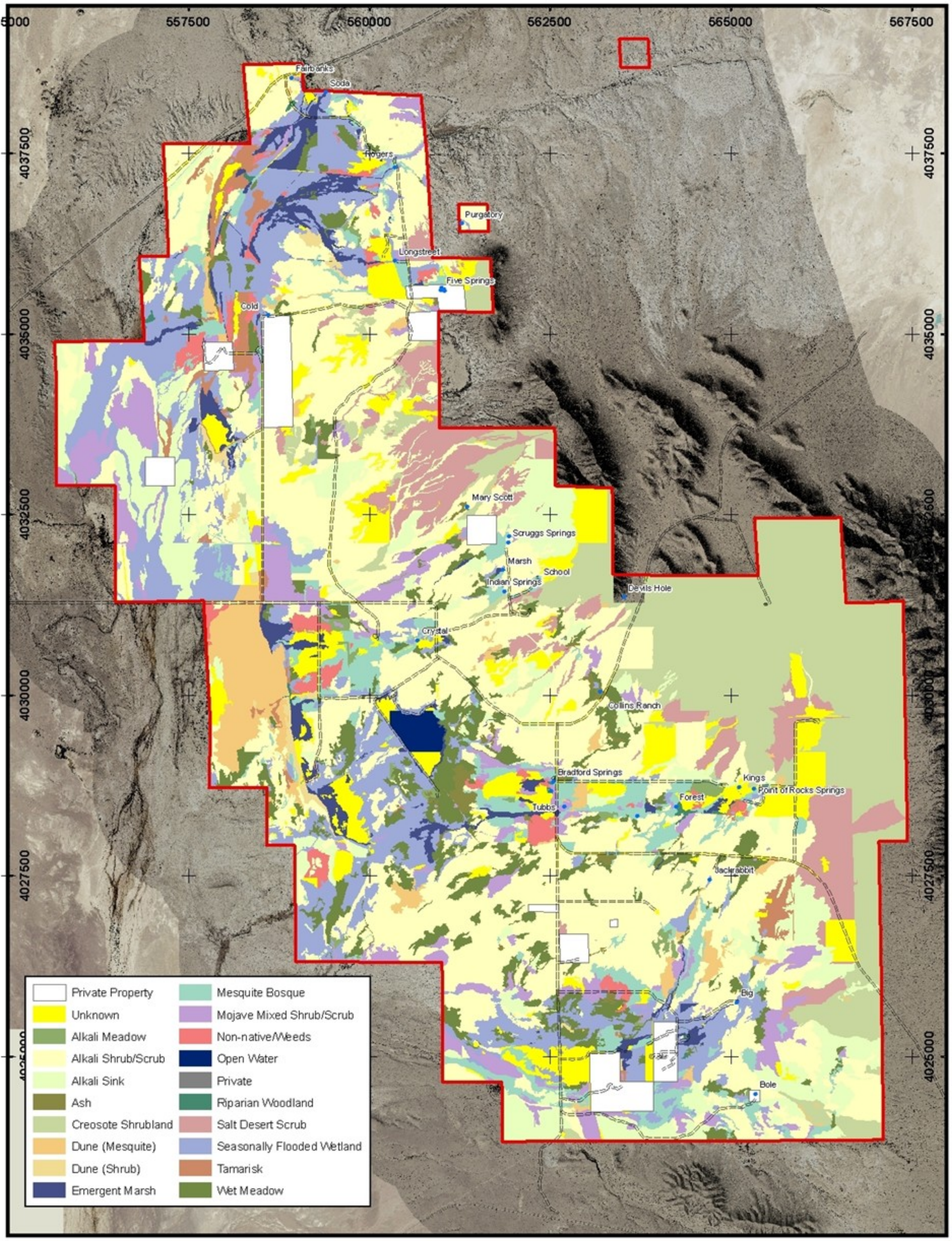

Figure 2. Vegetation community type map of the Ash Meadows National Wildlife Refuge.

sima) and Russian knapweed (*Acroptilon repens*) found throughout Carson Slough, as well as in the parceled wet meadows created adjacent to Rogers Spring where spring water once flowed unobstructed into the slough. The Refuge is in the habitat restoration stage and will remain so for many years. Goals of the restoration plan include restoring natural hydrology and native vegetation communities, establishing a baseline of existing vegetation communities, and managing and recovering rare and endangered species occurring on the Refuge (McKelvey 2007). The U.S. Fish and Wildlife Service is conducting long-range, strategic management and restoration planning at AMNWR to accomplish the recovery goals of ecosystem and species restoration. The recovery objective for the Refuge is: "delisting for all species but the Devil's Hole pupfish, which can only be downlisted to threatened status" (Sada 1990).

PRELIMINARY VEGETATION MAPPING AND CLASSIFICATION

The consulting firm BIO-WEST, Inc. undertook two studies designed to assist the AMNWR with its restoration efforts. The first study involved mapping all vegetation communities to a fine scale (0.25 acres), with the objective of providing a baseline data set for evaluation of management actions and future vegetation change, while the second included a comprehensive survey of distribution and abundance for twelve rare plant species. Completion of vegetation mapping on the Refuge has resulted in 6,237 delineated polygons (Figure 2). Of the delineated polygons, 5,913 (or 95 percent) have been assigned a preliminary alliance. Alliance assignments will be referred to as preliminary until classification is finalized. These classifications are being derived from multiple sources including *Alliances of the Mojave Desert* (USGS 2004), the National Vegetation Classification System (Grossman et al. 1998), and community data available on NatureServe (USGS 2004).

As currently assigned, the alliances comprising the highest total acreage on the Refuge are the *Atriplex confertifolia* Shrubland Alliance, the *Larrea tridentata-Ambrosia dumosa* Shrubland Alliance, and the *Isocoma acradenia* Shrubland Alliance. Several delineated vegetation communities do not correspond to any previous classifications. Often this is the result of a Refuge community that has a typical dominant species occurring with an atypical co-dominant. An example of this is the *Atriplex confertifolia* Shrubland Alliance compared with the *Atriplex confertifolia-Suaeda moquinii* Shrubland Alliance. The first is a common community throughout the desert southwest. However, communities with both *Atriplex confertifolia* and *Sueda moquinii* occurring as co-dominants have not been classified. In these cases a new alliance classification may be written to best represent the vegetation community. Once final classifications have been assigned, botanical descriptions will be developed for each of the newly created alliances.

Association classifications are also currently in the developmental stage. Many of the common botanical associations are applicable to communities at the Refuge. However, a significant number of the delineated polygons contain associations of plants that are not commonly recognized in current classifications. These associations are being thoroughly researched in order to identify appropriate resources for classification assignments. As with the alliance classifications, we expect to develop several new association classifications to accurately describe the communities at the Refuge (BIO-WEST 2008).

The vegetation mapping effort has resulted in a clearer picture of the diverse composition of vegetation communities that exist within AMNWR (Figure 2). Common vegetation communities that have been identified include Alkali Sink (an extensive shrubland community dominated by succulent shrubs such as Mojave seablite, [*Suaeda moquinii*] that occur adjacent to seasonally flooded wetlands and along desert washes), as well as a variety of wetland communities. Lowland Riparian Woodlands are found in the lowest elevations of the Refuge; they support a variety of canopy species such as velvet ash (*Fraxinus velutina*), mesquite (*Prosopis*), and narrow-leaf willow (*Salix exigua*). One of the more unique community types is the Alkali Playa community found west of Crystal Reservoir and Lower Marsh. This community may support the largest populations of rare and endemic plants on the Refuge.

The western portion of the Refuge also supports well-established populations of salt cedar, Russian knapweed, and five-hook bassia (*Bassia hyssopifolia*). The salt cedar communities function as riparian woodlands and in some cases may provide important wildlife habitat. Several of the abandoned agricultural fields have been infested with five-hook bassia. However, these fields currently receive enough seasonal inundation to sustain recruiting populations of native wetland vegetation.

Fairly intact transitional Upland and Desert Shrubland communities are present in the central and eastern portions of the Refuge. The Alkali Shrub community type transitions from a mesic phase as the topography rises in elevation from west to east. A noticeable change in vegetation composition occurs as whiteflower rabbitbrush (*Chrysothamnus albidus*)-dominated communities become replaced by alkali goldenbush (*Isocoma acradenia*) in the higher elevations where the water table is less accessible. Moving up into the alluvial fans, what was once classified as part of Creosote Shrubland is now classified as Salt Desert Shrubland composed of desert holly (*Atriplex hymenelytra*), shadscale saltbush *(Atriplex confertifolia*), and spiny hopsage (*Grayia spinosa*).

Creosote bush-dominated communities tend to persist in the alluvial fans east of Devil's Hole and south along the eastern Refuge boundary in dry uplands and pavement soils. Approximately 5,000 acres of Creosote bush Shrubland is found throughout the NE corner of the refuge. It is dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) and is one of the most common vegetation types in the Mojave Desert (MacMahon 2000).

The central-eastern portions of the Refuge are home to some of the most extensive old field disturbances and remnants of agricultural activities conducted prior to the Refuge's inception. Many of the non-native old fields contain Russian knapweed (*Acroptilon repens*), thistle spp. (*Cirsium* spp.) and tamarisk (*Tamarix* spp.). Old field non-native vegetation is largely the result of physical manipulation of land and land cover during agricultural uses. Old agricultural fields around the dam northeast of Point of Rocks are largely covered in annual grasses and forbs but some creosote bush and mesquite are also recolonizing. The Alkali Seep and transitional shrubland communities east of the Cold Spring private property have emerged as an important location for several endemic species such as Ash Meadows sunray, Ash Meadows blazingstar, and Ash Meadows ivesia.

Alkali Meadow is a community exclusive to the Amargosa Valley and Owens Valley ecosystems. The community is a low-elevation grassland, typically with moist alkaline soils. Evaporation of surface water often leaves a crumbled salt crust over the soils. Alkali Meadow is dominated by inland salt grass (*Distichlis spicata*) and alkali sacaton (*Sporabolis airoides*). Arctic rush (*Juncus arcticus*) and whiteflower rabbitbrush are associated species. The federally listed spring loving centaury and Ash Meadows ivesia are found in this community. Alkali meadows are indicative of shallow water tables. Alkali flats peculiar to Ash Meadows sustain the highest concentrations of the federally-listed Amargosa niterwort.

Extensive Alkali Shrubland communities dominated by *Atriplex* species (*A. lentiformis, A. canescens*, and *A. confertifolia*) are found in areas where groundwater is approximately 2-6 meters deep. At AMNWR, Alkali Shrubland covers 5,000 acres and comprises over 20% of the area. Alkali Meadow and Alkali Shrubland vegetation are distributed in close proximity to one another. In many places, there are raised mounds where the groundwater may be slightly deeper than surrounding alkali meadows. In these places, saltgrass, alkali sacaton, and *Atriplex* shrub cover increases. Other shrub species include matchbrush (*Gutierrezia sarothrae*), alkali goldenbush, and greasewood (*Sarcobatus vermiculatus*). Mesquite bosque vegetation is found predominantly around spring vents and outflow channels. The dominant overstory species include mesquite (*Prosopis* spp.), Fremont cottonwood (*Populus fremontii*), and velvet ash (*Fraxinus velutina*).

Emergent vegetation is found only at the springs and along permanent lakes and reservoirs. Emergent vegetation covers about 130 acres and comprises 0.5% of the refuge. Common species include *Typha* spp., spikerush (*Eleocharis*) spp., bulrushes, and rush species. Wetlands associated with the spring complexes include both native and non-native plant associations.

RARE PLANT SURVEY METHODS

Prior to the establishment of the Refuge, little quantitative information was available on the life history strategies, population genetics, demography, community associations, habitat requirements or abundance of plant species endemic to Ash Meadows. Implementation of the recovery plan for the seven listed endemic plant species will be successful only when these characteristics are known and disturbed environments are appropriately managed. Five additional at-risk plant species have been identified as species of concern at Ash Meadows, bringing the total to 12 targeted species for rare plant studies (Tables 1, 2).

Beginning in 2007, BIO-WEST conducted the first comprehensive inventories of rare, endemic and listed plant species that occur within Refuge boundaries. The purpose of the rare plant studies was to obtain a baseline of existing ecological conditions and rare plant distributions as a foundation for future monitoring of changes in the status of rare plant species. The information provided by these studies will assist with planning future habitat-restoration activities and can be correlated with wildlife studies to understand benefits and potential detriments resulting from these management strategies.

Floristic field surveys were initiated in March 2007 and continued through late October 2008. Survey methods and intensity depended on the size of the area, investigator skill, size of the target species, and topography. Prior to conducting the field surveys, the area was analyzed to determine potential habitat for each species of interest. Potential habitat types for each species were identified in part by literature, background maps provided by Refuge staff, and observations from field visits in prior years. An intuitive controlled survey (the most commonly used and efficient method of surveying for rare plant abundance), was initially employed in 2007. The data from these initial surveys were used to design a more detailed methodology for surveying the distribution each target species during the 2008 field season. Surveyors at each population documented the estimated number of individuals, plant phenology, population distribution in terms of approximate area, and associated vegetation. As a general rule plant occurrences less than

Table 1. Status of Endangered, Threatened, and Sensitive species occurring in Ash Meadows National Wildlife Refuge

Taxon Name		**Agency Status**					**NV Heritage Ranks**	
Scientific	**Vernacular**	**FWS**	**BLM**	**FS**	**NV**	**NNPS**	**Global**	**State**
Arctomecon merriamii	White bearpoppy		S	S		W	3	3
Astragalus phoenix	Ash Meadows milkvetch	T	S		F	T	2	2
Calochortus striatus	Alkali mariposa lily		S	S		W	2	1
Centaurium namophilum	Spring-loving centaury	T	S		F	T	2Q	2
Cordylanthus tecopensis	Tecopa birds'-beak		S			T	2	2
Enceliopsis nudicaulis var. *corrugata*	Ash Meadows sunray	T	S		F	T	2	2
Eriogonum concinnum	Darin buckwheat					W	2	2
Grindelia fraxinopratensis	Ash Meadows gumplant	T	S		F	T	2	2
Ivesia kingii var. *eremica*	Ash Meadows ivesia	T	S		F	T	1-2Q	1-2
Mentzelia leucophylla	Ash Meadows blazing-star	T	S		F	T	1Q	1
Nitrophila mohavensis	Amargosa niterwort	E	S		F	E	1	1
Phacelia parishii	Parish phacelia					W	2-3	2-3
Salvia funerea	Death Valley sage					W	3	1
Sisyrinchium funereum	Death Valley blue-eyed grass					T	2-3	1
Sisyrinchium halophilum	Nevada blue-eyed grass						4-5	4
Sisyrinchium radicatum	St. George blue-eyed grass					W	2?Q	1-2
Spiranthes infernalis	Ash Meadows ladies-tresses					T	1	1

FWS (Endangered Species Act administered by USDI Fish and Wildlife Service): E - endangered; T - threatened
BLM/FS (USDI Bureau of Land Management, USDA Forest Service): S - special status or sensitive; W - watch
NV (state of Nevada): F - fully protected
NNPS (Nevada Native Plant Society): W - watch list; T - threatened; E - endangered
Nevada Heritage Program ranks (Global = worldwide; State = within Nevada): 1 - critically imperiled; 2 - imperiled; 3 - vulnerable; Q - taxonomic status in question; ? - rank uncertain

0.25 acres in size were documented as a point feature and occurrences larger than 0.25 acres were mapped as polygon features. Specific systematic methods of sampling for the 12 rare species of interest used during the 2008 field season are shown in Table 2 (Ballard 2008).

RARE PLANT SURVEY RESULTS

Amargosa niterwort (*Nitrophila mohavensis*): Listed on May 20, 1985, Amargosa Niterwort is the only endangered plant at Ash Meadows and is restricted to the Amargosa River drainage (Knight and Clemmer 1987). This member of the Chenopodiaceae is an extremely hardy dwarf rhizomatous perennial that is tolerant of high soil salinity and alkalinity. It occupies the most localized habitat of any plant species endemic to Ash Meadows and is often the only species present in its habitat. *N. mohavensis* is found in areas with heavy salt crusts created by evaporation of standing water. These sites are characterized by barren, moist alkali flats with sandy loam soils (~57% sand) encrusted with a layer of salt with a pH near 8.4. *Distichlis spicata* (inland saltgrass) is sometimes found either on the periphery, or occasionally intermixed within Amargosa niterwort populations (Mozingo and Williams 1980). Without adequate surface water, this habitat may be taken over by saltgrass. Reveal (1978a) noted that Amargosa niterwort is sensitive to disturbance and does not reinvade sites where salt crust overlying the soil has been disturbed. Additional associated species include *Atriplex confertifolia* (shadscale saltbush)*,* Mojave seablite, and a more widely distributed congener *Nitrophila occidentalis* (boraxweed; Soil and Ecology Research Group 2004). Two other listed species, Ash Meadows ivesia (*Ivesia kingii*) and Tecopa birds beak (*Cordylanthis tecopensis*) are also found in this type of habitat.

At the time of listing, the only known location for Amargosa niterwort was Tecopa, California (Otis Bay and Stevens Ecological Consulting 2006). Since that time, several populations have been documented at the Refuge and just outside its western boundary. The Nevada Natural Heritage Program (NNHP) estimated the population of this species across its entire range at 13,000 individuals in 1997 (Morefield 2001). According to the recently published five-year review for the species, the Crystal Reservoir population was estimated at 10,000 ramets (above-ground stems), and the West Refuge Boundary population was estimated at approximately 50 ramets (USFWS 2007b). The two popula-

Table 2. Systematic surveying protocols according to species.

Scientific Name	Common Name	Sampling Protocol
Arctomecon merriamii	White bearpoppy	Individual count census and transect method
Astragalus phoenix	Ash Meadows milkvetch	Transect method
Calochortus striatus	Alkali mariposa lily	Individual count census
Centaurium namophilum	Spring-loving centaury	Population census and negative sampling
Cordylanthus tecopensis	Tecopa bird's-beak	Population census
Enceliopsis nudicaulis var. *corrugata*	Ash Meadows sunray	Transect method
Eriogonum concinnum	Darin buckwheat	Not located
Grindela fraxinopratensis	Ash Meadows gumplant	Population census
Ivesia kingii var. *eremica*	Ash Meadows ivesia	Population census
Mentzelia leucophylla	Ash Meadows blazingstar	Individual count census and transect method
Nitrophila mohavensis	Amargosa niterwort	Individual count census
Phacelia parishii	Parish phacelia	Not located
Salvia funerea	Death Valley sage	Not located
Sisyrinchium spp.*	Blue-eyed grass	Population census
Spiranthes infernalis	Ash Meadows ladies-tresses	Individual count census and population census

*Includes *Sisyrinchium funereum*, *S. halophilum*, and *S. radicatum*.

tions mentioned in the five-year review were the only populations known to occur on the Refuge at that time.

Surveys conducted during 2008 extended the boundaries of the two known populations and added new occurrences. Some new populations were surveyed in the area just north of the outflow canal of Crystal Reservoir. In addition, occurrences noted during the 2007 reconnaissance that were scattered across the west shore of Lower Marsh were resurveyed as well as populations found southwest of Crystal Reservoir. These areas included the drainage from Crystal Reservoir just north of the Refuge boundary and the Big Spring and Jackrabbit Spring drainage complex toward the western Refuge boundary. Also, a portion of critical habitat located in the west corner of the Refuge directly west of the Lower Marsh access road was mapped and inventoried. This population is referred to as the "Central Carson Slough" population by USFWS (2007b). The population was mapped in its entirety, including portions that fell just outside the Refuge boundary, and the entire population estimate for this polygon was included in the 2008 total.

White Bearpoppy (*Arctomecon merriamii*): White bearpoppy is a Mohave Desert endemic known from Clark, Lincoln, and Nye Counties in Nevada, and from the Death Valley region of California. This species occurs in salt desert shrub communities on ridges, rocky slopes, gravelly canyon washes, and old lakebeds derived from carbonate rock sources, often in hard clay soils or with shadscale saltbush. It is a clump-forming perennial plant with large white flowers borne individually on the tips of leafless stems. *A. merriamii* can be distinguished from the golden-flowered Las Vegas bearpoppy (*A. californica*) by its scapose stems, larger capsules, and flower color.

The NNHP rare plant fact sheet states that there have been approximately 129 occurrences documented throughout its Mojave Desert range. The estimated range-wide population is > 20,000 individuals (Morefield 2001) (Table 3). While there is no documented evidence of the number of known individuals within the Refuge prior to this study, it is believed that the distribution has remained limited with low abundance of individuals (H. Hundt, AMNWR, 2007, pers. comm.).

Field crews conducted reconnaissance in areas of potential habitat for this species between 2,000 and 6,200 feet in elevation and within Salt Desert Scrub communities on alluvial gravel substrates. These areas included the northernmost portion of the Refuge just north and south of the Invite Road, the area surrounding Devils Hole, the alluvial fans surrounding Point of Rocks, and the extreme southeast corner of the Refuge. No plants were found during these searches. However, several previously undocumented populations were discovered and surveyed throughout the 2008 field season. These included the area just south of Peterson Road

Table 3. Population estimates for surveyed plant species at Ash Meadows NWR.

Scientific Name	Common Name	Most Recent Population Estimate	2008 Survey Population Estimate AMNWR
Arctomecon merriamii	White bearpoppy	20,000*	193
Astragalus phoenix	Ash Meadows milkvetch	1800	11,643
Calochortus striatus	Alkali mariposa lily	unknown	6984
Centaurium namophilum	Spring-loving centaury	4290*	4,468,571
Cordylanthus tecopensis	Tecopa bird's-beak	4379*	829,918
Enceliopsis nudicaulis var. *corrugata*	Ash Meadows sunray	1849	50,954
Grindela fraxinopratensis	Ash Meadows gumplant	81,000	376,632
Ivesia kingii var. *eremica*	Ash Meadows ivesia	3862	486,798
Mentzelia leucophylla	Ash Meadows blazingstar	358	3763
Nitrophila mohavensis	Amargosa niterwort	10,050	78,406
Sisyrinchium spp.*	Blue-eyed grass	unknown	99,822
Spiranthes infernalis	Ash Meadows ladies-tresses	1107	14,209
* Range-wide estimate			

near the Cold Spring private property, just northwest of Longstreet Road but south of Peterson Road, and near a large spring drainage between the eastern Refuge border and Longstreet Road. Many of the occurrences were found within habitat for species such as Ash Meadows sunray, Ash Meadows milkvetch, and Ash Meadows blazingstar. These habitats typically included mesic Alkali Shrublands with sandy soils and occasional deep washes. There is some evidence from the NNHP that occasionally moist sandy soils could serve as potential habitat indicators for this species (Moorefield 2001). The broad transect survey methods for the Ash Meadows sunray and Ash Meadows milkvetch likely contributed to the discovery of the new populations. The total population surveyed in 2008 was approximately 193 individuals (Table 3). There is some potential for locating additional populations as the Ash Meadows sunray surveys are completed during the 2009 field season.

Ash Meadows Milkvetch (*Astragalus phoenix*): Ash Meadows milkvetch is endemic to AMNWR. A federally protected species, it has been documented fairly extensively in the past, including studies directed at recovery of the species. The NNHP documents 13 occurrences for a total estimated population of 1,943 individuals within the Ash Meadows area (Morefield 2001). Previous surveys conducted by the USFWS in 2000 documented several populations within the Refuge totaling 1,800 individuals (Pavlik and Stanton 2006).

Prior to 2006 populations were known from south of Rogers Spring and west through the northern portion of Purgatory, within the Cold Springs private property, south of Bradford Spring, east and west of Ash Meadows Road, and north and south of South Spring Meadows Road. Survey areas included potential habitat consisting of alkaline soils, desert washes, and barren flats (Reveal 1978b). Because this is commonly known to occur in habitats similar to those of Ash Meadows Sunray, both species could be surveyed together.

Several new populations of Ash Meadows milkvetch were discovered during the Ash Meadows Sunray transect surveys. Large populations were discovered adjacent to the Cold Spring private property. Other notable populations were inventoried in the area between Rogers and Longstreet Springs, directly west of the junction of Ash Meadows Road and South Spring Meadows Road, and west of Jack Rabbit Spring. The estimated total population is approximately 11,643 individuals (Table 3).

Alkali Mariposa Lily (*Calochortus striatus*): NNHP reports only four occurrences of alkali mariposa lily across its entire known range in Clark and Nye counties, Nevada and adjacent California. Morefield (2001) lists the estimated population of the species as "unknown."

Several populations documented during the 2007 reconnaissance at AMNWR were surveyed in 2008. These populations included a number of locations immediately south of Collins Ranch, just west of Warm Springs and north of the access road to Bole Spring. Several new populations were located and surveyed including one at the bend in West Spring Meadows Road. A large population was surveyed within an Alkali Shrubland community east of Crystal Reservoir. An additional population was mapped and surveyed in the southeast corner of the Refuge. The recorded population for species surveyed during this study totals 6,984 individuals (Table 3).

Spring-loving Centaury (*Centaurium namophilum*): Spring-loving centaury is an annual plant that is endemic to AMNWR and its immediate surroundings. It is currently listed as a threatened species by the USFWS. The last confirmed survey reported by NNHP was in 1986 and documented 19 occurrences for an estimated population in excess of 4,290 individuals (Morefield 2001). The draft five-year review mentions six mapped populations within the Refuge totaling over 2,900 acres in comparison to the approximately 29 acres last reported to the NNHP (Morefield 2001, USFWS 2008). According to the draft five-year review, population trends are insufficiently documented (USFWS 2008).

Survey area criteria for this species included seeps, wet meadows, and spring channel banks throughout AMNWR. In 2008, spring-loving centaury was found to be very widespread across the Refuge, populating habitats from seasonally flooded wetlands to seasonally moist Alkali Meadows and the edges of some Alkali Shrubland communities. It appeared that nearly any location on the Refuge containing surface or sub-surface water at any time during the year would produce a population. As surveys continued, a blooming trend for certain populations became apparent. Blooms were seen in "waves" for individual populations and subpopulations, or different parts of a single population would bloom at different times during the season.

In the Peterson Reservoir area, extensive populations extended throughout surrounding drainages. As in the Rogers Spring and Carson Slough drainages, populations extend until they encounter what may be hydrologic barriers. Observed occurrences were so extensive that it became necessary to map areas of non-occurrence. The total population from the 2008 surveys has been estimated at 4,468,571 individuals.

Clearly the current population estimates are a significant increase from the last confirmed survey data provided to the NNHP (USGS 2004). It is clear that populations of this annual plant fluctuate widely from season to season; however, the likelihood that the number of individuals would dip as low as previously recorded estimates seems doubtful.

Tecopa Bird's-Beak (*Cordylanthus tecopensis*): Tecopa bird's-beak is a hemiparasitic summer annual plant that is a Nevada Sensitive Species. It is known from approximately ten extant occurrences across a narrow range in California (Death Valley) and Nevada (AMNWR) (Morefield 2001). Its habitat includes Mohave Desert scrub and alkali flats and meadows below 2,700 feet. It always grows with *Distichlis spicata*, which may be its principal host. Tecopa bird's-beak is also a known associate of the spring-loving centaury and often occurs within the same habitat types (Otis Bay and Stevens Ecological Consulting 2006). Population estimates provided by the NNHP document >4,379 total individuals.

Because of their similar habitat requirements, populations of Tecopa bird's-beak were mapped and surveyed in conjunction with spring-loving centaury in 2008. New occurrences were discovered along the shores of lower Crystal Marsh as well as on the west side of the marsh within old agricultural fields. The agricultural field population extended intermittently to the western Refuge boundary. In addition, a significant population was found associated with a new spring-loving centaury population in a narrow band of velvet ash located northwest and southeast of Collins Ranch. This area appears to be an important site for multiple rare and endemic species at the Refuge. The total population of Tecopa bird's beak documented in the 2008 field season is approximately 829,918 individuals.

Ash Meadows Sunray (*Enceliopsis nudicaulis* var. *corrugata*): Ash Meadows sunray is an endemic variety of a widely distributed species that has been listed as threatened by the USFWS. The variety is almost strictly endemic to Ash Meadows with a few individuals reported from outside the Refuge in eastern California**.** It is largely restricted to strongly alkaline, poorly drained, saline soils associated with springs and dry washes but with the water table some distance below the surface. Lower elevation alkali clay soils in Ash Meadows have a shallow underlying water table that makes the habitat unsuitable. This species is associated with Ash Meadows milkvetch, shadscale saltbush, matchbrush, alkali goldenbush, basin yellow cryptantha (*Cryptantha confertifolia*) and white bearpoppy at elevations from 2,100 to 2600 feet. It is generally found on dry to sometimes moist sites that are on open, hard, white clay hills with calcareous hardpans. Populations on the Refuge are found in occasionally moist alkaline soils, spring and seepage areas, and dry desert washes. The plants can also occasionally be found in salt desert shrubland and desert pavement habitats (Morefield 2001; Otis Bay and Stevens Ecological Consulting 2006). The last confirmed population estimates for this plant were reported following its listing as a threatened species.

The 2008 survey was directed at locating the plants throughout all potential habitat types occurring within the Refuge. Cruise transects 40 meters apart were used to survey large tracts of Ash Meadows. Of the more than 9,000-acres of potential habitat, nearly 6,000 acres have been surveyed to date. Ash Meadows sunray has been found throughout the areas mapped by the Refuge in 2006. In several cases known populations have been extended beyond previous distribution boundaries. New occurrences were documented west of known populations mapped along Ash Meadows Road, as well as on the alluvial fans east of Point of Rocks and south of Jackrabbit Spring. A single occurrence was also documented adjacent to Lower Crystal Marsh. The preliminary population estimate, calculated with approximately two-thirds of the survey complete, is 50,954 individuals. The remaining survey area includes habitat within the central portion of the Refuge that has long been known to support this plant. It is likely that upon completion of the surveys, the final population estimate will increase by several thousand.

Ash Meadows Gumplant (*Grindelia fraxinopratensis*): Ash Meadows gumplant was listed as threatened by the USFWS in 1985. The plant is considered an endemic species primarily occurring within AMNWR with a limited distribution in neighboring Inyo County, California. NNHP documented 16 occurrences across the known range for the species and estimated a population of more than 13,000 individuals in 1986 (Morefield 2001). The USFWS estimated the Refuge's population at approximately 81,000 individuals following a 1998 survey (USFWS 2007a).

Distribution data provided by the USFWS in 2000 and Refuge staff in 2006 indicate that populations of *G. fraxinopratensis* occur in spring drainages and marsh habitats throughout the Refuge. Notably, both data sets show a significant presence of this species along the Fairbanks and Rogers Spring drainages. However, BIO-WEST botanists involved with the 2007 reconnaissance and the 2008 surveys indicate that plants found at these locations are actually not members of this species. At this time BIO-WEST has been unable to confirm occurrences north or west of the Warm Springs complex.

The Alkali Meadows south of Crystal Reservoir contain very large populations of Ash Meadows gumplant. Known populations were also documented in the Alkali Meadows of the Big Spring/Jackrabbit Spring drainage complex both east and west of South Spring Meadows Road. Another known population was inventoried south of Ash Meadows Road as it intersects South Spring Meadows Road. New populations were surveyed between the Warm Springs Complex and West Spring

Meadows Road, as well as just north of Devils Hole Road in the Collins Ranch area, east of Crystal Reservoir and between the south end of Lower Crystal Marsh and the Refuge boundary. Due to a short bloom time, several occurrences west of the Refuge office were not surveyed in 2008. The total estimated population at this time is 376,632 individuals, a number that will likely increase upon completion of surveys.

Ash Meadows Ivesia (*Ivesia kingii*): Endemic to the Refuge, Ash Meadows ivesia is a federally-listed threatened species. It is a perennial plant with a prostrate growth form. As is the case with many of the endemic Refuge plants, there is little current information regarding its abundance. According to the USFWS, the distribution of this species is limited to Nye County, Nevada, and likely limited to within AMNWR boundaries. Population estimates by the NNHP in the 1980s indicated there were as many as nine occurrences; these areas contained an estimated 3,862 individuals (Morefield 2001).

The majority of the 2008 surveys confirmed populations occurring within historic distribution areas on the Refuge. However, field crew members were unable to locate plants within several previously documented areas believed to contain populations and extant populations appeared significantly smaller. However, a visit in the Jackrabbit Spring area led to the discovery of several new populations. New populations, fairly large in size, were also surveyed in close proximity to West Spring Meadows Road where it makes a sharp turn to the west. Also, multiple, substantial populations were located and surveyed between Crystal Reservoir and West Spring Meadows Road. Another population was documented in a seepage area interrupting an upland habitat just east of the Cold Spring private property. Finally, populations occurring just north and south of Big Springs Road were surveyed. The current estimated population of Ash Meadows ivesia is 486,798 individuals (Table 3).

Ash Meadows Blazingstar (*Mentzelia leucophylla*): This endemic biennial herb was listed as a threatened species in 1985. The plant's distribution appears to be strictly limited to areas within the Refuge (Morefield 2001; Otis Bay and Stevens Ecological Consulting 2006). Recent information regarding species abundance is limited. Surveys in 1986 documented *M. leucophylla* from 8 locations with an estimated population of 358 individuals (Morefield 2001). Distribution maps provided by the Refuge from 2006 internal surveys show confirmed populations at Purgatory, the Warm Springs Complex, and along West Spring Meadows Road.

Additional populations of Ash Meadows blazingstar were discovered during surveys for Ash Meadows sunray and Ash Meadows milkvetch. Because of its biennial life form, *M. leucophhylla* was observed in rosette as well as in flower. Starting in mid-March, BIOWEST field crews began recording populations south of Peterson Road near the Cold Spring private property boundary. In addition, new blazingstar populations were documented just south of Rogers Spring and west of Longstreet Road, intermixed with a large white bearpoppy population southeast of the Warm Springs Complex access road and directly north of the "T" junction of South Spring Meadows Road and West Spring Meadows Road. These populations were surveyed and their boundaries extended. The estimated population is 3,763 individuals (Table 3).

Blue-Eyed Grass Species (*Sisyrinchium* species): Previously, three species of blue-eyed grass were thought to occur at the Refuge: Death Valley blue-eyed grass (*Sisyrinchium funereum*), Nevada blue-eyed grass (*S. halophilum*), and St. George blue-eyed grass (*S. radicatum*) (C. Baldino 2007 pers. comm.). However, Cholewa (in letter, 2003) suggested that *S. halophilum* probably does not extend as far south as the refuge. She based her statement on the discovery that many herbarium specimens that had been identified as that species were incorrect. Blue-eyed grass species are extremely difficult to differentiate, so there is ongoing debate and confusion as to exactly which species actually exist on the Refuge.

Such problems are not new in *Sisyrinchium*. Species-level taxonomy of *Sisyrinchium* has long been disputed. Recent molecular work has clarified the limits of the genus and helped identify important morphological characters delineating it from closely related genera (Karst, unpublished). However, much more phylogenetic work, based on cladistic analysis of molecular data, is needed to understand species relationships within the genus (Cholewa and Henderson 2002).

Species of *Sisyrinchium* are not easily distinguished. White flowers may occur in otherwise blue-flowered species, and vivipary occasionally occurs, where plants produce seeds that germinate before they detach from the parent. Furthermore, vegetative characteristics, while distinctive in some species, may overlap greatly in wide-ranging species. Writers of past floras sometimes were unaware of such phenotypic plasticity, or were inconsistent in their use of terminology. Some taxonomists have thought differences too subtle and chosen to lump species (Cholewa and Henderson 1984, 2002). Because of the taxonomic confusion surrounding the blue-eyed grass plants growing within refuge boundaries, the BIO-WEST 2008 field surveys combined all occurrences of blue-eyed grass into a *Sisyrinchium* spp. category.

As documented by Cholewa and Henderson (2002), *Sisyrinchium funereum* populations occur mostly within Death Valley. These populations contain numerous individuals. *Sisyrinchium radicatum* is more widely distributed, growing in Clark, Nye, and Lincoln Counties, Nevada, and Washington County, Utah. In Clark County, it occurs in Pine Canyon and Ash Spring and is also known from Pine Creek and Red Rock Canyon-Calico Basin in the Spring Mountains. In Nye County, it is known from Big Springs in Ash Meadows, and Pahrump Valley. In Lincoln County, it is known from Pahranagat lakes and Pahranagat Valley – Ash Springs. The threats to these populations are currently unknown. *Sisyrinchium demissum* is a closely related species that overlaps the known range of the two species known to occur on AMNWR.

Known populations of blue-eyed grass were visited and surveyed throughout the Refuge. Several previously undiscovered populations were documented including occurrences just south and east of Jackrabbit Spring. Large populations were surveyed in the area directly south of Crystal Reservoir, expanding habitat from the 2007 findings. New populations were also located adjacent to the Cold Springs private property, with the large Ash Meadows ladies-tresses population northeast of Rogers Spring but south of Longstreet Road, and in a spring drainage leading from the eastern Refuge border in the north section of the Refuge. The estimated blue-eyed grasses population is 99,822 individuals (Table 3).

Ash Meadows ladies-tresses (*Spiranthes infernalis*): A Refuge endemic, Ash Meadows ladies- tresses is currently being considered for Federal listing (Otis Bay and Stevens Ecological Consulting 2006). NNHP survey records from 1998 show 15 locations with an estimated population of 1107 individuals (Morefield 2001).

New populations documented during the 2008 survey were found in several seep habitats The population was estimated at 14,209 individuals. Several occurrences were observed late in the field season when the plants had passed the flowering period and will be revisited during 2009. Because there can be significant variability in the number of individuals that bloom from season to season, it may be necessary to revisit surveyed locations to determine an accurate population estimate after new locations are added.

The 2008 rare plant surveys of the twelve sensitive and endemic species that exist at AMNWR revealed larger populations and new locations of additional populations of these species than had been previously documented and aided in determining clearer population estimates, population location boundaries, and the associated vegetation communities these species exist in. Additional planned surveys in 2009 may aid in more accurately determining the biogeography of the rare, endemic and listed Plants of the Ash Meadows National Wildlife Refuge.

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Assessing Vulnerability to Climate Change Among the Rarest Plants of Nevada's Great Basin

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Abstract. The Great Basin of Nevada provides habitat for many narrowly distributed endemic plant species. To assess the vulnerability of 33 of the rarest of these plants to climate change, I used the elevation range of all reported locations as a surrogate measure of their bioclimatic envelopes. The results show that 14 of these taxa occur on or near the valley floors, nine taxa occur in montane habitats, and 10 taxa occur at high elevations. While the majority of the 33 taxa are restricted to highly specialized edaphic habitats, valley endemics are distributed through a smaller elevation span than montane or high elevation endemics. In addition, valley habitats have less variability in slope and aspect and their highly specialized habitats do not occur above the valley floor. These habitat restrictions are likely to constrain migration in response to climate change. Montane and high elevation habitats are more diverse topographically and, although often specialized, are more common both locally and regionally. This imposes fewer constraints on natural migration and offers more conservation options in the face of climate change. Our inability to accurately predict the actual parameters of climate change and its effects at a scale relevant to rare species will require a comprehensive inventory and monitoring effort to identify those species affected by climate change. An integrated long-term seed storage program will ensure adequate representation for genetic conservation.

Pollen, woodrat midden, tree-ring, and lake level data spanning the past 50,000 years has demonstrated that the Great Basin is highly sensitive to climatic change (Wharton et al. 1990). During the 20th Century, an average annual warming of 0.3 to 0.6 °C occurred and projections for the next century are for an additional rise of 2 to 5 °C (Cubashi et al. 2001; Wagner 2003). Alterations to the precipitation regimes are harder to predict, but seem likely to include a greater proportion falling as rain, decreasing winter snowpack, and earlier arrival of spring conditions, thereby affecting runoff and plant phenology (Mote et al. 2005; Snyder and Sloan 2005).

The basin-and-range topography that characterizes the Great Basin of Nevada has generated much interest among biogeographers and numerous seminal works have been published focused on the distribution and relationship of its vascular flora or specific aspects of plant endemism in this region (Billings 1978; Charlet 1996; Harper and Reveal 1978; Holmgren 1972a; Pavlik 1989; Reveal 1979; Shreve 1942; Wells 1983). A published proceedings of a symposium on intermountain geography includes numerous papers on many aspects of biogeography in the Great Basin (Harper and Reveal 1978). Several sources of information are available on the rare plants of Nevada (Morefield 2001; Mozingo and Williams 1980) or parts of Nevada (Anderson et al. 1991; Spahr et al. 1991; Weixelman and Atwood undated). A conservation blueprint for the Great Basin has been prepared that includes general discussions of the ecological systems represented and their associated species conservation targets and identifies a portfolio of 20 priority landscape scale conservation sites; climate change and adaptation options are also discussed but no explicit assessment of species vulnerability was conducted (Nachlinger et al. 2001).

Narrowly endemic plants are expected to be at far greater risk of extinction from climate change than are more widespread plants because of their limited range, small populations, and genetic isolation (Committee on Environment and Natural Resources 2008; Peters and Darling 1985). Alpine plants are often identified as at particular risk due to isolation and lack of an "escape route" (Grabherr et al. 1995; Halloy and Mark 2003). Among the observed and predicted effects of climate change on plant species are phenological changes, trophic level disruptions, range shifts and contractions, and extinctions (Parmesan 2006). Documented effects include an accelerated trend in upward shift of alpine plants in the Swiss Alps over the last few decades (Walther et al. 2005), a significant upward shift in optimum elevation of forest plants in Europe in the 20th century (Lenoir et al. 2008), a decline of arctic-alpine plants from 1989-2002 in Glacier National Park (Lesica and McCune 2004), and an advance in the mean flowering dates of lilac and honeysuckle in the western United States of 2 and 3.8 days per decade, respectively (Cayan et al. 2001).

Extinction is predicted for 3–21 percent of the flora in Europe, 38–45 percent in the Cerrado of Brazil, 32–

63 percent in the alpine flora of New Zealand, and 41–51 percent of endemics in South Africa and Namibia (Fischlin et al. 2007). In the Great Basin, range contractions or extinctions have been predicted for higher elevation mammals, butterflies, birds and plants (Murphy and Weiss 1992; Van de Ven et al. 2007; Wagner 2003). Populations of pika (*Ochotona princeps*) have already been reduced by 28 percent compared to the number of populations known earlier in the 20th century (Beever et al. 2003). Grayson (2000) has posited that during the Middle Holocene (5,000–8,000 years before present), a period characterized by a decrease in summer precipitation and an increase in temperatures, the small mammal fauna of the Great Basin decreased in species richness and evenness as a result of a series of local extinctions and near-extinctions coupled with an increase in taxa well-adapted to xeric conditions.

The objective of this study was to conduct an initial assessment of the vulnerability of the rarest plants of the Great Basin of Nevada to climate change based on geographical and ecological data from the literature, stored in data bases and files maintained by the Nevada Natural Heritage Program, Carson City, Nevada, and stored in files maintained by the U.S. Fish and Wildlife Service at the Nevada Fish and Wildlife Office, Reno, Nevada.

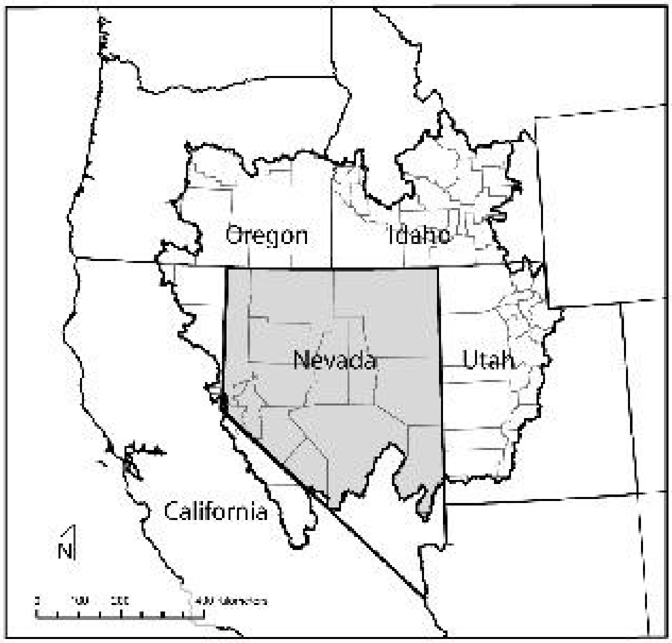

Figure 1. Location of the study area in the Great Basin of Nevada, an area of about 54,741 km^2 ; the larger dark outline is the boundary of the Great Basin Restoration Initiative as delineated by the U.S. Bureau of Land Management based primarily on floristic similarity.

STUDY AREA

The study area encompassed the Great Basin within the State of Nevada. The term "Great Basin" was first used in 1844 by the explorer John Fremont in reference to the large closed hydrologic basin lying between the Sierra Nevada of California and Nevada to the west and the Wasatch Front of Utah to the east with slight extensions into Oregon and Idaho (Tingley and Pizarro 2000). This analysis focuses on the floristic Great Basin within Nevada (Holmgren 1972a), an area of roughly 54,741 km^2 that includes all of Nevada north of the Mojave Desert with the exception of the Carson Range along the eastern side of Lake Tahoe (Figure 1).

In general, precipitation increases and temperature decreases with elevation in the Great Basin, although physiographic factors can exacerbate temporal and spatial variation in climatic patterns. The complex terrain, with its large differences in altitude and the consequent distortion of air currents creates high variability in local precipitation and short periods of intense rainfall followed by very long periods without precipitation (Hidy and Kleiforth 1990). Rapid heat loss at night results in cool air descending to valley floors where pooling in closed basins creates diurnal temperature inversions (Beatley 1975). Along the southern boundary of the study area, air and soil temperature regimes on two valley floor sites, separated by only 90 m horizontally and 1.5 m vertically, were found to influence the distribution of dominant shrub species. The composition of herbaceous perennials and winter annuals on the same two sites was similar, although temperature influenced the initiation of vegetative growth in herbaceous perennials and the germination success of winter annuals (Beatley 1969, 1975). Predicting local climates and the climatic responses of highly localized endemic plant populations, therefore, is at best a challenging approximation.

METHODS

I used ecologic and geographic data stored by the Nevada Natural Heritage Program and the U.S. Fish and Wildlife Service, including various status assessment reports prepared for many of the rare plant taxa, to determine the reported minimum and maximum elevations of all known populations of the rarest plants within the study area. All taxa ranked as G1, G1G2, or T1 were included in this study. G1 ranked species are considered critically imperiled based on a very high risk of extinction due to extreme rarity (often five or fewer populations), very steep declines, or other factors; T1 ranks are applied to infraspecific taxa that meet the same criteria as for the G1 ranks (Natureserve 2009). I assessed a total of 167 reported locations of 33 taxa with ranks of G1, G1G2, or T1 ranks (Table 1).

I used the reported minimum and maximum elevation of all known locations for each of the 33 taxa as a surrogate for the combined effects of temperature and precipitation, the principal climatic factors affecting plant distribution in the Great Basin (Billings 1949; Comstock and Ehleringer 1992; Fautin 1946). Van de Ven and others (2007) used actual temperature and precipitation data to construct bioclimatic models of potential climatic change in the White Mountains of California and Nevada at the western edge of the Great Basin, but such data are relatively sparse for the interior Great Basin. Climate stations are typically clustered near towns and skewed toward lower elevations; there are few climate stations above 2500 m. Moreover, due to the complex topography of the Western United States and the coarse resolution of most climate models, even the best climate models display biases at regional scales (Bonfils et al. 2008). All 33 taxa are highly localized endemics with geographic ranges that are considerably smaller than could be predicted by the best regional climate models.

While approaches that incorporate additional factors such as slope, aspect, and geologic substrate have been used with some success to develop predictive models of potential habitat for a few rare plants in the Great Basin of Utah (Aitken and others 2007), field surveys conducted by experienced botanists for many of these 33 taxa have consistently found that only a small portion of their predicted range contains suitable habitat. Therefore, the objective of this study was to compare the climatic niches of rare plants, rather than to develop predictive distribution models.

RESULTS

The rarest plants of the Great Basin of Nevada (i.e., those with a G1, G1G2, or T1 rank) can be placed into three broad elevation bands. Those bands reflect occurrence: 1) below the lower limits of tree distribution on or near valley floors; 2) within a narrow montane zone dominated by pinyon-juniper woodlands and associated shrublands or subalpine; or 3) near or above timberline (Figure 2, Table 1).

The lowest elevation group is comprised of 14 taxa that have a median population altitude below 2000 m. All but one of these taxa are endemic to Nevada (Figure 2). Eleven taxa, *Eriogonum tiehmii*, *E. argophyllum*, *E. ovalifolium* var. *williamsiae*, *E. diatomaceum*, *Castilleja salsuginosa*, *Johanneshowellia crateriorum*, *Boechera falcifructa*, *Mentzelia argillicola*, *M. tiehmii*, *Frasera gypsicola*, and *Potentilla basaltica* have a reported elevational amplitude of less than 244 m, with nine of these distributed across less than 129 m of elevation (Figure 2). Two additional species, *Sclerocactus blainei* and *Mimulus ovatus*, are reported from an elevational amplitude of less than 50 m. The lone anomaly to the general pattern of restricted elevational range among the lowest elevation group was *Penstemon floribundus*, with populations spanning 1,009 m.

The middle elevation group is comprised of nine taxa, all but one of which are thought to occur only in Nevada (Figure 2). The median altitudes of all known populations of these taxa fell between 2,000 m and 2,746 m, although three taxa have some populations near or above 3,000 m. Six of these taxa, *Tonestus graniticus*, *Lewisia maguirei*, *Collomia renacta*, *Eriogonum microthecum* var. *arceuthinum*, *E. douglasii* var. *elkoense,* and *Trifolium andinum* var. *podocephalum* had elevational amplitudes of less than 280 m. This relatively narrow elevation span is comparable to those typical of the valley taxa, and an argument could be made to make only two groupings based on a division at 2,500 m (Figure 2). Such a division would, however, mask an ecological distinction based on a notable difference between valley and montane endemics in their edaphic specialization, discussed in more detail in the following section. The remaining three taxa, *Penstemon tiehmii*, *P. pudicus*, and *P. moriahensis* had reported elevational amplitudes of 640 m, 782 m, and 1,128 m, respectively.

The highest elevation group is comprised of ten taxa, seven of which are considered endemic to Nevada. Only three of the ten taxa, *Draba serpentina*, *Boechera ophira*, and *Ipomopsis congesta* var. *nevadensis* had reported elevational amplitudes of less than 200 m. Two taxa, *Primula capillaris* and *Penstemon rhizomatosus,* had reported elevational amplitudes of 381 m and 366 m, respectively. The remaining five taxa, *Viola lithion*, *Eriogonum holmgrenii*, *Potentilla cottami*, *Polemonium chartaceum*, and *Cymopterus goodrichii* had reported elevational amplitudes between 747 m and 1,158 m. Only three, *Polemonium chartaceum*, *Eriogonum holmgrenii*, and *Draba serpentina*, were restricted to sites above treeline (Figure 2).

DISCUSSION

Overview

Many of the rarest plant taxa in the Great Basin of Nevada are found below the lower limits of tree distribution. These low elevation taxa (median elevation below 2,000 m) had the narrowest bioclimatic envelope, as estimated from their reported elevational amplitudes, with 11 of 14 (79 percent) spanning less than 244 m. If other elevation bands are considered, 17 of the 20 taxa (85 percent) with an elevational span of less than 280 m have a median elevation below 2,377 m (Figure 2). Among the ten highest elevation taxa, only three (30 percent) have a reported elevational amplitude of less than 200 m (one of these is likely more widely distributed as discussed below), and four of them (40 percent) are known to occur over more than 700 m of elevation.

These results oppose the prediction that alpine species are at particular risk due to isolation and lack of an "escape route" (Grabherr et al. 1995; Halloy and Mark 2003). Perhaps this can be attributed to unusual features of plant endemism in the western United States in general and, more specifically, in the Intermountain West. Kruckeberg (1986) reformulated earlier works characterizing the processes of soil formation and vegetation development (Jenny 1941; Major 1951) to account for plant diversity in any region. He noted that topography, parent material, and the timing of geological processes or events created a patchiness or discontinuity of edaphic phenomena that creates additional opportunity for biological discontinuity. i.e., speciation. He termed endemic taxa that result from this process "geoedaphics" (Kruckeberg 1986). Rajakaruna (2004) provided a review that emphasized the role that unusual soil conditions play in the diversification of plant species.

Although Kruckeberg (1986) emphasized the role of bedrock (and especially serpentine) outcrops in the evolution of geoedaphics, in an earlier paper Kruckeberg and Rabinowitz (1985), cast a broader net with respect to narrowly distributed endemics (*sensu* Mason 1946a,b), noting that unique taxa associated with "gypsum, serpentine, limestone, alkaline and heavy metal soils are well known to field botanists in many parts of the world." While few, if any, serpentine outcrops are known from the Great Basin in Nevada, the Calcareous Mountains Section of the Intermountain region, which lies primarily in the eastern half of Nevada and adjacent southwestern Utah, is recognized as the richest area of the Great Basin for plant endemism (Holmgren1972a). Elsewhere, examples of Great Basin plants restricted to exposures of carbonate bedrock are

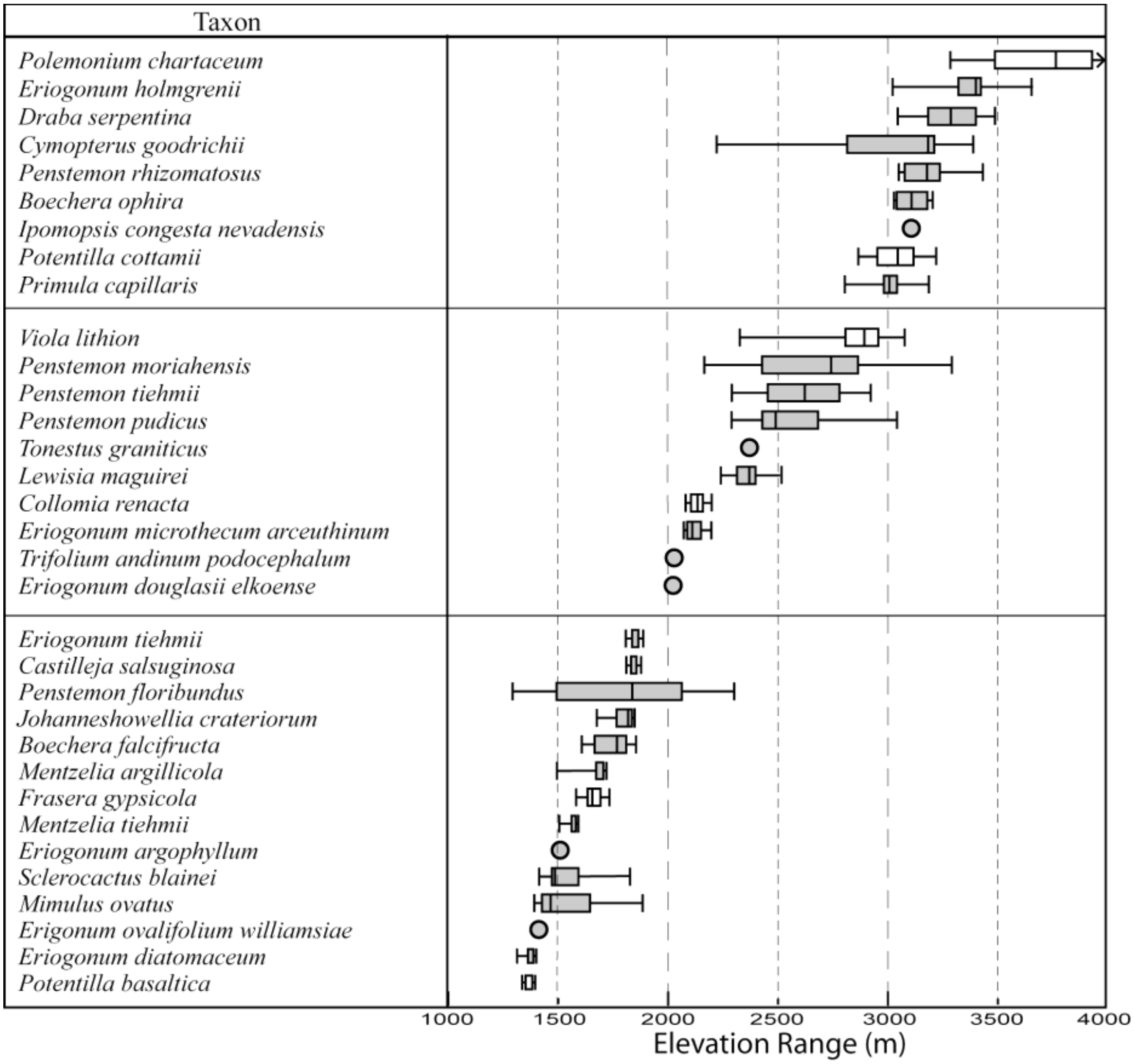

Figure 2. Elevation ranges of reported localities of the 33 rarest plants (NatureServe G1, G1G2, and T1 ranks) in the Great Basin of Nevada. The rectangles in each box-and-whisker plot show the 50 percent of the populations that occur between the 25th and 75th percentiles and the median elevation. Species are ranked by median elevation. Circles indicate plants known from only a single site. Shading shows plants endemic to Nevada.

Table 1. Rare Plant Taxa in the Great Basin of Nevada Assessed for Vulnerability to Climate Change.

Taxon	**No. of Pop's**[a]	**Life Form**[b]	**Habitat(s)**
High Elevation Endemics (n=9)			
Polemonium chartaceum H. Mason	1 (6)	pf	Rocky slopes, talus, fellfields
Eriogonum holmgrenii Reveal	4	pf	Quartzite/limestone outcrops, slopes, ridges
Draba serpentina (Tiehm & P. Holmgren) Al-Shehbaz & Windham	4	pf	Quartzite slopes and cliffs
Penstemon rhizomatosus N.H. Holmgren	6	pf	Limestone talus and cliffs
Cymopterus goodrichii Welsh & Neese	7	pf	Quartzite and limestone talus
Boechera ophira (Rollins) Al-Shehbaz	13	pf	Steep slate or limestone scree/talus
Ipomopsis congesta (Hook.) V.E. Grant var. *nevadensis* (Tidestr.) Tiehm	1	pf	Carbonate-derived soils or scree?
Potentilla cottamii N.H. Holmgren	2 (2)	pf	Quartzite cracks and crevices
Primula capillaris N.H. Holmgren & A. Holmgren	4	pf	Moist meadows in glacial till
Montane Endemics (n=10)			
Viola lithion N.H. Holmgren & P.K. Holmgren	5	pf	Limestone/dolomite cracks, crevices, ledges
Penstemon moriahensis N.H. Holmgren	8	pf	Gravelly and/or silty carbonate soils
Penstemon tiehmii N.H. Holmgren	3	pf	Soil pockets on steep volcanic talus/scree
Penstemon pudicus Reveal & Beatley	6	pf	Volcanic rocky soils, crevices, boulder piles
Lewisia maguirei A.H. Holmgren	8	ge	Carbonate scree/shallow soils steep slopes/ ridges
Tonestus graniticus (Tiehm & L.M. Shultz) G.L. Nesom & D. Morgan	1	pf	Granite cliffs and outcrops
Collomia renacta E. Joyal	2	an	Volcanic lithosols
Eriogonum microthecum Nutt. var. *arceuthinum* Reveal	2	pf	Tuffaceous knolls, bluffs, and rocky flats
Trifolium andinum Nutt. var. *podocephalum* Barneby	1	pf	Tuffaceous bluffs and soils
Eriogonum douglasii Benth. var. *elkoense* Reveal	1	pf	Sandy to gravelly flats and slopes
Valley Endemics (n=14)			
Eriogonum tiehmii Reveal	6	pf	Rocky clays derived from mixed sedimentary rock
Castilleja salsuginosa N.H. Holmgren	2	pf	Seasonally moist alkaline clays/siliceous geothermal sinter
Penstemon floribundus D. Danley	8	pf	Volcanic talus, slopes, or colluvium
Johanneshowellii crateriorum Reveal	7	an	Sandy pumice flats and slopes

Table 1. continued

Taxon	No. of Pop's[a]	Life Form[b]	Habitat(s)
Boechera falcifructa (Rollins) Al-Shehbaz	9	pf	Zonal soils with big sagebrush zone
Mentzelia argillicola N.H. Holmgren & P.K. Holmgren	5	pf	Alkaline clays/silts of Pliocene lake beds
Frasera gypsicola (Barneby) D.M. Post	10	pf	Alkaline clays/silts of Pliocene lake bed; spring mounds
Mentzelia tiehmii N.H. Holmgren & P.K. Holmgren	7	pf	Alkaline clays/silts of Pliocene lake beds
Eriogonum argophyllum Reveal	1	an	Siliceous geothermal sinter
Sclerocactus blainei S.L. Welsh & Thorne	3	ps	Alkaline volcanic and calcareous clay soils
Mimulus "ovatus"[c]	9	pf	Sandy to gravelly flats and slopes
Eriogonum ovalifolium Nutt. var. *williamsiae* Reveal	1	pf	Siliceous geothermal sinter
Eriogonum diatomaceum Reveal, J. Reynolds & Picciani	11	pf	Diatomaceous earth deposits
Potentilla basaltica Tiehm & Ertter	9	pf	Moist alkaline meadows

[a] Number of reported populations in Nevada included in study; populations outside of Nevada included are shown in parentheses.
[b] pf = perennial forb; ge = geophyte; an = annual; ps = perennial succulent.
[c] Recent taxonomic revisions have left this western Nevada endemic, formerly included in *Mimulus ovatus*, without a name.

well-documented in the White Mountains of California and Nevada (Marchand 1973; Mooney 1966; Mooney et al. 1962; Morefield 1992; Wright and Mooney 1965) and on altered andesites in western Nevada (Billings 1950). In an analysis of plant distributions in the Mojave-Intermountain transition zone, Meyer (1978) found that endemic plants showed a high degree of habitat specialization and that edaphically restricted species were much better represented in xeric, than in mesic, community types.

Kruckeberg and Rabinowitz (1986) also provided case histories of *Astragalus phoenix* and *Mentzelia leucophylla*, both narrow edaphic endemics known from flats, washes, and knolls of calcareous alkaline soils at Ash Meadows National Wildlife Refuge in Nye County, Nevada. Ash Meadows lies on the periphery of, and shares many ecological features with, the adjacent Great Basin; paleosoils on which these two species occur are the partially dissected remnants of a large Pleistocene playa. Numerous examples also exist of endemism or rarity in Great Basin plants associated with soils derived from volcanic ash (Grimes 1984), sand dunes (Holmgren 1979; Pavlik 1989a), geothermal features (Holmgren 1972b; Reveal 1972, 1981), Pliocene and Pleistocene lake and playa sediments, including gypsum mounds, (Forbis 2007; Holmgren and Holmgren 2002; Reveal 1972), diatomaceous earth deposits (Reveal et al. 2002), and pumice deposits (Reveal 2004a). A detailed discussion of examples of edaphic endemism among the rarest plants of the valley, montane, and high elevation habitats of the study area is presented in subsequent sections.

In most cases, the specialized habitats of these taxa are more properly characterized as a substrate rather than a well-developed soil. Sand deposits, shallow gravel sinters, pumice fields, and volcanic ash exposures in the valleys and the scree and talus slopes of the mountains are typically dynamic, unstable substrates shaped by erosional processes. Mineral material dominates the soil profile, little organic material is present, and soil horizons are poorly differentiated, if they are even present. In a few cases, such as paleosoils developed on ancient lake beds, moist alkaline clays, or playa edges, the soils are better developed, although in the case of the former lake beds a duripan is common within a short distance of the surface and the surface itself may be armored with desert pavement. The marked aridity of the Great Basin also slows the rate of soil development. While the degree of soil development has a substantial influence on the floristic composition and structure of more common, widespread plant communities, it appears to be less important in specialized edaphic endemics. In these habitats, physical soil factors (or perhaps, in some cases, soil chemistry) may have greater influence on the ability of species to establish and persist.

Valley Endemics

The 14 rarest plants below 2000 m all occur on valley floors within a matrix of zonal vegetation dominated by *Artemisia tridentata* ssp. *wyomingensis* or various salt desert shrubs (Figure 2, Table 1). Most occur on azonal soils developed from surficial deposits that overlie the underlying bedrock, in some cases by thousands of meters (Table 1). *Eriogonum diatomaceum*, for example, is restricted to diatomaceous earth deposits (Reveal et al. 2002). *Mentzelia argillicola*, *M. tiehmii*, and *Frasera gypsicola* are typically found on sediments comprised of calcareous silts, clays, and air-deposited ash beds that accumulated in Middle Pliocene-Early Pleistocene lakes (Tschanz and Pampeyan 1970), although the latter two species also occur on Pliocene spring mounds with high gypsum content (Forbis 2007). *Frasera gypsicola* is also rarely found in saline bottomlands (Smith 1994). *Johanneshowellia crateriorum* is known only from sandy pumice flats and slopes (Reveal 2004a) associated with the Quaternary Lunar Crater volcanic field (Kleinhampl and Ziony 1985). The habitats of *Sclerocactus blainei* and *Mimulus ovatus* have been described as igneous or calcareous gravels with a clay matrix (Heil and Porter 1994; Welsh and Thorne 1985) and sandy to gravelly slopes derived from siliceous sinter or hydrothermally-altered andesite (Morefield 2001), respectively. *Eriogonum argophyllum*, *E. ovalifolium* var. *williamsiae*, and *Castilleja salsuginosa* are all associated with geothermal features, either growing in siliceous sinter gravels (*Erigonum* spp.), or in moist alkaline clays or weathered travertine (*Castilleja*) (Holmgren 1972b; Reveal 1972, 1981). *Potentilla basaltica* is also restricted to alkaline wet meadows (Tiehm and Ertter 1984).

The remaining low elevation species do not fit the same pattern of adaptation to azonal soils in the valleys. *Boechera falcifructa* appears to be the only lower elevation species that occurs on zonal soils; the association of known populations with cryptogammic soils crusts within the *Artemisia tridentata* ssp. *wyomingensis* zone suggests that it may once have been more widely distributed but subsequently reduced by livestock trampling (Morefield 1997). The only plant among the lowest elevation group to grow only on soils directly weathered from bedrock is *Eriogonum tiehmii*, which occurs on rocky clay soils derived from interbedded sedimentary rocks, including claystones, shales, tuffaceous sandstones and limestones (Morefield 1995; Reveal 1985). *Penstemon floribundus* is unique among the lower elevation taxa for the breadth of its altitudinal distribution (Figure 2); it is reported to occur on a wide variety of substrates derived from volcanic rocks (Danley 1985; Knight 1988). Extensive inventories for *P. floribundus*, endemic to the remote Jackson Range in northwestern Nevada, have not been conducted and the species may be more common*.

Montane Endemics

The nine plant species in this group occur within the narrow montane zone dominated by various species of *Artemisia* or the extensive woodlands of *Pinus monophllya* and *Juniperus osteosperma* typical of mountain ranges in the central Great Basin (Figure 2, Table 1). In higher mountains, these forests may be comprised of other conifers, including *Abies concolor*, *P. flexilis*, and less commonly, *P. longaeva* (Charlet 1996). In contrast to the valley endemics, eight of the nine montane taxa occur either on poorly developed soils directly weathered from underlying bedrock, or in scree, talus, or bedrock ledges, cliffs, and crevices (Table 1). The exception is *Eriogonum douglasii* var. *elkoense* reported from sandy to gravelly flats and slopes with *Artemisia nova* and mixed grasses (Reveal 2004b). The primary substrate affinities of the other eight taxa include tuffaceous volcanic sediments (*Trifolium andinum* var. *podocephalum* (Barneby 1989) and *Eriogonum microthecum* var. *arceuthinum* (Reveal 2004b)), volcanics (*Collomia renacta* (Joyal 1986), *Penstemon pudicus* (Reveal and Beatley 1971), and *P. tiehmii* (Holmgren 1998)), granite (*Tonestus graniticus* (Tiehm and Shultz 1985)), and carbonates (*P. moriahensis* (Holmgren 1979), *Lewisia maguirei* (Holmgren 1954; Williams 1981), and *Viola lithion* (Holmgren 1992)). In general, these substrates are common regionally and locally and the presumed rarity of these taxa is most likely determined by other ecological or historical factors.

