

Characterizing Rare Plant Habitat for Restoration in the San Bernardino National Forest

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Abstract—Surface mining of limestone in the San Bernardino Mountains has caused loss of native vegetation and of habitat for four carbonate-endemic plant taxa. This paper characterizes features of carbonate substrates and of habitat occupied by two of these species: Cushenbury milkvetch (*Astragalus albens*) and Cushenbury buckwheat (*Eriogonum ovalifolium* var. *vineum*) to assist in developing revegetation success criteria for mined lands.

Carbonate substrates in the San Bernardino Mountains were vegetationally and floristically distinct from non-carbonate substrates. In addition to the endemic plant species, we found five indicator taxa and 15 characteristic taxa for carbonate. At the same time, 36% of the taxa on non-carbonate soil did not occur on carbonate. Habitats occupied by Cushenbury milkvetch and Cushenbury buckwheat were distinguished from general carbonate substrate by higher percentage soil calcium, different slope angles, surface soil characteristics, and floristic composition.

As human populations and subsequent demands on natural resources increase, native species and plant communities are disappearing at an alarming rate (Ehrlich 1992, Franklin 1993). Habitat loss is the leading cause of species decline (Ehrlich 1988, p. 21). On public lands, timber harvest, cattle grazing and surface mining are leading causes of habitat loss and modification (Losos and others 1993). The decline and extinction of many plant species has led to increased listing activities under the Federal Endangered Species Act (16 U.S.C. 1531 *et seq.*).

On the San Bernardino National Forest in southern California, surface mining of limestone has caused loss and degradation of native vegetation in general and of habitat for four plant taxa endemic to carbonate substrates (limestone and dolomite). These species are Cushenbury milkvetch (*Astragalus albens*), Cushenbury buckwheat (*Eriogonum ovalifolium* var. *vineum*), Parish's daisy (*Eriogonon parishii*) and Parish's oxytheca (*Oxytheca parishii* var. *goodmaniana*). One additional species, San Bernardino bladderpod (*Lesquerella kingii* ssp. *bernardina*), is threatened primarily by ski area development on public land and housing development on private land. All five

of these taxa have been proposed for listing under the Federal Endangered Species Act (USFWS 1991).

Over 1,600 acres of potential habitat for these taxa has already been lost to mining activities including road construction, mineral extraction, processing plant construction and deposition of waste material. Additional degradation has resulted from erosion and from deposition of windblown dust. Restoration of these disturbed areas provides the only hope of re-creating habitat for these taxa. Reclamation of mined lands has been required since 1974 (USFS 1974). Unfortunately, most of the existing disturbance predates these requirements and thus will never be reclaimed. On many sites where reclamation is legally required, revegetation is not feasible due to physical conditions of the post-mining landscapes (for example, lack of topsoil, steep slopes or inaccessibility) and the cost of such efforts. The arid climate of the region further complicates the picture and limits restoration potential. Also, until recently requirements have been very general and the limited amount of revegetation that has been accomplished has focused on erosion control activities. Most often only a few species were planted and these most often were not native to the planting sites. These plantings in no way reflect predisturbance ecosystems or recreate the ecosystems on which the rare species depend. Where revegetation of new disturbance is undertaken, SBNF mine reclamation standards now require establishment of 50% of the predisturbance cover and 15% of the predisturbance species richness on a site (USFS 1991). Obviously, detailed baseline descriptions of pre-disturbance conditions are necessary to establish success criteria and to meet these standards. Such descriptions are important for restoring native ecosystems in general; they are even more important when dealing with endangered species habitat. Unfortunately, such descriptions are most often lacking.

The purpose of this research was to characterize vegetational and abiotic features of carbonate substrate and of habitat occupied by two of the five carbonate-endemic plants species mentioned above: Cushenbury milkvetch and Cushenbury buckwheat. This research is part of a larger study that will also include the other carbonate endemic plant species. While the focus of this paper is restoration, quantitative descriptions of rare plant habitats can be important in identifying potential but previously unknown habitat, developing integrated conservation strategies (Falk 1992), assessing and prioritizing sites for protection (DeVelice and others 1988; Lesica 1993) and evaluating sites for potential reintroduction or introduction of the target species into suitable but unoccupied habitat (Falk 1992, p. 414-415).

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Study Area

The San Bernardino Mountains lie at the eastern end of the Transverse Mountain Ranges of southern California. Wedged between coastal southern California to the south and west, the Mojave Desert to the north and the Sonoran Desert to the southeast, the San Bernardino Mountains support a high degree of vegetational and floristic diversity (Minnich 1976). There is also a relatively high degree of endemism, with at least 20 plant taxa entirely restricted to the mountain range (Krantz 1987 and 1990; Smith and Berg 1988).

Cushenbury milkvetch and Cushenbury buckwheat are found on the north slope of the San Bernardino Mountains, on carbonate substrate. The portion of the mountain range occupied by these taxa borders the Mojave Desert. Elevations range from approximately 1,300 to 2,500 meters. Dominant vegetation types in the study area include blackbrush scrub, piñon woodlands, piñon-juniper woodlands and yellow pine woodlands; piñon woodlands and piñon-juniper woodlands are the most extensive types. Precipitation ranges from 1 to 4 cm per year, falling primarily as winter rain. Snowfall is common but does not persist through the winter. Summer thunder showers occur infrequently in most years, accounting for no more than 20% of the annual precipitation. Temperatures in the study area range from winter nighttime lows of -1.4° to summer daytime highs of 28°C .

Methods

Sampling Design

The study area was stratified into carbonate substrate, non-carbonate substrate, occupied Cushenbury milkvetch habitat and occupied Cushenbury buckwheat habitat. Plots were selected as follows:

Carbonate Plots (n=88)—Plots were located on carbonate substrate by randomly selecting two points within each cadastral section of land that had more than 5% coverage of carbonate surface deposits (Geo/Resource Consultants, Inc. 1981; Brown 1992). All plots were located more than 200 m from a mapped boundary between carbonate and non-carbonate substrates to avoid edge effects and map error. A total of 88 carbonate plots were sampled; nine of these plots supported Cushenbury milkvetch and 19 supported Cushenbury buckwheat.

Non-Carbonate Plots (n=73)—Within each section sampled for carbonate plots, two random points that occurred off of mapped carbonate substrate were randomly selected. If a section had 100% carbonate surface deposit coverage, non-carbonate plots were located in adjacent sections of land. All plots were located more than 200 m from a mapped boundary between carbonate and non-carbonate substrates to avoid edge effects and map error.

Plant-Centered Plots (n=58)—One to two plots were randomly located within each section containing at least one occurrence of either Cushenbury milkvetch (n=30) or Cushenbury buckwheat (n=28). To qualify as a Cushenbury milkvetch sample, the plot had to contain a minimum of

20 Cushenbury milkvetch plants. Cushenbury buckwheat samples needed at least 15 Cushenbury buckwheat plants to qualify.

The results presented here are preliminary. We sampled approximately one-half of the available carbonate substrate and two-thirds of the occupied habitat for both Cushenbury milkvetch and Cushenbury buckwheat in 1992 and 1993. We will sample the remaining carbonate substrate and remaining populations of all five rare taxa during 1994 and 1995.

