

DISTRIBUTION OF HANGING GARDEN VEGETATION ASSOCIATIONS ON THE COLORADO PLATEAU, USA

James F. Fowler¹

USDA Forest Service
Rocky Mountain Research Station
2500 South Pine Knoll Drive
Flagstaff, Arizona 86001, U.S.A.

N.L. Stanton

Department of Zoology and Physiology
University of Wyoming
Laramie, Wyoming 82071-3265, U.S.A.

Ronald L. Hartman

Rocky Mountain Herbarium
Department of Botany
University of Wyoming
Laramie, Wyoming 82071-3265, U.S.A.

ABSTRACT

Hanging gardens are island-like habitats dominated by mesophytic-hydrophytic plant communities, growing on seeps on the xeric canyon walls of the Colorado Plateau in the American West. We measured the abundance of species and physical microhabitat characteristics of 73 individual hanging gardens during the growing seasons of 1991–1993. Cluster analysis of a simplified Morisita community similarity index matrix produced four distinct clusters of herbaceous vegetation: *Adiantum capillus-veneris*, *Aquilegia micrantha*, *Calamagrostis scopulorum*, and *Cirsium rydbergii* Herbaceous Associations. These associations are based on species abundance and are floristically described via summary tables showing dominance, constancy, and presence of hanging-garden endemic species. Univariate comparisons of species richness, hanging garden size, and dominance show that the *A. capillus-veneris* and *A. micrantha* associations tend to be smaller, less species rich, and have higher dominance values than the *C. scopulorum* and *C. rydbergii* associations. Two associations were dominated by species endemic to hanging gardens: *Aquilegia micrantha* and *Cirsium rydbergii*. These four hanging garden associations contrast with previous local vegetation surveys which place all hanging garden communities into one vegetation type despite the lack of a common dominant or constant species.

RESUMEN

Los jardines colgantes son hábitats como islas dominados por comunidades de plantas mesófitas-hidrófitas, que crecen en las filtraciones de las paredes secas de los cañones de la Meseta de Colorado en el oeste de los Estados Unidos. Medimos la abundancia de especies y características físicas del microhábitat de 73 jardines colgantes individuales durante las épocas de crecimiento de 1991–1993. El cluster análisis de una matriz simplificada del índice de similitud de la comunidad de Morisita produjo cuatro grupos distintos de vegetación herbácea asociada: *Adiantum Capillus-veneris*, *Aquilegia micrantha*, *Calamagrostis scopulorum*, y *Cirsium rydbergii*. Estas asociaciones se basan en la abundancia de las especies y son descritos florísticamente en una tabla que muestra la dominancia, la constancia, y la presencia de las especies endémicas en los jardines colgantes. Las comparaciones univariantes de la riqueza de especies, el tamaño del jardín colgante y su dominancia muestran que las asociaciones de *A. capillus-veneris* y de *A. micrantha* tienden ser más pequeñas, menos ricas en especies, y tienen valores más altos en la dominancia que las asociaciones de *Calamagrostis scopulorum* y de *Cirsium rydbergii*. Dos asociaciones están dominadas por especies endémicas de los jardines colgantes: *Aquilegia micrantha* y *Cirsium rydbergii*. Estas cuatro asociaciones de jardines colgantes contrastan con los estudios locales previos de vegetación que colocan todas comunidades del jardines colgantes en un solo tipo de vegetación a pesar de la falta de una especie común, dominante o constante.

The lush plant growth of hanging gardens on canyon walls in the entrenched drainage system of the Colorado Plateau attracted the attention of early botanists and pioneers (Welsh & Toft 1981). Powell (1895), the first scientific explorer of the Colorado River canyon, noted the “oak glens,” ferns and mosses on moistened sandstone, and rich vegetation associated with seeps “in marked contrast to the general appearance of naked rock” within what is now Glen Canyon NRA (Fig. 1). Many subsequent visitors have noted the island-like boundary between hanging gardens and their xeric canyon-wall surroundings (Woodbury 1933; Malanson & Kay 1980; Welsh 1989). The microclimate of the larger hanging gardens often contrasts sharply with the surrounding high desert: water is abundant, soils are moist, and canyon walls offer periodic shade (Malanson 1980; Welsh & Toft 1981). Hanging gardens are also relatively small, mostly less than one hectare, further contributing to the island-like effect, visually similar to the inselberg (granitic and gneissic rock outcrop) communities found in North and South America, Africa, and Australia (Barthlott & Porembski 2000). However, in contrast to the much better studied inselberg systems (Grogger & Barthlett 1996; Porembski et

¹Correspondence: James F. Fowler, USDA Forest Service, Rocky Mountain Research Station, Southwest Forest Science Complex, 2500 S. Pine Knoll Drive, Flagstaff, Arizona 86001, U.S.A.; jffowler@fs.fed.us

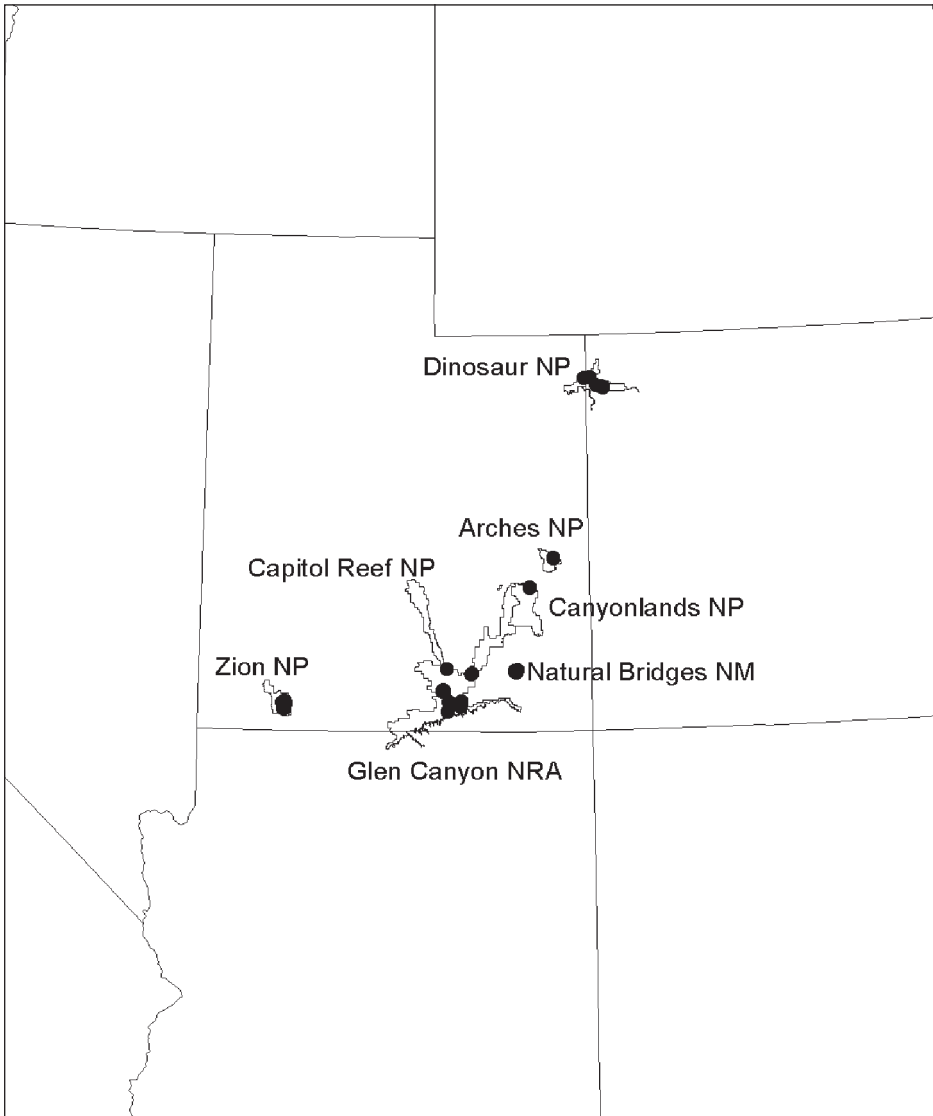


FIG. 1. Study areas and locations of hanging garden plant communities sampled on the Colorado Plateau during the summers of 1991–1993.

al. 1996; Sarthou & Villers 1998), hanging gardens are moist vegetation islands rather than xeric vegetation islands (Szarzynski 2000) embedded within bedrock expanses.

Hanging gardens are dominated by mesophytic and hydrophytic herbaceous vegetation (Malanson 1980; Welsh & Toft 1981; Welsh 1989) which develops at and downslope from ground-water seepage zones within the exposed aquifer along crossbedded sandstone canyon walls. Ground-water “sapping” erosion processes (Higgins 1984; Laity & Malin 1985; Baker 1990; Dunne 1990; May et al. 1995) produce the physical hanging garden habitat: perennially wet rock walls and/or wet, subirrigated colluvial soils (May et al. 1995). They are often located in wet theater-headed valleys formed “by weakening or removal of basal support as a result of enhanced weathering and erosion” by water seepage (Laity & Malin 1985, p. 203). These diffuse-discharge,

seepage erosion areas are the result of ground water moving through highly transmissive aquifers, down the dip planes to where impermeable layers within or below an aquifer intersect a canyon wall, as well as along deep fractures within the aquifer (Laity & Malin 1985; Dunne 1990; May et al. 1995), and are distinctly different from point-source erosion processes caused by discharge at springs (Higgins 1984). Ground-water sapping processes provide both the raw material for colluvial soil development and water for subirrigation of vegetation growing on that habitat.

Floristic work has elucidated the flora associated with hanging garden habitats (Eastwood, 1896; Clover & Jotter 1944; Harrison et al. 1964; Welsh & Moore 1968; Welsh 1986a, b; Shultz et al. 1987; Welsh 1989), including several species endemic to hanging gardens (Harrison et al. 1964; Welsh 1989; Fowler et al. 1995; Welsh et al. 2003). Microhabitat affinities for several hanging garden plant species have also been described (Welsh & Toft 1981; Welsh 1989).

Woodbury (1933), Welsh and Toft (1981), and May et al. (1995) have proposed hanging garden classification systems based on microhabitats and geomorphology. Woodbury (1933) briefly described hanging garden seral associates in Zion NP as part of a park-wide vegetation classification monograph. Malanson (1980, 1982) and Malanson and Kay (1980) measured frequency of species occurrence, species richness, and calculated similarity indices to investigate the effects of flooding frequency, dispersal distance, plant dispersal types, and physical habitat characteristics on species assemblages in 29 small hanging gardens in Zion NP. These studies did not measure species abundance or take a phytosociological approach. In this study, we measured canopy coverage for each vascular plant species on 73 hanging gardens in a regional study, classified them into herbaceous associations, and examined the regional distribution of those associations.

STUDY AREA

The study area was located on the Colorado Plateau in Utah and Colorado (Fig. 1), a major portion of the known geographic range of hanging gardens. Field work was conducted on hanging gardens at seven National Park Service units during the summers of 1991–1993: Arches NP, Canyonlands NP, Capitol Reef NP, Dinosaur NP, Glen Canyon NRA, Natural Bridges NM, and Zion NP (Fig. 1). We selected most of the larger, known hanging gardens in each park unit and many smaller ones that we were able to locate. Hanging gardens that were too small to use the vegetation sampling methods described below were excluded from this study.

METHODS

We defined hanging garden habitats as predominately herbaceous vegetation growing on permanently wet soil and wet rock surfaces, originating from seeps on canyon walls in sandstone aquifers (Malanson & Kay 1980). Hanging gardens were delineated from the surrounding bedrock and xeric soils by the presence of wet rock surfaces and/or wet soils (May et al. 1995). The hanging garden boundary with a riparian community, when present, was defined by where colluvial soils stop and alluvial soils begin (May et al. 1995).

Each hanging garden was visually separated into the following microhabitats: seepline, wet wall, ledge, and wet colluvial soil to stratify vegetation sampling. Seeplines are drier, linear microhabitats that develop at fractures in the sandstone or, more often, at horizontal impervious bedding planes on canyon walls and at the back of small alcoves. Wet walls included inverted, vertical, or sloping rock surfaces below seeps that moisten the sandstone surface or have sufficient discharge to produce thin sheet flows of water with occasional drip points. Ledge microhabitats are of sufficient horizontal width to support strips of hydrophytic vegetation in depressions with wet, saturated soil. Wet colluvial soil microhabitats are complex in shape and composed of wet, subirrigated colluvial soils located downslope of seepage zones, sometimes within and/or below a larger alcove created by groundwater sapping. Since these soils develop directly from the weathering of sandstone, they are obviously very sandy and may be virtually saturated near seeps.

We collected data on the following physical parameters: length of major axis, aspect, elevation, map location, and geologic formation. Hanging garden size was calculated from major axis length and the mean of ten equally spaced widths taken during vegetation sampling.