High Elevation Endemics

Five of the nine high elevation endemics show a preference toward a particular geologic substrate (Table 1). Those reported to occur only on quartzite or other siliceous substrates include *Draba serpentina* (Al-

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*Surveys conducted subsequent to the preparation of this manuscript have confirmed *P. floribundus* to be more common and to occur on the highest peaks of the Jackson Range (A. Tiehm, personal communication).

Shehbaz and Windham 2007; Tiehm and Holmgren 1991), *Boechera ophira* (Morefield 2003) and *Potentilla cottamii* (Holmgren 1987). *Penstemon rhizomatosus* is reported only from carbonate substrates (Holmgren 1998) while *Cymopterus goodrichii* is known from slate and limestone sedimentary rocks (Welsh and Neese 1980). *Ipomopsis congesta* var. *nevadensis* may also occur on carbonate substrates but no systematic surveys have been completed (Morefield 2001). *Eriogonum holmgrenii* is reported from quartzitic, carbonate, and granitic substrates (Goodrich 1979; Reveal 1965), while *Polemonium chartaceum* occurs on rhyolite in the Sweetwater Range of California (Hunter and Johnson 1983), on open slopes of metavolcanics and nonbasic rocks at the summit of White Mountain Peak in the White Mountains of California (Crowder and Sheridan 1972; Morefield 1992; Rundel et al. 2008; Van de Ven et al. 2007), and on granitic rocks in the Boundary Peak area of the White Mountains in California and Nevada (Kartesz 1987; Pritchett and Paterson 1998). Similar to their montane counterparts, these taxa are typically found on poorly developed soils derived directly from weathered bedrock or in association with scree, talus, or bedrock ledges, cliffs, and crevices. These substrates and habitats are common regionally and locally and the presumed rarity of these taxa is most likely determined by other ecological or historical factors. The sole exception to this among the high elevation species is *Primula capillaris*, which occurs on moist meadow soils derived from glacial till (Holland 1995; Holmgren and Holmgren 1974).

Vulnerability to Climate Change

The vulnerability of any plant species or population to climate change is influenced by many factors in addition to climate and substrate, including physiological tolerances, life-history strategies, phenological plasticity, relative probabilities of extinctions and colonizations, dispersal abilities, and disruptions in plant-pollinator or herbivorous insect-host plant interactions (Parmesan 2006). Unfortunately, few data exist on most of these factors for any plants, including the 33 plants examined herein. This analysis, therefore, provides preliminary predictions that will be tested as climate change progresses over the coming decades.

Previous studies have concluded that with progressive climate change we can expect ongoing upward shifts in both forest and alpine plant species and subsequent declines in arctic-alpine plants at the southern margin of their range (Lenoir et al. 2008; Lesica and McCune 2004; Walther et al. 2005). The results reported here suggest that losses of endemic plants in the Great Basin may be highest within the lower elevation sagebrush and salt desert zones. This is consistent with similar results reported from Utah where the highest levels of plant endemism were found between 1000 m and 2000 m (Ramsey and Shultz 2004). Meyer (1978) also found that the percentage of edaphically restricted species in the Mojave-Intermountain transition zone dropped sharply with an increase in altitude. This may be because xeric environments tend to be more heterogeneous than mesic habitats in response to variables other than moisture and heterogeneous environments tend to restrict the migration of specialized plant species, thus reinforcing endemism.

Previously published studies of climate change in the Great Basin have largely focused on the montane biogeography of birds and mammals (e.g., Beever 2003; Brown 1971, 1978; Lawlor 1998), phytogeography (Billings 1978; Harper et al. 1978) or dominant tree and shrub distributions (Wells 1983; West et al. 1978). Most often these studies have applied colonization-extinction models (*sensu* MacArthur and Wilson 1967) to mountain ranges as “sky islands” within an homogenous “sagebrush sea” rather than actual landscape patterns of local plant endemism. While such imagery has popular appeal, it can mask the reality that low elevation ”sea” contains many distinctive ecological islands supporting edaphic plant endemics, contributing significantly to the overall biodiversity of the Great Basin.

This is not simply a matter of scale because ecological islands in the valleys are more-or-less equivalent counterparts in both area and isolation to subalpine and alpine habitats on ridges and peaks. The principal difference with respect to vulnerability to climate change is that montane and higher elevation habitats possess a nearly continuous array of microclimates produced by variations in slope and aspect across a wide range of elevation. In contrast, valley habitats have much less variation in either slope or aspect within a much narrower elevation range. Thus, lower elevation plant endemics are likely to have fewer ecological options as their bioclimatic envelope shifts. This greater vulnerability to climate change is compounded by the fact that valley habitats are also more susceptible to invasion by non-native plants and habitat modification or destruction by human activities (e.g. transportation or energy corridors and off-road recreation).

Conceptual Model

Based on the foregoing analysis, I am proposing a conceptual model for assessing the potential effects of climate change on rare plants in the Great Basin of Nevada; this model also may have general application throughout areas of the west with similar “basin-and-range” topography (Figure 3a). The model begins with a generic Great Basin landscape of playas, sand dunes, and terraces comprised of older lake sediments on valley fill. At the base of the bounding range, the valley fill is overlain by alluvial fan deposits. The bounding range in this model is comprised of bedded carbonates overlain by more erosion-resistant quartzite, a typical landscape throughout much of eastern Nevada. In other parts of the Great Basin, the ranges may be comprised of volcanic rocks or, locally, intrusive granitic rocks.

The valley currently provides suitable habitat for endemic plants that are typically restricted to specialized edaphic conditions, such as playa edges, the periphery of sand dunes, or specific microhabitats within older lake sediments. Montane endemics are restricted to carbonate or siliceous rock types or, in some cases, are more restricted to habitats characterized by coarse materials weathered from various substrates, such as gravels, angular slates, talus, or scree. At the highest elevations are the mountaintop endemics in subalpine-alpine habitats or, in the lower mountain ranges, on ridge tops within lower vegetation zones (Figure 3b).

As climate changes, populations of those endemic plants with the most restrictive and least common habitat constraints are likely to shrink in areal extent and become more isolated from one another. This is most likely to happen in the valleys, where many of the rarest endemics occur. But all plants restricted to highly specialized habitats, such as mountain tops or carbonate substrates, are vulnerable when physiological limits are exceeded as their bioclimatic envelope shifts to unsuitable habitats. Less specialized endemics may be less susceptible to habitat shifts but are still likely to decrease in extent since less area is available at higher elevation (Figure 3c). The eventual outcome of this scenario is likely to be extirpation of populations and eventual species extinctions throughout the landscape, with the highest rates likely in the valleys where the greatest edaphic specializations occur (Figure 3d). As noted

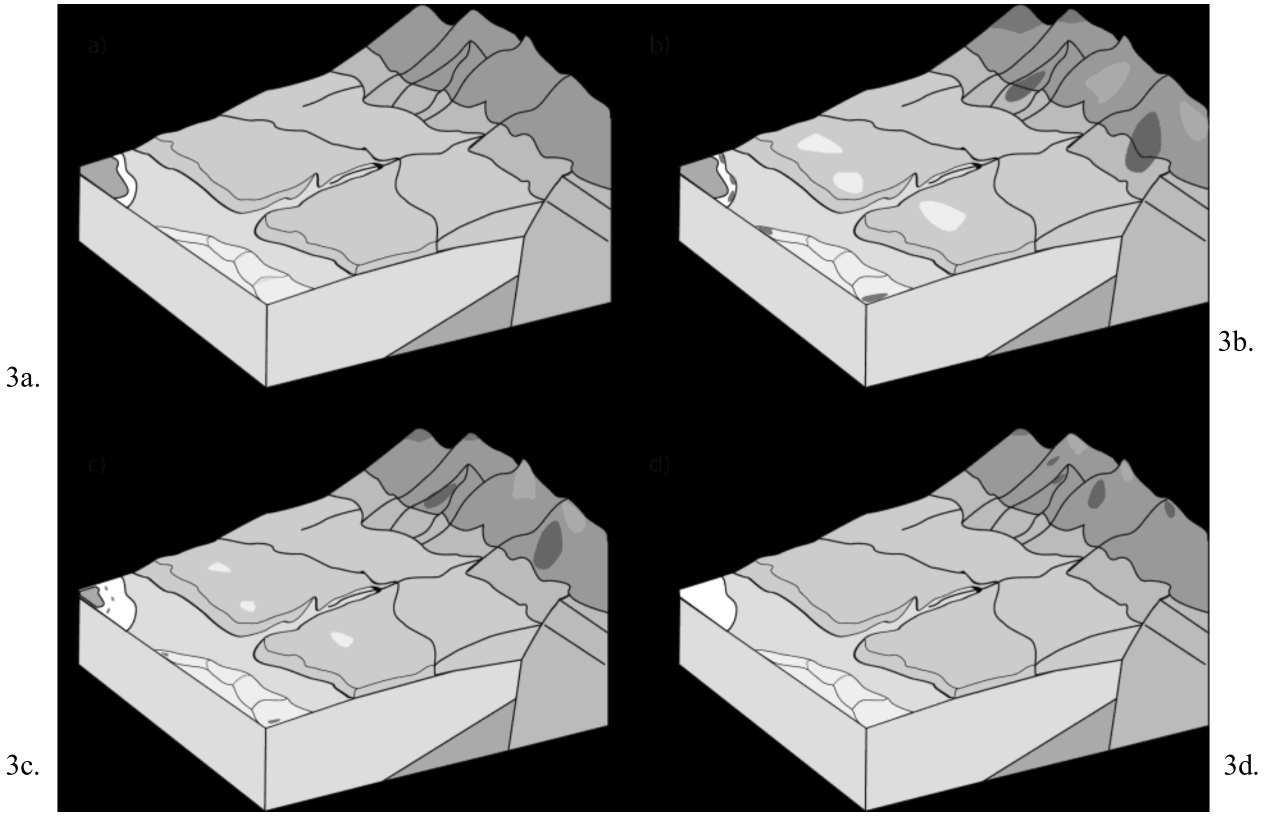

Figure 3. Conceptual model of the effects of climate change on endemic plants in the Great Basin. a) Generalized landscape typical of the Great Basin in eastern Nevada showing a playa lake, sand dunes, and Pliocene-Pleistocene lake sediments on the valley floor, overlain by alluvial, and a fault-block mountain range comprised of a band of carbonate sediments overlain by erosion resistant quartzite that forms the ridge; b) the current landscape occupied by endemic plant populations restricted to playa edges, sand dunes, carbonate rocks, montane plants that occur on both carbonates and quartzite, and higher elevation plants; c) as climate change progresses, populations of plants restricted to specialized habitats contract in place, while those less specialized migrate upward or onto more suitable aspects as their bioclimatic envelope shifts; d) eventually, populations of plants on highly specialized habitats are extirpated and the taxa go extinct while other species continue to migrate upward where less habitat area is available.

earlier, however, the physiological limits of most species are unknown and may not be exceeded. Or species may be able to adapt at a pace commensurate with the rate of climate change. Alternatively, climate change may facilitate the migration of competitors into the specialized habitats of these species. Many uncertainties remain not only about the parameters of climate change itself, but also about its potential effects on rare plant species.

Conservation Strategies

We cannot predict with any certainty which of these 33 plant taxa, or for that matter the roughly 150 additional G2 taxa (those with fewer than 20 known occurrences), will be most affected by climate change. Nevertheless, several conservation actions can be identified to better ensure the long-term conservation of plant diversity in the Great Basin. Julius and others (2008) identified adaptation options with an overall goal of maximizing resilience to climate change and noted that establishing current baselines, identifying thresholds, and monitoring for changes will be essential elements of any adaptation approach.

Clearly, inventory and monitoring are critical elements of a conservation strategy for these rare plants Yet only 23 percent of the 167 reported populations of the 33 rarest taxa have even been visited in the past decade, and population estimates are available for fewer than half of these populations (USFWS, unpublished data). Quantitative monitoring programs are in place, or in progress, for only five of the taxa. Without a concerted effort to establish baselines and a commitment to long-term monitoring, many populations could vanish without our knowledge, potentially compromising the long-term viability of species and certainly resulting in a loss of genetic resources.

To inventory and monitoring, we can add *ex situ* approaches as an, admittedly less than ideal, but necessary element at least for genetic conservation. *Ex situ* conservation has long been regarded as an option of last resort among plant conservationists, in part, because of concern that it might be viewed as an acceptable alternative to the conservation of wild habitats. In the face of climate change, however, many botanists now recognize that *ex situ* conservation has a place among a portfolio of scientifically based techniques that support the primary objective of retaining plant diversity in the wild. Such techniques are requisite for restoration and relocation actions, especially when integrated with regional conservation for both ecosystems and suites of species (Guerrant and Pavlik 1997; Maunder et al. 2004; Pavlik 1996).

Fortunately, both the infrastructure and successful models for comprehensive and integrated approaches for *ex situ* conservation of plant genetic resources exist. The Center for Plant Conservation (CPC; www.center for plantconservation.org), is dedicated solely to preventing the extinction of America's imperiled native flora. Hosted at the Missouri Botanical Garden in St. Louis, Missouri, CPC coordinates a network of 33 participating institutions throughout the country which maintain plant material (seeds, cuttings, etc.) of the most imperiled plant species in their region as part of the National Collection of Endangered Plants, totaling some 700 species.

Representation of the rarest plants of the Great Basin in the National Collection, however, is poor. Seeds of only two of the 33 taxa in this study, *Eriogonum argophyllum* and *Eriogonum ovalifolium* var. *williamsiae*, are in long-term conservation storage at participating institutions at the Red Butte Garden in Salt Lake City, Utah, and the Berry Botanical Garden in Portland, Oregon, respectively. Among the 11 participating institutions in the western United States, the Berry Botanical Garden has the most comprehensive collection with 53 taxa conserved, although only a few of these are from the Great Basin, as delineated here, and it is uncertain how representative these samples are of the full range of genetic diversity among these few taxa. The Red Butte Garden, the designated primary seed repository for the Great Basin has 22 taxa conserved, most of which are plants endemic to Utah.

Seed collection and long-term storage is also coordinated by the Bureau of Land Management's Seeds of Success project established in 2001 in partnership with the Royal Botanic Gardens, Kew (http://www.nps.gov/plants/sos/) to collect, conserve, and develop native plant materials for stabilizing, rehabilitating and restoring lands in the United States. This partnership has now grown to include many partners who have collected over 6,689 seed accessions. While the focus of Seeds of Success is on common species, it nevertheless provides a useful model for a comprehensive, landscape-based program of targeted seed collection.

CONCLUSIONS

While climate change poses ecosystemic challenges to many species, narrowly distributed and highly specialized taxa are particularly at risk. Among the rarest plants in Great Basin of Nevada, the majority of those likely to be at greatest risk are restricted to azonal edaphic habitats in the valleys. A comprehensive and integrated program of adaptation options is essential to maximize the resilience of their ecosystems to change. In particular, inventory, monitoring, and *ex situ* conservation are needed to ensure that baseline data are available against which demographic changes in these taxa can be evaluated and to ensure that genetic resources representative of the diversity within these taxa are conserved. Conservation of the full range of genetic diversity will enhance the capability of future botanists to conserve these species in the wild, whether through population enhancement or translocation to new suitable sites.

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Sentry Milkvetch (*Astragalus cremnophylax* var. *cremnophylax*) Update

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Abstract. The Grand Canyon endemic *Astragalus cremnophylax* var. *cremnophylax* (Sentry milkvetch) was listed as an endangered species in 1990. There are 725 plants within three populations on the South Rim, all found in shallow soils upon large flat Kaibab limestone platforms. Habitat specificity and reduced number of plants make Sentry milkvetch vulnerable to extinction. Recovery plan actions completed in 2008 include seed collection and parking lot removal to allow habitat restoration and population expansion. Planned recovery plan actions include establishment of an *ex situ* population, seed production, and development of techniques for population augmentation and creation of artificial populations.

The Grand Canyon National Park endemic *Astragalus cremnophylax* Barneby var. *cremnophylax* (Sentry milkvetch) was listed as an endangered species by the US Fish and Wildlife Service and protected from trampling by South Rim sightseers in 1990. There are approximately 725 individuals known in three locations, all on the South Rim of Grand Canyon. Sentry milkvetch occurs in shallow, well-drained soils or porous limestone pavement in crevices and depressions in large flat Kaibab limestone platforms in unshaded openings in the pinyon-juniper woodland along the canyon edge. The underlying bedrock limestone stores water and is critical to its growth and development (USFWS 2006).

Sentry milkvetch is a small, mat-forming perennial plant (Figure 1) and has a thick taproot and woody caudex. Pale purple flowers appear from late April to early May, with seed set in late May to June. Its tiny seeds tend to fall in the mat of the plant; therefore the plant does not spread and remains isolated.

Threats to Sentry milkvetch include small population size, vulnerability to drought and stochastic events, digging by ground squirrels and bighorn sheep (Figure 2), low reproductive capacity, limited seed dispersal, limited habitat, and reduced genetic diversity and vigor (Allphin et al. 2005).

RECOVERY CRITERIA AND OBJECTIVES

In order to downlist the species, the Sentry Milkvetch Recovery Plan (USFWS 2006) requires achievement, maintenance and long-term protection of at least four viable Sentry milkvetch populations of at least 1,000 individuals each, for a total of at least 4,000 individuals in the wild. Recovery will be attained when there are eight viable Sentry milkvetch populations of 1,000 individuals each, with long-term protection.

Figure 1. A mature Sentry milkvetch with a quarter for scale.

Figure 2. Bighorn sheep damage to Sentry milkvetch.

RECOVERY PLAN ACTIONS

Completed Actions 2006-2008

In 2006, recovery plan actions for the species began. Grand Canyon NP has completed annual monitoring of the Maricopa Point population each year (2006-2008) and performed a complete census of the Maricopa Point population in 2008. We installed permanent photo-points in all three populations in summer 2008. Grand Canyon NP and the Arboretum at Flagstaff collected 2600 seeds from 74 individuals in the summer of 2008 (Figure 3). The Arboretum at Flagstaff completed seed germination studies, initiated greenhouse seed production. established an *ex situ* population, and conducted mycorrhizal studies of the species. Grand Canyon NP completed parking lot removal, trail rerouting and shuttle bus stop relocation from Sentry milk-vetch habitat adjacent to the Maricopa Point population to allow habitat restoration and population augmentation and expansion (Figure 4). In addition, two suitable areas for artificial population establishment were selected in Spring 2008.

Planned Actions 2009-2013

Recovery plan actions planned for 2009-2013 include restoration of disturbed habitat and completion of seeding and planting trials at Maricopa Point. Acquisition of a passive solar greenhouse in 2009 will provide a dedicated facility for seeding trials, seed and plant production for introduction trials at Maricopa Point, and will create an *ex situ* Sentry milkvetch population. Through these trials we plan to develop techniques for creation of artificial populations, increase the number of individuals at Maricopa Point, and establish new pilot populations in suitable areas near Maricopa Point (Figure 5). A discovery survey of the westernmost portions of the south rim will be completed in 2009. Soil seed bank studies and ecological observations to determine pollinators will be conducted in 2009-2010. Additionally, interpretative materials will be developed and displayed at the Grand Canyon Visitor Center. Cooperating agencies in planned recovery actions include Grand Canyon National Park, US Fish and Wildlife Service, The Arboretum at Flagstaff, Grand Canyon Association, National Park Service, Center for Plant Conservation, Northern Arizona University Environmental Monitoring and Assessment (EMA) and Coconino National Forest.

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Figure 3. Seed collection, summer 2008.

Figure 4. Parking lot removal adjacent to population, September 2008, readied the site for restoration to be completed in 2010-2012.

Figure 5. Suitable area selected for Sentry milkvetch artificial population.

Figure 6. A Painted lady butterfly visits Sentry milk-vetch.

USFWS 2006. Sentry Milk-vetch (*Astragalus cremnophylax* Barneby var. *cremnophylax* Barneby) Recovery Plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, i-vii + 44pp.

ADDENDUM

This paper reported on the earliest efforts of Grand Canyon National Park to begin implementation of the 2006 USFWS recovery plan for Sentry milkvetch. Since my presentation at the University of Utah in 2009, four years of intensive work to recover this species has been completed. Some of this work is documented in Falk and others (2011) and Busco and others (2011).

Preliminary pollination studies in spring 2010 established the identity of three pollinators - two mason bee (*Osmia ribifloris* and *O. ribifloris ribifloris,* Figure 7) and a hoverfly (Syrphidae) (Busco et al. 2011). We have confirmed the presence of these generalist pollinators throughout Sentry milkvetch populations in repeat studies in 2011 and 2012.

At the time of my presentation in 2009, only 725 individuals of Sentry milkvetch were known. Today there are an estimated 3552 known naturally-occurring individuals in wild populations, and 425 plants in reintroduction areas. The increase in numbers within wild populations is largely the result of the discovery of new groups of Sentry milkvetch plants on limestone fingers above the rim and on lower limestone levels below the rim during revisits to these populations in 2010-2012 (Figure 8), as well as the result of continued protection of the Maricopa Point population. While two of the three populations are apparently stable or increasing in number, the third small population is increasingly threatened. The area below the rim of this population has crumbled away and fallen into the canyon; the few remaining individuals on a solitary boulder above may likely follow.

Figure 7. A Mason bee (*Osmia ribifloris ribifloris*) pollinating Sentry milkvetch.

Plant reintroductions at Maricopa Point began in July 2010 and continue to this date (Figure 9). The first small planting trial was completed in July 2010 – 5 Sentry milkvetch plants that were planted from greenhouse-grown plants at that time are all alive today. Seeds were less successful in that reintroduction - 10 groups of three seeds each were sown in April 2011 and today one seedling from this cohort is alive and has reached reproductive maturity. Of eighty greenhouse-grown plants and

Figure 8. Newly discovered Sentry milkvetch population in Grand Canyon National Park.

Figure 9. First large-scale reintroduction site for Sentry milkvetch.

240 seeds sown in the restored parking lot area adjacent to the Maricopa Point population in July 2011, 51% survive. Fourteen have set seed on site and produced 58 seedlings. In addition, another 44 milkvetch seedlings have become established from seed that either washed in from the adjacent Sentry milkvetch population or were present in the soil seed bank and germinated. Of seeds planted in 2011, 15.8% produced seedling plants that are now alive. In total, there are now 181 sentry milk-vetch plants growing in this reintroduction site where habitat beneath a parking lot removed in 2008 was uncovered and restored.

We seeded a second reintroduction area at Maricopa Point in 2012. Two additional seeding trials were carried out at the Maricopa Point reintroduction areas in July 2012 with 518 seeds. We also tested seeding techniques and watering regimens for this species that will provide information for continued large-scare reintroduction efforts.

Finally, we have received a three-year National Park Service grant to complete installation and establishment of two new reintroduction plantings. This funding will continue the momentum of successful reintroduction efforts. If we can successfully establish these two new populations and maintain the two large naturally-occurring sentry milk-vetch populations, Grand Canyon National Park will be well on its way to downlisting the species within the next ten years.

Additional References

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A Tale of Two Single Mountain Alpine Endemics: *Packera franciscana* and *Erigeron mancus*

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Abstract. Both the San Francisco Peaks ragwort, *Packera franciscana* and the La Sal daisy, *Erigeron mancus* are endemic to treeline/alpine habitats of the single mountain they inhabit. There is little habitat available for these plant species to migrate upward in a warming climate scenario. For *P. franciscana*, 2008 estimates indicate over 18,000 ramets in a 4 m band along a recreational trail in the Arizona San Francisco Peaks, a trail-side population centroid of 3667 m, and that the population is producing and dispersing seed. We also mapped the 2008 distribution of *E. mancus* patches along the La Sal Mountain crestline in Utah.

Both the San Francisco Peaks ragwort, *Packera franciscana* (Greene) W.A. Weber and A. Löve, and the La Sal daisy, *Erigeron mancus* Rydberg, are endemic to treeline and alpine habitats of the single mountain they inhabit. *Packera franciscana* is known only from the San Francisco Peaks in Arizona (Greenman 1917, Trock 2006) (Figure 1) where it has been reported to mostly occur between 3525 m and 3605 m elevation (Dexter 2007) or more generally 3200-3800 m (Trock 2006) with a range size of 85 ha (Dexter 2007). Since the elevation of the highest peak on the mountain is 3851 m, there is little habitat available for the plant to migrate upward in a warming climate scenario, and it has been widely speculated that the species is vulnerable to extinction due to climate change. In 1985 the distribution of *P. franciscana* on the San Francisco Peaks was mapped (Dexter 2007), but prior to our study, no published data were available on species abundance. *Erigeron mancus* only inhabits the La Sal Mountains in Utah (Cronquist 1947) (Figure 1) where it occurs in alpine meadows between 3000-3800 m elevation (Nesom 2006). In sharp contrast to *P. franciscana* which predominately inhabits loose talus slopes (USFWS 1983), *E. mancus* occupies stable substrates, which greatly facilitates field measurements. No published information about the population biology of these species is available. Consequently, *P. franciscana* was listed as a Threatened species under the Endangered Species Act by the U.S. Fish and Wildlife Service (1983) and *E. mancus* is on the Forest Service Region Four Sensitive Plant List.

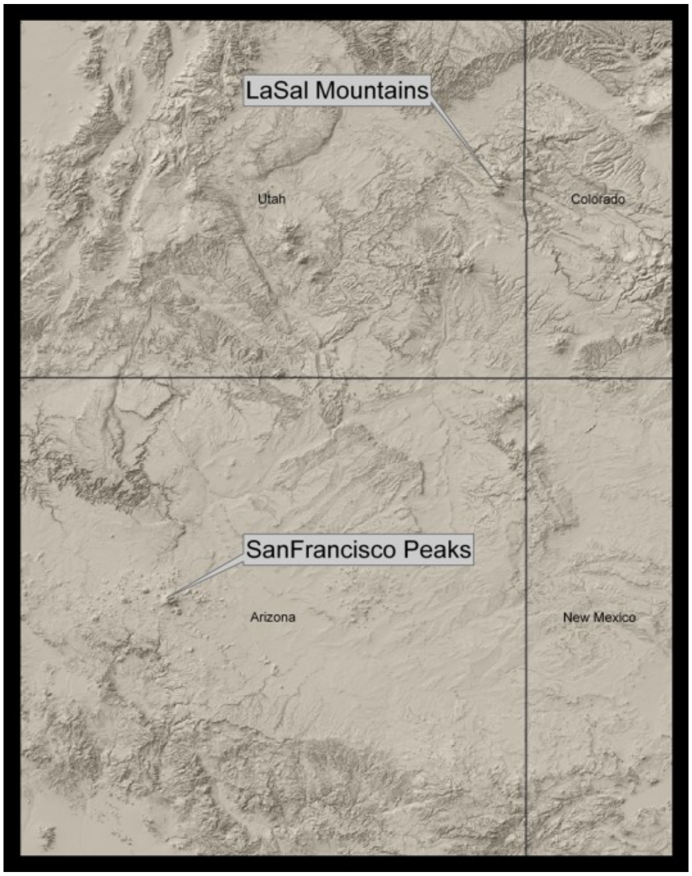

Figure 1. Map of the two study areas as isolated single mountains on the Colorado Plateau.

Kruckeberg and Rabinowitz (1985) note that narrow endemics can be locally abundant in specific habitats but geographically restricted, a description that may fit both species. Biologists have noted that *P. franciscana* is fairly abundant locally (Trock 2006, USFWS 1983) and our observations concur. We know of no density or population size data to support this observation, yet such data are critical for recovery of the species under the Endangered Species Act. In a changing climate scenario with increased temperatures and changes in amount, type, and patterns of precipitation, it becomes difficult to predict population trends. Our study will define baseline population densities along permanent transects under the current climate and allow the detection of future population trends. Specifically, our objectives are to: 1) establish a statistically robust sampling protocol for long-term population density trends; 2) determine the elevation of patch centroids along these transects to allow early detection of altitudinal migration driven by climate change; and 3) provide data for ongoing formal species assessments, management responses, and, in the case of *P. franciscana,* revision of the 20-year old Species Recovery Plan (Phillips and Phillips 1987).

METHODS

In September 2008 (after the monsoon rains), we established an elevational transect along a designated recreational trail through *Packera franciscana* habitat to estimate the density of *P. franciscana* ramets, mid-September flowering/fruiting phenology, and the population centroid elevation as it intersects the trail (Figure 2). Sample points were established at 25 m intervals along a transect starting at 3550 m elevation and extending 1425 m along the trail to an elevation of 3798 m. At each sample point we counted *P. franciscana* ramets (upright stems) within 12 individual 1 m^2 frames arranged to

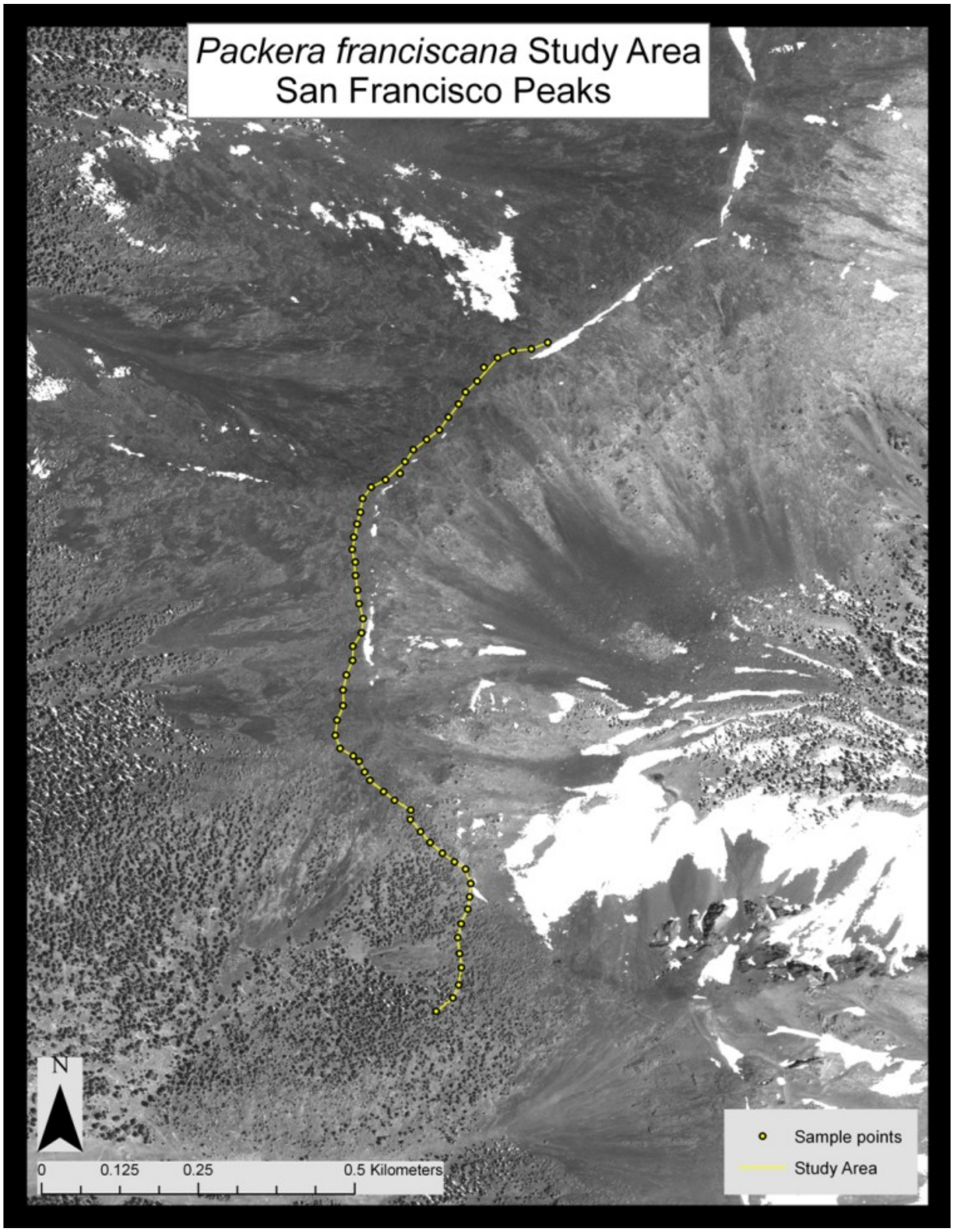

Figure 2. Location of the *Packera franciscana* trailside transect on the outslope of the volcanic caldera at and above treeline.

allow flexibility for trail curvature (Figure 3). Sampling frames were omitted when they overlapped previously counted frames, covered recent trail maintenance areas, or covered vertical drop-off > 5 m. Counts of ramets with flower, fruit, or both were also made within each frame. Coordinates for latitude, longitude, and elevation were made for each sample point with a Trimble® Geo XT 2005 Series GPS. Descriptive statistics were calculated with SAS/STAT 9.1 (2002-2003). Population centroid was calculated as the mean elevation of occurrence weighted by the number of ramets / sample point.

In July 2008, we mapped polygons of *E. mancus* patches with the Trimble® Geo XT 2005 Series GPS in three areas near and within Mt. Peale Research Natural Area, which is located in the Middle Group of peaks on La Sal Mountain. These polygons were plotted on a topographic map with ArcMap 9.2.

RESULTS

The September 2008 density estimate for *P. franciscana* along the recreational trail was 3.19 ramets / m^2 (SE □ 1.09), indicating that there are over 18,000 ramets in the 4 m band along the transect. A population centroid was located at 3667 m elevation. We counted a total of 1881 ramets of which 91 percent were vegetative, eight percent were in fruit, and one percent were flowering. Only seven ramets were in both flower and fruit.

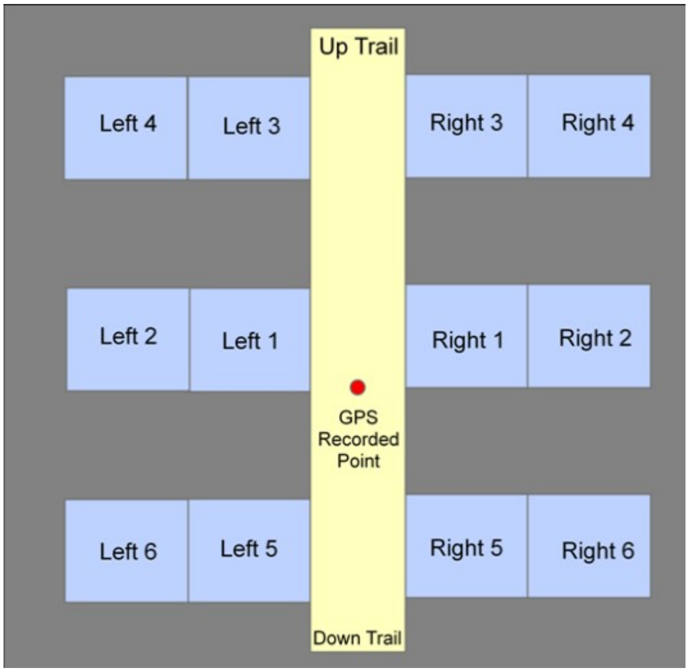

Figure 3. Arrangement and sampling sequence of 1 m^2 frames to measure ramet density.

Erigeron mancus mapping work in July 2008 revealed a relatively continuous series of *E. mancus* patches along the west ridge up to Mt. Laurel in the La Sal Middle Group of peaks, from the talus field at 3725 m down to 3475 m just above treeline, as well as along the La Sal Middle Group crestline at 3650 m (Figure 4). Our observations indicate that it can be abundant within its microhabitat niche on dry, windy ridgelines but less abundant to absent on nearby more mesic midslopes

DISCUSSION

Phillips and Peterson (1980) reported a *P. franciscana* population density range of 50-370 plants per 100 m^2 on the San Francisco Peaks but did not clearly define plants as ramets or genets (clumps or clones) (Figure 5). However, later references to clump size would indicate that they were using the latter concept. On a per 100 m^2 basis, our density measurements are similar at the upper end of their density range (319 vs. 370), which is probably a reflection of the different “plant” definitions. Given the difficulty of defining and counting clumps and clones in the field, ramets provide a more accurate way to assess population density. Even though ramet density may inflate the number of functional plants, it is an accurate reflection of photosynthetic and reproductive potential. Phillips and Peterson (1980) also reported that 13% of the *P. franciscana* plants were adult (sexually reproducing) which again is comparable to the 9% of ramets we sampled which were flowering and/or fruiting. These results and our estimate of >18,000 *P. franciscana* ramets in a very small portion of its range would indicate that the species is persisting and reproducing.

We interpret the successful production of fruit, which we observed actively dispersing by upslope winds in mid-September, as an indication that *P. franciscana* can sexually reproduce on the San Francisco Peaks. Seed viability studies may provide additional support for this interpretation. Examination of plant root systems would be necessary to determine if ramets originate from seed or from existing perennial rhizotamous clones. Rhizomes can produce large patches of ramets which may be the primary method of reproduction (USFWS 1983) but we also found single isolated ramets during our sampling which could be the result of seed dispersal or rhizome fragments moving downslope in the talus substrate *P. franciscana* inhabits. Plants inhabiting the upper portions of talus slopes would seem to be the result of seed dispersal since avalanches and downslope creep of talus fields would carry existing *P. franciscana* plants downslope. We noted dead *P. franciscana* plants at the base of some avalanche chutes. The population centroid of 3667 m we measured is above the 3525-3605 m elevation range for most *P. franciscana* noted by Dexter (2007) and near the upper end of the 3350-3750 m main

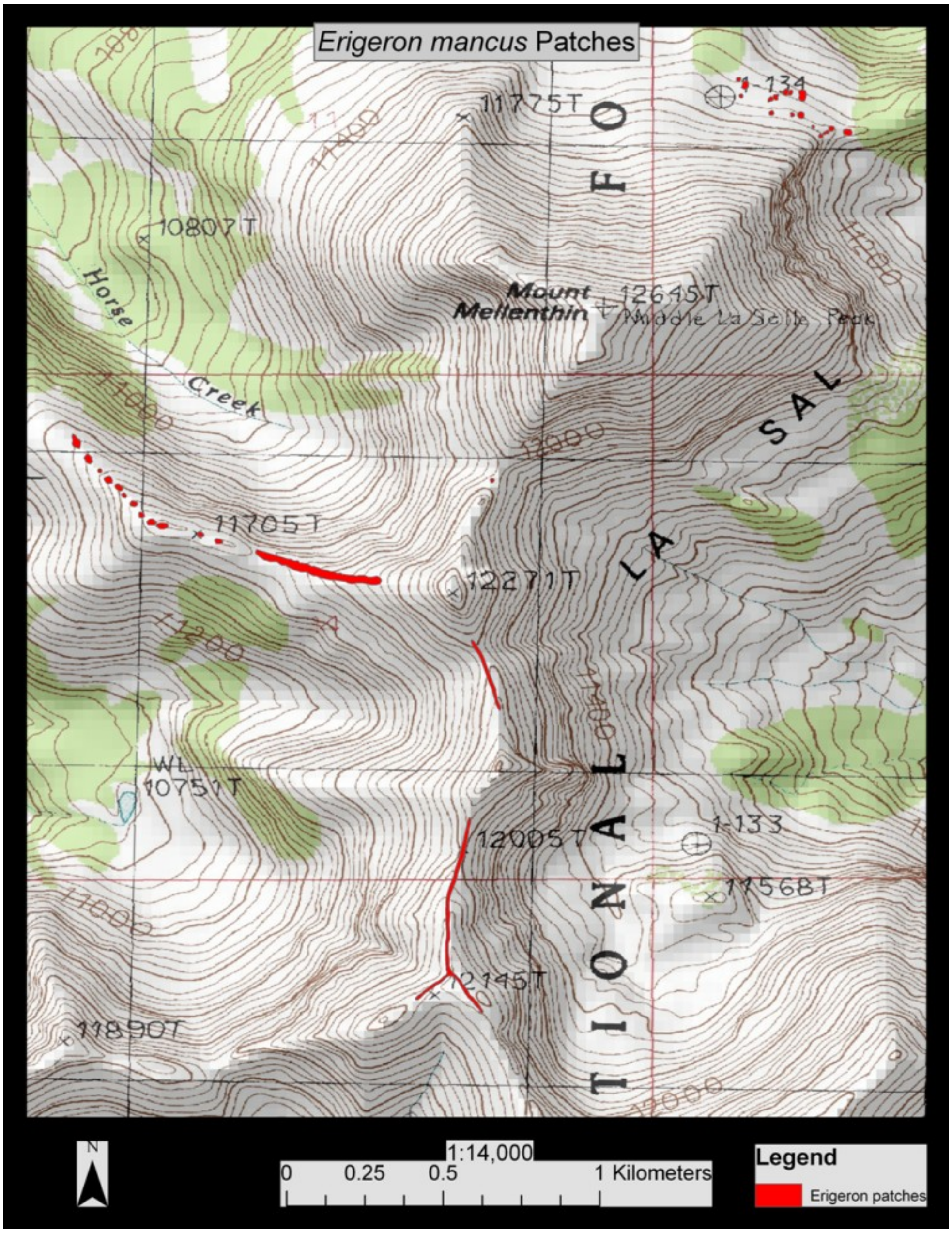

Figure 4. *Erigeron mancus* patches along the ridge up to Laurel Mt. and along the crest-line of the Middle Group of La Sal mountain.

occurrence range in earlier reports (Phillips and Peterson 1980, U.S. Fish and Wildlife Service 1983). However, our transect is located on a drier west-southwest slope which may account for the higher occurrence elevation. More mesic slopes may have lower patch centroids; a hypothesis we intend to test by establishing a northeast aspect, trail-side transect in 2009.

We plan the second trail-side transect and annual measurements of both transects to detect *P. franciscana* population trends. Sampling in subsequent years may indicate trends in population density, changes in September phenology, or elevational migration within its habitat. We also plan to measure the change in *E. mancus* density along an elevational transect through the *E. mancus* patches shown in Figure 4. By measuring patch widths along this elevational transect, we can calculate patch size and, using our density measurements, can then estimate population size for this area. Changes in population density and the elevation of population centroids over time for both species may allow detection of climate change effects as well as provide managers with accurate data on which to base land and recreation use decisions.

ACKNOWLEDGEMENTS

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Figure 5. Clonal habit of *Packera franciscana*.

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Addendum

The planned population size and density estimates for *E. mancus* were completed in summer 2009 and published in 2010 (Fowler and Smith 2010). We also added the second trailside transect for *P. franciscana* in 2009 and published the 2008-2009 results in Fowler and Sieg (2010). A second *P. franciscana* manuscript covering the 2010-2012 time frame is in preparation.

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Long-term Population Demographics and Plant Community Interactions of *Penstemon harringtonii*, an Endemic Species of Colorado's Western Slope

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Abstract. *Penstemon harringtonii* is an endemic species of Colorado's western slope. Known from only six counties, Harrington's penstemon is threatened primarily by habitat degradation and destruction in rural areas that are experiencing relatively rapid development and recreational pressure. Annual demographic monitoring since 1996 has not identified statistically significant changes in the overall number of rosettes, although significant inter-annual variation occurs at the two study sites. Additional research has focused upon the interactions of *P. harringtonii* with *Artemisia tridentata* (big sagebrush) and local plant species richness, and competition for soil moisture. Weak negative correlations between *P. harringtonii* and *A. tridentata* have been documented at both study sites, although the two sites have opposite trends in the correlation of *P. harringtonii* and species richness. Ordination techniques (nonmetric multi-dimensional scaling, NMS) are being explored as a means to find patterns that could increase our understanding of the rare species' interactions with the dominant shrub (*A. tridentata*), local plant species diversity, and soil moisture. NMS found a positive correlation between species richness and the higher density *P. harringtonii* quadrats, although no strong relationships were identified between the rare species and soil moisture. Additional sites will be sampled in 2009 and 2010 to test hypotheses concerning the potential drivers of *P. harringtonii* density and provide guidance in the development of appropriate management and restoration methods.

Long-term monitoring of *Penstemon harringtonii* Penland (Scrophulariaceae) was initiated in 1996 to determine population trends of this rare species. The penstemon is threatened by land development for homes and ski areas, oil and natural gas development, overgrazing, and off-road vehicle use (CoNPS 1997, Panjabi and Anderson 2006). Formerly a Category 2 candidate for listing under the Endangered Species Act (ESA), *P. harringtonii* is endemic to western Colorado (USDA NRCS 2009) and populations have been documented from six counties within the state (Eagle, Garfield, Grand, Pitkin, Routt, and Summit)(Panjabi and Anderson 2006, Spackman et al. 1997). Currently, *P. harringtonii* is listed as a sensitive species by the U.S. Bureau of Land Management Colorado State Office and the USDA Forest Service Region 2. The species is ranked G3/S3 by The Nature Conservancy Natural Heritage ranking system (Spackman et al. 1997). Based upon the S3 ranking, the species is considered vulnerable to extirpation in the state and only 74 occurrences have been documented (Panjabi and Anderson 2006).

The majority of populations occur in habitats dominated by *Artemisia tridentata* (big sagebrush), a hydraulic lifting species (Caldwell et al. 1998). The interaction between *A. tridentata* and growth of herbaceous plants such as *P. harringtonii* is unclear, although soil moisture and precipitation are acknowledged as limiting factors for primary production in semiarid sagebrush steppe ecosystems (Horton and Hart 1998).

Initial goals of the project were to document population trends at two study sites, although this has been expanded into understanding the species' relationship to *A. tridentata* density, soil moisture, and plant community composition with the ultimate goal of improving our management of the species and its habitat. We hypothesized that areas with lower densities of *A. tridentata* will have higher densities of *P. harringtonii* and greater species richness due to reduced competition for water. Although destruction or degradation of *P. harringtonii's* habitat is the greatest threat, an understanding of the species' interactions with big sagebrush and soil moisture may augment management of extant populations and restoration of degraded areas. Additionally, an understanding of the relationships between sagebrush, soil moisture and species richness may assist our ability to manage for diverse ecosystems.

METHODS

Plant Species

Penstemon harringtonii is a potentially long-lived perennial forb in the Scrophulariaceae. A distinctive characteristic of the species is the exsertion of the two lower stamens from the blue to pink/lavender corollas (Figure 1). Flower production and seedling recruitment are thought to be episodic and probably related to seasonal precipitation and available soil moisture (Panjabi and Anderson 2006). The species is found in open sagebrush (*A. tridentata*) and less commonly in pinyon-juniper plant communities between 1951 and 2865m elevation. All major threats are based on increased human use and development in the region for housing, ski areas, resource extraction, grazing, and recreation (CoNPS 1997, Spackman et al 1997).

Study Sites

Two geographically and ecologically diverse populations of *P. harringtonii* have been monitored since 1996. The Eagle study site is a sagebrush-steppe community near the town of Eagle, CO and is at an elevation of 2100m (Buckner and Bunin 1992). The site was roller-chopped in the 1980s (BLM personal communication) to decrease shrub cover and promote graminoid forage for cattle grazing and has relatively low sagebrush cover (6.99%). The Gypsum study area is located near the town of Gypsum, CO at an elevation of 2200m (Buckner and Bunin 1992). Relative to the Eagle site, this area has much higher cover of sagebrush (25.57%) and lower densities of *P. harringtonii*. Sagebrush cover was determined using the line-intercept method on the aerial cover of the shrubs and consisted of ten 60m transects per site. Based on a two-sample t-test, the amount of sagebrush cover was significantly different between the two study sites ($P < 0.0001$, alpha = 0.05, n = 10).

Long-term Demographic Study

At each site a 40 x 60m macroplot was installed at a location containing *P. harringtonii* and 1 x 60m quadrats were sampled within the macroplot based on a stratified random sampling method. The goal of the monitoring was to be statistically capable of detecting a 20% change in the populations of *P. harringtonii* and was designed with the analysis having a power of 95% with a 1% chance of making a false-change error (Type I). Sample size and power analyses were conducted on the two initial years of data (1996 and 1997) to determine the appropriate number of quadrats for each site (Elzinga et al. 1998). The eight quadrats sampled at the Eagle site and 12 at Gypsum were sufficient to meet the desired power of the study. Within each quadrat the following data were collected: x and y coordinates, number of rosettes, and presence or absence of flowers, fruits and herbivory. The quadrats were censused annually in early to mid-June. Repeated measures Analysis of Variance (ANOVA) and paired t-tests were utilized to determine statistically significant differences in rosette numbers over time or between years, respectively. Data were log transformed for statistical analysis.

Figure 1. *Penstemon harringtonii* (Photo by Carol Dawson).

Plant Community Analysis

In the summer of 2005 additional sampling of the macroplots was conducted as part of a Denver Botanic Garden internship investigating the relationship between *A. tridentata* density, soil moisture and the rare penstemon. Species richness and the density of sagebrush and Harrington's penstemon were determined for 4 x 2m plots randomly located within the existing macroplots at the Eagle and Gypsum study sites. Sample size and power analysis determined that 17 and 20 plots were necessary for the Eagle and Gypsum study areas, respectively (Elzinga et al. 1998). Sample size was estimated using the 2005 data and a confidence level of 90%. Analysis of the plant community data was conducted using Non-metric Multi-dimensional Scaling (NMS), a non-parametric multivariate ordination technique capable of detecting and describing vegetation patterns between the sites and correlating this information to species richness, soil moisture, and sagebrush density. The NMS used a Sorenson distance matrix and the presence or absence of plant species for the primary data matrix. The secondary matrix consisted of species richness per plot, categorical values for the ratio of *Penstemon* to *Artemisia* densities, and a dummy variable designating within which site the data are associated. Multi-Response Permutation Procedures (MRPP) provided a non-parametric statistical method to test for differences between groups (study sites) by comparing the heterogeneity within groups against the probability of occurrence by random chance. This type of randomization or permutation test provides an 'A' statistic and a 'P' value that is used to determine if the two study sites are statistically significant from each other based on species compositions. Both NMS and MRPP were conducted in PC-Ord version 5.0 software (MjM Software 1999). Linear regression and correlation coefficients (R^2) were determined between penstemon and sagebrush densities, soil moisture, and species richness using Microsoft Excel.

RESULTS

Long-term Demographic Study

The 13 years of monitoring documented statistically significant variation in the number of rosettes per quadrat using a repeated measures ANOVA (Between subjects: P<0.0001, n=20, df=18) and also found that time and the time by site interaction term were significant (Within subjects effects: Time P=0.0037, Time*Site P=0.0169). Figures 2 and 3 illustrate the mean number of rosettes per plot over the 13 years of monitoring. The paired t-test found no significant difference in rosette number between the first and last years of the monitoring (P=0.39, N=20), regardless of whether the two sites were analyzed together or separately. Based on the two statistical methods, we conclude that there is no significant change in overall rosette densities at either site, but that the two sites differ from each other and have been highly variable during the course of the monitoring.

Plant Community Analysis

The Eagle and Gypsum samples were clearly segregated by NMS and MRPP based on their different species composition in the three-dimensional ordination space (Figure 4). The MRPP test found significant differences between the two sites, based on their species compositions (P<0.00001, A=0.237, n=37). The NMS ordination identified a three-dimensional solution with reasonable stress and instabilities levels (stress = 14.085, instability = 0.00049). Red vector lines within Figure 4 illustrate the direction and magnitude of the correlations (R^2 > 0.20) between secondary matrix variables (species richness, site, dominance) and the species

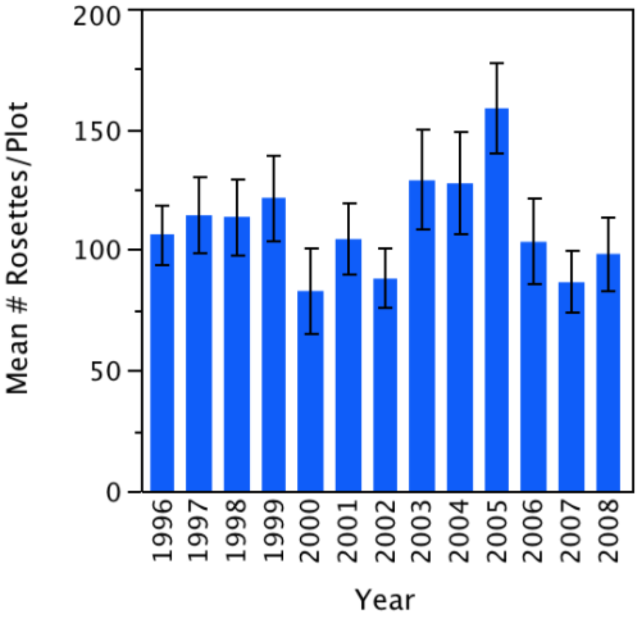

Figure 2. Mean number of *Penstemon harringtonii* rosettes per plot for each year of monitoring at the Eagle study site (1996 to 2008)(n = 8 plots). Error bars represent +/- 1 SE.

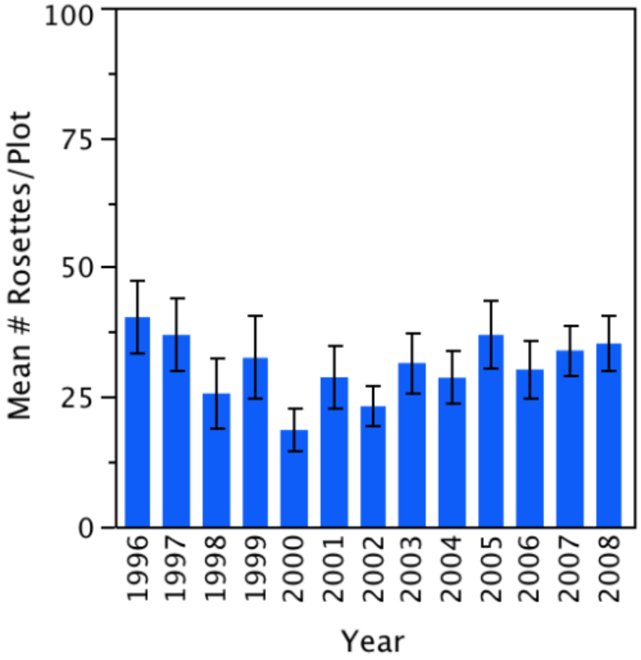

Figure 3. Mean number of *Penstemon harringtonii* rosettes per plot for each year of monitoring at the Gypsum study site (1996 to 2008)(n = 12 plots). Error bars represent +/- 1 SE.

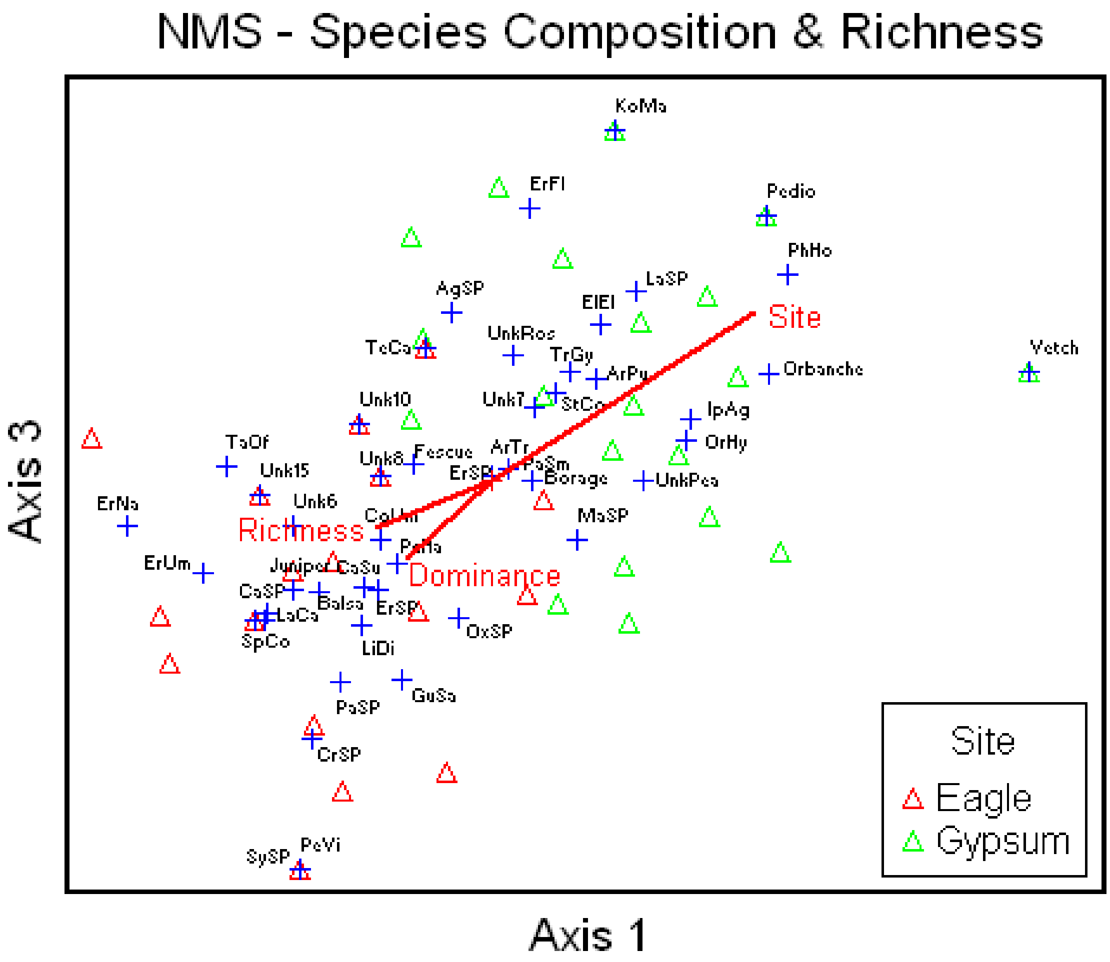

Figure 4. Non-metric Multi-dimensional Scaling (NMS) of the plant species composition at the two study sites (Eagle and Gypsum). Triangles represent quadrats and plus signs are plant species with species codes as labels. Red vectors represent correlation coefficients with $R^2 > 0.20$ and are directionally aligned to plant species to which the vector variables are positively correlated. The length of the vector represents the magnitude of the correlation.

data from the primary matrix. The vector for ‘species richness’ is oriented towards the sample space primarily occupied by the Eagle plots and represents a positive correlation between the Eagle samples and plots with higher species richness. The ‘dominance’ vector represents a ratio of *P. harringtonii* and *A. tridentata* densities and documents the positive correlation of the higher penstemon ratios with the Eagle samples. ‘Site’ is a categorical or ‘dummy’ variable necessary to code the sites and distinctly segregates the two study sites. Ordination analysis of soil moisture data and densities of Harrington’s penstemon or sagebrush did not determine any significant relationships or strong correlations. Although simple linear regressions determined that the Gypsum site had a weak negative relationship ($R^2 = 0.15$) between the penstemon and sagebrush densities. Using linear regression to compare species richness with penstemon or sagebrush density, the two study sites had weak R^2 values, but the general trends were always opposite between the sites. At the Eagle site, species richness was positively related to penstemon density ($R^2 = 0.0856$) or sagebrush density ($R^2 = 0.0857$). Conversely, at the Gypsum location the densities of penstemon and sagebrush were negatively correlated to species richness ($R^2 = 0.108$ and $R^2 = 0.125$, respectively).

DISCUSSION

The monitoring data documents that the *P. harringtonii* populations at Eagle and Gypsum are stable over the 13 years of monitoring (Figures 2 and 3), although they fluctuated greatly and reached the lowest population sizes during the droughts of the early 2000s. Increasing drought severity or frequency could have negative consequences for this species, especially if its habitat becomes more fragmented by development or degraded due to overuse. These results cannot be extrapolated to all populations of Harrington’s penstemon, but provide quantitative data concerning the population trends and supports the idea that the species is reproductive (data not presented) and recruitment is probably occurring at these locations. This monitoring project provided minimal data to inquire into the interactions of the plant community and resource use within the ecosystem. The multivariate ordination (NMS) analysis found interesting relationships between species richness and penstemon density (Figure 4), although linear regressions had weak results. We hypothesized that water is a driving resource in the system and that higher sagebrush density indirectly reduces species richness and penstemon density due to its control over the soil moisture and possibly space and nutrients. Our current data cannot support this hypothesis, but the initial analysis of the plant community data found interesting and relevant interactions that could lead to a better understanding of the rare species' population and community dynamics. Sampling of additional sites and increased measuring of soil moisture will assist in the development of theories that relate sagebrush and penstemon densities to the availability of water and the effects of inter-specific competition.

The Eagle study site was roller-chopped in the 1980s to reduce sagebrush cover and improve the system for grazing. This disturbance may have reduced sagebrush's control over soil moisture and provided an appropriate disturbance for increased recruitment and establishment of *P. harringtonii*. An understanding of this ecosystem's plant community dynamics and competition for water may provide clues to improving habitat of the rare penstemon, especially if the rate of habitat loss continues to accelerate in this rapidly developing region. If we improve our knowledge of the resources (water) and processes (disturbance) that regulate *P. harringtonii* it may be possible to develop management and restoration practices that promote higher density populations of the species by the manipulation of sagebrush cover and surface disturbance.

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Conservation and Restoration Research at The Arboretum at Flagstaff

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Abstract. The Colorado Plateau is experiencing increased climate change effects and population expansion. Many native plant species are at risk for becoming rare or threatened, and it is challenging to secure local, native plant seed for use in restoration. Here we highlight two examples of our conservation efforts for *Astragalus cremnophylax* var. *cremnophylax* in the Grand Canyon and *Purshia subintegra* in the Verde Valley of central Arizona, and discuss our involvement in a local native plant propagation movement conducted by the US Forest Service and the Museum of Northern Arizona. The Arboretum has been working toward rare plant conservation and restoration efforts for over 25 years.

SENTRY MILK-VETCH CONSERVATION

Astragalus cremnophylax var. *cremnophylax* (Figure 1) was listed as a species of concern in 1980 and was bumped up to endangered species status in 1990. This tiny legume is found only at Grand Canyon National Park (GCNP) in limestone outcrops. Threats to this species include development of the park and climate change.

In 2005, The Arboretum began working with GCNP and The U.S. Fish and Wildlife Service to conserve this rare species. The initial task was to increase seed availability through *ex-situ* propagation. Typically, seeds are propagated in sterile potting mix that can provide mixed results in terms of seed germination and growth. In an effort to improve seedling performance, we examined the effects of different soil treatments: 1) potting soil with *Rhizobium* added and 2) potting soil with a native inoculum added versus traditional potting soil. After five months of growth, seedlings propagated with a native soil inoculum had significantly greater aboveground volume than seedlings grown in either of the other two treatments (Figure 2). We are currently tracking these plants to determine if these differences will translate into increased seed production. Ultimately, we aim to conserve Sentry Milk-vetch by expanding established and adding new populations at GCNP.

Figure 1. *Astragalus cremnophylax* var. *cremnophylax* in bloom. Photo by Julie Crawford.

Figure 2. *Astragalus cremnophylax* var. *cremnophylax* grown with a native soil inoculum (left) and in standard, sterile potting soil (right). Photo by Sheila Murray.

ARIZONA CLIFFROSE RESTORATION

Purshia subintegra, or Arizona cliffrose, is known from four populations in central Arizona, with the largest population occurring in the Verde Valley. This xeric, evergreen member of the Rosaceae was listed as endangered in 1984. Major threats include development, overgrazing and climate change. The Arizona Department of Transportation funded work by The Arboretum from

1996-2000 in response to road construction that would result in a loss of Arizona cliffrose habitat. The Arboretum developed a protocol for propagating Arizona cliffrose via cuttings (Figure 3), as recent droughts had prevented the species from producing seed. Additionally, The Arboretum examined ways in which the propagated cuttings (Figure 4) could be put back in the field onto protected sites. Since out-planting in 2001, the Research Department has been involved in monitoring the new populations. We are happy to report that the new populations are doing well.

ARIZONA NATIVE PLANT PROPAGATION

In 2007, The Arboretum began a collaborative project with the U.S. Forest Service and The Museum of Northern Arizona to collect and propagate native seeds for use in local restoration efforts (Figure 5). This project arose in response to a high demand and lack of supply of local seed genotypes that were crucially needed after large scale forest fires hit the area in 2002.

The first phase of the project is to collect and propagate seeds of native species that appeal to land managers for use in re-vegetation projects. Plant species are being chosen for their wildlife forage quality and likelihood of propagation success. We are also focusing on species that are not already in commercial production. Our goal is to start small, but eventually produce a reliable source for local seed genotypes that can be used by local land managers.

Figure 3. Sheila Murray collects cuttings of *Purshia subintegra* in the Verde Valley, AZ. Photo by Joyce Maschinski.

ACKNOWLEDGEMENTS

The Research Department at The Arboretum at Flagstaff (a.k.a. Kris and Sheila) would like to thank all of our wonderful volunteers and the following groups for financial support: The U.S. Fish and Wildlife Service, Arizona Department of Transportation, and The U.S. Forest Service.

Figure 4. An Arboretum volunteer helps re-pot *Purshia subintegra* in the research greenhouse. Photo by K. Haskins.

Figure 5. The research greenhouse at The Arboretum; where plant propagation will take place. Photo by K. Haskins.

The Digital *Atlas of Utah Plants*: Determining Patterns of Biodiversity and Rarity

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Abstract. The digital *Atlas of Utah Plants* is a web-based revision of the *Atlas of the Vascular Plants of Utah* by B. Albee, L. Shultz, and S. Goodrich, published in 1988 by the University of Utah Museum of Natural History. The hard copy version provided distribution maps for 2,438 native or naturalized plant species and an appendix with generalized locations for 399 additional species that are either extremely rare, recently introduced, or at the edges of their ranges – and known from one population. The new digitized version allows analysis of original data from pre-1988 herbarium collections (mapped at coarse level, resolution at approximately 10 km^2) and brings in herbarium records for post-1988 collections (most of which are mapped at high resolution with global positioning devices) as well as more than 6,000 observations and records of rare species from the database for the Utah Natural Heritage program. While specific location sites for rare species are not displayed on the web-based version, the presence of rare species is highlighted on the grid map displayed for each species. The digital version provides a tool for tracking reports of new records as well as a tool for analyzing patterns of diversity. Open access to these records is currently available and species lists have been compiled for each major ecoregion in the state.

The on-line version of the Atlas of Utah Plants by Leila Shultz, R. Douglas Ramsey, and Wanda Lindquist is a revision of the *Atlas of the Vascular Plants of Utah* (Albee et al.1988). The new digital version displays a source code for each mapped point, new records, general locations for rare species, and nomenclatural updates.

The original Atlas was based on the authors' examination of approximately 400,000 herbarium specimens of Utah plants housed within the natural history collections of Brigham Young University (BRY), University of Utah (UT), Utah State University (UTC), the Forest Service Herbarium in Ogden (OGDF), and several Bureau of Land Management and Park Service herbaria. Although the original maps were hand-plotted on a gridded base map from specimens that were not entered in a database, the herbarium location for each voucher was color-coded on the map. These original maps are archived at the University of Utah Museum of Natural History's Garrett Herbarium (Shultz et al. 1998; Ramsey and Shultz 2004).

METHODS

Technicians at the Remote Sensing/Geographic Information System laboratory of Utah State University hand-digitized the original maps. The first on-line version was sorted by family name with access through a web site. Development of GIS layers follows the methodology reported in Ramsey and Shultz (2004). The 1992 version remained unchanged until the development of the digital version (Shultz et al. 2007).

