A Quantitative Measure of Plant Association on Ranges in Good and Poor Condition

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The classification of plant species as indicators of the condition of the range is a major problem in modern range management. It is well known that the more palatable plants are replaced with less palatable plants when ranges are overgrazed. However, a particular plant species may be relatively unpalatable during a particular season or on a particular site but may be readily eaten during another season or on another site where plant association is different.

Seldom is the presence or absence of a single species used as the only indicator of range condition; usually several species are considered. Plants are often classed as increaser or decreaser plants depending on their reaction to grazing stress. A range in a deteriorated condition displays a greater abundance of increaser or less palatable plants; whereas, one in good condition has a greater abundance of decreaser or more palatable plants.

The identification of plants as indicators generally is a product of opinion based upon general observation. However, a quantitative confirmation of such classifications of indicator species for broad range types is desirable. For this reason a study of selected fence-line contrasts displaying good and poor range on alluvial benchlands in the Escalante desert in southern Utah was conducted during the fall of 1958 to determine if plant species were distributed independently over the areas or if they were associated with one another and with condition of the range.

Procedure

A total of 31 fence-line contrasts were studied. The areas sampled represented broad alluvial fans produced by outwash material from small canyons or arroyos (Figure 1). The locality receives about 8 inches of annual precipitation, about 60 percent as snow during the fall and winter and the remainder as rain during the spring and summer. Maximum temperatures during the summer reach 100° F. and mini-

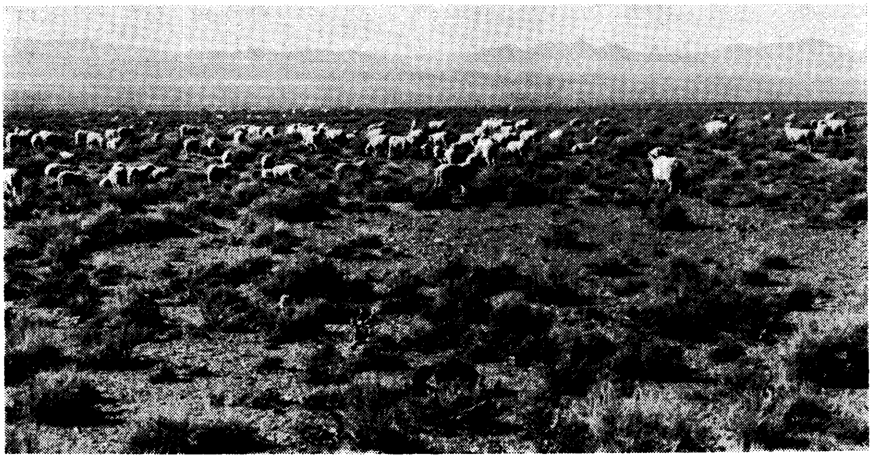

FIGURE 1. A broad view of a valley basin from the base of west-facing foothills. Foreground shows typical range on an alluvial fan.

mum temperatures during the winter drop as low as 20° below zero.

In each of the 31 areas, 6 plots, (5 x 5-foot) were located equal distance apart on a grid line running parallel with the fence and on each side of it. The data were recorded for each 1 x 5-foot sgement in the plot by moving a 1 x 5-foot frame along the 5 x 5-foot plat frame for five consecutive readings. Thus by adding the first two readings, the plot size was 2 x 5 feet, the first three readings a 3 x 5-foot plot, the first four readings a 4 x 5-foot plot and all five readings a 5 x 5-foot plot. As a result five different plot sizes were obtained and used for evaluating the effect of plot size on the interpretation of data.

One side of the fence had been protected from livestock grazing for at least the last 20 years, whereas, the other side had been grazed abusively for many years. The protected side represented range in good condition and the unprotected side displayed poor range condition. Protected areas consisted of road and railroad right-of-ways, exclosures, and ungrazed areas owned by land speculators who did not graze livestock.

Four prominent species found on most study areas were selected for study. These were winterfat *(Eurotia lanata)*, yellowbrush *(Chrysothamnus stenophyllus)*, Indian ricegrass *(Oryzopsis hymenoides)*, and galleta grass *(Hilaria jamesii)*.