Data Collection

Each random point served as the center of a 0.04 hectare plot. Aspect, slope (degrees) and elevation (m) were recorded in each plot. A northness index was calculated as $(\sin(\text{slope in degrees}) \times \cos(\text{aspect in degrees}))$. A soil sample was taken in the center of each plot to approximately 30 cm depth; pH, total extractable calcium and total extractable magnesium were determined for each soil sample. Percentage cover was estimated for surface coverage of outcrop, boulder, rock, cobble, gravel, soil and litter. Percentage cover of each overstory species, shrub layer species and perennial bunchgrass was recorded. Total canopy and shrub cover were then calculated for each plot. In 1992 percentage cover was recorded in classes while absolute cover was recorded in 1993. Mean values of percent cover of variables for each group were calculated and compared using only plots in which absolute cover was recorded. Abundances of all herb layer species were recorded in the following categories: 1) rare, 2) occasional, 3) frequent, 4) abundant, 5) dominant; only presence-absence data were used in comparisons. Densities of Cushenbury milkvetch, Parish's daisy, Cushenbury buckwheat and Parish's oxytheca were also recorded. Species richness and Shannon's diversity index were calculated for each plot. Additionally, total species richness was calculated for each comparison group. Nomenclature follows Munz (1974) for all genera except *Cryptantha* and *Phacelia* which follows Hickman (1993).

Data Analysis

The following comparisons were made:

- 1) Carbonate (n=88 for frequency; n=40 for cover) vs. non-carbonate plots (n=73 for cover and frequency).
- 2) Cushenbury milkvetch-centered (n=30 for frequency; n=15 for cover) vs. carbonate plots not occupied by Cushenbury milkvetch (n=79 for frequency; n=38 for cover).
- 3) Cushenbury buckwheat-centered (n=28 for frequency and cover) vs. carbonate plots not occupied by Cushenbury buckwheat (n=69 for frequency; n=31 for cover).

Species frequency data were used to determine characteristic and indicator species for each group. Characteristic species were those with high fidelity (greater than 80% of the occurrences within one group and occurring in greater than 5% of the plots in that group) and/or high constancy (occurrence in more than 25% of the plots in a group). Indicator species were species with both high fidelity and high constancy and that also had significant differences in percent cover between comparison groups.

The Mann-Whitney U test was used to compare groups for all sampled environmental variables, percentage cover of characteristic overstory species, shrub species and perennial bunchgrasses, densities of rare species, species richness per plot, Shannon's diversity index per plot, total overstory cover and total shrub cover height. The non-parametric Mann-Whitney U test was chosen due to the non-normal nature of the data. Differences were considered significant if p was less than 0.01.

Results

Comparison of Carbonate and Non-Carbonate Substrates

Carbonate plots ranged in elevation from 1,440 m to 2,374 m; non-carbonate plots were between 1,304 m and 2,401 m. Carbonate plots had significantly higher mean values of pH ($U=1,670$, $p<0.0001$), percentage extractable calcium ($U=683$, $p<0.0001$) and percentage extractable magnesium ($U=1,630$, $p<0.0001$). Carbonate plots also occurred on significantly steeper slope angles ($U=2,085$, $p<0.001$; Table 1).

Total species richness was greater in non-carbonate plots (226 species) than in carbonate plots (189 species). Mean species richness per plot and Shannon's diversity index did not differ significantly between groups (Table 1). In this comparison, 48 species were found only in carbonate plots and 81 were found only in non-carbonate plots.

Two overstory species (singleleaf pinyon pine, *Pinus monophylla*, and Joshua tree, *Yucca brevifolia*), five shrub species (Great Basin sagebrush, *Artemisia tridentata*;

mormon tea, *Ephedra viridis*; sticky snakeweed, *Gutierrezia microcephala*; beavertail cactus, *Opuntia basilaris*; and antelope bitterbrush, *Purshia glandulosa*) and four bunchgrass species (Fendler's bluegrass, *Poa fendleriana*; bottlebrush squirreltail grass, *Sitanion hystrix*; coronate needlegrass, *Stipa coronata* ssp. *depauperata*; and desert needlegrass, *Stipa speciosa*) were characteristic of both carbonate and non-carbonate substrates (Table 2). Only one herb species, *Gilia austro-occidentalis* was characteristic of both groups (Table 3). Total overstory cover and total shrub cover did not differ between groups (Table 2).

No indicator species were identified for non-carbonate substrates. One overstory species (shrub live oak, *Quercus turbinella*), seven shrub species (false indigo, *Amorpha californica*; California buckwheat, *Eriogonum fasciculatum* var. *pollifolium*; goldenbush, *Haplopappus linearifolius*; prickly phlox, *Leptodactylon pungens*; Parry's nolina, *Nolina parryi*; grizzly bear cactus, *Opuntia erinacea*; and *Salvia dorrii*) and one bunchgrass species (bluegrass, *Poa secunda*) were characteristic of non-carbonate substrates (Table 2). An additional 20 herbs were also characteristic of non-carbonate plots (Table 3). All of these species were either completely absent or were infrequently encountered on carbonate substrate. While its occurrence was characteristic of both substrate types, bottlebrush squirreltail grass had significantly higher mean percentage cover in non-carbonate plots.

Carbonate plots supported five indicator taxa: Utah juniper (*Juniperus osteosperma*), mountain mahogany (*Cercocarpus ledifolius*), yellow rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *stenophilus*), San Bernardino buckwheat (*Eriogonum microthecum* var. *corymbosoides*),

Table 1—Mean values of environmental variables, species richness and diversity and densities of rare plant species in carbonate and non-carbonate plots. An asterisk denotes a significant difference between the two substrate types as determined by the Mann-Whitney U test.

Variable	Carbonate			Milkvetch-centered		
	n	Mean	SD	n	Mean	SD
pH*	88	6.0	0.3	73	5.5	0.6
% Calcium*	88	16.6	8.7	73	2.6	6.3
% Magnesium*	88	2.6	2.8	73	0.9	1.4
Slope (°)	88	29.9	10.8	73	13.8	10.6
Northness	88	0.09	0.5	73	−0.0001	0.5
Elevation (m)	88	1917.0	217.0	73	1905.0	222.0
% Outcrop cover	40	5.1	10.5	73	4.9	9.7
% Boulder cover	40	1.5	2.6	73	6.9	13.0
% Rock Cover	40	5.8	5.7	73	6.2	5.7
% Cobble Cover	40	9.9	7.0	73	8.1	8.0
% Gravel Cover	40	5.0	5.9	73	8.0	7.0
% Soil Cover	40	5.8	5.4	73	11.0	11.0
% Litter Cover	40	5.4	7.2	73	6.8	11.8
Species Richness	88	20.5	5.6	73	19.3	5.8
Shannon's Diversity Index	88	0.9	0.2	73	0.9	0.2
Cushenbury Milkvetch Density ¹	88	4.6	26.7	73	1.1	9.0
Parish's Daisy Density	88	0.1	0.5	73	0.0	0.0
Cushenbury Buckwheat Density	88	3.8	11.9	73	0.0	0.0
Parish's Oxytheca Density	88	14.2	62.0	73	0.0	0.0

¹Two plots mapped as non-carbonate substrate supported Cushenbury milkvetch. However, one of these plots had an extractable calcium content of 7.5% and the other had an extractable calcium content of 29.8%. Cushenbury milkvetch did not occur in plots that did not have calcium in the soil.