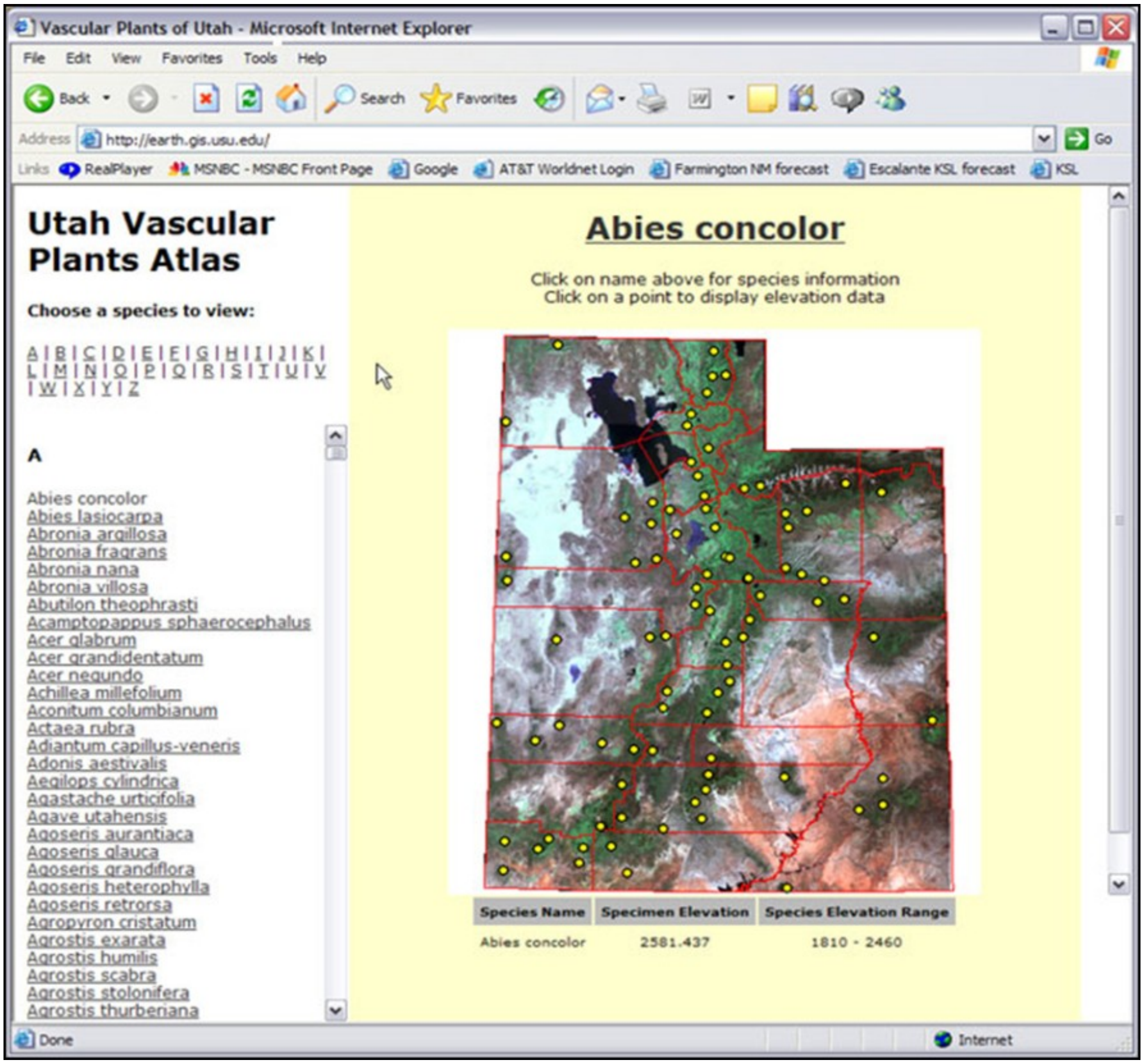
Voucher specimens on which the atlas is based represent more than 150 years of work by scores of dedicated professionals and amateurs, many of whom devoted their lives to tracking down unusual plants in some of the most isolated and physically challenging areas in North America. Authors of the original atlas (Beverly Albee, Leila Shultz, and Sherel Goodrich) spent approximately seven years critically examining and mapping locations for these approximately 400,000 collections that are housed primarily in Utah herbaria. Each point on the original maps is color-coded to show which herbarium houses the voucher for a particular record. Original maps are archived at the University of Utah's Garrett Herbarium (UT). While the lack of specific voucher data is somewhat of a handicap, this problem will be corrected as on-line retrieval systems are developed through the developing consortium of herbaria in Utah. Once these data are available, users should be able to retrieve specific location records through the internet links to individual herbaria, or a consortium of herbaria (see the Intermountain Herbarium website for new reports, at http://herbarium.usu.edu/holdings_ specimen _ database.htm).

RESULTS

Digitized version. The digital version allows for analysis of distribution patterns and patterns of diversity within the state. The composite geographic information system for 2,840 plant species provides approximately 77,000 locations (some with multiple records) in 10 X 10 km grids (roughly equal to a township). The digital version displays new geographic records, new species, and the more than 500 nomenclatural changes that have taken place since publication of the hard copy in 1988 (Figure 1). Additions include approximately 8,000 new location records (including 6,000 locality records from the Utah Natural Heritage program data files that are mapped at the resolution of township and range), and new entries for more than 400 rare species that were not included in the 1988 publication (including new reports in Welsh et al. 2003). It is based on a real-time mapping system that draws from numerous data layers and displays records on a map of Utah with a choice of backgrounds (satellite image, state map with county boundaries, or one with Nature Conservancy ecoregion boundaries). When viewing the distribution map, clicking on a point allows one to see the source of the information (see explanations below) as well as the elevation of the specific location.

Nomenclatural updates and addition of rare species. Name changes resulting from nomenclatural revisions (Flora of North America 1993 – 2006) involve approximately 16% of the names in the Utah flora. We worked to make the transition to new names as painless as possible: "old names" are retained, but shown in italics. When you click on an italicized name, you will be taken to the accepted "new name". Common names and nomenclatural changes are based on the USDA Plants Database (2009). Rare plants are highlighted in red letters, with the species taken from the state sensitive plant list (based on the Utah Native Plant Society [2009] and Bureau of Land Management Sensitive Species List).

Species checklists. Species checklists for each of the major ecoregions in the state are provided on the web page. The checklists are found by clicking on the name of an eco-region on the right side of the web page. Information for each species listed includes the common



Utah Vascular Plants Atlas

Choose a species to view:

A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z

A

Abies concolor
Abies lasiocarpa
Abronia argillosa
Abronia fragrans
Abronia nana
Abronia villosa
Abutilon theophrasti
Acamptopappus sphaerocephalus
Acer glabrum
Acer grandidentatum
Acer negundo
Achillea millefolium
Aconitum columbianum
Actaea rubra
Adiantum capillus-veneris
Adonis aestivalis
Aegilops cylindrica
Agastache urticifolia
Agave utahensis
Agoseris aurantiaca
Agoseris glauca
Agoseris grandiflora
Agoseris heterophylla
Agoseris retrorsa
Agropyron cristatum
Agrostis exarata
Agrostis humilis
Agrostis scabra
Agrostis stolonifera
Agrostis thurberiana

Abies concolor

Click on name above for species information
Click on a point to display elevation data

Species Name	Specimen Elevation	Species Elevation Range
Abies concolor	2581.437	1810 - 2460

Figure 1. Sample Page from the Digital Atlas of Utah Plants (http://earth.gis.usu.edu/plants) showing distribution of *Abies concolor* (White fir). A color-corrected satellite image is chosen as the background (note other choices available, including ecoregions), courtesy of the Remote Sensing/GIS Lab at Utah State University.

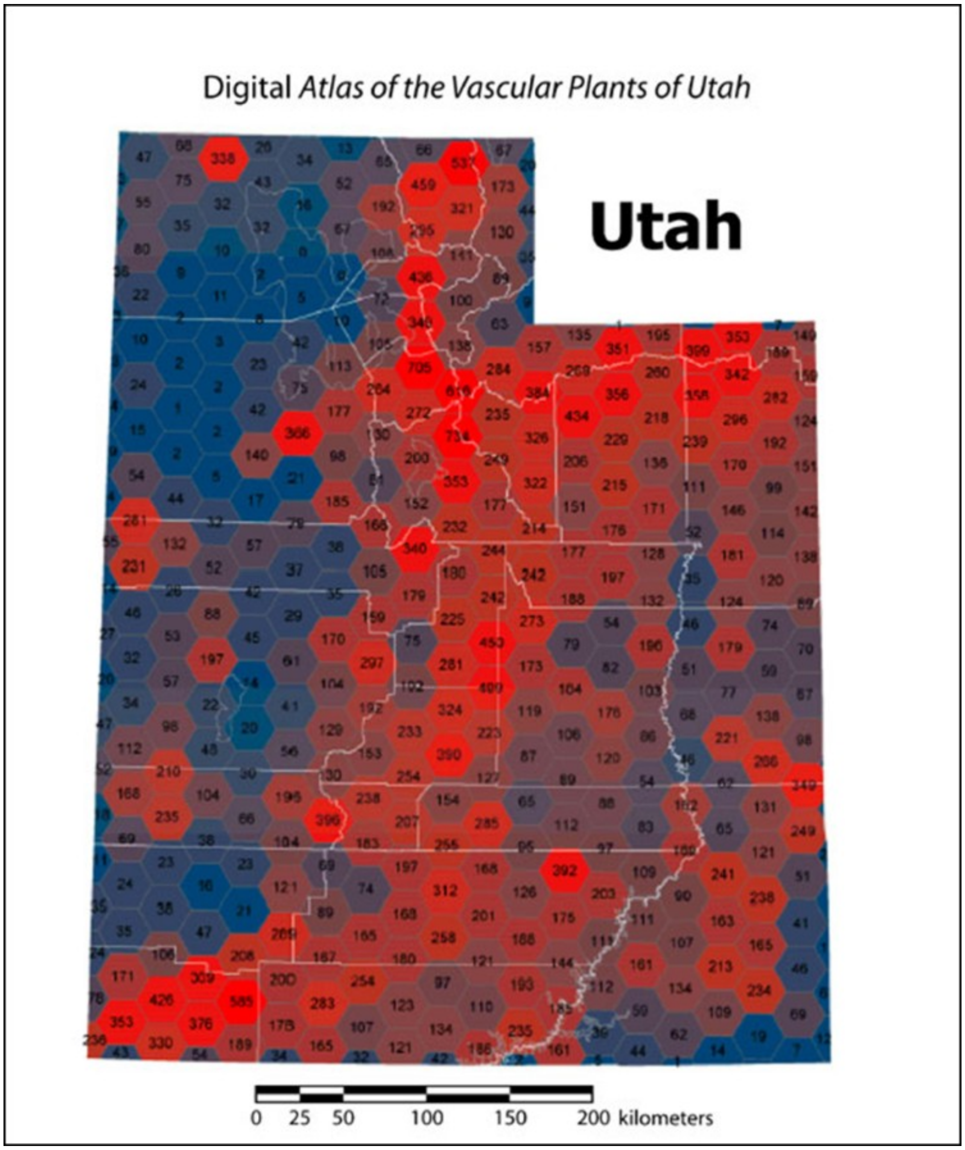


Figure 2. Species richness patterns based on voucher specimens (Albee et al. 1988), relative to a hexagonal grid sampling frame (EPA 649 km^2 sampling frame). Areas highest in species richness are shown in red, with lowest species richness shown in blue. Patterns of species richness generally correlate with elevation: the higher the richness, the higher the elevation (Ramsey and Shultz 2004).

name, family name, growth form (tree, shrub, grass, or forb), known elevational range within Utah, acronym code (USDA PLANTS database), and notation as to whether the species is native or introduced. Rare plants are also highlighted in red on these checklists.

Analysis of biodiversity patterns. The digital version allows reports of total species richness by ecoregion as well as diversity within a uniform grid system (Figure 2). The layers also can be manipulated to analyze patterns of species diversity between ecoregions. For comparisons of ecoregions within the state, see Shultz and others (2000).

DISCUSSION

Anyone attempting to represent the distribution of a biological organism knows that distributions are not static and that maps can do no better than represent the distribution of a species at a specified point in time. Changing landscapes have a profound effect on the distribution of a species. In addition, the development of an atlas of plants contains a number of inherent problems -- primarily regarding accurate identification and scale. Due to the diversity of the vascular plants (with more than 20,000 species in North America according to the Flora of North America Editorial Committee 1992--2006), reports of plant species generally cannot be trusted unless accompanied by a voucher specimen. That constraint severely limits the sample size and skews the kind of species represented by vouchers. In general, common species are under-represented in herbarium collections. However, rare occurrences are usually well-represented in herbarium collections and consequently, distribution maps of rare species are highly reliable as to the total range of a species.

When mapping from herbarium vouchers, botanists have the advantage of having a verifiable report that can be re-examined (and re-mapped) if the distribution is questionable. There is much biological and climatically important information to be gained from the mapping of a species distribution, but the user of a map should understand how the data are collected in order to understand what kinds of analyses can be performed. The first thing a user should understand is that a dot on a map will not guide the user to a specific spot on the ground. Imprecise location data for older herbarium specimens makes it impossible to map most reported plant distributions at a fine scale. New herbarium records, however, generally provide location data collected by global positioning systems. While these readings might be off by a hundred meters or so, the level of accuracy represents a considerable improvement over the older records. In order to understand how to interpret the reported distributions, one must first understand that the maps represent *ranges of species* rather than precise locations on the landscape.

In developing the first atlas for Utah plants (Albee et al. 1988), the authors were fully aware that development of a collection database would be preferable to simply creating dot maps. However, constraints of time, cost of equipment, and limits of available technology in the “early days” of computers made it impossible to consider the development of a collection database. By our rough estimate, we calculated that such an undertaking would take at least twenty years. In addition, we knew that we would be overwhelmed by the problems inherent in mapping from a literal translation of herbarium data. We chose instead to spend our time checking the identification of each specimen, using the most current monographic or floristic treatments available. If a collection could not be mapped to the accuracy of township and range, we did not represent it with a dot. We could not map between twenty and thirty percent of all collections, and specimens from locations that were already mapped were not mapped again. We did, however, color-code each dot as to the herbarium from which the record was obtained. A questionable distribution, or one of particular interest, can thus be traced by consulting the archived maps at the University of Utah. A correction of distribution maps thus requires re-examination of specimens – a procedure that is highly recommended in the event of new studies or generic revisions.

The lack of database-generated maps is not a great handicap at this time, but there should be considerable improvement in the future. If we (the authors) had access to a graphics tablet or a system for creating bar codes when we initiated the project, we would have simply placed a bar code on the specimen and linked it to a dot on a base map underlain by a graphics tablet. That kind of system would have been time-efficient, allowing later linkage to a database. Undoubtedly, new maps will be generated as collection databases are developed, and we can only hope that they will represent greater scale as well as a better way to track species distributions through time.

For the present, the digitized atlas provides good estimates of species ranges within Utah, a mechanism for generating species lists for any specified area, relatively current nomenclature, and highly accurate estimates as to the number and distribution of rare species in the state. The authors of this paper encourage the use of the digitized atlas and invite readers to visit the “Virtual Utah” website at http://earth.gis.usu.edu/utah/.

ACKNOWLEDGEMENTS

A grant from the Bureau of Land Management made this modern (post-2005) digital revision possible. Curators of the S.L. Welsh Herbarium of Brigham Young University (BRY), the Garrett Herbarium of University of Utah (UT), and the Intermountain Herbarium of Utah State University (UTC), provided enormous support throughout the years of examination of specimens. Since 2004, digital records from UTC and Utah Valley University (UVSC) have been added, for which we thank Michael Piep and Renee Van Buren. Staff associated with collections housed with various National Parks, Forests, and Bureau of Land Management offices in the state helped by providing access to collections. R. Douglas Ramsey had the vision to see the potential in developing the geospatial format and provided the technical support that made the project happen. Ben Franklin of the Division of Wildlife Resources sent records of rare species collections and observations in buffered, digitized format--a contribution of inestimable value. Walt Fertig provided his voucher data for Grand Staircase Escalante Monument, specimens deposited at BRY and UTC. Bonnie Banner, Thad Tilton, Tom Van Neil, Kent Braddy, and Chris Garrard of the Remote Sensing Lab of USU helped develop the geo-referenced database and create the original digital interface. Wanda Lindquist provided the programming expertise that allowed us to incorporate nomenclatural revisions, link to new data layers, and create species checklists. She designed the new web interface and integrated the complex system of new data layers.

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Addendum

A tool that allows users to extract species lists in database form, with accompanying information about species, has been added to the Digital Database website. Users can draw a polygon of any size within the Utah borders (using the ‘limit area’ command) and download a species list in .dbf format (using the ‘get list’ command). The list will be accompanied by information that includes common names, currently accepted acronyms, growth form, elevational range, nativity, etc. in an electronic format that can be incorporated into spreadsheets or database programs. The reference for the site is:

Shultz, L.M., R.D. Ramsey, W. Lindquist, and C. Garrard. Utah State University, Logan, UT. (http://earth.gis.usu.edu/plants/).

Molecular Genetic Diversity and Differentiation in Clay Phacelia (*Phacelia argillacea* Atwood: Hydrophyllaceae)

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Abstract. Clay phacelia (*Phacelia argillacea* Atwood) was listed as federally endangered in 1978. It is known from only two populations in Spanish Fork Canyon, Utah. Samples were taken in each of three years from each of these two populations. We used AFLP markers to assess the genetic relatedness between the two populations and degree of differentiation between *P. argillacea* and three of its congeners. Six AFLP primer combinations resulted in 535 reliable marker loci of which 124 were polymorphic. *Phacelia argillacea* is genetically distinct from both its close and distant congeners. The two *P. argillacea* populations were not strongly differentiated, suggesting that gene flow between these populations probably occurred historically. In contrast, cohorts establishing in different years within a population were often genetically differentiated. Sampling in a single year would seriously underestimate genetic diversity in this species.

Phacelia argillacea Atwood (clay phacelia) is a narrow endemic presently known from two locations approximately 8 kilometers apart in the Spanish Fork Canyon, Utah County, Utah (Figure 1). The genus *Phacelia* is the largest in the Hydrophyllaceae. *Phacelia argillacea* is a member of the Crenulatae group of section *Phacelia*, subgenus *Phacelia* and is thought to be most closely allied to *P. glandulosa* Nutt., a species of wide distribution in extreme eastern Utah, western Colorado, Wyoming, eastern Idaho, and Montana (Atwood 1975). Another apparently closely allied species is the recently described *P. argylensis* Atwood (Welsh et al. 2003), known only from the type location in Argyle Canyon, Carbon County, Utah (Figure 1). The Crenulatae group (which consists of approximately 35 species) differs from other species of *Phacelia* in producing four-seeded capsules, faveolate seeds with a central ridge on the ventral side, and have a chromosome number of n=11 (Atwood 1975).

Recent taxonomic work in the genus *Phacelia* has confirmed the placement of *P. glandulosa* within the Crenulatae but has not included either *P. argillacea* or *P. argylensis* (Garrison 2007, Gilbert et al. 2005). Our goal was to examine molecular genetic diversity within and among the two known populations of *P. argillacea* as a necessary step in designing strategies for introducing new populations of this species on public land. We also wanted to make a preliminary assessment of the degree of differentiation between *P. argillacea* and its close congeners *P. glandulosa* and *P. argylensis*. We included the more distant congener *P. crenulata* Torr. ex S. Wats. as an out group in the analysis.

Phacelia argillacea is an annual or biennial and has years when few or no actively growing plants are present. Its seeds germinate from spring to late summer or early fall and produce a rosette of leaves which grows during the winter months and bolts in the spring to produce a flowering shoot (Armstrong 1992, Meyer personal observation). The species is an edaphic endemic that is confined to steep hillsides of the Green River shale formation. Because of its restricted habitat and small and widely fluctuating population size, *P. argillacea* was declared an endangered species in 1978 (US Fish and Wildlife Service 1978, 1989).

In 1990, The Nature Conservancy purchased the Tucker site, which at the time was the only known extant population for *P. argillacea*, and fenced it to prevent damage from grazing and trampling by deer and sheep and from disturbance caused by highway and railroad construction (Armstrong 1992). The plant was later rediscovered at the Railroad site, further down the canyon (Figure 1, inset). This population is on private land and is not fenced or managed for conservation. Known impacts to the Railroad site are highway widening coupled with the construction of a retaining wall, subsequent erosion, and trailing and grazing of domestic and native ungulates. *P. argillacea* may also be threatened by invasive weeds and drought.

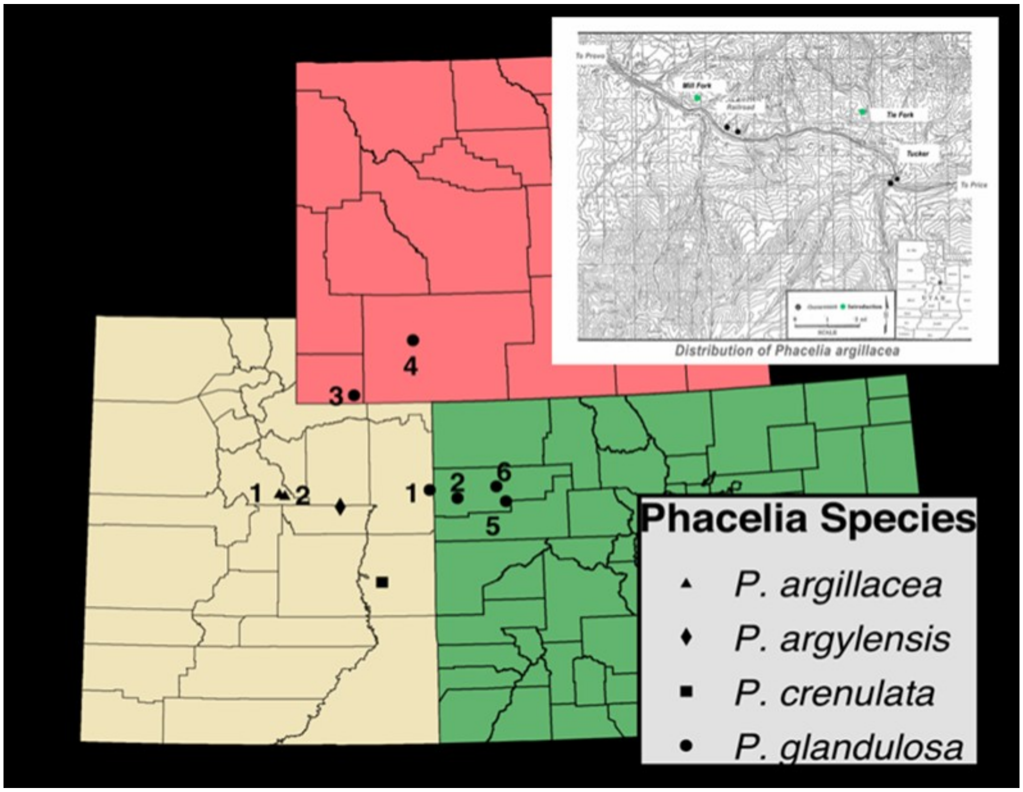

Figure 1. Collection sites for four species of *Phacelia* included in the AFLP (Amplified Fragment Length Polymorphism) study. Tissue samples were field-collected or greenhouse-grown tissue for *P. argillacea* and *P. glandulosa* for Site 2, while samples from the other *P. glandulosa* sites and for *P. argylensis* were obtained from specimens in the Brigham Young University herbarium. (Inset shows Spanish Fork Canyon, Utah, with extant *P. argillacea* subpopulations in black, reintroduction sites in green).

Through U.S. Fish and Wildlife funding, a working group was organized in 2004 to focus on the introduction of *P. argillacea* into suitable and presumably previously occupied habitat on public land in Spanish Fork Canyon, an action recommended in the recovery plan for this species (US Fish and Wildlife Service 1989). Because many endangered plants with small population sizes and fragmented populations, such as *P. argillacea*, suffer higher risk of extinction due to genetic drift and inbreeding as well as stochastic environmental effects, an introduction program is almost essential for rare plants like *P. argillacea* (Kang et al. 2005). In 2007, seeds produced from greenhouse-grown individuals from the Tucker site were introduced at two new sites on US Forest Service land. The inset in Figure 1 depicts the location of the reintroduction sites (Mill Fork and Tie Fork) with reference to the extant *P. argillacea* populations.

Analysis of the genetic diversity within and between the *P. argillacea* populations was also necessary because the species had never been studied at the molecular level. Analysis of the genetic diversity of an endangered plant species is a key element in the estimation of the viability of a population and can assist in conservation programs (Ronikier 2002, Kang et al. 2005). Data were also needed to address the question of whether *P. argillacea* was truly a distinct species or simply a disjunct population of *P. glandulosa*. Amplified Fragment Length Polymorphism (AFLP) was the molecular marker chosen to quantify genetic diversity. AFLPs were chosen because they have the potential to resolve genetic differences for individual identification and require no prior sequence knowledge of the organism. In this study AFLP analysis was used to address the following questions with regard to reintroduction of *P. argillacea*: (a) What is the level of genetic diversity in the two populations? (b) Is there genetic differentiation between the two populations? (c) Do samples collected within a population within a single year represent a random sample of genetic variation, or is there genetic differentiation between years? (d) Is *P. argillacea* genetically distinct from its close congeners *P. argylensis* and *P. glandulosa?* The answers to these questions should help to inform reintroduction efforts for this organism.

MATERIALS AND METHODS

Sample Collection

Phacelia argillacea leaf tissue samples were collected from Tucker in the 2006 and 2008 field seasons and from Railroad in the 2006, 2007, and 2008 field seasons. A single basal leaf was removed nondestructively from each individual. The 2004 Tucker samples represent half-sibling progeny from wild-collected seeds of 15 maternal individuals (a total of 53 plants) in the 2004 field season. These individuals were grown for seed production. *Phacelia crenulata* samples represented individuals greenhouse-grown from seeds of a bulk wild collection. *Phacelia argylensis* and some *P. glandulosa* samples were collected from Brigham Young University Herbarium; specimens were annotated as sampled for this study. The remaining *P. glandulosa* samples represent bulk population samples from two closely adjacent populations collected by Frank Smith in 2007 (Figure 1).

DNA Extraction and AFLP Analysis

Fresh leaf tissue samples for DNA extraction were dried over silica gel, lypophilized, or frozen at -80C immediately after collection. DNA was extracted from tissue samples using a Qiagen Plant Mini Kit (QIAGEN, Inc., Valencia, CA) with minor modifications in the protocol to achieve a higher concentration of DNA.

AFLP analysis was carried out following Vos et al (1995) with minor modifications. The enzymes EcoRI and MseI were used for DNA digestion. Each plant sample was fingerprinted with six primer combinations. The primer extensions used were *Eco*AA/*Mse*A, *Eco*AA/*Mse*G, *Eco*AA/*Mse*T, *Eco*AC/*Mse*A, *Eco*AC/*Mse*G, and *Eco*AC/*Mse*T. Fragment separation and detection was carried out on a LI-COR 4300 DNA Analysis System (LI-COR Biosciences, Lincoln, NE) on a 6.5% polyacrylamide gel. Only unambiguous bands (50 – 350 bp) were scored for presence or absence. Bands that were monomorphic among all samples were discarded from analysis of polymorphic bands. Principal components analysis was performed on the complete data set, on data from the three close congeners alone, on data from *P. argillacea* alone, and on data from the Tucker half-sib families alone. We used SAS software (SAS Institute, Cary, NC) for the analysis.

RESULTS

AFLP analysis produced a total of 535 reliably reproducible bands, 124 of which were polymorphic. Seventy-five of these bands were polymorphic only between *P. crenulata* and the other *Phacelia* species (*P. glandulosa, P. argylensis*, and *P. argillacea*; Table 1). This clearly demonstrated that the *P. glandulosa* group is strongly genetically differentiated from *P. crenulata*, the putative distant congener in the study. The three close congeners were much more genetically similar. *Phacelia argillacea* exhibited nine bands that were polymorphic with *P. argylensis*, seven polymorphic bands within *P. glandulosa* from herbarium material, and seven polymorphic bands within *P. glandulosa* collected by Frank Smith in western Colorado. An unexpected result was that the Smith collections were even more differentiated from other *P. glandulosa* than was *P. argillacea*, with 15 bands polymorphic between the two groups. In contrast, *P. argylensis* was closely similar to the herbarium-collected *P. glandulosa* group, with only 3 polymorphic bands. Within *P. argillacea*, we observed a total of 30 polymorphic bands, however no polymorphic bands were found between the Tucker and Railroad populations, suggesting low genetic differentiation.

When we analyzed data from all four *Phacelia* species included in the study, the first principal component represented 79% of the total variation and clearly separated *P. crenulata* form the other three species, reflect-

Table 1. Number of polymorphisms identified using the AFLP (amplified fragment length polymorphism) technique between or within pairs of species or, in the case of *P. glandulosa*, within-species groups.

	P. argylensis	*P. glandulosa* (H)	*P. glandulosa* (F)	*P. crenulata*
P. argillacea	9	7	7	78
P. argylensis		3	18	93
P. glandulosa (H)			15	87
P. glandulosa (F)				83

(H) Herbarium-collected samples from individual herbarium specimens.
(F) Field-collected bulk samples from two closely adjacent populations.

ing the distant relationship between it and the other *Phacelia* samples. This was a consequence of the large number of AFLP bands that were polymorphic between *P. crenulata* and the other three species (Table 1).

PCA was then used to analyze the relationships between *P. argylensis*, *P. glandulosa*, and *P. argillacea*. The first two principal components represented 9.2 and 7.2% of the total variation. The *P. argillacea* samples clearly grouped separately from samples of the other two species (Figure 2). In contrast, *P. argylensis* grouped closely with the herbarium-collected *P. glandulosa* group, calling its status as a separate species into question. The field-collected western Colorado *P. glandulosa* was most distant from the herbarium-collected *P. glandulosa* group, as was also indicated by the large number of polymorphic bands between these two sets of collections, suggesting that it perhaps represents an undescribed taxon within the group (Table 1).

When PCA was applied to data from the *P. argillacea* samples from both populations and among different years, the first two principal components, which explained 7.5 and 2.9% of the total variation, provided enough separation to compare populations and years (Figure 3). The resulting data grouped each sample with cohorts from the same year more closely than by population. For example, there was no overlap between Tucker 2006 samples and the 2004 and 2008 samples from the same population. Similarly, there was no overlap between Railroad 2008 samples and the 2006 and 2007 samples of the same population. In addition, individuals from the Railroad population were surrounded

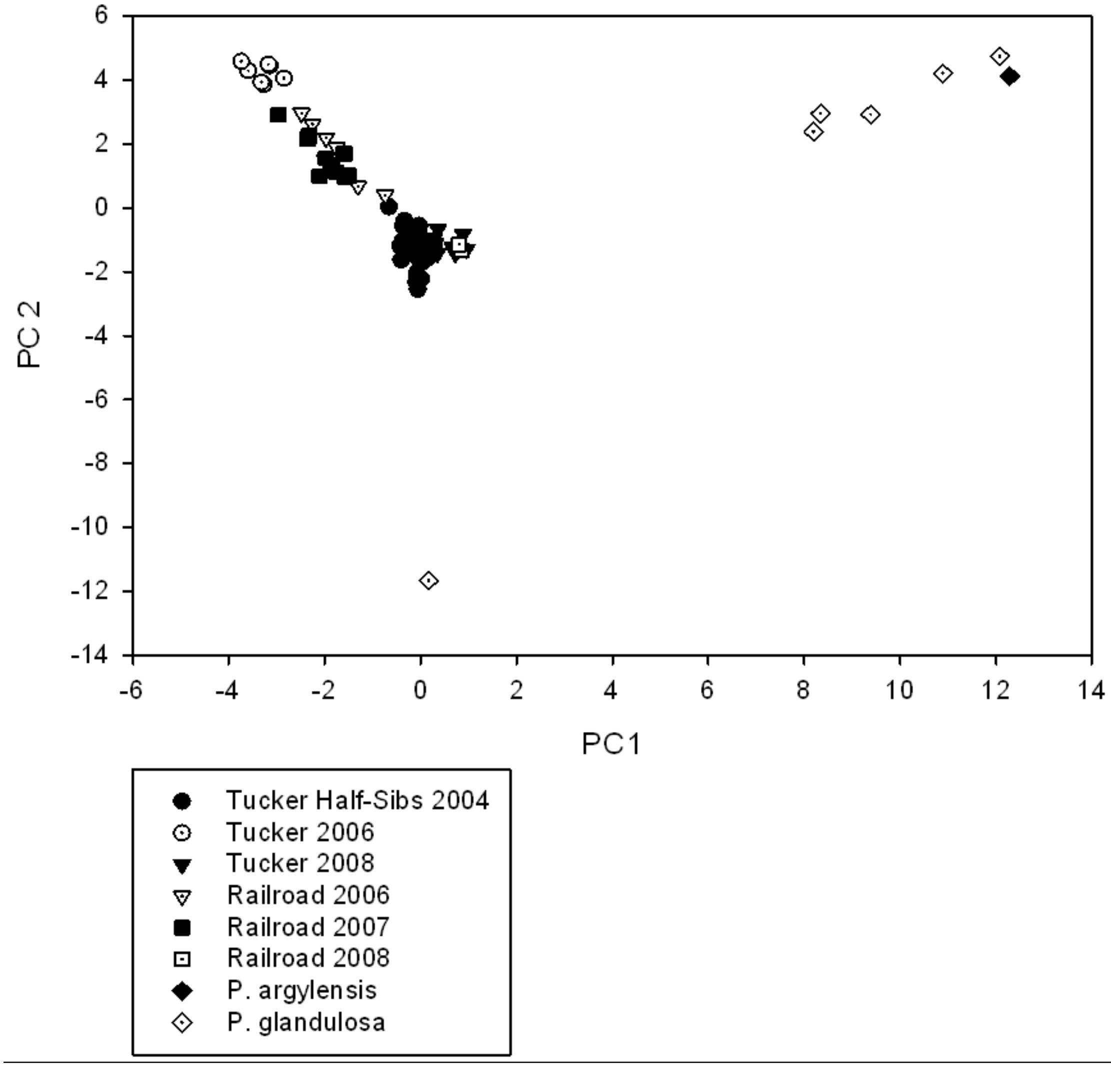

Figure 2. Scores on the first two axes from Principal Components Analysis of AFLP (amplified fragment length polymorphism) data for three species of *Phacelia*. The *P. glandulosa* point near the lower left hand corner of the graph represents two bulked field-collected samples from closely adjacent populations; all other points represent individual plants, or multiple individuals with identical genotypes.

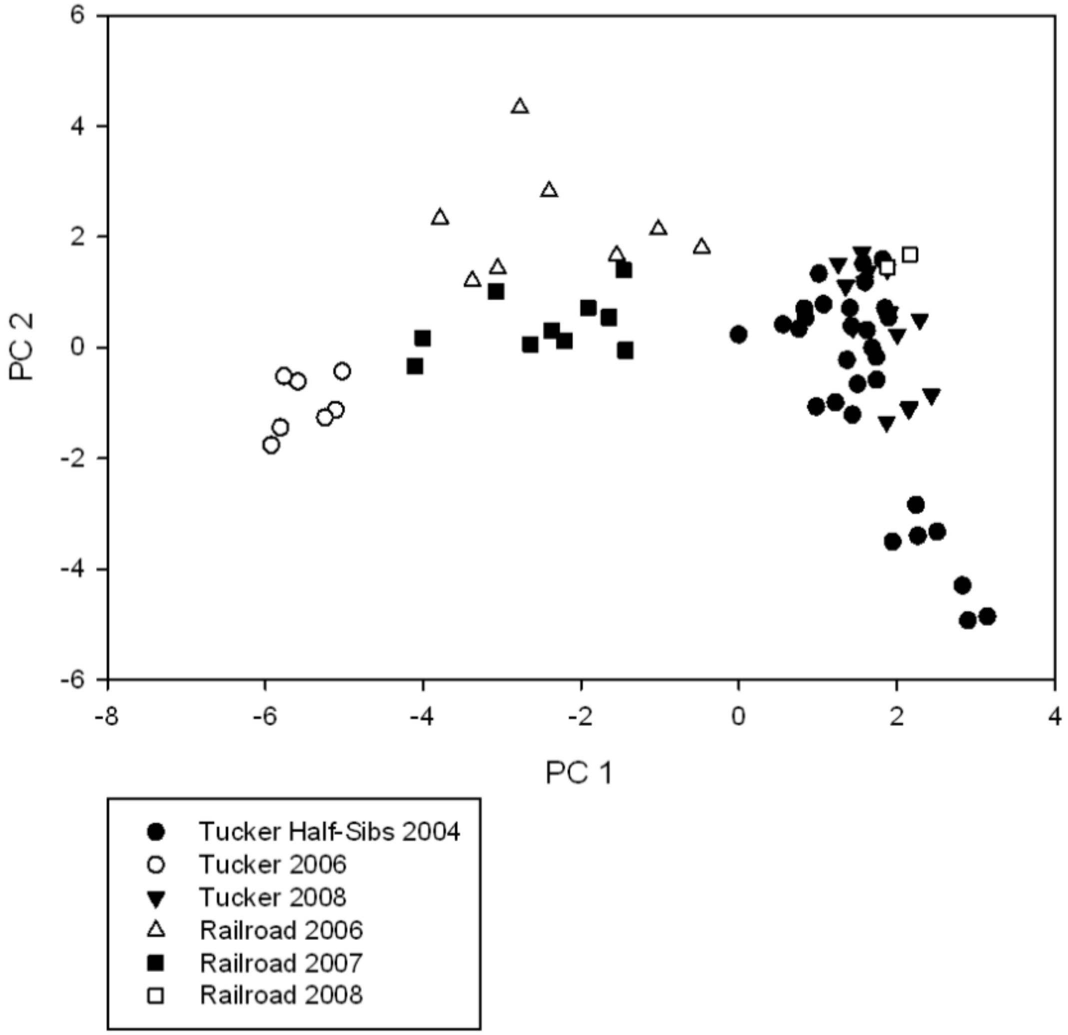

Figure 3. Scores on the first two axes from Principal Components Analysis of AFLP (amplified fragment length polymorphism) data for *P. argillacea* individuals collected from each of two populations in each of three years.

by Tucker individuals on the plot, showing no clear genetic differentiation between the two populations.

PCA was also used to differentiate the greenhouse-grown half-sib individuals from Tucker 2004. The first two principal components, even though they explained only 3.4 and 1.7% of the total variation, generally separated the samples into their respective families (Figure 4). The graphs indicate that members of half-sib families tend to resemble each other more closely than samples belonging to different half-sib families.

DISCUSSION

Although the AFLP marker system is not well suited for phylogenetic analysis *per se*, it is useful for examining the degree of genetic distinctness among closely related populations and species. In this study, PCA analysis of the AFLP bands suggests that *P. argillacea* is distinct from both its closest congeners (*P. argylensis* and *P. glandulosa*). Additionally, these results indicated that *P. argylensis* is more closely related to *P. glandulosa* than is *P. argillacea*, and may not be distinct from *P. glandulosa*. Our analysis also suggests that the differences within *P. glandulosa* as presently described may be greater than the differences between *P. glandulosa* and *P. argillacea*. A close examination of the population that was the source of the field-collected P. *glandulosa* samples from western Colorado may reveal that these samples represent a distinct and previously undescribed taxon.

The AFLP analysis revealed that *P. argillacea* appears to have a surprising amount of genetic diversity for a species of such limited distribution. Of the total polymorphic bands encountered, 24%, or 30 bands, were polymorphic just within *P. argillacea*. These polymorphisms were distributed within populations, as there were no polymorphic bands between the Tucker and Railroad populations, and the PCA showed no distinct pattern by population. Instead, the PCA of *P.*

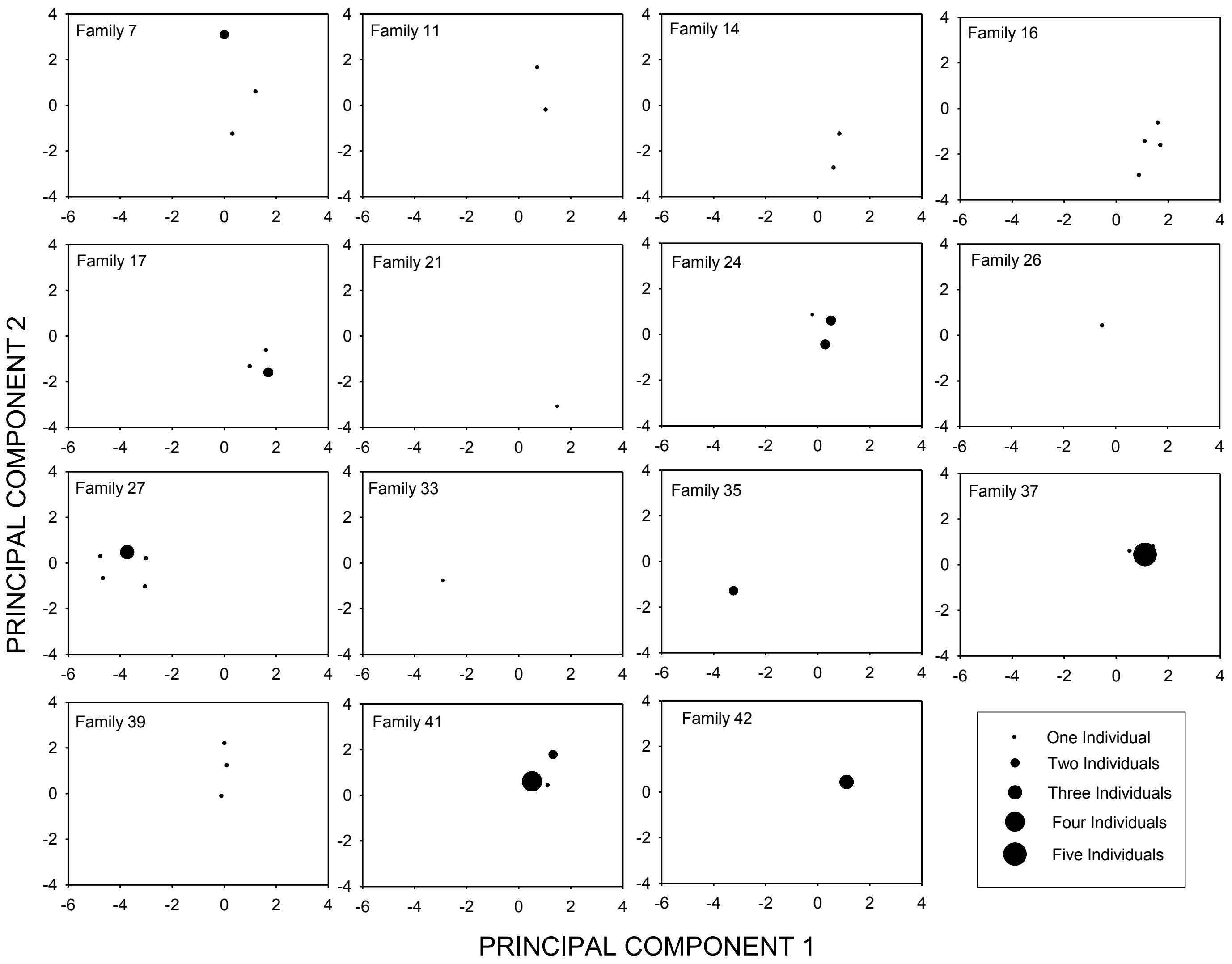

Figure 4. Scores on the first two axes from Principal Components Analysis of AFLP (amplified fragment length polymorphism) data for greenhouse-grown individuals belonging to 15 half-sib familes collected from the *P. argillacea* Tucker population in 2004. Point size reflects number of individuals with identical AFLP genotypes.

argillacea indicated that individuals tended to group together by year much more than by population. These data suggest a persistent seed bank, which means a fraction of the seeds not only remain in the soil, but are viable for at least one year after production (Thompson and Grime 1979). A site characterization study of *P. argillacea* supported this hypothesis by suggesting that the seed bank reservoir contains an accumulation of seeds from many different years (Armstrong 1992). Preliminary results from a long term seed retrieval study with *P. argillacea* also support the existence of a long-lived seed bank in this species. Few or no seeds have germinated in the field during the first two years, and most are still in a state of primary dormancy (Meyer unpublished data). This type of seed bank structure has also been reported in *Phacelia secunda*. Seeds from *P. secunda* were collected and allowed to germinate, and after three years a considerable fraction of the seeds remained viable but ungerminated (Cavieres 2001).

PCA also suggests that collections from a single year and population of *P. argillacea* would depict a very narrow genetic diversity within the organism. A persistent seed bank can function as a genetic memory by accumulating seed genotypes from different years (Cabin et al. 1998). In the case of the rare annual *Clarkia springvillensis*, analysis of seed bank samples illustrated significantly higher within-seed bank genetic diversity when compared to the adult population (McCue and Holtsford 1998). The same could be true for *P. argillacea*, as evidenced by the pattern seen in the PCA (Figure 3). The seed bank must have a higher genetic diversity than the established plants in any one year, because of the wide range of diversity seen when comparing years. A similar situation was found in *Phacelia dubia*, which has small population size and was thought to suffer from genetic drift and bottlenecking. However, analysis of the seed bank and adult plants from different years showed that no alleles were lost. The seed bank was found to store the full range of different genotypes (del Castillo 1994). Our study suggests that *P. argillacea* exhibits this type of age-structured seed bank and genetic pattern. In addition, the age and genotype of a seed may play a part in permitting it to germinate and establish in a particular kind of year. Allowing only certain genotypes to germinate each year would produce a pattern similar to the one found in Figure 3, with little or no overlap in genotypes between years.

CONCLUSIONS

In the current reintroduction efforts with *P. argillacea*, by selecting seeds collected in just one year we may be severely limiting the genetic base of this species. As the data from this study and similar studies suggest, in cases of a persistent seed bank, the parents of each year's crop can differ from the seedling cohorts found in the years before and after (Figure 4). By using only greenhouse-grown seeds produced from the Tucker 2004 seed collection, we were inadvertently selecting for only a few specific genotypes. With individuals from just one year, the reintroduction program will almost surely suffer from inbreeding and genetic bottlenecks. To broaden the genetic base of this organism and allow for establishment of successful new populations of *P. argillacea*, the reintroduction program needs to include collections from several years and from both populations.

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A Taxonomic Revision of *Astragalus lentiginosus* var. *maricopae* and *Astragalus lentiginosus* var. *ursinus* Two Taxa Endemic to the Southwestern United States

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Abstract. Two taxa in the *Astragalus lentiginosus* complex of Section *Diphysi*, *Astragalus lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus*, have been historically overlooked by taxonomists and have had an uncertain taxonomic status. *Astragalus lentiginosus* var. *maricopae* is a highly endangered endemic (likely totaling less than 5,000 individuals primarily due to habitat loss from development) and confined to a small region of igneous and granitic alluvial fans in the vicinity of Scottsdale and the Verde River drainage in northern Maricopa Co., Arizona. The second variety, *A. lentiginosus* var. *ursinus*, is a highly restricted limestone talus endemic (totaling less than 5,000 individuals) and is confined to a small region of the Beaver Dam Mountains in Mohave Co., Arizona and Washington Co., Utah. Two morphological principal coordinates analyses (PCoA) were used on vouchers of these two varieties and nearly 150 specimens from related taxa in Section *Diphysi.* The results of the first PCoA showed that the floral and pod morphology of *A. lentiginosus* var. *maricopae* contributed highly to its distinctiveness when compared to other varieties, especially *A. lentiginosus* var. *wilsonii* (its geographically closest relative). These results combined with field observations indicate that *A. lentiginosus* var. *maricopae* is a morphologically unique and highly endangered taxon that is threatened by disturbance and development throughout its known range. Based on the second PCoA, *A. lentiginosus* var. *ursinus* trends toward smaller pods and flowers than its geographically nearest relative (*A. lentiginosus* var. *mokiacensis*) and is herein recognized at the varietal level. *Astragalus lentiginosus* var. *ursinus* is more ecologically specialized than *A. lentiginosus* var. *maricopae*. However, most of the population is in a wilderness area and is threatened by recreational activities, not extirpation by suburban development.

Marcus E. Jones (1923) was one of the first taxonomists to attempt to write a comprehensive treatment of species previously considered related to *Astragalus lentiginosus* Douglas ex Hook., a species described almost a century earlier by Hooker (1831). After Hooker's publication, new species were added to this complex by Asa Gray (1849, 1865) and Sereno Watson (1871), but the complex remained poorly known until the late 19th century. In 1898, Jones proposed a set of new combinations, placing some species from Section *Diphysi* A. Gray (*sensu* Gray 1863) as varieties within a greatly expanded concept of *Astragalus lentiginosus* (Jones 1898). Jones' concept of *A. lentiginosus* remained relatively unchanged and culminated in his *Revision of North-American Species of Astragalus* (Jones 1923) which was ignored by taxonomists for two decades (Barneby 1964). Jones' core varietal concepts in *Astragalus lentiginosus* are largely accepted today, mainly due to the eloquence and precision of Rupert C. Barneby in his 1945 and 1964 monographs.

Barneby (1945) was the first to make explicit and unambiguous the relationships between the 40 varieties of *Astragalus lentiginosus* and their placement into *Astragalus* Section *Diphysi*. Although many new varieties would be described and old ones further refined over the next 60 years (see Barneby 1956, 1989, Isely 1998, Kearney & Peebles 1960, Munz & Keck 1959, Welsh 1978, 1993, 2003), the recognition of 42 varieties remains even in the latest monograph (Welsh 2007). Despite the many revisions of this complex, the best description of the extremes of the diversity within the *A. lentiginosus* complex was published by Barneby in his first monograph:

> "The varieties of *A. lentiginosus*, as known at present, are not of equal stature: some, indeed, are doubtfully distinct, while others appear to be isolated and might, in another group of the genus, pass as species of the first rank. It is noticeable, however, that every example of the latter type is comparatively little known, whereas all those represented by extensive collections are found to intergrade at some point with a related variety" (1945: 70).

The *Astragalus lentiginosus* complex can be divided into two major groups based on pod morphology. The first group, comprising the majority of the varieties of this complex, is distinguished by the presence of a deciduous, bladdery inflated, biloculate, ovoid to orbicular pod. These characters were viewed as the most representative by Barneby (1964) and used to distinguish

Section *Diphysi* from other putatively related sections. The thickness or texture of the valve walls, the type and distribution of pubescence on the valves, and the degree of closure of the locules by the septum (if it is complete and fused to the funicular flange throughout or just within a portion of the body of the pod) is highly variable throughout the range of this species.

The second group within this complex is characterized by having scarcely inflated (cylindrical to ventricose in shape and slightly inflated dorsally, if at all), thick papery to leathery, elliptic, narrowly oblong, to linear pods. The septum is generally incomplete in this group, either semi-bilocular (the septum partially divides the two locules) or sub-unilocular (the septum is less than half the width of the locule). Unlike the first group, the pods are either deciduous or long-persistent.

These scarcely inflated taxa were first comprehensively described by Rydberg (1929) as Section *Palantia* Rydb. within the genus *Tium* Medik., based on the similarity of the pod morphology. The remaining members of Section *Diphysi* were split and included in the old world genus *Cystium* Steven. The degree to which these characteristics define a section or species is a major source of disagreement among all monographs of this complex (Barneby 1945, 1964, Isely 1998, Jones 1923, Rydberg 1929, Welsh 2007). The long-persistent pods in one taxon, *A. lentiginosus* var. *mokiacensis* (A. Gray) M.E. Jones, was the primary character that lead Barneby (1989) to retain it within the Section *Preussiani* M.E. Jones, a section distantly related to Section *Diphysi*. Vastly different interpretations of the significance of this character have led to often disparate views of the species boundaries and delimitations surrounding these taxa (Alexander 2005, Barneby 1964, 1989, Welsh 2007). When the taxa with persistent pods are delimited as varieties, *Astragalus lentiginosus* becomes the only documented North American species of *Astragalus* to have forms with both persistent and deciduous pods. All other examples proposed by taxonomists have been split at the species or the sub-sectional level in recent monographs.

In the most recent revision, Alexander (2008) considered all of the scarcely inflated varieties of *A. lentiginosus* to be a single evolutionary lineage and referred to them collectively as the *Palantia*, based on Rydberg's sectional name. The *Palantia* consists of *A. lentiginosus* var. *bryantii* (Barneby) J.A. Alexander, *A. lentiginosus* var. *iodanthus* (S. Watson) J.A. Alexander, *A. lentiginosus* var. *maricopae* Barneby, *A. lentiginosus* var. *mokiacensis* (including *A. lentiginosus* var. *trumbullensis* S.L. Welsh & Atwood), *A. lentiginosus* var. *palans* (M.E. Jones) M.E. Jones, *A. lentiginosus* var. *pseudiodanthus* (Barneby) J.A. Alexander, *A. lentiginosus* var. *ursinus* (A. Gray) Barneby, and *A. lentiginosus* var. *wilsonii* (Greene) Barneby. The name, *Palantia*, is not used herein in a nomenclatural sense as a sub-generic or sectional name. It is unusual in botany for a collective name to be required for clarity when referring to groups of morphologically similar varieties. However, with over 40 varieties and 4 or 5 lineages that are similar morphologically, a collective naming convention for *A. lentiginosus* is necessary to refer to these groups. As such, the *Palantia* is used as a convenient, informal name for the varietal group with scarcely inflated pods and is italicized following the common literary convention for unfamiliar Latin words.

Within the *Palantia*, two taxa, *Astragalus lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus* have been historically overlooked by taxonomists and have an uncertain taxonomic status. *Astragalus ursinus* A. Gray (first reduced to a variety of *A. lentiginosus* by Barneby 1964) was the first to be described in 1878, along with *A. mokiacensis* A. Gray (Gray 1878). Gray was the first to propose a close relationship between these taxa and *A. lentiginosus* var. *iodanthus* (at that time, and until only recently, this taxon was delimited as a species). The affinity of the types of *A. ursinus* to extant populations has been controversial since the taxon was first described (Alexander 2005, 2008, Barneby 1964, Jones 1923, Welsh 1978, 2007, Welsh & Atwood 2001). In some recent taxonomic treatments (Barneby 1989, Welsh 1993), the types have been regarded as an insignificant variant of *A. lentiginosus* var. *palans*. However, in others *A. lentiginosus* var. *ursinus* is recognized as an insignificant variant of *A. lentiginosus* var. *mokiacensis* (Alexander 2005, Welsh 2007, Welsh & Atwood 2001).

Based on a combination of field surveys, morphometric analyses and chloroplast haplotype analyses, *Astragalus lentiginosus* var. *ursinus* was found to be genetically distinct from its geographically closest relative, *A. lentiginosus* var. *mokiacensis* (Alexander 2008, Alexander & Liston, in prep). In addition, *Astragalus lentiginosus* var. *ursinus* is a highly restricted limestone talus endemic (totaling less than 5,000 individuals), and is confined to a small region of the Beaver Dam Mountains in Mohave County, Arizona and Washington County, Utah (Alexander 2008).

The second species, *Astragalus lentiginosus* var. *maricopae*, was first described in Barneby's (1945) monograph. It is often confused with *A. lentiginosus* var. *yuccanus* due to similar floral morphology (size and color) and has remained poorly known since it was first described. The floral and pod morphology are highly distinct when compared to the other members of the *Palantia.* If it were placed within any other section of the genus, it would be recognized at the species-level. It has universally been recognized as a variety of *A. lentiginosus* in all major monographs, but has only recently been found to be a restricted endemic (Alexander 2008).

Though *A. lentiginosus* var. *maricopae* is morphologically distinct from its geographically closest relative, *A. lentiginosus* var. *wilsonii*, it is not as genetically differentiated as *A. lentiginosus* var. *ursinus* is from *A. lentiginosus* var. *mokiacensis* (Alexander 2008, Alexander & Liston, in prep). Alexander (2008) also found that *A. lentiginosus* var. *maricopae* is a highly endangered endemic (likely totaling less than 5,000 individuals primarily due to habitat loss from suburban development) and confined to a small region of igneous and granitic alluvial fans in the vicinity of Scottsdale and the Verde River drainage in northern Maricopa County, Arizona.

In this study, morphological principal coordinates analyses (PCoA), cluster analyses, and cladistic analyses are used to detect the degree of morphological differentiation between *Astragalus lentiginosus* var. *maricopae, A. lentiginosus* var. *ursinus* and the remaining taxa of the *Palantia* and whether this differentiation corresponds to species or varietal delimitations in preparation for monographic revision of the *A. lentiginosus* complex.

MATERIALS AND METHODS

Field observations and voucher specimens were made from spring 2001 to summer 2004 throughout the range of the *Palantia*. Most populations were visited several times and were observed during early flower, maturity, and senescence. Vouchers for this study are deposited at NY, OSC, RSA, UNLV, and UVSC.

Herbarium specimens were examined at UC in December of 1999, BRY in August of 2000, GH in August of 2002, NY in October of 2003, and UNLV in July of 2002 and 2003. Additional herbarium specimens were obtained on loan from BRY, CAS, DS, K, POM, RM, and RSA.

Specimens from taxa in *Astragalus* Section *Diphysi* were examined for two morphological PCoA studies. The first, the 153 specimen *Palantia* PCoA, focused on heavily sampling all members of the group and was designed to evaluate the morphological distinctiveness of *A. lentiginosus* var. *maricopae*. 103 specimens of *A. lentiginosus* var. *palans* were used representing all major regions of its range, including the type population. Also included were multiple specimens of *A. lentiginosus* var. *bryantii* (10), *A. lentiginosus* var. *ursinus* (10), and *A. lentiginosus* var. *wilsonii* (15). Due to the poor nature of most herbarium specimens of *A. lentiginosus* var. *maricopae*, 5 specimens were collected in the field in 2005 for the morphological analysis. To ensure that the range of regional variation was present in the PCoA, representative specimens (one except where noted) were included from these morphologically similar and geographically proximal varieties: *A. lentiginosus* var. *ambiguus* Barneby (the type specimen); *A. lentiginosus* var. *araneosus* (Sheld.) Barneby; a population of a *A. lentiginosus* (from Chloride, Mohave County, Arizona, interpreted herein as an intermediate to *A. lentiginosus* var. *yuccanus* M.E. Jones) considered part of *A. lentiginosus* var. *ambiguus* in Barneby (1964); *A. lentiginosus* var. *iodanthus*; *A. lentiginosus* var. *mokiacensis* (2 type specimens); *A. lentiginosus* var. *pseudiodanthus*; *A. lentiginosus* var. *stramineus* (Rydb.) Barneby (the type specimen); *A. lentiginosus* var. *vitreus* Barneby (the type specimen); and *A. lentiginosus* var. *yuccanus* (the type specimen).

The second, the 43 specimen *Astragalus lentiginosus* var. *mokiacensis* PCoA, focused on further evaluating the morphological distinctiveness of *A. lentiginosus* var. *ursinus*. Fifteen specimens from throughout the range of *A. lentiginosus* var. *ursinus* were examined, including the type specimens. For comparison, 28 specimens from throughout the range of *A. lentiginosus* var. *mokiacensis* (including the type specimens) were examined. Multiple specimens and types of the synonym, *A. lentiginosus* var. *trumbullensis* S.L. Welsh & N.D. Atwood were included in this study. These data are a modified version of the data used in Alexander (2005).

In both PCoA's, duplicate specimens or specimens from the same locality were used to determine the character states of missing data. Qualitative characters that were found to be polymorphic within a single individual were excluded.

The morphological matrices for both studies were transformed into a Gower (1971) similarity matrix, a process that is not sensitive to data sets with mixed ordinal, nominal, continuous, and ratio data types. The matrix was then used in the PCoA. A Kendall's *tau* correlation between the PCoA axes and all morphological characters was used to determine the magnitude of the contribution of characters to the overall analysis (Easdale et al. 2007, Hammer et al. 2001). All correlations and PCoA analyses were performed using Paleontological Statistics (PAST) version 1.76 (Hammer et al. 2001). A Euclidean distance dendrogram was also created using PAST for the cluster analysis.

PAUP* for Windows version 4.0 beta 10 (Swofford, 2002) was used to assess the relationships among 30 specimens of the *Palantia* and Section *Diphysi* using cladistic methodologies.

The PCoA, cluster, and parsimony analyses were used to address the following questions:
1) Do populations of *A. lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus* form groups discrete from the other members of the *Palantia* ?
2) Which morphological characters contribute to the observed groups?
3) Are these groups morphologically differentiated from the closely related and geographically proximal varieties of *A. lentiginosus*?

RESULTS

Distribution maps (Figures 1, 2) show the localities of specimens of *Astragalus lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus* examined for this study. Specific vouchers labeled in figures are shown in Table 1. A detailed list of the vouchers examined can be found in the Taxonomic Treatment and in Appendix 1.

Of the 24 morphological characters examined for the 153 specimen *Palantia* PCoA, two were constant and not used (Table 2), one was discarded due to character state scoring issues, and 22 were variable. The first component of the PCoA explained 22.1% of the total variance (Table 3). The largest correlations to the first axis were from pod raceme orientation (podro), degree of pod incurve (podpi), pod pedicel orientation (podpo), banner color (bannc), and pod persistence (poddp). The second component of the PCoA explained 11.8% of the total variance. The largest correlations to the second axis were from pod pubescence (podpu), leaf abaxial pubescence (leafab), pod shape in cross section (podsc), and pod inflation (podin). All other components of the PCoA explained less than 10% of the total variance. The scatterplot of the first two components of the PCoA is shown in Figure 3.

Of the 24 morphological characters examined for the 43 specimen *Astragalus lentiginosus* var. *mokiacensis* PCoA, 12 were found to be variable in this subset of the data (Table 4). The first component of the PCoA explained 48.4% of the total variation (Table 5). The largest correlations to the first axis were from pod shape in

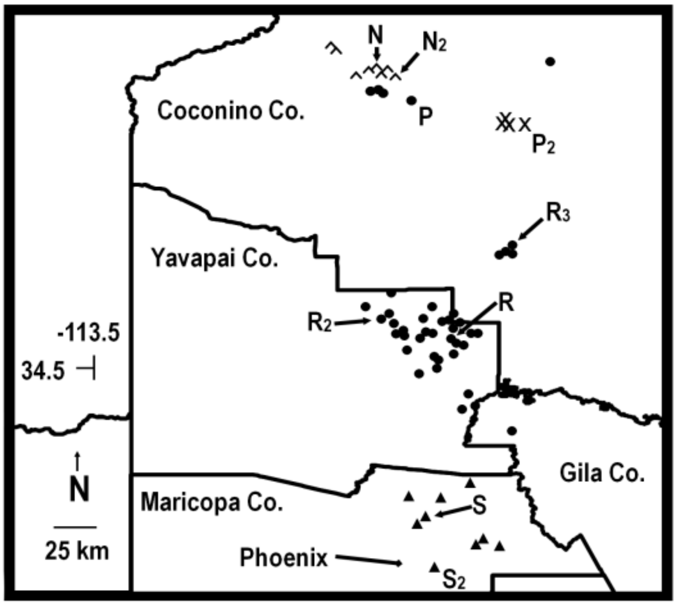

Figure 1. Distribution map of *Astragalus lentiginosus* var. *maricopae* in Arizona. The distributions of *Astragalus lentiginosus* var. *bryantii* and *A. lentiginosus* var. *wilsonii* are shown for reference. Table one contains the legend of letter codes used for specific vouchers shown. Vouchers and major populations are labeled as follows: (caret), *A. lentiginosus* var. *bryantii*; (upward triangle), *A. lentiginosus* var. *maricopae*; (circle), *A. lentiginosus* var. *wilsonii*; (**X**), Cameron population of *A. lentiginosus* var. *wilsonii* putatively intermediate to *A. lentiginosus* var. *palans*.

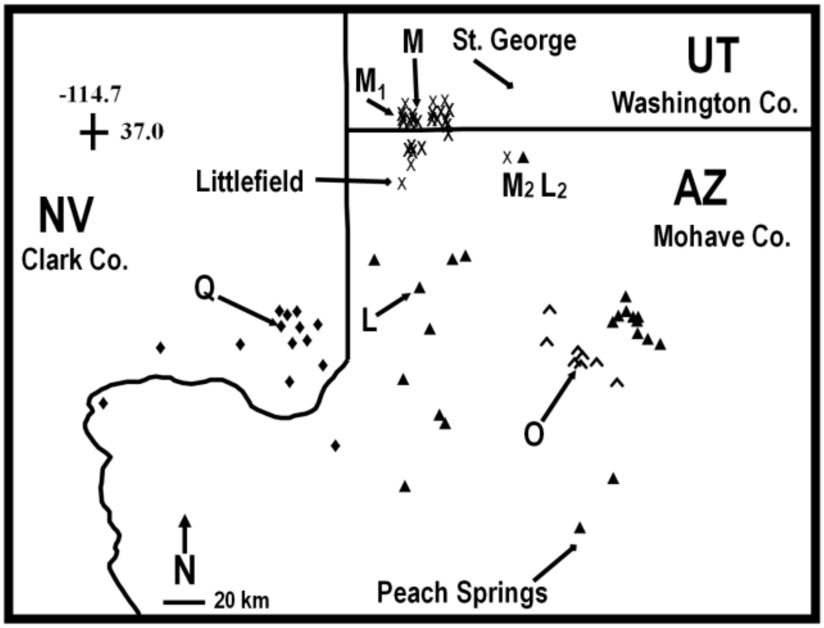

Figure 2. Distribution map of *Astragalus lentiginosus* var. *ursinus*. The distribution of *A. lentiginosus* var. *mokiacensis* is shown for reference. Table 1 contains the legend of letter codes used for specific vouchers shown. Taxa are labeled as follows: (X) *A. lentiginosus* var. *ursinus*; (upward triangle) *A. lentiginosus* var. *mokiacensis*, *mokiacensis* minor variant; (diamond*) A. lentiginosus* var. *mokiacensis*, Gold Butte minor variant; (caret*) A. lentiginosus* var. *mokiacensis*, *trumbullensis* minor variant. For a taxonomic treatment for the morphological variants shown herein for *A. lentiginosus* var. *mokiacensis*, see Alexander (2005, 2008).

Table 1. Specific vouchers identified in the PCoA, cluster analysis, and parsimony figures.

The Map Code column identifies vouchers on the distribution maps and PCoA figures. Label data for vouchers of *A. lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus* can be found in the Taxonomic Treatment and the data for all other varieties can be found in Appendix 1. Vouchers collected by Alexander with letters in brackets (i.e. *Alexander 2367* [A]) are specific individuals on vouchers measured for the morphological analyses. Type: H=Holotype, L=Lectotype, I=Isotype, IL=Isolectotype, P=Paratype, v=type vicinity

Taxon	Type	Map Code	Herbarium	Voucher
A. lentiginosus var. *ambiguus*	H, I	B	RSA, CAS	*Ripley & Barneby 3403*
A. lentiginosus var. *ambiguus* (intermediate to var. *yuccanus*)		D	OSC, UNLV	*Alexander 2325*
A. lentiginosus var. *araneosus*	I	A	NY, ORE, GH	*Jones s.n.* from June 1880; *Jones 1807* from June 1880
A. lentiginosus var. *bryantii*	H	N	CAS	*Bryant s.n.* 15 Dec. 1939
A. lentiginosus var. *bryantii*		N_2	GH	*Holmgren et al. 15609*
A. lentiginosus var. *iodanthus*	v	J	NY, ORE	*Jones s.n.* from May 1882; *Jones 3837* from May 1882
A. lentiginosus var. *maricopae*	v	S	OSC, UNLV	*Alexander 1621* [A]
A. lentiginosus var. *maricopae*	v	S_1	OSC, UNLV	*Alexander 1621* [C]
A. lentiginosus var. *maricopae*	H	S_2	US	*Harrison 1790*
A. lentiginosus var. *mokiacensis* (putative type locality)	L, IL	L	GH, NY	*Palmer 105*
A. lentiginosus var. *mokiacensis* (published type locality)	L,IL	L_2	GH, NY	*Palmer 105*
A. lentiginosus var. *mokiacensis*		Q	NY, POM	*Jones 5058*
A. lentiginosus var. *palans*	H,I	E	POM, GH	*Eastwood s.n.* June 1892
A. lentiginosus var. *palans* (type of *A. amplexus*)	H,I	F	RM, GH	*Payson 335*
A. lentiginosus var. *palans*	P	G	GH	*Eastwood s.n.* May 1892
A. lentiginosus var. *palans*		H	NY	*Barneby 13104*
A. lentiginosus var. *palans*		H_1	NY	*Demaree 43807b*
A. lentiginosus var. *palans*		H_2	NY	*Holmgren & Holmgren 12796*
A. lentiginosus var. *palans*		H_3	NY, POM, BRY	*Jones 5218*
A. lentiginosus var. *palans*		H_4	NY	*Jones 5218a*
A. lentiginosus var. *palans*		H_5	NY	*Raven 13079*
A. lentiginosus var. *palans*		H_6	NY	*Ripley & Barneby 8662*
A. lentiginosus var. *palans*		H_7	NY	*Weber 4735*
A. lentiginosus var. *pseudiodanthus*	v	K	OSC, UNLV	*Alexander 1631*
A. lentiginosus var. *stramineus*	H,I	T	NY, GH	*Palmer s.n.* in 1870

Table 1, continued

Taxon	Type	Map Code	Herbarium	Voucher
A. lentiginosus var. *ursinus* (published type locality)	L,IL	M	GH, NY	*Palmer s.n.* 1877
A. lentiginosus var. *ursinus*		M_1	OSC, UNLV	*Alexander 2120* [A]
A. lentiginosus var. *ursinus* (Mokiak Pass elements mounted with the type by Gray)		M_2	GH	*Palmer s.n.* 1877
A. lentiginosus var. *vitreus*	H,I	U	POM, NY	*Maguire & Blood 4413*
A. lentiginosus var. *wilsonii*	v	R	OSC, UNLV	*Alexander 2367* [A]
A. lentiginosus var. *wilsonii*	v	R_2	OSC, UNLV	*Alexander 2334* [D]
A. lentiginosus var. *wilsonii* (type locality)	H,I	R_3	ND	*Wilson s.n.* from May 1893
A. lentiginosus var. *wilsonii* (population intermediate with var. *bryantii*, var. *mokiacensis*, or var. *ursinus*)		P	CAS	*Eastwood 5748*
A. lentiginosus var. *wilsonii* (population putatively intermediate to var. *palans*)		P_2	NY	*Demaree 43807*
A. lentiginosus var. *yuccanus*	H	C	POM	*Jones 3886*

cross section (podsc), pod shape in longitudinal section (podsl), pod pedicel orientation (podpo), leaf abaxial pubescence (leafab), keel length (keell), calyx teeth shape (calyxs), and pod orientation on raceme. The second axis of the PCoA explained 11.7% of the total variation. The largest correlation to the second axis was from leaf adaxial pubescence (leafad). Moderate correlations were obtained for pod stipe length (pods), calyx teeth shape (calyxs), and wing color (wingc). A scatterplot of the first two coordinates of the PCoA is shown in Figure 4.

