HABITAT AND COMMUNITY RELATIONSHIPS OF CLIFFROSE (*COWANIA MEXICANA* VAR. *STANSBURIANA*) IN CENTRAL UTAH

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Abstract.—Cliffrose (*Cowania mexicana* var. *stansburiana* [Torr.] Jepson) community measurements were taken in central Utah. Data revealed a high between-site similarity of 78.5%. Soil analysis for sites showed most macronutrients, and some micronutrients, relatively low. Cover of cliffrose was found to increase with increases in soil magnesium ($p \leq 0.01$). Plants growing on the sites have adapted life cycles to exploit moisture and nutrients during seasons of maximum availability. Prevalent species in the community were cheatgrass (*Bromus tectorum*), cliffrose, madwort (*Alyssum alyssoides*), and bluebunch wheatgrass (*Agropyron spicatum*). Annual grasses were the most important life form to community composition; the second was shrubs. Ratios between soil nutrients and cliffrose tissue nutrients indicate active transport of some elements. Data indicated a steady decline in establishment of new cliffrose individuals on the sites since 1957. This lack of reproductive success is most likely due to a combination of factors but appears most influenced by the elevated levels of annual plants (mainly cheatgrass) on the sites. If the cliffrose communities in central Utah are to be maintained, special attention to their management must be considered and implemented.

Cliffrose (*Cowania mexicana* var. *stansburiana* [Torr.] Jepson) (McMinn 1939) is an evergreen shrub, a member of the rose family, and is found growing on dry, rocky slopes in the western United States (McArthur et al. 1983). The plant ranges from 1 to 4 m in height, but under favorable circumstances near the south rim of the Grand Canyon it becomes a small tree 6 to 8 m high (Dayton 1931, Blauer et al. 1975).

In central Utah it is characteristically found associated with limestone areas on west and southwest slopes at elevations between 1,200 and 2,400 m. Elsewhere, it is found on granitic, volcanic, and other igneous formations where it is most often associated with juniper, pinyon, mountain mahogany, serviceberry, sagebrush, live oak, and other moderately dry site (xerophytic) shrubs and small trees (U.S. Forest Service 1937). The geographical range of cliffrose reaches from western Colorado to California and from northern Utah to Mexico (McMinn 1939, McArthur et al. 1983).

Although its herbage has a bitter taste, cliffrose is a valuable browse species for many animals. On the Kaibab Plateau of northern Arizona, degree of twig use on cilffrose was, for many years, viewed as an indicator of hunting pressure needed to control the deer herds (McCulloch 1966). Since cliffrose is found mostly on low-elevation deer winter ranges, is evergreen, and stands above the snow and within reach to permit grazing, it is one of a few available food sources for deer during the critical winter period.

The importance of cliffrose as forage for both livestock and wildlife has stimulated studies dealing with its potential in range revegetation and in reclamation (McCulloch 1969 and 1971, Alexander et al. 1974, Plummer 1974, Giunta et al. 1975, Evans and Young 1977). Other studies have dealt with its utilization by deer and livestock and its response to browsing (Jensen and Scotter 1977, McCulloch 1978, Neff 1978, Jensen and Urness 1981).

Smith (1957) compared the nutritional value of cliffrose with other important range shrubs. His data show cliffrose to be average when compared with other shrubs. Welch et al. (1983) found cliffrose to have winter crude protein levels of 8.8% and winter in vitro digested dry matter contents of 36.7%. Both of these values rank well among comparable values for other winter forages.

Other works on cliffrose include seed germination (Piatt and Springfield 1973, Stevens et al. 1981, Young and Evans 1981), hybridization and introgression of cliffrose into bitterbrush (Stutz and Thomas 1963, Blauer et al. 1975, Koehler and Smith 1981,

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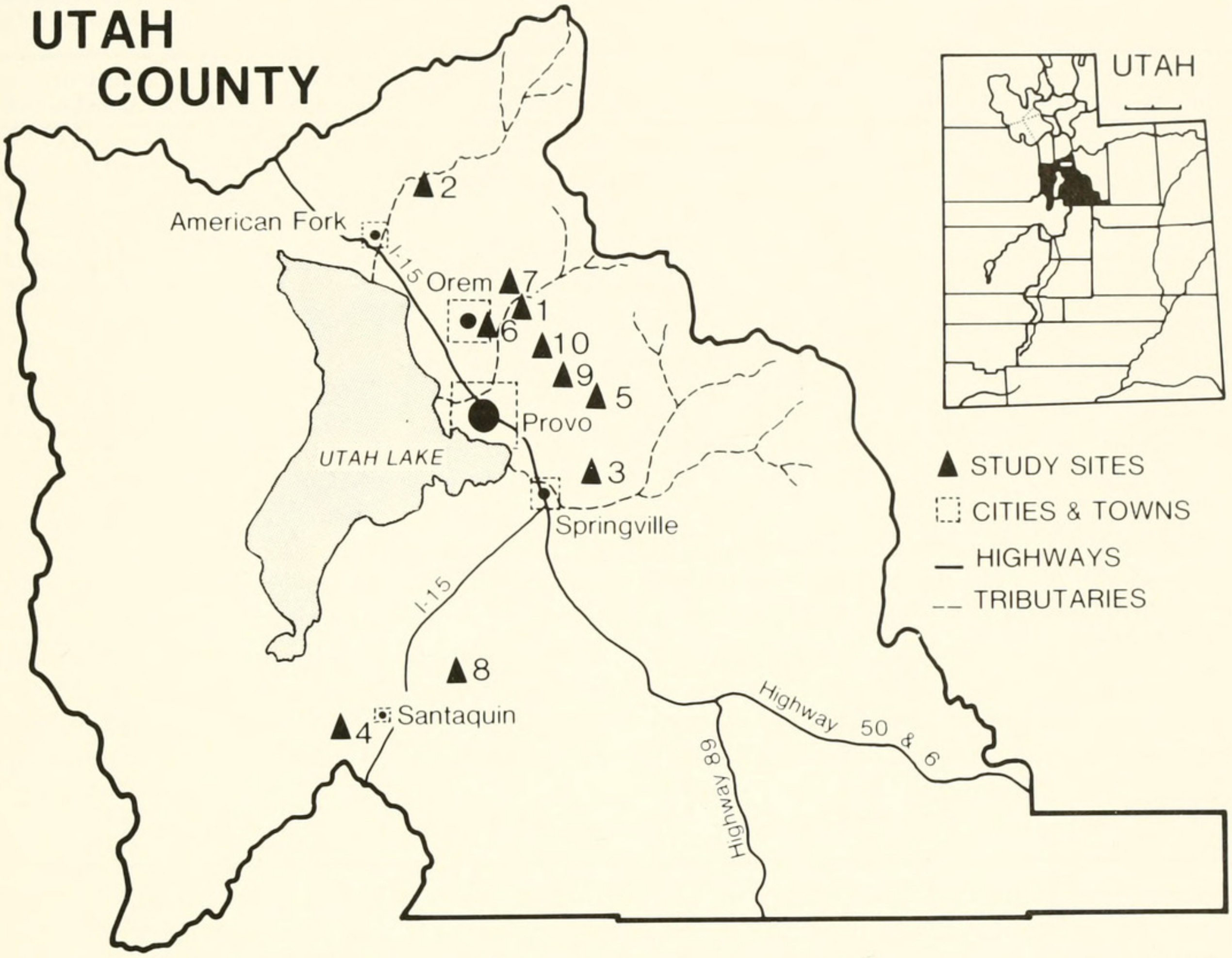

Fig. 1. A map of the study area (Utah County) in central Utah. The site names are: (1) Edgemont–Provo Canyon Junction; (2) American Fork Canyon; (3) Springville; (4) Santaquin; (5) Rock Canyon; (6) Provo River bottom; (7) Northern Provo Canyon; (8) Spring Lake; (9) Southern Indian Hills; and (10) Northern Indian Hills.

McArthur et al. 1983), secondary chemistry (Haynes and Holdsworth 1980) nitrogen-fixing ability (Righetti and Munns 1980, Nelson 1983, Righetti et al. 1968), and root morphology (Cline 1960).

A literature search revealed few studies addressing the ecology and habitat requirements of cliffrose. However, some studies were found dealing with the subject. Fairchild and Brotherson (1980) discussed the microhabitat relationships of six major shrubs in Arizona (which included cliffrose); Mortensen (1970) studied the ecological variations of leaf anatomy of apache plume (*Fallugia paradodoxa*), cliffrose, bitterbrush (*Purshia* sp.), and mountain mahogany (*Cercocarus* sp.); Stutz and Thomas (1964) and McArthur et al. (1983) studied habitat differences between antelope bitterbrush and Stansbury cliffrose; and Koehler and Smith (1981) described sites where desert bitterbrush and Stansbury cliffrose grow together with desert bitterbrush occupying slightly lower elevations.

Since cliffrose assumes a vital role in sustaining wildlife, and since there is a lack of studies dealing with its habitat relationships, this study of cliffrose was undertaken to further our understanding of its habitat requirements. Our objectives were to investigate the habitat and community relationships of cliffrose in central Utah where it is growing near the limit of its northern range (Cole 1982, McArthur et al. 1983) and to determine factors affecting its growth and establishment. This information should aid in the formulation of management plans to improve wildlife winter range.