Table 2—Frequency and mean percentage cover values for overstory, shrub and bunchgrass species characteristic of carbonate and non-carbonate substrates. High fidelity and high constancy species are designated by “F” or “C”, respectively. Indicator species (I) are those with high fidelity, high constancy and a significant difference in mean percentage cover between the sample groups. For frequency, carbonate n=88 and non-carbonate n= 73. For cover, carbonate n= 40 and non-carbonate n=73.

Species	Carbonate			Non-carbonate		
	Mean	SD	Freq	Mean	SD	Freq
Overstory Layer						
<i>Juniperus osteosperma</i>	3.9	6.2	53 ^I	0.9	2.6	10
<i>Pinus monophylla</i>	17.5	12.4	81 ^C	16.1	17.5	57 ^C
<i>Quercus turbinella</i>	0.0	0.0	0	2.6	7.0	10 ^F
<i>Yucca brevifolia</i>	0.7	1.8	34 ^C	1.2	3.2	24 ^C
Total Overstory Cover	23.2	17.0	—	28.6	21.0	—
Shrub Layer						
<i>Amorpha californica</i>	0.1	0.8	1	0.2	1.0	7 ^F
<i>Artemisia tridentata</i>	1.7	4.0	26 ^C	5.9	10.5	34 ^C
<i>Cercocarpus ledifolius</i>	11.3	12.1	47 ^I	1.0	3.6	8
<i>Chrysothamnus viscidiflorus</i> ssp. <i>stenophilus</i>	3.3	3.4	64 ^I	1.0	2.2	8
<i>Echinocereus engelmannii</i>	0.01	0.1	16 ^F	0.1	0.3	3
<i>Ephedra viridis</i>	2.5	3.5	69 ^C	1.5	2.5	33 ^C
<i>Eriogonum fasciculatum</i> var. <i>polifolium</i>	0.2	0.5	14	1.8	3.8	27 ^C
<i>Eriogonum microthecum</i> var. <i>corymbosoides</i>	1.9	2.4	31 ^I	0.0	0.0	0
<i>Forsellesia nevadensis</i>	1.2	3.8	13 ^F	0.0	0.0	0
<i>Gutierrezia microcephala</i>	0.5	1.2	25 ^C	1.9	5.3	19 ^C
<i>Haplopappus linearifolius</i>	0.3	1.1	8	2.0	4.1	29 ^C
<i>Leptodactylon pungens</i>	0.0	0.0	0	0.2	0.7	12 ^F
<i>Nolina parryi</i>	0.0	0.0	0	0.3	1.2	6 ^F
<i>Opuntia basilaris</i>	0.4	0.7	32 ^C	0.01	0.8	36 ^C
<i>Opuntia erinacea</i>	0.0	0.0	0	0.2	0.7	7 ^F
<i>Purshia glandulosa</i>	1.0	2.5	31 ^C	3.4	4.7	40 ^C
<i>Salvia dorrii</i>	0.0	0.0	0	0.5	3.2	9 ^F
<i>Salvia pachyphylla</i>	0.9	2.4	22 ^C	0.3	1.1	9
<i>Yucca whipplei</i>	0.1	0.4	5 ^F	0.0	0.0	0
Total Shrub Cover	36.2	17.5	—	39.1	24.6	—
Bunchgrass						
<i>Oryzopsis hymenoides</i>	0.5	0.5	49 ^I	0.1	0.2	5
<i>Poa fendleriana</i>	0.4	0.5	33 ^C	0.3	0.5	22 ^C
<i>Poa secunda</i>	0.02	0.2	2	0.1	0.3	8 ^C
<i>Sitanion hystrix</i>	0.5	0.5	42 ^C	0.7	0.5	50 ^C
<i>Stipa coronata</i> ssp. <i>depauperata</i>	1.1	1.5	70 ^C	2.1	1.2	39 ^C
<i>Stipa speciosa</i>	0.3	0.5	30 ^C	0.5	0.5	37 ^C

and Indian ricegrass (*Oryzopsis hymenoides*). Mean percentage cover of each of these taxa differed significantly from their cover in non-carbonate plots (U=960, p<0.01, U=622, p<0.0001, U=813.5, p<0.001, U=949, p<0.01, U=914.0, p<0.01, respectively). Carbonate plots supported four characteristic shrub species (Engelmann’s hedgehog cactus, *Echinocereus engelmannii*; Nevada greasewood, *Forsellesia nevadensis*; rose sage, *Salvia pachyphylla*; and our Lord’s candle, *Yucca whipplei* var. *caespitosa*) and 11 characteristic herb species (Tables 2 and 3). Four of these herbs (Shockley’s rock cress, *Arabis shockleyi*; desert paintbrush, *Castilleja chromosa*; Eaton’s penstemon, *Penstemon eatonii*; and southern mountain phlox, *Phlox austromontanum*) had both high constancy and fidelity in carbonate plots. While its occurrence was characteristic of both substrate types, desert needlegrass had significantly higher mean percentage cover in carbonate plots.

Cushenbury milkvetch was found in nine carbonate

plots, *Erigeron parishii* was found in 2 plots, Cushenbury buckwheat was found in 19 plots and Parish’s oxytheca was found in 9. San Bernardino bladderpod was not found in any plots because sampling completed thus far is below the elevational limits of this taxon. Of these species only Cushenbury milkvetch was found in any plots that were mapped as non-carbonate. However, percentage extractable calcium for the two “non-carbonate” plots in which Cushenbury milkvetch was found was 7.5% and 29.8%, indicating that these plots were mapped incorrectly.

Cushenbury Milkvetch

Carbonate plots ranged in elevation from 1,440 to 2,374 m; Cushenbury milkvetch plots were between 1,469 and 2,011 m. Cushenbury milkvetch-centered plots had significantly higher values of percentage extractable calcium (U=818.5, p<0.01) and on the average they occurred at lower elevations (U=574.0, p<0.0001) and on signifi-

Table 3—Frequency of herbaceous species characteristic of carbonate and non-carbonate substrates. High fidelity and high constancy species are designated by “f” or “c”, respectively.