In PAUP*, an heuristic search of 100 random addition sequences with TBR branch swapping was started with the data set of 21 morphological characters from 30 specimens of the *Palantia* and related members of *A. lentiginosus*. All 21 characters were parsimony informative. Sixteen most parsimonious trees of length 110 were recovered (HI = 0.5636; RI = 0.6416; CI = 0.4364; RC= 0.2800). Figures 5-8 are the strict consensus of trees of length 110 with major characters state changes mapped on the clades. The clades in this analysis have low support. A bootstrap analysis of 10,000 replicates resulted in only five clades having 70% or higher support (*pseudiodanthus* & *iodanthus*, clade A, 73%; *vitreus* 4413 to *yuccanus* 3886, clade B, 73%; *yuccanus* 3886 & *ambiguus* 2325, clade C, 87%; *wilsonii* 2367A & 2334D clade, 75%; *maricopae* 1621A & 1621C, clade E, 95%). Only banner color (Figure 5), pod persistence (excluding the reversal to a deciduous pod in *A. lentiginosus* var. *wilsonii, Eastwood 5748;* Figure 6), pod raceme orientation (Figure 7) and degree of pod incurve (not shown) had a high consistency with little or no character state reversals.

A dendrogram (Figure 9) of a Euclidean similarity matrix obtained from a cluster analysis showed nearly the same topology as the tree obtained from the parsimony analysis.

DISCUSSION

Outgroup selection in this study proved to be problematic. Barneby (1964) proposed that a plant similar to the small flowered *Astragalus lentiginosus* var. *salinus* (a taxon with bladdery inflated pods) was the ancestor to the members of the *A. lentiginosus* complex and that this complex was closely related to Section *Inflati* A. Gray, a large species complex with unilocular, bladdery inflated pods. Nuclear inter-transcribed spacer (ITS) DNA sequence data have shown that *A. lentiginosus* has an identical sequence to that of *A. purshii* Douglas ex Hook. (and an almost identical sequence to that of *A. utahensis* (Torr.) Torr. & A. Gray) of Section *Argophylli* A. Gray (a section composed primarily of taxa with

Table 2. List of 24 morphological characters and their abbreviations used in the 153 specimen *Palantia* PCoA. Two were constant (C: calyxd, calyxo) and not used in the PCoA, parsimony or cluster analysis. One (O: calyxs) was not used due to the finding that it was variable on the same plant (and within most calyces). For a list of character states for the characters below, see Appendix 2. Characters were coded as multistate continuous variation (R), binary state (B), or multistate (M).

1. Adaxial leaflet pubescence (Leafad) M
2. Abaxial leaflet pubescence (Leafab) M
3. Leaf and stem hair length (leafh) R
4. Leaflet number (leafn) M
5. Inflorescence length in flower (inflw) R
6. Calyx tube length (calyxl) R
7. Calyx pubescence density (calyxd) M, C
8. Calyx teeth shape (calyxs) M, O
9. Calyx teeth orientation (calyxo) M, C
10. Keel length (keell) R
11. Keel color (keelc) M
12. Banner color (bannc) M
13. Inflorescence length in fruit (infr) R
14. Pod pedicel orientation (podpo) M
15. Pod length X width ratio (podr) R
16. Pod deciduous or persistent (poddp) B
17. Pod shape, longitudinal section (podsl) M
18. Pod shape, cross section (podsc) M
19. Pod orientation on raceme (podro) M
20. Pod orientation, degree of pod incurve (podpi) R
21. Pod inflation (podin) M
22. Pod valve texture (podt) M
23. Pod pubescence (podpu) M
24. Pod valve color (podvc) M

scarcely inflated, unilocular, leathery, deciduous pods), and not to members of Section *Inflati* (4-6 base pair divergence; Alexander, unpublished data, Wojciechowski et al. 1993, 1999). The ITS sequence data suggest that a deciduous, unilocular, leathery, scarcely inflated pod is the putative ancestral state in this complex. Based, in part, on these data, members of Section *Argophylli* were used as outgroups for chloroplast haplotype analyses in Knaus (2008). Taxa in other putatively closely related sections (Section *Monoenses* Barneby, Section *Cystiella* Barneby, Section *Circumdati* (M.E. Jones) Barneby, or Section *Platytropides* Barneby; all of which have taxa with inflated pods) have not been fully investigated in molecular analyses. The selection of any member of Section *Argophylli* as an outgroup automatically polarizes the ancestral state of the group as a unilocular or partially bilocular, scarcely inflated, deciduous pod. In addition, haplotypes within the *Argophylli* sampled by Knaus (2008) were found to be nearly twenty steps more distant from the haplotypes examined in the *Palantia*. Finding that *A. lentiginosus* var. *iodanthus* and *A. lentiginosus* var. *pseudiodanthus* (both of which have been universally delimited as species until Alexander 2009), are not highly genetically or morphologically distinct from *A. lentiginosus* is a problem for outgroup selection in this study, primarily with the parsimony analysis and the genetic analyses (Alexander & Liston, in prep). The terminal taxa in this study are also not recognized at the species level, which violates assumptions in parsimony analyses. As a result, robust phylogenetic conclusions cannot be made with these data.

Instead, the cladistic analyses were used to investigate patterns of character state changes within the *Palantia*. *Astragalus lentiginosus* var. *iodanthus*, and *A. lentiginosus* var. *pseudiodanthus* were selected as outgroups based on their relatively greater genetic and morphologic distance from the *Palantia* based on the results from Alexander (2008), Knaus (2008), and Alexander & Liston (in prep). Even if the inflated varieties related to *A. lentiginosus* var. *yuccanus* were used as outgroups for the *Palantia*, the morphological trends discussed herein would not change (see Figures 5-8) since the major clades of the *Palantia* would still be split in two clades. More thorough molecular analyses of species potentially closely related to Section *Diphysi* (with both inflated and scarcely inflated pods) are needed before a robust molecular and morphological phylogenetic study, with a satisfactory outgroup, can be attempted.

Despite this, conclusions of the taxonomic status of *Astragalus lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus* can be made. The results of the PCoA analyses and the genetic analyses (Alexander & Liston, in prep) indicate that species level delimitations for many of the *Palantia* have much weaker support than previously thought by Alexander (2005). *Astragalus*

Table 3. Results of the 153 specimen *Palantia* PCoA. This analysis used 21 variable characters. Each is listed in the Kendall rank correlations below.

Eigenvalues

	1	2
	1.36	0.72

Percent of Total Variance Explained

	22.06	11.75

Kendall rank correlations and probabilities
(between PCoA coordinates and morphological characters, significance of $p<0.01$ **)**

	Coordinate 1			**Coordinate 2**	
Character	**Coor.**	**p**	**Character**	**Coor.**	**p**
podro	-0.74199	1.53E-43	podpu	0.44149	1.83E-16
podpi	-0.6441	3.11E-33	leafab	0.42442	2.48E-15
podpo	-0.61511	1.86E-30	podsc	-0.39081	3.15E-13
bannc	0.45194	3.52E-17	podin	0.35769	2.55E-11
poddp	0.38672	5.53E-13	infr	0.26397	8.54E-07
infw	0.34604	1.10E-10	poddp	0.19461	0.000284
keelc	0.3342	4.60E-10	podpo	0.19041	0.000384
podpu	0.25695	1.65E-06	leafad	0.18968	0.000404
leafad	-0.18824	0.000448	podr	0.18246	0.000668
podsl	0.18605	0.000522	leafh	-0.18197	0.000691
podvc	0.18153	0.000711	podro	0.17445	0.001141
infr	0.16137	0.002618	bannc	-0.15075	0.004936
podsc	-0.1608	0.002713	leafn	-0.11294	0.035197
podr	0.15021	0.005092	podpi	0.11117	0.038165
leafab	-0.14858	0.005593	keell	-0.09653	0.071838
podt	0.14735	0.006002	inflw	0.058972	0.27146
podin	0.10765	0.044697	podsl	-0.05458	0.30878
leafn	0.084548	0.11488	podt	-0.03684	0.49213
leafh	0.047053	0.38024	calyxl	-0.03251	0.54434
calyxl	0.02045	0.70294	podvc	-0.01985	0.71124
keell	-0.01187	0.82477	keelc	-0.00504	0.92517

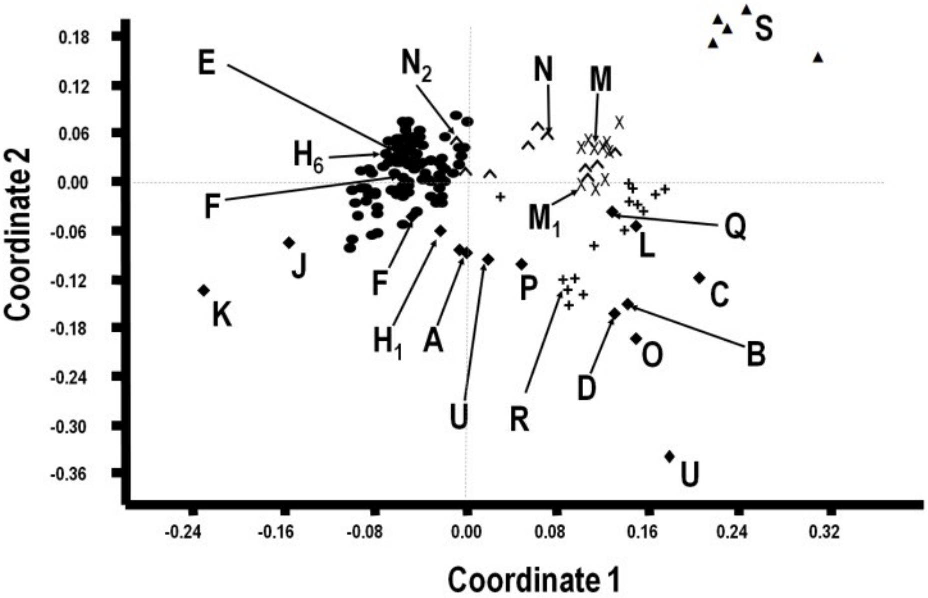

Figure 3. Scatterplot of the 153 specimens *Palantia* PCoA using 21 variable, morphological characters. The first and second axes represent 33.5% of the variation. Taxa are labeled as: (circle), *Astragalus lentiginosus* var. *palans* including the Cameron, Arizona specimens; (caret), *A. lentiginosus* var. *bryantii*; (upward triangle), *A. lentiginosus* var. *maricopae*; (**X**), *A. lentiginosus* var. *ursinus*; (+), *A. lentiginosus var. wilsonii* including South Rim, Arizona specimens. Relevant specimens of these and other taxa (diamonds) are labeled with letters. Table one contains the legend of letter codes used for specific vouchers shown.

Table 4. List of 12 morphological characters from the 43 specimen *Astragalus lentiginosus* var. *mokiacensis* PCoA. This analysis used a modified version of the data used in Alexander (2005). For a list of character states for character below, see Appendix 2. Characters were coded as multistate continuous variation (R), binary state (B), or multistate (M).

1. Adaxial leaflet pubescence (leafad) M
2. Abaxial leaflet pubescence (leafab) M
3. Calyx tube length (calyxl) R
4. Calyx teeth shape (calyxs) M
5. Keel length (keell) R
6. Wing color (wingc) M
7. Pod length X width ratio (podr) R
8. Pod pedicel orientation (podpo) M
9. Pod shape, longitudinal section (podsl) M
10. Pod shape, cross section (podsc) M
11. Pod orientation on raceme (podro) M
12. Pod stipe length (pods) R

lentiginosus var. *maricopae, A. lentiginosus* var. *mokiacensis*, and *A. lentiginosus* var. *ursinus*, all with persistent pods (an otherwise dependable species-level character in *Astragalus* according to Barneby 1964), were confirmed to be closely related to varieties of *A. lentiginosus* with deciduous pods (*A. lentiginosus* var. *palans* and *A. lentiginosus* var. *wilsonii*). A haplotype network derived from an analysis of chloroplast microsatellites (Alexander & Liston, in prep) shows *A. lentiginosus* var. *maricopae* is neither highly genetically differentiated from *A. lentiginosus* var. *palans*, *A. lentiginosus* var. *wilsonii*, nor *A. lentiginosus* var. *ursinus*. *Astragalus lentiginosus* var. *ursinus* was found to be more genetically similar to the long distance disjunct, *A. lentiginosus* var. *wilsonii*, than to its geographically proximal relative, *A. lentiginosus* var. *mokiacensis* (Alexander 2008, Alexander & Liston, in prep).

Though *Astragalus lentiginosus* var. *maricopae* is not highly genetically differentiated from its geographically nearest relative, *A. lentiginosus* var. *wilsonii*, it is distinct morphologically. The PCoA analysis shows that the specimens of *A. lentiginosus* var. *maricopae* form a morphologically distinct group away from *A. lentiginosus* var. *mokiacensis*, *A. lentiginosus* var. *wilsonii*, and *A. lentiginosus* var. *ursinus*. The distance is not farther than *A. lentiginosus* var. *pseudiodanthus* is from the larger cluster of *A. lentiginosus* var. *palans*. Also, the inflated members of *A. lentiginosus* sampled (see Figure 3: *A. lentiginosus* var. *araneosus*, A; versus *A. lentiginosus* var. *stramineus,* T) in this study are also spread an equivalent distance apart. The presence of a yellow flower and cylindrical pods contributed highly to the *A. lentiginosus* var. *maricopae* group. Though the flower color of *A. lentiginosus* var. *maricopae* was reported by Barneby (1964) to be ochroleucous in the type description, field observations in 2005 and 2006 revealed that the flower is yellow to light yellow in color, but not as deep a yellow as that found in European *Astragalus*, *Thermopsis*, or *Trifolium*. Ochroleucous flowers in *Astragalus* tend to have a cream tint and dry a whitish-tan, or tend to be distinctly white, basally, and grade to a yellowish tint, apically, especially in age. The flower color, the distinctiveness of the pod morphology, and the range disjunction could be utilized as support for a species-level delimitation for this taxon. However, *A. lentiginosus* var. *maricopae* is not the only variety in this complex with yellowish flowers. Though some individuals of the southern California endemic, *A. lentiginosus* var. *nigricalycis* M.E. Jones, seem to have creamish to greenish-white flowers, most have yellow flowers that dry to a darker yellow in age. Also, *A. lentiginosus* var. *bryantii* has pods that are narrower, longer, and more tubular than those in *A. lentiginosus* var. *maricopae* (see the taxonomic treatment below for more specific morphological differences). When considering both the genetic and morphological data, *A. lentiginosus* var. *maricopae* is just one of several taxa at the extreme edge of the range of variation in *A. lentiginosus* and one of the most morphologically distinct varieties in the *Palantia*.

In contrast*, Astragalus lentiginosus* var. *ursinus* is genetically distinct from its nearest relative, *A. lentiginosus* var. *mokiacensis* (Alexander 2008, Alexander & Liston, in prep). The two are, however, much more sim-

Table 5. Results of 43 specimen *Astragalus lentiginosus* var. *mokiacensis* PCoA. This analysis used 12 variable characters. Each is listed in the Kendall rank correlations below.

Eigenvalues					
	1	2			
	1.78	0.43			
Percent of Total Variance Explained					
	48.4	11.69			
Kendall rank correlations and probabilities (between PCoA coordinates and morphological characters, significance of $p<0.01$ **)**					
	Coordinate 1			**Coordinate 2**	
Character	**Coor.**	**p**	**Character**	**Coor.**	**p**
podsc	0.70279	3.10E-11	leafad	0.64461	1.12E-09
podsl	0.63309	2.19E-09	pods	-0.46988	8.98E-06
podpo	-0.62722	3.08E-09	calyxs	-0.42388	6.18E-05
leafab	-0.59087	2.35E-08	wingc	-0.40029	0.000155
keell	0.56143	1.12E-07	calyxl	0.3434	0.001174
calyxs	0.51427	1.17E-06	keell	0.28243	0.007607
podro	0.50395	1.91E-06	podr	-0.20812	0.049202
leafad	-0.44579	2.52E-05	leafab	0.14938	0.15805
wingc	-0.41754	7.95E-05	podsl	-0.11041	0.29678
calyxl	0.40494	0.00013	podro	0.089105	0.39975
podr	0.38362	0.000289	podpo	0.00618	0.95343
pods	0.31768	0.002681	podsc	0.009412	0.92912

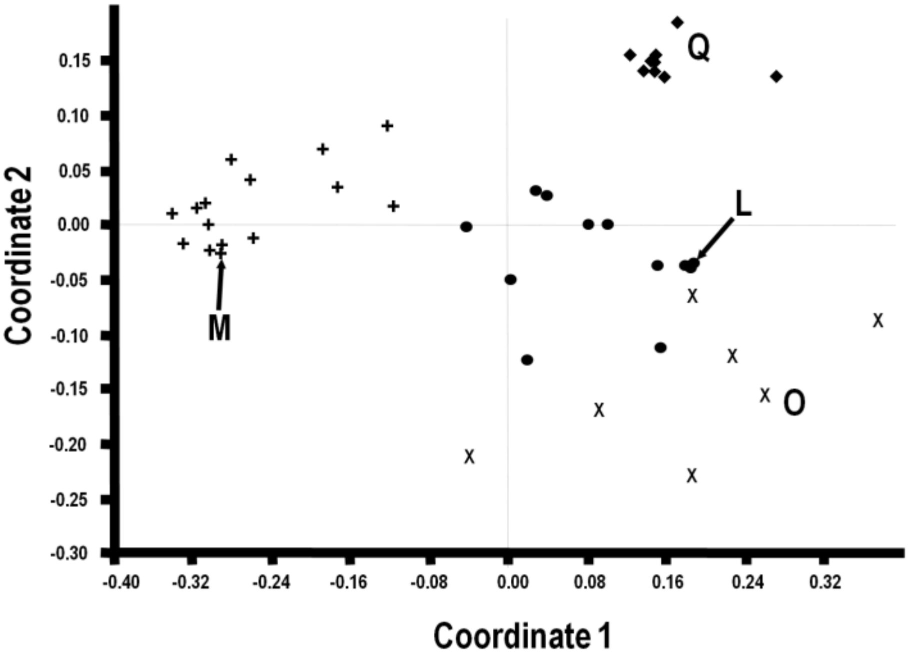

Figure 4. Scatterplot of the 43 specimen, *A. lentiginosus* var. *mokiacensis* PCoA using 12 variable, morphological characters. The first and second axes represent 60.1 % of the variation. Taxa and variants are labeled as: (circle) *mokiacensis* minor variant; (X) *trumbullensis* minor variant; (diamond) Gold Butte minor variant; (+) *A. lentiginosus* var. *ursinus* (See Table 1 for the legend of letter codes used for specific vouchers shown). For a taxonomic treatment of the morphological variants shown herein for *A. lentiginosus* var. *mokiacensis*, see Alexander (2005, 2008).

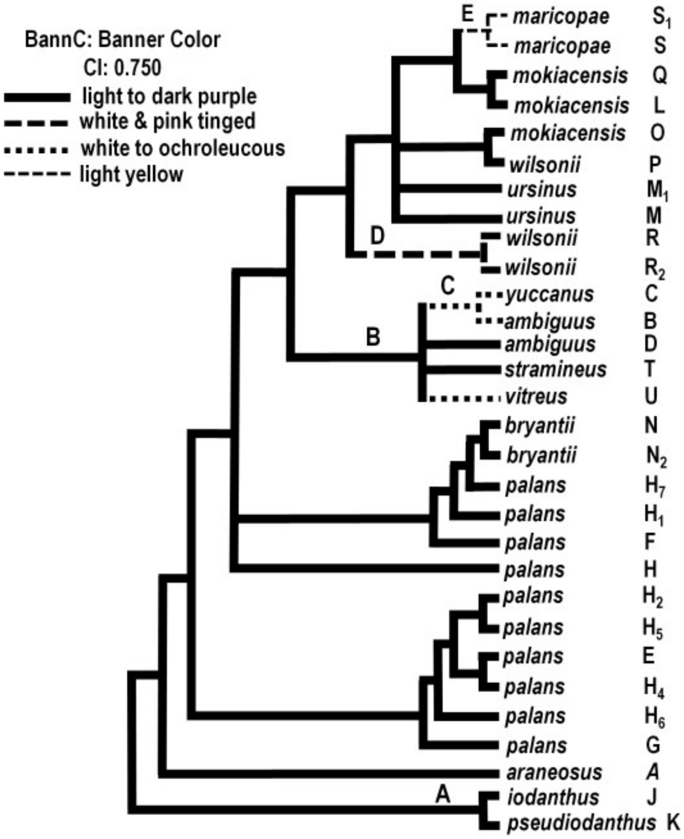

Figure 5. Strict consensus of 16 most parsimonious trees of length 110 showing banner color (bannc) character state changes. The letters above branches are the only highly supported clades in the tree (above 70% bootstrap support; see the results section for values for each of these lettered clades). Table 1 contains the legend of letter codes used for specific vouchers shown to the right of the taxon labels.

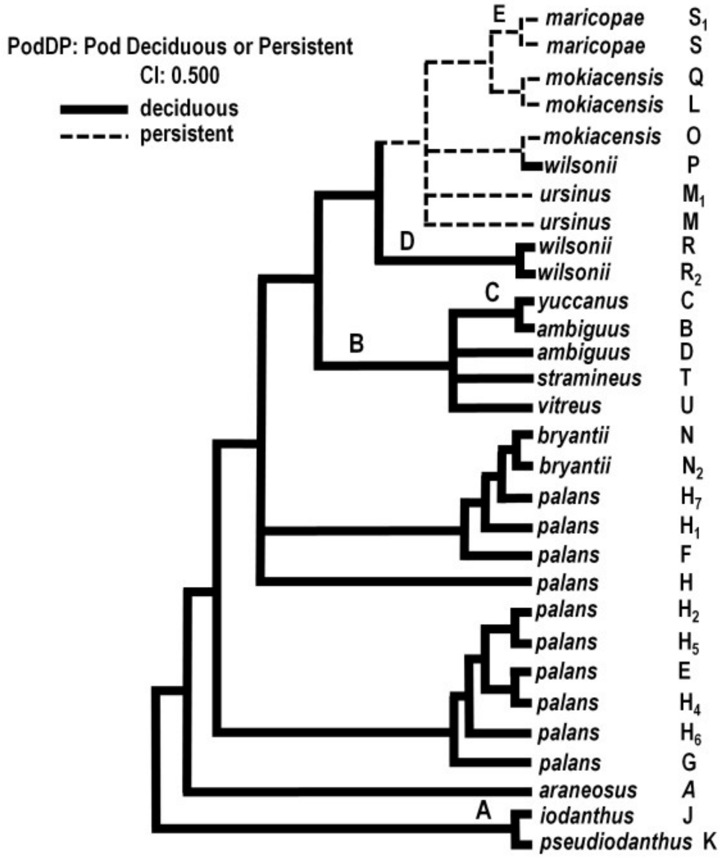

Figure 6. Strict consensus of 16 most parsimonious trees of length 110 showing pod deciduous or persistent (podpd) character state changes. The letters above branches are the only highly supported clades in the tree (above 70% bootstrap support; see the results section for values for each of these lettered clades). Table one contains the legend of letter codes used for specific vouchers shown to the right of the taxon labels.

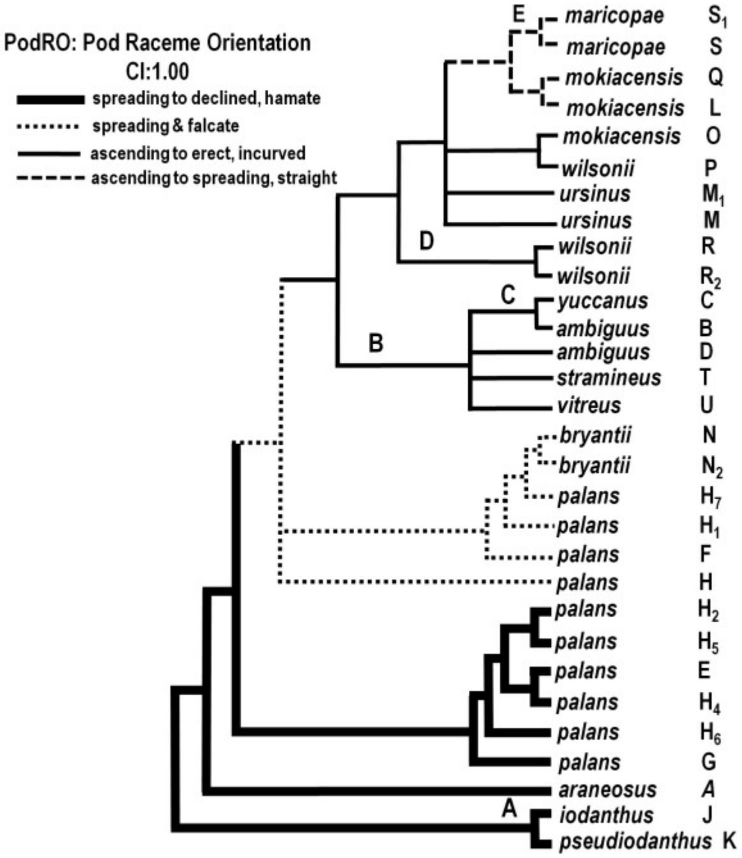

Figure 7. Strict consensus of 16 most parsimonious trees of length 110 showing pod raceme orientation (podro) character state changes. The letters above branches are the only highly supported clades in the tree (above 70% bootstrap support; see the results section for values for each of these lettered clades). Table one contains the legend of letter codes used for specific vouchers shown to the right of the taxon labels.

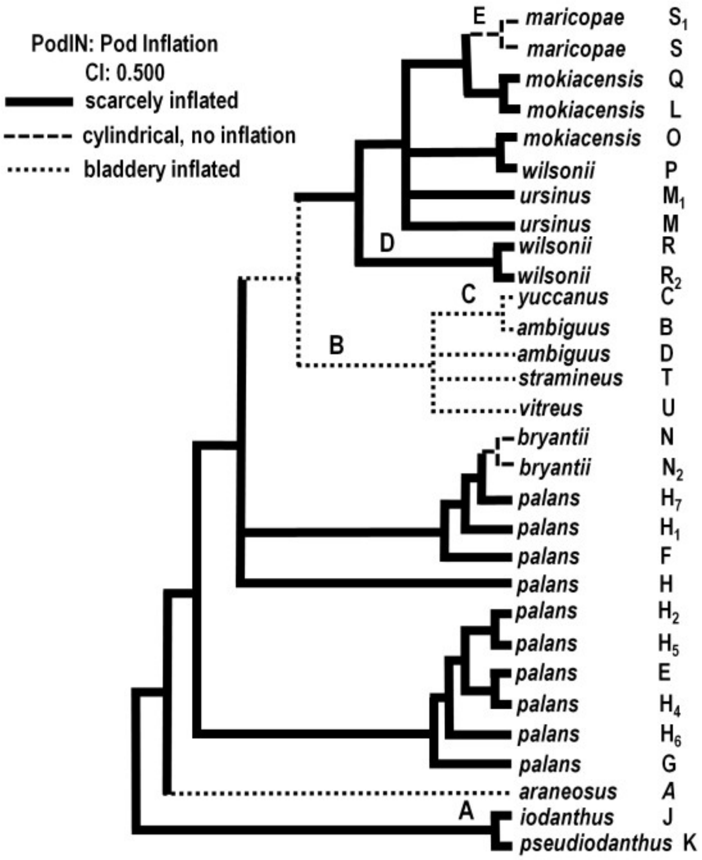

Figure 8. Strict consensus of 16 most parsimonious trees of length 110 showing pod inflation (podin) character state changes. The letters above branches are the only highly supported clades in the tree (above 70% bootstrap support; see the results section for values for each of these lettered clades). Table one contains the legend of letter codes used for specific vouchers shown to the right of the taxon labels.

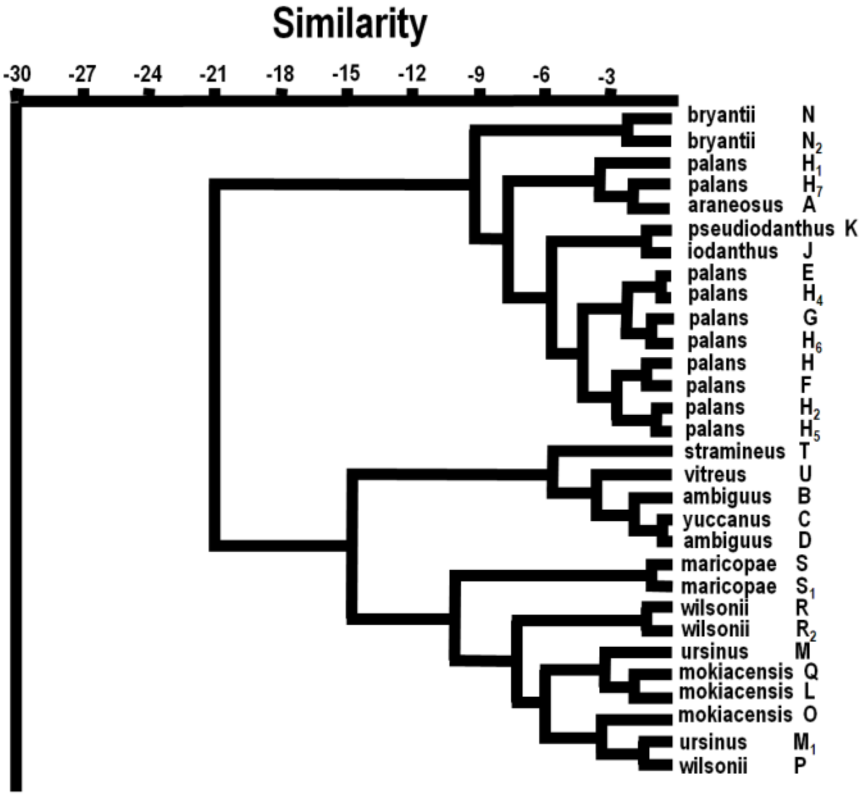

Figure 9. Cluster analysis dendrogram of the morphological data from 30 specimens of the *Palantia* based on a Euclidean distance matrix calculated by PAST ver. 1.76. Table one contains the legend of letter codes used for specific vouchers shown to the right of the taxon labels.

ilar morphologically than *A. lentiginosus* var. *maricopae* is to *A. lentiginosus* var. *wilsonii.* The morphological similarity and geographic proximity of *A. lentiginosus* var. *mokiacensis* and *A. lentiginosus* var. *ursinus* (the nearest populations are at least 20 km apart in adjacent mountain ranges) has been the primary evidence for placing them into the same taxon in the latest monograph (Welsh 2007). The morphological distinctiveness of *A. lentiginosus* var. *ursinus* is subtle, but it is, nevertheless, present. In the *A. lentiginosus* var. *mokiacensis* PCoA analysis, specimens of *A. lentiginosus* var. *ursinus* appear to grade into the specimens of *A. lentiginosus* var. *mokiacensis* (including the type specimens of *A. lentiginosus* var. *trumbullensis*). The parsimony and cluster analyses also show *A. lentiginosus* var. *ursinus* in the same region of the tree as *A. lentiginosus* var. *mokiacensis*. However, *A. lentiginosus* var. *ursinus* does not share haplotypes with *A. lentiginosus* var. *mokiacensis*. It shares the most haplotypes with *A. lentiginosus* var. *wilsonii* (Alexander & Liston, in prep). Based on the lack of shared haplotypes with *A. lentiginosus* var. *mokiacensis* and a trend toward smaller pods and flowers (see the taxonomic treatment below for more specific morphological differences), *A. lentiginosus* var. *ursinus* is recognized herein at the varietal level following the delimitation proposed by Barneby (1945, 1964).

Taxonomic Treatment

The taxonomic revision herein is a first step in a full monograph of the *Astragalus lentiginosus* complex. As such, the specimens used in the morphological analysis are labeled in a separate voucher list. Where applicable, a list of specimens examined by the author but not yet included in morphological analyses is also included. Species delimitations in the taxonomic revision follow a phenetic species concept (Sokal, 1973; Luckow 1995). The original goal of this study was to apply a phylogenetic species concept, however, the genetic and morphologic data obtained could not be analyzed robustly using cladistic methodologies. Primarily, population level data are largely ignored since the smallest taxonomic units of phylogenetic analyses are species (Nixon & Wheeler 1990, Cracraft 1983, Luckow 1995). Table 1 is a list of notable specimens identified in maps in this revision. Following the key are complete taxonomic treatments for *A. lentiginosus* var. *maricopae* and *A. lentiginosus* var. *ursinus*. Treatments for the other taxa in the key can be found in Alexander (2008).

Key to the *Palantia* and related varieties of *Astragalus lentiginosus*

1. Pod, in longitudinal section, linear, lanceolate, oblong, or elliptic, the shape cylindrical and not inflated or ventricose and scarcely inflated dorsally or laterally, the valves stiffly papery to coriaceous, bilocular, semi-bilocular, or sub-unilocular, the septum to 2.5 mm wide and not fused to the funicular flange.

  2. Pods long-persistent, sessile on a minute boss on the receptacle or contracted at the base into an incipient stipe 0.4 to 0.7 (1.0) mm long.

    3. Banner light yellow, without a central white or striped spot (immaculate); keel slightly darker than the banner, drying yellowish brown and immaculate; wings slightly darker than the banner, drying yellowish brown. ……………………………………………………………………………..*A. lentiginosus* var. *maricopae*

    3. Banner light to dark purple with a white & purple striate central spot; keel light purple & dark purple maculate; wings light to dark purple, sometimes with white tips.

      4. Pods straight or slightly incurved, 20-28 (-32) mm long, 4-7.1x longer than wide, the pedicel ascending or spreading, straight or curved; leaflets glabrous to moderately pubescent adaxially, at least sparsely pubescent abaxially; [=*A. mokiacensis*, *A. lentiginosus* var. *trumbullensis*]……………………………… ……………………………………………………………………………*A. lentiginosus* var. *mokiacensis*

      4. Pods incurved, 13-20 (-23) mm long, 2.4-4.7x longer than wide; the pedicel ascending or erect, straight or curved; leaflets glabrous adaxially, glabrous or sparsely pubescent abaxially; [=*A. ursinus*] ………. ……………………………………………………………………………………*A. lentiginosus* var. *ursinus*

  2. Pods deciduous (sometimes tardily so) by a cellular abscission layer between the receptacle and gynoecium, sessile on a minute boss on the receptacle or contracted at the base into an incipient stipe or gynophore 0.3 to 0.5 (0.7) mm long.

    5. Pods semi-bilocular to nearly bilocular, the septum 1-2.5 mm wide, the body incurved 120-180°, incurved less than 90°, or straight, the valves in cross section cordate, obcordate, or terete, in longitudinal section elliptic, linear, or oblong.

      6. Pods falcate to hamate (nearly circular), occasionally lunate, incurved to 120-180°, the pedicel deflexed or declined……………………………………………………………………. *A. lentiginosus* var. *palans*

      6. Pods lunate to falcate, incurved less than 90° to nearly straight, the pedicel erect, ascending, or spreading.

7. Pods spreading, 6-8.8 times longer than wide, incurved less than 90°, the valves stiff papery, in longitudinal section linear or narrowly oblong……………………………….*A. lentiginosus* var. *bryantii*

7. Pods ascending to erect, 4-6 times longer than wide, incurved less than 90° or nearly straight, the valves leathery to thick leathery (subligneous), often with prominent reticulate veins, in longitudinal section narrowly elliptic or oblong …………………………………….*A. lentiginosus* var. *wilsonii*

5. Pods semi-bilocular to sub-unilocular, the septum to 1.5 mm wide, the body incurved to 180° (in most individuals nearly circular), the valves in cross section oblong, obcordate, or triangular, in longitudinal section narrowly elliptic, lanceolate, or linear.

8. Stems arising from a superficial root-crown; herbage glabrous to strigulose, rarely villosulous with hairs to 1.0 mm long; habitat various; [=*A. iodanthus*] ……………………*A. lentiginosus* var. *iodanthus*

8. Stems arising from a subterranean root-crown; herbage densely villous to villosulous with hairs 0.7-1.2 mm long; habitat sandy pockets of alluvial fans and stabilized dunes; [=*A. pseudiodanthus*] ……….. ……………………………..………………………………. *A. lentiginosus* var. *pseudiodanthus*

1. Pod, in longitudinal section, ovoid to globose, the shape terete to didymous, bladdery inflated, the inflation dorsiventrally and laterally, or bladdery-ventricose and the inflation greater dorsally and laterally than ventrally, the valves papery membranous to stiffly papery (occasionally coriaceous), bilocular, the septum over 2 mm wide and weakly fused to the

1. *Astragalus lentiginosus* var. *maricopae*

Astragalus lentiginosus var. *maricopae* Barneby, Leafl. W. Bot. 4:140. 1945.

TYPE: U.S.A. ARIZONA: MARICOPA CO.: roadside near Tempe, 4 May 1926, *G.J. Harrison 1790* (HOLOTYPE: US!). Map: Figure 1.

Short lived perennial herbs, 3-8 dm tall; stems ascending, single or several in clumps from a superficial root crown; herbage glabrous to sparsely strigulose with basifixed hairs; stipules 3-8 mm long, ovate-, lance- or deltoid-acuminate, mostly recurved, partially or fully amplexicaul-decurrent, none connate; leaves 6-16 cm long; leaflets 15-23 (25), ovate, suborbicular, or obovate, the apex obtuse or emarginate, 5-22 mm long; peduncles erect, 5-14 cm long; racemes 13-30 (35) flowered, early elongating, flowers ascending to spreading, the axis becoming (3) 5-12 (20) cm long in fruit; calyx 7-9 mm long, white-, black-strigulose or mixed, the campanulate or cylindric tube 4.5-5.5 (6.5) mm long, the teeth, subulate to lance-acuminate, 1-2.5 mm long; petals light lemon yellow, drying ochroleucous to brownish; banner 14-16.5 mm long; keel (10) 11-13 mm long, immaculate; wings 12-15 mm long, whitish with light lemon yellow tip; ovary glabrous; ovules 22-26; fruiting pedicels persistent, ascending or spreading, straight or curved; pod persistent, ascending or spreading, straight or incurved less than 90, in longitudinal section linear or narrowly oblong, in cross section cordate or terete, (17) 19-23 x 3-4 mm, 5-6 (6.2)x longer than wide, sessile on a minute boss on the receptacle or contracted at the base into an incipient stipe to 0.5 mm long, the valves thinly fleshy, becoming coriaceous, stramineous, semi-biloculate to nearly biloculate (but not fused to the funicular flange), the septum 1.5-2 mm wide, the beak unilocular; dehiscence apical, through the beak while still attached to the raceme.

Habitat. In mixed shrub communities, in sandy, gravely washes (sometimes among boulders) derived from Precambrian granites and Tertiary volcanic rocks.

Distribution. In northern Maricopa County, found in the foothills and alluvial fans in vicinity of Cave Creek, Fish Creek, Scottsdale, and Tempe; to be expected in the foothills and alluvial fans from Scottsdale and Tempe east to the mountains along both sides of the Verde River drainage, southward to its confluence with the Salt River, and west to the alluvial fans in the vicinity of Saguaro Lake (see *Lehto 510* from 1962 below).

Phenology. Flowering from February - April; fruiting from April - June.

Astragalus lentiginosus var. *maricopae* has been largely overlooked by most botanists since it was first described in 1945. Based on similar floral morphology, is has been confused with *A. lentiginosus* var. *yuccanus*. On the valley floor and alluvial fans northeast of Phoenix, Scottsdale, and Tempe, this taxon has become very rare (and nearly extirpated throughout its historically known range) due to extensive suburban housing and golf course development. The population sampled for molecular analysis in the vicinity of Scottsdale has already been developed, since home construction was well underway when the samples were collected. This variety is the most unique morphologically, and the most endangered of all the *Palantia*.

Voucher specimens examined for the morphologic analysis. USA. ARIZONA: MARICOPA CO.: west of intersection of Westland Drive and Pima Rd, Scottsdale, February 2005 (fl, fr), *Alexander 1621* [individuals A, C, D, E] (OSC, UNLV); along Horseshoe Dam Rd, 0.5 mi below dam, 02 March 1989 (fl), *C.L. Jones 5*, (GH, NY, RSA)

Voucher specimens examined (to be included in future morphological analyses). U.S.A. ARIZONA:

MARICOPA CO.: 10 mi E of Scottsdale rd, 27 mi NE of Scottsdale, 24 March 1960 (fl, imm fr), *Crosswhite et al 496* (NY); Scottsdale rd, between Bell Rd & Carefree, 27 April 1974 (fl, fr), *Engard et al. 203* (NY); 26 mi NE of Scottsdale along Hwy 87, 28 March 1973 (fl), *Higgins 6445* (NY); Hwy 87, 2.7 mi SW of Saguaro Lake, 14 April 1962 (fl, fr), *Lehto 510* (NY); Cave Creek, 23 April 1977 (fl, fr), *Lehto 21306* (NY); Carefree, 23 April 1977 (fl, fr), *Lehto 21308* (NY).

2. *Astragalus lentiginosus* var. *ursinus*

Astragalus lentiginosus var. *ursinus* (A. Gray) Barneby, Leafl. West. Bot. 4: 133. 1945. *Astragalus ursinus* A. Gray, Proc. Am. Acad. Arts Sci. 13: 367. 1878. *Tium ursinum* (A. Gray) Rydb., N. Amer. Fl. 24: 398. 1929. TYPE: U.S.A. ARIZONA OR UTAH: MOHAVE CO. OR WASHINGTON CO.: Beaver Dams [west slope of Beaver Dam Mountains, the type locality was erroneously published by Gray as Bear Valley, Iron Co., Utah], 20-28 Apr 1877, *E. Palmer s.n.* (LECTOTYPE: GH, designated by Alexander, in prep; ISOLECTOTYPE: K). Map: Figure 2.

Perennial herbs, 2-4 dm tall; stems erect and ascending in clumps from a superficial root crown; herbage glabrous to sparsely strigulose with basifixed hairs; stipules 3-8 mm long, triangular- or deltate-acuminate, mostly reflexed, partially or fully amplexicaul-decurrent, none connate; leaves 2-9 cm long; leaflets 11-17 (19), suborbicular, obovate, or oblong, the apex obtuse or emarginate, 5-11 mm long; peduncles erect, 4-10 cm long; racemes 7-15 (20) flowered, early elongating, flowers ascending, the axis becoming 3-9 (-11) cm long in fruit; calyx 4-8 mm long, white-, black-strigulose or mixed, the campanulate or cylindric tube 3-6 mm long, the teeth deltate, subulate to lance-acuminate, 0.8-3 mm long; petals pink purple, drying violet; banner 12-16 mm long, purple with a white, purple striate spot; keel 8.5-13 mm long, light to dark purple maculate; wings 10.5-16 mm long, purple with dark purple tip or purple with a white tip; ovary glabrous or sparsely strigulose; ovules 22-24; fruiting pedicels persistent, erect or ascending, straight or curved; pod long-persistent, erect or ascending, in longitudinal section oblong or narrowly elliptic, in cross section cordate or terete, straight or incurved less than 90°, 10-23 x 4-5 mm, 2.4-4.7x longer than wide, sessile on a minute boss on the receptacle or contracted at the base into an incipient stipe to 0.7 (1.0) mm long, the valves thinly fleshy, becoming coriaceous, stramineous to reddish, semi-biloculate to nearly biloculate (but not fused to the funicular flange), the septum 2-2.5 mm wide, not extended into the beak, the ventral suture sometimes prominent, the beak unilocular; dehiscence apical, through the beak while still attached to the raceme.

Habitat. In mixed shrub communities with *Larrea* and *Yucca brevifolia*, in gravely washes and talus slopes derived from the Permian Kaibab Formation (limestone), Toroweap Formation (limestones and sandstones), Hermit Formation (sandstones and siltstones), Queantoweap Sandstone, Permian-Pennsylvanian Callville Limestone, and Mississippian Redwall Limestone; with *Penstemon petiolatus* and other limestone crevice species on limestone cliffs of various Paleozoic limestones, especially the Kaibab Formation and Callville Limestone.

Distribution. Washington Co., Utah, in the southern end of the Beaver Dam Mountains in the vicinity of Bulldog Knolls and Bulldog Canyon, north to Cedar Pockets Wash on the slopes of the peak south of Jarvis Peak; in adjacent Mohave Co., Arizona, south to the mouth of the Virgin River Gorge, and Hedricks Canyon in the Virgin Mountains; to be looked for in the vicinity of Mokaac Mountain, Wolf Hole Mountain, Quail Canyon or Quail Hill on the northern edge of the Shivwits Plateau, Mohave Co., Arizona.

Phenology. Flowering from March - April; fruiting from April - May.

The type collections of *Astragalus ursinus* are a drought depauperate, limestone crevice form of *A. lentiginosus* var. *ursinus.* The depauperate morphology of the types, especially with respect to the small flower size, has contributed to a perennial fog of confusion surrounding this variety's taxonomic relationships. It is only slightly differentiated morphologically from *A. lentiginosus* var. *mokiacensis* and imperfectly distinguished from some *A. lentiginosus* var. *mokiacensis* populations in habitat preference (with respect to the small number of plants per population growing within limestone crevices only). Both varieties have populations that inhabit limestone talus slopes below cliff faces. The genetic analysis (Alexander 2008, Alexander & Liston, in prep) shows that *A. lentiginosus* var. *ursinus* is distinct from *A. lentiginosus* var. *mokiacensis* and more closely related to *A. lentiginosus* var. *palans* and *A. lentiginosus* var. *wilsonii.* Additionally, *Astragalus lentiginosus* var. *ursinus* and *A. lentiginosus* var. *wilsonii* are the only two members of the *Palantia* with erect to ascending fruiting pedicels and erect to ascending, incurved to nearly straight pods.

Of further note, Alexander (2005) cites the lectotypifications for *Astragalus mokiacensis* and *A. ursinus* as being published in Taxon. However, these two lectotypifications have not yet been published due to technical circumstances beyond the author's control. The citation of the lectotype above should not be considered the formal lectotypification of *Astragalus ursinus.*

Voucher specimens examined for the morphological analysis. U.S.A. ARIZONA OR UTAH: MOHAVE CO. OR WASHINGTON CO.: Beaver Dams [Beaver

Dam Mountains, mislabeled as Bear Valley and Beaver Valley by Gray], 20-28 Apr 1877 (fl, fr), *Palmer s.n.* (GH, K*)*. ARIZONA: MOHAVE CO.: Virgin Narrows about 5 mi NE of Littlefield, 2 Jun 1977 (fl, fr), *Gierisch 3954* (BRY, NY); Hedricks Canyon [Virgin Mountains], T40N R15W S23, 2 Apr 1981 (fl, imm fr), *Gierisch & Morgart 4824* (BRY, NY). UTAH: WASHINGTON CO.: Beaver Dam Mountains, Bull Dog Canyon, 25 Apr 2003 (fr), *Alexander 1388* (OSC, UNLV), 6 May 2005 (fl,fr), *Alexander 2120* (OSC,UNLV), 6 May 2005 (fl, fr), *Alexander 2121* (OSC,UNLV), 6 May 2005 (fl, fr), *Alexander 2127* (OSC,UNLV); Bulldog Knolls, 6 May 2006 (fl, fr), *Alexander 2132* (OSC,UNLV), 6 May 2006, *Alexander 2134* [individuals A,B,C] (OSC, UNLV), 6 May 2006 (fl, fr), *Alexander 2135* (OSC, UNLV); Bull Dog Knolls, S slope of S knoll, T43S R18W S28, 1097 m, 21 Apr 1986 (fl, fr), *Baird 2324* (BRY); Bulldog Knolls, north knoll, T43S R18W S21, 341 m, 28 Mar 1986 (fl, imm fr), *Higgins & Barnum 16267* (BRY, NY); Bulldog Canyon, Beaver Dam Mountains, W slope, T43S R18W S26, 381 m, 15 Apr 1983 (fl, fr), *Neese & Welsh 13062* (BRY, NY); Cedar Pockets wash, along a sequential drainage, T43S R17W S20, 1219 m, 5 May 1986 (fr), *Welsh & Atwood 23742* (BRY).

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APPENDIX 1

List of vouchers used in morphometric analyses not cited in the Taxonomic Revision

Note: All vouchers listed herein have been seen by the author. The "!" designation is not used herein as a result.

***Astragalus lentiginosus* var. *ambiguus* Barneby** U.S.A. ARIZONA: MOHAVE CO.: Peach Springs, 11 May 1941, *Ripley & Barneby 3403* (RSA).

***Astragalus lentiginosus* var. *araneosus* (Sheld.) Barneby** U.S.A. UTAH: MILLARD CO.: Frisco, June 1880, *Jones 1807* [June 1880, *Jones s.n.*, interpreted herein as an isotype] (NY, ORE, GH).

***Astragalus lentiginosus* var. *bryantii* (Barneby) J.A. Alexander** U.S.A. ARIZONA: COCONINO CO.: head of Phantom Canyon in Grand Canyon, 15 December 1939, *Bryant s.n.* (CAS); 10 yds N of Colorado River, 11 mi S of Phantom Ranch, directly N of Grand Canyon Village, 11 April 1960, *Crosswhite 642* (NY); at mouth of Hermit Creek, in sand, Grand Canyon of the Colorado River, 10 April 1917, *Eastwood 5991* (GH); "Utah Flat", Grand Canyon N.P., ca. 0.83 mi NW of Phantom Ranch and Bright Angel Creek, 09 April 1993, *Hodgson & Anderson 2085* (NY); Colorado River, Bass Rapids, 108 miles below Lees Ferry, 01 May 1971, *Holmgren, et al. 15502* (NY); Colorado River, Grand Canyon near confluence of Clear Creek, 3.5 miles upriver from Kaibab Suspension Bridge (near Phantom Ranch), 1 mile up Clear Creek Canyon, 08 May 1971, *Holmgren, et al. 15609* (GH, NY); Colorado River, Grand Canyon, Shinumo Creek, 108.5 river mi below Lees Ferry, 17 air mi NW of Grand Canyon Village, 10 May 1971, *Holmgren, et al. 15615* (NY); Grand Canyon N.P., at confluence of Bright Angel Creek and Colorado River, 20 March 1968, *Spellenberg 1826.*

***Astragalus lentiginosus* var. *iodanthus* (S. Watson) J.A. Alexander** U.S.A. NEVADA: CARSON CITY (ORMSBY) CO.: Empire City [Carson City vicinity], 19 May 1882, *Jones 3837* [May 1882, *Jones s.n.*, interpreted herein as a duplicate] (NY, ORE).

***Astragalus lentiginosus* var. *mokiacensis* (A. Gray) M. E. Jones** U.S.A. ARIZONA: MOHAVE CO.: Hidden Canyon, ca. 0.5 mi W of corral, 36.5366°N 113.7388°W, 1159 m, 25 May 2002 (fr), *Alexander 1304* (OSC, UVSC), 02 May 2003 (fl, fr), *Alexander 1398* (NY, OSC, UNLV, UVSC); Hidden Canyon wash, 36.5291°N 113.7283°W, 1189 m, 02 May 2003 (fl, fr), *Alexander 1500* (OSC, UNLV); Whitmore Canyon, below Kinney Point, 02 May 2003 (fl, fr), *Alexander 1502* (OSC, UNLV, UVSC); on the N slope of Garnet Mountain [Iron Mountain], 20 Apr 1997 (fl, fr), *Alexander et al. 846* (UNLV); 11 mi S of Mt. Trumbull village, Parashant (Trail) Canyon, 26 Apr 1974 (fl, fr), *Atwood 6029* (BRY, NY); 30 mi S of Mt. Trumbull village, Andrus Canyon, 28 Apr 1974 (fl, imm fr), *Atwood 6056* (NY); 9 mi S of Mt. Trumbull village, head of Parashant (Trail) Canyon, 28 Apr 1974 (fl, imm fr), *Atwood 6087* (BRY, NY); Andrus Canyon, 3 mi W of Andrus Point, T32N R10W S6, 26 Apr 1999 (fr), *Atwood & Furniss 24293* (BRY, NY, RM, UNLV, US); Andrus Canyon, 3 mi W of Andrus Point, T32N R10W S6, 26 Apr 1999 (fl, imm fr), *Atwood & Furniss 24300* (BRY, NY); Andrus Canyon, 1 mi W of Andrus Point, T32N R10W S10, 26 Apr 1999 (fl, fr), *Atwood & Furniss 24302* (BRY, NY); drainage below Andrus Spring, T33N R12W S20, 19 Apr 2000 (fl, imm fr), *Atwood et al. 25058* (BRY, NY); 1 mi S of Trail Canyon summit, Parashant-Andrus rd, T33N R10W S2, 19 Apr 2000 (fl, fr), *Atwood et al. 25095* (BRY, NY); 2 mi S of Mt. Trumbull school house, near Griffiths Knoll, T34N R10W S1-S2, 1600 m, 21 Apr 2000 (fl, fr), *Higgins et al. 20277* (BRY, NY); Bar Ten Ranch [Hells Hollow], T33N R9W S14, 21 Apr 2000 (fl, fr), *Higgins et al. 21171* (BRY, NY, OSC); 12.5 km (7.8 miles) south of Mt. Trumbull, Whitmore Canyon, T34N R9W S29, 1600 m, 25 May 1979 (fl, fr), *Holmgren et al. 9172* (BRY, NY); Shivwits Plateau, wash 0.5 mi W of Cupe Spring [Cupe Seep], Grassy Point, Lake Mead National Recreation Area, 21 May 1977 (fl, fr), *Leary 1646* (UNLV); Grand Canyon of the Colorado River near Peach Springs [erroneously labeled as “Fort Mohave”], May 1884 [Apr 27] (fr), *Lemmon 3116* (GH); Peach Spring, on hills, Grand Canyon of the Colorado River, Jun 1884 (fr), *Lemmon 3326* (GH, UC); Mokiak Pass, [Palmer's “Juniper Mountains” in the vicinity of Grand Wash], 28 Apr-2 May or 2-4 Jun 1877 (fl, fr), *Palmer 105* (GH, K, NY, MO, POM, US); top of Grand Wash Cliffs above Vulture Canyon [Andrus Canyon vicinity], at lowermost end of Grand Canyon, T32N R10W S6, 1280 m, 19 Mar 1977 (fl, imm fr), *Phillips III 77-1* (NY); [Whitmore Canyon vicinity], T34N R9W S18, 1585 m, 2 Jun 1978 (fl, fr), *Smith & Gierisch 1091* (BRY, NY, 2 sheets); Cottonwood Wash, sandy wash bottom, T37N R15W S28, 1539 m, 20 May 1987 (fl, fr), *Thorne & Atwood 5256* BRY); NEVADA: CLARK CO.: Gold Butte, NW edge, Granite Spring vicinity, 36.2847°N 114.1920°W, 10 Apr 2001 (fl, fr), *Alexander 1147* (OSC, UNLV); Gold Butte, southwest foothills, 36.2712°N 114.2137° (W, 10 Apr 2001 (fl, fr), *Alexander 1148* (OSC, UNLV); Quail Springs Wash, Gold Butte area, 36.2585°N 114.2028°W, 1220 m, 3 May 2003 (fl, fr), *Alexander 1503* (OSC); Grapevine Spring, Gold Butte area, 36.23990°N 114.1742°W, 4200 ft (1280 m), 3 May 2003 (fl, fr), *Alexander 1505* (OSC, UNLV); Twin Springs Wash, 36.1819°N 114.2222°W, 976 m, 17 May 2003 (fl, fr), *Alexander 1510* (OSC, UNLV); Black Mountains, northwest slope, on a ridge E of Pinto Valley, Lake Mead National Recreation Area, Z11 723894 m E 4012957 m N, 900 m, 13 Apr 1997 (fl, fr), *Alexander & Birgy 795* (UNLV); E of Gold Butte, ca. 1.6 mi S of Summit Pass, in gravely wash, 31 May 2001 (fr), *Alexander & Carlson 1160* (OSC); Mica Spring [Gold Butte area], 1219 m, 13 Apr 1894 (fl, fr), *Jones 5058* (BRY, NY, UC, US); 3.1 mi S of Gold Butte in Cataract Wash, 20 May 1977 (fl, imm fr), *Leary & Niles 1910* (NY, UNLV); Grapevine Spring Creek, near Jumbo Peak, near reservoir, Gold Butte area, T19S R70E S3, 1280 m, 26 May 1977 (fl, fr), *Leary & Niles 1947* (UNLV); Quail Spring Wash, about 1.3 mi SW of Gold Butte, 25 Apr 1997 (fl, fr), *Niles et al. 4806* (UNLV); Garden Spring area, 3 mi NE of Gold Butte, T19S R70E S11, 1150 m, 19 Apr 1997 (fl, fr), *Niles et al. 4932* (NY, UNLV); Garnet Valley, north base of Bonelli Peak, T20S R69E S25, 9 May 1997 (fl, fr), *Niles et al. 4988* (UNLV); New Spring Wash, ca 1 rd mi S of Summit Pass, 1128 m, 15 Apr 1986 (fr), *Pinzl 7032* (NY, UNLV).

***Astragalus lentiginosus* var. *palans* (M.E. Jones) M.E. Jones** U.S.A. ARIZONA: COCONINO CO.: ca 0.5 mi S of Page, 01 May 2000, Atwood & Welsh 25360 (NY, RM); E abutment of Glen Canyon Dam, S of hwy, 5 May 1998, *Atwood & Welsh 26924* (NY); Glen Canyon damsite, 7 June 1961, *Barneby 13114* (CAS, NY, RSA); ca 2 rd mi S of Page, along AZ 89, 11 May 1991, *Christy 493* (NY); Navajo Power Plant pipeline, 4 mi SE of Page, 15 April 1972, *Davey s.n.* (NY); base of Leche-E Rock, 15 April 1973*, Hevly & Jenness s.n.* (NY); Lake Powell, NW of Page, ca 0.5 mi NE of Glen Canyon Dam, 3 May 1996, *Hufford 1130* (NY); Bitter Springs on rd to Page, 19 May 1973, *LeDoux et al. 753* (NY), *LeDoux et al. 781* (NY); US Hwy 89, ca 8 mi SW of Page, 22 May 1973, *Spellenberg et al. 3228* (NY); NE part of Antelope Island, ca 5 mi NNE of Page, 14 April 1987, *Tuhy & Holland 2927* (NY); NAVAJO CO.: 12 mi N of Kayenta, 6 June 1961, *Barneby 13104* (CAS, NY, RSA); Mystery Valley, in region of Monument Valley, 16 April 1963, *McClintock s.n.* (CAS), 11 April 1963, *McClintock s.n.* (CAS); 4 mi W of Kayenta, 30 April 1981, *Welsh 20381* (NY, RSA);

COLORADO: DELTA CO.: Dominguez Creek, W of the Gunnison River below Bridgeport, 0-1.5 mi up Dominguez Canyon, 19 May 1982, *Atwood & Thompson 8773* (NY); MESA CO.: NW end of Sinbad Valley at head of Salt Creek Canyon, 26 May 1983, *Atwood 9262* (CAS, NY); 2 mi E of Bedrock, Paradox Valley, 23 May 1984, *Atwood et al. 9728* (NY); 6 mi SSW of Grand Junction, Rough Canyon, base of sandstone wall, 18 May 1988, *Dorn 4886* (NY, RM); open slope 10 mi S of Gateway, 11 June 1949, *Harrington 4423* (RM); Grand Junction, Colorado Monument Park, 03 June 1921, *Osterhout 6142* (RM, RSA); Colorado N.M., west entrance, white hills, 17 May 1982, *Siplivinsky 3273* (RM); Colorado N.M., head of Ute Canyon, within park boundary, 25 May 1982*, Siplivinsky 3379* (RM); near hq. Colorado N.M., 6 mi S of Fruita, mesa summit, 21 May 1948, *Weber 3840* (CAS, DUD, RM, US); MONTROSE CO.: La Sal Creek, 4 mi S of Paradox, near cliff dwellers mine, 20 May 1982, *Atwood & Thompson 8798* (NY, RM); Monogram Mesa, 6 mi W of Vancorum, 3 June 1961, *Barneby 13046* (CAS, NY, RSA); Paradox Valley, N slope, 25 April 1986, *Franklin 2838* (NY, RM); ca 18 air mi NW of Naturita, ca 2.5 air mi S of Bedrock, E side Dolores River Canyon, E facing slope on W side canyon, 17 June 1995, *Moore 5502* (RM); Slick Rock Canyon, Dolores River, ca 18 air mi W of Naturita, at mouth and surrounding area of Leach Creek, SW facing wash, 05 July 1995, *Moore 6334* (RM); Slick Rock Canyon, Dolores River, ca 18 air mi W of Naturita, at mouth and surrounding area of Leach Creek, SW facing wash, 05 July 1995, *Moore 6335* (RM); near Naturita, SW Colorado, dry hills, 22 May 1914, *Payson 335* (RM); SAN MIGUEL CO.: Colorado side of Island Mesa, 27 May 1998, *Atwood & Trotter 23617* (NY); roadside, rocky cedar breaks,1 mi S of Gladel, 09 June 1951*, Penland & Hartwell 4178* (RM); W end Gypsum Valley, rocky mouth of Hamm Canyon, 09 June 1949, *Weber 4735* (CAS, DUD, RM, RSA, UC, US); UTAH: CARBON CO.: ca 1.5 mi N of Emery Co. line along US Hwy 50-6, 29 April 1965*, Welsh 3875* (NY); EMERY CO.: San Rafael Swell, Chimney Rock flats, 17 May 1979, *Harris 116* (RM); near junction of Lower Black Box Rd to Swazys Leap and Sulphur Spring, 19 May 1992, *Heil & Hyder 7132* (RSA); San Rafael Swell, near Temple Mtn, 30 April 1968, *Higgins & Reveal 1277* (NY, RM); San Rafael Swell, 18 May 1915, *Jones s.n.* (UC), 12 May 1914, *Jones s.n.* (POM); Red Plateau, SW of Woodside, along rd to Castledale, 6.9 mi W of US 50, 5 June 1958, *Raven 13079* (CAS, GH, NY); Red Plateau, SE of Woodside, 13 June 1947, *Ripley & Barneby 8675* (RSA); rocky draw, San Rafael Swell, 22 mi W of Green River on I-70, 1mi E of rest area just below Rattlesnake Bench, 28 April 1979, *Shultz et al. 3113* (NY, RM, RSA); Summerville [Wash], at Woodside, 27 April 1977, *Welsh & Taylor 14624* (NY); GARFIELD CO.: upper E end of Choprock Bench, ca 30 mi ESE of Escalante, 6 May 1987, *Tuhy & Holland 3127* (NY, RSA); head of North Wash, 28 April 1981, *Welsh 20368* (NY, RSA); GRAND CO.: Kane Springs Rd, 13 mi S of Moab, [no date], *Atwood 7478* (NY); Sandflat Rd, E of Moab 12 mi., ca 0.25 mi W of Forest Service boundary, 20 May 1982, *Atwood & Thompson 8787* (NY,RM); Arches N.M., 5 mi NW of Moab, 21 May 1984, *Atwood et al. 9695* (NY); 11 mi N of Moab, 18 May 1955, Barneby 12753 (CAS, NY, RSA); 1 mi N of Moab, 14 April 1940, *Beath 48* (RM); Arches road, 04 May 1947, *Beath s.n.* (RM); near Moab, 17 May 1940, *Beath & Goodding 6-373* (RM); 8 mi NW of Moab, along UT Hwy 160, 28 April 1961, *Bright 135* (NY); between Moab and bridge, 13 May 1933, *Cottam 5623* (RM); hillside in the Colorado River Canyon, a little below Salt Wash, NE of Moab, 9 May 1961, *Cronquist 8974* (GH, NY, RSA); slope E above Hwy 128, 0.15 mi N of Pole Canyon, 05 May 1985, *Franklin 1391* (NY, RM); Red Hills SE above White Ranch along Colorado River, 07 May 1985, *Franklin 1421* (NY, RM); 3.7 mi due E of Moab, sand flats among sandstone fins, 17 April 1986, *Franklin 2679* (RM); Mat Martin Point, sand pockets on slickrock, 12 May 1986, *Franklin 2933* (RM); Sevenmile Mesa, point W of confluence of Dolores River and Fisher Cr., ca 25 mi due NE of Moab, 18 May 1986, *Franklin 3104* (RM); Onion Creek, 22 May 1984, *Goodrich et al. 20398* (NY); N end of La Sal Mountains, Fisher Valley, 22 May 1984, *Goodrich et al.* 20414 (NY); 1 mi NE of Moab, 0.5 mi along UT Hwy 128, along Colorado River, 30 April 1961, *Hanson 148* (NY); on edge of Colorado River, Moab, clay buttes, 09 May 1933, *Harrison 5945* (RM); cliffs above headquarters, S edge of Arches N.M., sandy terraces among rocks, 25 April 1947, *Harrison 11123* (RSA, US), *Harrison s.n.* (UC); south of Courthouse Towers, Arches N.M., sandy flat, 17 May 1950, *Harrison 11383* (US, UC); The 'Neck" 13 miles due WSW of Moab, sand rock ridge, 11 June 1941, *Harrison et al. 10286* (US); Arches N.M., 29 June 1948, *Howell 24752* (CAS,RSA); near Skyline Arch, Arches N.M., 7 September 1968*, Howell & True 44906* (CAS,NY); 10 mi N of Moab, sandy plain, 17 June 1955, *Isely 6460* (RSA, US); Castle Valley, May 1931, *Jones s.n.* (POM); red sandstone banks just north of Kane Springs, ca. 15 miles south of Moab, 21 April 1966, *Ledingham 4694* (UC); 5 mi N of Moab, 08 June 1939, *Porter 1796* (RM), *Porter 1797* (RM); San Sige [illegible] Hollow, Grand River Canon [Grand River Canyon near Moab, June 1899], 1899, *Purpus s.n.* (UC); sandy slopes near headquarters, Arches N.M., near Moab, 6 June 1962*, Rever & Belcher 73* (NY); W of Thompson, 13 June 1947, *Ripley & Barneby 8662* (RSA); Spanish Valley, 4.5 mi E of Moab, along roadside in town, 03 May 2000, *Spencer 1487* (NY, RM);

Ida Gulch, 2.5 mi SE of Hwy 128 along Colorado River, E of Castle Valley Rd, slopes below Priests and Nuns, 11 May 1986, *Thorne et al. 4614* (RM); Sego, 2 mi N of Thompson, 30 April 1965, *Welsh 3881* (NY); Castle Valley, ca 4.5 mi E of junction with UT Hwy 128, 3 May 1968, *Welsh 7018* (NY); Castle Valley, ca 4.5 mi E of junction with UT Hwy 128, 29 May 1968, *Welsh & Moore 7170* (NY); KANE CO.: 5 mi S of Glen Canyon N.R.A. boundary, along Hole-in-the-Rock Rd., 23 April 1996, *Atwood & Furniss 20795* (NY); Willow Tank, 41 mi SE of Escalante, 8 June 1961, *Barneby 13127* (CAS, NY, RSA); abandoned "Pareah" townsite near the Paria River, 3 May 1986, *Shultz & Shultz 9931* (NY); Willow Tank, ca 17 mi S of Garfield Co. line, along road to Hole-in-the-Rock, 04 May 1962, *Welsh 1687* (NY, US); Lake Powell, Driftwood Canyon, Driftwood Garden, 27 May 1986, *Welsh 22102* (NY); Paria townsite, 5 May 1970, *Welsh & Atwood 9727* (NY); SAN JUAN CO.: south of Mexican Hat along Hwy 63, 14 May 1970, *Atwood 2486* (NY); Navajo Twins, N side of Bluff, 20 May 1985, *Atwood & Furniss 11009* (NY); E of Monticello, 28 April 1998, *Atwood & Trotter 23411* (NY); ca 15 mi W of Mexican Hat, along bench above San Juan River, 28 April 1998, *Atwood & Trotter 23423* (NY); E slope of Navajo Mountain, 23 June 1973, *Atwood & Trotter 5334* (NY); Copper Canyon, S of Monitor Mesa, 22 May 1985, *Atwood et al. 11057* (NY); 14 mi W of Blanding, 19 May 1955, *Barneby 12785* (CAS, NY, RSA); 10 mi W of Blanding on US Hwy 95, 30 April 1961, *Bright 83* (NY); Goose Necks, 01 May 1935, *Cottam 5837* (RM); between Blanding and Bluff, hillsides, 17 April 1928, *Cottam 6693* (RM, 2 sheets), *Cottam 6703* (RM); Goosenecks of San Juan River, 12 April 1938, *Cronquist 1104* (RM); Montezuma Canyon, 29 May 1892, *Eastwood s.n.* (GH); Montezuma Canon, 01 June 1892, *Eastwood s.n.* (RM, POM, UC); 25 mi W of Hanksville, 14 May 1940, *Goodding & Beath 48* (RM); 8 mi E of Halls Crossing, 23 May 1983, *Higgins & Welsh 13216* (NY); ca 5 mi E of Mexican Hat, 24 May 1983, *Higgins & Welsh 13291* (NY); slopes above Gretchen Bar, 54 mi below Hite on the Colorado River, 04 May 1954, *Holmgren & Goddard 9980* (CAS); black streak cliffs, vicinity of Bluff, 24 June 1944, *Holmgren & Hansen 3439* (NY); Mendenhall Loop, riverside below the Mendenhall Stone Cabin, ca mi 31, 2.5 km W of Mexican Hat, 11 June 1997, *Holmgren & Holmgren 12796* (NY); Bluff, 24 May 1919, *Jones s.n.* (POM); 14 mi due SW of La Sal summit of Rone Bailey Mesa, 4 June 1985, *Neese & Welsh 16993* (NY); Bluff, south exposure, 03 April 1966, *Pederson 12* (GH); W of Bluff, 22 May 1943, *Ripley & Barneby 5603* (RSA); along San Juan River, near Bluffs, 25-29 August 1911, *Rydberg & Garrett 9914* (NY, RM, US); 12.2 mi S of Moab, 22 May 1976, *Shultz 2151* (RSA), *Shultz & Bolander 2151* (NY); Bluff area, 1 mi E of Needles Overlook, along roadsides in sand, 22 May 1976, *Shultz & Shultz 1854* (NY,US); Rone Bailey Mesa ca 22 mi NNW of Monticello, 01 July 1984, *Tuhy 1581* (RM); head of Red Canyon, ca 12 mi SW of Natural Bridges N.M., 29 April 1981, *Welsh 20374* (RSA); Bluff, 29 April 1961, *Welsh 1501* (NY); Comb Reef, 17 mi W of Blanding, 1 mi from Perkins Ranch, 30 April 1961, *Welsh 1510* (NY); head of Red Canyon, ca 12 mi SW of Natural Bridges N.M., 29 April 1981, *Welsh 20374* (NY); Whirlwind Draw, Clay Hills Divide, 30 April 1966, *Welsh 5206* (NY); W of Grand View Point, top of Murphy's Ridge, 18 May 1968, *Welsh 7076* (NY); S Six Shooter Peak platform, Davis Canyon, 11 May 1982, *Welsh et al. 21100* (NY); between Natural Bridges N.M. and Blanding along UT Hwy 95, 22 April 1967, *Wetherell & Finzel 633* (NY); WASHINGTON CO.: 2 mi W of Springdale, 15 April 1938, *Cronquist & Gaupin 1106* (BRY); Hurricane, 4 mi due SW of Rockville, 22 May 1977, *Foster 3766* (NY); Coalpits Wash, 5 May 1988, *Franklin & Thorne 5930* (BRY); 9 mi E of Hurricane along Hwy 59, 20 May 1971, *Higgins & Welsh 4227* (NY); sandy desert, 5 miles east of Virgin, 11 May 1937, *Hitchcock 3025* (GH); Virgin, 14 May 1894, *Jones 5215e* (US); Rockville, 14 May 1894, *Jones 5215e* (DUD, 3 sheets, NY, UC); Rockville, 15 May 1894, *Jones 5218* (DUD, GH, NY, RM), 14 May 1894, *Jones 5218* (RM, US, UC); Virgen City, 14 May 1894, *Jones 5218a* (US); Rockville, 15 May 1894, *Jones 5218a* (DUD, POM); Zion N.P, Petrified Forest, 13 April 1972, *R.A. Nelson 9930* (RM); Zion N.P, Petrified Forest, 13 April 1972, *R.A. Nelson 9937* (RM); 2 mi N of Hurricane, 10 April 1966, *Stevens 140* (BRY); Petrified Forest sector, 2 mi N of Rockville, 06 May 1988, *Welsh & Clark 23986* (BRY, RM); WAYNE CO.: Capitol Reef entrance to Grand Wash, 24 May 1975, *Harrison 1688* (RM); Horseshoe Canyon, ca 1 mi up Horseshoe Canyon, Canyonlands N.P., 20 May 1990, *Heil et al. 5895* (RSA); Capitol Reef entrance to Grand Wash, 24 May 1975, *K. Harrison 1688* (NY); canyon bed of Fremont Canyon, N of Fruita, 05 May 1940, *Maguire 18115* (RM); 23.8 mi W of Loa, 3 May 1977, *Neese & White 2752* (NY); Barrier (Horseshoe) Canyon, 19 April 1970, *Welsh 9593* (NY); road to North Point ca 1 mi NE of French Spring above Orange Cliffs, 30 May 1970, *Welsh & Atwood 9870* (NY).