Some plots had all of these species present; whereas, others had various combinations. Only the presence or absence of each of the four species was recorded.

Results And Discussions

Analysis of data was made by the conventional chi-square procedure for measuring independence and by the procedure suggested by Cole (1949) for obtaining the coefficient of interspecific association.

Chi-square determination from a 2 x 2 contingency table dealing with the presence and absence of two species is a test of association or independence of plant sociability. Plants may be associated because of mutual habitat requirements or tolerances or because one species may be dependent upon another.

Chi-square values do not measure the degree of association. Thus, the size of chi-square is not indicative of the magnitude of association since the absence of both species in plots may cause a large chi-square value yet contribute little to plant sociability.

Generally, only two species are compared at a time by chi-square analysis for a test of independence. The amount of association among three or more species can be determined by chi-square tests but this is of limited practical value unless some peculiar relation is suspected.

In this study it was desired to measure the amount of association between species and between each major species and the condition of the range—good or poor. The association of a species with range condition was likewise tested by chi-square.

The coefficient of interspecific association expresses the proportion of maximum interspecific association either positive or negative (Cole, 1949). If two species occur together as frequently as possible the positive associa-

Table 1. A 2 x 2 x 2 contingency table for winterfat and yellowbrush under good and poor range conditions and chi-square calculations.

Species[1] S_1	S_2	Range condition	Observed frequency	Expected frequency	$(O-E)^2/E$
Winterfat	Yellowbrush		(O)	(E)	(χ^2)
0	0	poor	11	24.37	7.34
0	0	good	23	24.37	0.08
0	1	poor	76	55.13	7.90
0	1	good	49	55.13	0.68
1	0	poor	27	32.65	0.97
1	0	good	53	32.65	12.68
1	1	poor	72	73.86	0.05
1	1	good	61	73.86	2.24
	Total		372	372.00	31.94

[1]Figures 0 and 1 represent the absence and presence in plots for species above them in each case, respectively.

tion is equal to plus one; if they occur together the minimum possible number of times the association is equal to minus one; and if the number of joint occurrences is exactly as expected with the hypothesis of independent scattering of two species no association is indicated and the coefficient is equal to zero.

The computation of the coefficient of interspecific association (C) and its standard error (s_c) is calculated by the following three formulae, where a, b, c, and d represent the four cells in a 2 x 2 contingency table:

When $ad \geqq bc$:

$$C \pm s_c = \frac{ad-bc}{(a+b)\ (b+d)} \pm \sqrt{\frac{(a+c)\ (c+d)}{n(a+b)\ (b+d)}}\ ;$$

when $bc > ad$ and $d \geqq a$:

$$C \pm s_c = \frac{ad-bc}{(a+b)\ (a+c)} \pm \sqrt{\frac{(b+d)\ (c+d)}{n(a+b)\ (a+c)}}\ ;$$

when $bc > ad$ and $a > d$:

$$C \pm s_c = \frac{ad-bc}{(b+d)\ (c+d)} \pm \sqrt{\frac{(a+b)\ (a+c)}{n(b+d)\ (c+d)}}\ .$$

The t value is equal to C/s_c.

Size of Plot

The frequency of occurrence of a species not only depends upon its abundance and social tendencies but also upon size of the sample plot.

If the size of the plot is large, almost all of the species in the biota may appear in the majority of the plots. If the size of the plot is small, even the most abuandant species may occur in only a small fraction of the plots. Species possessing large growth forms might not appear at all or in conjunction with other species if the plots are small.

The importance of plot size in evaluating plant association from frequency data cannot be overemphasized.

If the plot is small and plants are large, not more than one plant may appear in the plot, thus suggesting a negative association. Plots must be amply large to allow all plants to appear together as pairs under normal growth conditions and spacial distribution. Extremely large plots may include all of the abundant species and therefore suggest positive association. Sparce species cannot be evaluated properly unless the plot is large enough to include them a sufficient number of times. This however, may eliminate proper evaluation of the major species. In most cases, a test of association between a minor and a major species is impossible. A minor species may be tested for independence or association with another minor species and a major species with another major species, but the former test will require larger plots than the latter.