Species	Carbonate n=88		Non-carbonate n=73	
	Frequency	Designation	Frequency	Designation
<i>Abronia nana-covillei</i>	5	f	0	
<i>Arabis dispar</i>	0		5	f
<i>Arabis shockleyi</i>	26	c,f	4	
<i>Arenaria macradenia</i>	19	f	0	
<i>Artemisia ludoviciana</i>	0		6	f
<i>Castilleja chromosa</i>	40	c,f	6	
<i>Caulanthus major</i>	27	c	13	
<i>Chaenactis santolinoides</i>	1		9	f
<i>Cryptantha confertiflora</i>	5	f	0	
<i>Cryptantha utahensis</i>	1		4	f
<i>Descurainia pinnata</i>	32	c	19	
<i>Draba corrugata</i>	7	f	0	
<i>Draba cuneifolia</i>	5	f	0	
<i>Dudleya abramsii</i>	1		4	f
<i>Eriastrum densifolium</i>	1		6	f
<i>Eriastrum sapphirinum</i> ssp. <i>sapphirinum</i>	0		13	f
<i>Erigeron aphanactis</i>	0		6	f
<i>Eriogonum inflatum</i>	5	f	0	
<i>Eriogonum kennedyi</i>	1		4	f
<i>Eriogonum ovalifolium</i> var. <i>vineum</i>	20	f	0	
<i>Eriogonum saxatile</i>	1		11	f
<i>Eriogonum umbellatum</i> var. <i>munzii</i>	1		5	f
<i>Eriogonum wrightii</i> var. <i>subumbellatum</i>	1		11	f
<i>Eriophyllum lanatum</i>	0		14	f
<i>Gayophytum diffusum</i>	1		4	
<i>Gilia austro-occidentalis</i>	58	c	24	c
<i>Linanthus breviculus</i>	0		9	f
<i>Lotus strigosus</i>	0		7	f
<i>Machaeranthera canescens</i>	1		7	f
<i>Mentzelia mojavnensis</i>	1		4	f
<i>Monardella linoides</i>	1		5	f
<i>Oxytheca parishii</i> var. <i>goodmaniana</i>	9	f	0	
<i>Penstemon eatonii</i>	24	c,f	5	
<i>Penstemon labrosus</i>	0		4	f
<i>Phacelia fremontii</i>	42	c	18	
<i>Phlox austromontanum</i>	28	c,f	4	
<i>Senecio bernardinus</i>	0		4	f

cantly shallower slope angles than randomly located plots on carbonate ($U=613$, $p<0.0001$; Table 4). Cushenbury milkvetch-centered plots also had significantly lower percentage cover of litter ($U=148.0$, $p<0.01$).

Total species richness was greater in carbonate plots without Cushenbury milkvetch (181 species) than in Cushenbury milkvetch-centered plots (136 species). While total species richness was lower, mean species richness per plot ($U=452$, $p<0.000001$) and Shannon's diversity index ($U=418$, $p<0.00001$) were both significantly greater in Cushenbury milkvetch-centered plots (Table 4). In this comparison, 19 of the species sampled were restricted to Cushenbury milkvetch plots while 64 species were found only in carbonate plots that did not support Cushenbury milkvetch.

Three overstory species (Utah juniper, singleleaf pinyon pine, and Joshua tree), six shrub species (Great Basin sagebrush, yellow rabbitbrush, Mormon tea, sticky snakeweed, beavertail cactus, and antelope bitterbrush) and three bunchgrass species (Fendler's bluegrass, coronate needlegrass, and desert needlegrass) were characteristic of both groups (Table 5). Six herb species, *Arabis pulchra*, Shockley's rock cress, desert paintbrush, tansey mustard, (*Descurainia pinnata*), *Gilia austro-occidentalis* and Fremont's phacelia (*Phacelia fremontii*) were also characteristic of both groups (Table 6). Total overstory cover and total shrub cover did not differ between groups (Table 5).

Two overstory species (mountain juniper, *Juniperus occidentalis* var. *australis*, and canyon live oak, *Quercus*

Table 4—Mean values of environmental variables, species richness and diversity and densities of rare plant species in Cushenbury milkvetch-centered plots and carbonate plots that did not support Cushenbury milkvetch. An asterisk denotes a significant difference between the two substrate types as determined by Mann-Whitney U test.

Variable	Carbonate			Milkvetch-centered		
	n	Mean	SD	n	Mean	SD
pH	79	6.0	0.4	15	6.1	0.2
% Calcium*	79	16.2	9.0	30	21.3	6.8
% Magnesium	79	2.7	2.9	30	3.0	6.0
Slope (°)*	79	20.8	10.8	30	12.1	5.7
Northness	79	0.098	0.497	30	−0.009	0.570
Elevation (m)	79	1929.0	223.0	30	1737.0	150.0
% Outcrop Cover	38	5.3	10.7	15	5.3	8.4
% Boulder Cover	38	1.5	2.6	15	0.4	0.7
% Rock Cover	38	5.7	5.8	15	2.9	3.0
% Cobble Cover	38	9.6	7.0	15	7.1	4.6
% Gravel Cover	38	5.2	6.0	15	6.2	6.5
% Soil Cover	38	5.7	5.6	15	4.0	2.9
% Litter Cover*	38	5.5	7.4	15	2.3	3.6
Species Richness*	79	20.0	5.4	30	28.5	8.3
Shannon's Diversity Index*	79	0.9	0.2	30	1.1	0.2
Cushenbury Milkvetch Density*	79	0.0	0.0	30	87.1	69.4
Parish's Daisy Density	79	0.1	0.5	30	1.0	3.0
Cushenbury Buckwheat Density	79	4.2	12.5	30	2.5	8.0
Parish's Oxytheca Density	79	15.8	65.2	30	0.0	0.0

chrysolepis) and nine shrub species (service-berry, *Amelanchier utahensis*; big berry manzanita, *Arctostaphylos glauca*; Mojave ceanothus, *Ceanothus greggii* var. *vestitus*; mountain mahogany; Engelmann's hedgehog cactus; San Bernardino buckwheat; Nevada greasewood; prickly pear cactus, *Opuntia littoralis*; Mexican paperbag bush; *Sala-zaria mexicana*; and rose sage) and two bunchgrass species (Indian ricegrass and bottlebrush squirreltail grass) were characteristic of carbonate plots that did not support Cushenbury milkvetch. Three of the shrub layer species (mountain mahogany, San Bernardino buckwheat and rose sage) and the two bunchgrass species had both high constancy and fidelity. However, only mountain mahogany was a true indicator species in that it had a significantly higher mean percentage cover than was found in Cushenbury milkvetch-centered plots ($U=121$, $p<0.01$). Five herb species, including Cushenbury buckwheat and Parish's oxytheca were also characteristic of carbonate based plots (Table 6).

Cushenbury milkvetch-centered plots did not support any indicator species. These plots did support four characteristic shrub species (blackbrush, *Coleogyne ramosissima*; Mojave mound cactus, *Echinocereus triglochidiatus* var. *mojavense*; desert almond, *Prunus fasciculatus*; and Mojave yucca, *Yucca schidigera*), one characteristic bunchgrass (sand dropseed, *Sporobolus cryptandrus*) and three characteristic herb species (*Allium* sp., *Eriastrum saphirinum* ssp. *saphirinum* and *Phacelia douglasii*) (Tables 5 and 6). Both blackbrush ($U=112.5$, $p<0.001$) and Mojave yucca ($U=140.5$, $p<0.01$) had significantly higher cover in Cushenbury milkvetch-centered plots. While their occurrences were characteristic of both groups, Joshua tree ($U=127.5$, $p<0.01$) and desert needlegrass ($U=154$, $p<0.01$)

had significantly higher mean percentage cover in Cushenbury milkvetch-centered plots.