The following voucher specimens examined for the morphological analysis from the vicinity of Cameron are putative populations of *A. lentiginosus* var. *palans* intermediate to *A. lentiginosus* var. *wilsonii*.
U.S.A. ARIZONA: COCONINO CO.: roadside, 6 mi W of Cameron, 08 April 1938, *Cronquist & Gaupin 1105* (RM); Painted Desert, Cameron, low areas and roadsides, 22 April 1961, *Demaree 43807* (DUD, NY, US); ca 5 mi W of Cameron, 8 April 1978, *Gierisch 4183*

(NY); 4 mi W of Cameron on Hwy 64, 18 March 1968, *Hitchcock 25614* (NY, OSC); Rainbow Lodge, south end of Navajo Mountain, 11 June 1938, *Peebles & Smith 13939* (GH, NY, US); 10 mi SW of Cameron, Hwy 64, 7 April 1957, *Strickland 21* (NY).

Astragalus lentiginosus **var.** ***pseudiodanthus*** **(Barneby) J.A. Alexander** U.S.A. NEVADA: NYE CO.: sand dunes N of Tonopah, May 2003 (fl,fr), *Alexander 1631* (OSC, UNLV).

Astragalus lentiginosus **var.** ***stramineus*** **(Rydb.) Barneby** U.S.A. ARIZONA: MOHAVE CO.: "southeastern Utah" [southwestern slope Beaver Dam Mountains, near Littlefield], June 1870, *Palmer s.n.* (NY, US).

Astragalus lentiginosus **var.** ***vitreus*** **Barneby** U.S.A. UTAH: WASHINGTON CO.: 5 mi W of Leeds, 19 May 1933, *Maguire & Blood 4413.* (POM, CAS).

Astragalus lentiginosus **var.** ***wilsonii*** **(Greene) Barneby** U.S.A. ARIZONA: YAVAPAI CO.: sandy washes north of Cottonwood, 1 June 2005 (fl, fr), *Alexander 2334* [individuals B, E, J, K] (NY, OSC, UNLV, UVSC); south of the boundary of Montezuma Castle National Monument, 2 June 2005 (fr), *Alexander 2339* [individual F] (OSC, UNLV), 2 June 2005 (fl, fr), *Alexander 2340* [individuals A, D]; in scrubland 1.3 mi west of I-17, near junction of FR 9204F and AZ Hwy 179 2 June 2005 (fr), *Alexander 2367* [individuals A, B] (NY, OSC, UNLV, UVSC); on roadcut 0.1 mi west of I-17, along AZ Hwy 179, 02 June 2005 (fr), *Alexander 2368* (OSC, UNLV).

The following vouchers specimens examined for the morphological analysis are putative populations of *A. lentiginosus* var. *wilsonii* along the South Rim of the Grand Canyon that are intermediate to *A. lentiginosus* var. *bryantii*, *A. lentiginosus* var. *mokiacensis*, or *A. lentiginosus* var. *ursinus*. U.S.A. COCONINO CO.: Kaibab Trail, 10 May 1940 (fl, fr), *Collom KT24* (US); Grand View Trail, Grand Canyon of the Colorado River, 16 June 1916 (fl, fr), *Eastwood 5748* (CAS, GH, UC); Grand Canyon [Bright Angel Trail vicinity], June 1915 (fr), *Macbride & Payson 945* (GH, RM); Kaibab Trail, Grand Canyon N.P., 23 May 1938 (fl, fr), *Nelson & Nelson 2799* (RM); near El Tovar, South Rim Grand Canyon, 3 June 1947 (fr), *Ripley & Barneby 8472* (RSA).

Astragalus lentiginosus **var.** ***yuccanus*** **M.E. Jones** U.S.A. ARIZONA: MOHAVE CO. : Yucca, 13 May 1884, *Jones 3886* (POM, GH, NY, US).

Appendix II
List of morphological characters and character states used in the morphometric analyses

Adaxial leaflet pubescence (leafad): 1. densely pubescent (surface obscured, overlap); 2. moderately pubescent (some hair overlap, gap less than 0.2 mm); 3. sparsely pubescent to subglabrate (uneven to evenly across surface with no overlap, or just confined to midrib & base); 4. entirely glabrous (or just a few hairs at base)

Abaxial (lower) leaflet pubescence (leafab): 1. densely pubescent (surface obscured, overlap); 2. moderately pubescent (some hair overlap, gap less than 0.2 mm); 3. sparsely pubescent to subglabrate (uneven to evenly across surface with no overlap, or just confined to midrib & base); 4. entirely glabrous (or just a few hairs at base)

Leaf and stem hair length (leafh): average of 3, in mm.

Leaflet number (leafn): average of 3, in mm.

Inflorescence length in flower (inflw): average of 3, in mm.

Calyx tube length (calyxl): average of 3, in mm.

Calyx pubescence density (calyxd): 1. densely strigulose (surface obscured, overlap); 2. moderately strigulose (some hair overlap); 3. evenly & sparsely strigulose; 4. entirely glabrous (or just a few scattered hairs).

Calyx teeth shape (calyxs): 1. deltoid; 2. lance-subulate, subulate; 3. subulate-setaceous; 4. lance-attentuate; 5. lance-acuminate.

Calyx teeth orientation (calyxo): 1. erect to spreading ; 2. loosely long recurving.

Keel length (keell): average of 3, in mm.

Keel color (keelc): 1. light to dark purple maculate; 2. tan to pink maculate tipped; 3. ochroleucous, not maculate; 4. yellow.

Wing color (wingc): 1. purple, dark purple tipped; 2. purple, white tipped; 3. white, pink-purple tipped; 4. ochroleucous; 5. yellow.

Banner color (bannc): 1. purple & white with purple striate central spot; 2. whitish to ochroleucous & pink tinged; 3. tan ochroleucous to whitish; 4. yellow.

Inflorescence length in fruit (infr): average of 3, in mm.

Pod pedicel orientation (podpo): 1. ascending to spreading, straight; 2. ascending to spreading, arched; 3. appressed to erect, straight; 4. recurved, arched

Pod length & width ratio (podr): average of 3, in mm.

Pod deciduous or persistent (poddp): 1. deciduous; 2. persistent.

Pod shape, longitudinal section (podsl): 1. seculate & abruptly acute apically; 2. seculate & attenuate apically; 3. elliptic, narrowly elliptic, lunate & acute apically; 4. oblong, narrowly oblong & attenuate apically; 5. linear; 6. lanceolate, widest at base & attenuate apically; 7. oval, ovoid, broadly ovoid; 8. obovoid, broadly obovoid; 9. subglobose; 10. clavate-oblanceolate.

Pod shape, cross section (podsc): 1. subterete, dorsiventrally compressed, when obcordate, the suture shallowly sulcate; 2. obcordate & laterally compressed, broadly to narrowly (obcompressed), suture deeply sulcate; 3. didymous & dorsi-ventrally compressed, broadly to narrowly; 4. cordate & dorsi-ventrally compressed, broadly to narrowly; 5. cordate & laterally compressed, broadly to narrowly.

Pod orientation on raceme (podro): 1. ascending, erect & beak & 1/2 pod curved inward; 2. ascending to spreading, straight; 3. spreading, declined & beak to 1/2 pod recurved; 4. spreading & slightly curved inward from middle (lunate, falcate); 5. spreading & beak to 1/2 pod incurved to 180° (hamate).

Pod orientation, degree of pod incurve, coded range (podpi): 1. <90 (45-60) (lunate); 2. ~90 (60-120) (hamate); 3. 90-180 (120-180) (circular).

Pod inflation (podin): 1. bladdery inflated; 2. scarcely inflated; 3. not inflated, cylindrical (no locule cavity, seeds surrounded by valves).

Pod stipe/gynophore length (pods): average of 3, in mm.

Pod valve texture (podt): 1. papery-membraneous (translucent); 2. papery, (opaque); 3. firm or stiff papery (not transparent); 4. leathery (valves thin); 5. leathery to subligneous (valves thick).

Pod pubescence (podpu): 1. sparse & minutely scaly pubescent; 2. densely white strigulose; 3. sparsely to moderately white strigulose; 4. mostly glabrous.

Pod valve color (podvc): 1. mottled; 2. reddish tinged; 3. greenish to tannish, no mottling or tint.

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Ecology of Rusby's Milkvetch (*Astragalus rusbyi*), a Rare Endemic of Northern Arizona Ponderosa Pine Forests

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Abstract. Rusby's milkvetch (*Astragalus rusbyi* Greene) is endemic to basaltic soils northwest and west of Flagstaff, Arizona. Recent interest in this species is due in part to its addition to the U.S. Forest Service Region 3 sensitive species list in 1999 and its occurrence in ecological restoration projects and proposed fuels reduction projects that involve tree thinning and prescribed burning. Some of its habitat has been subjected to large wildfires over the last few decades, and other areas have undergone ecological restoration treatments, while much of its range in ponderosa pine forest is slated to undergo such treatments in the near future. In a ponderosa pine restoration study area northwest of Flagstaff, *A. rusbyi* was an indicator species of remnant grass patches and increased following tree thinning and prescribed burning. However, in an area less than 3 km away, there appeared to be no relationship to restoration treatments, trees per ha, pine basal area, or canopy cover, but *A. rusbyi* did appear to be sensitive to an extreme drought event in 2002 and may have remained dormant in that year, a pattern that has been observed in other rare *Astragalus* species. *A. rusbyi* has a foliar nitrogen content of 4.4% and a foliar C:N mass ratio of 11. It is classified as a competitive ruderal species, meaning it is able to compete well with other understory species, but is not very tolerant of stresses, such as deep shade. We currently do not have a thorough understanding of the ecology of this species, or the effects of ecological restoration or fuels reduction treatments. In this paper we will discuss ecology of other members of the genus *Astragalus* and explore the relationships of *A. rusbyi* to moisture, vegetation treatments and overstory mortality.

Astragalus is believed to be the largest genus of flowering plants in the world, with over 2500 species worldwide and over 400 species in North America alone, primarily in arid regions of the western U.S. The highest diversity in North America is centered in the Great Basin and on the Colorado Plateau (Barneby 1989, Sanderson 1991). *Astragalus* species are often found in marginal habitats or on specialized soil types, and their geographic ranges are strongly skewed towards narrow endemism (Barneby 1964, 1989; Sanderson 1991). Along with a limited dispersal ability possessed by many members of the genus, there is widespread local differentiation and geographic speciation, particularly in the areas of the western U.S. where it achieves the highest levels of diversity (Sanderson 1991, Lesica et al. 2006). However, due to restricted ranges and habitats, some *Astragalus* species may exhibit low genetic variability and reduced fitness from inbreeding depression (Karron et al. 1988, Allphin et al. 2005, Breinholt et al. 2009). Neoendemism is common in the intermountain regions of North America where there are large numbers of both widespread, recently evolved species, as well as narrowly endemic species, which are often associated with extreme edaphic conditions and reduced competition from dominant species (Lesica et al. 2006). Lesica and his co-authors suggest that restricted ranges and high local abundances of neoendemic species may be due more to patterns and processes of speciation than to ecological tolerance. The small ranges exhibited by many *Astragalus* species in the western U.S. may be due to recent speciation and an insufficient amount of time for these species to have increased their ranges significantly (Lesica et al. 2006). Reticulate evolution may not be widespread in the *Astragalus* genus, for many members of the genus appear to exhibit allopatry (geographic isolation) along with high levels of local endemism and little hybridization (Sanderson 1991).

The type specimen of *A. rusbyi* was collected by Henry Hurd Rusby on July 2, 1883 on Mt. Humphreys, near Flagstaff Arizona (Welsh 2007) and was first described by Edward Lee Greene in 1884 (Greene 1884). *A. rusbyi* is a slender perennial averaging 15-40 cm in height. It also has a fairly deep taproot (D.C. Laughlin, personal communication, 2008). It grows primarily in meadows in ponderosa pine forests and in aspen groves (Barneby 1964, Welsh 2007), but it also may be found in moderately dense ponderosa pine forests. Populations are mainly concentrated on basaltic soils in two areas in northern Arizona: around the San Francisco Peaks (primarily on the southern and western sides of the Peaks) and also the vicinity of Kendrick Mountain (Figure 1). Collections from areas to the south, including Oak Creek Canyon and Yavapai County are of uncertain validity. It is ranked G3 (vulnerable) by NatureServe (2009) and is on the U.S. Forest Service sensitive species list for Region 3 (Southwestern Region).

A. rusbyi has been placed in the section *Strigulosi,* which contains approximately 35 species found mainly in the Mexican highlands north to Arizona and New Mexico and generally associated with oak and pine forests (Barneby 1964, Spellenberg 1974). Section *Strigulosi* is thought by some authors to be the most primitive group of *Astragalus* species in North America. The majority of the evidence, including research on chromosome numbers and more recent molecular phylogenetic data, currently points to an Old World origin for *Astragalus,* presumably in the steppes and mountains of southwestern and south-central Asia and the Himalayan Plateau (Spellenberg 1976, Wojciechowski 2005).

Astragalus rusbyi has a chromosome number of 11 (2n=22) (Spellenberg 1974). Morphologically, it appears to be most closely related to two other members of section *Strigulosi*, *A. egglestonii* and *A. longissimus*, with which it shares technical features (Barneby 1964). Like most members of *Strigulosi*, *A. rusbyi* flowers from mid-summer onward into the fall, varying in abundance in response to the amount and timing of summer rains. *Astragalus rusbyi* is differentiated from these species of *Astragalus* by minor differences in characters of its pendulous, stipitate, bilocular, trigonously compressed pods (Barneby 1964). However, the ranges of these three species do not overlap and they maintain geographic isolation from one another with no observed intermediate populations.

ECOLOGY OF ENDEMIC WESTERN SPECIES

Astragalus is a very large genus with little ecological information available for the vast majority of species. However, many uncommon and rare species share characteristics with each other that may directly affect monitoring and conservation planning for *A. rusbyi*. For example, some species exhibit prolonged vegetative dormancy, such as *A. scaphoides* (Bitterroot milkvetch) and *A. sinuatus* (Whited's milkvetch) of the sagebrush steppe of the Pacific Northwest, or dormancy during dry years, as demonstrated by *A. schmolliae* (Schmoll's milkvetch) of Mesa Verde National Park, in southwestern Colorado (Anderson 2004, Gamon 1995, Lesica and Steele 1994). *A. scaphoides* plants may utilize prolonged vegetative dormancy as a bet-hedging strategy in an effort to conserve resources while avoiding the risk inherent in funneling resources into aboveground growth (Gremer et al. 2012). Lesica (1995) found that *A. scaphoides* plants may remain dormant belowground for as long as five years before reappearing. Dormancy may be inferred in other species, such as *A. ripleyi*, due to an increased number of visible plants in years of above average precipitation (Ladyman 2003). Barneby (1964) notes that *A. rusbyi*, like most members of section *Strigulosi* varies in "vigor and abundance in proportion to amount and timing of summer rains," but prolonged vegetative dormancy has not been established.

Many *Astragalus* species exhibit large underground storage organs (*A. scaphoides*), a vigorous creeping root system (*A. cicer* – chickpea milkvetch), or long taproots (*A. ampullarioides* – Shivwits milkvetch) (Jennifer Gremer, unpublished data; Mark Miller, personal observation; Horvath 2002). These extensive rooting systems exhibited in the genus may be linked to observed patterns of vegetative dormancy. *A. ripleyi* (Ripley's milk-

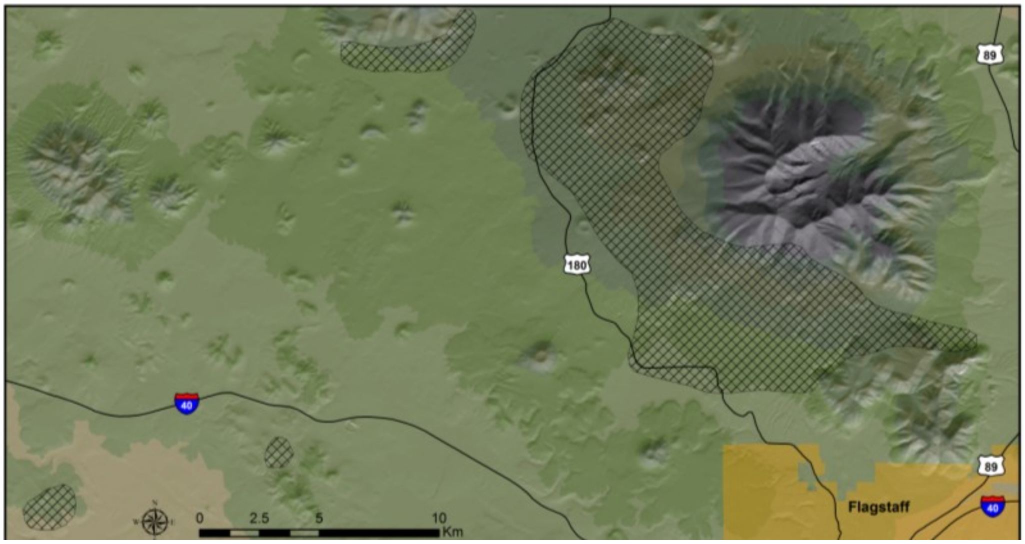

Figure 1. Known range of *Astragalus rusbyi* in northern Arizona based on herbarium collections and research studies (figure compiled by J.E. Crouse and D. L. Crisp).

vetch), a species of ponderosa pine forests in north-central New Mexico and south-central Colorado, reproduces by seed, but plants tend to allocate resources toward survival of individual plants, and it is believed to build up root stock reserves when aboveground parts are consumed (Ladyman 2003). Direct evidence supports an ability to lie dormant for two years, but monitoring has not yet been used to establish if it can remain dormant for a longer period.

Although a number of *Astragalus* species contain toxins (such as miserotoxin or swainsonine) or accumulate selenium, thus making them poisonous to livestock, there are also many species that are highly desirable to herbivores. Lesica (1995) found fecundity losses in *A. scaphoides* due to livestock and insect herbivory ranging from 14-90% at two sites. Observations have confirmed that inflorescences are consumed by ants and moth larvae. Loss of seeds to weevil predation ranged from 0-33%. Sugars such as those found in flower nectar may increase palatability. Lesica also found very low recruitment, accounting for less than 17% of population growth. However, despite heavy losses in reproductive output and low recruitment, populations can continue to persist and increase in size. He suspects that persistence of many populations of long-lived plants may be more reliant on growth and survival of established plants than on recruitment from seed. Herbivory by cattle and game has also been observed in *A. terminalis* (railhead milkvetch), and seed predation in *A. ripleyi* may be the cause of significant seed loss (Heidel and Vanderhorst 1996, Ladyman 2003). Apparently, like *A. scaphoides*, this species has low recruitment rates and allocates a significant amount of resources toward maintenance of the root system. *A. ripleyi* is also consumed by a number of arthropods (aphids, treehoppers, carpenter ants), rodents and large mammals, including cattle, elk, deer, sheep and goats. A ninety percent reduction in fruit production due to herbivory was observed in *A. ampullarioides* (Shivwits milkvetch), which the authors suggest could have a significant impact on reproductive output (Miller et al. 2007). The toxicity of *A. rusbyi* is unknown.

The effects of disturbances, such as tree thinning or burning, on *Astragalus* species vary widely. *A. ripleyi* is thought to be a “fire evader” rather than a stress tolerator (Ladyman 2003). Following fire, plants have been observed in areas where they have not been detected before, presumably emerging from dormant root systems underground. However, the stress-tolerator category may be appropriate, for a pattern of rapid colonization following fire and drought has also been observed in this species (Ladyman 2003).

Thinning activities in pinyon-juniper woodlands at Mesa Verde National Park appeared to cause an increase in *Poa fendleriana* (muttongrass) that could result in undesirable competition impacts on *A. schmolliae* (Anderson 2004). Grass seeding post-fire also has the potential to cause negative impacts on this species. Drought is deleterious, but it is likely tolerant of fire because of a deep taproot. However, monitoring indicates that while fire may confer short-term benefits, it may also have long-term detrimental impacts (Anderson 2004).

OBSERVATIONS FROM FIELD STUDIES

A. rusbyi has a very small range in northern Arizona, with the bulk of its population limited to a band approximately 18 x 7 km (11 x 4.5 mi) in size to the west and north of the San Francisco Peaks and a few scattered populations to the west (Figure 1). Some of its habitat has been subjected to large wildfires over the last few decades; other areas have undergone ecological restoration treatments (tree thinning and prescribed burning); and much of its range in ponderosa pine forest is slated to undergo such treatments in the near future. Increasing tree densities of ponderosa pine, and a cessation of frequent fires in ponderosa pine forests since Euro-American settlement of this area of the Southwest have been well documented (Covington and Moore 1994, Fulé et al. 1997).

We currently do not have a thorough understanding of the basic ecology of this species. Additionally, we have insufficient knowledge of the effects of increased tree densities, tree thinning, or fire on the population dynamics. However, some limited information is available from large landscape scale studies within its range. Fisher and Fulé (2004) installed 121 20x50 m permanent monitoring plots on the south side of the San Francisco Peaks (specifically Agassiz Peak). Plots were established in five forest types: ponderosa pine, mixed conifer, aspen, spruce/fir and bristlecone pine. Overstory measurements and plant community data were collected between 2000 and 2003. *A. rusbyi* was found to be an indicator species for ponderosa pine forest, with an indicator value of 36.5 ($p<0.01$). Six of the 14 ponderosa pine indicator species were nitrogen fixers, and one other species was an *Astragalus* (*A. humistratus*). A large part of the study area was burned in the high-intensity Leroux Fire of 2001 (26 plots) and these plots were measured a year after the fire in May 2002. Ten plots contained *A. rusbyi* prior to the fire, but it was inventoried on only two plots following the fire, which was an 80% decrease. However, 2002 was an extremely dry year with precipitation at levels 77% below normal in the vicinity of the Fort Valley area (Laughlin et al. 2008), so the absence of this species in the monitoring plots could have been due to drought, vegetative dormancy, the detrimental impacts of high-intensity fire, or a combination of other factors.

In a research area near Flagstaff, AZ which was designed to study the effects of ecological restoration

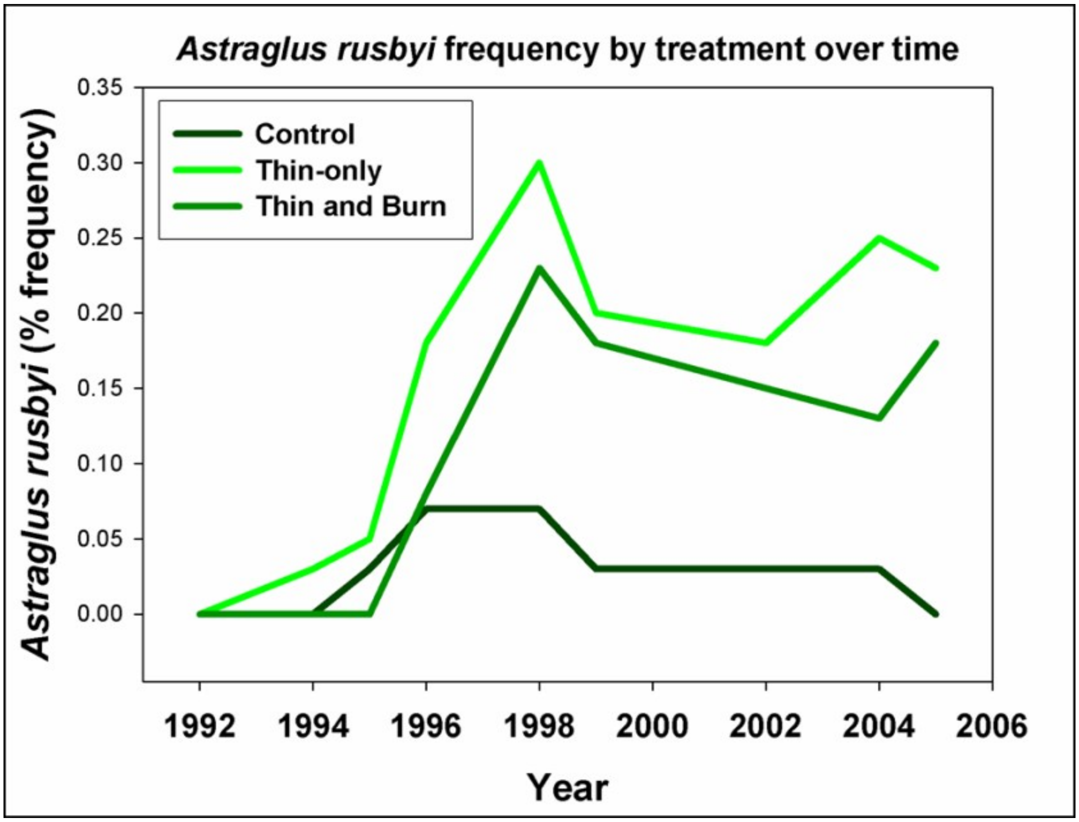

Figure 2. Frequency of *Astragalus rusbyi* by treatment over time at G.A. Pearson Natural Area near Flagstaff, AZ.

treatments (G.A. Pearson Natural Area), Laughlin and others (2008) found *A. rusbyi* to be an indicator species of both thinned treatments and treatments that involved thinning plus burning (mean indicator value of 25.0; p<0.001) (Figure 2). Thus it exhibited a positive response to either type of treatment, whether thinning alone or a combination of thinning and burning. *A. rusbyi* (along with two other legumes) was also found to be an indicator species of remnant grass patches (small open areas consisting of native grasses and forbs) with a mean indicator value of 26.8 (p=0.013). It would appear from this study that ecological restoration treatments, whether they involve thinning plus prescribed burning, or prescribed burning alone, have neutral to positive effects on *A. rusbyi.*

However, in another restoration study area less than 3 km away, no significant effects, either positive or negative, were observed with thinning and prescribed burning treatments and there was no correlation found between the presence of *A. rusbyi* and trees per ha, pine basal area, or canopy cover. In this study, there was no “thinning only” component, but rather, treatments were designed to examine the effects of various levels of tree thinning, and these treatments were all combined with prescribed burning, with the exception of the controls. There is a total of 240 plots divided up into three blocks, each with a control, and 3 units with different thinning levels. Presence/absence and frequency data were collected on all plant species, and data collection was not targeted specifically toward *A. rusbyi*. Pre-treatment data were collected in 1998, and the study sites were thinned in 1999 and burned in 2000/2001. Although there was no significant effect on plant density from the ecological restoration treatments (p=0.242), there was a sharp decline in 2002, a year of extreme drought (Figure 3). However, populations in some of the units appeared to return to pre-2002 levels within four years. Determining why there are differences in responses to ecological restoration treatments between these two sites would be purely speculative. The G.A. Pearson Natural Area is fenced to exclude both domestic and wild ungulates, so vegetation would have been spared the effects of grazing. This area also received fairly labor-intensive fuel treatments prior to burning, including removal of slash by hand and addition of herbaceous vegetation from a nearby prairie prior to burning.

Surveys conducted in 2008 within an area of *A. rusbyi* habitat to the northwest of the San Francisco Peaks that is slated for fuels reduction treatments revealed high levels of mortality of overstory trees, especially quaking aspen (*Populus tremuloides*) (D. L. Crisp, personal observations, 2008). Numerous populations of *A. rusbyi*, varying in size from a few to several hundred plants, were also noted in areas that exhibited heavy tree mortality.

D.C. Laughlin (personal communication, 2009) collected trait data on 137 ponderosa pine understory species, including *A. rusbyi*, and found that, on average, it has a higher specific leaf area (24 mm^2/mg) and higher nitrogen and phosphorous concentrations in its foliar tissue (4.4% and 0.18%, respectively) (Figure 4). Because of the high nitrogen content, it has a relatively high net photosynthetic rate. On average, it also has a lower leaf dry matter content (0.19 mg/mg) and foliar C:N mass ratio (10.7). Combined with its high photosynthetic rate and comparatively tall stature (with an average height of 31 cm), it is able to compete well with other understory species, but is not very tolerant of stresses such as deep shade. The combined trait data place it in the category of a competitive ruderal species (Hodgson et al. 1999).

CONCLUSIONS

As previously mentioned, little is known of the ecology of this locally abundant but narrowly endemic species, and much of its known range is slated to undergo various thinning and prescribed burning activities in the very near future. Many *Astragalus* species are long-lived, recruit slowly by seed, and maintain long-lived seeds in the soil seed bank. Whether *A. rusbyi* utilizes a similar strategy is unknown but could be determined from additional research. We currently do not have a thorough understanding of the population dynamics of this species over time. Rigorous long-term demographic monitoring would be valuable in determining population baselines and is essential for understanding the ecology and conservation and habitat needs of this species. Such monitoring can also reveal patterns that might be caused by precipitation fluctuations. From the information available, it appears to have a large taproot, which should give some resistance to the impacts of drought and fire, but high-intensity fire or burning at peak growth times could be detrimental. It has shown positive to no effects from tree thinning and prescribed burning operations in ecological restoration research studies, but additional research that specifically targets this species would be useful before we can draw firm conclusions.

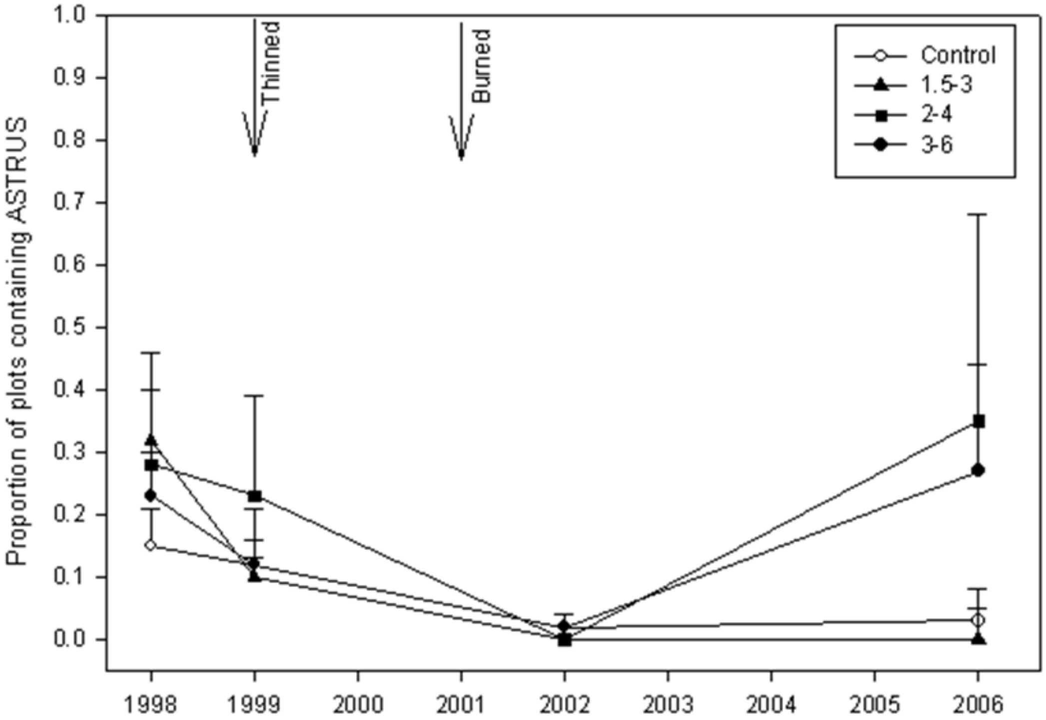

Figure 3. Proportion of permanent monitoring plots through time containing *Astragalus rusbyi* at an ecological restoration study area near Flagstaff, AZ. Treatments were randomly assigned within each block and included (a) no thinning, no burning (control), (b) 1.5-3 tree replacement (high-intensity thinning), (c) 2-4 tree replacement (medium-intensity thinning), and (d) 3-6 tree replacement (low-intensity thinning). All treatment units were thinned in 1999 and subsequently treated with prescribed fire in spring 2000 (Block 3) and spring 2001 (Blocks 1 and 2).

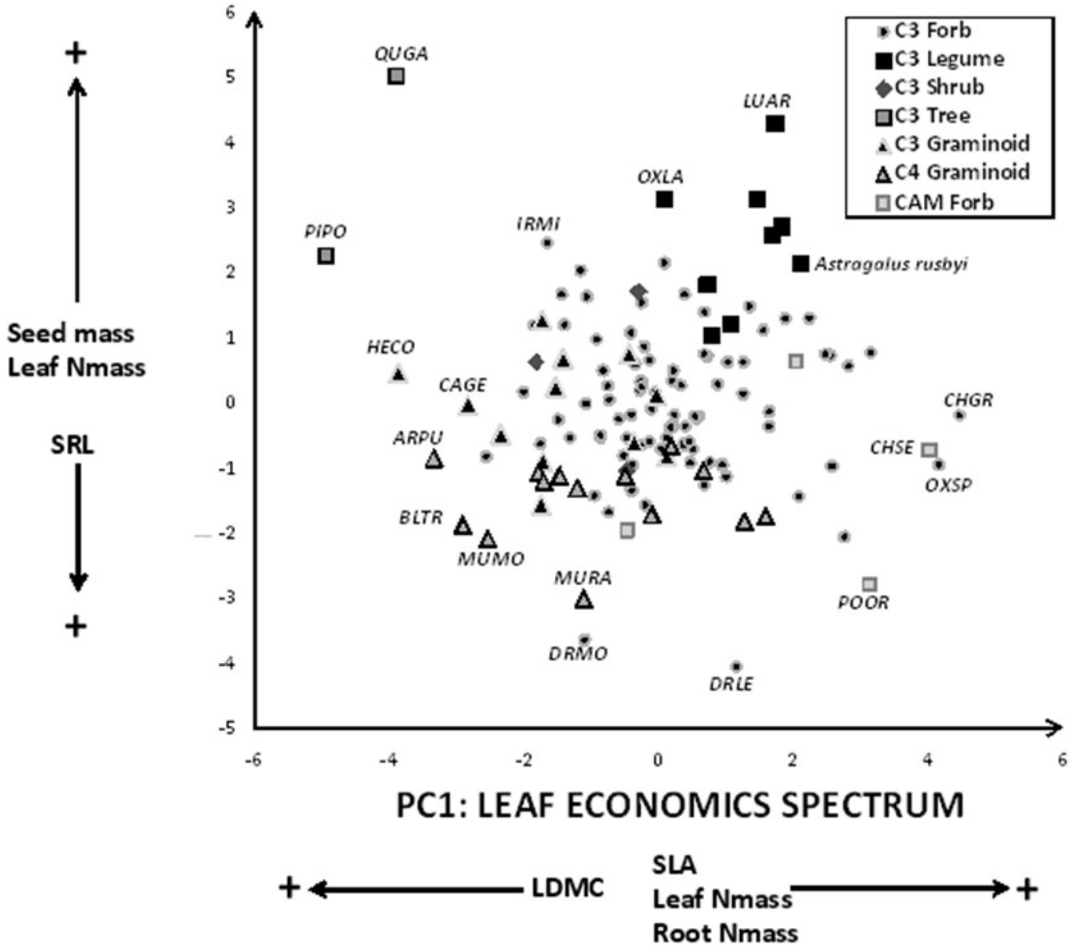

Figure 4. *Astragalus rusbyi* is located at the positive end of the 'leaf economic spectrum' because of its high specific leaf area and tissue nitrogen concentration. This scatterplot illustrates the results of a principal components analysis of 133 plant species and 10 functional traits (adapted from Laughlin 2009) that occur in southwestern USA ponderosa pine forests. Species symbols are coded by plant functional types. A few species names are highlighted: ARPU = *Aristida purpurea*, BLTR = *Blepharoneuron tricholepis*, CAGE = *Carex geophila*, *HECO = Hesperostipa comata*, IRMI = *Iris missouriensis*, LUAR = *Lupinus argenteus*, MUMO = *Muhlenbergia montana*, OXLA = *Oxytropis lambertii*, PIPO = *Pinus ponderosa*, QUGA = *Quercus gambelii*.

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Long-term Responses of *Penstemon clutei* (Sunset Crater Beardtongue) to Root Trenching and Prescribed Fire: Clues for Population Persistence

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Abstract. *Penstemon clutei* A. Nelson (Sunset Crater beardtongue) is narrowly endemic to the cinder hills and volcanic fields northeast of Flagstaff, Arizona. Disturbances such as wildfire, tornadoes, logging activity, and tree mortality from bark beetle outbreaks appear to stimulate regeneration of this species, but the manner in which populations persist between events is still largely unknown. From 1994-2000, we examined *P. clutei* responses to prescribed burning and root trenching treatments that were experimentally implemented as proxies for surface fire and reduced tree densities that might be observed following natural disturbance. We revisited this experiment in 2008 to assess long-term effects of the treatments. We also collected soil samples at this time to evaluate the importance of a persistent seed bank in population dynamics. In 2008, the mean number of *P. clutei* plants on trenched plots had declined with time, but was still significantly higher than on the control plots (mean density of 7.4 plants in trenched plots vs. 0.6 plants in control plots). There was no significant difference in density between burned and unburned plots. Only 21 *P. clutei* seedlings emerged from 176 soil seed bank samples, and we found no correlation between the number of *P. clutei* plants aboveground and the number of emergents from the samples. A targeted study to obtain samples near the base of reproductively mature plants produced 9 emergents from 30 samples. Results from this work suggest that disturbances that reduce competition for soil resources may be associated with long-term population persistence. Latent seed banks appear to be of only minor importance in recovery after disturbance; however, additional research with larger sample sizes would allow for greater confidence in this conclusion. We also recommend that additional long-term research be conducted on the response of this species to specific disturbances and stressors such as wildfire, tree mortality from bark beetle outbreaks, and water limitations.

Penstemon clutei (Sunset Crater beardtongue) is a narrow endemic that occurs on volcanic soils to the northeast of Flagstaff in northern Arizona. The species is primarily restricted to tephra deposits from the Sunset Crater eruption (estimated dates of eruption vary from approximately 1040-1100 AD) at an elevation of approximately 2135 m (7000 ft), but a disjunct population is also present on older cinder cones about 20 km to the northwest of Sunset Crater (Figure 1). *P. clutei* is typically found in open ponderosa pine forests and pinyon-juniper woodlands in areas containing a sparse understory, commonly on fairly coarse and dry, cindery soils that lie over a series of finer textured sandy or silty bands, which may alternate with coarse layers of cinders (Abella and Covington 2006, Phillips et al. 1992). The type specimen was collected by Willard Clute in July 1923 north of the San Francisco Peaks in "lava sand," and was described and named by Aven Nelson from the University of Wyoming (Nelson 1927). Growing to about 50-75 cm (20-30 in) in height, *P. clutei* has bluish-green glaucous leaves with serrated margins and gradually inflated, deep pink corollas. It is a very showy and attractive specimen plant and is readily available to gardeners through the horticultural trade. Flowering times vary by year, but it has been observed to flower from April through early September. It is ranked G2 (imperiled) by NatureServe (2009) and is on the U.S. Forest Service sensitive species list for Region 3 (Southwestern Region) (Arizona Game and Fish Department 2003; D. C. Crisp, personal communication, 2009).

There is speculation that *P. clutei* is descended from *P. pseudospectabilis* (desert penstemon) and that geographic isolation occurred following the Sunset Crater eruption (Bateman 1980), or it may be intermediate between *P. pseudospectabilis* and *P. palmeri* (Palmer's penstemon) (Clokey and Keck 1939). Phylogeny reconstruction of the genus *Penstemon* using nuclear and chloroplast sequence data and parsimony analysis produced incongruent results (Wolfe et al. 2006). Strict consensus trees generated from ITS (Internal Transcribed Spacers) placed *P. clutei* in a polytomy with *P. bicolor* (pinto beardtongue), *P. floridus* (Panamint beardtongue), *P. palmeri*, and *P. rubicundus* (Wassuk Range beardtongue). In contrast, strict consensus trees generated from chloroplast sequence data placed *P. clutei* as sister to *P. centranthifolius* (scarlet bugler) (Wolfe et al. 2006). With both methods (ITS and chloroplast sequence), the genera within the tribe Cheloneae had high bootstrap values. However, few terminal line-

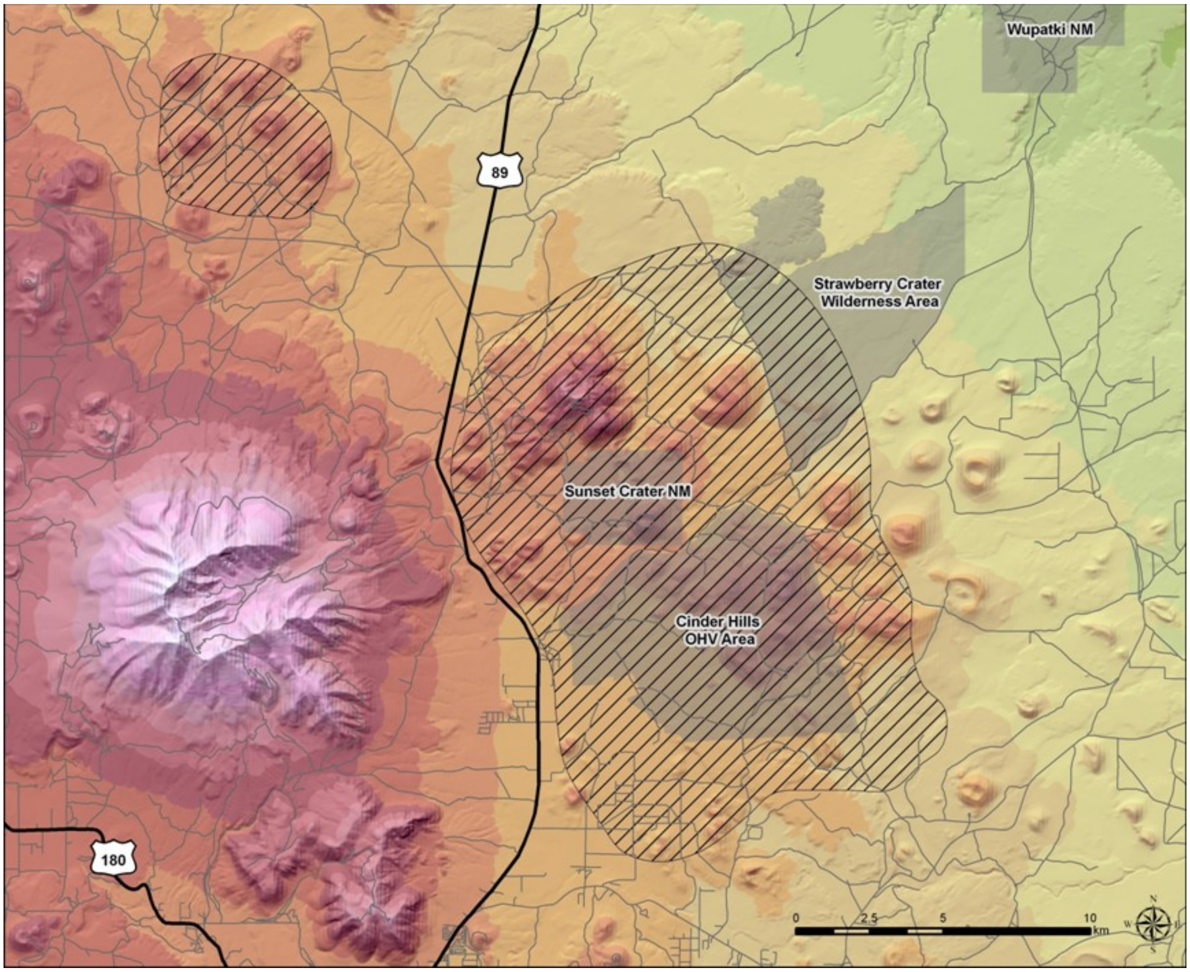

Figure 1. Range of *Penstemon clutei* (Sunset Crater beardtongue) in northern Arizona.

ages of sister taxa within the *Penstemon* clade had bootstrap values above 70%, which is the generally accepted value for moderate to strong support. The contradictory results are likely due to hybridization and/or rapid speciation among penstemons. Wolfe and her co-authors (1998) have documented hybridization among some *Penstemon* species and have also demonstrated that pollen-mediated gene flow occurs via hummingbird vectors.

Many narrow endemics are found in extreme edaphic conditions, including recent volcanic soils (Lesica et al. 2006). Characteristic of many of these species are high population growth rates but poor dispersal rates. Their restricted ranges may in some cases be due more to recent evolution than to ecological tolerance: it may simply be the case that some species have not yet had time to spread across the landscape and may therefore be relatively young (neoendemics) (Lesica et al. 2006). Neoendemism is common in intermountain regions of western North America, and *P. clutei* is likely a fairly recently evolved species.

Little is currently known about the ecology of *P. clutei,* and information in the scientific literature is sparse. It is believed to be a short-lived perennial like many other taxa in the genus *Penstemon*, perhaps living five to seven years on average. No long-term population studies following individual plants have been conducted to date in its natural habitat, so estimates of its longevity are purely speculative at this time. Observations in the field have suggested a link to disturbances. Prolific growth was observed following the Burnt Fire in 1973 (Goodwin 1979) and the Hochderffer Fire in 1996 (Fulé et al. 2001). It has also been observed growing in large numbers in the path left by a tornado (Crisp 1996) as well as surrounding *Pinus edulis* (pinyon pine) trees that were killed by drought and bark beetles in 2002-2003 (J.D. Springer, personal observations, 2008 and 2009). Phillips and others (1992) noted vigorous plants and high seedling numbers in areas of past disturbance, especially from logging operations. Plants were particularly prevalent near decaying logs and stumps. Large numbers of reproductively mature plants are also sometimes found in a ring surrounding recent *Pinus ponderosa* (ponderosa pine) snags (Fulé et al. 2001).

Because plants had been noted to emerge in abundance following wildfire, two prescribed burning studies were established by the U.S. Forest Service, but results were inconclusive (Nagiller 1992). We initiated a study in 1992 to test the hypothesis that restoration of historic ecosystem conditions may enhance the sustainability of this species (Fulé et al. 2001). This study encompassed several components, including seed germination studies, a field seeding trial, a prescribed burning study and a trenching experiment. We initiated the prescribed burning component in 1994 to test the hypothesis that prescribed fire would increase *P. clutei* density by removing litter and competing vegetation. The results suggest that prescribed burning caused a significant decline in density by as much as 75%. However, density also declined in two of the three control areas (in one area also by as much as 75%). So, while prescribed burning appears to be responsible for the death of mature plants, natural population declines may also occur in the absence of disturbance.

After evaluating results from the prescribed burning experiment, we investigated the possibility that vigorous responses following fires were a result of mortality of overstory trees and removal of root competition (Fulé et al. 2001). We initiated a study in 1998 to test the hypothesis that cutting root competition through trenching would increase *P. clutei* density. In 1999, one year following the trenching, there was a significant difference in density between trenched (mean of 104.9 plants/plot) and control plots (14.0 plants/plot), mostly in the form of seedlings. By 2000, densities had declined to an average of 30.6 vs. 1.5 plants in the trenched and control plots, respectively, mostly due to the death of seedlings. Two preliminary conclusions were drawn from the trenching study: 1) trenching had a positive effect on *P. clutei* reproduction, and this trend was still evident a year later, and 2) increases in *P. clutei* were likely due to reduced root competition with overstory trees. Although our earlier germination experiments indicated that *P. clutei* did not exhibit innate seed dormancy under laboratory conditions (see Fulé et al. 2001), we were puzzled over the dramatic field response to root trenching. A field seeding trial of *P. clutei* showed very poor rates of establishment (0.1-0.6%), with no seedlings establishing after an April seeding, and only a minimal number establishing following an October seeding (Fulé et al. 2001). Determining whether *P. clutei* maintains a persistent soil seed bank is crucial for conservation and management efforts. The combined results from our previous studies suggest that it does not form a persistent seed bank, that there may be dissimilarities in germination rates between plants from different habitats, and that field emergence is extremely low and/or seedling mortality is high. Collecting *P. clutei* seeds from additional habitats could yield new information on whether this species exhibits cyclic dormancy patterns or dormancy that differs in contrasting habitats.

It remains largely unknown, then, how long populations of *P. clutei* plants persist on the landscape following disturbance, what mechanism this species employs to colonize an area following disturbance, or how it is able to disperse across the landscape. In an effort to gain answers to some of these questions, we revisited the study area ten years after root trenching and 13-14 years following prescribed burning. Our objectives were to assess the long-term effects of the prescribed burning and trenching treatments and to evaluate the importance of a persistent seed bank in population dynamics.

METHODS

Fulé and others (2001) described methods of our previous prescribed burning and root trenching studies in detail, but we will also summarize them here. The experimental studies described in this and the 2001 paper were established in 1992-1994 and conducted on Coconino National Forest lands in the vicinity of O'Leary Peak, adjacent to Sunset Crater National Monument (Figure 1). The elevation of the study area is approximately 2100-2300 m (6890-7550 ft). Soils are cindery and deep, well-drained Vitrandic Ustochrepts and Typic Ustorthents (Miller et al. 1995). Weather records from Sunset Crater National Monument, 1 km south of the study area, include an annual precipitation average of 42.7 cm (16.8 in) (1969-2008), with most precipitation occurring in winter and during the summer monsoon (July-September). However, annual precipitation has varied widely in recent decades from a low of 23.6 cm (9.3 in) in 1989 to 66 cm (26.0 in) in 1992. The average minimum temperature in January is -11° C and the average maximum temperature in July is 29° C.

We established an experiment to study the effects of prescribed burning on the *P. clutei* community in 1994. Forty *P. clutei* plant-centered plots were established, each with a 2.5 m radius circle (area = 19.6 m^2) centered 0.3 m northwest of an existing plant. *P. clutei* was tallied in four categories: seedling, second-year plant, mature plant, and dead. Field experience indicated that the distinctions between the living plant categories were approximate. Plots were randomly selected for burn or control treatments, and burning was conducted in September 1994. Burn season effects were tested on a second experimental site immediately north of the fall burning site, and twenty randomly selected plots were burned in April 1995. The fall burn plots were re-measured in July 1995. All 80 plots, including spring and fall burns, were re-measured in August/September 1996; August 1997; August 1998; and August/September 2008. Changes in *P. clutei* density were analyzed with repeated measures analysis of variance (Systat 8.0, SPSS Science, Chicago). Data were square-root transformed to meet ANOVA assumptions. In 2008, data were cube-root transformed, and the software used was JMP 8.0 (SAS, Cary, NC).

In October 1997 we established ten new experimental plots for root trenching within the low-elevation burning study area. Each plot was paired with a nearby control plot from the original burn experiment. The number of trenched plots was eventually dropped to eight due to off-road vehicle damage and other factors. The below ground effects of tree removal were simulated by digging a narrow trench approximately 1 m deep around each plot. Trenches were located 50 cm outside the plot boundary to avoid physical disturbance within the measured area and were lined with plastic sheeting to minimize tree root regrowth (Milne 1979). Trenches were backfilled immediately after lining, and plots were re-measured in August 1998, September 1999, August 2000 and August/September 2008. *P. clutei* density was analyzed as described for the prescribed burning study above.

In 2008, we collected two soil seed bank samples from each of the 80 prescribed burning study plots and also from the trenched plots (176 total). Samples were collected to a depth of 5 cm, approximately 15 cm away from the original plot center to the east and west, and each core was approximately 70 cm^3 in volume. We also collected 30 targeted seed bank samples 15 cm to the east and west of reproductively mature individuals that were located outside of plots. Seeds are dispersed in the fall and winter, and germination is thought to occur during late spring and early summer rains, so we collected soil seed bank samples in late August and early September, presumably after germination occurred, but before new seeds were dispersed, in an effort to capture seeds in the persistent soil seed bank. We sieved samples to remove large cinders and placed the soil samples on potting soil in gallon-sized pots. Samples were placed in the greenhouse in September 2008 and received artificial light, one application of Miracle Gro® and daily watering for five months, using the seed emergence method (Ter Heedt et al. 1996).

RESULTS

In 2008, thirteen and fourteen years after spring and fall burning, respectively, there was no significant difference in *P. clutei* density between burned and unburned plots (Figure 2). Mean density in burned plots (combined spring and fall burns) was 0.9 live plants, and mean density in control plots was 0.6 live plants. Over the course of this study, there has been a general decline in *P. clutei* in both burned and control plots. However, there was still a significant difference in mean density between trenched and control plots ten years

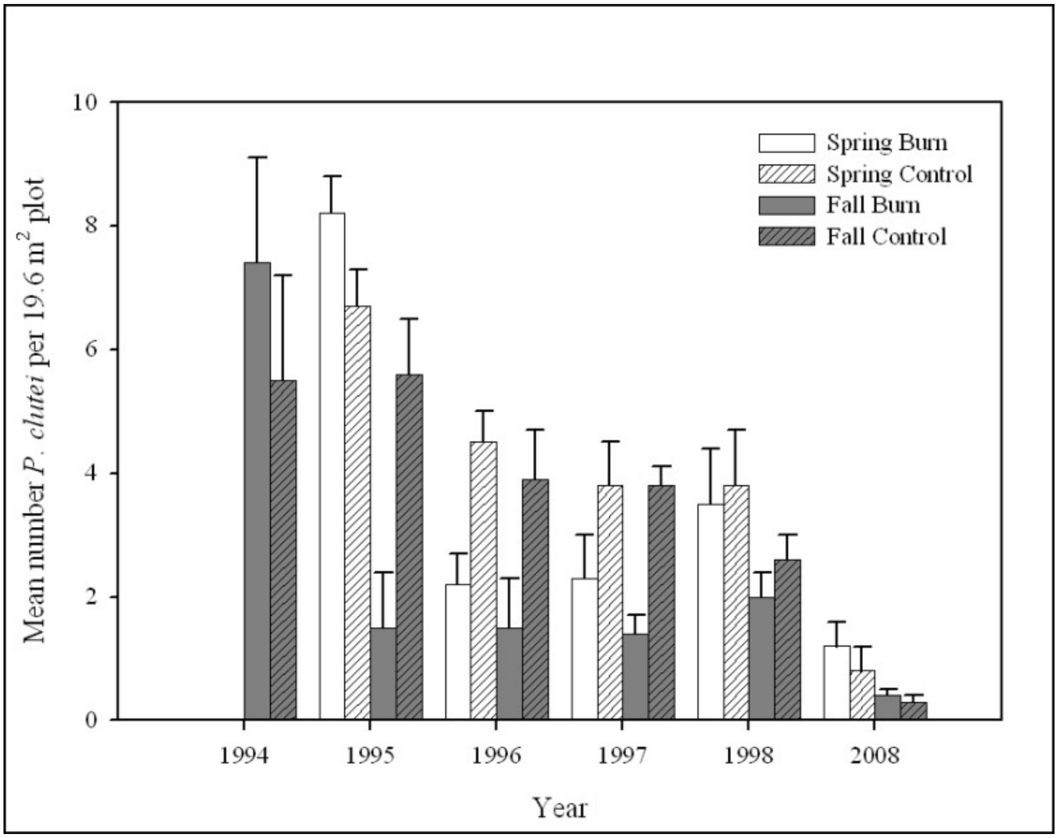

Figure 2. Mean density of *Penstemon clutei* plants following a prescribed burn study near Sunset Crater National Monument in northern Arizona. Pre-treatment data were collected in 1994 and 1995. Bars indicate standard error.

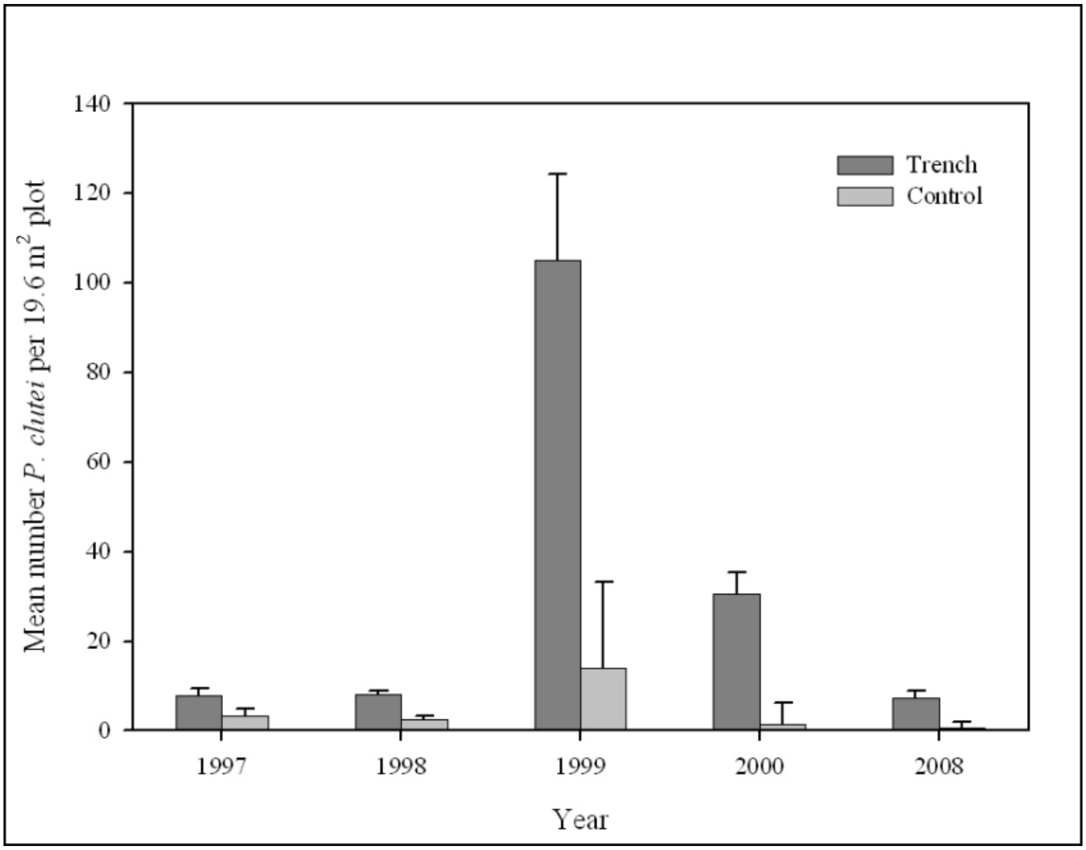

Figure 3. Mean density of *Penstemon clutei* plants following a root trenching experiment near Sunset Crater National Monument in northern Arizona . Pre-treatment data were collected in 1997. Bars indicate standard error (each plot was 19.6 m^2; n=80; p value in 2008 was <0.01).

after the first re-measurement, with mean density in trenched plots significantly higher ($p<0.01$; F=7.8). There was also a highly significant treatment effect over time ($p <0.0001$; F= 31.4) (Figure 3). In addition, 75% of the trenched plots contained living plants in 2008 (mostly reproductively mature plants), whereas only 43% of the control plots contained living individuals, and these were all young plants (one year or less). No control plots contained mature plants. Overall, the mean density of plants was 7.4 in trenched plots and 0.6 in control plots.

There was no correlation between the number of live *P. clutei* plants in the study plots and the number of emergent seedlings in the soil seed bank samples taken from these same plots ($r^2 = 0.008$). Eighteen seedlings emerged from the samples collected from the plots used in the prescribed burning study. However, nearly all of these seedlings (94%) emerged from control (unburned) plots, and of the 40 unburned plots sampled, 8 of these produced seedlings (20%). Of the four seedlings that emerged from the soil seed bank samples collected from the trenching experiment, three (75%) emerged from the trenched plots, and one seedling emerged in a control plot. Thirteen percent of the soil seed bank samples taken from trenched plots produced seedlings. In the targeted study, nine seedlings emerged in total, and 17% of the samples produced seedlings.

DISCUSSION

The results from our re-measurements suggest that *P. clutei* populations gradually decline over time in the absence of some type of disturbance, but that plants may remain in the area for at least a decade, or possibly much longer. Populations are still present around logging slash left in place following operations in the early part of the 20th century (J.D. Springer, personal observations, 2009). We do not currently understand why this species may undergo long-term declines in established populations. Although the Southwest appears to be in a long-term dry period, weather records from Sunset Crater National Monument indicate that annual precipitation was above average for 9 out of the 17 years since the study was initiated. However, the records from which we obtained our average have only been kept since 1969.

Our study indicates the positive effect of reduced root competition may last at least ten years. This effect is presumably due to increased soil moisture availability but is possibly also due to increased nutrient availability or a combination of the two. Coomes and Grubb (2000) point to a number of studies showing that root trenching can lead to an increase in the availability of mineral nitrogen. Research by Selmants and Hart (2008) indicates that there are large carbon and nitrogen pools and fluxes under the canopies of one-seed juniper (*Juniperus monosperma*) in soils around Sunset Crater. Soils under juniper and pinyon pine canopies are generally higher in both carbon and nitrogen than are intercanopy sites, but these levels vary according to the age of the soils, which are of volcanic origin in this region.