From the present study it is indicated that plot size is adequate when the species being compared (four or more) show some negative and some positive associations when all paired combinations are tested. If the plots are too small, a preponderance of negative associations will appear and if the plots are too large, a preponderance of positive associations will appear. The data likewise suggest that a plant to be tested for interspecific association should appear in at least 30 percent of the plots.

It was found that plots 1 x 5 and 2 x 5 feet were too small since most of the species associations tested were negative but plots 3 x 5, 4 x 5, and 5 x 5 feet gave about equal positive and negative associations among the plant species and no material difference in results was found among the three plot sizes.

Plant Association Analysis

Data for evaluating species association in the following discussion was taken from 5 x 5-foot plots.

Winterfat and Yellowbrush. The association of winterfat, yellowbrush, and range condition can be evaluated by calculating the chi-square values for these two species and range condition in various combinations.

The total chi-square value for both species and range condition was determined by constructing a 2 x 2 x 2 contingency table.

The observed frequency values were obtained from the field data involving 186 plots on poor range and 186 on adjacent good range. The probability of presence (p) was calculated by the relation of

$$\frac{\text{species occurrence on plots}}{\text{total number of plots}}$$

and the probability of absence (q) was obtained by the formula $1 - p = q$.

The following p and q values for estimating the expected frequencies for table 1 are:

$p_1 = 213/372 = .5726$ and

$q_1 = 1 - .5726 = .4274$

$p_2 = 258/372 = .6935$ and

$q_2 = 1 - .6935 = .3065$

Probability for occurrence for poor condition (P_p) is $186/372 = .50$ and likewise for good range condition (P_g) is $186/372 = .50$.

Expected values for table 1 were determined by the following calculations where subscripts 0, 1, and 2 refer to no species, species 1, and species 2, respectively:

E_{00} poor $= (q_1)\ (q_2)\ (p_p)n =$
$(.4274)\ (.3065)\ (.50)\ (372) = 24.37$

E_{00} good $= (q_1)\ (q_2)\ (p_g)n =$
$(.4274)\ (.3065)\ (.50)\ (372) = 24.37$

E_{01} poor $= (q_1)\ (p_2)\ (p_p)n =$
$(.4274)\ (.6935)\ (.50)\ (372) = 55.13$

E_{01} good $= (q_1)\ (p_2)\ (p_g)n =$
$(.4274)\ (.6935)\ (.50)\ (372) = 55.13$

E_{10} poor $= (p_1)\ (q_2)\ (p_p)n =$
$(.5726)\ (.3065)\ (.50)\ (372) = 32.64$

E_{10} good $= (p_1)\ (q_2)\ (p_g)n =$
$(.5726)\ (.3065)\ (.50)\ (372) = 32.64$

E_{11} poor $= (p_1)\ (p_2)\ (p_p)n =$
$(.5726)\ (.6935)\ (.50)\ (372) = 73.86$

E_{11} good = $(p_1)(p_2)(p_g)n$ = (.5726) (.6935) (.50) (372) = 73.86

The total chi-square from Table 1 is 31.94 with 4 degrees of freedom. However, this value includes three chi-square values, one for species 1 (s_1) and species 2 (s_2) association, another for s_1 and range condition, and a third for s_2 and range condition. These must be subtracted from 31.94 to give the corrected chi-square value for the three factors with one degree of freedom (Table 2).

The chi-square values presented in Table 2 were calculated from simple 2 x 2 contingency tables as follows:

		Winterfat (s_1) +	Winterfat (s_1) −	
Yellowbrush (s_2)	+	a 133 (147.7)	b 125 (110.3)	258
	−	c 80 (65.3)	d 34 (48.7)	114
		213	159	372

The observed values (0) for presence and absence appear in each cell unbracketed and the expected values (E) appear beneath each observed value in brackets.