Cushenbury Buckwheat

Carbonate plots that did not support Cushenbury buckwheat ranged in elevation from 1,506 m to 1,927 m; Cushenbury buckwheat-centered plots were between 1,426 m and 2,390 m. Cushenbury buckwheat-centered plots had significantly higher mean values of percentage extractable calcium ($U=449.5$, $p<0.0001$) and on the average they occurred on sites where rock outcrop cover was significantly higher ($U=245.5$, $p<0.01$; Table 7).

Total species richness was greater in carbonate plots without Cushenbury buckwheat (185 species) than in Cushenbury buckwheat-centered plots (107 species). Neither mean species richness nor Shannon's diversity index differed between groups (Table 7). In this comparison, 25 species were restricted to Cushenbury buckwheat plots while 82 species were found only in carbonate plots that did not support Cushenbury buckwheat.

Three overstory species (Utah juniper, singleleaf pinyon pine and Joshua tree), nine shrub species (Great Basin sagebrush, mountain mahogany, yellow rabbitbrush, Mojave mound cactus, Mormon tea, San Bernardino buckwheat, sticky snakeweed, beavertail cactus and antelope bitterbrush) and four bunchgrass species (Indian ricegrass, Fendler's bluegrass, coronate needlegrass and desert needlegrass) were characteristic of both Cushenbury buckwheat-centered plots and carbonate plots without this species (Table 8). Six herb species, *Arabis pulchra*, desert paintbrush, jewelflower (*Caulanthus major*), tansy mustard, *Gilia austro-occidentalis*, (*Penstemon eatonii*),

Table 5—Frequency and mean percentage cover values for overstory, shrub and bunchgrass species characteristic of Cushenbury milkvetch-centered plots and carbonate plots that did not support Cushenbury milkvetch. High fidelity and high constancy species are designated by “F” or “C,” respectively. Indicator species (I) are those with high fidelity, high constancy and a significant difference in mean percentage cover between the sample groups. For frequency, Cushenbury milkvetch plots n=30 and carbonate n=79. For cover, Cushenbury milkvetch=15 and carbonate n=38.

Species	Carbonate			Milkvetch-centered		
	Mean	SD	Freq	Mean	SD	Freq
Overstory Layer						
<i>Juniperus occidentalis</i> var. <i>australis</i>	1.6	4.7	5 ^F	0.0	0.0	0
<i>Juniperus osteosperma</i>	3.6	6.1	47 ^C	4.6	6.8	19 ^C
<i>Pinus monophylla</i>	17.9	12.6	74 ^C	10.5	8.0	29 ^C
<i>Quercus chrysolepis</i>	3.7	7.3	16 ^F	<0.001	<0.001	1
<i>Yucca brevifolia</i>	0.8	1.8	29 ^C	2.8	4.3	25 ^C
Total Overstory Cover	23.6	17.7	—	22.2	15.4	—
Shrub Layer						
<i>Amelanchier utahensis</i>	0.4	1.1	9 ^F	0.0	0.0	0
<i>Arctostaphylos glauca</i>	3.5	8.2	18 ^F	3.2	11.6	4
<i>Artemisia tridentata</i>	1.8	4.1	22 ^C	0.8	1.4	8 ^C
<i>Ceanothus greggii</i> var. <i>vestitus</i>	3.0	8.7	15 ^F	<0.001	<0.001	1
<i>Cercocarpus ledifolius</i>	11.4	12.4	46 ^I	0.2	0.5	4
<i>Chrysothamnus viscidiflorus</i> ssp. <i>stenophilus</i>	3.2	3.5	58 ^C	3.0	3.4	23 ^C
<i>Coleogyne ramosissima</i>	1.1	5.7	12	15.4	11.7	16 ^C
<i>Echinocereus engelmannii</i>	0.01	0.1	13 ^F	<0.001	<0.001	3
<i>Echinocereus triglochidiatus</i> var. <i>mojavense</i>	0.1	0.3	18	0.3	0.4	10 ^C
<i>Ephedra viridis</i>	2.4	3.6	62 ^C	2.0	2.4	24 ^C
<i>Eriogonum microthecum</i> var. <i>corymbosoides</i>	1.1	2.5	27 ^{C,F}	0.1	0.4	6
<i>Forsellesia nevadensis</i>	1.2	3.9	12 ^F	0.4	1.1	3
<i>Gutierrezia microcephala</i>	0.5	1.3	24 ^C	1.0	1.9	8 ^C
<i>Lepidium fremontii</i>	0.1	0.6	5	0.4	0.5	9 ^C
<i>Opuntia basilaris</i>	0.4	0.7	29 ^C	0.5	0.6	19 ^C
<i>Opuntia littoralis</i>	0.1	0.7	12 ^F	0.03	0.1	2
<i>Prunus fasciculatus</i>	0.3	0.9	12	1.4	3.3	9 ^C
<i>Purshia glandulosa</i>	1.0	2.6	25 ^C	3.7	5.6	18 ^C
<i>Salazaria mexicana</i>	0.1	0.5	5 ^F	0.0	0.0	0
<i>Salvia pachyphylla</i>	1.0	2.4	22 ^{C,F}	0.2	0.6	3
<i>Yucca schidigera</i>	0.03	0.2	9	1.9	2.4	14 ^C
Total Shrub Cover	36.1	17.9	—	40.0	15.8	—
Bunchgrasses						
<i>Aristida fendleriana</i>	0.1	0.2	13	0.5	0.8	14 ^C
<i>Oryzopsis hymenoides</i>	0.6	0.8	44 ^{C,F}	0.3	0.6	10 ^C
<i>Poa fendleriana</i>	0.7	1.0	31 ^C	0.5	0.7	8 ^C
<i>Sitanion hystrix</i>	0.2	0.4	36 ^{C,F}	<0.001	<0.001	2
<i>Sporobolus cryptandrus</i>	0.01	0.1	1	0.03	0.1	4 ^F
<i>Stipa coronata</i> ssp. <i>depauperata</i>	1.2	1.3	64 ^C	1.7	2.8	20 ^C
<i>Stipa speciosa</i>	0.3	0.5	29 ^C	1.0	1.1	20 ^C

and Fremont’s phacelia were also characteristic of both groups (Table 9). Total overstory cover and total shrub cover did not differ between groups (Table 8).