Vegetation

On each hanging garden, the herbaceous, vascular plant vegetation stratum was systematically sampled (Cochran 1977; Krebs 1989) using 20 × 50 cm quadrats and six cover classes to estimate canopy cover for each species (Daubenmire 1959) in each microhabitat. Woody plants less than two m tall were included in the herbaceous stratum canopy estimates; the few occurrences of isolated trees were not included. The major axis of each microhabitat was divided into ten equal segments. Widths were measured beginning with a random starting point along the initial segment and at subsequent equal-segment lengths. A random point was chosen along each width to determine placement of the lower left corner of the sampling frame (20 cm side). Edge quadrats were proportionally weighted to include only the portion within the hanging garden. Total floristic composition (Daubenmire 1959, 1961), vascular plants only, was recorded during canopy cover sampling and during an additional visual search (approximately one hr) on each hanging garden. Voucher specimens for each species were collected. These were identified by B. E. Nelson, Herbarium Manager and R. L. Hartman, Curator of the Rocky Mountain Herbarium at the University of Wyoming and are deposited there and at the respective parks. Vascular plant nomenclature follows Flora of North America Editorial Committee (1993+) and Welsh et al. (2003) in that order of priority.

Floristics of each herbaceous association are described in summary stand tables by floristic criteria (Meuller-Dombois & Ellenberg 2002) and follow the definitions and analysis techniques of the U. S. National Vegetation Classification (ESA 2006). Diagnostic classes for this study were dominance determined by absolute canopy cover (Daubenmire 1959), constancy (frequency of occurrence) (Daubenmire 1952; Meuller-Dombois & Ellenberg 2002), and endemism.

Indices

Plant community diversity (heterogeneity) was measured as two separate components (Krebs 1989): species richness (McIntosh 1967) and dominance. Dominance in a community was determined by the proportion $d = N_{\text{Max}}/N_{\text{T}}$ (Berger & Parker 1970) where N_{Max} = number of individuals in the most abundant population and N_{T} = the total number of individuals in the community. Canopy coverage estimates were used as $N_{\text{Max}}/N_{\text{T}}$ since both are proportional measures of species community importance.

Classification of hanging garden vegetation was based on cluster analysis of simplified Morisita (Horn 1966) community similarity indices for 73 hanging gardens calculated from species-level canopy coverage estimates of existing vegetation. An exception is the genus *Carex*. Our canopy coverage estimates for six species in this genus were combined since consistent, vegetative separation of species was not possible. These indices were placed in a community similarity matrix for cluster analysis in SYSTAT 9 (SYSTAT 1999a) using the complete linkage method (farthest neighbor) on maximum Euclidean distances between indices.

Statistics

Statistical analyses were performed with SYSTAT 9 (1999a). Plant species richness, species dominance, and hanging garden size data were analyzed by General Linear Model ANOVA. Dominance and hanging garden size were log transformed (SYSTAT 1999b) to achieve normal distributions prior to ANOVA tests. Homogeneity of variances was checked post hoc and Tukey HSD tests were used for pairwise comparisons of ANOVA results to detect significant differences between vegetation associations.

The statistical association between geologic formation and the putative herbaceous associations was described using the Pearson Chi-square goodness-of-fit test to detect the presence of an association (Loether & McTavish 1976; Wilkinson et al. 1996), and a proportional reduction in error measure (PRE), Goodman-Kruskal's lambda, to measure the strength of statistical association (Wilkinson et al. 1996). PRE statistics describe how much error is reduced in predicting the column variable when the row variable is known for association tables (Wilkinson et al. 1996).

RESULTS

Vegetation Classification

Species lists with abundance estimates for species are in Appendix I. Cluster analysis of the simplified

Morisita community similarity index (Krebs 1989) matrix classified the 73 hanging garden vascular plant communities into four associations plus one dissimilar cluster (Fig. 2): *Adiantum capillus-veneris*, *Aquilegia micrantha*, *Calamagrostis scopulorum*, and *Cirsium rydbergii* Herbaceous Associations. Euclidian distance classification thresholds (Fig. 2) ranged from 1.03 for separating the *Cirsium rydbergii* Herbaceous Association from the dissimilar group to 1.31 for separating the *C. rydbergii* and the *Adiantum capillus-veneris* Herbaceous Associations. The dissimilar cluster (n=11) had hanging garden communities with little similarity within the cluster (mean similarity index of 0.069) and had no plant species consistently in common.

The distribution of the four herbaceous associations across the seven geologic formations was different than expected by chance alone ($p=0.0098$), the lambda statistic indicating a 25% improvement in being able to predict the herbaceous association when the geologic formation is known (Table 1). The *A. micrantha* and *C. scopulorum* Herbaceous Associations were widespread on the Colorado Plateau (Table 1). Both were found in five parks and five sandstone geologic formations, differing in only one park and one geologic formation; the *C. scopulorum* Herbaceous Association was found on the Humbug formation omitted from Table 1. The *C. rydbergii* Herbaceous Association was found only in the central part of the Colorado Plateau: two parks and three formations (Table 1). The *A. capillus-veneris* Herbaceous Association was found on the same geologic formation as the *C. rydbergii* Herbaceous Association but was more widespread (Table 1). The *A. capillus-veneris* and *C. rydbergii* Herbaceous Associations were notably absent from the Cedar Mesa and Weber formations, which were found only in our Natural Bridges NM and Dinosaur NP study sites respectively. However, there were significant, positive statistical associations between geologic formations and herbaceous associations (Table 1). The strongest ones being between the *A. micrantha* Herbaceous Association and the Weber formation and between the *C. rydbergii* Herbaceous Association and the Navajo formation.

***Adiantum capillus-veneris* Herbaceous Association**

Floristics of the *Adiantum capillus-veneris* Herbaceous Association are defined in Table 2. The dominant species in this association was *Adiantum capillus-veneris* which covered from 32–93% of the herbaceous canopy in the 11 hanging gardens classified here (Fig. 2). Pairwise simplified Morisita community similarity indices ranged from 0.48 to 0.99. Both *A. capillus-veneris* and *Epipactis gigantea* had high constancy. *Adiantum capillus-veneris* was found in seep line and wet wall microhabitats, whereas *E. gigantea* was found in seep line microhabitats and on the upper portion of wet soil microhabitats next to vertical canyon walls with wetter seep lines. *Epipactis gigantea* and the Genus *Carex* also had high canopy cover on some hanging gardens. The vegetation was dominated by ferns, forbs, and graminoids (Table 2), but woody plants were occasionally present as isolated individuals or at the drier edges of the wet soil/rock habitats characteristic of hanging gardens.

Species diversity was relatively low in this association as shown by high dominance values, a measure of community evenness, as well as low species richness (Table 3). Dominance values were significantly higher than in *Calamagrostis scopulorum* and *Cirsium rydbergii* Herbaceous Associations (ANOVA $F = 5.02$, $p = 0.0036$; Tukey HSD $p = 0.0167$ and 0.044 respectively). Five species endemic to hanging gardens were found in this association (Table 2). The overall size of hanging gardens with this association was comparatively small (Table 3), significantly smaller than hanging gardens in the *Cirsium rydbergii* and *Calamagrostis scopulorum* Herbaceous Associations (see below) (ANOVA $F = 7.21$, $p = 0.0003$; Tukey HSD $p = 0.0003$ and 0.0266 respectively).

***Aquilegia micrantha* Herbaceous Association**

The *Aquilegia micrantha* Herbaceous Association was dominated by the hanging garden endemic *A. micrantha*, a constant species with an average canopy cover of 29% (Table 4). *Aquilegia micrantha* predominately grew on wet colluvial soil microhabitats. *Calamagrostis scopulorum* was also a constant species in this herbaceous association, but with less than 5% average cover. Pairwise simplified Morisita community similarity indices ranged from 0.28 to 1.00 for this association. With the exception of small *Pinus edulis* plants, which occurred in trace amounts of cover on 47% of these hanging gardens, woody plants rarely occurred (Table 4).

In addition to *A. micrantha*, four other hanging garden endemic species were found on these sites, but

TABLE 1. Percentage of hanging garden vegetation associations found on each of five geologic formations (row percentages). Pearson Chi Square ($X^2 = 34.8798$, $p = 0.0098$) and Goodman-Kruskal's lambda ($\lambda = 0.2564$ PRE) statistics indicate the existence and strength of statistical association respectively. Positive "+" and negative "-" indicate the statistical association between a geologic formation and a vegetation association. Cell Chi Square contributions are shown below cell percentages for each row followed by two letter park codes (shown in Fig. 2) to indicate geographic distribution. Observed geologic formations are Jurassic Entrada sandstone, Jurassic Navajo sandstone, Jurassic Navajo sandstone/Jurassic Kayenta formation contact zone, Permian Cedar Mesa sandstone, Pennsylvanian-Permian Weber sandstone. Vegetation associations are Adca, *Adiantum capillus-veneris*; Aqmi, *Aquilegia micrantha*; Casc, *Calamagrostis scopulorum*; Ciry, *Cirsium rydbergii*. N = 60, note that 2 geologic formations with only 1 hanging garden each were omitted from this table.

Geologic Formation	Herbaceous Vegetation Association			
	Adca	Aqmi	Casc	Ciry
Entrada n = 7	n = 11 29% 0.4002 AR	n = 17 43% 0.5211 AR	n = 19 0% - 2.4500 AR	n = 11 29% 0.4002
Navajo n = 17	35% + 2.6675 CR, GC, ZI	6% - 3.0243 GC	18% 1.4626 GC, ZI	41% + 4.8386 GC
Navajo/Kayenta n = 17	18% 0.0044 GC, ZI	18% 0.6852 CL, GC	53% 1.5634 CL, ZI	12% 0.4001 GC
Cedar Mesa n = 8	0% 1.4667	50% 1.3255 NB	50% 0.5143 NB	0% 1.4667
Weber n = 9	0% 1.6500	67% + 4.6676 DI	33% 0.0071 DI	0% 1.6500

at lower constancy (Table 4). This association was significantly less species rich than the *C. scopulorum* and *C. rydbergii* Herbaceous Associations (see below) (ANOVA $F = 3.79$, $p = 0.015$; Tukey HSD $p = 0.0248$ and 0.0372 respectively). Dominance values averaged 0.59, not significantly different than the other three associations (Table 3). Hanging gardens in this association were also significantly smaller in average size than hanging gardens classified in the *C. rydbergii* association (see below) (ANOVA $F = 7.21$, $p = 0.0003$; Tukey HSD $p = 0.0009$, Table 3).

***Calamagrostis scopulorum* Herbaceous Association**

Floristics of the *Calamagrostis scopulorum* Herbaceous Association are defined in Table 5. As the dominant species, *C. scopulorum* had an average cover of 31% and a range of 13–66% (Table 5). *Calamagrostis scopulorum* grew in larger clumps on wet colluvial soil microhabitats and as smaller patches on seep line and wet wall microhabitats. Several *Carex* species also occurred in these hanging gardens (Table 5). The hanging garden endemic *A. micrantha* was moderately constant and ranged up to 11% total cover. Simplified Morista community similarity indices ranged from 0.27 to 0.99 among the 23 hanging gardens classified into this association.

Species diversity in this association was relatively high as shown by high species richness and low dominance (Table 3). This association was significantly richer than the *A. micrantha* Herbaceous Association (ANOVA $F = 3.79$, $p = 0.0003$; Tukey HSD $p = 0.0248$), and its dominance values were significantly lower than the *A. capillus-veneris* Herbaceous Association (ANOVA $F = 5.02$, $p = 0.0036$; Tukey HSD $p = 0.0167$). Three hanging garden endemic taxa were found on the 23 hanging gardens classified in this association (Table 5). The *C. scopulorum* Herbaceous Association tended to contain large hanging gardens (Table 3), significantly larger than hanging gardens in the *A. capillus-veneris* Herbaceous Association (ANOVA $F = 7.21$, $p = 0.0003$; Tukey HSD $p = 0.027$).