Study Area

The study area, confined to central Utah (Fig. 1), is located along the west face of the

TABLE 1. Highs, lows, means, standard deviations, and coefficients of variation for abiotic factors associated with the cliffrose sites in central Utah.

Abiotic factors	High	Low	Mean	Standard deviation	Coefficient of variation
		General site factors			
% Gravel	62.0	30.0	48.7	10.3	21.1
% Sand	76.0	3.0	53.6	23.9	25.9
% Silt	41.0	15.0	27.9	8.5	30.5
% Clay	34.0	10.0	18.3	7.5	41.0
% Organic matter	7.1	2.5	4.8	1.6	33.3
Soil penetrability (cm)	28.0	9.0	17.9	7.4	41.3
Soluble salts	477.0	330.0	398.4	48.1	12.1
Aspect (degrees)	330.0	140.0	244.0	58.5	24.0
% Slope	73.0	2.0	42.8	26.2	61.2
Elevation (m)	1591.0	1472.0	1562.0	38.9	2.5
pH	7.7	7.6	7.7	0.04	0.5
		Soil nutrients			
Nitrogen (%)	0.230	0.054	0.129	0.053	41.1
Phosphorus (ppm)	17.4	7.3	12.8	3.8	29.7
Potassium (ppm)	369.7	85.2	175.5	101.9	58.1
Calcium (ppm)	6850.0	3825.0	5763.4	912.0	15.8
Magnesium (ppm)	258.0	113.3	190.1	66.5	35.0
Sodium (ppm)	356.3	21.8	96.9	120.9	124.8
Zinc (ppm)	9.7	1.1	4.2	2.6	61.9
Iron (ppm)	13.4	4.3	6.7	2.6	37.8
Manganese (ppm)	12.4	2.6	6.2	2.7	43.5
Copper (ppm)	2.7	0.6	1.3	0.6	43.0

Wasatch Mountains between American Fork Canyon on the north and the town of Santaquin on the south, a distance of 64 km. The cliffrose communities selected for study were chosen from the largest and most dense stands in the area and were thought to represent optimal habitat for the species in this part of its range.

The Wasatch Mountains are primarily composed of sedimentary limestone formations high in calcium carbonate. Rainfall in the area averages 422 mm (NOAA 1922–72), with approximately 280 mm falling between October and April (USDA 1972). The average annual temperature is 10.6 C, with frost-free period averaging 150 days (USDA 1972).

Perennial grasses, predominantly bluebunch wheatgrass (*Agropyron spicatum*), make up 65 to 85% of the original plant cover, with shrubs accounting for another 10 to 20%. The dominant shrubs in the area are: gambel oak (*Quercus gambelii*), big sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), and snowberry (*Symphoricarpos oreophilus*) (USDA 1972).

METHODS

Vegetation

Ten study sites were selected from the cliffrose communities in central Utah. A 10 x 10 m study plot (0.01 ha) was established at each site. Plot boundaries were delineated using a 40-m cord with loops at each corner. Corners were secured by steel stakes. Subsampling was done using twenty 0.25m^2 quadrats placed at regular intervals within the study area. Percent cover by species (Daubenmire 1959) and by life form (Ostler et al. 1981) was estimated at each quadrat. Field data were collected during September and October 1981. Maximum annual growth for most species encountered had been reached and the annuals, though dry, were still in place.

Individual cliffrose plants as well as branches and twigs were randomly selected for sampling from each site. Average cliffrose twig length (current year's growth) on the individuals was calculated by measuring 3 twigs from 10 branches for a total of 30 measurements per study site. Leaves and current-year

TABLE 2. A comparison of average nutrient and standard deviation values for cliffrose sites in central Utah and native plant sites sampled throughout the state.

Soil nutrient factors	Cliffrose sites		Native plant sites throughout Utah*	
	$\overline{X}$	S	$\overline{X}$	S
Nitrogen (%)	0.129	0.053	0.153	0.09
Phosphorus (ppm)	12.8	3.8	42.1	43.1
Potassium (ppm)	175.5	101.9	329.0	144.1
Calcium (ppm)	5763.0	912.0	7178.0	4457.0
Magnesium (ppm)	190.1	66.5	398.8	196.4
Sodium (ppm)	96.9	102.9	—	—
Zinc (ppm)	4.2	2.6	2.1	2.3
Iron (ppm)	6.7	2.6	—	—
Manganese (ppm)	6.2	2.7	—	—
Copper (ppm)	1.3	0.6	2.1	1.4

*Data obtained from Woodward (1981).

stem growth were collected and separated for chemical tissue analysis. Tissue mineral concentrations were obtained for nitrogen, phosphorus, potassium, calcium, magnesium, zinc, manganese, iron, and copper for both leaf and stem material. Analysis of tissue was performed as described by Graham et al. (1970).

Stem cross sections were taken from five randomly selected cliffrose individuals per site to estimate stand age. The cross sections were later sanded and annual growth rings counted to determine stem age (Ferguson 1970). Stem ages were averaged to determine average stand age. Each growth ring was assumed to equal one year. Density of cliffrose was determined by counting all plants within the 0.01 ha study plot.

Degree of hedging by wildlife was categorized using nine form classes: 1 = all available, lightly hedged; 2 = all available, moderately hedged; 3 = all available, heavily hedged; 4 = largely available, lightly hedged; 5 = largely available, moderately hedged; 6 = largely available, heavily hedged; 7 = mostly unavailable; 8 = unavailable due to height; 9 = unavailable due to hedging (Anderson 1974).

Soils

Three soil samples were obtained from opposite corners and the center of each plot. Samples were taken from the top 30 cm of the soil profile. The samples were analyzed for texture (Bouyoucos 1951), organic matter (Graham 1948), pH, soluble salts, and mineral composition. Soil reaction was calculated using a glass electrode pH meter. A Beckman electrical conductivity bridge was used to determine total soluble salts. Determinations for pH and soluble salts were made on 1:1 g/v soil-water paste (Russell 1948). A buffered 1.0 neutral normal ammonium acetate solution was used to extract exchangeable calcium, magnesium, potassium, and sodium (Jackson 1958, Hesse 1971, Jones 1973). Zinc, manganese, iron, and copper were extracted from the soils using DTPA (diethylene-triamine-pentaacetic acid) extracting agent (Lindsay and Norvell 1969). Ion concentrations were determined using a Perkin-Elmer Model 403 atomic absorption spectrophotometer (Isaac and Kerber 1971). Soil phosphorus was extracted with sodium bicarbonate (Olsen et al. 1954). Total nitrogen analysis was determined by using macro-Kjeldahl procedures (Jackson 1958).

Altitudes were obtained with an altimeter. Percent slope was measured with a clinometer. Aspect was determined with a compass. Soil penetrability was measured with a thin steel rod (0.65 cm diameter) which was pushed into the soil as far as possible by hand.

Data Analysis

Data were analyzed using means, standard deviations, coefficient of variation, and regression analyses. Tests were used to determine significant relationships between cliffrose performance and various environmental factors (Ott 1977).

All species were ranked in descending order of ubiquity using a constancy x average frequency (C x F) index, and a prevalent species list was prepared for the cliffrose community following Warner and Harper (1972). Species diversity was based on MacArthur