Abella and Covington (2006) obtained samples from a number of soil types across the Coconino National Forest, including black and red cinder soils in the vicinity of Sunset Crater, and determined that black cinder soils contain the driest surface soils among those tested. These soils are very sandy (>90% concentration at 0-15 cm depth), and contained the fewest plant species per plot. Red cinder soils are also quite sandy (averaging 63% concentration at 0-15 cm depth). Soil samples taken from red cinders contained no calcium carbonate, but these soils had higher organic carbon and total nitrogen than the black cinder soils, and they also had higher soil moisture. *P. clutei* populations in pinyon-juniper woodlands are typically found on these older, red cinder soils.

The soils on which *P. clutei* grows, then, are arguably some of the harshest in northern Arizona and are susceptible to extreme environmental fluctuations. Seedling mortality is high, but once plants reach maturity, they have adapted to the harsh, arid environment by means of a large taproot or thick lateral roots (D.W. Huffman, personal observations, 2008) and thick leaves. The species also must have developed adaptations to be able to rapidly colonize following disturbance, perhaps through longevity, rapid dispersal, high germinability, or a persistent soil seed bank. Soil seed banks buffer populations against environmental variation, and seed dormancy is a mechanism of escape from unfavorable conditions in time (compared to dispersal, which is an escape in space) (Doak et al. 2002). Short-lived perennials in areas of high environmental variation, which includes most rare plants in the Southwest, often rely on the soil seed bank for recruitment (Doak et al. 2002). *P. lemhiensis* (Lemhi penstemon) and *P. palmeri* have been documented to buffer populations against environmental fluctuations by maintaining a persistent soil seed bank (Heidel and Shelly 2001, Meyer and Kitchen 1992). Conversely, long-lived perennials are often more reliant on growth and survival of established plants than on recruitment from seed or soil seed banks (Lesica 1995). If a species does not exhibit innate dormancy, it is unlikely that it forms a soil seed bank. Because *P. clutei* plants have been observed to appear in large numbers following a disturbance such as the Hochderffer Fire (P.Z. Fulé, personal observation, 1997 and 1998), conventional thinking is that this species forms a persistent soil seed bank (Phillips et al. 1992), but it may also maintain genetic diversity through existing reproductively mature plants scattered across the landscape, or exhibit rapid dispersal rates following disturbance. While it does seem from our study that *P. clutei* may form a minor persistent seed bank, the degree of its importance in recovery following disturbance is unknown, and larger sample sizes from additional habitats are necessary in order to make inferences about its significance for recruitment following disturbance.

Meyer et al. (1995) found a diversity of germination timing mechanisms in 38 Intermountain West *Penstemon* species. Seeds of many of these species diverge into two fractions. One fraction does not exhibit dormancy and will germinate readily under optimal conditions in the first year. The other fraction may respond to chilling cues and become nongerminable, allowing for between-year carryover in the soil seed bank. Meyer and her co-authors (1995) found this strategy to be especially common in populations of penstemons from middle elevation areas that have unpredictable winters. Meyer and Kitchen (1992) discovered that *P. palmeri* seeds undergo cyclic dormancy changes in the field. Moist chilling induces secondary dormancy in about half of the seeds, while moisture combined with summer temperatures removes secondary dormancy. These mechanisms allow for a persistent soil seed bank and for seeds that can persist from year to year without burial. The result is that some seeds germinate in the spring, while those seeds that are rendered dormant by chilling are carried over in the soil seed bank. Another fruitful area of research for this species could include seed augmentation studies to determine if a paucity of viable seeds may be limiting establishment. Abella (2008) conducted such a study with *P. virgatus* (upright blue beardtongue) in a ponderosa pine forest not far from our study site and found that under particular experimental conditions, the site environment (e.g., tree overstory) apparently was more limiting to recruitment than either leaf litter thickness or seed availability.

Our results also indicate that prescribed burning alone does not seem to be a useful management tool for this species, as it appears to kill reproductively mature individuals leading to potential decreases in available seeds for future recruitment. An experiment involving use of prescribed fire as a management tool for *P. lemhiensis* returned variable results (Heidel and Shelly 2001). Fire appeared to cause mortality of adult plants ranging from 25-75%. However, the burning caused an increased recruitment rate of 4600-6400%. As we pointed out in our previous paper (Fulé et al. 2001), patchy tree mortality does appear to benefit *P. clutei*. Tree mortality from the 2002-2003 bark beetle outbreak among pinyon pines appears to be correlated with dramatic increases in the number of reproductively mature individuals on the south-facing slopes of cinder cones in the vicinity of Sunset Crater and Indian Flat (J.D. Springer, personal observations, 2008 and 2009).

Although some *P. clutei* populations contain hundreds or thousands of individuals, populations are often widely dispersed, and there are a few major threats that could jeopardize this species in the future. The entire range of *P. clutei* has not yet been mapped; however, a large portion of its known range falls within the Cinder Hills OHV (off-highway vehicle) area (Figure 1). Most of this area is not fenced and OHV use spills outside the boundaries shown in the map. Although *P. clutei* appears to benefit from disturbance, whether disturbance is beneficial or detrimental depends on the type of disturbance and the amount of impact. No quantifiable data has yet been collected on the impacts of OHV activity on this species, but anecdotal evidence points to OHVs as a direct factor in adult *P. clutei* mortality (J.D. Springer, personal observations, 2008). OHV activity causes above- and belowground soil impacts, resulting in decreased soil moisture, increased soil bulk density, and increased water infiltration time, which have been shown to negatively impact plant species in the area, such as ponderosa pine (Kennedy 2005).

While OHV use and impacts can be controlled, potential negative changes to *P. clutei* habitat from climate change cannot. Climate models predict a more arid climate in the southwestern U.S. in the coming decades (Seager et al. 2007). This species already lives in a harsh environment, and any major decreases in available soil moisture could significantly impact its long-term viability. Additional threats include potential hybridization with other *Penstemon* species brought to the area for horticulture or highway revegetation purposes, herbivory, insect damage and urban expansion.

Determining the long-term population dynamics of this species is integral to future conservation management planning and points out the direct need for long-term monitoring, particularly in the face of potential climate change and unmanaged OHV use in the center of its habitat. Teasing out whether *P. clutei* population declines occur from disturbance, absence of disturbance, senescence, competition, drought, climate change, interactive effects, or other as yet undetermined factors will be critical for understanding future conservation and management needs for this species.

ACKNOWLDEGMENTS

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¡Viva thamnophila! Ecology of Zapata Bladderpod (*Physaria thamnophila*), an Endangered Plant of the Texas-Mexico Borderlands

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Abstract. Conserving rare plants is dependent upon our ability to identify, manage and restore their habitat. We examined the plant community associates and habitat requirements of *Physaria thamnophila*, an endangered herbaceous perennial of the Tamaulipan shrubland of south Texas, at four sites from 2003 to 2007. At each site, vegetation height structure and species composition were sampled concurrently with intermittent censuses of *P. thamnophila*. We found significant and interesting differences among sites and years, as well as between our quantitative results and previous descriptions of *P. thamnophila*'s community and habitat. Existing plant community descriptions and mapped soil types do not provide a close match with our field observations. Finally, we discuss the application of these results to conservation of *P. thamnophila* and restoration of its community.

An endangered plant that is a member of a fragmented and altered remnant plant community poses many challenges to conservation workers. In addition to threats to its (usually) few and small known populations, two additional challenges are faced. One, the detection of additional populations is often hampered by uncertainty in identifying its habitat; and two, uncertainty about its habitat requirements hampers management and restoration efforts. *Physaria thamnophila* (Zapata bladderpod; Brassicaceae) is one such plant. This endangered herbaceous perennial of south Texas grows in remnants of Tamaulipan thornscrub, likely on a specific but as yet poorly defined soil type and geologic substrate. Prior to the present study, the structure and composition of the specific plant community in which Zapata bladderpod occurs had been examined quantitatively for only one site (Sternberg 2005).

The U.S. Fish and Wildlife Service (USFWS) Recovery Plan (USFWS 2004) highlights the need for better knowledge of the habitat and community in which *P. thamnophila* lives for several purposes, including discovering additional populations, locating sites for establishing new populations, and restoring and managing its habitat. This study addresses these goals by providing a detailed, quantitative description of the habitat and community of four sites with persistent (as defined by NatureServe 2002) *P. thamnophila* populations. The results will not only be useful for *P. thamnophila* conservation, but can improve our ability to manage and restore one of the communities that comprise the Tamaulipan thornscrub ecosystem.

SPECIES

Physaria thamnophila (Rollins and E.A. Shaw) O'Kane and Al-Shehbaz (formerly *Lesquerella thamnophila*) is a federally listed endangered species (USFWS 2004) with a global conservation ranking of G1 (critically imperiled; NatureServe 2009). It is a short-lived perennial with a rosette of silvery- or gray-green leaves covered with stellate trichomes (Figure 1) and one to several flexuous, sprawling to ascending flowering stems. The yellow flowers give rise to subglobose silicles on recurved pedicels (Rollins and Shaw 1973) (Figure 2). It usually flowers in spring (February to April), but can flower during midsummer or as late as September in response to rain (Poole et al. 2007; Sternberg 2005). Germination has not been observed, but probably occurs in response to rainfall in cool weather. Under prolonged dry conditions, all of the plant's leaves may die, making some surviving plants very difficult to locate.

Figure 1. *Physaria thamnophila* rosette leaves.

SITES

All known populations of *P. thamnophila* (eight verifiably extant, one not accessible, and one historic population; data on file, Natural Diversity Database, Texas Parks and Wildlife Department, Austin, TX) are in Starr and Zapata Counties, Texas, between Zapata and Roma, a distance of 69 km (Figure 3). All populations occur in remnant Tamaulipan thornscrub vegetation (Poole et al. 2007). For this study, we examined all sites with at least 100 plants to which we had access. Other sites were excluded due to small populations, lack of access to private land, or discovery too late to include in the study. Three of the four sites in this study (Arroyo Ramirez, Arroyo Morteros, and Cuellar) were in the Lower Rio Grande Valley National Wildlife Refuge. The fourth study site, Santa Margarita, was on private land. All four sites were within 18 km of each other in Starr County, Texas, between Falcon Dam (26° 33' N, 99° 09'W) and Roma (26° 24'N, 99° 01'W).

The climate in this region is hot and often dry. At Falcon Dam, the nearest station in the National Oceanic and Atmospheric Administration (NOAA) data base, the months of July and August have the highest means of daily maximum temperatures (37.6° C and 37.5° C, respectively) and January has the lowest mean daily minimum temperature (7.7 ° C) (NOAA 2009). Between 1963 and 2007, average annual precipitation at Falcon Dam was 515 mm. However, annual precipitation varied widely, as during those 45 years, there were 7 years with more than 600 mm and 9 years with less than 400 mm annual precipitation. During our study, 2003 and 2004 were wet (804 mm and 671 mm, respectively) and 2005 was dry (353 mm). However, precipitation in the area occurs largely as isolated thunderstorms, and likely varied among sites.

Most known populations occur on the edges of terraces above the Rio Grande flood plain. *Physaria thamnophila* populations have been found on the Jackson, Yegua and Laredo formations (Bureau of Economic Geology 1976; Poole et al. 2007; USFWS 2004), all of which are Eocene calcareous sandstones and clays. All four study sites were on Eocene sandstones: Cuellar and Arroyo Morteros on the Yegua Formation, and Arroyo Ramirez and Santa Margarita on the Jackson Group (Bureau of Economic Geology 1976). Arroyo Morteros, Arroyo Ramirez, and Santa Margarita were located along the edge of the cliff that marks the edge of the flood plain of the Rio Grande; Cuellar was ~ 3000 m from the flood plain in an area without a cliff.

Figure 2. *Physaria thamnophila* fruiting stem.

Known *P. thamnophila* populations occur on shallow, well-drained sandy loam soil. Soils at known sites are mapped as members of the Zapata, Maverick, Catarina, or Copita series as described by the Natural Resources Conservation Service (NRCS) (Poole et al. 2007; USFWS 2004). These highly calcareous soils are derived from Eocene sandstone, clay and shale. Catarina soils are derived from Frio and Yegua formation parent material; these and Maverick soils contain up to 15 percent gypsum. Copita soil is derived from weakly consolidated calcareous sandstone of the Jackson Formation and is only slightly (2 percent) gypsiferous (NRCS 2009; Thompson et al. 1972). The soils at our study sites have been described as follows: Arroyo Morteros: Copita, Zapata and Catarina; Arroyo Ramirez: Jimenez-

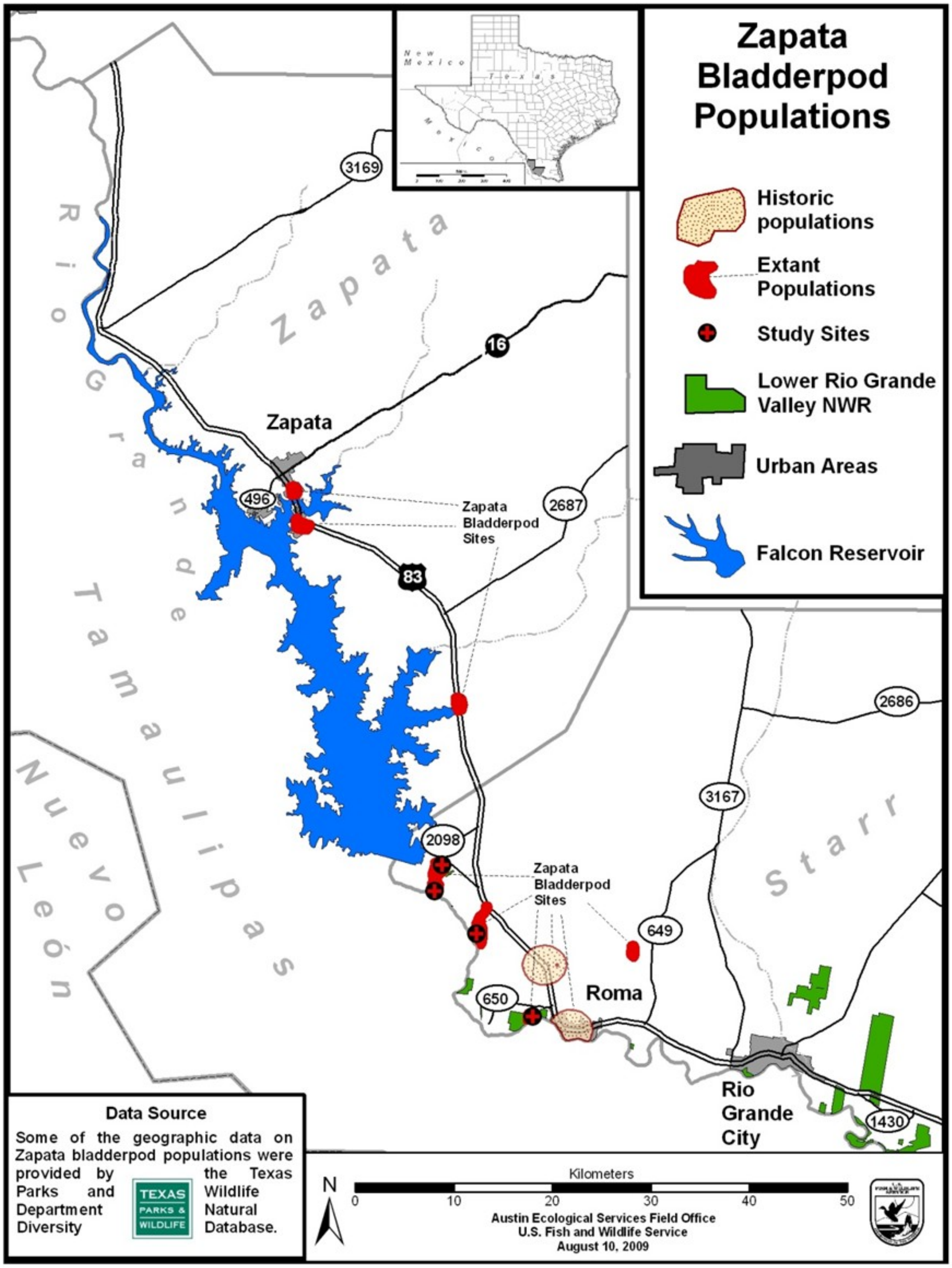


Figure 3: *Physaria thamnophila* distribution, Starr and Zapata Counties, Texas.

Quemado; Cuellar: Catarina; Santa Margarita: Maverick, eroded and Jimenez-Quemado (NRCS 2009). However, soils maps for these areas lack precision and the inclusion of *P. thamnophil*a sites within Jimenez-Quemado soil polygons is incorrect (see Discussion). In some sites, fossil oyster shells or gypsum crystals were conspicuous.

METHODS

Vegetation Data Collection

Vegetation data were collected once at Arroyo Ramirez, Arroyo Morteros, and Santa Margarita and twice at Cuellar in conjunction with intermittent censuses of the study sites (Fowler et al. 2011). Cuellar vegetation was sampled in 2002 and 2007, Arroyo Ramirez in 2003, Santa Margarita in 2004, and Arroyo Morteros in 2007. Due to limitations of time and personnel, we set up study plots at one site each year in 2002-2005. In each site, permanent circular plots marked with rebar were located randomly along transects. Some of the Cuellar census plots did not have vegetation data collected in one or both years and were dropped from analyses.

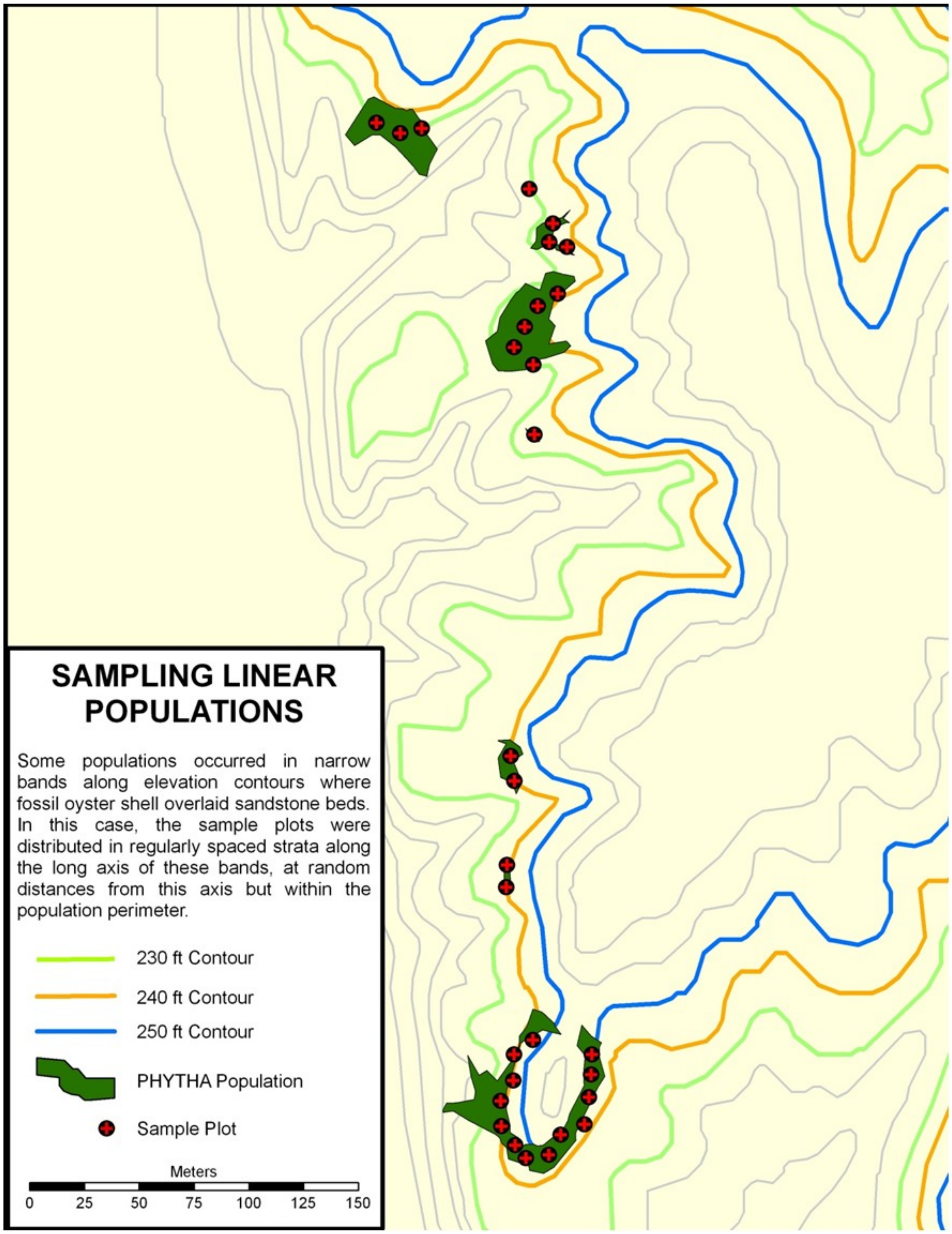
At Cuellar, 30 plots were located in an uncleared area and 30 plots in an area that had been brush-cleared using a 'Woodgator©' (roller-chopper) in December 2000. This decreased shrub canopy (see Results) and significantly increased herbaceous species richness and grass abundance in the cleared area (Fowler et al. 2011). A transect ran along the margin between the two areas, with the plots on either side. In each of the other three sites, transects were located to sample the entire *Physaria thamnophila* population. The full extent of the Santa Margarita population was unknown at the beginning of this study, and the Arroyo Ramirez and Arroyo Morteros populations were discovered in fall 2002 and summer 2004, respectively. Therefore, we first conducted reconnaissance surveys to map the populations' extents using GPS. The two roughly linear populations that followed rocky outcrops, Arroyo Ramirez and Santa Margarita, were each sampled by running a discontinuous transect (excluding unoccupied habitat) along the long axis, through the approximate midline of the population. The transect length was then divided into 30 strata, with plots located within each stratum at random distances either side of the transect line. There were 30 plots at Santa Margarita (Figure 4) and 34 plots at Arroyo Ramirez. At Arroyo Morteros, where the population occupied a large, irregular polygon, we placed 58 plots along ten parallel transects of different lengths, spaced 38m apart. The initial plot in each transect was located a random distance between 0.1 m to 10 m along the transect, with successive plots spaced 13.8 m apart.

By 2007, the cleared portion of Cuellar was quite similar to the other three sites in herbaceous species richness and grass abundance (Fowler et al. 2011). Arroyo Morteros had on average somewhat greater herbaceous species richness than the other sites (12 species per plot, on average, versus 6 to 10 in the other sites; Fowler et al. 2011).

Vegetation data from each plot were collected in five circular subplots. Each subplot was 0.25m in radius. One of these subplots was centered on the plot's central point, and the other four were centered around points located on the circumference of the circle at the distal ends of four radial lines emanating from the central point (two parallel and two perpendicular to the transect). In each subplot, the presence/absence of each species was recorded in each of 4 height categories. These categories were 0.0 to 0.5 m, 0.5 to 1.0 m, 1.0 to 2.0 m, and 2.0 to 3.0 m above ground. No plants were taller than 3 m. Species names follow USDA PLANTS database (2012) with the exception of *Physaria* and *Paysonia*, for which we follow the treatment of Al-Shehbaz and O'Kane (2002). Most common species, particularly woody dominants, were identified in the field. We collected voucher specimens when species were encountered in flower; specimens are being prepared for deposit at the University of Texas herbarium (TEX-LL).

It was not always possible to definitively identify species at the time when they were first observed. As a result, in a few cases the interim identifications used for unknown species were not consistent between years. Therefore, for analysis we pooled (a) the two *Chamaesyce* (Euphorbiaceae) species; (b) *Chaetopappa bellioides* and *Aphanostephus skirrhobasis* (Asteraceae); and (c) *Chamaesaracha sordida* and *Physalis cinerascens* (Solanaceae). This reduced the number of 'species' in the analyses from 150 to 147. For simplicity, each of these three pairs of species is referred to simply as a species. 'Bare ground' was recorded as a 148th 'species'. A few plants could never be identified; almost all of these were without fruits or flowers and many were grasses. These have been left as unknown species 1, unknown grass, etc. in Table 1.

The number of subplots in each plot in which the species occurred was used to quantify the abundance of each species. The abundance of a given species in a plot therefore had a value between 0 and 5. For *P. thamnophila* only, counts of numbers of individuals in each plot were also available. However, censuses of *P. thamnophila* were conducted in all sites in 2006 and 2007 only. We calculated the density of *P. thamnophila* in each plot by dividing the number of individuals in the plot by the plot's area, for each plot separately. *P. thamnophila* densities in 2006 and in 2007 were then averaged, for each census plot separately.



SAMPLING LINEAR POPULATIONS

Some populations occurred in narrow bands along elevation contours where fossil oyster shell overlaid sandstone beds. In this case, the sample plots were distributed in regularly spaced strata along the long axis of these bands, at random distances from this axis but within the population perimeter.

Figure 4. Sampling design for discontinuous sites.

Table 1. Species composition in *Physaria thamnophila* study plots by site

Scientific Name	Family	>1 m tall?	# Sites w/sp[a]	% of Subplots Occupied in Each Site[b]						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Abutilon fruticosum	Malvaceae		1	-	-	0.74	-	-	-	-
Acacia berlandieri	Fabaceae		1	-	-	-	-	-	-	0.67
Acacia rigidula	Fabaceae	X	5	47.20	33.06	60.00	39.26	46.55	24.12	18.00
Acalypha monostachya	Euphorbiaceae		2	-	-	-	-	-	1.18	9.33
Acleisanthes obtusa	Nyctaginaceae		2	-	-	2.22	-	-	2.35	-
Acourtia runcinata	Asteraceae		1	-	-	-	-	-	-	0.67
Allionia incarnata	Nyctaginaceae		3	-	-	-	-	0.34	8.82	3.33
Aloysia macrostachya	Verbenaceae	X	3	-	2.42	-	13.33	-	0.59	3.33
Argythamnia humilis var. *humilis*	Euphorbiaceae		5	0.80	-	0.74	2.22	0.69	1.18	0.67
Aristida purpurea	Poaceae		5	17.60	1.61	28.89	4.44	11.72	42.94	66.67
Aristolochia sp.	Aristolochiaceae		1	-	-	-	-	-	-	0.67
Astragalus nuttallianus	Fabaceae		2	-	-	0.74	2.22	-	-	-
Astragalus sp. 2	Fabaceae		1	-	-	-	-	0.34	-	-
Ayenia pilosa	Sterculiaceae		5	-	-	2.96	2.22	0.34	4.12	2.67
Bahia absinthifolia	Asteraceae		1	-	-	-	-	0.69	-	-
Bothriochloa laguroides ssp. *torreyana*	Poaceae		1	-	-	-	-	-	1.18	-
Bouteloua repens	Poaceae		1	-	-	-	-	-	-	0.67
Bouteloua trifida	Poaceae		5	16.80	-	8.15	1.48	9.66	8.24	2.67
Cardiospermum dissectum	Sapindaceae		1	-	-	-	-	-	16.47	-
Celtis ehrenbergiana	Ulmaceae	X	2	-	-	0.74	-	1.03	-	-
Celtis laevigata	Ulmaceae		1	-	-	-	-	-	0.59	-
Cenchrus spinifex	Poaceae		2	-	-	2.22	-	0.69	-	-
Cevallia sinuata	Loasaceae		1	-	-	-	-	3.45	-	-
Chaetopappa bellioides and *Aphanostephus skirrhobasis* var. *kidderi*	Asteraceae		5	1.60	-	19.26	3.70	50.00	4.12	14.67
Chamaesaracha sordida and *Physalis cinerascens*	Solanaceae		3	-	-	-	4.44	26.55	-	8.67

Table 1. continued

Scientific Name	**Family**	**>1 m tall?**	**# Sites w/sp**[a]	**% of Subplots Occupied in Each Site**[b]						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Chamaesyce laredana and *C. cinerascens*	Euphorbiaceae		4	24.00	14.52	5.93	11.85	6.55	-	6.00
Cissus trifoliata	Vitaceae		2	-	-	-	0.74	0.69	-	-
Citharexylum brachyanthum	Verbenaceae	X	4	0.80	0.81	1.48	2.96	2.07	0.59	-
Commelina erecta	Commelinaceae		4	-	-	-	1.48	0.69	0.59	2.67
Condalia spathulata	Rhamnaceae		1	-	-	-	-	0.34	-	-
Convolvulus equitans	Convolvulaceae		3	-	-	0.74	0.74	0.69	-	-
Cooperia sp.	Liliaceae		2	-	-	-	-	-	1.76	1.33
Croton incanus	Euphorbiaceae	X	1	-	-	-	-	-	12.94	-
Cynanchum barbigerum	Asclepiadaceae	X	4	-	-	1.48	2.96	1.72	2.94	-
Cyperus sp.	Cyperaceae		5	0.80	-	2.96	0.74	6.21	1.18	1.33
Dalea nana	Fabaceae		2	4.00	-	8.89	-	-	0.59	-
Dalea pogonathera	Fabaceae		1	-	-	-	-	0.34	-	-
Digitaria cognata	Poaceae		4	-	-	2.96	-	0.34	7.65	16.00
Diospyros texana	Ebenaceae	X	4	0.80	-	0.74	-	3.45	2.35	4.00
Echinocactus texensis	Cactaceae		1	-	-	-	-	-	0.59	-
Echinocereus enneacanthus	Cactaceae		3	-	-	-	-	0.34	1.76	0.67
Echinocereus poselgeri	Cactaceae		4	-	0.81	-	1.48	0.34	1.76	0.67
Echinocereus reichenbachii ssp. *fitchii*	Cactaceae		1	-	-	-	-	-	-	0.67
Ephedra antisyphilitica	Ephedraceae	X	3	0.80	-	0.74	-	-	18.24	4.00
Eragrostis curtipedicellata	Poaeae		3	-	-	0.74	0.74	3.79	-	-
Eriogonum greggii	Polygonaceae		1	-	-	-	-	-	-	26.67
Erioneuron pilosum	Poaceae		2	-	-	-	-	-	4.12	0.67
Escobaria emskoetteriana	Cactaceae		2	-	-	-	-	-	0.59	0.67
Evolvulus alsinoides	Convolvulaceae		3	-	-	8.15	9.63	8.97	-	-
Eysenhardtia texana	Fabaceae	X	5	-	-	2.22	1.48	6.21	7.65	4.67

Table 1. continued

Scientific Name	**Family**	**>1 m tall?**	**# Sites w/sp[a]**	**% of Subplots Occupied in Each Site[b]**						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Ferocactus hamatacanthus var. *sinuatus*	Cactaceae		2	-	-	-	-	-	0.59	2.00
Fleischmannia incarnata	Asteraceae		1	-	-	-	-	0.34	-	-
Florestina tripteris	Asteraceae		1	-	-	-	-	0.34	-	-
Forestiera angustifolia	Oleaceae	X	5	0.80	8.06	2.22	8.15	23.10	4.71	6.00
Galium sp.	Rubiaceae		4	-	-	5.93	4.44	1.38	-	9.33
Galphimia angustifolia	Malphigiaceae		4	-	-	2.22	1.48	3.79	-	2.00
Gamochaeta pensylvanica	Asteraceae		1	-	-	-	-	1.03	-	-
Gilia incisa	Polemoniaceae		1	-	-	2.22	-	-	-	-
Grusonia schottii	Cactaceae		1	0.80	-	-	-	-	-	-
Guaiacum angustifolium	Zygophyllaceae		4	3.20	2.42	2.96	1.48	-	3.53	1.33
Heliotropium confertifolium	Boraginaceae		2	-	-	-	-	1.03	-	3.33
Heliotropium curassavicum	Boraginaceae		1	-	-	-	-	0.34	-	-
Herissantia crispa	Malvaceae		2	-	-	-	-	0.69	1.18	-
Heterotheca sp.	Asteraceae		1	-	-	-	-	0.34	-	-
Hibiscus martianus	Malvaceae		3	-	-	0.74	0.74	-	0.59	-
Ibervillea lindheimeri	Cucurbitaceae		2	-	-	-	-	0.34	-	0.67
Jatropha dioica	Eupohorbiaceae	X	5	4.80	3.23	5.93	7.41	11.38	5.88	3.33
Jefea brevifolia	Asteraceae		2	0.80	-	-	-	-	-	1.33
Justicia pilosella	Acanthaceae		2	-	-	-	-	0.34	1.18	-
Karwinskia humboldtiana	Rhamnaceae	X	5	1.60	5.65	4.44	9.63	7.93	12.35	16.00
Koeberlinia spinosa	Capparaceae	X	1	-	0.81	-	-	-	-	-
Krameria ramosissima	Krameriaceae		5	8.00	4.84	7.41	7.41	3.45	16.47	10.00
Lantana achyranthifolia	Verbenaceae		1	-	-	-	-	6.90	-	-
Lantana urticoides	Verbenaceae		2	-	-	-	1.48	1.72	-	-
Lepidium lasiocarpum var. *wrightii*	Brassicaceae		1	-	-	-	-	2.76	-	-
Leucophyllum frutescens	Scrophulariaceae	X	5	30.40	52.42	62.96	72.59	13.79	11.76	11.33

Table 1. continued

Scientific Name	**Family**	**>1 m tall?**	**# Sites w/sp**[a]	**% of Subplots Occupied in Each Site**[b]						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Linum lundellii	Linaceae		5	-	-	14.07	10.37	2.07	1.18	2.67
Lippia graveolens	Verbenaceae	X	5	6.40	12.10	13.33	19.26	3.10	22.94	8.00
Lupinus texensis	Fabaceae		1	-	-	-	-	-	-	1.33
Lycium berlandieri	Solanaceae		2	-	-	-	-	0.34	0.59	-
Macrosiphonia lanuginosa	Apocynaceae		1	-	-	-	-	-	-	0.67
Mammillaria heyderi	Cactaceae		1	-	-	-	-	-	2.35	-
Mammillaria sphaerica	Cactaceae		1	-	-	-	-	-	0.59	-
Manfreda longiflora	Agavaceae		1	-	-	-	-	-	0.59	-
Maurandya antirrhiniflora	Scrophulariaceae	X	1	-	-	-	-	6.55	-	-
Melampodium cinereum	Asteraceae		5	25.60	9.68	29.63	27.41	23.79	3.53	4.67
Melinis repens	Poaceae		1	-	-	-	-	0.34	-	-
Mimosa texana (*M. wherryana*)	Fabaceae	X	5	8.80	13.71	13.33	13.33	11.72	5.29	12.67
Nama hispidum	Hydrophyllaceae		4	-	-	20.74	28.89	41.38	-	1.33
Oenothera laciniata	Onagraceae		3	-	-	8.89	7.41	10.34	-	-
Opuntia engelmannii	Cactaceae	X	4	0.80	-	1.48	0.74	2.41	2.94	-
Opuntia leptocaulis	Cactaceae	X	4	-	1.61	-	1.48	0.34	1.18	0.67
Opuntia sp.	Cactaceae		1	-	-	-	-	-	0.59	-
Oxalis dichondrifolia	Oxalidaceae		3	-	-	5.19	2.22	1.38	-	-
Palafoxia texana	Asteraceae		2	-	-	1.48	-	7.24	-	-
Panicum hallii	Poaceae		1	-	-	-	-	0.69	-	-
Parietaria pensylvanica	Urticaceae		4	-	-	3.70	1.48	9.66	-	1.33
Parkinsonia texana var. *texana* (*Cercidium texanum*)	Fabaceae	X	4	1.60	3.23	4.44	2.96	3.10	0.59	-
Parthenium confertum	Asteraceae		3	4.00	2.42	2.96	3.70	22.76	-	-
Paspalum setaceum	Poaceae		1	-	-	-	-	0.34	-	-
Passiflora tenuiloba	Passifloraceae		2	-	-	-	-	0.34	2.35	-

Table 1. continued

Scientific Name	**Family**	**>1 m tall?**	**# Sites w/sp[a]**	**% of Subplots Occupied in Each Site[b]**						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Paysonia lasiocarpa	Brassicaceae		1	-	-	-	-	1.72		-
Pennisetum ciliare	Poaceae		3	-	-	0.74	-	11.38	9.41	-
Phacelia congesta	Hydrophyllaceae		1	-	-	-	-	2.07	-	-
Phemeranthus aurantiacus	Portulacaceae		2	-	-	-	0.74	0.34	-	-
Phyllanthus polygonoides	Euphorbiaceae		5	-	-	21.48	9.63	8.97	7.06	4.67
Physaria thamnophila	Brassicaceae		5	20.80	1.61	22.22	5.93	24.14	25.29	17.33
Plantago hookeriana	Plantaginaceae		3	-	0.81	2.96	2.22	9.66	-	-
Polygala lindheimeri	Polygalaceae		5	30.40	50.00	24.44	48.15	5.52	20.59	14.67
Portulaca sp.	Portulaceae		1	-	-	-	-	1.72	-	-
Rivina humilis	Phytolaceae		1	-	-	-	-	-	1.76	-
Salvia ballotiflora	Lamiaceae		1	-	-	-	-	0.69	-	-
Schaefferia cuneifolia	Celastraceae	X	3	2.40	0.81	2.22	-	0.34	-	-
Senna bauhinioides	Fabaceae		3	-	-	1.48	2.96	0.69	-	-
Setaria leucopila	Poaceae		4	0.80	-	-	-	1.03	1.76	0.67
Setaria ramiseta	Poaceae		2	-	-	6.67	4.44	-	-	-
Setaria texana	Poaceae		1	-	-	-	-	7.93	-	-
Sida abutifolia	Malvaceae		3	-	-	7.41	6.67	4.48	-	-
Sideroxylon celastrinum	Sapotaceae	X	3	-	-	-	-	0.34	11.76	4.67
Sonchus oleraceus	Asteraceae		2	-	-	1.48	0.74	-	-	-
Spermolepis echinata	Apiaceae		1	-	-	-	-	2.07	-	-
Sporobolus cryptandrus	Poaceae		5	6.40	-	5.19	1.48	1.72	5.88	3.33
Synthlipsis greggii	Brassicaceae		3	-	-	-	-	4.14	2.94	10.00
Tetraclea coulteri	Verbenaceae		3	-	-	2.96	0.74	2.41	-	-
Thamnosma texana	Rutaceae		5	28.80	11.29	39.26	28.15	6.90	10.00	7.33
Thymophylla pentachaeta	Asteraceae		5	38.40	3.23	71.11	54.07	50.00	11.18	5.33
Tiquilia canescens	Boraginaceae		4	21.60	6.45	13.33	11.85	6.55	0.59	-
Tridens muticus	Poaceae		5	18.40	1.61	7.41	0.74	2.07	12.94	14.67
Turnera diffusa	Turneraceae		1	-	-	-	-	-	58.82	-

Table 1. continued

Scientific Name	Family	>1 m tall?	# Sites w/sp[a]	% of Subplots Occupied in Each Site[b]						
				CL02 cl	**CL02 un**	**CL07 cl**	**CL07 un**	**AM07**	**AR03**	**SM04**
Unidentified cactus seedling	Cactaceae		1	-	-	-	-	-	-	0.67
Unknown grass	Poaceae		5	8.00	0.81	25.93	24.44	21.03	11.18	1.33
Unknown legume	Fabaceae		1	-	-	-	0.74	-	-	-
Unknown 1			1	1.60	-	-	-	-	-	-
Unknown 2			2	3.20	2.42	0.74	1.48	-	-	-
Unknown 3			1	1.60	-	-	-	-	-	-
Unknown 4			1	0.80	-	-	-	-	-	-
Unknown 5			5	2.40	1.61	4.44	7.41	0.69	5.29	0.67
Unknown 6			1	-	-	-	-	-	-	1.33
Unknown 7			1	-	-	-	-	-	1.76	-
Urochloa ciliatissima	Poaceae		1	-	-	-	-	1.03	-	-
Urochloa texana	Poaceae		1	-	-	0.74	-	-	-	-
Verbena sp 1.	Verbenaceae		2	-	-	2.22	-	2.76	-	-
Verbena sp 2.	Verbenaceae		3	-	-	2.22	0.74	1.72	-	-
Wedelia texana (A. Gray) B.L. Turner	Asteraceae		5	2.40	-	19.26	0.74	4.48	0.59	0.67
Yucca treculeana	Agavaceae	X	2	-	-	-	0.74	0.34	-	-
Zanthoxylum fagara	Rutaceae	X	1	-	-	-	-	1.03	-	-
Ziziphus obtusifolia	Rhamnaceae		4	-	-	0.74	-	0.69	0.59	0.67
Bare ground (no plants in subplot)			5	0.80	7.26	-	-	0.34	4.12	3.33

[a] **Number of sites with this species:** Cuellar cleared and uncleared counted as different 'sites' due to treatment difference

[b] **Site codes:** CL cl = Cuellar cleared; CL un = Cuellar uncleared; AM = Arroyo Morteros; AR = Arroyo Ramirez; SM = Santa Margarita. Numbers 02-07 refer to year of vegetation data collection.

RESULTS

Differences in Vegetation Among Sites

A total of 150 vascular plant species occurred in at least one vegetation plot in a least one site (Table 1). Sixty-six of these species occurred in only one of the four sites (pooling Cuellar treatments). While the vegetation of the four sites was similar in many ways, the relative abundances of species differed among sites (Table 1). In Arroyo Morteros, *Thymophylla pentachaeta*, *Acacia rigidula*, and *Chaetopappa bellioides*/ *Aphanostephus skirrhobasis* var. *kidderi* were most abundant; in Arroyo Ramirez, *Aristida purpurea*, *Turnera diffusa*, *Acacia rigidula*, and *Polygala lindheimeri*; in Santa Margarita, *Aristida purpurea* and *Eriogonum greggii*; and in Cuellar, *Acacia rigidula*, *Leucophyllum frutescens*, *Polygala lindheimeri*, and *Melampodium cinereum*. Sites also differed in the abundances of less common species (Table 1). A MANOVA (multivariate analysis of variance) comparing the abundances of all species (except *P. thamnophila* and 'bare ground', for a total of 146 'species' after the pooling described in the Methods) among the five site x treatment combinations (Cuellar treatments not pooled) was highly significant (Cuellar 2007 vegetation data used; Hotelling-Lawley Trace, $F = 9.44$, df = 548, 114.71, $P < 0.0001$).

The four sites also differed in vegetation structure (Figure 5). The lack of vegetation above 1m in the cleared portion of Cuellar in 2002 was due to its treatment, while the uncleared portion of Cuellar had the densest canopies. The regrowth in the Cuellar cleared portion is apparent in a comparison of the 2002 and 2007 graphs (Figure 5). Among uncleared sites, Arroyo Ramirez had the most open canopies, and Arroyo Morteros the tallest.

Relationships Between *P. thamnophila* Presence and Neighboring Species

Twenty-nine species, including *P. thamnophila*, were present in 25 percent or more of the subplots. These species, except for *P. thamnophila*, were used as the dependent variables in a MANOVA. In this MANOVA, site and *P. thamnophila* presence/absence in the 2007 census were the independent variables. Cuellar 2007 vegetation data were used in this analysis and the two Cuellar treatments were considered to be 2 different 'sites', for a total of 5 site-treatment combinations. Both of the independent variables were highly significant (site-treatment combination: Hotelling-Lawley Trace F = 20.67; df = 112,476; $P < 0.0001$; presence/absence: Hotelling-Lawley Trace F = 1.93; df = 28,143; $P = 0.0066$).

Because the MANOVA found significant effects of *P. thamnophila* presence we followed it with ANOVAs (univariate analyses of variance). Six of 28 ANOVAs on the same 28 species had *P*-values less than 0.05 associated with the effect of *P. thamnophila* presence/absence. In each of these ANOVAs, presence/absence, df = 1, was the second factor in a hierarchical sums of squares table that had site, df = 3, as the first factor. Thus these P-values reflect the amount of variation that presence/ absence accounted for above-and-beyond the variation accounted for by site-year combination. Plots that had *P. thamnophila* had on average more *Diospyros texana* ($P = 0.0424$), *Acacia rigidula* ($P = 0.0043$), unidentified seedling grasses ($P = 0.0068$), *Mimosa texana* ($P = 0.0012$), and *Chamaesaracha sordida* + *Physalis cinerascens* ($P = 0.0293$), and less *Tiquilia canescens* ($P = 0.0293$), than plots without *P. thamnophila*. These positive and negative associations with *P. thamnophila* should be regarded as tentative, due to multiple testing issues, deviations from the multivariate normal assumption, and correlations among abundances of the different species. Only *Mimosa texana* meets the Bonferroni criterion for significance (for 28 tests, $P < 0.00183$ to give an overall $P < 0.05$).

Relationships Between *P. thamnophila* Density and Neighboring Species

A stepwise regression was used (SAS PROC REG) with the average 2006/2007 density of *P. thamnophila* as the dependent variable. Site was included as a class variable (df = 3). All 148 'species' except bare ground and *P. thamnophila* were available to the regression procedure. A criterion of $P < 0.05$ was used to retain variables in the model. Eighteen taxa met this criterion. Thirteen of them were negatively associated with *P. thamnophila*: *Acleisanthes obtusa*, *Acourtia runcinata*, *Citharexylum brachyanthum*, *Thymophylla pentachaeta, Echinocactus texensis*, *Echinocereus reichenbachii* ssp. *fitchii*, *Galphimia angustifolia*, *Nama hispidum*, *Oenothera laciniata*, *Portulaca* sp., *Sideroxylon celastrinum*, *Synthlipsis greggii*, and *Tridens muticus*. Five were positively associated with *P. thamnophila*: *Acacia rigidula*, *Cyperus* sp., *Evolvulus alsinoides*, *Melampodium cinereum*, and *Passiflora tenuiloba*.

DISCUSSION

Community Composition: General

Each of the study sites had a rich plant community that contained shrubs, forbs, graminoids, and cacti (Table 1). The shrubs *Acacia rigidula* and *Leucophyllum frutescens* dominated all four sites. While all four study sites were similar enough to be described as having the same plant community, there were some interesting differences among them. These include *Turnera diffusa*, found in 59 percent of samples at Arroyo Ramirez but absent from other sites; *Eriogonum greggii,* itself a

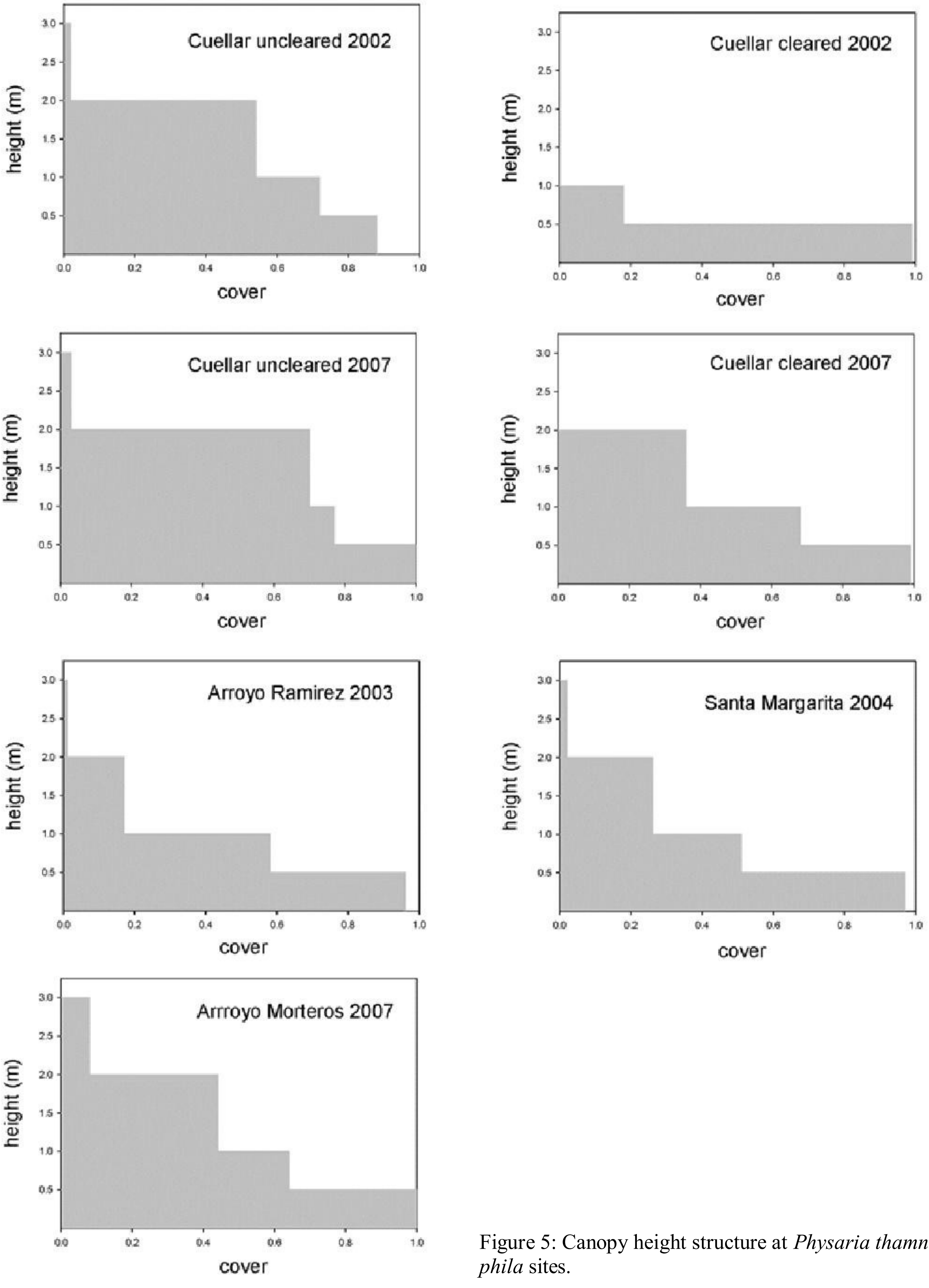


Figure 5: Canopy height structure at *Physaria thamnophila* sites.

somewhat rare plant, found in 27 percent of subplots at Santa Margarita only; and the shrub *Forestiera angustifolia,* which occurred in 23 percent of subplots at Arroyo Morteros, but was infrequent at other sites. Since there was no evidence that *P. thamnophila* was declining at any of the sites, each of these slightly different plant communities is evidently suitable for *P. thamnophila.*

Community Composition: Comparisons with Other Studies

The plant community of our study sites, quantified in Table 1, does not match previously identified plant communities of the region. It also differs in some important details from previously published lists of the plant species associated with *Physaria thamnophila.* These differences may be attributed to site selection, scale of observation, method of community description (sampling vs. observation of visual dominants), and, for herbaceous species, year effects.

The Recovery Plan (USFWS 2004) stated that *P. thamnophila* occurs in "an open *Leucophyllum frutescens* (cenizo) - *Acacia berlandieri* (guajillo) shrubland alliance" (*Acacia rigidula - Leucophyllum frutescens - Acacia berlandieri* Shrubland Alliance; NatureServe 2009). The plant community we observed may be a component association of this alliance. However, *A. berlanderi* was rarely encountered in our study. Among the plant associations described by NatureServe (2009), the best match to the community we observed is the *Acacia rigidula - Leucophyllum frutescens - Acacia berlandieri* Shrubland Association (CEGL007759). However, this "broadly defined type" is not described in sufficient detail to make it useful in defining *P. thamnophila* habitat. Our sites somewhat resembled the *Acacia rigidula* - *Leucophyllum frutescens* - *Hechtia glomerata* Shrubland Association (CEGL007760; NatureServe 2009). However, this association occurs on saline clay soils. Furthermore, *Hechtia glomerata,* while observed in the vicinity of *P. thamnophila* sites, was not encountered in study plots. The more general *Acacia rigidula* Shrubland Association (CEGL003874) is too broadly defined to be useful in identifying *P. thamnophila* habitat.

Jahrsdoerfer and Leslie (1988) described a "Chihuahuan (or Falcon) thorn forest" community in this area, but listed only two dominant species: *A. rigidula* and *Mimosa biuncifera. M. biuncifera* does not occur in this area, but the name has been misapplied to *M. texana*; and thus, it is likely they were referring to *M. texana.* Other plant community classifications for South Texas, including McLendon (1991) and Bezanson (2000), describe associations similar to NatureServe's. These communities include species that were not important in our study, and occur on different substrates.

NRCS Ecological Site Descriptions also list different species mixes than those we encountered. Copita soils belong to the Gray Sandy Loam Ecological Site; Catarina, to the Saline Clay Ecological Site, and Mavericks to the Rolling Hardland Ecological Site. The plant communities of these ecological sites are described as having more mid-grasses and different forbs than our study sites, as well as a different mix of dominant shrubs. Jimenez and Quemado soils belong to the undescribed Gravelly Ridge Ecological Site, while their associated "unnamed, minor components" have not been assigned to an ecological site. Zapata soils are in the undescribed Shallow Ridge Ecological Site (NRCS 2009)

Wu and Smeins (1999) listed sixteen woody species associated with *P. thamnophila*, including *A. rigidula, L. frutescens, Karwinskia humboldtiana, Krameria ramosissima*, and *Jatropha dioica*, all of which were frequently encountered in our plots. However, they also listed species that we did not find to be closely associated with Zapata bladderpod, including *Prosopis glandulosa, Hechtia glomerata, Acacia berlandieri,* and *A. greggii*. They noted a diverse herbaceous understory but did not list species. Although their report does not describe the method for characterizing vegetation, we suspect that this study reported visual dominants or species common in the general area, but not necessarily associated with *P. thamnophila* at a finer scale.

Sternberg (2005) listed 22 woody and herbaceous species associated with *P. thamnophila* at Cuellar. Even though his sampling method covered the entire population area and ours focused on the cleared area and adjacent uncleared habitat, most of the frequently encountered species were important in both studies. However, there were some notable differences. For example, Sternberg did not report the woody species *Mimosa texana*, nor did he encounter several herbaceous species that we observed in 10 percent or more of subplots. Among the important herbaceous species that Sternberg did not observe, a few were most abundant in the cleared portion of Cuellar (*Tridens muticus, Aristida purpurea*), while others were only identified in 2007, following a relatively wet winter (for example, *Phyllanthus polygonoides* and the annuals *Nama hispidum* and *Linum lundellii*).

Relationships Between *P. thamnophila* and Individual Plant Species

A number of species that were common on upland soils in the region were absent or uncommon in our study sites. *Acacia berlandieri*, *Prosopis glandulosa*, *Ziziphus obtusifolia*, *Zanthoxylum fagara*, *Cordia boissieri,* and *Lycium berlandieri* are common members of upland plant communities in the region (Bezanson 2000; NatureServe 2009; NRCS 2009; USFWS 2004), but were absent or uncommon in our study sites. *A. ber-*

landeri, cited as a community dominant in the Recovery Plan (USFWS 2004), appeared in the vegetation data in only one of our four study sites. This species is a dominant at Santa Margarita immediately upslope of the *P. thamnophila* population that is on a different soil type. *Prosopis glandulosa* never occurred within our study plots. The inclusion of *Prosopis* in the Recovery Plan was based on a site that we did not study, an abandoned trailer park which has subsequently been overtaken by invasive buffelgrass (*Pennisetum ciliare*), leaving only a small remnant on highway right-of-way (J.M. Poole, Texas Parks and Wildlife Department, personal communication 20 July 2009). Other species mentioned in the Recovery Plan that we encountered infrequently include *Celtis ehrenbergiana*, *Yucca treculeana*, *Ziziphus obtusifolia*, and *Guaiacum angustifolium*, which are common visual dominants in the region that were not closely associated with P. *thamnophila* at our sites. These species may be better suited to sites with deeper soils or more favorable soil chemistry.

Two common invasive grasses of the area, buffelgrass (*Pennisetum ciliare* (L.) Link) and Kleberg bluestem (*Dichanthium annulatum* (Forssk.) Stapf), are also conspicuous by their absences or low abundances in the four study sites. It seems likely that *P. thamnophila*, like other native grasses and forbs of south Texas (Sands et al. 2009), is out-competed by these invasive grasses. The plots in which *P. ciliare* was encountered should be monitored to determine its effect on *P. thamnophila.*

Associated species' negative or positive correlation with *P. thamnophila* may have a number of explanations. Some of the negative correlations may reflect very localized competition. For example, a plot in which *Thymophylla pentachaeta* or *Nama hispidum* were very abundant (especially in 2007) may have been colonized by these species in response to winter rain, and they in turn excluded *P. thamnophila.* Some negative correlations may reflect microsites not suitable for *P. thamnophila*, such as hardpan, where *Tiquilia canescens* was relatively common. *Synthlipsis greggii* seems to use different microsites and topographic positions than *P. thamnophila;* however, we did not quantify this observation.

*Acacia rigidula'*s positive correlation with *P. thamnophila* may indicate facilitation, probably because as a legume it may create a soil patch with relatively high nitrogen content. Alternatively, its presence may indicate that the plot is not bare hardpan, but rather is favorable to vegetation in general. The other shrub that was positively correlated with *P. thamnophila* was the legume *Mimosa texana*. This shrub, although not rare, has a restricted range and may be more indicative of *P. thamnophila* habitat. A "characteristic species of the arid, sandy-soil Falcon Woodlands, which cover a small upland part of Starr and Zapata Counties" (Ideker 1999), *M. texana* was present at all study sites in 5 to14 percent of subplots.

The positive correlation of *P. thamnophila* with perennial herbaceous species such as *Melampodium cinereum* and *Evolvulus alsinoides* is probably related to its similar microhabitat requirements and response to precipitation and shrubs. Other species with significant correlations were present in low frequency and are inconclusive.

Edaphic Requirements of *P. thamnophila*

Although *P. thamnophila* populations are mapped on several soil series, our observations in the field indicate very similar soils and geologic substrates at all sites. All four populations of *P. thamnophila* occur on a sandstone substrate (Figure 6), on yellowish, highly erodible, highly calcareous soils. All other Texas populations to which we and other observers have had access have similar yellowish sandy soils and occur on sandstone. Wu and Smeins (1999) report Copita and Zapata sandy loam soils as the substrate for *P. thamnophila,* and clarified that sites mapped as Catarina soils (saline, gypsiferous clay) are actually on sandy inclusions. Their analyses of soil from four *P. thamnophila* sites found very high calcium, high sulfur, and very low nitrogen levels.

We believe that use of NRCS digital soil maps at a level of detail beyond which they were intended has led to confusion about the soils on which *P. thamnophila* occurs. *P. thamnophila* has never been found on Jimenez-Quemado soils (*contra* Poole 1989 and USFWS 2004). The parent material of these soils is gravelly alluvium, deposited by ancient, high-velocity streams on the high terraces over the Rio Grande (Thompson et al. 1972). The Jimenez-Quemado soil polygons contain inclusions of "unnamed, minor components" and rock outcrops. These outcrops, rather than Jimenez or Quemado soils, are likely habitat for *P. thamnophila*.

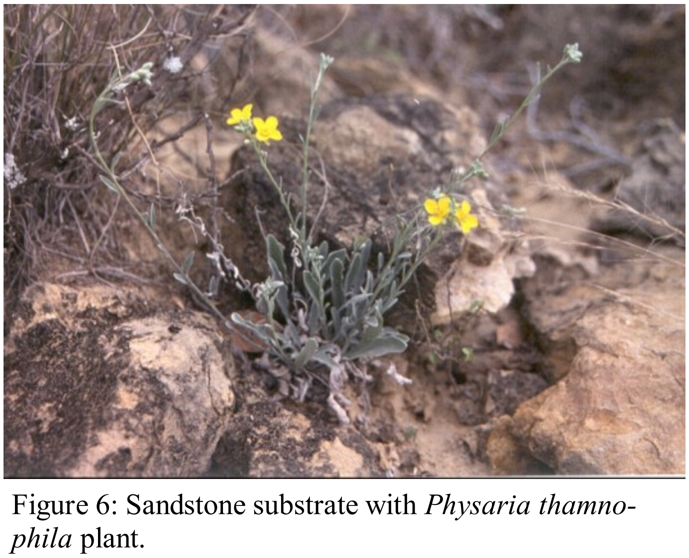


Figure 6: Sandstone substrate with *Physaria thamnophila* plant.

The underlying geology at the sites is complex. The Yegua and Jackson Formations were deposited in part of the Gulf Coast geosyncline known as the Rio Grande Embayment during Eocene cycles of sedimentation. Land subsidence and marine transgressions and regressions produced fluctuating sea levels and deposition of "complexly interbedded sands, silts, and clays" as well as marine shales (Preston 2009). Dumble (1902) provided a detailed site-specific description of this complex stratigraphy. Reporting on outcrops of "buff sandstone" near Roma (in the vicinity of our study sites), he describes sections of "greenish-yellow clays" with gypsum, oyster beds, buff clays, sandy clays, and indurated sandstone.

At two of our study sites that were on bluffs along the Rio Grande, two layers of buff to yellowish sandstone were interspersed with other substrates or oyster shell deposits. Fossil oyster shell beds occurred upslope from all four study sites. Gypsum crystals occurred on the soil surface in many places. The alternating layers of sandstone with fossil oyster shell, shale and clay may explain the presence of gypsum at the sites, even though the sandy soils (Copita and Zapata) are only weakly gypsiferous. The layers of different substrates may create microsites where water is more available due to seepage from relatively permeable layers located over impermeable or less permeable layers. Several species we encountered in this study are members of genera that are documented as tolerating gypsum, particularly *Tiquilia,* but also *Nama, Eriogonum*, and *Acleisanthes* (Moore and Jansen 2007). We have no evidence that *P. thamnophila* is a gypsum endemic; however, it tolerates gypsum.

All four sites were undergoing active gully erosion to the degree that some slopes could be called badlands. All four sites also appeared to have high rates of sheet erosion as well, especially in the bare areas between shrubs. While erosion probably does not directly benefit *P. thamnophila*, high erosion rates likely reduce the number of competing species that can live in the site, and perhaps their densities. High erosion rates may be one factor contributing to the positive association between shrubs and *P. thamnophila*, especially *P. thamnophila* seedlings within our sites (Fowler et al. 2011). By slowing the rate of erosion in their immediate vicinity, shrubs may increase seedling survival there. High erosion rates may also explain why roller-chopping part of Cuellar increased the density of *P. thamnophila* there (Fowler et al. 2011), as the woody debris left by this treatment may also have reduced the erosion rate. However, we cannot exclude other positive effects that shrubs may have upon *P. thamnophila*.

These edaphic features (high erosion rates, highly calcareous soils, perhaps the presence of gypsum) could be used to search for sites where additional populations might occur. They also provide some guidance for identifying sites suitable for introduction or reintroduction. Although we do not believe that *P. thamnophila* requires high soil erosion rates, the presence of gypsum, or even calcareous soils, all of these probably reduce the number and density of competing species. Ecologically, *P. thamnophila* is apparently a stress-tolerator (*sensu* Grime 1977, 2001), rather than a strong competitor or a ruderal species. This may also be true of many of its associates.

Conservation Applications

The Recovery Plan (USFWS 2004) called for (a) identification of sites where additional populations might occur; (b) identification of sites most suitable for attempts to establish new populations; (c) identification of tracts most appropriate for mitigation purposes, should that be necessary; (d) development of management plans; and (e) development of habitat restoration objectives. The vegetation structure and composition data presented here, especially that of Table 1 and Figure 5, provide quantitative objectives for each of these tasks. Whereas visually dominant species mentioned in previous work can still be used to search for general areas of suitable native thornscrub vegetation, the species composition presented here provides a finer scale focus for identification of suitable habitat. The qualitative description of likely soil types provided above could be used to guide searches for new populations and identify sites for introduction or reintroduction. It would also be helpful to know the gypsum content of the soils. Management and restoration projects can use Table 1 and Figure 5 to help set quantitative objectives.

It should be noted that this study was not designed to compare sites with and without *P. thamnophila*, so results do not definitively identify what it is about these four sites that made them different from similar sites in the region. Additionally, we did not attempt to characterize small, remnant, disturbed sites, which are also important to the species' conservation. In any case, with so few *P. thamnophila* populations, the absence of *P. thamnophila* from any particular site is hard to interpret. *P. thamnophila* may be absent from suitable sites due to chance, poor dispersal, disease, herbivory, or other factors, which is often a problem in studying endangered species (Hanski and Ovaskainen 2002). Experienced biologists will no doubt make their own judgments from the data we provide.

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Intraspecific Cytotype Variation and Conservation: An Example from *Phlox* (Polemoniaceae)

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Abstract. Information on genetic structure in rare plants, such as patterns of genetic diversity, differentiation and gene flow, is useful when planning management strategies for conservation. However, few studies of genetic structure in rare plants include an investigation of intraspecific cytotype variation. A number of reviews have suggested that cytotype variation, or variation in chromosome structure or number, may be more widespread in natural populations than previously thought. A recent review of federally listed plant species found that 75% of species belonged to genera exhibiting both interspecific and intraspecific cytotype variation. Cytotype variation among populations of rare plants raises intriguing questions about the origin(s), extent, evolutionary relationships, and ecological differentiation of various cytotypes. While traditional cytological methods may not be feasible for population level sampling, advances in the accuracy and cost of flow cytometry now make examination of intraspecific cytotype variation possible. We initiated an investigation of cytotype variation in the genus *Phlox* (Polemoniaceae) using flow cytometry. *Phlox* comprises ca. 65 species in North America and includes many poorly studied endemic taxa in the western United States. Our results indicate noteworthy variation in chromosome numbers (ploidy level) across a subset of western taxa. A detailed study of two endemic species of conservation concern, *P. amabilis* and *P. woodhousei*, revealed that these species are made up of diploid, tetraploid and hexaploid populations. Ongoing analyses suggest that these populations are spatially, ecologically, and genetically differentiated. These results caution against the common assumption of homoploidy of species based on limited data and indicate the value of incorporating an understanding of cytotype variation into conservation biology studies.

The interdisciplinary field of conservation biology aims to provide the knowledge and tools necessary for the long-term preservation of biodiversity. Studies of population genetics are one important source of information for conservation biology. These studies can provide basic information about populations of rare plants such as levels of genetic variation, the distribution of genetic variation within and among populations, the degree of population fragmentation and isolation, the patterns of historical and contemporary gene flow, the levels of inbreeding, the effective population size, the presence of taxonomic distinctiveness, and the occurrence of hybridization (Booy et al. 2000; Ellis and Burke 2007; Murray and Young 2001). Ultimately, this basic information can be combined with other sources of data to form more effective conservation strategies.

One component of genetic variation that is often overlooked in studies of rare plants is intraspecific cytotype variation (De Lange et al. 2008; Severns and Liston 2008). Intraspecific cytotype variation ranges from chromosomal inversions and translocations to variation in the number of whole genomes present (polyploidy). Recent reviews have suggested that intraspecific cytotype variation may be more widespread in natural plant populations than previously thought (Soltis et al. 2007; Suda et al. 2007). It may also be widespread in populations of rare, threatened and endangered plants. A survey of cytotype variation in 416 US federally listed plant taxa found that cytotype data were available for only 182 of these taxa (44%). Of these 182 taxa, 158 belonged to genera with *interspecific* cytotype variation (87%; New World congeners with aneuploidy or polyploidy), and 121 belonged to genera with at least one taxon showing *intraspecific* cytotype variation (66%; Severns and Liston 2008). Intraspecific cytotype variation can be important when planning conservation strategies because it has the potential to affect patterns of genetic diversity and gene flow. Knowledge of such variation may also be important for clarifying taxonomy, identifying unique evolutionary lineages (perhaps accompanied by ecological differentiation), and determining appropriate populations for reintroduction or augmentation (De Lange et al. 2008; Murray and Young 2001; Severns and Liston 2008).

Recent advances in the application of flow cytometry to evolutionary and population biology studies now make the assessment of cytotype variation across large taxonomic and spatial scales possible (Kron et al. 2007).