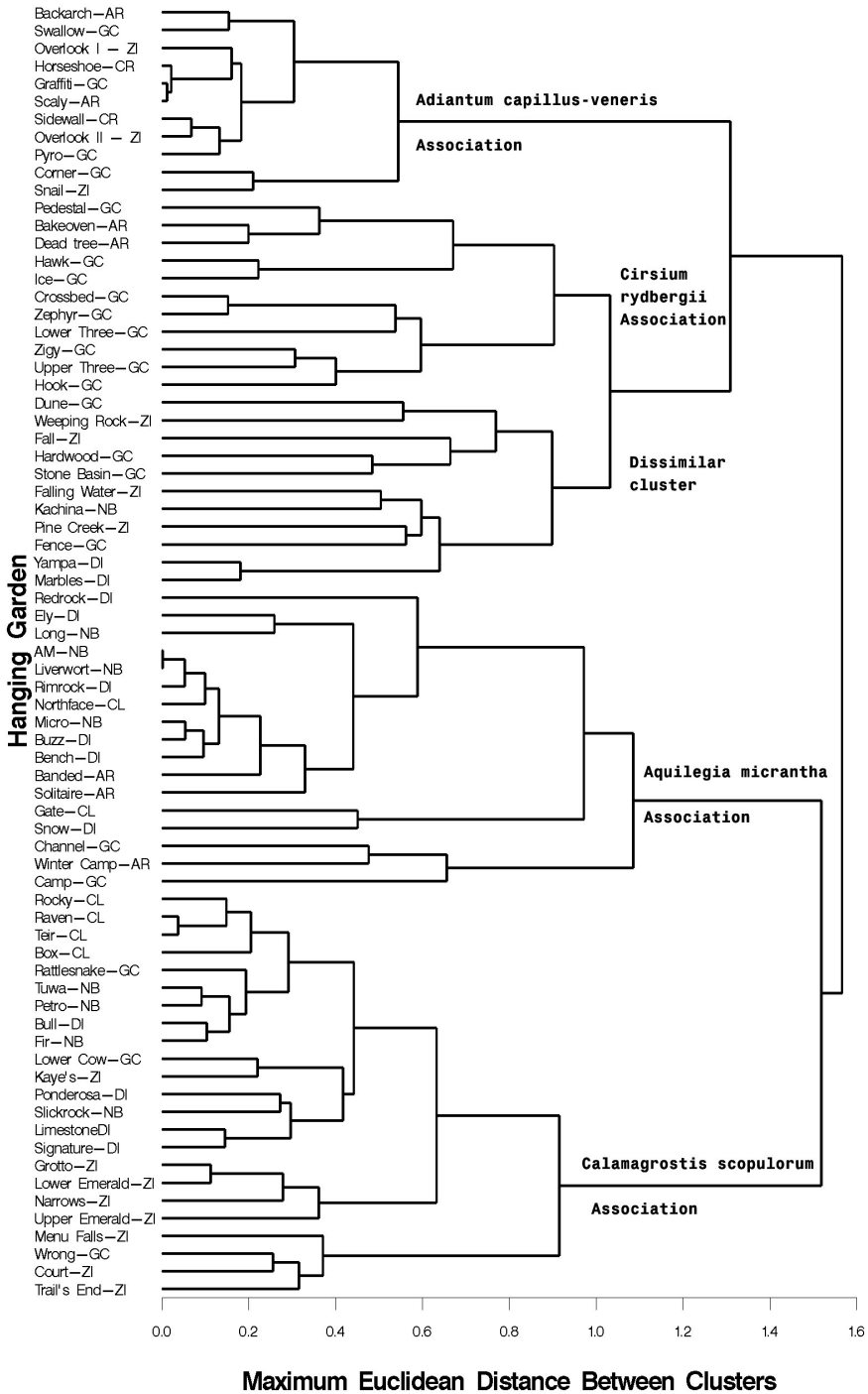


FIG. 2. Cluster tree showing four hanging garden herbaceous vegetation associations and a dissimilar cluster based on cluster analysis of simplified Moristia community similarity indices. Names refer to 73 individual hanging garden plant communities. Two letter codes following hanging garden names refer to individual parks: AR = Arches (NP); CL = Canyonlands (NP); GC = Glen Canyon (NRA); ZI = Zion (NP); CR = Capitol Reef (NP); NB = Natural Bridges (NM); DI = Dinosaur (NP).

TABLE 2. Stand table for the *Adiantum capillus-veneris* Herbaceous Association showing canopy cover, diagnostic classes, and constancy for all species with a constancy ≥ 0.40 and/or species endemic to hanging gardens. Constant species are defined as constancy ≥ 0.60 , and "t" is defined as less than 0.5 % canopy cover. N = 11.

Species	Diagnostic class	Constancy	Average % cover	Minimum % cover	Maximum % cover
<i>Adiantum capillus-veneris</i>	dominant, constant	1.00	57	32	93
<i>Epipactis gigantea</i>	constant	0.82	2	0	16
<i>Aquilegia micrantha</i>	endemic	0.27	1	0	8
<i>Cirsium rydbergii</i>	endemic	0.36	2	0	8
<i>Mimulus eastwoodiae</i>	endemic	0.55	t	0	2
<i>Primula specuicola</i>	endemic	0.27	t	0	2
<i>Zigadenus vaginatus</i>	endemic	0.09	t	0	t
<i>Carex</i> sp.		0.45	3	0	18
<i>Petrophytum caespitosum</i>		0.45	t	0	2

TABLE 3. Mean values (± 1 SE) for hanging garden size, species richness, and dominance of four hanging garden herbaceous associations. Also shown are number of sites (N) and number of hanging garden endemic plants species found (HGE) in each association. Values followed by the same letter within each column do not differ at $P < 0.05$ in Tukey's HSD *post hoc* tests.

Hanging garden vegetation association	Size m ²	Species Richness	Dominance	N	HGE
<i>Adiantum capillus-veneris</i>	68 \pm 20 ^a	14 \pm 2 ^{ab}	0.71 \pm 0.05 ^a	11	5
<i>Aquilegia micrantha</i>	167 \pm 45 ^{ab}	12 \pm 1 ^a	0.59 \pm 0.06 ^{ab}	17	5
<i>Calamagrostis scopulorum</i>	314 \pm 80 ^{bc}	18 \pm 2 ^b	0.48 \pm 0.04 ^b	23	3
<i>Cirsium rydbergii</i>	587 \pm 168 ^c	18 \pm 2 ^b	0.41 \pm 0.03 ^b	11	5

TABLE 4. Stand table for the *Aquilegia micrantha* Herbaceous Association showing canopy cover, diagnostic classes, and constancy for all species with a constancy ≥ 0.40 and/or species endemic to hanging gardens. Constant species are defined as constancy ≥ 0.60 , and "t" is defined as less than 0.5 % canopy cover. N = 17.

Species	Diagnostic class	Constancy	Average % cover	Minimum % cover	Maximum % cover
<i>Aquilegia micrantha</i> endemic	dominant, constant,	1.00	29	9	54
<i>Calamagrostis scopulorum</i>	Constant	0.82	4	0	32
<i>Cirsium rydbergii</i>	Endemic	0.24	1	0	8
<i>Mimulus eastwoodiae</i>	Endemic	0.35	1	0	11
<i>Primula specuicola</i>	Endemic	0.24	t	0	2
<i>Zigadenus vaginatus</i>	Endemic	0.35	2	0	19
<i>Carex</i> sp.		0.41	2	0	10
<i>Pinus edulis</i>		0.47	t	0	t

Cirsium rydbergii Herbaceous Association

The hanging garden endemic *Cirsium rydbergii* dominated this association with an average of 23% canopy coverage (Table 6). These hanging gardens also had nine additional constant species (Table 6). Two of these were co-dominants, *A. capillus-veneris* and *Schyzacharium scoparium*, and three were endemic to hanging garden habitats: *A. micrantha*, *Mimulus eastwoodiae*, and *Primula specuicola*. One additional hanging garden endemic species was also found at low constancy in these hanging gardens: *Zigadenus vaginatus*. *Cirsium rydbergii* and *A. micrantha* were found throughout the wet colluvial soil microhabitat and *Z. vaginatus* was often

TABLE 5. Stand table for the *Calamagrostis scopulorum* Herbaceous Association showing canopy cover, diagnostic classes, and constancy for all species with a constancy ≥ 0.40 and/or species endemic to hanging gardens. Constant species are defined as constancy ≥ 0.60 , and "t" is defined as less than 0.5 % canopy cover. N = 23.

	Diagnostic class	Constancy	Average % cover	Minimum % cover	Maximum % cover
<i>Calamagrostis scopulorum</i>	dominant	1.00	31	13	66
<i>Carex</i> sp.	constant	0.65	3	0	20
<i>Aquilegia micrantha</i>	endemic	0.43	2	0	11
<i>Zigadenus vaginatus</i>	endemic	0.22	1	0	14
<i>Mimulus eastwoodiae</i>	endemic	0.22	t	0	t
<i>Adiantum capillus-veneris</i>		0.57	4	0	30
<i>Epipactis gigantea</i>		0.48	1	0	16
<i>Maianthemum stellatum</i>		0.57	3	0	20
<i>Toxicodendron rydbergii</i>		0.48	t	0	11

TABLE 6. Stand table for the *Cirsium rydbergii* Herbaceous Association showing canopy cover, diagnostic classes, and constancy for all species with a constancy ≥ 0.40 and/or species endemic to hanging gardens. Constant species are defined as constancy ≥ 0.60 , and "t" is defined as less than 0.5 % canopy cover. N = 11.

Species	Diagnostic class	Constancy	Average % cover	Minimum % cover	Maximum % cover
<i>Cirsium rydbergii</i>	dominant, constant, endemic	1.00	23	1	48
<i>Adiantum capillus-veneris</i>	co-dominant, constant	0.91	10	0	23
<i>Schizachyrium scoparium</i>	co-dominant, constant	0.64	15	0	50
<i>Carex</i> sp.	constant	0.91	7	0	19
<i>Aquilegia micrantha</i>	constant, endemic	0.82	3	0	14
<i>Primula specuicola</i>	constant, endemic	0.91	1	0	3
<i>Mimulus eastwoodiae</i>	constant, endemic	0.64	3	0	8
<i>Calamagrostis scopulorum</i>	constant	0.64	2	0	13
<i>Petrophytum caespitosum</i>	constant	0.64	2	0	12
<i>Epipactis gigantea</i>	constant	0.73	1	0	5
<i>Zigadenus vaginatus</i>	endemic	0.27	1	0	13
<i>Castilleja linearifolia</i>		0.45	t	0	2
<i>Dichanthelium acuminatum</i>		0.55	4	0	26

found in the upper portions of the wet colluvial soil microhabitat next to canyon walls. *Mimulus eastwoodiae* and *P. specuicola* were often attached directly to vertical or inverted, wet rock surfaces. Simplified Morisita community similarity indices ranged from 0.06 to 0.90 among the 11 hanging gardens in this association.

Species richness was relatively high (Table 3), significantly higher than in the *A. micrantha* Herbaceous Association (ANOVA $F = 3.79$ $p = 0.015$; Tukey HSD $p = 0.0372$). Dominance values were low (Table 3), significantly lower than in the *A. capillus-veneris* Herbaceous Association (ANOVA $F = 5.02$, $p = 0.0036$, Tukey HSD $p = 0.0044$). Similar to the *C. scopulorum* Herbaceous Association, this association occurred on large hanging gardens; the average size was significantly larger than in the *A. capillus-veneris* and *A. micrantha* Herbaceous Associations (ANOVA $F = 7.21$, $p = 0.0003$; Tukey HSD $p = 0.0003$ and 0.0009 respectively).

DISCUSSION

The *A. capillus-veneris* and *A. micrantha* Herbaceous Associations tend to grow on smaller hanging gardens that are less diverse; i.e., have low species richness and high dominance values (Table 3). The *A. capillus-veneris* Herbaceous Association is dominated by relatively dry seep microhabitats and by rhizomatous

stands of *A. capillus-veneris* which grow on and near narrow seep lines formed in the Navajo sandstone. The *A. micrantha* association is dominated by *A. micrantha* which grows on the less wet colluvial soil microhabitats, especially on Cedar Mesa and Weber sandstone formations. Note that these two geologic formations and the Entrada formation were found in only one park each and thus also act as surrogates for geography. In contrast, the hanging gardens with *C. scopulorum* and *C. rydbergii* Herbaceous Associations tended to be larger and, by implication, wetter: i.e., large wet colluvial soil microhabitats. They also tend to be more diverse: i.e., more species rich and low species dominance (Table 3).

The dissimilar cluster (Fig. 2) may represent a collection of unique plant communities which are not part of any herbaceous association. Alternatively, with further sampling on the Colorado Plateau, we may find that some of the hanging gardens within this cluster do represent undiscovered herbaceous associations. Further research is needed.

Neither Tuhy and MacMahon (1988) nor Romme et al. (1993) attempted to classify the vegetation of individual hanging gardens but rather placed all hanging gardens into one vegetation type. We found no species that all hanging gardens had in common (much less a common dominant) which precludes a single hanging garden herbaceous association. The alliance name on NatureServe (2006), Aquilegia micrantha saturated hanging garden herbaceous vegetation, would obviously work for the *A. micrantha* Herbaceous Association but not for the remaining three associations since neither *A. micrantha* nor any other species was constant or dominant across all four associations described in this paper (Tables 2, 4, 5, 6). Four separate alliances would seem to be necessary in spite of a common distinct habitat.

NatureServe (2006) also lists two hanging garden herbaceous associations inside our study area: *A. micrantha* - *M. eastwoodiae* and *A. micrantha* - *C. scopulorum* Herbaceous Vegetation, each association being named for its dominant species. *Aquilegia micrantha* and *C. scopulorum* are shown as characteristic species for both associations, but no data are shown for canopy coverage or constancy. In addition, no publications are cited that have this type of data and the link to VegBank (2006) indicates that no plot-observations are available, precluding further comparison. Woodbury's (1933) *fern-columbine* associates in Zion NP hanging gardens is habitat-based and seems to overlap the *A. capillus-veneris* and *C. scopulorum* Herbaceous Associations described in this paper.