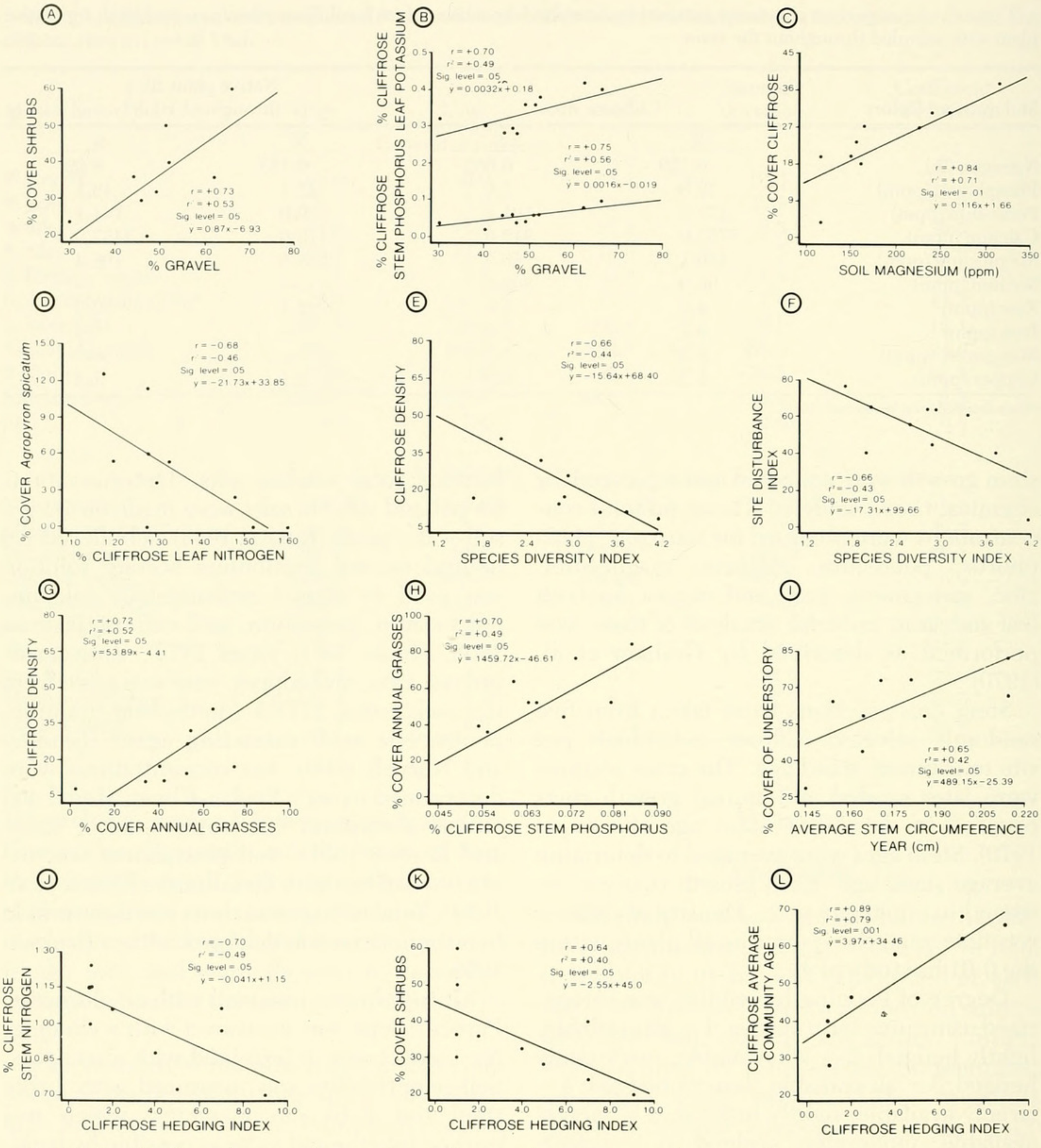

Fig. 2. Results of correlation and regression analyses with respect to site factors and vegetation parameters on the cliffrose areas: (A) the relationship between soil gravel and percent shrub cover; (B) the relationship between gravel and phosphorus and potassium in cliffrose leaf tissue; (C) the relationship between soil magnesium and cliffrose cover; (D) the relationship between cliffrose leaf nitrogen and cover of *Agropyron spicatum*; (E) the relationship between species diversity and cliffrose density; (F) the relationship between species diversity and site disturbance; (G) the relationship between annual grass cover and cliffrose density; (H) the relationship between stem phosphorus in cliffrose and annual grass cover; (I) the relationship between mean stem circumference of cliffrose and understory cover; (J) the relationship between hedging of cliffrose stems and stem nitrogen content; (K) the relationship between hedging of cliffrose stems and shrub cover; (L) the relationship between hedging of cliffrose stems and mean community age.

and Wilson's (1963) index. Plant nomenclature follows Arnow et al. (1980).

Cluster analyses (Sneath and Sokal 1973), using a dendrogram based on the cover contributions of various species at the 10 sites, were used to order the study sites.

RESULTS AND DISCUSSION

Environmental Relationships

HABITAT RELATIONSHIPS.—Cliffrose in our area generally occurred on sites with a south west exposure and an average slope of 43%.

TABLE 3. The mean, standard deviation, and coefficient of variation for nutrient ratios between cliffrose organs and soil samples. Large ratios for all nutrients, except calcium, indicate nutrient pumping has been implemented by cliffrose.

Nutrients	Leaf/soil	Stem/soil	Leaf/stem
Nitrogen	$\bar{x}$ = 12.4	$\bar{x}$ = 9.4	$\bar{x}$ = 1.39
	S = 5.8	S = 5.1	S = .28
	CV = 47.8	CV = 54.3	CV = 20.1
Phosphorus	$\bar{x}$ = 55.9	$\bar{x}$ = 46.3	$\bar{x}$ = 1.31
	S = 19.2	S = 17.2	S = .50
	CV = 40.2	CV = 49.3	CV = 38.2
Potassium	$\bar{x}$ = 24.1	$\bar{x}$ = 22.3	$\bar{x}$ = 1.16
	S = 9.7	S = 11.0	S = .25
	CV = 40.2	CV = 49.3	CV = 21.6
Calcium	$\bar{x}$ = 2.7	$\bar{x}$ = 2.3	$\bar{x}$ = 1.12
	S = .6	S = .62	S = .19
	CV = 22.2	CV = 27.0	CV = 17.0
Magnesium	$\bar{x}$ = 18.2	$\bar{x}$ = 10.0	$\bar{x}$ = 1.77
	S = 10.8	S = 4.1	S = .34
	CV = 59.3	CV = 41.0	CV = 19.2
Zinc	$\bar{x}$ = 126.5	$\bar{x}$ = 80.3	$\bar{x}$ = 1.65
	S = 52.8	S = 33.8	S = .60
	CV = 41.7	CV = 42.1	CV = 36.4
Manganese	$\bar{x}$ = 8.4	$\bar{x}$ = 5.0	$\bar{x}$ = 1.71
	S = 4.7	S = 2.7	S = .37
	CV = 56.0	CV = 38.5	CV = 21.6
Copper	$\bar{x}$ = 6.9	$\bar{x}$ = 7.8	$\bar{x}$ = .88
	S = 2.8	S = 3.0	S = .09
	CV = 40.6	CV = 38.5	CV = 10.2

TABLE 4. A prevalent species list for the study sites. Species are ranked by importance based on the C x F index. Letters in parentheses designate the species life-form class and origin: P = perennial; A = annual; S = shrub; F = forb; G = grass; N = native; and I = introduced.

Species	Percent constancy	Average frequency	C x F index	Percent average cover
1. *Bromus tectorum* (AGI)	100	90.0	9000	36.9
2. *Cowania mexicana* (PSW)	100	64.0	6400	23.7
3. *Alyssum alyssoides* (AFI)	90	40.0	3600	3.5
4. *Agropyron spicatum* (PGM)	80	35.6	2850	4.6
5. *Poa secunda* (PGM)	40	31.3	1252	1.4
6. *Bromus japonicus* (AGI)	30	35.0	1050	0.9
7. *Linaria dalmatica* (PFI)	10	75.0	750	1.0
8. *Chrysothamnus nauseosus* (PSN)	60	10.8	650	1.2
9. *Sisymbrium altissimum* (AFI)	50	12.0	600	0.2
10. *Sporobolus cryptandrus* (PGM)	20	17.5	350	0.2
11. *Erodium cicutarium* (AFI)	10	35.0	350	0.0
12. *Artemisia ludoviciana* (PFR)	40	7.5	300	0.3
13. *Artemisia tridentata* (PSN)	60	4.2	250	0.7

Elevation varied little across the sites and averaged 1,562 m (Table 1). The communities were located along the gravelly shoreline of ancient Lake Bonneville, which covered much of the western half of Utah approximately 12,000 years ago (Bissell 1968). Seven of the sites had gravelly sandy loam soils, two occurred on gravelly loams, and one on a gravelly clay loam. Soils on the sites were heavily skeletal (48.7% gravel by weight), had an av-

TABLE 5. A comparison of the mean, standard deviation, and coefficients of variation for mineral content in cliffrose stems and leaves. A paired t-test was used to determine significant nutrient differences between organs.

Cliffrose nutrient*	Stems			Leaves			Paired t-test significance level
	$\bar{X}$	S	CV	$\bar{X}$	S	CV	
Nitrogen (%)	1.00	0.20	20.0	1.40	0.10	7.1	.001
Phosphorus (ppm)	0.06	0.02	33.3	0.07	0.01	14.3	NS
Potassium (ppm)	0.30	0.07	23.3	0.34	0.05	14.7	.05
Calcium (ppm)	1.30	0.27	20.8	1.40	0.16	11.4	.05
Magnesium (ppm)	0.17	0.04	23.5	0.30	0.90	30.0	.001
Zinc (ppm)	22.90	6.30	27.5	22.70	5.30	23.3	NS
Iron (ppm)	488.40	156.00	31.9	763.70	229.00	30.0	.01
Manganese (ppm)	25.70	4.60	17.9	43.60	10.50	24.1	.001
Copper (ppm)	9.00	1.50	16.7	7.80	0.75	9.6	.01

TABLE 6. An interregional comparison of plant nutrient concentrations for cliffrose in central Utah, cliffrose in Arizona, and the average of 11 rosaceous plants sampled in Wisconsin.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	(%)					(ppm)			
Cliffrose (central Utah)									
Leaves	1.4	0.07	0.34	1.4	0.30	764	44	23	8
Stems	1.0	0.06	0.30	1.3	0.17	488	26	23	9
Cliffrose (northern Arizona)	1.0	0.06	0.34	1.0	0.12	76	9	19	7
Rose family (Wisconsin)**	1.5	0.28	1.50	1.0	0.48	154	375	44	5
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	(%)					(ppm)			
Soil nutrients									
(central Utah)	0.13	13	176	5763	190	7	6	4	1.32
(northeast Arizona)*	0.07	11	116	2358	639	5	4	2	0.46

*Data from Fairchild and Brotherson (1980).
**Data from Gerloff et al. (1964).

erage penetrability of 17.9 cm, and showed an average texture of gravelly sandy loam. Adjacent finer-textured soils of the old lake bottom apparently create a barrier to many shrubs, including cliffrose, confining them to the well-drained, lighter-textured soils of the foothills.