Flow cytometry is a method that quantifies nuclear DNA content by measuring the relative fluorescence of isolated nuclei that have been stained with a fluorescent dye. This method offers several advantages over traditional cytological methods including: 1) sample preparation and processing is relatively easy and rapid (allowing for large sample sizes), 2) sample material does not need to be actively dividing (a variety of tissues can be used, including dried and frozen material), and 3) sampling is relatively non-destructive (enabling studies of sensitive plants; Kron et al. 2007; Suda et al. 2007). Thus, flow cytometry provides a practical means by which intraspecific population level cytotype data can be gathered.

The genus *Phlox* has been an important system for plant evolutionary studies of polyploidy, hybridization, and ecology (Ferguson and Jansen 2002; Ferguson et al. 1999; Grant 1959; Levin and Schaal 1970; Levin and Smith 1966; Wherry 1955). *Phlox* comprises ca. 65 species of annual and perennial herbs distributed predominantly in North America with a center of diversity in the western United States. We are using flow cytometry to study cytotype variation across this genus. The present study focuses on a broad sample of western, upright perennial *Phlox* species with special emphasis on two endemic species of conservation concern found in coniferous forests in Arizona and New Mexico, *P. amabilis* and *P. woodhousei*. These two species are closely related (Ferguson et al. 2012) and very similar based on gross morphology, sharing a characteristic woody-based upright perennial growth form, thick linear leaves and notched petals. However, their geographic distributions do not overlap, and they are readily distinguished by differences in style length and stigma placement relative to anther position. These taxa have been variously classified as distinct species or conspecifics (Cronquist et al. 1984; Wherry 1955). Our objectives for the present study were to examine 1) taxonomic and large-scale spatial patterns of cytotype variation across a subset of western *Phlox* taxa and 2) fine-scale spatial patterns of cytotype variation within and among populations of *P. amabilis* and *P. woodhousei*.

METHODS

The present study includes samples from seven species of upright, perennial *Phlox* from Arizona, California, Colorado, Idaho, Montana, Nevada, Utah and Wyoming (Table 1). For determination of cytotype, several leaves were collected from one to five individual plants at each sampling location for each taxon and stored on ice until nuclear extraction. Voucher specimens for each population were deposited at the Kansas State University Herbarium (KSC).

We determined the cytotype of each sample of *Phlox* using flow cytometry. Flow cytometry measures nuclear DNA content, which can then be interpreted in terms of ploidy level, especially when closely related taxa are studied and when knowledge of ploidy level is independently assessed through conventional chromosome counts (Suda et al. 2007; Halverson et al. 2008). For each sample of *Phlox*, we placed 100-300 mg of chilled leaf tissue into a petri dish with 1.5 ml of chopping buffer, modified from Bino and others (1993) as described by Davison and others (2007). We chopped the leaves finely with a new razor blade and filtered the resulting liquid through a 30 µm filter into a microcentrifuge tube. Tubes were centrifuged at 500 x g for 7 min, the supernatant removed, the pellet re-suspended in 700 µl propidium iodide staining solution (50 mg/ml; BioSure), and 2µl of chicken erythrocyte nuclei singlets added (CEN internal standard; BioSure). Samples were protected from light and stored on ice for at least 30 min before analysis on a Becton Dickinson FACS Calibur flow cytometer at the Kansas State University Flow Cytometry Facility. The amount of fluorescence was measured for ~10,000 nuclei per sample. Resulting histograms were visually inspected for the presence of clear nuclear populations from the *Phlox* sample and the CEN internal standard, and mean peak values were calculated using the program Cell Quest (Becton Dickinson). Nuclear DNA content was calculated as the *Phlox* sample mean peak value divided by the CEN internal standard mean peak value multiplied by the 2*C*-value of the CEN internal standard (2.5 pg; Dolezel and Bartos 2005). Ploidy level was inferred for each sample based on the calculated DNA content. Inferred ploidy level was linked with chromosome count data for several samples.

RESULTS AND DISCUSSION

A total of 140 samples from seven species of *Phlox* collected from 63 locations were assessed for cytotype variation (Table 1). When cytotype was measured in multiple individuals from a single location, average nuclear DNA content was calculated. We did not detect any cytotype variation within populations based on our limited sampling. The results from flow cytometry were interpreted as measures of ploidy level rather than absolute measures of DNA content (see Suda et al. 2007). Results from chromosome counts confirmed ploidy levels of 2x, 4x, and 6x (for five samples; Table 1).

Cytotype varied throughout the species studied and appeared to reflect both taxonomy and geography (Table 1). Populations of *P. caryophylla* and *P. cluteana* were diploid, while populations of *P. aculeata* were tetraploid; all of these taxa are fairly narrow endemics. In general, populations of the wide-ranging *P. longifolia* and *P. stansburyi* were geographically structured, with

Table 1. Samples included in this study. Voucher information, collection locality, number of individuals cytotyped (N), DNA content and inferred cytotype are noted. Taxon recognition for *P. stansburyi* follows Ferguson and others (2012); intraspecific classification for *P. longifolia* (including *P. longifolia* and *P. viridis* sensu Wherry [1955]) is under ongoing investigation and is not proposed here.

Taxon	Voucher	County	State	Location Detail	N	DNA content (pg)	Cytotype
P. aculeata	Sidells 116	Twin Falls Co.	ID		1	14.65	4X
P. aculeata	CF 789	Butte Co.	ID		3	15.43	4X
P. aculeata	CF 787	Bonneville Co.	ID		2	18.67	4X
P. caryophylla	CF 653	Archuleta Co.	CO		1	7.61	2X
P. cluteana	CF 651	Apache Co.	AZ		1	8.14	2X
P. cluteana	SDF 51008-2	Apache Co.	AZ		3	8.84	2X
P. longifolia	SDF 42908-3	Navajo Co.	AZ		3	8.37	2X
P. longifolia	SDF 43008-1	Coconino Co.	AZ		3	8.60	2X
P. longifolia	SDF 42908-1	Navajo Co.	AZ		3	8.74	2X
P. longifolia	SDF 51008-1	Apache Co.	AZ		3	8.88	2X
P. longifolia	SDF 50408-1	Coconino Co.	AZ		3	8.89	2X
P. longifolia	SDF 50908-1	Coconino Co.	AZ		3	9.17	2X
P. longifolia	SDF 50708-1	Mojave Co.	AZ		3	9.27	2X
P. longifolia	SDF 50808-1	Mojave Co.	AZ		3	16.79	4X
P. longifolia	SDF 50808-2	Mojave Co.	AZ		4	17.28	4X
P. longifolia	CF 728	Eagle Co.	CO		1	15.25	4X
P. longifolia	CF 727	Mesa Co.	CO		1	16.71	4X
P. longifolia	CF 788	Butte Co.	ID		3	7.60	2X
P. longifolia	CF 806	Lemhi Co.	ID		1	14.27	4X
P. longifolia	CF 603	Clark Co.	ID		1	14.67	4X
P. longifolia	CF 792	Butte Co.	ID		3	15.25	4X
P. longifolia	CF 589	Custer Co.	ID		1	15.41	4X
P. longifolia	CF 794	Custer Co.	ID		3	15.67	4X
P. longifolia	CF 786	Jefferson Co.	ID		2	18.67	4X
P. longifolia	CF 601	Beaverhead Co.	MT		1	13.63	4X
P. longifolia	CF 710	White Pine Co.	NV		1	17.11	4X
P. longifolia	CF 724	Beaver Co.	UT		1	8.38	2X
P. longifolia	CF 702	Sevier Co.	UT		1	15.00	4X
P. longifolia	CF 611	Summit Co.	UT		1	21.90	4X
P. longifolia	CF 734	Carbon Co.	WY		1	13.98	4X[a]
P. longifolia	CF 215	Sublette Co.	WY		1	14.65	4X

Table 1. continued

Taxon	Voucher	County	State	Location Detail	N	DNA content (pg)	Cytotype
P. longifolia	CF 617	Beaver Co.	UT		1	15.25	4X
P. longifolia	CF 606	Lincoln Co.	WY		1	14.51	4X
P. stansburyi var. *brevifolia*	SDF 50208-2	Yavapi Co.	AZ		4	8.60	2X
P. stansburyi var. *brevifolia*	SDF 50308-2	Yavapi Co.	AZ		3	9.18	2X
P. stansburyi var. *brevifolia*	SDF 50508-3	Coconino Co.	AZ		4	9.63	2X
P. stansburyi var. *brevifolia*	CF 630	Mono Co.	CA		1	8.31	2X
P. stansburyi var. *brevifolia*	CF 718	Kane Co.	UT		1	10.49	2X
P. stansburyi ssp. *stansburyi*	SDF 42808-1	Cochise Co.	AZ		3	8.18	2X
P. stansburyi ssp. *stansburyi*	SCS 18	Lander Co.	NV		1	15.85	4X
P. stansburyi ssp. *superba*	SDF 50908-2	Coconino Co.	AZ		3	18.86	4X
P. stansburyi ssp. *superba*	CF 634	Inyo Co.	CA		1	10.54	2X
P. stansburyi ssp. *superba*	CF 704	Nye Co.	NV		1	7.31	2X
P. stansburyi ssp. *superba*	CF 705	Nye Co.	NV		1	12.01	2X
P. stansburyi ssp. *superba*	CF 713	Nye Co.	NV		1	15.69	4X
P. stansburyi ssp. *superba*	CF 707	White Pine Co.	NV		1	18.87	4X
P. amabilis	CF 780	Yavapai Co.	AZ	Camp Woods	1	8.28	2X
P. amabilis	CF 775 / SDF 51507-2	Yavapai Co.	AZ	Thumb Butte	3	8.41	2X[b]
P. amabilis	SDF 51707-1	Mojave Co.	AZ	Black Rock	1	8.81	2X
P. amabilis	SDF 51807-2 / 50708-4	Mojave Co.	AZ	Death Valley Spring	5	16.92	4X
P. amabilis	SDF 50208-4	Yavapai Co.	AZ	Watson Lake	2	17.58	4X
P. amabilis	SDF 50308-1	Yavapai Co.	AZ	Mingus Mtn	4	24.52	6X[b]
P. amabilis	SDF 51407-2	Coconino Co.	AZ	Hobble Mtn	3	24.54	6X
P. amabilis	SDF 50508-1	Coconino Co.	AZ	Kaibab Lake	3	26.36	6X
P. woodhousei	CF 770	Coconino Co.	AZ	Oakcreek	1	8.81	2X
P. woodhousei	SDF 50108-3	Coconino Co.	AZ	Stoneman	3	8.89	2X[b]
P. woodhousei	SDF 51407-1	Coconino Co.	AZ	Bill Williams	1	9.02	2X
P. woodhousei	SDF 50807-1	Catron Co.	NM	Reserve	1	16.50	4X
P. woodhousei	SDF 50108-1	Gila Co.	AZ	McFadden Peak	5	16.89	4X

Table 1. continued

Taxon	Voucher	County	State	Location Detail	N	DNA content (pg)	Cytotype
P. woodhousei	SDF 42908-2	Navajo Co.	AZ	Showlow	3	17.76	4X
P. woodhousei	SDF 50108-2	Coconino Co.	AZ	Strawberry	6	18.13	4X[b]
P. woodhousei	SDF 43008-2	Gila Co.	AZ	Sharp Creek	8	20.06	4X
P. woodhousei	SDF 51107-2	Gila Co.	AZ	Sierra Ancha	1	27.16	6X

[a] inferred ploidy level supported by published mitotic chromosome count from the same population (Löve, 1971; counted by Daniel J. Crawford; a voucher specimen from New York Botanical Garden [Crawford 76, June 1970] was also consulted).
[b] inferred ploidy level supported by meitoic chromosome counts conducted in laboratories of the authors.

tetraploid populations located in the northern portion of the range and diploid populations located in the southern portion of the range. Cytotype in some populations of *P. stansburyi* subsp. *superba* could not be reliably determined due to wide variation in DNA content, and further study of this taxon is needed. This preliminary survey indicates that cytotype variation may be a useful character for clarifying historically complicated taxonomic divisions (as suggested by Kron et al. 2007) among these *Phlox* species.

An in-depth survey of cytotype variation in *P. amabilis* and *P. woodhousei* revealed that these species were made up of diploid, tetraploid and hexaploid populations and that some cytotypes were restricted to specific portions of the range (Table 1; Figure 1). For example, most populations of *P. woodhousei* were associ-

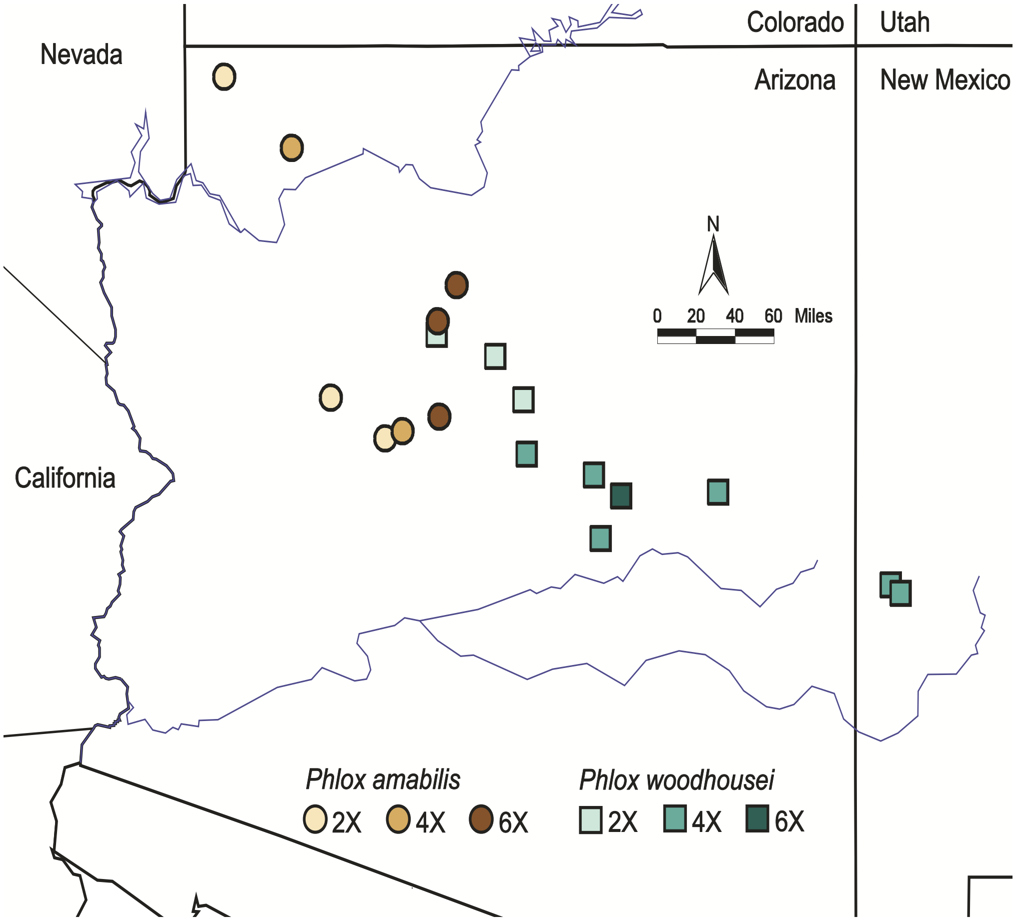

Figure 1. Map showing the locations and ploidy levels of 18 populations of *Phlox amabilis* and *P. woodhousei* sampled for this study.

ated with the Mogollon Rim formation, but diploid populations appeared to be restricted to the western end of the rim. Hexaploid populations of *P. amabilis* were restricted to the easternmost portion of the range and appeared to be associated with magnesium rich igneous rock formations (data not shown). It is possible that such differences in distribution among cytotypes within species reflect ecological differentiation, which could result in local adaptation (Schonswetter et al. 2007; Buggs and Pannell 2007; Paun et al. 2007). Preliminary analysis of genetic variation in *P. amabilis* and *P. woodhousei* also supports differentiation among cytotypes (data not shown). We are continuing to investigate this unexpected variation in cytotype in both species using insights from genetics and ecology.

CONCLUSIONS

The results of this survey of cytotype variation among these western *Phlox* taxa demonstrate the value of such knowledge for the study of plant diversity, evolution, and conservation. The use of flow cytometry allowed us to gather data easily and rapidly on cytotype variation across expanded sample sizes that included multiple species from multiple locations throughout their ranges as well as population level sampling in species of conservation interest. We found that cytotype was variable not only among species but also among populations within species. This variation appears to be related to taxonomy, geography, and possibly ecology. Continued studies of cytotype variation in *Phlox* will provide valuable data for resolving taxonomic divisions as well as insight into the evolutionary diversification of this group. The detailed analysis of cytotype variation in *P. amabilis* and *P. woodhousei*, combined with results from ongoing population genetic work, suggest the presence of unique evolutionary lineages and ecological differentiation, both of which are important when planning conservation strategies. Taken together with recent reviews, these results emphasize the value of incorporating an understanding of cytotype variation into conservation biology studies.

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Prioritizing Plant Species for Conservation in Utah: Developing the UNPS Rare Plant List

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Abstract. Rare plant lists are an important tool for identifying and prioritizing species for conservation attention. Over a dozen systems have been derived for ranking the rarity and conservation priority of plant and animal species, each differing in emphasis, methods, and biological and anthropogenic criteria. In 2007 I developed a new ranking protocol for the flora of Wyoming that combines aspects of the NatureServe, International Union for Conservation of Nature (IUCN), and US Fish and Wildlife Service systems and the classic paper "Seven forms of Rarity" by Deborah Rabinowitz. The so-called "Wyoming protocol" was adopted by the Utah Native Plant Society's Rare Plant Committee to develop an updated rare plant list for Utah. In this protocol, species or varieties are assessed using seven qualitative criteria: Utah's contribution to global distribution, number of populations in the state, number of individuals, habitat specificity, intrinsic rarity, magnitude of threats, and population trend. Individual criteria are rated on a binary scale (0 for unthreatened, 1 for at risk) based on expert opinion. Species for which no data are available are scored "unknown". The values for each criterion are summed to derive a minimum and maximum potential score for each taxon. The minimum score is calculated by summing each individual score and treating any unknown criteria as 0. The maximum score is derived in the same way, except that unknown criteria are given a value of 1. The two summary scores are averaged to determine a conservation priority rank. Those taxa that are at risk for a large number of criteria have higher conservation priority ranks than those species that are at risk for only a few criteria. This simple method allows practitioners to rapidly identify the relatively small subset of species of high or extremely high conservation priority (those with limited ranges, few populations, low numbers, high habitat specificity, high intrinsic rarity, high threats, and downward trends) and those species with significant data gaps in need of additional study. Being able to differentiate among species based on their priority score enables conservationists and managers to better allocate limited resources to those taxa most in need. The UNPS Utah rare plant list developed by the Rare Plant Committee and attendees of a breakout ranking session at the Fifth Southwestern Rare Plant Conference is presented in Appendices 1-4, with modifications adopted at subsequent Utah Rare Plant meetings from 2010-2012.

Experts predict that one-fifth to one-third of all vascular plant species in the United States are threatened with local or range-wide extinction (Center for Plant Conservation 2000). This number is only likely to increase as plant habitat becomes increasingly fragmented and disturbed by development, climate change, or invasion by non-native weeds. Not all plant species, however, are equally imperiled. Some species are naturally rare due to their limited range, high habitat specificity, or low population size (Rabinowitz 1981), but may not be in imminent danger because their population trends are stable or threats are presently low. Because so many species are potentially vulnerable and conservation resources (time, funding, and personnel) are nearly always inadequate, conservation biologists have a dilemma determining which species should be the highest priority for attention (Noss and Cooperrider 1994; Regan 2005).

Rare species lists can be an important tool for identifying and prioritizing those taxa (species, subspecies, and varieties) most vulnerable to extinction. Over the past 40 years conservation biologists have proposed more than a dozen ranking systems for creating state or national rare species lists (Andelman et al. 2004). Ranking schemes often differ widely in their emphasis on inherent rarity, degree of threat, vulnerability of extinction as well as their scoring methods and overall complexity and transparency (Akcakaya et al. 2000; Faber-Langendoen et al. 2009; IUCN 2001; O'Grady et al. 2004; Rabinowitz 1981; Regan et al. 2004; Spence 2012, US Fish and Wildlife Service 1983). These systems also utilize different criteria for ranking, including abundance, number of populations, geographic range, area of occupancy, population trend, intrinsic rarity, taxonomic distinctiveness, ecological significance, population viability, habitat condition or degree of fragmentation, magnitude and imminence of threats, and number of protected populations (Andelmann et al. 2004; Beissinger et al. 2000; Breininger et al. 1998; Holsinger 1992; IUCN 2001; Keith 1998; Mace et al. 2008; Millsap et al. 1990; Panjabi et al. 2005; Rabinowitz 1981; Regan et al. 2004; Spence 2012; US Fish and Wildlife Service 1983).

Ideally, a ranking system should have a strong biological basis, recognize the significance of threats and trends, be easy to apply and update with available information (while recognizing the importance of data gaps), and be transparent (Fertig 2011). Each ranking system has its merits, but none meet all of these criteria. For example, the US Fish and Wildlife Service (1983) system for listing species under the US Endangered Species Act is heavily weighted towards threats and taxonomic distinctiveness at the expense of other aspects of rarity (Master et al. 2000). The IUCN (2001) protocol focuses chiefly on population size, trends, and likelihood of extinction but is dependent on quantitative viability data that are not always available for vascular plants. One advantage of the IUCN protocol, however, is its recognition of "data deficient" species (Akçakaya et al. 2000). Rabinowitz (1981) introduced a simple, but elegant, binary ranking system using just three components of rarity: geographic range, abundance, and habitat specificity. But several additional biological and anthropogenic criteria (such as threat) were not incorporated, which limits the suitability of the Rabinowitz system for prioritizing among different kinds of rare species.

The most widely used ranking protocol today is the natural heritage system, first developed by The Nature Conservancy in the 1970s (Master 1991) and now administered by NatureServe. In this system, full species or varieties are assigned a conservation rank on a scale of 1 (critically imperiled) to 5 (demonstrably secure) across their entire global range (G rank) and at a subregional scale (state/province, or S rank). Traditionally, G and S ranks were based on the number of occurrences (discrete biological populations), abundance, or risk of extinction as determined by expert opinion (Master et al. 2000). In the past decade, NatureServe protocols have become more quantitative and consider additional ranking criteria, including long and short-term trends, area of occupancy, condition of occurrences, intrinsic rarity, and threat (Faber-Langendoen et al. 2009; Regan et al. 2004). Unfortunately, the revised NatureServe ranking protocol has become more complex and less transparent. Individual ratings are weighted differently, some criteria are used only conditionally, and scores are tallied by a "black box" computer algorithim (Faber-Langendoen et al. 2009).

As part of my doctoral dissertation on plant conservation in Wyoming (Fertig 2011), I developed a hybrid ranking protocol by borrowing components of each of the preceding systems. As a starting point, I adopted most of the rarity factors from NatureServe (Regan et al. 2004), added the uncertainty components of IUCN (2001), and included an emphasis on threats from the US Fish and Wildlife Service (1983). The ranking system itself is a modification of the qualitative, binary scoring employed by Rabinowitz (1981), expanded to include additional criteria. I added a simple scoring component to classify plant species into six different rarity classes reflecting each taxon's overall conservation priority (Fertig 2009, 2011).

In 2007, I beta-tested the "Wyoming protocol" at the annual Utah rare plant meeting sponsored by the Utah Native Plant Society (UNPS) and Red Butte Garden. Following the meeting, the UNPS state board voted to reestablish a rare plant committee and charged it with applying this ranking system to the entire Utah vascular plant flora in order to create a new, prioritized list of rare plant species for the state. A draft version of the list was presented at a special session of the Fifth Southwestern Rare and Endangered Plant Conference, held at the University of Utah in March 2009. Based on feedback from meeting participants and other experts, the list was revised and published in November 2009 (Fertig 2009). The list has since been updated twice (Fertig 2010a, 2012) based on additional input from the UNPS Rare Plant Committee, attendees of the Society's annual rare plant meeting, and review of new literature.

The purpose of this paper is to briefly describe the Wyoming ranking protocol and its application to the flora of Utah. Appendices 1-4 include the current lists of Utah plants on the Extremely High Priority, High Priority, Watch, and Need Data lists. The paper concludes with a comparison of the current list to previous rare plant lists for Utah and a discussion of additional applications and future directions.

METHODS

Ranking Criteria

The Wyoming protocol is based on seven biological and anthropogenic factors that influence the conservation priority of a vascular plant species. These criteria are:

1. Geographic range. Geographic range takes into account the state's contribution to the total global distribution of a species. Six geographic range categories are recognized (Table 1). Local and regional endemics have highly restricted global distributions, ranging from single populations covering a few acres to less than 250,000 km^2 (an area about the size of the state of Wyoming). Widespread species, defined as occupying a global range in excess of 250,000 km^2, can still be considered rare if state populations are widely isolated from the core of the species' range (disjunct) or are at its very edge (peripheral). A small number of plant species may occur widely but are limited to small, often scattered or discontinuous habitats and occupy less than 5% of the state (sparse). Species that are introduced to the state are not included in the rankings.

2. Number of Populations. This criterion is based on the number of extant populations of a species within Utah (occurrences outside the state are not considered). Populations are defined as aggregations of individual plants within a specific geographic area that are separated from other populations by a physical barrier, extensive area of unsuitable habitat, or sufficient distance to prevent gene flow (usually about 1-2 km). The num-

Table 1. Scores for Ranking Factors.

Ranking Factor	Category or Condition	Points
1. Geographic Range (only taxa native to the state are scored)	Local endemic (global range less than 16,500 km^2 or about 1 degree of latitude x 2 degrees of longitude)	2
	Regional endemic (global range covering 16,501-250,000 km^2 or an area about the size of Wyoming)	1
	Disjunct (globally widespread but state population is isolated from the main contiguous range of the species by a gap of more than 800 km)	1
	Peripheral (globally widespread but state population is at the margin of its continuous range and occupies less than 5% of the state's area near state boundary)	1
	Sparse (globally widespread, but distribution patchy and discontinuous in the state and covering less than 5% of the state's area)	1
	Widespread (occurs widely across North America [covering more than 250,000 km^2] and across the state [occupying well over 5% of the area])	0
	Unknown	0-1
2. Number of Populations	Low (fewer than 25 extant populations in state)	1
	Medium to High (25 or more extant populations in state)	0
	Unknown	0-1
3. Abundance	Low (depends on life history of species, but typically less than 30,000 individuals for perennials [higher numbers allowable for annuals] or occupying an area of less than 3000 acres in state)	1
	Medium to High (known from well over 30,000 individuals for perennials or occupying an area greater than 3000 acres in state)	0
	Unknown	0-1
4. Habitat Specificity	High ("Specialist" restricted to one or a few specialized geologic substrates, soil types, or vegetation types)	1
	Medium to Low ("Generalist" found in numerous geologic substrates, soil types, or vegetation types)	0
	Unknown	0-1
5. Intrinsic Rarity	High (unusual life history, dependence on rare or specialized pollinators, poor dispersal, low fecundity, poor seedling survival, etc.)	1
	Medium to Low (no unusual life history or biological attributes limiting establishment or persistence	0
	Unknown	0-1
6. Magnitude and Imminence of Threats	High (current or foreseeable threats significant or broad in scale or scope	1
	Medium to Low (threats minimal or limited to small percentage of populations now or in the foreseeable future)	0
	Unknown	0-1
7. Population Trend	Decreasing (short to long-term decline in number, size, or vigor of populations)	1
	Increasing, stable, or oscillating around a mean	0
	Unknown	0-1

ber of populations is not necessarily equivalent to the number of collections of a species, especially if these collections are from the same general area.

3. Abundance. Abundance refers to the number of individual plants known statewide. If census data are lacking, abundance can be approximated from the relative dominance of a species within its area of occupied habitat.

4. Habitat Specificity. This factor assesses the degree to which a species is a habitat specialist restricted to a particular soil or geologic substrate (edaphic endemics) or vegetation type, or is a generalist found in a wide variety of substrates or plant communities.

5. Intrinsic Rarity. Analogous to habitat specificity, intrinsic rarity addresses those attributes of a species' life history that may limit its establishment or persistence. Examples include low fecundity, poor dispersal, low seedling survival, low genetic diversity, or dependence on specialized pollinators.

6. Magnitude and Imminence of Threats. This criterion assesses the scope, severity, and immediacy of current or future negative impacts on a species. Potential threats include habitat destruction, over-collection, herbivory, trampling or soil compaction from recreation, or competition from invasive plants.

7. Population Trend. Trend is the change in population size, extent, and vigor over time.

Assigning scores to each criterion

Following the model of Rabinowitz (1981), six of the seven preceding criteria are scored using a binary rating (high/low or increasing/decreasing). A score of 1 is assigned to those conditions that make a species highly vulnerable to extinction or extirpation, while a score of 0 is given for conditions that only moderately impact or do not adversely affect a species' persistence in the state. The only exception is geographic range in which three scores are possible (0, 1, or 2) to allow greater weighting of locally endemic species**.** If there is insufficient data to rate a specific criterion, or available information is inconclusive, a value of "U" (unknown) may be assigned. Scores for individual criteria are shown in Table 1.

Scoring is based on a review of pertinent literature, specimen databases, and expert knowledge and should be supported by corroborating data. Scores can be tabulated in a spreadsheet or in a simple data form (see Table 2 for an example).

Determining conservation priority

Once the ranking form or table is completed, the individual scores for each of the seven ranking factors are summed to derive both a minimum and potential (maximum) score (Table 2). These scores can range from 0 to 8. The minimum score includes only those factors for which information is available, with any unknowns scored as 0. The potential score includes the same values but with unknowns given a "worst case" score of 1. The minimum and potential scores are then averaged (with the sum rounded down) to derive an overall score (Table 2).

The final score can be used to assign each species to one of the following six conservation priority categories:

Extremely High (7 or 8 points): species at extreme risk of extirpation across its range due to all seven of the following conditions: limited geographic range, small number of populations, low number of individuals, high habitat specificity, high intrinsic rarity, high threats, and downward population trend.

High (6 points): species at high risk of extirpation rangewide or in the state. High priority species are scored as vulnerable for at least six of the seven ranking criteria.

Watch (5 points): species currently secure but vulnerable to downward changes in status. These taxa are scored as vulnerable for at least five of the seven ranking criteria.

Medium (4 points): species secure rangewide but vulnerable to extirpation in the state. Medium priority species are scored as vulnerable for at least four of the seven ranking criteria.

Low (0-3 points): species secure rangewide and in the state. These species are scored as vulnerable for three or less of the seven ranking criteria.

Need Data: insufficient data available to score species for at least three of the seven ranking criteria. If information were available. these species would likely be ranked as Extremely High, High, Watch, or Medium priority rather than Low priority.

An example of ranking a Utah species

The following example demonstrates the application of the Wyoming protocol. *Penstemon gibbensii* is a narrow endemic of extreme NE Utah (Daggett County), adjacent NW Colorado, and SC Wyoming, earning it 2 points for geographic range. In Utah, it is known from a single occurrence in the Browns Park area (1 point for low number of populations) containing approximately 700 plants (1 point for low number of individuals) (Utah Division of Wildlife Resources 1998). It is restricted to barren white shales of the Browns Park Formation (1 point for high habitat specificity). Little is known about the pollination biology or life history of *P. gibbensii* (Heidel 2009), suggesting an "unknown" score is appropriate for intrinsic rarity. Threats from trampling, soil erosion, and over-collection by gardeners are high throughout its range (1 point for threats). Trends in Utah are unknown, although some populations in Wyoming appear to be declining (Heidel 2009). The minimum score for *P. gibbensii* is 6 points, while the potential score is 8. The average of the two scores is 7, earning *P. gibbensii* a place on the UNPS Extremely High priority list.

RESULTS

The UNPS Rare Plant Committee met in January 2009 to apply the Wyoming protocol to the entire flora of Utah. Based on the fourth edition of *A Utah Flora* (Welsh et al. 2008) and other recent literature (such as *The Flora of North America* and *Intermountain Flora*) we started with a pool of 4273 taxa* of vascular plants known to be native or introduced in Utah. We immediately removed 1017 cultivated and naturalized (non-native) taxa, as we deemed these not to be of conservation importance in the state. Of the 3160 species native to Utah, we eliminated another 1421 common and widespread taxa (mostly ranked S4 or S5 by NatureServe) of

Table 2. Sample Ranking Form

Species			
Date Scored		**Evaluators**	
Ranking Factors	**Scores** Select one score per ranking factor in either column A or B		**Comments**
	Column A	**Column B**	
1. Geographic Range	Local Endemic (2) ____ Regional Endemic, Disjunct, Peripheral, or Sparse (1) ____ Widespread (0) ____	Unknown (1) ____	
2. Number of Populations	Low (1) ____ Medium to High (0) ____	Unknown (1) ____	
3. Abundance	Low (1) ____ Medium to High (0) ____	Unknown (1) ____	
4. Habitat Specificity	High (1) ____ Medium to Low (0) ____	Unknown (1) ____	
5. Intrinsic Rarity	High (1) ____ Medium to Low (0) ____	Unknown (1) ____	
6. Magnitude and Imminence of Threats	High (1) ____ Medium to Low (0) ____	Unknown (1) ____	
7. Population Trend	Downward (1) ____ Stable, Oscillating or Upward (0) ____	Unknown (1) ____	
TOTALS	Sum of scores in Column A ____	Sum of scores in Column B ____	Sum of scores in Column A + B ____
Conservation Priority* ____________________	**Minimum** (based on total score in Column A) ____	**Potential** (based on sum of scores in Columns A + B) ____	**Averaged** (based on average of scores in Columns A + B rounded down) ____

*Conservation Priority is based on the averaged point total: Extremely high priority = total score of 7 or 8 points, High priority = total score of 6 points, Watch list = total score of 5, Medium priority = total score of 4 points, Low priority = total score of 0-3 points.

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*Taxa include full species and unique subspecies and varieties, treated here in the phylogenetic sense of Cracraft (1987) as the smallest evolutionary units that are diagnosably distinct.

low conservation priority. The remaining 1739 taxa were then ranked by the committee using the Wyoming protocol. At this point another 927 taxa were assigned to the Low Priority list, leaving 812 species among the other categories (Extremely High, High, Watch, Medium, and Need Data). These remaining taxa comprised the first draft of the UNPS rare plant list, presented at the 2009 Southwest Rare Plant Conference.

Revisions suggested by the conference attendees and other specialists resulted in changes to the final score for over 100 taxa. These changes were reflected in the final UNPS rare plant list, published in the Society's membership publication, the *Sego Lily*, in November 2009 (Fertig 2009). The list has been revised twice since then. Twenty taxa were changed in rank due to new data and 11 newly described or discovered species were added (Fertig 2010, 2012).

Extremely High Priority At present, 31 Utah plant taxa are recognized as species of Extremely High conservation priority (Table 3, Appendix 1). This group represents just 1% of the entire flora of the state. To qualify as Extremely High priority, a species must have a limited geographic range, few populations, low number of individuals, high habitat specificity and intrinsic rarity, high threats, and a downward population trend. Nearly half (15 taxa) of these species are presently listed as Threatened or Endangered under the ESA, and another four species are candidates or proposed for listing. Another 14 of these species are designated as Sensitive by the BLM or Forest Service. Just two of the 31 Extremely High priority plant taxa lack any formal designation: *Iris pariensis* (a species with taxonomic questions that may be extinct) and *Viola clauseniana* (endemic to Zion National Park and increasingly threatened by competition from exotic plants and possible over-collection; Fertig 2010b). Since the initial UNPS list was published one species has been dropped from the Extremely High priority list (*Sclerocactus wetlandicus*, changed to High priority) and one species has been added (*Carex specuicola*, upgraded from the High priority list).

High Priority The High priority list presently contains 119 taxa, up from 114 recognized in 2009 (Table 3, Appendix 2). This group consists of only 3.8% of the native flora of Utah. High priority plant species generally have limited geographic ranges, low population size, few known occurrences, and high habitat specificity, but have lower intrinsic rarity, fewer threats, or stable trends (or these factors are unknown) compared to Extremely High priority taxa. Eight of the state's 24 federally listed Threatened or Endangered species are ranked High priority by UNPS, and two other species from this group are currently candidates for potential listing. Half of the High priority taxa (60 species) are listed as Sensitive by the BLM or Forest Service. The remaining 51 species have no status and consist mostly of species that were once considered for listing under the ESA (41 former Category 2 or 3C taxa), or are recently described (Atwood et al, 1991; Welsh and Atwood 2009).

Watch List The UNPS Watch list currently contains 264 taxa (Table 3, Appendix 3), or 8.4% of the native Utah flora. This category contains local or regional endemics with high habitat specificity or intrinsic rarity, but which are either locally abundant or apparently secure at present. If current conditions were to change significantly, however, these species could easily trend downward and become species of greater concern (and be rescored as Extremely High or High priority). At least 115 species in the Watch category were initially considered for potential listing under the ESA (Atwood et al. 1991, Ayensu and DeFilipps 1978; Greenwalt 1975, Welsh 1978, Welsh et al. 1975, Welsh and Chatterley 1985) in the 1970s and 1980s, but were subsequently dropped from consideration after better survey data found them to be less imminently threatened or rare. *Astragalus montii* is the only species currently listed under the ESA that is categorized on the Watch list (*Erigeron maguirei*, recently delisted, is also on the Watch list). Another 70 species in the Watch category are presently listed as Sensitive by the BLM or Forest Service. Over one-third of the changes to the UNPS list since 2009 have involved additions or status changes affecting the Watch category.

Medium Priority Another 329 plant species in Utah are currently ranked as Medium priority for conservation attention (Table 3)*. Species in this category are usually widespread globally but rare within the state, with few known occurrences, low numbers, or potentially high threats. A small subset of Medium priority species (including 13 listed as Sensitive by the BLM or Forest Service) are locally common regional endemics with stable trends and low threats that might otherwise be treated on the Watch list. Medium priority taxa account for 10.4% of the native flora of Utah.

Need Data A total of 115 taxa are presently on the UNPS Need Data list (Table 3, Appendix 4), or 3.6% of the state's native flora. This is the fastest growing category, as it tends to be the repository for newly described species or those discovered for the first time within Utah. Recent additions include *Astragalus kelseyae, Eremogone loisiae, Eriogonum domitum*, and *Navarretia furnissii*, all named as new species since 2009 (Corbin 2011, Grady and Reveal 2011; Holmgren and Holmgren 2011, Johnson et al. 2012). The Need Data list also includes species with unresolved taxonomic questions and those that have been reported for the state

*In the interests of space, the Medium priority list is not included in this paper, but is available by request from UNPS.

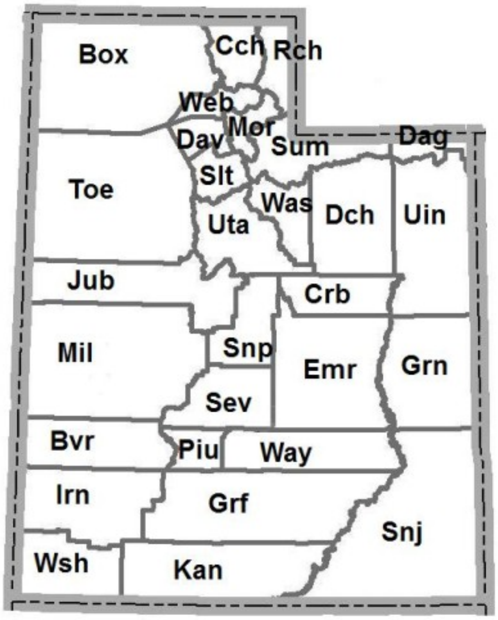

Figure 1. Utah Counties with three-letter codes used in Table 3 and Appendix 1-4.

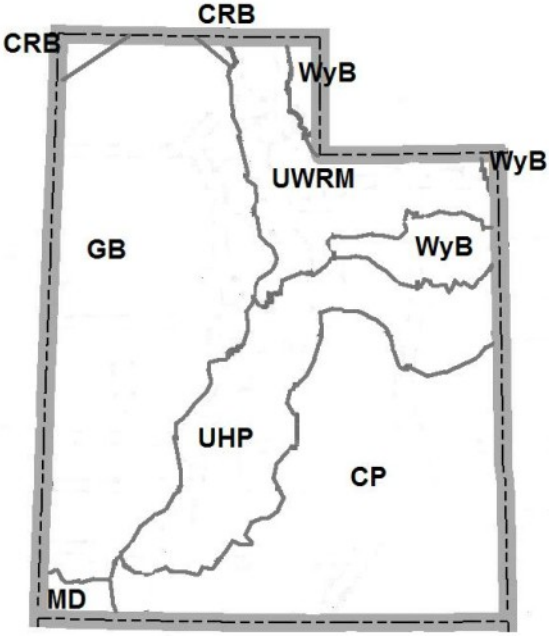

Figure 2. TNC Ecoregions of Utah, used in Table 3, as defined by Stein et al. (2000).

Table 3. Summary of UNPS Rare Plant List, 2009-2012

See text for explanation and scoring of each of the ranking categories. Counties are depicted in Figure 1. Ecoregions are defined as geographic regions with similar climate, topography, and vegetation, as defined by The Nature Conservancy (Stein et al. 2000) and are shown in Figure 2.

	State/County/TNC Ecoregion	**Extremely High**	**High**	**Watch**	**Need Data**	**Medium**	**Total**
State	Utah Statewide	31	119	264	115	329	858
County	Beaver County (Bvr)	0	8	13	8	24	53
	Box Elder County (Box)	1	2	10	6	28	47
	Cache County (Cch)	0	3	7	4	28	42
	Carbon County (Crb)	1	1	9	5	3	19
	Daggett County (Dag)	1	2	13	3	16	35
	Davis County (Dav)	0	0	2	2	6	10
	Duchesne County (Dch)	4	14	28	9	24	79
	Emery County (Emr)	5	8	24	17	23	77
	Garfield County (Grf)	1	17	49	17	49	133
	Grand County (Grn)	1	12	26	17	29	85
	Iron County (Irn)	0	5	18	7	23	53
	Juab County (Jub)	1	6	13	12	17	49
	Kane County (Kan)	3	25	52	12	67	159
	Millard County (Mil)	0	6	21	17	21	65

Table 3. Continued

	State/County/TNC Ecoregion	Extremely High	High	Watch	Need Data	Medium	Total
County	Morgan County (Mor)	0	0	2	0	1	3
	Piute County (Piu)	0	9	13	3	14	39
	Rich County (Rch)	0	1	4	5	9	19
	Salt Lake County (Slt)	0	8	12	2	20	42
	San Juan County (Snj)	2	13	39	15	63	132
	Sanpete County (Snp)	2	7	12	4	8	33
	Sevier County (Sev)	3	13	18	6	21	61
	Summit County (Sum)	0	1	5	3	15	24
	Tooele County (Toe)	1	3	13	5	13	35
	Uintah County (Uin)	6	15	36	10	23	90
	Utah County (Uta)	1	9	14	12	14	50
	Wasatch County (Was)	0	3	8	4	8	23
	Washington County (Wsh)	6	18	76	17	115	232
	Wayne County (Way)	6	12	13	11	22	64
	Weber County (Web)	0	3	6	4	9	22
TNC Ecoregion	Colorado Plateau (CP)	13	47	98	41	124	323
	Columbia River Basin (CRB)	1	1	2	2	19	25
	Great Basin (GB)	2	16	43	28	63	152
	Mohave Desert (MD)	4	11	44	12	67	138
	Utah High Plateaus (UHP)	9	36	69	28	63	205
	Utah-Wyoming Rocky Mtns (UWRM)	0	17	50	16	65	148
	Wyoming Basins (WyB)	7	12	21	11	19	70

in the literature with ambiguous supporting data. The majority of taxa in this category need additional information on trend, threats, and abundance. At least 15 of these species are designated as BLM or Forest Service Sensitive. *Eriogonum corymbosum* var. *nilesii* is a candidate for potential listing under the ESA, although a recent monograph questions the veracity of Utah reports (Reveal in Holmgren et al. 2012).

Low Priority The remaining 2302 native plant taxa of Utah are presently scored as Low conservation priority (72.8% of the total native flora). These species are usually widespread rangewide and within Utah, have numerous populations in the state, low habitat specificity and intrinsic rarity, stable to increasing trends, and few threats. These species are still important for the sake of conserving overall biodiversity, but rarely warrant individualized attention.

All told, 858 of Utah's 3160 native plant taxa (27.2%) have been identified as Extremely High, High, Watch, or Medium priority, or are on the UNPS need data list using the Wyoming protocol system. The distribution of these species across the state is not random. With 232 taxa of conservation concern (27% of the state total), Washington County has the highest number of species of conservation concern of any county in Utah (Figure 1, Table 3). This high richness can be explained in part by Washington County's location at the confluence of four major floristic regions: the Mojave Desert, Great Basin, Colorado Plateau, and Rocky Mountains. The next three counties with the greatest number of species of conservation concern (Kane, Garfield, and San Juan) are all, like Washington County, located on or near the southern boundary of the state. Additional counties with a high number of species of concern include Uintah, Duchesne, Grand, and Emery counties near the eastern border of Utah. By contrast, the number of rare species is relatively low in the northern and western tier of counties. Surprisingly few plant species of conservation concern occur in the greater Salt Lake City area, though this may be an artifact of under-sampling or reflect significant habitat losses over the last 150 years of settlement (Fertig 2009).

Ecoregions are defined as geographic areas with a similar climate, topography, and vegetation. The Nature Conservancy has developed a national ecoregional classification (Stein et al. 2000) that recognizes seven ecoregions in Utah (Figure 2*). Of these, the Colorado Plateau ecoregion has the highest number of plant species of conservation concern with 323 taxa, or 37.6% of the state total (Table 3). This region, which includes the canyon country and La Sal and Abajo mountains of southeast Utah, also has the highest number of endemic species in the state (Welsh and Atwood 2009). Although comparable in area to the Colorado Plateau, the Great Basin ecoregion has less than half as many species of concern (152 taxa). The Mohave Desert ecoregion of extreme southwestern Utah is the second smallest in area in the state (after the Columbia River Basin in the Grouse Creek and Raft River mountains of northwest Utah) but has the highest concentration of species of concern per unit area (138 taxa in all). The Utah High Plateaus, which extends from the Tavaputs Plateau and Book Cliffs of eastern Utah to the Wasatch Plateau, and Markagunt and Paunsaugunt plateaus of south-central Utah, has the second highest concentration of endemics and taxa of conservation concern (205 species, or 23.9% of the state total) (Table 3).

DISCUSSION

The UNPS rare plant list is just the latest in a long series of comparable publications dating back to the passage of the Endangered Species Act (ESA) of 1973. No plants were included in the very first official list of species protected under the ESA, but Congress directed the Smithsonian Institution to develop the first national list of vascular plants that might qualify for listing as Threatened or Endangered. That list appeared in 1975 and was based on the best available information at the time (Ayensu and DeFilipps 1978, Greenwalt 1975). The Smithsonian Institution cited 761 plant taxa as potentially Endangered, 1238 as Threatened, and 100 as extinct in the continental United States (another 1088 endangered, threatened, and extinct species were reported for Hawaii). Of these, 156 species were from Utah, including 56 listed as endangered, 91 threatened, and 9 extinct (Greenwalt 1975).

Welsh and others (1975) reviewed the Smithsonian publication and developed the first Utah-specific compilation of endangered, threatened, extinct, endemic, and rare plant species in 1975. Welsh and his co-authors recognized 66 Utah plant taxa as possibly endangered, 198 as threatened, 7 as extinct, and 20 as extirpated (extinct in Utah, but extant elsewhere). Most of the recommendations by Welsh and others (1975) were incorporated into a revised Smithsonian list (Ayensu and DeFilipps 1978) that became part of a proposal to list nearly 1700 plant species as Threatened or Endangered in 1976 (the proposal was ultimately dismissed).

These initial rare species lists were plagued by incomplete data and taxonomic problems. Of the 156 Utah species considered endangered, threatened, or extinct by the Smithsonian Institution in 1975, only 39 (25%) are still considered taxa of Extremely High or High conservation priority today. At least 13 of these species (8.3%) are no longer recognized as legitimate taxa. Another 28 species (18%) are now known to be much more common or less threatened and are classified as Low priority by UNPS. Eight of the nine species considered extinct in 1975 have been rediscovered (only *Cuscuta warneri* is still thought to be extirpated in Utah). Among the additional 225 state endemics and other potentially rare species evaluated by Welsh and others (1975), one half (112 taxa) are now scored as Low priority and 26 (11.5%) are no longer recognized taxonomically.

Over the next two decades new Utah rare plant lists were developed by the US Fish and Wildlife Service, Bureau of Land Management, US Forest Service, and non-governmental organizations (such as The Nature Conservancy and Utah Native Plant Society). The composition of these lists continued to evolve to reflect ever-improving knowledge of the distribution, abundance, and status of the state's flora (Atwood et al. 1991; Utah Division of Wildlife Resources 1998; Utah Native Plant Society 1980, 1982; Welsh 1978; Welsh and Chatterley 1985; Welsh and Thorne 1979). Threat of potential listings under the ESA prompted a large scale effort to survey rare species and remote corners of the nation for new taxa. During the period from 1975 to 1994 nearly 1200 new vascular plant taxa were described across North America, or approximately 60 new

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*Welsh and Atwood (2009) have developed a similar system of "geoendemic areas" to identify floristic regions of Utah. Their map depicts 12 subregions and differs from the TNC system in lumping the Columbia River Basin with the Great Basin and in more finely subdividing the Utah-Wyoming Rocky Mountains, Utah High Plateaus, Colorado Plateau, and Mohave Desert ecoregions.

species per year (Hartman and Nelson 1998). In Utah alone, over 250 new plant taxa have been named since the early 1970s (Welsh et al. 2008). Not surprisingly, most of these newly discovered species are narrow endemics with few or small populations and specialized habitat requirements, making them potential candidates for rare plant lists. Fifty-five percent of the current UNPS Extremely High priority list (17 species) and 52% of the High priority list (62 species) have only been named since 1978.

In the years since 1975, field surveys and taxonomic research have resulted in many plant taxa being removed from consideration as species of concern due to lack of threat, stable trends, or documented abundance. At least 772 of the current 2302 Utah plant taxa scored as Low priority by UNPS (33.5%) have been listed as potentially Endangered, Threatened, extinct, or otherwise rare at one time. Of the 28 Utah species that have been listed as Threatened or Endangered by the US Fish and Wildlife Service since 1978, four have subsequently been delisted (*Astragalus perianus, Erigeron maguirei, Echinocereus engelmannii* var. *purpureus*, and *Echinocereus triglochidiatus* var. *inermis*) because surveys have found them to be much more common, or the taxa are no longer recognized.

Future Applications

Rare plant lists have a short shelf life. The UNPS list has already been revised twice since it first appeared in 2009 and will need to be updated again in the coming year. With the publication of the final volume of the *Intermountain Flora* (Holmgren et al. 2012) at least 36 new native plant species have been documented in Utah which have not been evaluated by the UNPS Rare Plant Committee. Several of these species are narrow endemics that are likely to be ranked as Extremely High, High, or Watch list species when sufficient data are available for review. Other species currently on the Need Data list will also likely be placed in higher priority categories in the near future. Undoubtedly, there are more rare species still awaiting discovery in the years ahead. Results of on-going monitoring studies and field inventories will also improve our understanding of many species and result in shifts in their conservation priority.

In addition to Utah, the Wyoming protocol has been recently applied to the entire flora of Wyoming (Fertig 2011) and to Zion National Park (Fertig 2010b). In Zion, the park's initial list of over 200 species of concern was streamlined to 51 taxa, of which only 13 were deemed Extremely High or High priority. Some species were given a slightly different rank in the park compared to the state as a whole, reflecting differences in scale and data sufficiency (Fertig 2010b). The Idaho and Arizona native plant societies have also expressed interest in using this methodology to rank rare plants in their respective states. As it is used more frequently, the protocol will hopefully be strengthened and improved.

It is important to remember that the UNPS rare plant list has no binding legal authority and is only as accurate as the information used for ranking. The list and the listing process remain useful, however, because they provide a simple, repeatable, and transparent method to prioritize conservation action among hundreds of rare species. With conservation resources stretched thin and time running out, this form of triage may be critical to preserving Utah's most vulnerable botanical treasures.

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Appendix 1. UNPS Rare Plant List: Extremely High Priority Species

The following table lists 31 species scored as Extremely High priority for conservation attention in Utah based on the Wyoming protocol ranking system. Species are listed alphabetically by family and scientific name. Synonyms for family and species names are included in parentheses. See text for an explanation of the seven ranking criteria and scoring methods used to derive the minimum and potential scores. County codes are explained in Table 3. Legal Status: Bureau of Land Management (BLM) and US Forest Service (USFS) Sensitive = S; US Fish and Wildlife Service (USFWS) Candidate = C, Endangered = E, Proposed = P; Threatened = T.

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Agavaceae	*Yucca sterilis* (*Y. harrimaniae* var. *s.*)	Creeping yucca	2	1	1	U	1	1	U	6	8	Dch?, Uin; BLM:S
Asteraceae (Compositae)	*Townsendia aprica*	Last Chance townsendia	2	1	1	1	0	1	1	7	7	Emr, Sev, Way; USFWS: T
Brassicaceae (Cruciferae)	*Lepidium barnebyanum*	Barneby's pepperwort	2	1	1	1	U	1	U	6	8	Dch; USFWS: E
	Schoenocrambe argillacea (*Hesperidanthus a.*)	Clay reed-mustard	2	1	1	1	U	1	U	6	8	Uin; USFWS: T
	Schoenocrambe barnebyi (*Hesperidanthus b.*)	Barneby's reed-mustard	2	1	1	1	U	1	U	6	8	Emr, Way; USFWS: E
	Schoenocrambe suffrutescens (*Hesperidanthus s.*)	Shrubby reed-mustard	2	1	1	1	U	1	1	7	8	Dch, Uin; USFWS: E
Cactaceae	*Pediocactus despainii*	Despain's pincushion cactus	2	1	1	1	1	1	1	8	8	Emr, Way; USFWS: E
	Pediocactus winkleri	Winkler's pincushion cactus	2	1	1	1	1	1	1	8	8	Way; USFWS: T
	Sclerocactus brevispinus (*S. whipplei* var. *ilseae*)	Pariette hookless cactus	2	1	1	1	1	1	U	7	8	Dch, Uin; USFWS: T
	Sclerocactus wrightiae	Wright's fishhook cactus	2	0	1	1	1	1	1	7	7	Emr, Way; USFWS: E
Chenopodiaceae	*Atriplex canescens* var. *gigantea* (Not recognized by Holmgren et al. 2012)	Giant fourwing saltbush	2	1	1	1	U	1	U	6	8	Jub; BLM: S
Cyperaceae	*Carex specuicola*	Navajo sedge	1	1	1	1	1	1	1	7	7	Snj; USFWS:T Originally on High priority list
Fabaceae (Leguminosae)	*Astragalus ampullarioides*	Shivwits milkvetch	2	1	1	1	1	1	1	8	8	Wsh; USFWS: E
	Astragalus anserinus	Goose Creek milkvetch	2	1	1	1	0	1	1	7	7	Box; BLM: S; USFS: S; USFWS: C

Appendix 1. UNPS Rare Plant List: Extremely High Priority Species, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Fabaceae (Leguminosae)	*Astragalus holmgreniorum*	Holmgren's milkvetch	2	1	1	1	1	1	1	8	8	Wsh; USFWS: E
	Astragalus iselyi	Isely's milkvetch	2	1	1	1	0	1	1	7	7	Grn, Snj; BLM:S; USFS:S
	Astragalus lentiginosus var. *pohlii*	Pohl's milkvetch	2	1	1	1	1	1	U	7	8	Toe; BLM: S
	Trifolium variegatum var. *parunuweapensis*	Parunuweap clover	2	1	1	1	U	1	U	6	8	Kan; BLM: S
Hydrophyllaceae	*Phacelia argillacea*	Clay phacelia	2	1	1	1	0	1	1	7	7	Utah; USFWS: E
	Phacelia utahensis	Utah phacelia	2	1	1	1	U	1	1	7	8	Snp, Sev; BLM:S
Iridaceae	*Iris pariensis* (Included in *Iris missouriensis* in FNA)	Paria iris	2	1	1	U	U	1	1	6	8	Kan
Lamiaceae (Labiatae)	*Salvia columbariae* var. *argillacea*	Chinle chia	2	1	1	1	1	1	1	8	8	Kan, Wsh; BLM: S
Loasaceae	*Mentzelia argillosa*	Arapien stickleaf	2	1	1	1	0	1	1	7	7	Snp, Sev; BLM: S
Malvaceae	*Sphaeralcea gierischii*	Gierisch's globemallow	2	1	1	1	U	1	1	7	8	Wsh; BLM: S; USFWS:C
Papaveraceae	*Arctomecon humilis*	Dwarf bearclaw poppy	2	1	1	1	1	1	1	8	8	Wsh; USFWS:E
Polemoniaceae	*Gilia caespitosa* (*Aliciella c.*)	Rabbit Valley gilia	2	1	1	1	0	1	1	7	7	Way; BLM: S; USFS: S
Ranunculaceae	*Ranunculus aestivalis* (*R. acris* var. *aestivalis*)	Autumn buttercup	2	1	1	1	1	1	1	8	8	Grf; USFWS:E
Scrophulariaceae	*Penstemon gibbensii*	Gibbens' beardtongue	2	1	1	1	U	1	U	6	8	Dag; BLM: S
	Penstemon grahamii	Graham's penstemon	2	1	1	1	1	1	1	8	8	Crb, Uin; BLM: S; USFWS:P
	Penstemon scariosus var. *albifluvis*	White River penstemon	2	1	1	1	0	1	1	7	7	Uin; BLM: S; USFWS: C
Violaceae	*Viola clauseniana*	Clausen's violet	2	1	1	1	1	U	1	7	8	Wsh

Appendix 2. UNPS Rare Plant List: High Priority Species

The following table lists 119 species scored as High Priority for conservation attention in Utah based on the Wyoming protocol ranking system. Species are listed alphabetically by family and scientific name, with synonyms in parentheses. See text for an explanation of the seven ranking criteria and scoring methods used to derive the minimum and potential scores. County codes are explained in Table 3. Legal Status: Bureau of Land Management (BLM) and US Forest Service (USFS) Sensitive = S; US Fish and Wildlife Service (USFWS) Candidate = C, Endangered = E, Proposed = P; Threatened = T.

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Apiaceae (Umbelliferae)	*Cymopterus coulteri*	Two-leaf spring-parsley	2	1	U	1	0	1	U	5	7	Jub, Snp, Sev, Toe
	Cymopterus higginsii	Higgins' spring-parsley	2	1	1	1	0	1	0	6	6	Kan
	Lomatium latilobum	Canyonlands lomatium	2	1	1	1	0	1	U	6	7	Grn, Snj; BLM: S; USFS: S
	Lomatium scabrum var. *tripinnatum*	Virgin lomatium	2	1	U	1	0	1	U	5	7	Wsh
Apocynaceae	*Cycladenia humilis* var. *jonesii* (*C. jonesii*)	Jones' cycladenia	1	1	1	1	1	1	0	6	6	Emr, Grf, Grn, Kan; USFWS:T
Asclepiadaceae	*Asclepias welshii*	Welsh's milkweed	2	1	1	1	0	1	0	6	6	Kan; USFWS:T
Asteraceae (Compositae)	*Ambrosia x sandersonii* (*Hymenoclea s.*)	Sanderson's bur-sage	2	1	1	0	1	1	U	6	7	Wsh
	Chrysothamnus nauseosus var. *glareosus* (*Ericameria nauseosa* var. *glareosa*)	Marysvale rabbit-brush	2	1	1	1	0	U	1	6	7	Piu
	Cirsium virginense (included in *C. mohavense* in FNA)	Virgin thistle	1	1	1	1	0	1	1	6	6	Wsh; BLM: S
	Enceliopsis nudicaulis var. *bairdii*	Baird's nakedstem	2	1	1	1	0	1	1	7	7	Wsh
	Erigeron higginsii (included in *E. canaani* in FNA)	Higgins' daisy	2	1	1	1	0	1	U	6	7	Wsh
	Erigeron kachinensis	Kachina daisy	2	1	1	1	0	1	U	6	7	Snj; BLM: S; USFS: S; originally on Watch list
	Erigeon vagus var. *madsenii*	Madsen's daisy	2	1	1	1	1	0	U	6	7	Grf, Irn, Kan
	Haplopappus armerioides var. *gramineus* (*Stenotus a*. var. *g.*)	Grass goldenweed	2	1	U	1	0	1	U	5	7	Dch, Uit

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Asteraceae (Compositae)	*Haplopappus lignum-viridis* (*Ericameria l.*)	Greenwood goldenbush	2	1	1	1	1	0	U	6	7	Sev; BLM: S
	Haplopappus scopulorum var. *canonis*	Canyon spindly goldenbush	2	1	1	1	0	U	U	5	7	Snj
	Senecio castoreus (*Packera c.*)	Beaver Mountain groundsel	2	1	1	1	0	1	U	6	7	Bvr, Piu; USFS: S
	Senecio malmstenii (*Packera m.*)	Podunk groundsel	2	1	1	1	1	0	U	6	7	Grf, Irn, Kan; USFS: S
	Senecio musiniensis (*Packera m.*)	Musinea groundsel	2	1	1	1	U	0	U	5	7	Snp; USFS: S
	Thelesperma subnudum var. *maliterrimum* (*T. pubescens*)	Uinta greenthread	2	1	1	1	0	U	U	5	7	Dch, Uin; BLM: S; USFS: S
	Townsendia goodrichii	Goodrich's townsendia	2	1	1	1	0	U	U	5	7	Dch, Uin
	Townsendia jonesii var. *lutea* (included in *T. aprica* by some authors)	Sigurd townsendia	2	1	1	1	0	1	U	6	7	Jub, Piu, Sev; BLM: S; USFS: S
	Townsendia strigosa var. *prolixa*	Strigose townsendia	2	1	U	1	0	1	U	5	7	Dch, Grn; BLM: S
	Viguiera soliceps (*Heliomeris soliceps*)	Tropic goldeneye	2	1	0	1	1	1	0	6	6	Kan
	Xylorhiza cronquistii	Cronquist's woodyaster	2	1	1	1	1	0	U	6	7	Grf, Kan
	Xylorhiza glabriuscula var. *linearifolia*	Moab woodyaster	2	1	U	1	0	1	U	5	7	Grf, Grn, Snj, Way
Boraginaceae	*Cryptantha grahamii*	Graham's cryptanth	2	1	U	1	0	1	U	5	7	Dch, Uin; BLM: S
	Cryptantha semiglabra	Pipe Spring cryptanth	2	1	1	1	0	1	U	6	7	Wsh?
Brassicaceae (Cruciferae)	*Arabis falcatoria* (*Boechera falcatoria*)	Falcate rockcress	2	1	1	1	0	U	U	5	7	Box, Jub; USFS: S
	Arabis harrisonii (*Boechera harrisonii*)	Harrison's rockcress	2	1	1	1	0	U	U	5	7	Uta
	Draba ramulosa	Belknap Peak draba	2	1	1	1	0	1	U	6	7	Bvr, Piu; USFS: S
	Draba sobolifera	Creeping draba	2	1	1	1	0	1	U	6	7	Bvr, Piu; USFS: S
	Lepidium integrifolium	Entire-leaf pepperwort	1	1	1	1	0	1	1	6	6	Bvr, Rch, Snp, Sev, Uin

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Brassicaceae (Cruciferae)	*Lepidium montanum* var. *alpinum*	Wasatch pepperwort	2	1	1	1	0	U	U	5	7	Slt; USFS: S
	Lepidium montanum var. *stellae*	Stella's pepperwort	1	1	1	1	1	1	U	6	7	Grf, Kan
	Lepidium ostleri	Ostler's pepperwort	2	1	1	1	0	1	U	6	7	Bvr; BLM: S; USFWS: C
	Physaria chambersii var. *canaanii*	Canaan Peak twinpod	2	1	1	1	0	U	U	5	7	Grf
	Physaria grahamii (some authors include *P. acutifolia* vars. *repanda & purpurea*)	Graham's twinpod	2	1	1	1	0	U	U	5	7	Dch, Grn, Uin, Uta, Was
	Physaria rubicundula var. *tumulosa* (*P. t., Lesquerella t.*)	Kodachrome bladderpod	2	1	1	1	0	1	U	6	7	Kan; USFWS:E
Cactaceae	*Ferocactus acanthodes* (*F. cylindraceus*)	Desert barrel cactus	1	1	1	1	0	1	1	6	6	Wsh; originally on Watch list
	Pediocactus sileri	Siler's pincushion cactus	1	1	1	1	0	1	1	6	6	Kan, Wsh; USFWS:T
	Sclerocactus wetlandicus (*S. whipplei* var. *glaucus*)	Uinta Basin hookless cactus	2	0	1	1	0	1	1	6	6	Dch, Uin; USFWS:T (formerly on ExH list)
Capparaceae (Cleomaceae)	*Cleomella hillmanii* var. *goodrichii* (*C. palmeriana* var. *g.*)	Goodrich's stinkweed	2	1	1	1	0	1	U	6	7	Uin; BLM: S
Chenopodiaceae	*Krascheninnikovia lanata* var. *ruinina*	Ruin Park winterfat	2	1	1	1	0	1	U	6	7	Grn, Snj
Crassulaceae	*Dudleya pulverulenta* var. *arizonica* (*D. arizonica*)	Arizona live-forever	1	1	1	1	0	1	1	6	6	Wsh
Cuscutaceae	*Cuscuta warneri*	Warner's dodder	1	1	1	U	1	1	1	6	7	Mil; may be extirpated in UT
Cyperaceae	*Carex haysii* (included in *C. curatorum* by some authors)	Hays' sedge	2	1	1	1	0	1	U	6	7	Wsh; originally on Watch list
Fabaceae (Leguminosae)	*Astragalus ampullarius*	Gumbo milkvetch	1	1	1	1	1	1	U	6	7	Kan, Wsh; BLM: S
	Astragalus cronquistii	Cronquist's milkvetch	2	1	1	1	0	1	0	6	6	Snj; BLM: S
	Astragalus cutleri	Cutler's milkvetch	2	1	1	1	0	U	U	5	7	Snj
	Astragalus desereticus	Deseret milkvetch	2	1	1	1	U	1	0	6	7	Uta; USFWS:T

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Fabaceae (Leguminosae)	*Astragalus diversifolius*	Meadow milk-vetch	1	1	1	1	0	1	1	6	6	Jub, Toe; USFS: S
	Astragalus equisolensis (*A. desperatus* var. *neeseae*)	Horseshoe milk-vetch	2	1	1	1	0	1	U	6	7	Uin; BLM: S
	Astragalus hamiltonii	Hamilton's milk-vetch	2	1	1	1	0	1	U	6	7	Uin; BLM: S
	Astragalus harrisonii	Harrison's milk-vetch	2	1	1	1	0	1	U	6	7	Grf, Way
	Astragalus loanus	Glenwood milk-vetch	2	1	1	1	0	U	U	5	7	Sev; BLM: S
	Astragalus sabulosus var. *sabulosus*	Cisco milkvetch	2	1	1	1	0	1	U	6	7	Grn; BLM: S
	Astragalus sabulosus var. *vehiculus*	Stage milkvetch	2	1	1	1	0	1	U	6	7	Grn; BLM: S
	Astragalus serpens	Plateau milkvetch	2	1	1	1	0	U	U	5	7	Piu, Sev, Way
	Astragalus striatiflorus	Escarpment milk-vetch	2	1	1	1	0	1	U	6	7	Kan, Wsh; BLM: S
	Astragalus welshii	Welsh's milkvetch	2	1	1	1	0	U	U	5	7	Grf, Irn, Kan, Mill Piu, Way; BLM: S
	Trifolium friscanum (*T. andersonii* var. *f.*)	Frisco clover	2	1	1	1	0	1	U	6	7	Bvr; BLM: S; USFWS: C
Fagaceae	*Quercus gambelii* var. *bonina*	Goodhope oak	2	1	1	0	1	1	U	6	7	Snj
Fumariaceae	*Corydalis caseana* var. *brachycarpa*	Case's corydalis	2	1	1	0	0	1	1	6	6	Slt, Uta, Was, Web; USFS: S
Gentianaceae	*Frasera ackermaniae*	Ackerman's frasera	2	1	1	1	U	0	U	5	7	Uin; BLM: S
Hydrangeaceae (Saxifragaceae)	*Jamesia americana* var. *macrocalyx*	Wasatch jamesia	2	1	1	1	0	U	U	5	7	Jub, Slt, Uta, Was; USFS: S
Hydrophyllaceae	*Phacelia argylensis*	Argyle Canyon phacelia	2	1	1	1	0	1	U	6	7	Dch; BLM: S
	Phacelia cephalotes	Chinle phacelia	1	1	1	1	1	1	U	6	7	Kan, Snj, Wsh
	Phacelia cronquistiana	Cronquist's phacelia	1	1	1	1	1	1	U	6	7	Kan; BLM: S
	Phacelia demissa var. *heterotricha*	Brittle phacelia	2	1	0	1	1	1	U	6	7	Piu, Sev, Way

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Hydrophyllaceae	*Phacelia demissa* var. *minor*	Brittle phacelia	2	1	0	1	1	1	U	6	7	Dch, Uin
	Phacelia indecora	Bluff phacelia	2	1	1	1	0	1	U	6	7	Snj; BLM: S; originally on Watch list
	Phacelia pulchella var. *atwoodii*	Atwood's pretty phacelia	2	1	0	1	1	1	0	6	6	Kan; BLM: S
	Phacelia pulchella var. *gooddingii*	Goodding's pretty phacelia	1	1	1	1	1	1	U	6	7	Wsh
	Phacelia sabulonum (*P. pulchella* var. *sabulonum*)	Tompkins phacelia	2	1	0	1	1	1	U	6	7	Grf, Kan
Loasaceae	*Mentzelia shultziorum*	Shultz's stickleaf	2	1	1	1	0	1	U	6	7	Grn; BLM: S
	Petalonyx parryi	Parry's sandpaper-plant	1	1	1	1	0	1	1	6	6	Wsh; BLM: S
Malvaceae	*Sphaeralcea fumariensis* (*S. grossulariifolia* var. *fumariensis*)	Smoky Mountain globemallow	2	1	1	1	0	1	U	6	7	Kan: BLM: S
	Sphaeralcea janeae	Jane's globe-mallow	2	1	1	1	0	U	U	5	7	Grn, Snj, Way; BLM: S
	Sphaeralcea psoraloides	Scurfpea globe-mallow	2	1	1	1	0	U	U	5	7	Emr, Grn, Way; BLM: S
Onagraceae	*Camissonia exilis*	Meager camissonia	1	1	1	1	1	1	U	6	7	Kan
	Oenothera caespitosa var. *stellae*	Stella's evening-primrose	2	1	1	1	0	1	U	6	7	Emr, Grf, Kan, Snp
	Oenothera murdockii	Murdock's evening-primrose	2	1	1	1	0	1	U	6	7	Kan, Wsh; BLM: S
Ophioglossaceae	*Botrychium lineare*	Slender moonwort	1	1	1	U	1	1	U	5	7	Slt; USFS: S
Orchidaceae	*Cypripedium calceolus* var. *parviflorum*	Large yellow ladies-slipper	1	1	1	0	1	1	1	6	6	Cch, Grn, Slt, Sum, Uta, Web; USFS: S
	Spiranthes diluvialis (*S. romanzoffiana* var. *d.*)	Ute ladies-tresses	1	1	0	1	1	1	1	6	6	Cch, Dag, Dch, Grf, Slt, Toe, Uin, Uta, Way, Web; USFWS:T
Poaceae	*Elymus simplex*	Alkali wildrye	1	1	1	1	U	1	1	6	7	Dag
Polemoniaceae	*Gilia imperialis* (*G. latifolia* var. *i.*)	Cataract gilia	2	1	1	1	0	U	U	5	7	Emr, Grf, Kan, Snj, Way

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Polemoniaceae	*Gilia tenuis* (*Aliciella t.*)	Mussentuchit gilia	2	1	1	1	0	U	U	5	7	Emr, Sev; BLM: S
	Ipomopsis congesta var. *ochroleuca*	Arapien gilia	2	1	U	1	0	1	U	5	7	Snp, Sev
	Phlox hoodii var. *madsenii*	Madsen's carpet phlox	2	1	1	1	0	U	U	5	7	Way
Polygonaceae	*Eriogonum brevicaule* var. *huberi* (included in var. *laxifolium* by Holmgren et al. 2012)	Huber's wild buckwheat	2	1	1	1	0	U	U	5	7	Dch
	Eriogonum brevicaule var. *mitophyllum* (*E. mitophyllum*)	Lost Creek wild buckwheat	2	1	1	1	0	1	U	6	7	Sev; BLM: S
	Eriogonum brevicaule var. *promiscuum* (included in var. *laxifolium* by Holmgren et al. 2012)	Mount Bartles wild buckwheat	2	1	1	1	0	U	U	5	7	Crb
	Eriogonum corymbosum var. *cronquistii* (*E. cronquistii*)	Cronqist's wild buckwheat	2	1	1	1	0	U	U	5	7	Grf
	Eriogonum corymbosum var. *heilii*	Heil's wild buckwheat	2	1	1	1	0	1	U	6	7	Way
	Eriogonum corymbosum var. *matthewsiae* (included in var. *albiflorum* by Holmgren et al. 2012)	Springdale wild buckwheat	2	1	1	1	0	1	U	6	7	Wsh
	Eriogonum corymbosum var. *smithii* (*E. smithii*)	Flat top wild buckwheat	2	1	1	1	0	U	U	5	7	Emr, Way; BLM: S
	Eriogonum esmeraldense var. *tayei* (Included in var. *esmeraldense* by Holmgren et al. 2012)	Taye's wild buckwheat	2	1	1	1	0	U	U	5	7	Sev
	Eriogonum nummulare var. *ammophilum* (*E. ammophilum*)	Ibex wild buckwheat	2	1	1	1	0	U	U	5	7	Mil; BLM: S
	Eriogonum racemosum var. *nobilis* (included in *E. zionis* by Holmgren et al. 2012)	Bluff wild buckwheat	2	1	1	1	0	U	U	5	7	Kan, Snj; BLM: S

Appendix 2. UNPS Rare Plant List: High Priority Species, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Polygonaceae	*Eriogonum soredium*	Frisco wild buckwheat	2	1	1	1	0	1	U	6	7	Bvr; BLM: S
Portulacaceae (Montiaceae)	*Talinum thompsonii* (*Phemeranthus validulus*)	Thompson's talinum	2	1	1	1	0	U	U	5	7	Emr; BLM: S
Primulaceae	*Dodecatheon dentatum* var. *utahense* (*D. utahense*)	Hooker's shooting-star	2	1	1	1	1	0	0	6	6	Slt; USFS: S
	Primula domensis	House Range primrose	2	1	1	1	0	U	U	5	7	Mil; BLM: S
	Primula maguirei	Maguire's primrose	2	1	1	1	1	0	U	6	7	Cch; USFWS:T
Ranunculaceae	*Aquilegia holmgrenii* (formerly included in *A. elegantula*)	Holmgren's columbine	2	1	1	1	0	U	U	5	7	Grf
	Aquilegia rubicunda	Link Trail columbine	2	1	1	1	0	U	U	5	7	Emr, Sev; USFS: S
	Aquilegia scopulorum var. *goodrichii*	Goodrich's columbine	2	1	1	1	0	U	U	5	7	Dch; BLM: S
Rosaceae	*Ivesia shockleyi* var. *ostleri*	Shockley's ivesia	2	1	1	1	0	U	U	5	7	Bvr; BLM: S
Scrophulariaceae	*Castilleja aquariensis*	Aquarius paintbrush	2	1	0	1	1	1	0	6	6	Grf; USFS: S
	Castilleja parvula var. *revealii*	Reveal's paintbrush	2	1	1	1	1	0	U	6	7	Grf, Irn, Kan; USFS: S
	Penstemon flowersii	Flowers' penstemon	2	1	1	1	0	1	U	6	7	Dch, Uin
	Penstemon goodrichii	Goodrich's penstemon	2	1	1	1	0	1	U	6	7	Dch, Uin; BLM: S
	Penstemon x jonesii	Fuchsia penstemon	2	1	1	0	1	U	U	5	7	Kan, Wsh
	Penstemon pinorum	Pinyon penstemon	2	1	1	1	0	1	U	6	7	Irn; BLM: S; USFS: S
	Penstemon tidestromii (includes *P. leptanthus*)	Tidestrom's penstemon	2	1	1	1	0	1	U	6	7	Jub, Snp, Uta
	Penstemon wardii	Ward's penstemon	2	1	1	1	0	1	U	6	7	Mil, Piu, Snp, Sev; BLM: S; USFS: S
Violaceae	*Viola beckwithii*	Beckwith's violet	1	1	1	U	U	1	1	5	7	Box, Cch, Slt, Uta

Appendix 3. UNPS Rare Plant List: Watch List

The following table lists 264 species on the Watch List for potential conservation attention in Utah based on the Wyoming protocol ranking system. Species are listed alphabetically by family and scientific name, with synonyms in parentheses. See text for an explanation of the seven ranking criteria and scoring methods used to derive the minimum and potential scores. County codes are explained in Table 3. Legal Status: Bureau of Land Management (BLM) and US Forest Service (USFS) Sensitive = S; US Fish and Wildlife Service (USFWS) Candidate = C, Endangered = E, Proposed = P; Threatened = T.