Outside of Woodbury's (1933) study in Zion NP, there are no previously published studies that describe hanging garden associations. Most inselberg studies also classify vegetation by habitat (e.g., Burbanck & Platt 1964), but we found one with a phytosociological focus. Sarthou and Villiers (1998) conducted a regional vegetation study on three inselbergs in French Giana using relevé quadrats and tabular analysis. In spite of different techniques, their results were comparable to our study. They found six vegetation associations versus our four, and they found two French Gianan inselberg endemics versus our five hanging garden endemics. More interestingly, their most widespread vegetation association (with three subassociations) was dominated by *Pepiniatum geyskesii*, a French Gianan inselberg endemic. In our study, two vegetation associations were dominated by hanging garden endemics: the *A. micrantha* and the *C. rydbergii* Herbaceous Associations (Tables 4 & 6). Both studies illustrate the concept of insular vegetation on continental islands at a regional scale. Our study also looked at the regional distribution of these four herbaceous associations and found that each has a unique distribution on the Colorado Plateau (Table 1).

APPENDIX 1

Vascular plant species lists and species richness (R) for each hanging garden sampled. Canopy coverage estimates (0-100%) are shown to the right of the scientific name for species which fell within community sampling quadrats with T indicating less than 0.5%; no estimates were made for taxa not falling within sampling quadrats: **ARCH** = Arches NP, **CANY** = Canyonlands NP, **CARE** = Capitol Reef NP, **DINO** = Dinosaur NM, **GLCA** = Glen Canyon NRA, **NABR** = Natural Bridges NM, **ZION** = Zion NP.

ARCH Backarch HG R = 24

Anacardiaceae

Toxicodendron rydbergii 7

Asteraceae

Cirsium rydbergii 7

Pseudognaphalium microcephalum T

Heterotheca villosa var.

minor 1

Solidago velutina subsp. *sparsiflora*

Cyperaceae

Carex aurea 2

Euphorbiaceae

Euphorbia brachycera T

Fabiaceae*Dalea oligophylla* 3**Fagaceae***Quercus turbinella* T**Liliaceae***Zigadenus vaginatus* T**Onagraceae***Oenothera longissima***Orchidaceae***Epipactis gigantea* 2*Platantherera zothecina***Poaceae***Elymus canadensis* T*Muhlenbergia andina* 3*Dichanthelium**acuminatum* 1*Phragmites australis* 2*Schizachyrium scoparium* 1**Pteridaceae***Adiantum capillus-veneris* 48**Primulaceae***Primula specuicola* T**Ranunculaceae***Aquilegia micrantha* 9**Rosaceae***Rosa* sp.**Scrophulariaceae***Castilleja linariifolia**Mimulus eastwoodiae* TARCH Bake-oven Wall HG
R = 15**Asteraceae***Cirsium rydbergii* 1*Heterotheca villosa* var.*minor* 3**Cyperaceae***Carex aurea* 4**Euphorbiaceae***Euphorbia brachycera* T**Fabaceae***Dalea oligophylla* 1**Liliaceae***Zigadenus vaginatus* T**Orchidaceae***Epipactis gigantea* 3**Poaceae***Dichanthelium**acuminatum* 7*Schizachyrium scoparium* 32**Pteridaceae***Adiantum capillus-veneris* 23**Primulaceae***Primula specuicola* 2**Ranunculaceae***Aquilegia micrantha* 14*Clematis ligusticifolia* T**Santalaceae***Comandra umbellata* var.*pallida* 3**Scrophulariaceae***Mimulus eastwoodiae* TARCH Scaly HG R = 8**Anacardiaceae***Rhus aromatica* var.*simplicifolia**Toxicodendron rydbergii* 1**Asteraceae***Artemisia ludoviciana* var.*ludoviciana***Cyperaceae***Carex aurea* 1**Orchidaceae***Platantherera zothecina* T**Poaceae***Dichanthelium acuminatum***Pteridaceae***Adiantum capillus-veneris* 72**Scrophulariaceae***Mimulus eastwoodiae* 2ARCH Banded HG R = 6**Pinaceae***Pinus edulis***Poaceae***Dichanthelium acuminatum***Pteridaceae***Adiantum capillus-veneris* 6**Primulaceae***Primula specuicola***Ranunculaceae***Aquilegia micrantha* 33**Scrophulariaceae***Mimulus eastwoodiae* 11ARCH Winter Camp HG
R = 19**Anacardiaceae***Rhus aromatica* var.*simplicifolia* T**Asteraceae***Cirsium rydbergii**Heterotheca villosa* var.*minor* 16*Solidago velutina* subsp.*sparsiflora***Cyperaceae***Carex aurea* 1**Euphorbiaceae***Euphorbia brachycera* 2**Liliaceae***Zigadenus vaginatus* 7**Oleaceae***Fraxinus anomala***Onagraceae***Oenothera longissima* T**Orchidaceae***Epipactis gigantea* 15**Poaceae***Dichanthelium**acuminatum* 1*Phragmites australis* 9**Pteridaceae***Adiantum capillus-veneris* 19*Pellaea breweri***Primulaceae***Primula specuicola* 2**Ranunculaceae***Aquilegia micrantha* 29**Santalaceae***Comandra umbellata* var.*pallida* 2**Scrophulariaceae***Castilleja exilis**Mimulus eastwoodiae*ARCH Solitaire HG R = 16**Anacardiaceae***Rhus aromatica* var.*simplicifolia* T*Toxicodendron rydbergii***Asteraceae***Cirsium rydbergii* 1*Heterotheca villosa* var.*minor* 2*Solidago velutina* subsp.*sparsiflora* 1**Cyperaceae***Carex aurea* 7**Euphorbiaceae***Euphorbia brachycera* T**Liliaceae***Zigadenus vaginatus* 19**Orchidaceae***Epipactis gigantea* 5**Poaceae***Muhlenbergii thurberi* 3*Dichanthelium**acuminatum* 1**Pteridaceae***Adiantum capillus-veneris* 4*Pellaea glabella* subsp.*simplex***Primulaceae***Primula specuicola* 2**Ranunculaceae***Aquilegia micrantha* 38**Scrophulariaceae***Mimulus eastwoodiae* 1ARCH Dead Tree HG R = 18**Apocynaceae***Apocynum cannabinum***Asteraceae***Cirsium rydbergii* 5*Heterotheca villosa* var.*minor* 2**Cyperaceae***Carex aurea* 4**Euphorbiaceae***Euphorbia brachycera* T**Fagaceae***Quercus havardii***Juncaceae***Juncus ensifolius* var.*montanus***Liliaceae***Zigadenus vaginatus* 1**Orchidaceae***Epipactis gigantea* 5**Poaceae***Muhlenbergia andina* 1*Dichanthelium**acuminatum* 8*Schizachyrium scoparium* 19**Pteridaceae***Adiantum capillus-veneris* 11**Primulaceae***Primula specuicola* 3**Ranunculaceae***Aquilegia micrantha* 8**Santalaceae***Comandra umbellata* var.*pallida* 1**Scrophulariaceae***Castilleja exilis* T*Mimulus eastwoodiae* 8CANY Box HG R = 17**Apocynaceae***Apocynum cannabinum* 1**Asteraceae***Artemisia ludoviciana* subsp.*ludoviciana**Cirsium rydbergii* 16*Packera multilobata***Cyperaceae***Carex aurea* 2**Liliaceae***Maianthemum stellatum**Zigadenus vaginatus***Orchidaceae***Epipactis gigantea**Platantherera zothecina***Pinaceae***Pinus edulis*

Poaceae

Calamagrostis scopulorum
66

Phragmites australis

Ranunculaceae

Aquilegia micrantha 10

Rhamnaceae

Rhamnus betulifolia

Rosaceae

Rosa sp.

Scrophulariaceae

Castilleja linariifolia

Mimulus eastwoodiae

CANY Northface HG R = 13**Asteraceae**

Cirsium rydbergii 8

Betulaceae

Betula occidentalis

Cornaceae

Cornus sericea

Cyperaceae

Carex sp.

Fagaceae

Quercus gambelii

Liliaceae

Maianthemum stellatum

Zigadenus vaginatus

Orchidaceae

Platantherera zothecina

Poaceae

Calamagrostis scopulorum

Ranunculaceae

Aquilegia micrantha 54

Rosaceae

Amelanchier sp.

Rosa sp.

Scrophulariaceae

Mimulus eastwoodiae

CANY Raven HG R = 16**Anacardiaceae**

Rhus aromatica var.

simplicifolia

Toxicodendron rydbergii

Apocynaceae

Apocynum cannabinum T

Asteraceae

Cirsium arizonicum var.

bipinnatum

Berberidaceae

Berberis fendleri 3

Cyperaceae

Carex aurea 10

Orchidaceae

Platantherera zothecina

Pinaceae

Pinus edulis T

Poaceae

Calamagrostis scopulorum
48

Ranunculaceae

Aquilegia micrantha 10

Rhamnaceae

Rhamnus betulifolia 3

Rosaceae

Holodiscus dumosus

Rosa sp.

Rubiaceae

Galium sp.

Scrophulariaceae

Castilleja linariifolia

Mimulus eastwoodiae

CANY Gate HG R = 12**Anacardiaceae**

Toxicodendron rydbergii

Asteraceae

Cirsium arizonicum var.

bipinnatum 2

Cyperaceae

Carex aurea 9

Orchidaceae

Platantherera zothecina

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum

31

Muhlenbergia thurberi

Piptatherum micranthum

Ranunculaceae

Aquilegia micrantha 37

Rosaceae

Amelanchier sp.

Cercocarpus sp.

Rosa sp.

CANY Rocky HG R=7**Asteraceae**

Cirsium arizonicum var.

bipinnatum 8

Erigeron sparsifolius 1

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum

21

Ranunculaceae

Aquilegia micrantha 6

Santalaceae

Comandra umbellata var.

pallida 4

Scrophulariaceae

Mimulus eastwoodiae

CANY Tier HG R = 18**Agavaceae**

Yucca sp. T

Anacardiaceae

Toxicodendron rydbergii 1

Apocynaceae

Apocynum cannabinum T

Asteraceae

Cirsium calareum 1

Cyperaceae

Carex aurea 9

Fagaceae

Quercus gambelii T

Liliaceae

Maianthemum stellatum 4

Orchidaceae

Epipactis gigantea 3

Platantherera zothecina T

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum

49

Polemoniaceae

Gilia aggregata var.

maculata 2

Ranunculaceae

Aquilegia micrantha 11

Rhamnaceae

Rhamnus betulifolia

Rosaceae

Rosa sp. 2

Santalaceae

Comandra umbellata var.

pallida T

Scrophulariaceae

Castilleja linariifolia 1

Mimulus eastwoodiae T

CARE Sidewall HG R = 12**Anacardiaceae**

Toxicodendron rydbergii 19

Asteraceae

Cirsium arizonicum var.

bipinnatum 4

Heterotheca villosa var.

minor

Sonchus sp.

Equisetaceae

Equisetum laevigatum 1

Oleaceae

Fraxinus anomala

Orchidaceae

Epipactis gigantea

Poaceae

Elymus canadensis T

Dichanthelium

acuminatum 7

Pteridaceae

Adiantum capillus-veneris 56

Scrophulariaceae

Castilleja scabrida

Ulmaceae

Celtis reticulata 5

CARE Horseshoe HG R = 8**Apocynaceae**

Apocynum cannabinum

Asteraceae

Brickellia longifolia var.

longifolia

Liliaceae

Epipactis gigantea T

Oleaceae

Fraxinus anomala

Poaceae

Elymus canadensis

Elymus trachycaulus

Pteridaceae

Adiantum capillus-veneris 95

Scrophulariaceae

Mimulus eastwoodiae T

DINO Ponderosa HG R = 17**Asteraceae**

Cirsium ownbeyi 2

Erigeron nematophyllus

Heterotheca villosa var.

minor T

Cupressaceae

Juniperus osteosperma

Hydrangiaceae

Fendlerella utahensis

Liliaceae

Zigadenus vaginatus 14

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum

19

Muhlenbergia thurberi

Piptatherum micranthum

Poa fendleriana

Pteridaceae

Pellaea glabella subsp.

simplex

Ranunculaceae

Aquilegia micrantha 1

Rosaceae

Amelanchier sp.

Petrophytum caespitosum

Rubiaceae

Galium sp.

Scrophulariaceae

Castilleja linariifolia

DINO Yampa HG R = 18**Asteraceae**

Cirsium ownbeyi T
Erigeron nematophyllus 6
Heterotheca villosa var.
 minor 2

Packera multilobata
Taraxacum officinale

Caprifoliaceae

Symphoricarpos sp.

Hydrangiaceae

Fendlerella utahensis 9

Liliaceae

Zigadenus vaginatus 1

Linaceae

Linum lewisii

Poaceae

Calamagrostis scopulorum
Elymus repens 1
Hesperostipa comata var.
 comata 1

Pteridaceae

Pellaea glabella subsp.
 simplex

Ranunculaceae

Aquilegia micrantha 2

Rosaceae

Cercocarpus intricatus 7
Holodiscus dumosus T
Petrophytum caespitosum 7

Scrophulariaceae

Castilleja linariifolia T

DINO Bull HG R = 16**Aceraceae**

Acer negundo 2

Anacardiaceae

Rhus aromatica var.
 trilobata 1
Toxicodendron rydbergii 2

Asteraceae

Achillea millefolium T
Taraxacum officinale

Betulaceae

Betula occidentalis

Caprifoliaceae

Symphoricarpos sp. 2

Cornaceae

Cornus sericea

Liliaceae

Maianthemum stellatum 7

Orchidaceae

Platantherera zothecina 7

Pinaceae

Pseudotsuga menziesii

Poaceae

Calamagrostis scopulorum
 36

Primulaceae

Dodecatheon pulchellum
 var. *pulchellum*

Ranunculaceae

Clematis ligusticifolia

Rubiaceae

Galium sp.