Soil reaction was constant across all sites with the pH being slightly basic (7.7). Cline (1960) showed cliffrose to tolerate pH's ranging from 6.8 to 8.7. Soluble salts were low, ranging from 330 ppm to 477 ppm with a mean of 389 ppm (Table 1).

Average soil nutrient concentrations in sieved samples are also given in Table 1. Data show sodium concentrations to be the most variable among sites, with calcium being the least variable. Calcium was the most abundant essential element in the sampled and nitrogen the least abundant. Our sites were generally lower in all nutrients sampled (except for the micronutrient zinc) than a broad spectrum of range soils reported by Woodward et al. (1984) (Table 2). Because nutrient deficiencies in soils are difficult to document without controlled laboratory conditions, it is important to understand with respect to our cliffrose sites that soil skeletal material reduces the volume of available nutrient or water per unit depth of profile (Crowther and Harper 1965). This is because both the nutrient and water content of soils are often determined from sieved samples in which particles over 2 mm diameter are removed. Because our soils were so heavily skeletal, nutritional deficiencies on the cliffrose sites may be even more extreme than our data portray.

Infiltration rates and depths of percolation of water are highly correlated with soil texture (Croft and Bailey 1964). Gravelly soils allow water to percolate to depths which may only be available to deep-rooted plants. Water percolation may also leach nutrients to deeper layers. Correlation analysis revealed significant positive relationships ($p < 0.01$) between shrub cover (primarily cliffrose), stem phosphorus, and leaf potassium concentrations in cliffrose and percent gravel in the soil (Figs. 2A and 2B). Cline (1960) reports that most lateral branching in the roots of bitterbrush and cliffrose was within the top 30 cm, but when lateral branching occurred at deeper regions in the soil profile, it was extensive and appeared to correlate with increased availability of moisture and nutrients. The average rooting depth of cheatgrass, our major understory species, has been reported by Klemmedson and Smith (1965) to be 30 cm. Cline (1960), on the other hand, reported cliffrose rooting depth to average 120 cm, with the deepest depths reported at 300 cm. These differences may help to explain the positive relationships between mineral concetrations in cliffrose tissue and percent gravel in the soil. The greater the gravel content, the deeper the leaching and the greater the opportunity for the deep roots of cliffrose to come in contact with and absorb them. Because of the differences in rooting depth, and the fact that the period of most active moisture absorption for cheatgrass is in late fall and early spring (Klemmedson and Smith 1964), a time when moisture in deeper soil profile levels is usually abundant, we feel competition for moisture between adult cliffrose individuals and cheatgrass may be less severe than one might otherwise predict. Competition for available nutrients may also be less than one would normally anticipate.

Mineral Nutrient Relationships.—Due to the general absence of soil moisture and low levels of soil nutrient concentrations which are characteristic of cliffrose-dominated sites, cliffrose appears to have evolved strategies enabling it as a species to tolerate infertile environmental conditions. Cliffrose is evergreen and therefore can immediately begin to photosynthesize as soon as winter breaks. The plant flowers in spring, when soils are recharged with moisture and organic matter has been broken down releasing available nutrients to the soil. Also, since cliffrose is evergreen, its nutrient demands should be much less than for other plants that must reconstruct their foliage each year. Conservation of nutrients and the exploitation of resources during peak supply would favor the survival of cliffrose on pioneer sites (Harper and Buchanan 1982). Deep taproots, with regions of increased lateral branching, would also aid in survival during dry periods. Cliffrose may experience success on sites that are low in nitrogen because of its ability to fix nitrogen (Righetti and Munns 1980, Nelson 1983, Righetti et al. 1986).

The insolubility of iron in the alkaline soils of western United States often renders the element unavailable to plants (Mortvedt et al. 1972). Low concentrations of iron were recorded on several of our sites (Table 1). The ratio between iron in cliffrose leaves and the soil where it grows (Table 3) was 127. Ratios for all nutrients, except calcium, were relatively high, especially for the macronutrients (Table 3). This demonstrates that cliffrose, like other shrubs (Brotherson and Osayande 1980), has the ability to actively pump nutrients. This ability may also help explain how the plant is able to exist on sites that are somewhat nutrient deficient.

Positive correlations ($p \leq 0.05$) developed between percent cover of shrubs (predominantly cliffrose) and concentrations of stem phosphorus, stem nitrogen, stem copper, and leaf potassium in cliffrose which would indicate that where shrub cover is high, cliffrose does its best job of pumping nutrients. Cover of associated understory species also increased as soil nutrient concentrations increased. Cliffrose cover itself was found to be positively correlated ($p < 0.01$) with soil magnesium (Fig. 2C), yet parent material for the gravels of the cliffrose sites studied was calcium carbonate ($CaCO_3$). Dolomite ($CaCO_3$-$MgCO_3$) is relatively scarce in the areas near our study sites, and parent material for the Wasatch Mountains in central Utah is generally low in magnesium. So, local weathering patterns that free magnesium ions into the soil profile may be important to cliffrose ecology. For example, Brotherson et al. (1985) showed the distribution of plant communities to be strongly related to localized weathering patterns. Further, plant communities surrounding Utah Lake in central Utah show exchangeable magnesium concentrations ranging from 247 to 1,039 ppm (Brotherson and Evenson 1981). Brotherson and Evenson's (1981) data show magnesium to become progressively more concentrated in the more highly weathered soils as one moves from the mountain foothills to the valley floor, and finally to the lake's edge.

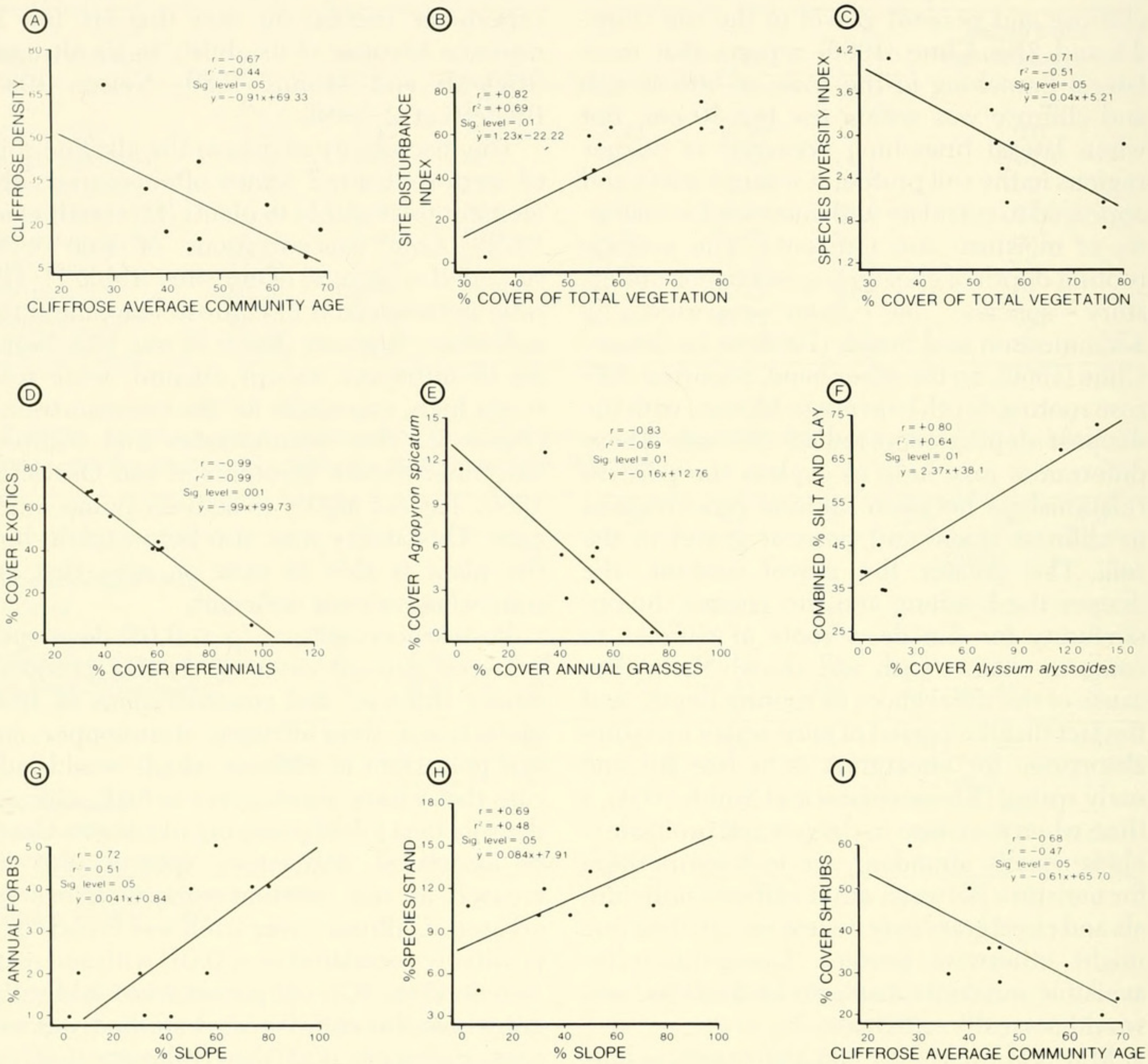

Fig. 3. Results of correlation and regression analyses with respect to site factors and vegetation parameters on the cliffrose areas: (A) the relationship between average community age and cliffrose density; (B) the relationship between cover of total vegetation and site disturbance; (C) the relationship between cover of total vegetation and species diversity; (D) the relationship between perennial cover and exotic cover; (E) the relationship between annual grass cover and cover of *Agropyron spicatum;* (F) the relationship between cover of *Alyssum alyssoides* and soil silt and clay; (G) the relationship between percent slope and number of annual forbs/stand; (H) the relationship between percent slope and number of species/stand; (I) the relationship between mean community age and shrub cover.