Expected values for each cell were calculated from the border totals as follows:

(213) (258) /372 = 147.7
(213) (114) /372 = 65.3
(159) (258) /372 = 110.3
(159) (114) /372 = 48.7

The χ^2 for testing departure from expected was calculated by the deviation squared divided by expected $[(0\text{-}E)^2/E]$ for each of the four cells. Thus, $x^2 = 1.46 + 1.96 + 3.31 + 4.44 = 11.17$ or by the formula

$$\chi^2 = \frac{(ad - bc)^2 n}{(a+c)\ (b+d)\ (d+c)\ (a+b)} = \frac{[(133)\ (34) - (80)\ (125)]^2 (372)}{(213)\ (159)\ (114)\ (258)} = 11.20$$

The slight difference in the values of χ^2 is a result of rounding figures.

In a smiliar manner the contingency tables involving range condition and species 1 and range condition and species 2 can be constructed and the χ^2 calculated as follows:

		Winterfat +	Winterfat −	
Condition	poor	a 99 (106.5)	b 87 (79.5)	186
	good	c 114 (106.5)	d 72 (79.5)	186
		213	159	372

		Yellowbrush +	Yellowbrush −	
Condition	poor	a 148 (129.0)	b 38 (57.0)	186
	good	c 110	d 76	186
		(129.0) 258	(57.0) 114	372

As shown in Table 2, chi-square value for winterfat and yellowbrush association over both range conditions (11.17) using all 372 plots is highly significant. The 2 x 2 contingency table for these two species indicates that they are negatively associated because they appear more frequently separated than is expected.

The χ^2 value of 2.48 for winterfat and condition resulted from winterfat occurrence being less than expected on poor range and more than expected on good range (Table 3). This indicates that winterfat decreases in presence on poor range and increases in presence on good range.

Yellowbrush and range condition analysis indicates that this plant decreases on good range and increases on poor ranges (Table 3).

Calculations for chi-square within the two range types and coefficients of interspecific association for the paired species combinations are shown in Table 4. Chi-square values for the association of winterfat and yellowbrush were significant ($p<.05$) for both good and poor range. Even though chi-square for poor range is almost twice as large as chi-square for good range, the coefficients of interspecific association show that they are associated to about the same degree on both range conditions. The negative value of the coefficients also shows that the association in each case is negative.

The total occurrence of winterfat on the plots decreased on poor range and the total occurrence of yellowbrush decreased on good range. Likewise, the occurrence of winterfat in the absence of yellowbrush decreased on poor range and similarly the occurrence of yellowbrush in the absence of winterfat decreased on good range.

Even though the changes in occurrence for each species were rather marked for good and poor range conditions, the type and degree of association between the species did not change materially. On both range conditions the individual species had a ten-

Table 2. Summary for analysis of frequency of occurrence for all possible pairs of species under the two range conditions in a 2 x 2 x 2 contingency table.

Association & Conditions Tested Species and species combinations					Degress of freedom	Value of χ^2
Winterfat	x	Yellowbrush	x	Range Condition	(4)	(31.94)
Winterfat	x	Yellowbrush	x	———	1	11.17**
Winterfat	x	———	x	Range Condition	1	2.48
———	x	Yellowbrush	x	Range Condition	1	18.26**
Remainder (Winterfat x Yellowbrush x Range Condition, Corrected)					1	0.03
Winterfat	x	Indian ricegrass	x	Range Condition	(4)	(25.91)
Winterfat	x	Indian ricegrass	x	———	1	6.56**
Winterfat	x	———	x	Range Condition	1	2.48
———	x	Indian ricegrass	x	Range Condition	1	16.42**
Remainder (Winterfat x Indian ricegrass x Range Condition, Corrected)					1	0.45
Winterfat	x	Galleta grass	x	Range Condition	(4)	(7.34)
Winterfat	x	Galleta grass	x	———	1	2.17
Winterfat	x	———	x	Range Condition	1	2.48
———	x	Galleta grass	x	Range Condition	1	1.04
Remainder (Winterfat x Galleta grass x Range Condition, Corrected)					1	1.65
Yellowbrush	x	Indian ricegrass	x	Range Condition	(4)	(45.58)
Yellowbrush	x	Indian ricegrass	x	———	1	10.83**
Yellowbrush	x	———	x	Range Condition	1	18.26**
———	x	Indian ricegrass	x	Range Condition	1	16.42**
Remainder (Yellowbrush x Indian ricegrass x Range Condition, Corrected)					1	0.07
Yellowbrush	x	Galleta grass	x	Range Condition	(4)	(28.76)
Yellowbrush	x	Galleta grass	x	———	1	9.38**
Yellowbrush	x	———	x	Range Condition	1	18.26**
———	x	Galleta grass	x	Range Condition	1	1.04
Remainder (Yellowbrush x Galleta grass x Range Condition, Corrected)					1	0.08
Indian ricegrass	x	Galleta grass	x	Range Condition	(4)	(67.56)
Indian ricegrass	x	Galleta grass	x	———	1	42.90**
Indian ricegrass	x	———	x	Range Condition	1	16.42**
———	x	Galleta grass	x	Range Condition	1	1.04
Remainder (Indian ricegrass x Galleta grass x Range Condition, Corrected)					1	7.20**