Salicaceae

Salix sp.

DINO Snow HG R = 8**Anacardiaceae**

Rhus aromatica var.
 trilobata 2

Cupressaceae

Juniperus osteosperma

Loasaceae

Mentzelia multicaulis 2

Orchidaceae

Epipactis gigantea 19

Pinaceae

Pinus ponderosa

Poaceae

Calamagrostis scopulorum
 19

Primulaceae

Dodecatheon pulchellum
 var. *pulchellum* 12

Ranunculaceae

Aquilegia micrantha 15

DINO Bench HG R = 17**Asteraceae**

Achillea millefolium
Ericameria nauseosa
Cirsium ownbeyi 2
Erigeron nematophyllus
Heterotheca villosa var.
 minor

Cupressaceae

Juniperus osteosperma

Cyperaceae

Carex aurea 2

Ephedraceae

Ephedra viridis

Hydrangiaceae

Fendlerella utahensis 1

Liliaceae

Zigadenus vaginatus 7

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum
Elymus elymoides var.
 brevifolius

Polypodiaceae

Pellaea glabella subsp.
 simplex

Ranunculaceae

Aquilegia micrantha 35

Rosaceae

Cercocarpus intricatus T

Salicaceae

Populus deltoides subsp.
 wislizenii

DINO Rimrock HG R = 9**Asteraceae**

Erigeron nematophyllus
Heterotheca villosa var.
 minor

Liliaceae

Zigadenus vaginatus 2

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum

Ranunculaceae

Aquilegia micrantha 19

Rosaceae

Cercocarpus intricatus
Petrophytum caespitosum

Scrophulariaceae

Castilleja linearifolia

DINO Signature HG R = 19**Asteraceae**

Ericameria nauseosa
Cirsium ownbeyi 4
Heterotheca villosa var.
 minor

Brassicaceae

Lepidium montanum var.
 jonesii

Cyperaceae

Carex aurea 2

Euphorbiaceae

Euphorbia brachycera

Liliaceae

Zigadenus vaginatus 2

Orchidaceae

Epipactis gigantea 16

Poaceae

Calamagrostis scopulorum
 37

Muhlenbergia thurberi

Dichanthelium

acuminatum T

Pteridaceae

Adiantum capillus-veneris T

Pellaea glabella subsp.
 simplex

Primulaceae

Dodecatheon pulchellum
 var. *pulchellum*

Ranunculaceae

Aquilegia micrantha 3
Clematis ligusticifolia 34

Rosaceae

Cercocarpus intricatus
Petrophytum caespitosum

Scrophulariaceae

Castilleja linariifolia

DINO Marbles HG R = 16**Asteraceae**

Erigeron nematophyllus 18
Heterotheca villosa var.
 minor 2

Xanthisma grindelioides T

Taraxacum officinale T

Berberidaceae

Berberis repens

Boraginaceae

Cryptantha sp. 1

Caprifoliaceae

Symphoricarpos sp. 1

Hydrangiaceae

Fendlerella utahensis 2

Pinaceae

Pinus edulis T

Poaceae

Achnatherum hymenoides T

Pteridaceae

Pellaea glabella subsp.
 simplex

Ranunculaceae

Aquilegia micrantha 1

Rosaceae

Cercocarpus intricatus 8
Holodiscus dumosus 3
Petrophytum caespitosum 5

Scrophulariaceae

Castilleja sp. T

DINO Buzz HG R = 7**Asteraceae**

Artemisia ludoviciana subsp.
 ludoviciana 6

Cyperaceae

Carex aurea 1

Fabaceae

Melilotus officinalis

Poaceae

Agrostis stolonifera 6
Calamagrostis scopulorum 2

Primulaceae

Dodecatheon pulchellum
 var. *pulchellum* 2

Ranunculaceae

Aquilegia micrantha 37

DINO Redrock HG R = 18**Asteraceae**

Toxicodendron rydbergii
Artemisia ludoviciana subsp.
ludoviciana 2
Heterotheca villosa var.
 minor 4

Taraxacum officinale 4

Brassicaceae

Lepidium latifolium 15

Cyperaceae

Carex aurea 5

Fabaceae

Melilotus albus
Melilotus officinalis

Liliaceae

Maianthemum stellatum

Orchidaceae

Platantherera zothecina 11

Poaceae

Agrostis stolonifera
Calamagrostis scopulorum 2
Muhlenbergia andina
Poa pratensis 2

Ranunculaceae

Aquilegia micrantha 18
Clematis ligusticifolia

Rosaceae

Petrophytum caespitosum 7

Ulmaceae

Celtis reticulata 4

DINO Limestone HG R = 29**Apocynaceae**

Apocynum cannabinum

Asclepiadaceae

Asclepias speciosa

Asteraceae

Artemisia ludoviciana subsp.
ludoviciana 2
Ericameria nauseosa
Cirsium ownbeyi 15
Tragopogon dubius T

Brassicaceae

Lepidium montanum var.
jonesii

Cyperaceae

Carex parryanna 2
Carex aquatilis var. *aquatilis*
Carex aurea

Equisetaceae

Equisetum laevigatum 1

Fabaceae

Melilotus officinalis T

Juncaceae

Juncus ensifolius var.
montanus

Lamiaceae

Mentha arvensis 2

Liliaceae

Maianthemum stellatum T

Onagraceae

Epilobium sp.
Oenothera caespitosa T

Poaceae

Calamagrostis scopulorum
 28

Elymus trachycaulus 1

Glyceria striata T

Koeleria macrantha

Phragmites australis 8

Poa pratensis

Pseudoroegneria spicata

Polygonaceae

Erigonum corymbosum var.
corymbosum

Ranunculaceae

Aquilegia micrantha 1
Clematis ligusticifolia 12

Rosaceae

Rosa woodsii 6

Violaceae

Viola sp.

DINO Ely HG R = 17**Asteraceae**

Crepis runcinata var. *glauca*
Erigeron nematophyllus

Betulaceae

Betula occidentalis

Euphorbiaceae

Euphorbia brachycera T

Hydrangiaceae

Fendlerella utahensis

Loasaceae

Mentzelia sp. 3

Pinaceae

Pinus edulis

Poaceae

Calamagrostis scopulorum 4
Muhlenbergia thurberi 1

Achnatherum hymenoides 1

Pteridaceae

Pellaea glabella subsp.
simplex 4

Primulaceae

Dodecatheon pulchellum
 var. *pulchellum* 1

Ranunculaceae

Aquilegia micrantha 13

Rosaceae

Cercocarpus intricatus
Petrophytum caespitosum 7

Santalaceae

Comandra umbellata var.
pallida 2

Scrophulariaceae

Castilleja linariifolia

GLCA Camp HG R = 19**Apocynaceae**

Apocynum cannabinum 3

Asteraceae

Artemisia ludoviciana subsp.
mexicana

Brickellia longifolia var.

longifolia T

Taraxacum officinale

Berberidaceae

Berberis repens

Betulaceae

Ostrya knowltonii

Cyperaceae

Carex aurea 10

Fabaceae

Cercis occidentalis var.
orbiculata 3

Fagaceae

Quercus gambelii

Orchidaceae

Platantherera zothecina 1

Poaceae

Calamagrostis scopulorum 4
Polypogon interruptus
Polypogon viridis

Pteridaceae

Adiantum capillus-veneris 15

Ranunculaceae

Aquilegia micrantha 9

Clematis ligusticifolia

Rhamnaceae

Rhamnus betulifolia

Rosaceae

Rubus neomexicanus 3

Scrophulariaceae

Mimulus eastwoodiae 3

GLCA Channel HG R = 11**Anacardiaceae**

Toxicodendron rydbergii T

Asteraceae

Cirsium rydbergii 1

Cyperaceae

Carex sp. T

Fagaceae

Quercus gambelii 2

Poaceae

Calamagrostis scopulorum 6

Pteridaceae

Adiantum capillus-veneris 7

Primulaceae

Primula specuicola 1

Ranunculaceae

Aquilegia micrantha 18

Rosaceae

Petrophytum caespitosum 5

Scrophulariaceae

Mimulus eastwoodiae 1

Vitaceae

Parthenocissus vitacea 2

GLCA Corner HG R = 13**Agavaceae**

Yucca sp. T

Anacardiaceae

Rhus aromatica var.
simplicifolia

Asteraceae

Artemisia ludoviciana subsp.
ludoviciana

Cirsium rydbergii 2

Cyperaceae

Carex aurea

Fagaceae

Quercus gambelii

Orchidaceae

Epipactis gigantea

Poaceae

Calamagrostis scopulorum
 14

Pteridaceae

Adiantum capillus-veneris 54

Rosaceae

Petrophytum caespitosum

Scrophulariaceae

Mimulus eastwoodiae

Ulmaceae

Celtis reticulata

Vitaceae

Parthenocissus vitacea 4

GLCA Crossbed HG R = 23**Agavaceae**

Yucca sp. 1

Anacardiaceae

Rhus aromatica var.
simplicifolia

Asteraceae

Brickellia longifolia var.

longifolia 1

Cirsium rydbergii 11

Erigeron sparsifolius

Tetraneuris ivesiana

Gutierrezia sarothrae T

Solidago velutina subsp.

sparsiflora 2

Cyperaceae

Carex curatorum 3

Loasaceae*Mentzelia cronquistii***Oleaceae***Fraxinus anomala***Orchidaceae***Epipactis gigantea***Poaceae***Andropogon glomeratus* var.
*scabriglumis**Calamagrostis scopulorum* 2*Dichanthelium acuminatum**Schizachyrium scoparium* 26**Polygonaceae***Eriogonum corymbosum*
var. *corymbosum* T**Pteridaceae***Adiantum capillus-veneris* 2**Primulaceae***Primula specuicola* 1**Rhamnaceae***Rhamnus betulifolia***Rosaceae***Petrophytum caespitosum*
12**Scrophulariaceae***Castilleja linariifolia***Ulmaceae***Celtis reticulata*GLCA Dune HG R = 20**Agavaceae***Yucca* sp. 7**Anacardiaceae***Rhus aromatica* var.
simplicifolia 3**Asteraceae***Symphotrichum chilense* T*Cirsium rydbergii* 9*Solidago velutina* subsp.
sparsiflora 2**Cyperaceae***Carex* sp. 19**Oleaceae***Fraxinus anomala***Orchidaceae***Epipactis gigantea***Poaceae***Andropogon glomeratus* var.
scabriglumis 1*Bromus tectorum* T*Calamagrostis scopulorum* 7*Muhlenbergia andina* T*Dichanthelium acuminatum***Pteridaceae***Adiantum capillus-veneris* 6**Primulaceae***Primula specuicola* 1**Rhamnaceae***Rhamnus betulifolia* 9**Rosaceae***Petrophytum caespitosum* 4**Salicaceae***Salix ligulifolia* 8**Scrophulariaceae***Castilleja linariifolia* 1**Ulmaceae***Celtis reticulata*GLCA Fence HG R = 19**Anacardiaceae***Rhus aromatica* var.
*trilobata**Toxicodendron rydbergii* 1**Asteraceae***Cirsium* sp. T*Heterotheca villosa* var.
minor 2*Solidago canadensis**Solidago velutina* subsp.
sparsiflora 1**Campanulaceae***Lobelia cardinalis* subsp.
*graminea***Cyperaceae***Carex* sp. 9**Fagaceae***Quercus gambelii***Liliaceae***Zigadenus vaginatus* T**Oleaceae***Fraxinus* sp. 2**Orchidaceae***Epipactis gigantea***Poaceae***Andropogon glomeratus* var.
scabriglumis 69*Dichanthelium acuminatum**Phragmites australis***Polemoniaceae***Gilia aggregata* var.
maculata 2**Pteridaceae***Adiantum capillus-veneris* 4**Primulaceae***Primula specuicola***Rosaceae***Petrophytum caespitosum*GLCA Graffiti HG R = 8**Asteraceae***Brickellia longifolia* var.
*longifolia***Orchidaceae***Epipactis gigantea* 5**Poaceae***Muhlenbergia* sp. T**Pteridaceae***Adiantum capillus-veneris* 93**Ranunculaceae***Aquilegia micrantha***Rhamnaceae***Rhamnus betulifolia***Rosaceae***Petrophytum caespitosum***Ulmaceae***Celtis reticulata*GLCA Hardwood HG R = 29**Anacardiaceae***Rhus aromatica* var.
simplicifolia 1**Asteraceae***Baccharis emoryi* 7*Cirsium rydbergii**Erigeron sparsifolius***Brassicaceae***Thelypodium integrifolium***Cyperaceae***Carex aurea**Cladium californicum* 6**Fabaceae***Cercis occidentalis* var.
*orbiculata***Fagaceae***Quercus gambelii* 3**Juncaceae***Juncus arcticus* 13**Oleaceae***Forestiera pubescens* 6**Orchidaceae***Epipactis gigantea***Poaceae***Calamagrostis scopulorum* 3*Elymus canadensis* T*Muhlenbergia andina**Dichanthelium**acuminatum*-T*Panicum virgatum* 7*Phragmites australis**Schizachyrium scoparium* T*Sphenopholis obtusata***Pteridaceae***Adiantum capillus-veneris* 9**Primulaceae***Primula specuicola* 1**Ranunculaceae***Clematis ligusticifolia* 1**Rhamnaceae***Rhamnus betulifolia* 1**Rosaceae***Petrophytum caespitosum* 1**Scrophulariaceae***Castilleja linariifolia**Mimulus eastwoodiae* T**Ulmaceae***Celtis reticulata***Vitaceae***Parthenocissus vitacea* 3GLCA Hawk HG R = 12**Asteraceae***Brickellia longifolia* var.
*longifolia**Cirsium rydbergii* 36**Cyperaceae***Carex aurea* 4**Fagaceae***Quercus gambelii* T**Poaceae***Calamagrostis scopulorum* 1*Muhlenbergia andina**Polygogon viridis* T**Pteridaceae***Adiantum capillus-veneris* 20**Primulaceae***Primula specuicola* T**Ranunculaceae***Aquilegia micrantha* T**Rosaceae***Petrophytum caespitosum***Scrophulariaceae***Mimulus eastwoodiae* 1GLCA Hook HG R = 28**Asteraceae***Artemisia ludoviciana* subsp.
ludoviciana 4*Herrickia glauca* var.*glauca* 4*Brickellia longifolia* var.*longifolia**Cirsium rydbergii* 49*Solidago* sp.*Sonchus asper***Cyperaceae** 6*Carex aurea**Carex curatorum***Equisetaceae***Equisetum hyemale* 2*Equisetum laevigatum***Fagaceae***Quercus gambelii* 2**Juncaceae***Juncus arcticus* 9**Liliaceae***Maianthemum stellatum* 5**Orchidaceae***Epipactis gigantea* T