The cliffrose sites were dominated in the understory by exotic annuals (Table 4), all of which exploit site moisture and nutrient reserves at a time of peak availability. These exotics sprout, use up much of the moisture and nutrient reserves, produce seed, and die by the time other plants are emerging from dormancy. Since these exotic annuals are such successful competitors, this could only happen if the overstory and the understory were exploiting different nutrient levels in the soil.

Correlation analysis indicated that as the percent cover of bluebunch wheatgrass increased, nitrogen concentrations in cliffrose leaves decreased ($p \leq 0.05$) (Fig. 2D). Also, cliffrose density was negatively correlated ($p \leq 0.05$) with species diversity (Fig. 2E), and species diversity was negatively correlated with site disturbance (Fig. 2F). Further, as cliffrose density increased, percent cover of annual grasses increased ($p \leq 0.05$) (Fig. 2G); and, concurrently, concentrations of phos-

TABLE 7. Measurements concerning cliffrose population density, plant age, community age, and plant anatomy.

Soil nutrient factors*	High	Low	Mean	Standard deviation	Coefficient of variation
Density (plants/ha)	6700.0	700.0	2450.5	1851.0	75.5
Average height (cm)	240.0	103.0	171.8	39.4	22.9
Average community age	68.6	28.3	49.5	13.6	27.5
Individual plant age	162.5	11.1	48.6	28.7	59.1
Average twig length (cm)	13.3	2.0	6.3	3.4	54.0

phorus in cliffrose stems increased ($p \leq 0.05$) (Fig. 2H). Understory cover (predominantly annual grasses) and average increase in circumference per year of cliffrose stems were also positively correlated ($p \leq 0.05$) (Fig. 2I). These facts tend to indicate a greater competition between cliffrose and deep-rooted perennial grasses for moisture and nutrients than between cliffrose and the more shallow-rooted annual grasses.

CLIFFROSE TISSUE CHEMISTRY.—The current annual growth of cliffrose stems and leaves was chemically analyzed for mineral nutrient content. Table 8 compares average nutrient values obtained for cliffrose stems and leaves. Tests for significant differences between stem and leaf nutrients were made using a paired t-test (Ott 1977). Significantly higher concentrations ($p < 0.05$) of minerals were found in cliffrose leaves than in cliffrose stems for all nutrients analyzed, with the exception of copper, phosphorus, and zinc. Copper concentrations were significantly lower in the leaves, whereas phosphorus and zinc showed no differences. The stem nutrient showing the least variability between sites was copper, while iron showed the most variability. Nitrogen concentration in the leaf was least variable, while iron and magnesium were the most variable leaf nutrients. High concentrations of iron were found in both leaves and stems of cliffrose (Table 5). Leaf samples were recollected from all the sites and reanalyzed to check against possible sample contamination. The samples were washed in distilled water, oven dried, and hand ground with a ceramic mortal and pestle. Results of the second analysis confirmed the accuracy of the first.

Nutrient values obtained for cliffrose in central Utah were compared with values for the species at other geographical locations (Fairchild and Brotherson 1980). Also, the values of this study were compared with analyses for other species of the rose family (Gerloff et al. 1964) (Table 6). The differences between cliffrose nutrient content in central Utah and those in northeastern Arizona are generally small and may be attributed to differences in the soil nutrient pool. Unfortunately, soil data for the Wisconsin study were not available. In comparing cliffrose chemistry in central Utah with that in northeastern Arizona and with other members of Rosaceae from Wisconsin, one notes tissue iron concentrations to be highest in cliffrose from central Utah. Soil samples for the Utah and Arizona studies are relatively low in available iron. At present, the high iron concentrations in cliffrose from central Utah remain unexplained. One will also note that average tissue manganese for rosaceous species from Wisconsin is much greater than values for either of the cliffrose studies. Soils in the eastern United States are generally acidic, which would make more manganese available for passive absorption. In the West, soils are generally alkaline, which keeps manganese relatively insoluble and unavailable for plant use. Hoffer (1941) points out that nitrogen fixation and ammonification processes are dependent on manganese; therefore, soils high in calcium carbonate are generally deficient in this element. The high differences in manganese concentrations between eastern and western United States plants are most likely due to availability in the soil. With the exception of calcium, macronutrient concentrations for cliffrose sites from both Utah and Arizona were lower than average concentrations found for rosaceous members in Wisconsin (Table 9). The parent material for the soils of cliffrose in central Utah and northeastern Arizona are high in calcium. Further research is needed to determine to what extent varying nutrient concentrations between different species can be attributed to natural selection as opposed to inaccurate sampling and analyzing techniques.

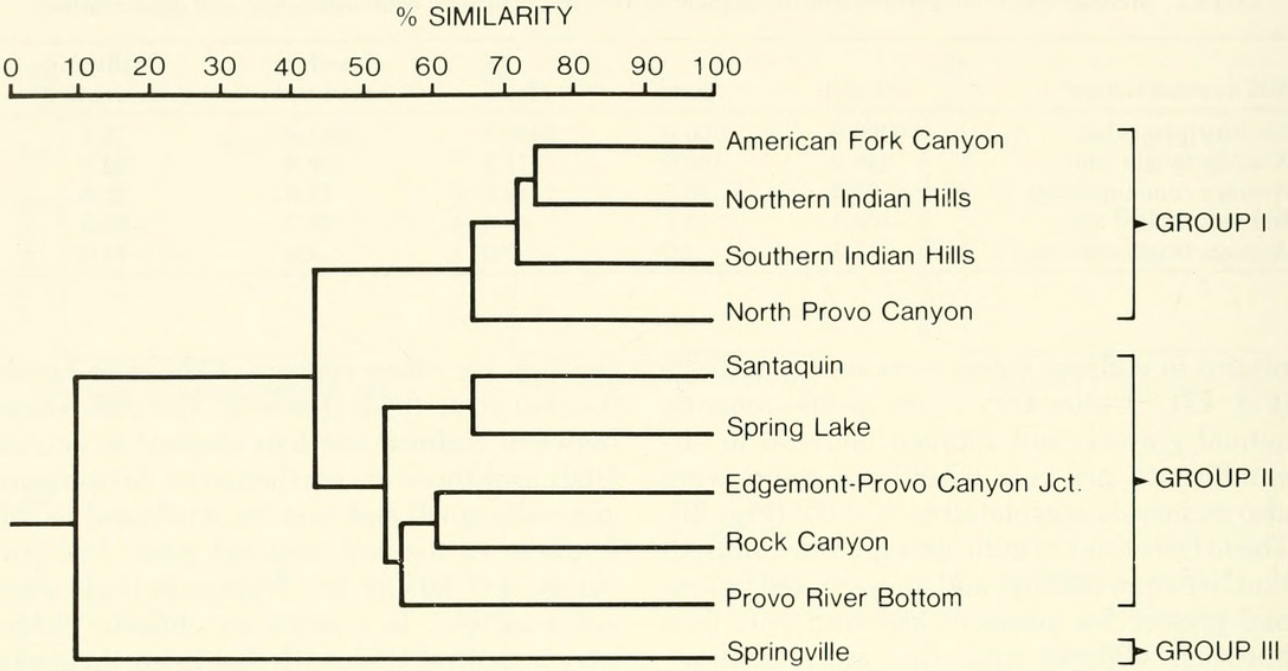

Fig. 4. A dendrogram showing cluster groups between study sites based on percent similarity of species cover by stand.

ANIMAL UTILIZATION.—Degree of hedging by wildlife showed a negative correlation ($p \leq 0.05$) with percent nitrogen found in the stems of cliffrose (Fig. 2J). This is best explained by the differential stem growth stimulated by varying degrees of plant pruning due to utilization. The greater the stem elongation, the more dilute stem nitrogen should become. Data also indicated that the older cliffrose communities were more heavily hedged than the younger communities.

Cliffrose utilization increased as percent cover of shrubs on the sites decreased ($p \leq 0.05$) (Fig. 2K). Also, utilization increased as community age of the cliffrose stands increased ($p \leq 0.05$) (Fig. 2L); and as the age of the cliffrose stands increased, cliffrose density decreased ($p \leq 0.05$) (Fig. 3A). Density measurements revealed central Utah cliffrose communities to have an average of 2,451 plants per hectare (Table 7). The average height of cliffrose on our study sites was 171.8 cm, with the shortest community averaging 103 cm and the tallest 240 cm (Table 7). Increases in utilization of the older cliffrose stands can most likely be attributed to older communities having fewer plants, which would tend to increase the grazing pressure per plant. Further, the large plants should provide better thermal cover, as well as better escape cover, thus providing incentive for animals to concentrate in their vicinity with resultant higher use.