Carbonate plots without Cushenbury buckwheat supported one characteristic overstory species (mountain juniper), seven characteristic shrub species (service-berry; Engelmann’s hedgehog cactus; winter fat, *Eurotia lanata*; goldenbush; silver cholla, *Opuntia echinocarpa*; prickly pear; and Mexican paperbag bush, *Salazaria mexicana*) and one characteristic bunchgrass species (bottlebrush squirreltail grass, Table 8). None of these were indicator species. The herbs Nevin’s birdbeak (*Cordylanthus nevini*), *Cryptantha nevadensis*, *Draba corrugata*, western wallflower (*Erysimum capitatum*), rattlesnake weed (*Euphorbia albomarginata*), common muilla (*Muilla maritima*),

southern mountain phlox, *Stephanomeria myrioclada*, and *Stephanomeria virgata* were characteristic of carbonate plots alone (Table 9). Only four of the species above had both high constancy and high fidelity: bottlebrush squirrel-tail grass, tansy mustard, Fremont’s phacelia, and southern mountain phlox. While its occurrence was characteristic of both substrate types, Fendler’s bluegrass ($U=260.0$, $p<0.01$) had significantly higher mean percentage cover in carbonate plots that did not support Cushenbury buckwheat.

Cushenbury buckwheat-centered plots also did not support any indicator species. This group had five characteristic shrub species (big berry manzanita, rubber rabbit-brush, blackbrush, rose sage and mojave yucca) and four herb species (desert sandwort, *Arenaria macradenia*;

Table 6—Frequency of herbaceous species characteristic of Cushenbury milkvetch plots and carbonate plots that did not support Cushenbury milkvetch. High fidelity and high constancy species are designated by “f” or “c,” respectively.

Species	Carbonate n=79		Milkvetch-centered n=30	
	Frequency	Designation	Frequency	Designation
<i>Allium campanulatum</i>	0		2	f
<i>Allium</i> sp.	2		8	c,f
<i>Arabis pulchra</i>	37	c	10	c
<i>Arabis shockleyi</i>	24	c	11	c
<i>Arenaria macradenia</i>	18		9	c
<i>Brickellia oblongifolia</i>	16	f	1	
<i>Castilleja chromosa</i>	34	c	16	c
<i>Caulanthus major</i>	26	c,f	1	
<i>Cordylanthus nevinii</i>	13	f	1	
<i>Cryptantha angustifolium</i>	0		3	f
<i>Cryptantha muricata</i>	0		2	f
<i>Cryptantha nevadensis</i>	11		8	c
<i>Cryptantha watsonii</i>	0		2	f
<i>Descurainia pinnata</i>	27	c	18	c
<i>Draba cuneifolia</i>	5		8	c
<i>Eriastrum sapphirinum</i> ssp. <i>sapphirinum</i>	0		8	c,f
<i>Eriogonum inflatum</i>	5		8	c
<i>Eriogonum parishii</i>	0		3	f
<i>Eriogonum maculatum</i>	0		4	f
<i>Eriogonum nidularium</i>	0		5	f
<i>Eriogonum ovalifolium</i> var. <i>vineum</i>	17	f	4	
<i>Festuca octoflora</i>	4		8	c
<i>Galium parishii</i>	5	f	0	
<i>Gilia austro-occidentalis</i>	52	c	25	c
<i>Nemacladus longiflorus</i>	0		3	f
<i>Nemacladus</i> sp.	3		11	c
<i>Oxytheca parishii</i> var. <i>goodmaniana</i>	9	f	0	
<i>Parishella californica</i>	0		7	f
<i>Penstemon eatonii</i>	23	c,f	2	
<i>Phacelia douglasii</i>	0		8	c,f
<i>Phacelia fremontii</i>	37	c	21	c
<i>Phlox austromontanum</i>	26	c,f	0	f

Table 7—Mean values of environmental variables, species richness and rare plant densities in Cushenbury buckwheat-centered plots and carbonate plots that did not support Cushenbury buckwheat. An asterisk denotes a significant difference between the two substrate types as determined by the Mann-Whitney U test.

Variable	n	Carbonate		n	Buckwheat-centered	
		Mean	SD		Mean	SD
pH	69	6.0	0.3	28	6.1	0.3
% Calcium*	69	15.4	8.7	28	22.9	4.3
% Magnesium	69	2.3	2.5	28	1.8	1.6
Slope (°)	69	18.6	10.8	28	19.6	10.3
Northness	69	0.05	0.51	28	0.08	0.49
Elevation (m)	69	1927.0	224.0	28	1861.0	219.4
% Outcrop cover*	31	5.0	11.9	28	6.7	7.2
% Boulder cover	31	1.4	2.8	28	2.2	3.8
% Rock Cover	31	5.7	6.2	28	6.3	4.5
% Cobble Cover	31	8.4	5.7	28	10.2	6.7
% Gravel Cover	31	5.7	6.7	28	4.0	2.1
% Soil Cover	31	6.1	6.0	28	3.8	2.8
% Litter Cover	31	6.4	8.1	28	2.7	1.5
Species Richness	69	20.7	5.9	28	22.9	7.1
Shannon's Diversity Index	69	0.9	0.2	28	1.0	0.2
Cushenbury Milkvetch Density	69	5.4	30.2	28	1.4	1.2
Parish's Daisy Density	69	0.1	0.5	28	1.4	4.3
Cushenbury Buckwheat Density	69	0.0	0.0	28	49.3	45.0
Parish's Oxytheca Density	69	7.1	38.3	28	0.6	1.9

Table 8—Frequency and mean percentage cover values for overstory, shrub and bunchgrass species characteristic of Cushenbury buckwheat-centered plots and carbonate plots that did not support Cushenbury buckwheat. High fidelity and high constancy species are designated by “F” or “C,” respectively. Indicator species (I) are those with high fidelity, high constancy and a significant difference in mean percentage cover between the sample groups. For frequency, Cushenbury buckwheat plots n=28 and carbonate n= 69. For cover, Cushenbury buckwheat n=28 and carbonate n=31.