Poaceae

Agrostis exarata
Andropogon glomeratus var.
scabriglumis T
Bromus tectorum T
Calamagrostis scopulorum T
Elymus canadensis 4
Muhlenbergia andina 2
Muhlenbergia thurberi
Dichanthelium
acuminatum T
Phragmites australis 2
Sphenopholis obtusata

Pteridaceae

Adiantum capillus-veneris 2

Primulaceae

Primula specuicola

Ranunculaceae

Aquilegia micrantha

Scrophulariaceae

Mimulus eastwoodiae

GLCA Ice HG R = 17**Anacardiaceae**

Toxicodendron rydbergii

Asteraceae

Aster sp.

Artemisia ludoviciana subsp.
ludoviciana

Brickellia longifolia var.
longifolia

Cirsium rydbergii 29

Cyperaceae 19

Carex lanuginosa

Equisetaceae

Equisetum sp.

Oleaceae

Fraxinus anomala

Orchidaceae

Platantherera zothecina

Poaceae

Calamagrostis scopulorum T

Pteridaceae

Adiantum capillus-veneris 22

Primulaceae

Primula specuicola

Ranunculaceae

Aquilegia micrantha 3

Rosaceae

Petrophytum caespitosum

Scrophulariaceae

Castilleja linariifolia
Heterotheca villosa var.

Scrophulariaceae

Mimulus eastwoodiae

Vitaceae

Parthenocissus vitacea 7

GLCA Lower Cow HG

R = 12

Anacardiaceae

Toxicodendron rydbergii 1

Asteraceae

Cirsium rydbergii
Solidago velutina subsp.
sparsiflora 1

Campanulaceae

Lobelia cardinalis subsp.
graminea 1

Cyperaceae

Carex curatorum 14

Fagaceae

Quercus gambelii T

Orchidaceae

Epipactis gigantea T

Poaceae

Calamagrostis scopulorum
 19

Phragmites australis

Pteridaceae

Adiantum capillus-veneris 4

Primulaceae

Primula specuicola 10

Ranunculaceae

Clematis ligusticifolia 2

GLCA Lower Three Garden

R = 8

Asteraceae

Cirsium rydbergii 21

Cyperaceae 8

Carex aurea

Carex curatorum

Poaceae

Dichanthelium
acuminatum 26

Muhlenbergia sp. 2

Primulaceae

Primula specuicola 3

Rosaceae

Petrophytum caespitosum
 10

Scrophulariaceae

Castilleja linariifolia 2

GLCA Pedestal HG R = 14**Agavaceae**

Yucca sp. 4

Asteraceae

Cirsium rydbergii 7
Heterotheca villosa var.
minor T

Cyperaceae 14

Carex aurea
Carex curatorum

Juncaceae

Juncus arcticus T

Onagraceae

Oenothera longissima 1

Orchidaceae

Epipactis gigantea T

Poaceae

Calamagrostis scopulorum T
Schizachyrium scoparium 32

Pteridaceae

Adiantum capillus-veneris 17

Ranunculaceae

Aquilegia micrantha 1
Clematis ligusticifolia 1

Rhamnaceae

Rhamnus betulifolia 1

GLCA Pyro HG R = 22**Asteraceae**

Artemisia ludoviciana subsp.
albula 2

Brickellia longifolia var.
longifolia T

Cirsium rydbergii 8

Coryza canadensis

Pseudognaphalium
lutealbum

Sonchus arvensis

Sonchus asper

Cyperaceae

Carex aurea 9

Scirpus sp.

Fabaceae

Cercis occidentalis var.
orbiculata

Fagaceae

Quercus gambelii

Orchidaceae

Epipactis gigantea T

Poaceae

Bromus rubens

Elymus canadensis T

Muhlenbergia andina

Dichanthelium
acuminatum 1

Polypogon monspeliensis

Pteridaceae

Adiantum capillus-veneris 68

Primulaceae

Primula specuicola

Scrophulariaceae

Mimulus eastwoodiae

Tamaricaceae

Tamarix ramosissima

Typhaceae

Typha sp. 6

GLCA Rattlesnake HG

R = 20

Asteraceae

Brickellia longifolia var.
longifolia T

Cirsium rydbergii T

Solidago sp. 6

Cyperaceae

Carex aurea 1

Fagaceae

Quercus gambelii 1

Juncaceae

Juncus ensifolius var.
montanus

Liliaceae

Maianthemum stellatum 4

Oleaceae

Forestiera pubescens T
Fraxinus anomala

Orchidaceae

Epipactis gigantea 3
Platantherera zothecina T

Poaceae

Agrostis exarata
Calamagrostis scopulorum
 56

Elymus canadensis T

Pteridaceae

Adiantum capillus-veneris 7

Ranunculaceae

Aquilegia micrantha 3

Rhamnaceae

Rhamnus betulifolia

Rosaceae

Petrophytum caespitosum

Scrophulariaceae

Mimulus eastwoodiae T

Vitaceae

Parthenocissus vitacea 4

GLCA Stone Basin HG

R = 15

Anacardiaceae

Toxicodendron rydbergii 1

Apocynaceae

Apocynum cannabinum 11

Asteraceae

Coryza canadensis T
Pseudognaphalium sp. 2
Solidago sp. 4

Campanulaceae

Lobelia cardinalis subsp.
graminea

Cyperaceae

Carex sp. 4

Poaceae

Andropogon glomeratus var.
scabriglumis

Bouteloua curtipendula var.
caespitosa
Calamagrostis scopulorum T
Elymus canadensis 3
Dichanthelium
acuminatum 14

Pteridaceae

Adiantum capillus-veneris 4

Scrophulariaceae

Castilleja linariifolia

Vitaceae

Parthenocissus vitacea 10

GLCA Swallow HG R = 11

Asteraceae

Cirsium rydbergii

Sonchus sp. T

Cyperaceae

Carex aurea 18

Orchidaceae

Platanthera zothecina 3

Poaceae

Calamagrostis scopulorum T

Pteridaceae

Adiantum capillus-veneris 42

Primulaceae

Primula specuicola 2

Ranunculaceae

Aquilegia micrantha 6

Clematis ligusticifolia

Rosaceae

Rubus neomexicanus

Scrophulariaceae

Mimulus eastwoodiae

GLCA Upper Three HG
R = 16

Asclepiadaceae

Asclepias latifolia

Asteraceae

Solidago velutina subsp.

sparsiflora

Cirsium rydbergii 40

Cyperaceae

Carex aurea 15

Fabaceae

Cercis occidentalis var.
orbiculata

Fagaceae

Quercus gambelii 1

Orchidaceae

Epipactis gigantea 1

Poaceae

Calamagrostis scopulorum
13

Muhlenbergia sp. 1

Dichanthelium acuminatum

*Schizachyrium scoparium*¹ 5

Pteridaceae

Adiantum capillus-veneris 1

Primulaceae

Primula specuicola T

Rosaceae

Petrophytum caespitosum

Scrophulariaceae

Castilleja linariifolia

Mimulus eastwoodiae T

GLCA Wrong HG R = 10

Anacardiaceae

Toxicodendron rydbergii 11

Apocynaceae

Apocynum cannabinum

Asteraceae

Artemisia ludoviciana subsp.

mexicana T

Solidago velutina subsp.

sparsiflora

Fagaceae

Quercus gambelii 1

Poaceae

Andropogon glomeratus var.

scabriglumis 25

Calamagrostis scopulorum

28

Dichanthelium

acuminatum 2

Polemoniaceae

Gilia aggregata var.

maculata

Pteridaceae

Adiantum capillus-veneris 50

GLCA Zephyr HG R = 17

Agavaceae

Yucca sp. 12

Anacardiaceae

Rhus aromatica var. *simpli-*
cifolia 2

Asteraceae

Cirsium rydbergii 31

Cyperaceae

Carex curatorum 4

Fagaceae

Quercus gambelii

Orchidaceae

Epipactis gigantea T

Poaceae

Andropogon glomeratus var.

scabriglumis

Muhlenbergia sp. T

Schizachyrium scoparium 50

Primulaceae

Primula specuicola T

Pteridaceae

Adiantum capillus-veneris 2

Ranunculaceae

Aquilegia micrantha 2

Rhamnaceae

Rhamnus betulifolia 2

Rosaceae

Petrophytum caespitosum 2

Scrophulariaceae

Castilleja linariifolia 2

Ulmaceae

Celtis reticulata

Urticaceae

Parietaria pennsylvanica T

GLCA Ziggy HG R = 30

Agavaceae

Yucca toftiae

Apocynaceae

Apocynum cannabinum T

Asteraceae

Artemisia ludoviciana subsp.

ludoviciana

Cirsium rydbergii 21

Conyza canadensis

Sonchus asper

Cyperaceae 3

Carex aurea

Carex curatorum

Eleocharis rostellata 12

Scirpus sp.

Fabaceae

Oxytropis sp.

Liliaceae

Zigadenus vaginatus 13

Onagraceae

Oenothera longissima

Orchidaceae

Epipactis gigantea T

Poaceae

Agrostis exarata

Bromus tectorum

Calamagrostis scopulorum 6

Muhlenbergia asperifolia

Muhlenbergia thurberi

Dichanthelium acuminatum

Phragmites australis T

Schizachyrium scoparium 10

Pteridaceae

Adiantum capillus-veneris 1

Primulaceae

Primula specuicola T

Ranunculaceae

Aquilegia micrantha 1

Clematis ligusticifolia

Rosaceae

Petrophytum caespitosum

Rosa woodsii

Scrophulariaceae

Mimulus eastwoodiae

Typhaceae

Typha sp.

NABR AM HG R= 5

Pinaceae

Pinus edulis T

Poaceae

Calamagrostis scopulorum

Ranunculaceae

Aquilegia micrantha 27

Rhamnaceae

Rhamnus betulifolia

Rosaceae

Cercocarpus montanus

NABR Fir HG R=11

Asteraceae

Cirsium undulatum

Heterotheca villosa var.

minor

Gentianaceae

Swertia radiata 2

Hydrophyllaceae

Phacelia sp.

Liliaceae

Zigadenus vaginatus 6

Pinaceae

Abies bifolia

Poaceae

Calamagrostis scopulorum

29

Poa fendleriana

Rosaceae

Amelanchier sp. 2

Holodiscus dumosus 2

Rubiaceae

Galium multiflorum var.

coloradoense

NABR Kachina HG R = 19

Apiaceae

Aletes macdougalii subsp.

breviradiatus 2

Asteraceae

Cirsium undulatum 5

Cirsium sp.