Community Relationships

COMMUNITY STRUCTURE.—A percent similarity index between communities was calculated using data based on measurements of cover. Cluster analysis was then used to group the cliffrose stands.

The cluster based on cover of individual species showed the sites to have an average percent similarity of 42.8% (Fig. 4). The dendrogram (Fig. 4) shows three relatively distinct groups. Cover data for stands in Group I, Group II, and Group III were averaged (Table 8). Group I had the greatest cover and was dominated by exotic annuals, mainly cheatgrass. Group II had the next greatest cover and was also dominated by annuals, but less so than in Group I. Percent perennial cover in Group II was slightly higher than in Group I, but cliffrose cover remained constant. Data showed the major life form for Group III to be perennial grasses. Unlike the other cliffrose study sites, this stand recorded few annuals during our original investigation. However, when reexamined in the spring (1982), spots originally recorded as bare ground were found to be heavily covered by the small introduced annual, jagged chickweed (*Holosteum umbel-*

TABLE 8. Cliffrose study sites as grouped by cluster analysis. Sites are grouped based on percent similarity of the averaged percent cover contributed by prevalent species. Figure 3 shows American Fork Canyon–Northern Provo Canyon in Group I, Santaquin–Provo River Bottom in Group II, and Springville in Group III. Letters in parentheses designate the species life-form class and origin: P = perennial; A = annual; S = shrub; F = forb; G = grass; N = native; and I = introduced.

Species	Group I	Group II	Group III
1. *Bromus tectorum* (AGI)	61.0	25.0	0.4
2. *Cowania mexicana* (PSW)	26.0	26.0	3.5
3. *Alyssum alyssoides* (AFI)	7.0	1.2	0.3
4. *Agropyron spicatum* (PGM)	2.3	5.1	11.5
5. *Poa secunda* (PGM)	0.3	0.1	10.5
6. *Bromus japonicus* (AGI)	0.2	1.6	0.0
7. *Linaria dalmatica* (PFI)	0.0	2.1	0.0
8. *Chrysothamnus nauseosus* (PSN)	3.1	0.0	0.0
9. *Sisymbrium altissimum* (AFI)	0.5	0.4	0.0
10. *Sporobolus cryptandrus* (PGM)	0.0	0.1	0.0
11. *Erodium cicutarium* (AFI)	0.1	0.0	0.0
12. *Artemisia ludoviciana* (PFR)	0.1	0.0	2.3
13. *Artemisia tridentata* (PSN)	1.0	0.1	3.1
Total cover	102.1	61.7	32.1

latum). According to Arnow et al. (1980), the plant grows on highly disturbed sites. Jagged chickweed was not found established to any degree of significance on any of the other sites following reexamination. In spite of this addition, Group III was distinctly different from the other groups in terms of plant cover composition. Total cover values and species composition showed major differences among the three groups (Table 8).

DIVERSITY.—Diversity has two conceptual aspects that deserve attention: (1) the number of species per unit area and (2) the evenness of abundance among the species present. Community diversity (MacArthur and Wilson 1963) on our sites varies from a high of 4.1 to a low of 1.7, with a mean of 2.8 (Table 9). The low figure was correlated with the highest incidence of cheatgrass on a site and indicates that only a few species were contributors to the vegetative composition. The high figure was associated with a site which had little cheatgrass cover and where several species were shown to contribute to the vegetative cover.

Assuming the cover contributed by exotics to be highly correlated with the degree of site disturbance (Klemmedson and Smith 1964), we formulated a disturbance index based on the amount of cover contributed by introduced species on our sites. Correlation analysis showed a positive relationship ($p \leq 0.01$) between the site disturbance index and percent cover of total vegetation (Fig. 3B). Further, a negative correlation ($p \leq 0.05$) was found between species diversity and total plant cover (Fig. 3C). As the site disturbance index increased, species diversity decreased (Fig. 2F). It appears, therefore, that site disturbance has tended to promote low diversity in the vegetation on our sites by allowing introduced annuals to invade into open areas where they complete their growth in the early spring while soil moisture is still abundant. The increased competition from the introduced exotics would have a crowding effect on other species and thus lead to an eventual decrease in diversity.

The prevalent species for the cliffrose sites in central Utah are listed in descending order based on the C x F index (Table 4). Again, the importance of exotics on our sites is illustrated. Cheatgrass (*Bromus tectorum*) is the most common species on the list, followed by cliffrose and madwort (*Alyssum alyssoides*), an introduced annual from Europe (Arnow et al. 1980). Nearly half the species on the list (6 out of 13) are introduced exotics (Table 4), all of which are extremely successful on disturbed sites. The data showed an average of 7.6 perennials and 3.9 annuals per stand, yet annuals contributed almost half the total cover (Table 9). Significant negative correlation ($p \leq 0.01$) also occurred between cover of perennials and cover of exotics (Fig. 3D), suggesting that perennials must decline before invading exotics can become abundant. The correlation between cover of annual grasses and the

TABLE 9. Highs, lows, means, standard deviations, and coefficients of variation for various biotic factors and life-form classes associated with the cliffrose sites in central Utah.

Factors	High	Low	Mean	Standard deviation	Coefficient of variation
% Total vegetative cover	80.0	33.8	59.7	13.9	23.3
% Exposed rock	34.1	3.1	20.1	9.7	48.3
% Bare ground	12.8	0.0	5.8	5.0	86.2
% Litter	26.4	6.6	14.8	6.4	43.2
% Mosses	13.4	0.0	3.1	4.9	158.1
% Lichens	4.1	0.0	1.3	1.4	107.7
% Trees	1.1	0.0	0.2	0.4	200.2
% Shrubs	60.3	20.2	35.4	12.2	34.5
% Perennial forbs	17.7	0.0	3.2	6.1	190.6
% Annual forbs	14.0	0.0	4.4	4.9	111.4
% Perennial grasses	65.9	0.0	11.9	19.8	166.4
% Annual grasses	74.4	1.1	45.1	19.7	43.7
% Perennials	96.6	23.5	50.5	20.9	41.4
% Annuals	76.5	3.4	49.5	20.9	42.2
% Exotics	76.1	3.4	51.1	20.7	40.5
# Perennials/study site	11.0	2.0	7.6	2.5	32.9
# Annuals/study site	7.0	2.0	3.9	1.6	41.0
# Shrubs/study site	6.0	2.0	3.8	1.3	34.2
# Species/study site	16.0	5.0	11.5	3.2	27.8
Species diversity index*	4.1	1.7	2.8	0.8	28.6

*MacArthur-Wilson (1963) diversity index.

perennial bluebunch wheatgrass (*Agropyron spicatum*) was also negative ($p \leq 0.01$) (Fig. 3E).

The distribution on our sites of the annual forb madwort is positively correlated ($p \leq 0.01$) with percent silt and percent clay in the soil (Fig. 3F). This relationship can most likely be attributed to the moisture and nutrient factors associated with finer-textured soils. The number of annual forbs on a site generally increased as the slope steepness increased ($p \leq 0.05$) (Fig. 3G). Also, the number of species per study site increased as slope steepness increased ($p \leq 0.05$) (Fig. 3H). This would indicate that the sites on the steeper slopes have more microhabitats and are probably less disturbed. The correlations may also be related to the reluctance of domestic grazing animals, the major disturbing influence of the past on these sites, to make use of the steeper slopes.

LIFE FORMS.—Cliffrose sites typically show environmentally stressed conditions related to such things as extremes in moisture, temperature, and soil nutrients. Plants that are successful on the sites are generally able to withstand a broad range of environmental fluctuations, or, as in the case of annuals, they complete their life cycles during hospitable times of the year. Of the total cover that averaged 59.7%, annual grasses contributed the largest part with 45.1%, shrubs furnished 35.4%, perennial grasses contributed 11.9%, annual forbs accounted for 4.4%, and perennial forbs contributed only 3.2% (Table 9). Gambel oak (*Quercus gambelii*) was the only tree found on the sites, and it played an insignificant role in the vegetation. Perennials contributed 50.5% of the total cover, while annuals contributed 49.5%. Averaging the constancy x frequency (C x F) index values of Table 4, we found annual grasses to be twice as important in the community as shrubs (Table 10). The C x F index reflects the uniformity with which individuals of a species are distributed across the site sampled rather than the amount of biomass produced. The values show annual forbs to be slightly more important than perennial forbs or perennial grasses in the community. Annuals (Table 10) were shown to have a higher prominence in the community than perennials.

CLIFFROSE AGE AND COMMUNITY STRUCTURE.—Cliffrose plants of varying basal circumferences were aged. Linear regression was used to establish an age-circumference relationship (Fig. 5). This relationship had an r^2 value of +0.73 and was significant at $p \leq 0.001$. The prediction equation for the relationships is $Y = 4.73$ (basal circumference) + 5.45. The average variation about the y-axis is ±6.7 years.

TABLE 10. Life forms listed in order of importance to the vegetative composition. Values were obtained by averaging the product of percent species constancy between sites and percent species frequency within sites for species of each life-form class.