Species	Carbonate			Buckwheat-centered		
	Mean	SD	Freq	Mean	SD	Freq
Overstory Layer						
<i>Juniperus occidentalis</i> var. <i>australis</i>	2.0	5.2	5 ^F	0.0	0.0	0
<i>Juniperus osteosperma</i>	3.4	6.2	39 ^C	7.8	7.5	23 ^C
<i>Pinus monophylla</i>	18.9	13.2	63 ^C	17.3	9.4	28 ^C
<i>Yucca brevifolia</i>	0.9	2.0	28 ^C	1.1	1.4	15 ^C
Total Overstory Cover	26.2	17.5	—	28.5	14.5	—
Shrub Layer						
<i>Amelanchier utahensis</i>	0.4	1.2	9 ^F	0.0	0.0	0
<i>Arctostaphylos glauca</i>	3.9	8.8	13	2.4	5.4	7 ^C
<i>Artemisia tridentata</i>	2.2	4.4	26 ^C	1.4	3.2	11 ^C
<i>Cercocarpus ledifolius</i>	9.0	11.9	32 ^C	7.5	10.1	17 ^C
<i>Chrysothamnus nauseosus</i>	0.61	1.3	10	0.4	0.9	7 ^C
<i>Chrysothamnus viscidiflorus</i> ssp. <i>stenophilus</i>	3.0	3.4	48 ^C	4.6	4.5	27 ^C
<i>Coleogyne ramosissima</i>	1.4	6.4	7	2.2	5.5	7 ^C
<i>Echinocereus engelmannii</i>	0.05	0.1	13 ^F	0.02	0.1	1
<i>Echinocereus triglochidiatus</i> var. <i>mojavense</i>	0.1	0.3	14 ^C	0.3	0.5	8 ^C
<i>Ephedra viridis</i>	2.3	3.8	50 ^C	2.3	3.8	28 ^C
<i>Eriogonum microthecum</i> var. <i>corymbosoides</i>	1.3	2.7	28 ^C	0.8	1.0	14 ^C
<i>Eurotia lanata</i>	0.1	0.5	4 ^F	0.02	0.1	1
<i>Gutierrezia microcephala</i>	0.5	1.2	20 ^C	1.2	2.1	9 ^C
<i>Haplopappus linearifolius</i>	0.4	1.3	8 ^F	0.0	0.0	0
<i>Opuntia echinocarpa</i>	0.4	0.1	5 ^F	0.0	0.0	0
<i>Opuntia basilaris</i>	0.8	0.4	28 ^C	0.3	0.4	10 ^C
<i>Opuntia littoralis</i>	0.2	0.7	11 ^F	0.0	0.0	0
<i>Purshia glandulosa</i>	1.0	2.6	28 ^C	2.1	4.0	10 ^C
<i>Salazaria mexicana</i>	0.1	0.5	4 ^F	0.0	0.0	0
<i>Salvia pachyphylla</i>	0.5	1.2	14	0.8	1.9	8 ^C
<i>Yucca schidigera</i>	0.03	0.2	8	0.4	0.8	8 ^C
Total Shrub Cover	34.6	17.9	—	38.2	11.4	—
Bunchgrasses						
<i>Oryzopsis hymenoides</i>	0.5	0.8	36 ^C	0.5	0.7	12 ^C
<i>Poa fendleriana</i>	0.8	1.0	30 ^C	0.2	0.4	8 ^C
<i>Sitanion hystrix</i>	0.3	0.5	40 ^{C, F}	0.0	0.0	0
<i>Stipa coronata</i> ssp. <i>depauperata</i>	1.1	1.5	51 ^C	2.1	1.2	25 ^C
<i>Stipa speciosa</i>	0.2	0.5	25 ^C	0.5	1.1	9 ^C

Shockley’s rock cress; brickellbush, *Brickellia oblongifolia* and *Phacelia douglasii*, Tables 8 and 9). Only *Phacelia douglasii* had both high constancy and high fidelity. While their occurrences were characteristic of both substrate types, Utah juniper (U=234.5, p<0.01) and coronate needlegrass (U=216.5, p<0.001) had significantly higher mean percentage cover in Cushenbury buckwheat-centered plots.

Discussion

It is clear from our results that carbonate substrates in the San Bernardino Mountains support vegetation that is distinct from vegetation found on adjacent non-carbonate substrates. Thus, carbonate soils contribute substantially to the native floristic and vegetational biodiversity of this portion of the mountain range. In addition to the five

rare plant species that are endemic to carbonate, we found five indicator and 15 characteristic taxa for carbonate substrates as compared to non-carbonate substrates. A total of 48 species were entirely restricted to randomly located carbonate plots. An additional 14 species were restricted to carbonate substrate in either random carbonate, Cushenbury milkvetch-centered or Cushenbury buckwheat-centered plots. At the same time, 36% of the taxa found on non-carbonate soil did not occur on carbonate at all, resulting in an overall lower species richness on carbonate. While total species richness was lower on carbonate, mean species richness per plot was not different between the groups. This pattern indicates that generally species characteristic of carbonate occurred on that substrate with relatively high constancy. On the other hand, species characteristic of non-carbonate had high fidelity to the substrate but more often occurred with low frequency.

Table 9—Frequency of herbaceous species characteristic of Cushenbury buckwheat plots and carbonate plots that did not support Cushenbury buckwheat. High fidelity and high constancy species are designated by “f” or “c,” respectively.

Species	Carbonate n=69		Buckwheat-centered n=29	
	Frequency	Designation	Frequency	Designation
<i>Arenaria macradenia</i>	14		10	c
<i>Arabis pulchra</i>	36	c	12	c
<i>Arabis shockleyi</i>	14		13	c
<i>Brickellia oblongifolia</i>	11		6	c
<i>Castilleja chromosa</i>	29	c	16	c
<i>Caulanthus major</i>	10	c	10	c
<i>Cordylanthus nevini</i>	12	f	2	
<i>Cryptantha nevadensis</i>	8	f	1	
<i>Descurainia pinnata</i>	29	c,f	7	c
<i>Draba corrugata</i>	4	f	0	
<i>Erysimum capitatum</i>	5	f	1	
<i>Euphorbia albomarginata</i>	7	f	0	
<i>Gilia austro-occidentalis</i>	43	c	24	c
<i>Muilla maritima</i>	4	f	0	
<i>Penstemon eatonii</i>	19	c	11	c
<i>Phacelia douglasii</i>	0		11	c,f
<i>Phacelia fremontii</i>	34	c,f	7	c
<i>Phlox austromontanum</i>	24	c,f	6	
<i>Stephanomeria myrioclada</i>	7	f	1	
<i>Stephanomeria virgata</i>	5	f	1	

Because plots in each group did not differ in terms of elevation, northness or slope angle, vegetational and floristic differences are thought to most likely be related to the carbonaceous nature of the soil. Limestone and dolomite soils have long been recognized for supporting unique species assemblages (Kruckeberg 1969; Major and Bamberg 1963; Whittaker 1975, p. 275-276; Whittaker and Niering 1968), endemic species (Barbour and others 1993, p. 138; Raven 1988, p. 122; Kruckeberg 1969 and 1991), and disjunct occurrences of species that are common in other regions (Major and Bamberg 1963; Kruckeberg 1991). Species richness has also often been found to be lower on carbonate soils (Wentworth 1981; Kruckeberg 1969). Mechanisms resulting in these patterns are complicated and are not always clear. Parent material plays a large role in physical and chemical soil properties (Kruckeberg 1969; Barbour and others 1993). Soils derived from limestone are known to generally be poorly developed, alkaline in pH, deficient in available nutrients and to have decreased water holding capacity (Barbour and others 1993; Whittaker 1975, p. 275-276). Some have suggested that differences in ionic contents of soil solution and soil exchange complexes between carbonate and non-carbonate substrates influence species distributions (particularly iron, manganese, phosphorous and potassium; Kruckeberg 1991 and 1969; Hutchinson 1967; Grime and Hodgson 1968; Marchand 1973). Others have related vegetational differences to physical properties such as higher reflectance and thus lower surface temperatures on carbonate (Wright and Mooney 1965). Neely and Barkworth (1984), Wentworth (1981), Goldin (1976), Noy Meir (1973), and Whittaker and Niering (1968) found that carbonate

substrates were generally more exposed and xeric than non-carbonate substrates. The insular nature of carbonate outcroppings may also contribute to reduced species richness (Ashton 1992; Kruckeberg 1991). Determining the extent to which any of these mechanisms might be operating in our study area was beyond the scope of this study. Certainly the observed lower species richness is at least in part a result of the fact that a wider range of plant communities (for example riparian woodlands, yellow pine woodland and Great Basin sagebrush scrub) were sampled only on non-carbonate substrates. These communities supported many species that were found nowhere else in the study area. Additional sampling will reveal whether these communities are actually not found on carbonate substrates or whether they are just uncommon.