Erigeron kachinensis 5

Heterotheca villosa var.

minor T

Celastraceae

Pachystima myrsinites T

Cyperaceae

Carex aurea T

Ephedraceae

Ephedra viridis 12

Gentianaceae

Swertia radiata T

Juncaceae

Juncus arcticus T

Liliaceae*Zigadenus vaginatus* 19**Orchidaceae***Epipactis gigantea* T**Pinaceae***Pinus edulis***Poaceae***Calamagrostis scopulorum* 4*Muhlenbergia thurberi* 5**Ranunculaceae***Aquilegia micrantha* T*Clematis ligusticifolia***Rhamnaceae***Rhamnus betulifolia* 4**Rubiaceae***Galium multiflorum* var.
*coloradoense***Santalaceae***Comandra umbellata* var.
pallida 1NABR Liverwort HG R = 9**Brassicaceae***Lepidium montanum* var.
jonesii T*Lesquerella rectipes***Cupressaceae***Juniperus osteosperma***Elaeagnaceae***Shepherdia rotundifolia***Pinaceae***Pinus edulis* T**Poaceae***Calamagrostis scopulorum***Pteridaceae***Cheilanthes feei***Ranunculaceae***Aquilegia micrantha* 49**Rosaceae***Petrophytum caespitosum*NABR Long HG R = 10**Berberidaceae***Berberis repens***Gentianaceae***Swertia radiata***Asteraceae***Erigeron kachinensis***Liliaceae***Zigadenus vaginatus***Pinaceae***Pinus edulis***Poaceae***Calamagrostis scopulorum* 4**Ranunculaceae***Aquilegia micrantha* 14**Rhamnaceae***Rhamnus betulifolia***Rosaceae***Cercocarpus montanus***Rubiaceae***Galium multiflorum* var.
*coloradoense*NABR Micro HG R = 4**Asteraceae***Cirsium* sp. 3*Erigeron kachinensis* 6**Poaceae***Calamagrostis scopulorum* 3**Ranunculaceae***Aquilegia micrantha* 48NABR Petro HG R = 9**Asteraceae***Cirsium undulatum* 11*Erigeron kachinensis* 7*Heterotheca villosa* var.
minor T**Cyperaceae***Carex aurea* 11**Gentianaceae***Swertia radiata***Orchidaceae***Platanthera* sp. 1**Poaceae***Calamagrostis scopulorum*
35**Pteridaceae***Adiantum capillus-veneris* T**Ranunculaceae***Aquilegia micrantha* TNABR Slickrock HG R = 14**Asteraceae***Cirsium* sp. 13*Cirsium arizonicum* var.
*bipinnatum**Cirsium undulatum**Heterotheca villosa* var.
*minor***Cyperaceae***Carex aurea* 2**Fagaceae***Quercus gambelii***Gentianaceae***Swertia radiata***Juncaceae***Juncus arcticus* 12**Liliaceae***Zigadenus vaginatus* T**Orchidaceae***Platanthera* sp.**Pinaceae***Pinus edulis* 2**Poaceae***Bromus tectorum**Calamagrostis scopulorum*
18*Muhlenbergia thurberi***Rubiaceae***Galium multiflorum* var.
coloradoense 5NABR Tuwa HG R = 10**Apiaceae***Aletes maddougali* subsp.
*breviradiatus***Asteraceae***Cirsium undulatum* 5**Cyperaceae***Carex aurea* 8**Gentianaceae***Swertia radiata* 4**Juncaceae***Juncus arcticus***Pinaceae***Pinus edulis* T**Poaceae***Calamagrostis scopulorum*
40*Muhlenbergia thurberi* 3**Ranunculaceae***Aquilegia micrantha* 2**Rhamnaceae***Rhamnus betulifolia*ZION Canyon Overlook IHG R = 14**Aceraceae***Acer negundo* var. *violaceum***Asteraceae***Brickellia californica* 2*Ageratina herbacea**Perityle tenella* T*Stephanomeria pauciflora***Fagaceae***Quercus turbinella* T**Orchidaceae***Epipactis gigantea* 16**Poaceae***Muhlenbergia thurberi* 5*Poa fendleriana***Pteridaceae***Adiantum capillus-veneris* 34**Rosaceae***Holodiscus dumosus**Petrophytum caespitosum* T**Saxifragaceae***Heuchera rubescens***Scrophulariaceae***Castilleja* sp.ZION Canyon Overlook IIHG R = 26**Asteraceae***Artemisia ludoviciana* subsp.
albula 3*Brickellia californica**Brickellia grandiflora* 6*Erigeron sionis* T*Heterotheca villosa* var.
minor 1*Perityle tenella**Solidago velutina* subsp.
*sparsiflora**Sonchus asper**Stephanomeria pauciflora* 1*Taraxacum officinale* T**Celastraceae***Pachystima myrsinites* 1**Fagaceae***Quercus turbinella***Onagraceae***Oenothera* sp.*Zauschneria latifolia* 2**Orchidaceae***Epipactis gigantea* 1**Poaceae***Bromus ciliatus**Bromus tectorum* 1*Muhlenbergia thurberi* T*Poa fendleriana* 1*Poa pratensis***Pteridaceae***Adiantum capillus-veneris* 33**Rosaceae***Cercocarpus intricatus**Petrophytum caespitosum* 2**Salicaceae***Populus fremontii* 3*Salix gooddingii***Scrophulariaceae***Castilleja scabrida* var.
*scabrida*ZION Court of thePatriarchs HG R = 20**Aceraceae***Acer negundo* var. *negundo* T**Agavaceae***Yucca utahensis***Asteraceae***Artemisia ludoviciana* subsp.
*ludoviciana**Perityle tenella**Solidago missouriensis**Sonchus asper***Cyperaceae***Carex aurea* 5

Equisetaceae

Equisetum laevigatum 5

Liliaceae

Maianthemum stellatum 2

Oleaceae

Fraxinus velutina

Orchidaceae

Epipactis gigantea

Poaceae

Agrostis exarata

Calamagrostis scopulorum
13

Muhlenbergia sp. 14

Poa pratensis 5

Pteridaceae

Adiantum capillus-veneris 13

Rosaceae

Petrophytum caespitosum

Rubiaceae

Galium trifidum

Saxifragaceae

Parnassia palustris var.
montanensis

Scrophulariaceae

Mimulus cardinalis

ZION Fall HG R = 14

Araliaceae

Aralia racemosa subsp.
bicrenata

Asteraceae

Erigeron sionis

Taraxacum officinale

Brassicaceae

Nasturtium officinale

Juncaceae

Juncus ensifolius var.
montanus T

Liliaceae

Maianthemum stellatum 6

Orchidaceae

Epipactis gigantea

Poaceae

Agrostis exarata

Pteridaceae

Adiantum capillus-veneris 20

Primulaceae

Dodecatheon pulchellum
var. *zionense* 32

Ranunculaceae

Aquilegia chrysantha 2

Aquilegia formosa var.
formosa

Rosaceae

Petrophytum caespitosum

Scrophulariaceae

Mimulus cardinalis

ZION Falling Water HG

R = 21

Aceraceae

Acer negundo var. *violaceum*

Anacardiaceae

Toxicodendron rydbergii

Araliaceae

Aralia racemosa ssp.
bicrenata

Asteraceae

Symphotrichum lanceola-
tum var. *hesperium* 30

Brickellia longifolia var.

longifolia

Cirsium sp.

Chrysothamnus scopulorum

Sphaeromeria ruthiae

Cyperaceae

Carex aurea 1

Hydrangiaceae

Jamesia americana var.
zionis

Liliaceae

Maianthemum stellatum

Oleaceae

Fraxinus velutina

Poaceae

Bromus ciliatus

Calamagrostis scopulorum
10

Pteridaceae

Adiantum capillus-veneris 2

Ranunculaceae

Aquilegia chrysantha 22

Clematis ligusticifolia

Rosaceae

Petrophytum caespitosum

Rubiaceae

Galium triflorum

Scrophulariaceae

Mimulus cardinalis

Violaceae

Viola sp. T

ZION Grotto HG R = 28

Aceraceae

Acer negundo var. *violaceum*

Anacardiaceae

Toxicodendron rydbergii

Araliaceae

Aralia racemosa subsp.
bicrenata 2

Asteraceae

Artemisia ludoviciana

Symphotrichum lanceola-
tum var. *hesperium*

Brickellia longifolia var.
longifolia

Cirsium neomexicanum

Berberidaceae

Berberis repens T

Brassicaceae

Erysimum capitatum

Caprifoliaceae

Symphoricarpos sp.

Celastraceae

Pachystima myrsinites

Hydrangiaceae

Jamesia americana var.
zionis

Liliaceae

Maianthemum stellatum 2

Poaceae

Bromus ciliatus

Calamagrostis scopulorum
33

Pteridaceae

Adiantum capillus-veneris 1

Adiantum aleuticum

Primulaceae

Dodecatheon pulchellum
var. *zionense* 19

Ranunculaceae

Aquilegia chrysantha 4

Aquilegia formosa var.
formosa

Rosaceae

Amelanchier alnifolia

Cercocarpus intricatus

Holodiscus dumosus

Petrophytum caespitosum

Rubiaceae

Galium triflorum T

Saxifragaceae

Heuchera rubescens

Scrophulariaceae

Mimulus cardinalis 6

Violaceae

Viola nephrophylla 2

ZION Kaye's HG R = 30

Anacardiaceae

Toxicodendron rydbergii 1

Asteraceae

Artemisia ludoviciana subsp.
ludoviciana T

Cirsium arizonicum

Taraxacum officinale T

Cyperaceae 19

Carex aurea

Carex curatorum

Equisetaceae

Equisetum hyemale

Fagaceae

Quercus turbinella

Hydrophyllaceae

Phacelia heterophylla

Juncaceae

Juncus ensifolius var.
montanus T

Liliaceae

Maianthemum stellatum T

Oleaceae

Fraxinus velutina

Orchidaceae

Epipactis gigantea

Poaceae

Agrostis exarata

Calamagrostis scopulorum
40

Muhlenbergia andina 1

Dichanthelium

acuminatum 2

Phragmites australis 1

Poa pratensis 2

Danthonia californica T

Pteridaceae

Adiantum capillus-veneris 3

Ranunculaceae

Aquilegia chrysantha 2

Aquilegia formosa var.
formosa

Clematis ligusticifolia

Rosaceae

Petrophytum caespitosum

Rubiaceae

Galium trifidum

Saxifragaceae

Heuchera rubescens

Parnassia palustris var.
montanensis

Scrophulariaceae

Mimulus cardinalis T

Violaceae

Viola sp. 1

ZION Lower Emerald HG

R = 12

Anacardiaceae

Toxicodendron rydbergii

Asteraceae

Herrickia glauca var.
glauca 1

Cyperaceae

Carex aurea

Liliaceae

Maianthemum stellatum 3

Orchidaceae

Epipactis gigantea 1

Poaceae

Agrostis exarata 5

Calamagrostis scopulorum
33

Pteridaceae*Adiantum capillus-veneris* 1**Primulaceae***Dodecatheon pulchellum*
var. *zionense* 25**Ranunculaceae***Aquilegia chrysantha* T**Scrophulariaceae***Mimulus cardinalis***Vitaceae***Vitis arizonica*ZION Menu Falls HG R = 23**Aceraceae***Acer negundo* var. *negundo***Anacardiaceae***Toxicodendron rydbergii***Apocynaceae***Apocynum cannabinum***Asteraceae***Baccharis salicina**Cirsium arizonicum**Sonchus asper***Cyperaceae** T*Carex aurea**Carex curatorum***Equisetaceae***Equisetum laevigatum***Fagaceae***Quercus turbinella***Liliaceae***Maianthemum stellatum***Oleaceae***Fraxinus velutina***Poaceae***Agrostis exarata**Bromus diandrus**Calamagrostis scopulorum*

13

*Polypogon viridis**Muhlenbergia* sp. 6**Pteridaceae***Adiantum capillus-veneris* 16**Ranunculaceae***Aquilegia chrysantha* 9*Aquilegia formosa* var.*formosa**Clematis ligusticifolia***Rosaceae***Petrophytum caespitosum***Scrophulariaceae***Mimulus cardinalis* 15ZION Narrows Trail HG

R = 26

Aceraceae*Acer negundo* var. *negundo* 4**Anacardiaceae***Toxicodendron rydbergii* T**Asteraceae***Artemisia ludoviciana* subsp.
*ludoviciana**Brickellia longifolia* var.*longifolia**Cirsium neomexicanum**Cirsium wheeleri**Sonchus asper***Berberidaceae***Berberis repens***Cannabaceae***Humulus lupulus* var.*neomexicanus***Cyperaceae***Carex aurea* T**Liliaceae***Maianthemum stellatum* 19**Orchidaceae***Epipactis gigantea***Poaceae***Bromus ciliatus**Bromus diandrus**Calamagrostis scopulorum*

26

*Elymus glaucus**Muhlenbergia andina**Achnatherum hymenoides***Pteridaceae***Adiantum capillus-veneris* 8**Primulaceae***Dodecatheon pulchellum*var. *zionense* 13**Ranunculaceae***Aquilegia chrysantha* 1*Aquilegia formosa* var.*formosa**Clematis ligusticifolia* T**Rosaceae***Petrophytum caespitosum***Scrophulariaceae***Mimulus cardinalis* T**Vitaceae***Vitis arizonica* 3ZION Pine Creek HG R = 6**Asteraceae***Herrickia glauca* var.*glauca* 8*Solidago velutina* subsp.*sparsiflora***Poaceae***Calamagrostis scopulorum**Poa fendleriana***Pteridaceae***Adiantum capillus-veneris***Primulaceae***Dodecatheon pulchellum*var. *zionense* 6ZION Snail HG R = 13**Anacardiaceae***Toxicodendron rydbergii***Asteraceae***Herrickia glauca* var. *glauca***Liliaceae***Maianthemum stellatum* T**Oleaceae***Fraxinus velutina***Orchidaceae***Epipactis gigantea***Poaceae***Bromus ciliatus**Calamagrostis scopulorum*