Life forms	Constancy x frequency index
Annual grasses	5025
Shrubs	2433
Annual forbs	1517
Perennial grasses	1483
Perennial forbs	525
Total annuals	6542
Total perennials	4441

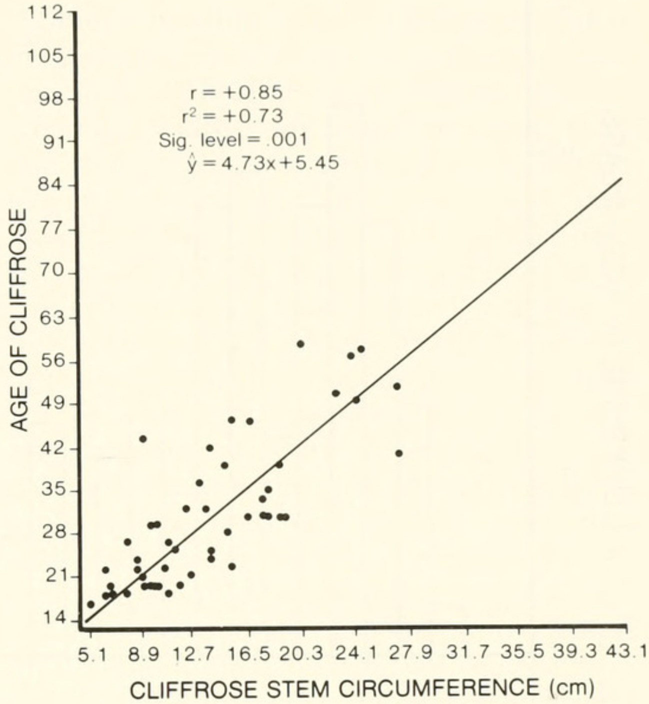

Fig. 5. The relationship between the circumference (cm) of cliffrose stems and the number of annual growth rings counted (age) of 50 cliffrose plants sampled.

Basal circumference measurements (30 per site) were randomly obtained for 9 of the 10 communities. The Springville community had only 18 living cliffrose plants. From these basal measurements, the plants of each stand were aged. By combining the estimated ages of the 288 plants studied, we constructed a histogram to show the general age distribution of cliffrose in central Utah (Fig. 6). The x-axis of the histogram shows the age classes (in 5-year intervals) and the year corresponding with the period of establishment for the age class. The y-axis is the number of plants found within each age class. The histogram shows the median cliffrose age to be between 25 and 30 years. The youngest plant found in any of the communities was 11 years, the oldest was 163 years, and the average age was 48.6 years (Table 7). The youngest average community age was 28.3 years, the oldest 68.6, and the mean was 49.5 years (Table 7).

CLIFFROSE ESTABLISHMENT.—The histogram indicates that since about 1957 there has been a steady decline in the establishment of cliffrose in central Utah. The graph also shows a substantial decline in numbers of new plants between the years 1942 and 1947. Correlation analysis showed the percent cover by shrubs (predominantly cliffrose) decreased as the average community age of cliffrose increased ($p \leq 0.05$) (Fig. 3I). The older cliffrose stands do not appear to be replacing themselves with younger plants (Figs. 3A and 6).

Reasons for establishment failure most likely represent a combination of factors. Some possible explanations should include: (1) cliffrose is cyclic in its establishment, (2) seed predation by rodents may be high, (3) plant diseases may be eliminating seedlings, (4) insects and/or small mammals may destroy seedlings, (5) climate may currently be unfavorable, (6) intraspecific competition between age classes may be extreme, (7) interspecific competition, (8) establishment requires trampling and utilization of the sites by livestock and wildlife, and (9) reproduction may be destroyed by fire.

Concern that small seedlings were overlooked during the initial data collecting period led us to reexamine all of the sites to confirm original findings. No seedlings were discovered at this time. Neither were seedlings found in any of the 200 0.25 m^2 quadrats used to estimate plant cover.

Cyclic Establishment: According to Alexander et al. (1974), cliffrose produces a good seed crop every 2 years, and young plants begin bearing seed as early as 5 years. Figure 7 is a graph comparing annual rainfall patterns with the number of cliffrose plants established each year during a 50-year period (1922–1972). Precipitation data were smoothed out using a 10-year running average to eliminate the visual impact of extremely high or low years and to emphasize long-term trends (Croft and Bailey 1964). In comparing precipitation and establishment trends, it appears that increases in rainfall may reduce cliffrose seedling success. The observed decline in

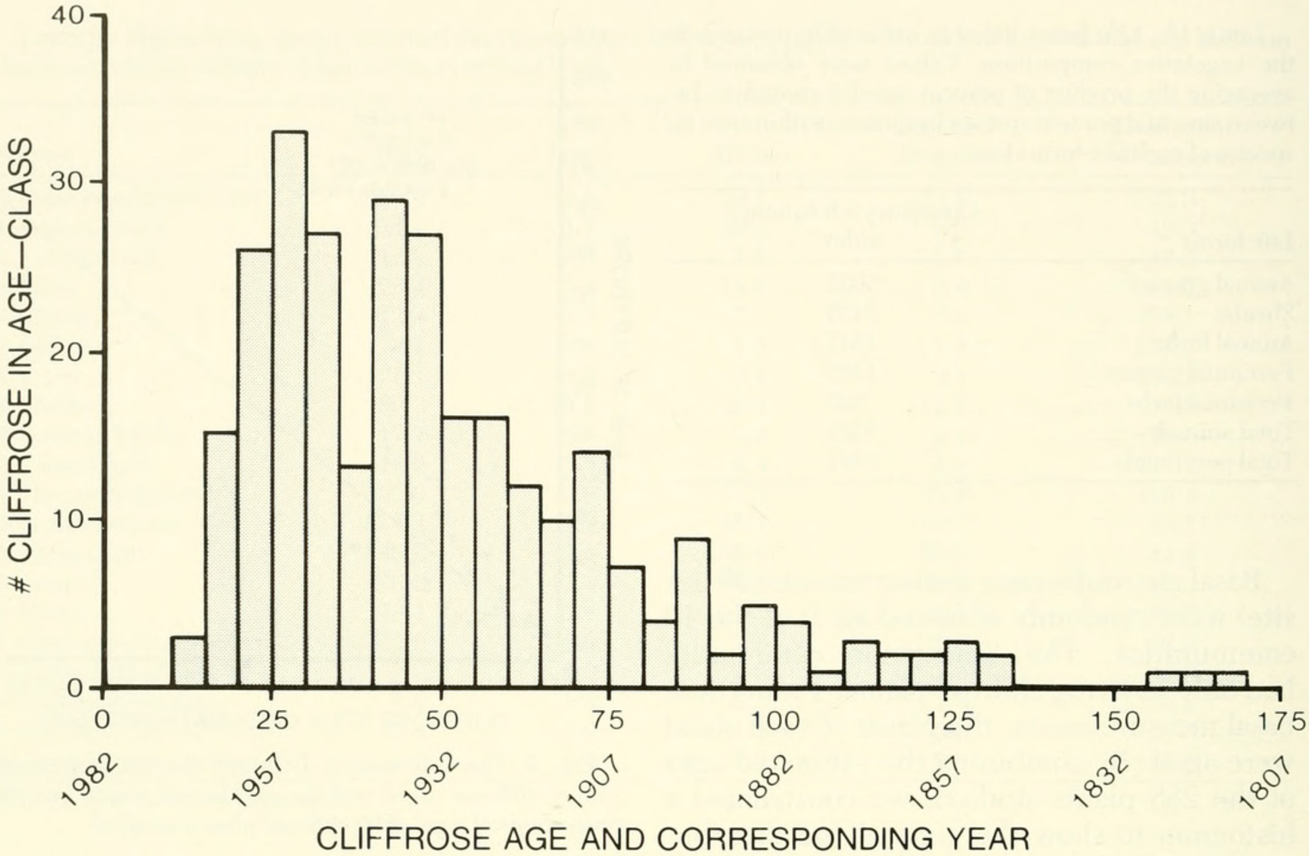

Fig. 6. A histogram depicting the establishment success and trend of cliffrose over the last 175 years.

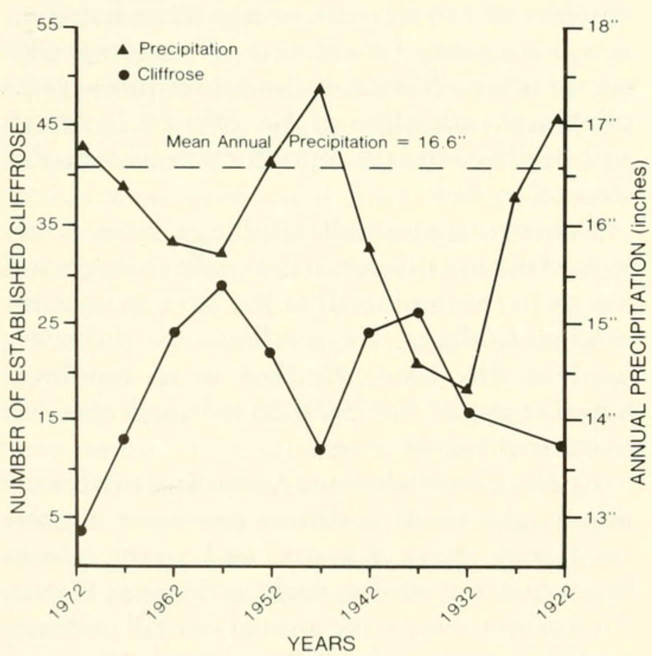

Fig. 7. A graph depicting the relationship between precipitation trends and cliffrose establishment success and trend over a 50-year period.

plants established between the years 1942 and 1947 (Fig. 6) was a peak rainfall period for the area considered. Comparison of the last 25 years for precipitation per year versus cliffrose establishment suggests that diminishing seedling success may be somewhat related to cyclic rainfall patterns.