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Adoxaceae	*Adoxa moschatellina*	Moschatel	1	1	1	1	0	U	1	5	6	Snj
Agavaceae	*Agave utahensis* var. *utahensis*	Utah century plant	1	1	1	1	0	1	U	5	6	Wsh
	Nolina microcarpa	Beargrass	1	1	1	0	0	1	1	5	5	Wsh
	Yucca kanabensis (*Y. angustissima* var. *k.*)	Kanab yucca	1	1	1	1	1	0	U	5	6	Kan, Wsh
	Yucca schidigera	Splinter yucca	1	1	1	0	0	1	1	5	5	Wsh; originally High priority
	Yucca toftiae (*Y. angustissima* var. *toftiae*)	Toft's yucca	2	1	1	1	0	0	U	5	6	Grf, Kan, Snj; originally High priority
Apiaceae (Umbelliferae)	*Angelica wheeleri*	Utah angelica	1	1	1	0	0	1	1	5	5	Cch, Jub, Piu, Slt, Sev, Uta; USFS:S
	Cymopterus acaulis var. *parvus*	Small spring-parsley	2	1	U	1	0	0	U	4	6	Mil, Toe
	Cymopterus beckii	Beck's spring-parsley	1	1	0	1	0	1	1	5	5	Kan, Snj, Way; BLM: S; USFS: S
	Cymopterus evertii	Evert's spring-parsley	1	1	1	1	0	U	U	4	6	Uin
	Cymopterus minimus	Least spring-parsley	2	1	1	1	0	0	U	5	6	Grf, Irn, Kan; USFS: S
	Cymopterus trotteri (*Oreoxis trotteri*)	Trotter's spring-parsley	2	1	1	1	0	0	U	5	6	Grn; BLM: S
	Lomatium graveolens var. *clarkii*	Clark's lomatium	2	1	1	1	0	0	0	5	5	Wsh
	Lomatium junceum	Rush lomatium	2	1	1	0	0	U	U	4	6	Emr, Grf, Sev, Way
	Musineon lineare	Utah musineon	2	1	1	1	0	0	U	5	6	Box, Cch
Asclepiadaceae	*Asclepias cutleri*	Cutler's milkweed	1	1	1	1	0	1	U	5	6	Grn, Snj
	Cynanchum utahense	Swallow-wort	1	1	1	0	0	1	1	5	5	Wsh
Asteraceae (Compositae)	*Artemisia campestris* var. *petiolata*	Petiolate wormwood	2	1	1	0	0	U	U	4	6	Dch; USFS: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Asteraceae (Compositae)	*Artemisia nova* var. *duchesnicola*	Duchesne sagebrush	2	1	1	1	0	0	U	5	6	Uin
	Aster kingii var. *barnebyana* (*Tonestus k.* var. *b., Herrickia k.* var. *b.*)	Barneby's aster	2	1	1	1	0	0	U	5	6	Jub, Mil; USFS: S
	Aster kingii var. *kingii* (*Tonestus k.* var. *k., Herrickia k.* var. *k.*)	King's aster	2	1	1	1	0	0	U	5	6	Slt, Uta; USFS: S
	Aster welshii (*Symphyotrichum w.*)	Welsh's aster	1	1	1	1	0	1	U	5	6	Bvr, Dch, Grf, Irn, Kan, Piu, Sum, Uta, Wsh, Way
	Baccharis viminea var. *atwoodii*	Atwood's seep-willow	2	1	U	0	0	1	U	4	6	Emr, Grn, Snj
	Chrysopsis jonesii (*Heterotheca jonesii*)	Jones' golden-aster	2	1	1	1	0	0	0	5	5	Grf, Kan, Wsh; USFS: S
	Chrysothamnus nauseosus var. *iridis* (*Ericameria nauseosa* var. *i.*)	Rainbow rabbitbrush	2	1	0	1	0	1	U	5	6	Snp, Sev
	Chrysothamnus nauseosus var. *psilocarpus* (*Ericameria nauseosa* var. *psilocarpa*)	Huntington rabbitbrush	2	1	1	0	0	U	U	4	6	Crb, Dch, Emr, Sev, Was
	Cirsium eatonii var. *harrisonii*	Harrison's thistle	2	1	U	1	0	0	U	4	6	Bvr, Piu
	Cirsium joannae	Joanna's thistle	2	1	1	1	0	0	U	5	6	Kan, Wsh
	Cirsium murdockii (*C. eatonii* var. *m.*)	Murdock's thistle	2	1	0	1	0	U	U	4	6	Dag, Dch, Uin
	Cirsium ownbeyi	Ownbey's thistle	1	1	1	1	0	1	U	5	6	Dag, Uin
	Enceliopsis argophylla	Silverleaf enceliopsis	1	U	U	1	0	1	1	4	6	Wsh
	Erigeron arenarioides	Wasatch daisy	2	1	1	1	0	0	0	5	5	Box, Slt, Toe, Uta, Web
	Erigeron canaani	Canaan daisy	2	1	1	1	0	0	0	5	5	Kan, Wsh
	Erigeron carringtoniae (included in *E. untermannii* in FNA)	Carrington's daisy	2	1	1	1	0	0	U	5	6	Emr, Snp; USFS: S
	Erigeron cronquistii	Cronquist's daisy	2	1	1	1	0	0	U	5	6	Cch; BLM: S; USFS: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Asteraceae (Compositae)	*Erigeron garrettii*	Garrett's daisy	2	1	1	1	0	0	U	5	6	Slt, Uta, Was; USFS:S
	Erigeron goodrichii	Goodrich's daisy	2	1	U	1	0	0	U	4	6	Dag, Dch, Sum?, Uin, Uta
	Erigeron huberi (included in *E. radicatus* in FNA)	Huber's daisy	2	1	U	1	0	0	U	4	6	Dch
	Erigeron maguirei (includes var. *harrisonii*)	Maguire's daisy	2	1	1	1	0	0	0	5	5	Emr, Way; BLM: S; USFWS former T
	Erigeron religiosus	Religious daisy	2	0	1	1	0	1	0	5	5	Grf, Kan, Snj, Wsh
	Erigeron sionis (includes vars. *sionis & trilobatus*)	Zion daisy	2	1	1	1	0	0	0	5	5	Grf, Irn, Kan, Wsh
	Erigeron untermannii	Untermann's daisy	2	1	0	1	0	U	U	4	6	Dch; BLM: S; USFS: S
	Erigeron ursinus var. *meyerae*	Meyer's daisy	2	1	1	0	U	0	U	4	6	Wsh
	Erigeron zothecinus	Alcove daisy	2	1	1	1	0	0	U	5	6	Grf, Grn, Kan, Snj
	Geraea canescens	Desert sunflower	1	1	1	0	0	1	1	5	5	Wsh
	Gutierrezia pomariensis	Orchard snakeweed	2	1	U	1	0	0	U	4	6	Dch, Uin
	Haplopappus racemosus var. *sessiliflorus* (*Pyrrocoma racemosa* var. *sessiliflora*)	Racemose goldenweed	1	1	1	1	0	U	U	4	6	Mil
	Haplopappus zionis (*Ericameria z.*)	Cedar Breaks goldenweed	2	1	1	1	0	0	U	5	6	Grf, Irn, Kan; BLM: S
	Hymenoxys helenioides (*Picradenia helenioides*)	Sneezeweed hymenoxys	1	1	1	0	1	U	U	4	6	Crb, Emr, Grf, Snp, Sev, Way
	Hymenoxys lapidicola	Rock hymenoxys	2	1	1	1	0	0	0	5	5	Uin; BLM: S
	Hymenoxys lemmonii	Alkali hymenoxys	1	1	1	1	0	U	U	4	6	Uin
	Layia platyglossa var. *breviseta*	Coastal tidytips	1	1	1	1	0	U	1	5	6	Snj
	Lepidospartum latisquamum	Nevada broom	1	1	U	1	0	1	U	4	6	Mil
	Perityle emoryi	Emory's rock-daisy	1	1	1	0	0	1	1	5	5	Wsh

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Asteraceae (Compositae)	*Perityle specuicola*	Alcove rock-daisy	2	1	1	1	0	0	U	5	6	Grn, Snj; BLM: S
	Peucephyllum schottii	Pygmy-cedar	1	1	1	1	0	1	U	5	6	Wsh
	Platyschkuhria integrifolia var. *oblongifolia*	San Juan bahia	1	1	1	1	0	U	U	4	6	Snj
	Senecio dimorphophyllus var. *intermedius* (*Packera dimorphophylla* var. *intermedia*)	La Sal groundsel	2	1	1	0	0	U	U	4	6	Dch, Grn, Snj, Snp, Sum
	Senecio fremontii var. *inexpectans*	Unexpected groundsel	2	1	1	1	0	0	U	5	6	Grn, Snj
	Senecio werneriifolius var. *barkleyi*	Barkley's groundsel	2	1	1	1	0	0	U	5	6	Grf, Kan
	Solidago spectabilis	Nevada goldenrod	1	1	U	1	0	1	U	4	6	Mil, Wsh
	Sphaeromeria ruthiae (*Artmeisia ruthiae*)	Ruth's chicken-sage	2	1	1	1	0	0	0	5	5	Kan, Wsh
	Stephanomeria tenuifolia var. *myrioclada* (*S. minor* var. *myrioclada*)	Slender wire-lettuce	1	1	1	1	0	U	U	4	6	Box
	Stephanomeria tenuifolia var. *uintahensis* (*S. minor* var. *u.*)	Uinta wire-lettuce	2	1	1	0	0	U	U	4	6	Uin
	Townsendia beamanii	Beaman's townsendia	2	1	1	0	U	0	U	4	6	Snj; BLM: S
	Townsendia condensata	Cushion townsendia	1	1	1	1	0	U	U	4	6	Bvr, Piu
	Townsendia mensana	Plateau townsendia	2	0	U	1	0	1	U	4	6	Dch, Uin
	Townsendia montana var. *caelilinesis*	Skyline townsendia	2	1	0	1	0	U	U	4	6	Dch, Snp, Was
	Townsendia montana var. *minima*	Bryce Canyon townsendia	2	1	1	1	0	0	U	5	6	Grf, Irn, Kan, Wsh
	Xylorhiza confertifolia	Henrieville woody-aster	2	1	0	1	0	1	U	5	6	Grf, Kan, Way
Boraginaceae	*Cryptantha barnebyi*	Barneby's cryptanth	2	1	0	1	0	1	U	5	6	Uin; BLM: S
	Cryptantha compacta	Mound cryptanth	2	1	0	1	0	U	U	4	6	Bvr, Mil, Toe; BLM: S
	Cryptantha creutzfeldtii	Creutzfeldt's cryptanth	2	1	0	1	0	1	U	5	6	Crb, Emr; BLM: S; USFS: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Boraginaceae	*Cryptantha elata*	Tall cryptanth	1	1	1	1	0	U	U	4	6	Grn
	Cryptantha johnstonii	Johnston's cryptanth	2	1	1	0	0	1	U	5	6	Emr
	Cryptantha jonesiana	San Rafael cryptanth	2	1	0	1	0	U	U	4	6	Emr
	Cryptantha ochroleuca (included in *C. compacta* by some authors)	Yellowish cryptanth	2	1	1	1	0	0	0	5	5	Grf; USFS: S
	Hackelia ibapensis	Deep Creek stickseed	2	1	1	1	0	0	U	5	6	Jub
Brassicaceae (Cruciferae)	*Arabis shockleyi* (*Boechera s.*)	Shockley's rockcress	1	1	1	1	0	U	U	4	6	Bvr, Jub, Mil, Toe
	Arabis vivariensis (*Boechera. fernaldiana* ssp. *v.*)	Park rockcress	2	1	1	1	0	0	U	5	6	Uin; BLM: S
	Descurainia pinnata var. *paysonii* (*D. incisa* var. *p.*)	Payson's tansymustard	1	1	1	1	0	U	U	4	6	Grn, Snj, Uin
	Draba kassii	Kass' draba	2	1	1	1	0	0	U	5	6	Toe
	Draba maguirei var. *burkei* (*D. burkei*)	Burke's draba	2	1	1	1	0	0	U	5	6	Box, Mor, Web; USFS: S
	Draba maguirei var. *maguirei*	Maguire's draba	2	1	U	1	0	0	U	4	6	Box, Cch, Web; USFS: S
	Lepidium huberi	Huber's pepperwort	1	1	1	1	0	U	U	4	6	Uin; BLM: S
	Lepidium montanum var. *claronense*	Claron pepperwort	2	1	1	1	0	0	U	5	6	Grf, Kan, Piu
	Lepidium montanum var. *heterophyllum*	Cedar Canyon pepperwort	2	1	1	0	0	1	U	5	6	Irn, Mil, Piu, Sev
	Lepidium montanum var. *neeseae*	Neese's pepperwort	2	1	1	1	0	0	U	5	6	Grf; USFS: S
	Lepidium nanum	Low pepperwort	1	1	1	1	0	U	U	4	6	Toe
	Physaria acutifiolia var. *purpurea* (included in *P. grahamii* in FNA)	Purple twinpod	2	1	1	1	0	0	U	5	6	Emr, Grn, Sev, Way
	Physaria arizonica (*Lesquerella arizonica*)	Arizona bladderpod	1	1	1	1	0	U	U	4	6	Grf, Kan, Wsh
	Physaria chambersii var. *sobolifera*	Claron twinpod	2	1	1	1	0	0	U	5	6	Grf
	Physaria floribunda	Mesa twinpod	1	1	1	1	0	U	U	4	6	Grn

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Brassicaceae (Cruciferae)	*Physaria garrettii* (*Lesquerella garrettii*)	Garrett's twinpod	2	1	1	1	0	0	U	5	6	Dav, Slt, Uta, Was; USFS: S
	Thelypodiopsis ambigua var. *erecta*	Kanab thelypody	1	1	1	1	0	1	U	5	6	Kan, Wsh?; BLM: S
	Thelypodiopsis sagittata var. *ovalifolia* (*Thelypodium sagittatum* var. *ovalifolium*)	Palmer's thelypody	1	1	1	1	0	U	U	4	6	Grf, Irn, Jub, Kan, Mil
	Thelypodium flexuosum	Zigzag thelypody	1	1	1	1	0	U	U	4	6	Bvr, Toe
Buddlejaceae	*Buddleja utahensis*	Utah butterflybush	1	1	1	1	0	1	0	5	5	Wsh
Cactaceae	*Echinocereus triglochidiatus* var. *mojavensis* (*E. mojavensis*)	Mohave claretcup	1	1	1	0	0	1	1	5	5	Bvr, Mil, Wsh
	Mamillaria tetrancistra	Pincushion cactus	1	1	1	0	0	1	1	5	5	Wsh
	Neolloydia johnsonii (*Echinomastus j.*)	Johnson's neolloydia	1	1	1	0	0	1	1	5	5	Wsh
	Opuntia echinocarpa (*Cylindropuntia echinocarpa*)	Pale cholla	1	1	1	0	0	1	1	5	5	Bvr?, Wsh
	Opuntia pulchella (*Grusonia p.*)	Sand cholla	1	1	U	1	0	1	U	4	6	Box, Jub, Mil, Toe, Wsh?
	Sclerocactus blainei	Blaine's fishhook cactus	1	1	U	1	0	1	1	5	6	Irn
Caryophyllaceae	*Silene nachlingerae*	Jan's catchfly	1	1	1	1	0	U	U	4	6	Bvr; USFS: S
Chenopodiaceae	*Atriplex gardneri* var. *bonnevillensis* (*A. bonnevillensis*)	Bonneville saltbush	1	1	U	1	0	1	U	4	6	Jub, Mil
	Atriplex obovata	New Mexico saltbush	1	1	U	1	0	1	U	4	6	Snj
	Atriplex pleiantha (*Proatriplex p.*)	Four Corners orach	1	1	1	1	0	U	U	4	6	Snj
	Atriplex wolfii var. *tenuissima*	Slender orach	1	1	1	1	0	U	U	4	6	Crb, Dch, Emr, Grf, Piu, Snp, Sev, Uin
	Corispermum welshii	Welsh's bugseed	1	1	U	1	0	1	U	4	6	Grf, Kan, Mil, Snj?
Cuscutaceae	*Cuscuta applanata*	Winged dodder	1	1	1	0	1	U	U	4	6	Wsh
	Cuscuta cuspidata	Toothed dodder	1	1	1	0	1	U	U	4	6	Slt, Uta, Web
Cyperaceae	*Carex crawei*	Crawe's sedge	1	1	1	1	0	U	U	4	6	Kan
	Carex curatorum (*C. scirpoidea* var. *c.*)	Canyonlands sedge	1	1	1	1	0	U	U	4	6	Kan, Snj, Uin

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Cyperaceae	*Carex diandra*	Lesser panicled sedge	1	1	1	1	0	U	U	4	6	Dch, Grf?
	Carex lasiocarpa	Slender sedge	1	1	1	1	0	U	U	4	6	Dag, Sev?, Uin
	Carex leptalea	Bristly-stalk sedge	1	1	1	1	0	U	U	4	6	Dag, Dch, Uin
	Carex livida	Pale sedge	1	1	1	1	0	U	U	4	6	Dch, Uin
	Carex microglochin	Subulate sedge	1	1	1	1	0	U	U	4	6	Dag, Dch, Emr
	Cladium californicum	Saw-grass	1	1	U	1	0	U	1	4	6	Kan, Snj
	Lipocarpha aristulata (*L. drummondii, Hemicarpha micrantha*)	Slender-rush	1	1	1	1	0	1	U	5	6	Kan
	Scirpus nevadensis (*Amphiscirpus n.*)	Nevada bulrush	1	1	1	1	0	U	U	4	6	Jub, Rch
Euphorbiaceae	*Euphorbia nephradenia*	Utah spurge	1	1	1	1	0	1	U	5	6	Emr, Grf, Kan, Way; BLM: S
Fabaceae (Leguminosae)	*Astragalus calycosus* var. *monophyllidus*	One-leaf milk-vetch	1	1	1	1	0	U	U	4	6	Sev
	Astragalus chloodes	Grass milkvetch	2	1	0	1	0	U	U	4	6	Uin
	Astragalus concordius (formerly included in *A. piutensis*)	Hairy-pod milk-vetch	2	1	U	0	0	1	U	4	6	Irn, Wsh
	Astragalus detritalis	Debris milkvetch	1	1	1	1	0	1	U	5	6	Dch, Uin
	Astragalus henrimontanensis (*A. argophyllus* var. *stocksii*)	Dana's milkvetch	2	1	1	0	0	U	U	4	6	Grf; USFS: S
	Astragalus jejunus	Starveling milk-vetch	1	1	1	1	0	U	U	4	6	Rch; USFS: S
	Astragalus lentiginosus var. *mokiacensis* (*A. m.;* some authors include var. *ursinus*)	Mokiak milkvetch	1	1	1	1	0	1	0	5	5	Wsh
	Astragalus limnocharis var. *limnocharis*	Navajo Lake milk-vetch	2	1	1	1	0	0	U	5	6	Irn, Kan; USFS: S
	Astragalus limnocharis var. *tabulaeus* (included in *A. montii* by some authors)	Table Cliff milk-vetch	2	1	1	1	0	0	U	5	6	Grf; USFS: S
	Astragalus lutosus	Dragon milkvetch	1	1	1	1	0	1	U	5	6	Dch, Uin, Uta, Was
	Astragalus malacoides	Kaiparowits milk-vetch	2	1	1	1	0	0	U	5	6	Grf, Kan

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Fabaceae (Leguminosae)	*Astragalus montii*	Heliotrope milk-vetch	2	1	0	1	0	U	U	4	6	Snp, Sev; USFWS: T
	Astragalus monumentalis	Monument milk-vetch	2	1	0	1	0	U	U	4	6	Grf, Snj
	Astragalus naturitensis	Naturita milkvetch	1	1	1	1	0	U	U	4	6	Snj
	Astragalus piscator	Fisher milkvetch	2	1	1	1	0	0	U	5	6	Grn, Snj, Way
	Astragalus saurinus	Dinosaur milk-vetch	2	1	0	1	0	U	U	4	6	Uin
	Astragalus uncialis	Currant milkvetch	2	1	1	0	0	1	U	5	6	Mil; USFS: S
	Astragalus wetherillii	Wetherill's milk-vetch	1	1	1	0	U	U	1	4	6	Grn
	Astragalus zionis var. *vigulus* ("*A. tephrodes*")	Guard milkvetch	2	1	1	0	0	1	U	5	6	Wsh; USFS: S
	Hedysarum boreale var. *gremiale*	Rollins' sweet-vetch	2	1	1	0	0	U	U	4	6	Uin
	Hedysarum occidentale var. *canone*	Coal Cliffs sweet-vetch	2	1	1	0	0	U	U	4	6	Crb, Dch, Emr; USFS: S
	Oxytropis besseyi var. *obnapiformis*	Maybell locoweed	1	1	U	1	0	1	U	4	6	Dag
	Oxytropis oreophila var. *jonesii*	Jones' locoweed	2	1	U	1	0	0	U	4	6	Emr, Grf, Grn, Irn, Snp, Uin
	Pediomelum aromaticum var. *aromaticum*	Aromatic bread-root	1	1	U	1	0	1	1	5	6	Emr?, Grn
	Pediomelum aromaticum var. *barnebyi*	Barneby's bread-root	1	1	1	1	0	1	U	5	6	Kan, Wsh; BLM: S
	Pediomelum aromaticum var. *tuhyi*	Tuhy's breadroot	2	1	0	1	0	U	U	4	6	SnJ; BLM: S
	Pediomelum epipsilum	Kane breadroot	2	1	0	1	0	1	U	5	6	Kan; BLM:S
	Pediomelum mephiticum	Skunk breadroot	1	1	1	0	0	1	1	5	5	Wsh
	Pediomelum pariense	Paria breadroot	2	1	1	1	0	0	U	5	6	Grf, Kan; USFS: S
	Pediomelum retrorsum (*P. megalanthum* var. *r.*)	Peach Springs breadroot	1	1	U	1	0	1	U	4	6	Wsh
	Psoralidium lanceolatum var. *stenostachys*	Rydberg's scurf-pea	2	1	U	1	0	0	U	4	6	Dav, Jub, Mil, Slt, Toe, Web
	Psorothamnus arborescens var. *pubescens*	Beauty indigo-bush	1	1	1	1	0	U	U	4	6	Kan
	Psorothamnus nummularius (*P. polydenius* var. *jonesii*)	Jones' indigo-bush	2	1	0	1	0	U	U	4	6	Emr; BLM: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Fabaceae (Leguminosae)	*Psorothamnus polydenius* var. *polydenius*	Glandular indigobush	1	1	U	1	0	1	U	4	6	Wsh
	Trifolium beckwithii	Beckwith's clover	1	1	1	0	0	1	1	5	5	Piu?, Sev
Gentianaceae	*Swertia gypsicola* (*Frasera gypsicola*)	White River swertia	1	1	1	1	0	1	U	5	6	Mil; BLM: S
Hydrangeaceae (Saxifragaceae)	*Jamesia americana* var. *zionis*	Zion jamesia	2	1	1	1	0	0	0	5	5	Kan, Wsh; USFS: S
	Jamesia tetrapetala	Basin jamesia	1	1	1	1	0	U	U	4	6	Mil; BLM: S; USFS: S
Hydrophyllaceae	*Phacelia austromontana*	Southern phacelia	1	1	1	0	0	1	1	5	5	Wsh
	Phacelia cottamii	Cottam's phacelia	2	1	0	1	0	1	U	5	6	Crb, Emr, Sev
	Phacelia glandulosa	Glandular scorpion-weed	1	1	U	1	0	1	U	4	6	Grn, Uin
	Phacelia mammillarensis	Nipple Bench phacelia	2	1	0	1	0	1	U	5	6	Grf, Kan
	Phacelia palmeri	Palmer's phacelia	1	1	1	1	0	1	0	5	5	Wsh
	Phacelia perityloides var. *laxiflora*	Crevice phacelia	1	1	1	1	0	1	0	5	5	Wsh
	Phacelia salina	Bitter Creek scorpion-weed	1	1	1	1	0	U	U	4	6	Snp, Toe
	Phacelia splendens	Eastwood's phacelia	1	1	U	1	0	1	U	4	6	Gra
	Phacelia tetramera	Four-parted phacelia	1	1	1	0	1	U	U	4	6	Web
	Tricardia watsonii	Three hearts	1	1	1	0	U	1	1	5	6	Wsh
Iridaceae	*Sisyrinchium douglasii* (*Olsynium d.*)	Purple-eyed grass	1	1	1	U	0	1	U	4	6	Toe
Juncaceae	*Juncus tweedyi* (*J. brevicaudatus*)	Tweedy's rush	1	1	1	0	0	1	1	5	5	Box
Lamiaceae (Labiatae)	*Stachys rothrockii*	Rothrock's hedge-nettle	1	1	U	1	0	1	U	4	6	Kan
Liliaceae	*Allium geyeri* var. *chatterleyi*	Chatterley's onion	2	1	1	0	0	U	U	4	6	Snj; USFS: S
	Allium passeyi	Passey's onion	2	1	0	1	0	U	U	4	6	Box
Loasaceae	*Eucnide urens*	Desert rock-nettle	1	1	1	1	0	1	U	5	6	Wsh
	Mentzelia goodrichii	Goodrich's stickleaf	2	1	1	1	0	0	U	5	6	Dch; BLM: S; USFS: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Loasaceae	*Mentzelia multicaulis* var. *flumensevera*	Sevier Canyon stickleaf	2	1	1	1	0	0	U	5	6	Piu, Sev
	Mentzelia multicaulis var. *uintahensis*	Uinta Basin stickleaf	1	1	U	1	0	1	U	4	6	Dch, Uin
Malvaceae	*Sphaeralcea caespitosa* var. *caespitosa*	Jones' globemallow	2	1	0	1	0	1	0	5	5	Bvr, Mil; BLM: S
Najadaceae	*Najas caespitosa* (included in *N. flexilis* by most authors)	Fish Lake naiad	1	1	1	0	U	1	1	5	6	Sev; USFS: S
Oleaceae	*Menodora spinescens*	Spiny menodora	1	1	1	1	0	1	0	5	5	Wsh
Onagraceae	*Camissonia atwoodii*	Atwood's camissonia	2	1	0	1	0	1	U	5	6	Kan
	Camissonia bairdii	Baird's camissonia	1	1	1	1	0	1	U	5	6	Wsh; BLM: S
	Camissonia claviformis var. *aurantiaca*	Clubpod camissonia	1	1	1	0	0	1	1	5	5	Wsh
	Camissonia claviformis var. *claviformis*	Clubpod camissonia	1	1	1	0	0	1	1	5	5	Wsh
	Camissonia claviformis var. *cruciformis*	Clubpod camissonia	1	1	1	0	0	1	1	5	5	Wsh
	Camissonia gouldlii	Gould's camissonia	1	1	1	1	0	1	U	5	6	Mil, Wsh; BLM: S
	Epilobium nevadense	Nevada willowherb	1	1	1	1	0	U	U	4	6	Irn, Mil, Wsh; BLM: S; USFS: S
	Oenothera deltoides var. *decumbens*	St. George evening-primrose	1	1	U	1	0	1	U	4	6	Wsh
Ophioglossaceae	*Botrychium multifidum*	Leathery grape fern	1	1	1	0	1	U	U	4	6	Dch
Orchidaceae	*Habenaria zothecina* (*Platanthera z.*)	Alcove bog-orchid	1	1	1	1	0	1	U	5	6	Emr, Grf, Grn, Snj, Uin
Papaveraceae	*Eschscholzia mexicana* (*E. californica* var. *m.*)	Mexican goldenpoppy	1	1	1	0	0	1	1	5	5	Wsh
	Papaver coloradense (*P. uintanense, P. kluanense, P. radicatum*)	Alpine Rocky Mountain poppy	1	1	1	1	0	U	U	4	6	Dag, Dch, Sum; USFS: S
	Platystemon californicus	Creamcups	1	1	1	0	0	1	1	5	5	Wsh
Poaceae (Gramineae)	*Andropogon glomeratus*	Bushy bluestem	1	1	1	1	0	U	U	4	6	Grf, Kan, Snj, Way
	Festuca dasyclada	Utah fescue	1	1	1	1	0	1	U	5	6	Emr, Grf, Snp

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Poaceae (Gramineae)	*Imperata brevifolia*	Satintail	1	1	1	1	0	U	U	4	6	Kan, Snj
	Panicum hallii	Hall's panicgrass	1	1	1	0	U	U	1	4	6	Bvr
	Stipa arnowiae	Arnow's ricegrass	1	1	1	0	1	U	U	4	6	Grf, Grn, Irn, Jub, Kan, Uin, Wsh
Polemoniaceae	*Ipomopsis spicata* var. *spicata* (*Gilia s.* var. *s.*)	Spike gilia	1	1	1	1	0	U	U	4	6	Dag
	Ipomopsis tridactyla (*I. spicata* ssp. t., *Gilia tridactyla*)	Cedar Breaks gilia	2	1	1	1	0	0	U	5	6	Irn, Piu
	Phlox lutescens (*P. austromontana* var. *lutescens*)	Yellowish phlox	2	1	1	0	0	U	U	4	6	Grf, Grn, Snj
	Phlox opalensis	Opal phlox	1	1	1	1	0	1	U	5	6	Dag
Polygonaceae	*Eriogonum acaule*	Stemless wild buckwheat	1	1	1	1	0	U	U	4	6	Rch
	Eriogonum aretioides	Widtsoe wild buckwheat	2	1	1	1	0	0	U	5	6	Emr, Grf; USFS: S
	Eriogonum brevicaule var. *loganum* (*E. loganum*)	Logan wild buckwheat	2	1	1	0	0	U	U	4	6	Cch, Mor, Rch; USFS: S
	Eriogonum cernuum var. *psammophilum* (var. not recognized by Holmgren et al. 2012)	Sand Dune nodding wild buckwheat	2	1	U	1	0	0	U	4	6	Grf, Kan, Snj; var. not recognized by Holmgren et al. (2012)
	Eriogonum corymbosum var. *albiflorum* (*E. thompsoniae* var. *a.*)	Virgin wild buckwheat	1	1	U	1	0	1	U	4	6	Wsh
	Eriogonum corymbosum var. *aureum* (*sensu stricto*)	Golden buckwheat	2	1	U	1	0	0	U	4	6	Wsh; does not include 'var. *glutinosum*'
	Eriogonum ephedroides (*E. brevicaule* var. *ephedroides*)	Ephedra wild buckwheat	2	1	0	1	0	1	U	5	6	Uin
	Eriogonum exaltatum (*E. insigne*)	Ladder wild buckwheat	1	1	1	1	0	1	0	5	5	Irn, Kan, Wsh
	Eriogonum heermannii var. *subspinosum*	Tabeau Peak wild buckwheat	1	1	1	1	0	1	0	5	5	Wsh
	Eriogonum mortonianum	Morton's wild buckwheat	2	1	1	0	0	U	U	4	6	Kan
	Eriogonum scabrellum	Westwater wild buckwheat	1	1	1	1	0	U	U	4	6	Emr, Grf, Grn, Kan, Snj

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Polygonaceae	*Eriogonum wrightii* var. *wrightii*	Wright's wild buckwheat	1	1	U	1	0	1	U	4	6	Wsh
	Koenigia islandica	Koenigia	1	1	1	1	0	U	U	4	6	Dch
	Pterostegia drymarioides	Pterostegia	1	1	U	1	0	1	U	4	6	Wsh
Polypodiaceae	*Adiantum pedatum* var. *aleuticum*	Northern maidenhair fern	1	1	1	1	1	0	U	5	6	Grf, Slt, Wsh
	Cheilanthes wootonii	Wooton's lip-fern	1	1	1	1	0	1	0	5	5	Wsh
	Cystopteris bulbifera	Bulblet bladder fern	1	1	1	1	0	U	U	4	6	Slt, Snj, Wsh
	Gymnocarpium dryopteris	Oak fern	1	1	1	1	0	U	U	4	6	Piu
Primulaceae	*Dodecatheon pulchellum* var. *zionense* (includes subvar. *huberi*)	Zion shooting-star	1	1	1	1	0	0	1	5	5	Crb, Grn, Kan, Snj?, Wsh
	Primula specuicola	Cave primrose	1	1	1	1	0	1	U	5	6	Grf, Grn, Kan, Snj, Way
Ranunculaceae	*Aquilegia atwoodii* (included in *A. fosteri* by Holmgren et al. 2012)	Atwood's columbine	2	1	1	1	0	0	U	5	6	Uin; BLM: S
	Aquilegia barnebyi	Shale columbine	1	1	1	1	0	1	U	5	6	Dch, Uin
	Aquilegia desolaticola	Desolation Canyon columbine	2	1	1	1	0	0	U	5	6	Grn; BLM: S
	Aquilegia fosteri (*A. formosa* var. *fosteri*, *A. desertorum*; may include *A. atwoodii*)	Foster's columbine	2	1	1	1	0	0	0	5	5	Wsh
	Aquilegia grahamii (*A. micrantha* var. *g.*)	Graham's columbine	2	1	1	1	0	0	U	5	6	Uin; USFS: S
	Aquilegia loriae (*A. micrantha* var. *l.*)	Lori's columbine	2	1	1	1	0	0	0	5	5	Kan
	Trautvetteria caroliniensis	Carolina tassel-rue	1	1	1	1	0	U	U	4	6	Snj
Rhamnaceae	*Ceanothus greggii* var. *franklinii*	Franklin's desert-lilac	2	1	1	0	0	U	U	4	6	Grf?, Grn, Snj
Rosaceae	*Crataegus douglasii* var. *duchesnensis*	Duchesne hawthorn	2	1	1	0	0	U	U	4	6	Dch, Uin, Was
	Ivesia utahensis	Utah ivesia	2	1	1	0	0	1	U	5	6	Slt, Sum, Uta, Was; USFS: S
	Potentilla angelliae	Angell's cinquefoil	2	1	1	0	0	1	U	5	6	Way; USFS: S

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	**Species**	**Common Name**	**Range**	**# Pops**	**# Indiv**	**Hab Spec**	**Intrin Rar**	**Threat**	**Trend**	**Min Score**	**Pot Score**	**County Dist. & Legal Status**
Rosaceae	*Rubus neomexicanus*	New Mexico thimbleberry	1	1	1	1	0	U	U	4	6	Grf, Snj
Rutaceae	*Ptelea trifoliata* var. *lutescens*	Hoptree	1	1	1	1	0	U	1	5	6	Grf?, Kan, Wsh
Salicaceae	*Salix arizonica*	Arizona willow	1	1	1	1	0	1	U	5	6	Grf, Irn, Snp, Sev; USFS: S
Saururaceae	*Anemopsis californica*	Yerba mansa	1	1	1	1	0	U	U	4	6	Uta, Wsh
Scrophulariaceae	*Castilleja parvula* var. *parvula*	Tushar paintbrush	2	1	1	1	0	0	U	5	6	Bvr, Grf, Piu; USFS: S
	Maurandya antirrhiniflora	Maurandya	1	1	1	0	0	1	1	5	5	Wsh
	Mimulus bigelovii var. *cuspidatus*	Bigelow's monkeyflower	1	1	1	0	0	1	1	5	5	Wsh
	Mohavea breviflora	Desert snapdragon	1	1	1	0	0	1	1	5	5	Wsh
	Penstemon abietinus	Firleaf penstemon	2	1	1	0	0	U	U	4	6	Sev, Uta
	Penstemon acaulis var. *acaulis*	Stemless penstemon	2	1	0	1	0	1	U	5	6	Dag; BLM: S; USFS: S
	Penstemon ammophilus	Sandloving penstemon	2	1	1	1	0	0	U	5	6	Grf, Kan, Wsh
	Penstemon angustifolius var. *vernalensis*	Vernal penstemon	2	1	1	0	0	1	U	5	6	Dag, Uin
	Penstemon atwoodii	Atwood's penstemon	2	1	1	1	0	0	U	5	6	Grf, Kan
	Penstemon barbatus var. *trichander*	Scarlet penstemon	1	1	1	1	0	U	U	4	6	Snj
	Penstemon bracteatus	Red Canyon penstemon	2	1	1	1	0	0	U	5	6	Grf; USFS: S
	Penstemon compactus	Bear River penstemon	2	1	1	1	0	0	U	5	6	Cch; USFS: S
	Penstemon duchesnensis (*P. dolius* var. *duchesnensis*)	Duchesne penstemon	2	1	0	1	0	1	U	5	6	Dch
	Penstemon franklinii	Franklin's penstemon	2	1	1	0	0	1	U	5	6	Irn; BLM: S
	Penstemon idahoensis	Idaho penstemon	1	1	1	1	0	U	U	4	6	Box; BLM: S; USFS: S
	Penstemon marcusii	Marcus Jones' penstemon	2	1	U	1	0	1	U	5	7	Crb, Emr
	Penstemon navajoa	Navajo Mountain penstemon	2	1	1	0	0	1	U	5	6	Snj

Appendix 3. UNPS Rare Plant List: Watch List, continued

Family	Species	Common Name	Range	# Pops	# Indiv	Hab Spec	Intrin Rar	Threat	Trend	Min Score	Pot Score	County Dist. & Legal Status
Scrophulariaceae	*Penstemon petiolatus*	Crevice penstemon	1	1	1	1	0	1	0	5	5	Wsh
	Penstemon scariosus var. *cyanomontanus*	Blue Mountain penstemon	2	1	1	1	0	0	U	5	6	Uin
	Penstemon sepalulus	Littlecup penstemon	2	1	U	1	0	0	U	4	6	Jub, Uta, Wsh?
Selaginellaceae	*Selaginella utahensis*	Utah spike-moss	2	1	1	1	0	0	0	5	5	Kan, Wsh
Violaceae	*Viola frank-smithii*	Bear River Range violet	2	1	1	1	0	0	U	5	6	Cch; USFS: S
	Viola purpurea var. *charlestonensis* (*V. charlestonensis*)	Charleston Mountain violet	1	1	1	1	0	1	0	5	5	Kan, Wsh; USFS: S
Zygophyllaceae	*Fagonia laevis*	Fagonia	1	1	1	1	0	1	U	5	6	Wsh

Appendix 4. UNPS Rare Plant List: Need Data List

The following table includes 115 species with three or more ranking criteria scored as "unknown". A large number of these species have only recently been named or discovered within Utah, and additional field surveys are needed to confirm their abundance, distribution, habitat needs, life history patterns, potential threats, and trends. Some species on the list have taxonomic questions that still need to be resolved. All of the plants included here have the potential to be ranked as extremely high or high priority, or as watch species, once needed studies are completed. Species are arranged alphabetically by family and species. Additional information is provided on county-level distribution (see Table 3 for codes) and data needs. Legal Status: Bureau of Land Management (BLM) and US Forest Service (USFS) Sensitive = S; US Fish and Wildlife Service (USFWS) Candidate = C.

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Apiaceae (Umbelliferae)	*Cymopterus basalticus*	Shadscale spring-parsley	Bvr, Mil	Info needed on # of indiviuals, threats, & trends
	Cymopterus crawfordensis	Crawford Mountain spring-parsley	Rch	Recently named, info needed on # of individuals, habitat specificity, threats, trends
Asteraceae (Compositae)	*Artemisia biennis* var. *diffusa*	Mystery wormwood	Grf	Taxonomic questions, info needed on # of populations, intrinsic rarity, threats, trends
	Artemisia parryi	Parry's wormwood	Grn, Snj	Info needed on # of individuals, threats, & trends
	Artemisia tridentata var. *parishii*	Parish's big sagebrush	SW UT	Info needed on distribution in UT, # of individuals, # of populations, threats, trends
	Chrysothamnus nauseosus var. *uintahensis* (*Ericameria* x *u.*)	Uinta rabbitbrush	Dag, Uin	Info needed on # of individuals, threats, & trends
	Crepis runcinata var. *aculeolata*	Utah hawksbeard	Kan	Taxonomic questions, info needed on habitat specificity, threats, & trends
	Erigeron katiae	Katie's daisy	Rch	Newly described, info needed on habitat specificity, threats, & trends
	Erigeron mancus	La Sal daisy	Grn, Snj	Recent research needs to be reviewed relating to # of populations, threats, & trends; USFS: S
	Erigeron watsonii	Watson's daisy	Reported	Info needed on # of individuals, habitat specificity, threats, & trends
	Haplopappus acaulis var. *atwoodii* (not recognized in FNA)	Atwood's goldenweed	Jub	Treated as var. *glabratus* by Welsh et al. (2008); info needed on # of individuals, habitat specificity, threats, & trends
	Haplopappus crispus (*Ericameria crispa*)	Pine Valley goldenbush	Mil?, Wsh;	Info needed on # of individuals, threats, & trends; BLM: S; USFS: S
	Haplopappus leverichii (*Isocoma leverichii, I. humilis*)	Canyon goldenweed	Wsh	Taxonomic questions, info needed on intrinsic rarity, threats, & trends; not seen since 1971
	Haplopappus racemosus var. *paniculatus* (*Pyrrocoma racemosa* var. *paniculata*)	Racemose goldenweed	Mil	Info needed on # of individuals, threats, & trends
	Haplopappus racemous var. *prionophyllus* (*Pyrrocoma racemosa* var. *prionophylla*)	Racemose goldenweed	Cch, Dch, Uta	Info needed on # of individuals, threats, & trends

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Asteraceae (Compositae)	*Hofmeisteria pluriseta* (*Pleurocoronis p.*)	Arrowleaf	Wsh?	Info needed on # of individuals, threats, & trends
	Lygodesmia grandiflora var. *doloresensis* (*L. doloresensis*)	Dolores River skeletonplant	Grn?	Confirmation needed whether this species is in UT; info needed on intrinsic rarity, threats, & trends; BLM: S
	Senecio bairdii	Baird's groundsel	Box	Newly described, info needed on habitat specificity, intrinsic rarity, threats, trends
	Senecio streptanthifolius var. *platylobus*	Wasatch groundsel	Uta, Web	Newly described, info needed on # of individuals, habitat specificity, threats, trends
	Senecio werneriifolius var. *malmstenoides*	Mt. Nebo groundsel	Jub, Uta	Newly described, info needed on # of individuals, threats, & trends
Brassicaceae (Cruciferae)	*Arabis goodrichii* (*Boechera g.*)	Goodrich's rockcress	Mil	Newly described, info needed on habitat specificity, threats, & trends; BLM: S
	Arabis holboellii var. *derensis* (*Boechera inyoensis*, included in *A. beckwithii* by some authors)	Desert Experimental Range rockcress	Mil	Taxonomic questions, info needed on # of individuals, threats, & trends
	Arabis lasiocarpa (*Boechera l.*)	Wasatch rockcress	Box, Cch, Rch, Slt, Uta	Info needed on habitat specificity, threats, & trends
	Arabis perennans var. *thorneae* (*Boechera selbyi* var. *t.*)	Thorne's rockcress	Uin	Recently described, info needed on habitat specificity, threats, & trends
	Arabis pulchra var. *duchesnensis* (*Boechera duchesnensis*)	Duchesne rockcress	Dch	Taxonomic questions; info needed on # of individuals, habitat specificity, & trends
	Arabis thompsonii (*Boechera t., B. pallidifolia*)	Thompson's rockcress	Snj	Newly described, info needed on habitat specificity, threats, & trends
	Boechera glareosa (*"Arabis glareosa"*)	Dorn's rockcress	Uin	Recently described narrow endemic of CO & UT (holotype from S side of Blue Mountain), info needed on # of individuals, habitat specificity, number of populations, threats, & trends
	Draba abajoensis (*D. spectabilis* var. *glabrescens*)	Abajo Peak draba	Grn, Snj	Recently described, info needed on # of individuals, intrinsic rarity, threats, & trends; USFS:S
	Draba pedicellata var. *pedicellata*	Cusick's draba	Toe	Recently documented in UT, info needed on # of individuals, threats, and trends
	Draba pennellii	Schell Creek draba	Jub	Recently documented in UT, info needed on # of individuals, threats, & trends; USFS: S
	Draba santaquinensis	Santaquin draba	Uta	Recently described narrow endemic from southern Wasatch Range, info needed on # of individuals, habitat specificity, # of populations, threats, & trends; USFS: S

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Brassicaceae (Cruciferae)	*Lepidium moabense* (included in *L. eastwoodiae* by some authors)	Moab pepperplant	Grf, Grn, Kan, Snj	Taxonomic questions, info needed on # of populations, intrinsic rarity, & trends
	Physaria acutifolia var. *repanda* (included in *P. grahamii* in FNA)	Indian Canyon twinpod	Crb, Dch, Emr, Sev, Uin, Uta, Was	Info needed on # of individuals, threats, & trends
	Physaria hemiphysaria var. *hemiphysaria*	Skyline bladderpod	Dch, Emr, Snp, Uta, Was	Info needed on # of individuals, threats, & trends
	Physaria hemiphysaria var. *lucens*	Tavaputs bladderpod	Crb	Info needed on # of individuals, threats, & trends
	Physaria navajoensis (*Lesquerella navajoensis*)	Navajo bladderpod	Kan?	Taxonomic questions; info needed on # of individuals, intrinsic rarity, threats, & trends
	Physaria neeseae	Neese’s twinpod	Grf, Wsh?	Newly described, info needed on # of individuals, threats, & trends
	Thelypodiopsis aurea	Golden thelypody	Snj	Info needed on # of individuals, threats, & trends
	Thelypodiopsis vermicularis	Wormwood thelypody	Box, Irn, Jub, Mil, Snp, Sev, Toe, Uta	Info needed on # of individuals, threats, & trends
	Thelypodium rollinsii	Rollins’ thelypody	Bvr, Crb, Jub, Mil, Piu, Snp, Sev	Info needed on # of individuals, threats, & trends
Cactaceae	*Coryphantha vivipara* var. *deserti*	Mohave pincushion cactus	Irn, Wsh	Info needed on # of individuals, number of populations, & trends
	Echinocactus polycephalus var. *polycephalus*	Manyhead barrel cactus	Wsh?	Reports from UT need confirmation; info needed on # of individuals, # of populations, & trends
	Echinocactus polycephalus var. *xeranthemoides* (*E. xeranthemoides*)	Manyhead barrel cactus	Kan?	Reports from UT need confirmation; info needed on # of individuals, # of populations, & trends
	Opuntia pinkavae (*O. basilaris* var. *woodburyi*)	Pinkava’s pricklypear	Kan, Wsh	May be represented by two forms in Utah; frequently hybridizes with other taxa; taxonomic problems; info needed on # of individuals, # of populations, & trends
	Sclerocactus pubispinus var. pubispinus	Great Basin fishhook	Bvr, Box, Irn, Jub, Mil, Toe	Info needed on # of individuals, # of populations, & trends
	Sclerocactus spinosior (*S. pubispinus* var. *s.*)	Desert valley fishhook	Jub, Mil, Sev	Info needed on # of individuals, # of populations, & trends
Caryophyllaceae	*Eremogone loisiae*	Lois’ sandwort	Box, Cch, Dav, Jub, Rch, Slt, Snp, Toe, Uta, Web	Recently named, info needed on # of individuals, threats, and trends

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Chenopodiaceae	*Atriplex gardneri* var. *welshii* (*A. welshii*)	Welsh's saltbush	Grn	Taxonomic questions; info needed on # of individuals, threats, & trends
	Atriplex powellii var. *minuticarpa* (*A. minuticarpa*)	Green River orach	Emr, Gra, Way	Info needed on # of individuals, threats, & trends
Fabaceae (Leguminosae)	*Astragalus brandegei*	Brandegee's milkvetch	Emr, Grf, Irn, Piu, Sev, Way	Info needed on # of individuals, threats, & trends
	Astragalus callithrix	Callaway milkvetch	Mil	Info needed on # of individuals, threats, & trends
	Astragalus desperatus var. *petrophilus*	Rock-loving milkvetch	Emr	Info needed on # of individuals, threats, & trends
	Astragalus eastwoodiae	Eastwood's milkvetch	Emr, Grf, Grn, Snj, Way	Info needed on # of individuals, threats, & trends
	Astragalus hornii	Horn's milkvetch	Wsh?	Reports for UT need confirmation; info needed on # of individuals, # of populations, & trends
	Astragalus kelseyae	Kelsey's milkvetch	Web	Newly described narrow endemic, info needed on # of individuals, habitat specificity, intrinsic rarity, & trends
	Astragalus laccoliticus (*A. chamaeleuce* var. *laccoliticus*)	Laccolite milkvetch	Grf, Way	Info needed on # of individuals, threats, & trends
	Astragalus lentiginosus var. *negundo*	Box Elder freckled milkvetch	Box	Newly described, info needed on # of individuals, threats, & trends
	Astragalus lentiginosus var. *stramineus*	Straw milkvetch	Wsh?	Reports from UT need confirmation; info needed on # of individuals, # of populations, & trends
	Astragalus pardalinus	Panther milkvetch	Emr, Grf, Grn, Way	Info needed on # of individuals, threats, & trends
	Astragalus pattersonii	Patterson's milkvetch	Crb, Emr, Grf, Snj, Sev, Uin, Way	Info needed on # of individuals, threats, & trends
	Astragalus pinonis	Pinyon milkvetch	Bvr, Jub	Info needed on habitat specificity, threats, & trends
	Astragalus preussii var. *laxiflorus*	Littlefield milkvetch	Wsh?	Reports for UT need confirmation; info needed on # of individuals, # of populations, & trends
	Astragalus pubentissimus var. *peabodianus*	Peabody's milkvetch	Emr, Grn	Taxonomic questions, info needed on # of individuals, threats, & trends; BLM: S
	Astragalus rafaelensis	San Rafael milkvetch	Emr, Grn	Info needed on # of individuals, threats, & trends
	Astragalus woodruffii	Woodruff's milkvetch	Emr, Grf, Way	Info needed on # of individuals, threats, & trends

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Fabaceae (Leguminosae)	*Dalea flavescens* var. *epica* (*D. epica*)	Hole-in-the-Rock prairie-clover	Grf, Snj	Taxonomic questions; info needed on # of individuals, threats, & trends; BLM: S
	Lupinus flavoculatus	Yellow-eye lupine	Wsh	Info needed on # of individuals, intrinsic rarity, & trends
	Pediomelum castoreum	Beaver Dam breadroot	Wsh?	Reports for UT need confirmation; info needed on # of individuals, # of populations, & trends
	Trifolium andinum var. *canone*	Canyon Mountains clover	Mil	Newly described, info needed on # of individuals, threats, & trends
	Trifolium andinum var. *navajoense*	Navajo clover	Snj	Newly described, info needed on habitat specificity, threats, & trends
	Trifolium andinum var. *wahwahense*	Wah Wah clover	Bvr	Newly described, info needed on # of individuals, threats, & trends
	Vicia americana var. *lathyroides*	Pavant vetch	Mil	Newly described, info needed on habitat specificity, threats, & trends
Gentianaceae	*Lomatogonium rotatum*	Marsh felwort	Dag	Info needed on # of individuals, threats, & trends
Hydrangeaceae (Saxifragaceae)	*Jamesia americana* var. *rosea*	Rosy cliff jamesia	Irn	Taxonomic questions, info needed on # of populations, intrinsic rarity, threats, trends
Hydrophyllaceae	*Phacelia crenulata* var. *orbicularis*	Henry Mountains phacelia	Grf, Way	Info needed on # of individuals, threats, & trends
	Phacelia petrosa	Forgotten phacelia	Grf, Snj	Info needed on # of individuals, threats, & trends
Liliaceae	*Calochortus ciscoensis*	Cisco mariposa	Dch, Grn, Uin	Newly described, info needed on # of individuals, threats, & trends
Loasaceae	*Mentzelia multicaulis* var. *librina*	Horse Canyon stickleaf	Crb, Emr	Info needed on # of individuals, threats, & trends; BLM: S
	Mentzelia thompsonii	Thompson's stickleaf	Grn, Uin	Info needed on # of individuals, threats, & trends
	Petalonyx nitidus	Shiny-leaf sand-paper-plant	Wsh?	Reports from UT need confirmation; info needed on # of individuals, # of populations, & trends
Nyctaginaceae	*Abronia fragrans* var. *harrisii*	Harris' fragrant sand-verbena	Emr, Grf, Uin	Taxonomic questions; info needed on # of populations, threats, & trends
Onagraceae	*Camissonia bolanderi*	Bolander's camissonia	Emr, Way?	Newly described, info needed on # of individuals, threats, & trends; BLM: S
Ophioglossaceae	*Botrychium boreale* (*B. pinnatum*)	Northern grape-fern	Sum	Taxonomic questions; info needed on habitat specificity, intrinsic rarity, threats, & trends
	Botrychium crenulatum	Dainty moonwort	Was	Info needed on # of individuals, # of populations, threats, & trends; USFS: S

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	**Species**	**Common Name**	**County Dist. & Legal Status**	**Information Needed**
Ophioglossaceae	*Botrychium hesperium*	Western moonwort	Jub, Sum	Confirmation needed, info needed on # of individuals, # of populations, threats, & trends
	Botrychium lanceolatum	Lance-leaf grape-fern	Jub	Info needed on habitat specificity, intrinsic rarity, threats, & trends
	Botrychium paradoxum	Paradox moonwort	Grf	Confirmation needed; info needed on # of individuals, # of populations, threats, & trends; USFS: S
Papaveraceae	*Argemone corymbosa* var. *parva* (*A. parva*)	San Rafael prickly-poppy	Grf, Grn, Snj,	Recently described; info needed on # of individuals, threats, & trends
Poaceae (Gramineae)	*Bouteloua uniflora*	One-flower grama	Reported, Zion NP	Confirmation needed; info needed on # of individuals, habitat specificity, # of populations, threats, & trends
	Leersia oryzoides	Rice cutgrass	Dav, Uta, Web	Info needed on # of individuals, threats, & trends
	Stipa scribneri (*Achnatherum s.*)	Scribner needle-grass	Way	Info needed on # of populations, threats, & trends
Polemoniaceae	*Ipomopsis congesta* var. *goodrichii*	Goodrich gilia	Dch	Info needed on # of individuals, threats, & trends
	Langloisia schottii (*Loeseliastrum s.*)	Schott’s langloisia	Wsh	Info needed on # of individuals, threats, & trends
	Navarretia furnissii	Furniss’s navarettia	Cch, Sum, Was	Recently named, info needed on # of individuals, intrinsic rarity, threats, & trends
	Phlox albomarginata	White-margined phlox	Rch	Info needed on # of individuals, habitat specificity, threats, & trends
	Phlox austromontana var. *jonesii* (*P. jonesii*)	Jones’ phlox	Kan, Wsh	Taxonomic questions; info needed on # of individuals, threats, & trends
	Phlox austromontana var. *prostrata*	Silver Reef phlox	Kan, Wsh	Taxonomic questions; info needed on # of individuals, threats, & trends
Polygonaceae	*Eriogonum brevicaule* var. *viridulum* (*E. viridulum*)	Duchesne wild buckwheat	Dch, Uin	Info needed on # of individuals, threats, & trends
	Eriogonum contortum	Grand Valley wild buckwheat	Emr, Grn	Info needed on # of individuals, threats, & trends
	Eriogonum corymbosum var. *hylophilum* (*E. hylophilum*)	Gate Canyon wild buckwheat	Dch	Info needed on # of individuals, threats, & trends
	Eriogonum corymbosum var. *nilesii*	Las Vegas wild buckwheat	Kan?	Authenticity of UT reports has been questioned by James Reveal (Holmgren et al.2012); info needed on # of individuals, habitat specificity, # of populations, & trends; BLM: S; USFWS: C

Appendix 4. UNPS Rare Plant List: Need Data List, continued

Family	Species	Common Name	County Dist. & Legal Status	Information Needed
Polygonaceae	*Eriogonum corymbosum* var. *revealianum*	Reveal's wild buckwheat	Grf, Kan, Piu, Way	var. *heilii* recently pulled out, updated status info needed on remaining pops, including # of individuals, threats, trends
	Eriogonum domitum	House Range wild buckwheat	Mil	Described in 2011, endemic to House Range; info needed on # of individuals, habitat specificity, threats, & trends
	Eriogonum howellianum	Howell's wild buckwheat	Jub, Mil, Toe	Info needed on # of individuals, threats, & trends
	Eriogonum jamesii var. *higginsii* (*E. arcuatum*)	Higgins' wild buckwheat	Snj	Variety not recognized by Reveal in Holmgren et al. (2012); info needed on # of individuals, threats, & trends
	Eriogonum lonchophyllum var. *lonchophyllum*	Longleaf wild buckwheat	Emr, Grn, Snj, Uin	Vars not recognized by Holmgren et al. (2012), including var. *saurinum*; info needed on # of individuals, threats, trends
	Eriogonum microthecum var. *tegetiforme* (Lumped with var. *lapidicola* by Holmgren et al. 2012)	Slender buckwheat	Jub?, Mil, Wsh	Taxonomic questions; info needed on # of individuals, threats, & trends
	Eriogonum panguicense var. *alpestre*	Cedar Breaks wild buckwheat	Irn	Taxonomic questions; info needed on threats & trends (move to Watch list in future)
	Eriogonum spathulatum var. *kayeae* (included in var. *spathulatum* by Holmgren et al. 2012), Welsh et al. (2008) include *E. artificis.*	Kaye's wild buckwheat	Bvr	Taxonomic questions. *E. artificis* considered a separate species by Reveal in Holmgren et al. (2012); info needed on # of individuals, threats, & trends; BLM: S
	Eriogonum spathulatum var. *natum* (*E. natum*)	Son's wild buckwheat	Mil	Info needed on # of individuals, threats, & trends
Rosaceae	*Potentilla diversifolia* var. *madsenii*	Madsen's cinquefoil	Kan	Newly described, info needed on # of individuals, threats, & trends
Scrophulariaceae	*Penstemon acaulis* var. *yampaensis* (*P. yampaensis*)	Yampa penstemon	Dag	Info needed on # of individuals, threats, & trends
	Penstemon cyananthus var. *judyae*	Judy's penstemon	Uta	Recently described, info needed on # of individuals, threats, & trends
	Penstemon moffatii	Mofatt penstemon	Dch, Emr, Grf, Grn, Snj, Uta, Way	Info needed on # of individuals, threats, & trends
	Penstemon nanus	Dwarf penstemon	Bvr, Irn?, Mil	Info needed on # of individuals, threats, & trends

Utah Native Plant Society

Utah Native Plant Society
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The Utah Native Plant Society was founded in 1978 with a mission to promote the conservation, appreciation, and stewardship of native plants in the wild and in home cultivation. Through its publications, annual member meeting/dinner, field trips, and chapter meetings, UNPS is active in connecting citizens of Utah and the west with the native flora that makes the Beehive State so special. UNPS also funds an annual scholarship and small grants program using proceeds from its on-line store and generous contributions from members.

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