15

*Polypogon viridis***Pteridaceae***Adiantum capillus-veneris* 32**Ranunculaceae***Aquilegia chrysantha* 1**Rosaceae***Petrophytum caespitosum***Rubiaceae***Galium aparine* var.*echinospermum***Scrophulariaceae***Mimulus cardinalis*ZION Trail's End HG R = 13**Asteraceae***Cirsium arizonicum* var.*arizonicum**Sonchus arvensis**Sonchus asper***Berberidaceae***Berberis repens* 1**Liliaceae***Maianthemum stellatum* 3**Orchidaceae***Epipactis gigantea***Poaceae***Bromus diandrus**Calamagrostis scopulorum*

15

Pteridaceae*Adiantum capillus-veneris* 19**Primulaceae***Dodecatheon pulchellum*var. *zionense* 12**Ranunculaceae***Aquilegia chrysantha***Scrophulariaceae***Mimulus cardinalis***Vitaceae***Vitis arizonica*ZION Upper EmeraldHG R = 33**Anacardiaceae***Toxicodendron rydbergii* 2**Apiaceae***Angelica pinnata* T**Apocynaceae***Apocynum cannabinum* 3**Asclepiadaceae***Asclepias hallii**Asclepias speciosa***Asteraceae***Artemisia ludoviciana* subsp.*ludoviciana**Cirsium* sp. T*Brickellia grandiflora**Sonchus arvensis**Sonchus asper***Berberidaceae***Berberis repens***Cyperaceae** 3*Carex aurea**Carex curatorum***Equisetaceae***Equisetum arvense***Liliaceae***Maianthemum stellatum* 20**Oleaceae***Fraxinus velutina* 1**Onagraceae***Oenothera longissima***Orchidaceae***Epipactis gigantea* T**Poaceae***Bromus tectorum**Calamagrostis scopulorum*

20

Elymus canadensis 3*Muhlenbergia andina* 1*Poa pratensis***Pteridaceae***Adiantum capillus-veneris***Primulaceae***Dodecatheon pulchellum*var. *zionense* 20**Ranunculaceae***Aquilegia chrysantha* T*Aquilegia formosa* var.*formosa***Rosaceae***Petrophytum caespitosum***Saxifragaceae***Heuchera rubescens***Scrophulariaceae***Mimulus cardinalis*

Mimulus guttatus

Violaceae

Viola sp. 3

Vitaceae

Vitis arizonica

ZION Weeping Rock HG.

R = 28

Apocynaceae

Apocynum cannabinum 1

Asteraceae

Artemisia ludoviciana subsp.

ludoviciana 1

Cirsium arizonicum var.

arizonicum

Berberidaceae

Berberis repens

Cyperaceae 7

Carex aurea

Carex curatorum

Fagaceae

Quercus gambelii

Quercus turbinella

Liliaceae

Maianthemum stellatum 7

Linaceae

Linum lewisii

Oleaceae

Fraxinus velutina

Poaceae

Bromus diandrus T

Calamagrostis scopulorum

18

Muhlenbergia thurberi

Panicum sp.

Phragmites australis 2

Polypogon interruptus 8

Pteridaceae

Adiantum capillus-veneris 7

Primulaceae

Dodecatheon pulchellum

var. *zionense* 2

Ranunculaceae

Aquilegia chrysantha 7

Aquilegia formosa var.

formosa

Clematis ligusticifolia

Rosaceae

Petrophytum caespitosum 1

Rubiaceae

Galium multiflorum var.

multiflorum

Scrophulariaceae

Mimulus cardinalis 30

Tamaricaceae

Tamarix ramosissima

Ulmaceae

Celtis reticulata

Violaceae

Viola sp. T

¹possibly *Andropogon glomeratus*; vegetative sample

ACKNOWLEDGMENTS

We thank C.L. May and J. Hak for their assistance and insight during the 1991–1993 field seasons. We also thank the National Park Service staff at each of the administrative units for their logistical support, especially V. Vieira, R. Harris, J. Belnap, and S. Petersburg. This research was supported by NPS-32752 to Stanton. John Spence and an anonymous reviewer provided helpful review comments.

REFERENCES

- BAKER, V.R. 1990. Spring sapping and valley network development; with case studies by R.C. Kochel, V.R. Baker, J.E. Laity, and A.D. Howard. In: C.G. Higgins and D.R. Coates, eds. Groundwater geomorphology; the role of subsurface water in earth-surface processes and landforms. Special Pap. Geol. Soc. Amer. 252, Boulder, CO. Pp. 235–244.
- BARTHOLOTT, W. and S. POREMBSKI. 2000. Vascular plants on inselbergs: systematic overview. In: W. Barthlott and S. Porembski, eds. Inselbergs, Ecological Studies Vol. 146. Springer-Verlag, Berlin. Pp. 103–116.
- BERGER, W.H. and F. L. PARKER. 1970. Diversity of planktonic Foraminifera in deep-sea sediments. *Science* 168: 1345–1347.
- BURBANCK, M.P. and R. B. PLATT. 1964. Granite outcrop communities of the Piedmont Plateau in Georgia. *Ecology* 45:292–306.
- CLOVER, E.U. and L. JOTTER. 1944. Floristic studies in the canyon of the Colorado and tributaries. *Amer. Midl. Naturalist* 32:591–642.
- COCHRAN, W.G. 1977. Sampling techniques, 3rd ed. John Wiley, New York.
- DAUBENMIRE, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. *Ecol. Monogr.* 22:301–330.
- DAUBENMIRE, R. 1959. A canopy-coverage method of vegetational analysis. *Northw. Sci.* 33:43–64.
- DUNNE, T. 1990. Hydrology, mechanics, and geomorphic implications of erosion by subsurface flow. In: C.G. Higgins and D.R. Coates, eds. Groundwater geomorphology; the role of subsurface water in earth-surface processes and landforms. Special Pap. Geol. Soc. Amer. 252, Boulder, CO. Pp. 1–28.
- EASTWOOD, A. 1896. Report of a collection of plants from San Juan County, in southeastern Utah. *Proc. Calif. Acad. Sci.* II 6:271–329.
- ECOLOGICAL SOCIETY OF AMERICA VEGETATION CLASSIFICATION PANEL. 2006. Description, documentation, and evaluation of associations and alliances within the U.S. National Vegetation Classification, ver. 4.5. Ecological Society of America, Washington, DC.
- FLORA NORTH AMERICA EDITORIAL COMMITTEE (eds.). 1993+. *Flora of North America North of Mexico* 13+ vols. Oxford Univ. Press, New York and Oxford.

- FOWLER, J.F., N.L. STANTON, R.L. HARTMAN, and C.L. MAY. 1995. Level of endemism in hanging gardens of the Colorado Plateau. In: P.G. Rowlands, C. van Riper III and M.K. Sogge, eds. Proceedings of the second biennial conference on research in Colorado Plateau National Parks. National Park Service Transactions and Proceedings Series NPS-NRNAU-NRTP-95/11. Pp. 215–223.
- GROGER, A. and W. BARTHLOTT. 1996. Biogeography and diversity of the inselberg (Laja) vegetation of southern Venezuela. *Biodiversity Letters* 3:165–179.
- HARRISON, B.F., S. L. WELSH, and G. MOORE. 1964. Plants of Arches National Monument. Brigham Young University Sci. Bull. Bio. Ser. 5:1–23.
- HIGGINS, C.G. 1984. Piping and sapping; development of landforms by groundwater outflow. In: R.G. Lafleur, ed. *Groundwater as a geomorphic agent*, Allen and Unwin, Boston, MA. Pp. 18–58.
- HORN, H.S. 1966. Measurement of "overlap" in comparative ecological studies. *Amer. Naturalist* 100:419–424.
- KREBS, C.J. 1989. *Ecological methodology*. Harper and Row, New York.
- LAITY, J.E. and M.C. MALIN. 1985. Sapping processes and the development of theater-headed valley networks on the Colorado Plateau. *Bull. Geol. Soc. Amer.* 96:203–217.
- LOETHER, H.J. and D.G. McTAVISH. 1976. *Descriptive and inferential statistics, an introduction*. Allyn and Bacon, Boston, MA.
- MALANSON, G.P. 1980. Habitat and plant distribution in hanging gardens of the narrows, Zion National Park, Utah. *Great Basin Naturalist* 40:178–182.
- MALANSON, G.P. 1982. The assembly of hanging gardens: effects of age, area, and location. *Amer. Naturalist* 119:145–150.
- Malanson, G.P. and J. KAY. 1980. Flood frequency and the assemblage of dispersal types in hanging gardens of the Narrows, Zion National Park, Utah. *Great Basin Naturalist* 40:365–371.
- McINTOSH, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. *Ecology* 48:392–404.
- MAY, C.L., J.F. FOWLER, and N.L. STANTON. 1995. Geomorphology of the hanging gardens on the Colorado Plateau. In: P.G. Rowlands, C. van Riper III and M.K. Sogge, eds. Proceedings of the second biennial conference on research in Colorado Plateau National Parks. National Park Service Transactions and Proceedings Series NPS-NRNAU-NRTP-95/11. Pp. 3–24.
- MUELLER-DOMBOIS, D. and H. ELLENBERG. 2002. *Aims and methods of vegetation ecology*. The Blackburn Press, Caldwell, NJ.
- NATURESERVE. 2006. NatureServe Explorer: An online encyclopedia of life. NatureServe, Arlington, VA. <<http://www.natureserve.org/explorer>> Accessed March 2006.
- POREMSKI, S., J.SZARZYNSKI, J-P. MUND, and W. BARTHLOTT. 1996. Biodiversity and vegetation of small-sized inselbergs in a west African rain forest (Tai, Ivory Coast). *J. Biogeogr.* 23:47–55.
- POWELL, J.W. 1895. *Canyons of the Colorado*. Argosy-Antiquarian Ltd., New York.
- ROMME, W.H., K.D. HEIL, J.M. PORTER, and R. FLEMING. 1993. *Plant communities of Capitol Reef National Park, Utah*. Technical Report NPS/NAUCARE/NRTR-93/02, National Park Service, Cooperative Park Studies Unit, Northern Arizona University, Flagstaff, AZ.
- SARTHOU, C. and J-F. VILLIERS. 1998. Epilithic plant communities on inselbergs in French Giana. *J. Veg. Sci.* 9: 847–860.
- SHULTZ, L.M., E.E. NEELY, and J.S. TUHY. 1987. Flora of the Orange Cliffs of Utah. *Great Basin Naturalist* 47:287–298.
- SYSTAT. 1999a. SYSTAT® 9 Software. SPSS, Inc., Chicago, IL.
- SYSTAT. 1999b. SYSTAT® 9 Statistics I. SPSS, Inc., Chicago, IL.
- SZARZYNSKI, J. 2000. Xeric islands: environmental conditions on inselbergs. In: W. Barthlott and S. Poremski, eds. *Inselbergs, Ecological Studies Vol. 146*, Springer-Verlag, Berlin. Pp. 37–48.
- TUHY, J.L. and J.A. MACMAHON. 1988. *Vegetation and relict communities of Glen Canyon National Recreation Area*. Final report NPS contract CX1200-6B076. Glen Canyon National Recreation Area, National Park Service, United States Department of the Interior, Page, Arizona, USA.
- VEGBANK. 2005. The Ecological Society of America. <<http://vegbank.org/vegbank>> Accessed March 2006.

- WELSH, S.L. 1986a. New taxa and combinations in the Utah flora. *Great Basin Naturalist* 43:254–260.
- WELSH, S.L. 1986b. New taxa in miscellaneous families from Utah. *Great Basin Naturalist* 43:261–264.
- WELSH, S.L. 1989. On the distribution of Utah's hanging gardens. *Great Basin Naturalist* 49:1–30.
- WELSH, S.L., N.D. ATWOOD, S. GOODRICH, and L.C. HIGGINS. 2003. *A Utah flora*, 3rd edition. Brigham Young Univ. Press, Provo, Utah.
- WELSH, S.L. and S.L. MOORE. 1968. Plants of Natural Bridges National Monument. *Proc. Utah Acad. Sci.* 45: 220–248.
- WELSH, S.L. and C.A. TOFT. 1981. Biotic communities of hanging gardens in southeast Utah. *Res. Rep. Nat. Geogr. Soc.* 13:663–681.
- WILKINSON, L., G. BLANK, and C. GRUBER. 1996. *Desktop analysis with SYSTAT*. Prentice Hall, Upper Saddle River, NJ.
- WOODBURY, A.M. 1933. Biotic relationships of Zion Canyon, Utah with special reference to succession. *Ecol. Monogr.* 3:147–245.