Cushenbury Milkvetch Habitat

Habitat occupied by Cushenbury milkvetch was generally similar to random sites on carbonate in terms of physical characteristics and dominant overstory and shrub layer species. Cushenbury milkvetch habitat did have higher percent calcium, shallower slope angles and less litter cover than carbonate sites that did not support this species. Occupied habitat was primarily distinguished by the lower frequency or absence of species generally found on carbonate, though a number of characteristic species were identified. It is interesting to note that Cushenbury buckwheat and Cushenbury milkvetch co-occurred only infrequently, and thus primarily occupied different microsites. Parish's daisy and Parish's oxytheca also rarely occurred with Cushenbury milkvetch, indicating different habitat requirements for these taxa.

Cushenbury Buckwheat Habitat

Occupied Cushenbury buckwheat habitat was also basically similar to random carbonate sites, differing physically only by having higher percent calcium in the soil and also higher surface exposure of rock outcrop. Dominant species were primarily similar. For both of these rare species, sampling may have been too coarse to detect microhabitat characteristics. Parish's daisy and Parish's oxytheca also rarely occurred with Cushenbury buckwheat, indicating different habitat requirements for these taxa.

Restoration Implications

The results presented above provide baseline data on environmental and vegetational characteristics of carbonate substrate, non-carbonate substrate, Cushenbury milkvetch habitat and Cushenbury buckwheat habitat. These parameters may be ecologically important to the rare species and to the functioning of the ecosystem as a whole. Replication of these characteristics in a revegetation program would thus be essential to returning ecosystem functions to a site. While our results may be used as broad scale restoration guidelines, there was sufficient environmental heterogeneity within the study area to warrant more detailed sampling. Such sampling could entail site specific studies detailing microhabitat characteristics to be restored. Alternatively, success criteria could be made more specific by developing a plant community classification and establishing criteria for each community. Such a classification will be developed once data collection is completed throughout the range of carbonate soils. Environmental features and characteristic and indicator species will be determined for each recognized community and this will refine knowledge of baseline species occurrences and percentage cover. We will then compare these data with data from site specific sampling to determine their application to individual sites or conditions. Even if site specific sampling remains a necessity, this data set will provide a framework for understanding how the vegetation of a particular site fits into that found in the whole range of carbonate substrate.

Notwithstanding the environmental heterogeneity, our results have several immediate applications, especially in terms of soil texture and chemistry characteristics. Assume you are restoring a limestone quarry and want to return species characteristic of carbonate soils to that site. You would need to apply topsoil that had a pH between 5.7 and 6.3 and a calcium content of between 7% and 25% (Table 1). Clearly based on the evidence presented here, application of a non-carbonate soil would be inappropriate. If you were specifically restoring Cushenbury milkvetch or Cushenbury buckwheat habitat you would want an even higher percentage of calcium in the soil, though the pH of general carbonate is adequate. The significantly higher pH in the three groups on carbonate substrates has implications for addition of soil amendments or mulches that would acidify the soil. Similarly, the relatively low percentage cover of litter found in these areas indicates that heavy mulching or other addition of organic matter to the soil would not likely be appropriate.

Based on our results, species used in revegetation efforts would also vary greatly depending on whether carbonate or non-carbonate areas were being revegetated. However, because of the heterogeneity discussed above, it is not possible to directly develop vegetation success criteria from the data presented here.

Attempting to develop success criteria from the existing mine revegetation standards (USFS 1991) has uncovered several shortcomings in the existing standards. First the species richness requirement of 15% of the predisturbance species richness is vague and is a low percentage. There is no stipulation for the area that needs to be included in sampling or surveying for species richness. This point is critical as species richness is known to vary greatly with the area sampled (Magurran 1988). For example, assume you are going to develop success criteria for revegetation of an old limestone quarry. If you used the total richness we found on carbonate (189 species) as the pre-disturbance guideline for reclaiming the quarry, 28 species would need to be planted. Clearly though, not all 189 species that occurred on carbonate substrates would occur on any one site. Thus total richness for carbonate represents an inflated richness measure for this purpose. Alternatively if you used the mean species richness per 0.04 hectare plot as the standard (20.5 species), only three species would meet the standard. Clearly, meeting the standard in this case would result in a very depauperate site. Granted these examples are extremes, but they illustrate the wide range of potential outcomes that would meet the letter of the reclamation standards as they are written now. An additional problem stems from the fact that there is no provision for which species are used to meet the species richness, cover or density standards. In general it would be preferable to focus on characteristic or indicator species as such taxa are likely to be more important in ecosystem functioning due to their higher cover and abundance in the ecosystem. An exception to this generality would be maintaining biodiversity through inclusion of any species that were found on a site that were not common elsewhere in the range.

Several recommendations can be made to improve the existing mine revegetation standards (USFS 1991). Adopting the following changes would greatly strengthen the standards and improve their utility in restoring ecosystems disturbed by mining in the San Bernardino Mountains.

- 1) Pre-disturbance species richness will be determined in one of two ways. If the site is small enough, a complete floristic survey will be conducted by a qualified botanist at times of year when all taxa can be properly identified. For larger sites that cannot feasibly be completely surveyed, sampling will be acceptable. Samples will be 0.04 hectare, circular plots. A sufficient number will be sampled such that when successive plots are sampled, species richness is not increased by more than 2%.
- 2) All overstory species will be represented in approximately the same proportion of density and cover as they occur naturally. Cover will be returned to 50% of the pre-disturbance overstory cover. Densities will be equal to the pre-disturbance densities.

- 3) 25% of the pre-disturbance shrub species will be returned to a site in approximately the same proportion of cover as they occur naturally. Priority in species selection will be placed on species characteristic of the habitat that was disturbed. Total shrub cover will be at least 50% of pre-disturbance cover.
- 4) 15% of the herb species will be returned to the site. Priority in species selection will be placed on species characteristic of the habitat that was disturbed.

Summary and Conclusions

In summary, documentation of natural vegetation and associated environmental characteristics is critical for setting restoration or revegetation success criteria. Such criteria are especially important where specialized edaphic conditions support unique vegetation or rare species. Even with such criteria, the difficulty of replicating unique edaphic conditions, the arid climate of the region and the unsuitability of post-mining conditions for revegetation make potential for successful restoration low and potential for great expense high. This limited restoration potential illustrates the importance of conserving intact ecosystems, especially those that support the proposed endangered plant species.

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