Predation: Seed and seedling predation by rodents is a subject addressed in several papers. Alexander et al. (1974) note that clusters of new cliffrose seedlings are quite common due to rodent caches. Young and Evans (1981) state that if caches are not found by rodents, the seedlings will die from intraspecific competition. They also point out that the rodent will often miss a seedling or two, which allows for plant establishment. Seed predation by rodents may in reality enhance species dispersal and establishment.

Disease: Lack of knowledge concerning diseases of cliffrose dictates that little be said concerning this subject. No papers addressing the topic were found in the literature. However, an exceptionally high rate of mortality has been noted for greenhouse-grown seedlings of both cliffrose and bitterbrush due to damping-off fungi. Though damping-off is common among greenhouse stock, bitterbrush and, even more so, cliffrose seemed to be especially susceptible to such diseases (B. L. Welch, personal communication). Cliffrose susceptibility to damping-off under natural conditions is not known. This could be an explanation for the apparent inverse relationship found between cliffrose establishment and average annual precipitation.

Insects: The impact of insects and their relationship with cliffrose is also not well known. Again the literature revealed no studies on the subject. Although little is known concerning the subject, insect predation should not be completely ruled out as a possible influencing factor.

Climate: Drought, as a possible explanation for the lack of seedling establishment in cliffrose since 1957, is not a good choice. Over the centuries, cliffrose has adapted to an environment which is, at times, extremely dry. Climatology records (NOAA 1922–1972) show that during the major periods of decreasing seedling establishment, average precipitation was above the normal amounts recorded for preceding years.

Competition: Intraspecific competition probably has little to do with the downward trend in recent years. It is difficult to imagine that a species which has been successfully established for hundreds of years would suddenly begin outcompeting itself into possible local extinction.

However, numerous studies have been published (interspecific competition) dealing with the extreme competitiveness demonstrated by exotic annuals (Stewart and Hull 1949, Piemeisel 1951, Holmgren 1956, Klemmedson and Smith 1964, Young et al. 1972, Giunta et al. 1975, Mack 1981, Mack and Pyke 1983), particularly cheatgrass.

Cheatgrass invasion into Utah is fairly recent, having been introduced around the turn of the century (Klemmedson and Smith 1964). Studies show that cheatgrass successfully outcompetes weeds and perennial grasses which are slow growing or spring germinating (Piemeisel 1951, Stewart and Hull 1949). Evans et al. (1967) state that cheatgrass consistently closes stands to the establishment of perennial grass seedlings. Warg (1938) and Hulbert (1955) obtained success for cheatgrass germinations (under optimum conditions) as high as 99.5%. The density obtained by cheatgrass can vary greatly, depending on the conditions. Stewart and Hull (1949) found cheatgrass to vary from 1,080 to 15,000 seedlings per m^2. This gives an idea of the potential competition for moisture that cheatgrass can exert if conditions are favorable.

Studies by Giunta et al. (1975) showed that in cheatgrass stands success in the germination and establishment of cliffrose was increased as width of soil scalps increased. They also showed the average number of cliffrose plants surviving after five years in a 100-linear-foot row to be 5, 13, 19, and 59 with scalp widths of 4, 8, 16, and 24 inches, respectively. Holmgren (1956) worked with bitterbrush. He stated that high mortality occurred in the better seedling stands during the first year or so after germination. Holmgren (1956) also states that moisture at the time of germination and during the initial growth period is probably the most crucial factor associated with bitterbrush seedling success. Holmgren's (1956) study shows bitterbrush germination rates for study plots that were cleared of all competition to be 90%, with 66% surviving after the first year. Plots in which only broadleaf weeds were allowed had a 91% germination, with 48% surviving the first year. Where only cheatgrass was allowed, germination was 46%, with 0% surviving after only three months. Holmgren (1956) then concludes, "In cheatgrass stands, few bitterbrush seedlings are able to survive the first summer. The competitive effect of cheatgrass generally becomes manifest early in the growing season, coinciding with its period of rapid growth."

According to Young and Evans (1981), even under optimum conditions germination of cliffrose rarely exceeds 60%. They credit the lack of success to the amount and type of dormancy found in the seeds and suggest that an ideal field stratification environment for cliffrose seeds is one with constant moisture near field capacity and a temperature of 0 to 5 C. Therefore, the environmental requirements for success in cliffrose germination and the potential response of cheatgrass when these conditions are obtained may well explain the apparent negative relationship of cliffrose with average annual rainfall. Competition between cliffrose seedlings and cheatgrass may become highly intense during years of increased average annual precipitation and therefore help explain the lack of cliffrose establishment on our sites in recent years.

Other introduced annuals of prevalence were madwort (averaging 3.5% cover) and Japanese chess (*Bromus japonicus*) (averaging only 1%, but found well established on some sites). Original data (collected in the fall) showed storksbill (*Erodium cicutarium*) to play a minor role in the cover composition (Table 4). However, when sites were reexamined in the spring, some communities had significant quantities of storksbill and jagged chickweed in their understory.

Disturbance: Practically all 10 study sites have a history of extensive grazing pressure by sheep, cattle, and wildlife. Because they furnish food and shelter, cliffrose stands would tend to concentrate livestock and wildlife. Such disturbance would open the sites to cheatgrass invasion and establishment.

Studies conducted by Cook and Harris (1952) showed that when cheatgrass was in the dough stage (usually around May) and turning purple, sheep ate the entire plant down to one-half inch above the ground. Hull and Pechanec (1947) observed that cattle and horses ate dry cheatgrass readily if ample water were available, and both cattle and sheep ate dry cheatgrass in the winter. Stewart and Hull (1949) estimated that cheatgrass utilization as low as 35 to 40% would allow reestablishment of perennial cover. Increased utilization and disturbance of cheatgrass, due to the higher concentration of grazing animals, would most likely aid in the establishment of cliffrose by trampling its seed into the ground and reducing the competition for moisture between cliffrose seedlings and cheatgrass. However, since livestock grazing permits on most of the study sites were revoked in 1957, cliffrose establishment by increasing utilization of cheatgrass is not a good choice to explain the success or failure of seedling success. In fact, 1957 is the same year the histogram in Figure 6 shows the success of cliffrose seedlings beginning to decline.

Fire: Many of the exotic annuals grow in dense stands where they generally complete their life cycle early in the growing season and then become dry and susceptible to summer wildfires. Young et al. (1972) say, "The fuel provided by early maturing, highly flammable alien annuals contributes to the incidence and spread of these species." McCulloch's (1969) study showed cliffrose stands to be drastically reduced by fire. Fire carried by a dense stand of dried exotic annuals was responsible for destroying over half the cliffrose community on the study plot in Springville. Where the fire had swept, no cliffrose plants survived.

Cliffrose Management.—Cliffrose seedlings, when allowed relative freedom from annual competition throughout the first growing season, have highly increased establishment success. It is believed decadent cliffrose communities could be rejuvenated by reducing competition as seldom as once every 10 to 15 years.

Areas that might be considered for effective competition reduction are biological, mechanical, and chemical. Concentrated grazing to increase soil disturbance and cheatgrass utilization may in some areas have practical application. Increasing seedling success by mechanically placing scattered soil scalps within cliffrose communities could also prove to be an effective managment practice.

In the past, few methods have been successful in controlling cheatgrass and other exotic annuals (Young et al. 1972). In recent years cheatgrass control with chemicals has received attention. Though not feasible for extensive rangeland control, chemicals have real promise in enhancement of perennial grasses and browse species (Klemmedson and Smith 1964).

Summary and Conclusions

Data indicate cliffrose site preference in central Utah is highly consistent. Cliffrose communities are generally located on steeper slopes which are exposed to environmental extremes. Soils associated with cliffrose are relatively low in most macronutrients and some micronutrients. Vegetative composition is dominated by exotic annuals (predominantly cheatgrass) with shrubs (predominantly cliffrose) being the next important life form. From the data it appears that competition for resources is less severe between mature cliffrose plants and annuals than between cliffrose and perennials. The nutrient concentrations in cliffrose tissue, relative to soil concentrations, indicate nutrient pumping has been implemented for adaptation to nutrient-poor sites. Age distribution of cliffrose shows a decline in successful seedling establishment over the last 25 years. Data from this study and others indicate that the major contributing factor responsible for the decline is competitive exclusion by exotic annuals (mainly cheatgrass). Destruction of cliffrose by fire due to dense stands of exotic annuals may also explain how exotic annuals eliminate plants competing with them for environmental resources. The negative factors influencing deterioration of cliffrose populations are most likely amplified in central Utah when cliffrose is at the northern edge of its natural range. Since habitat for cliffrose in central Utah is less than optimal, if cliffrose communities are to be maintained or enhanced, special attention to their management must be considered and implemented.

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