*Indicates significance at the .05 level of probability.
**Indicates significance at the .01 level of probability.

dency to occur separately more than expected (Table 4).

Winterfat and Indian ricegrass. The total χ^2 for measuring association between winterfat and Indian ricegrass without regard to range conditions over all 372 plots is 25.91 (Table 2). As shown by chi-square tests and coefficients of association in Table 4 these two species were significantly associated negatively on good range but they were dispersed somewhat independently on poor range with only a tendency to be negatively associated.

The presence of winterfat and Indian ricegrass jointly, increased on good range and decreased on poor range.

The joint presence of winterfat and Indian ricegrass and the presence of Indian ricegrass alone without winterfat decreased on poor range; whereas, the presence of winterfat in the absence of Indian ricegrass increased on poor range. The total presence of each species actually decreased on poor range compared to the total occurrence on good range (Table 4).

The tendency toward negative association between these two species could be a result of habitat factors such as texture of the soil. Indian ricegrass appears to prefer sandy soils and winterfat prefers somewhat heavier soils.

Winterfat and galleta grass. The χ^2 test for association between winterfat and galleta grass in all 372 plots regardless of range conditions was not significant (p<.05) and therefore the two species over both range conditions might be said to be independently distributed. However, as shown in Table 4, winterfat and galleta grass were

Table 3. Observed and expected frequencies on good and poor range conditions for five species of desert plants and the chi-square values.

Species and range condition[1]		Observed frequency	Expected frequency	χ^2
Winterfat and Condition				
0	poor	87	79.5	2.48
0	good	72	79.5	
1	poor	99	106.5	
1	good	114	106.5	
Yellowbrush and Condition				
0	poor	38	57.0	18.26**
0	good	76	57.0	
1	poor	148	129.0	
1	good	110	129.0	
Indian ricegrass and Condition				
0	poor	118	98.5	16.42**
0	good	79	98.5	
1	poor	68	87.5	
1	good	107	87.5	
Galleta grass and Condition				
0	poor	50	54.5	1.04
0	good	59	54.5	
1	poor	136	131.5	
1	good	127	131.5	

[1]Figures 0 and 1 represent absence and presence in plots for species above them in each case, respectively.
**Indicates significance at .01 level of probability.

positively associated on good range, but they were independently dispersed on poor range. This is a result of the pronounced increase of galleta grass and the reduction of winterfat plants on poor ranges compared to good ranges (Tables 3 and 4). Galleta grass increases by rhizomes and therefore has a tendency to increase as a sod grass and exclude other species adjacent to the parent plant when competition is released.

Yellowbrush and Indian ricegrass. The χ^2 values measuring association between these two species indicate that they were positively associated under both good and poor range conditions (Table 4). Even though yellowbrush increased and Indian ricegrass decreased on poor range compared to good range, the two species were found associated when present on the same area.

This suggests that prolonged heavy grazing may cause a replacement of Indian ricegrass with yellowbrush because they apparently have similar habitat adaptations.

The increased presence of yellowbrush and the increased absence of Indian ricegrass on poor ranges compared to good range were highly significant (Table 3) and likewise the persistent positive association that prevailed in spite of the marked floristic change with range condition was highly significant (Table 4).

Yellowbrush and galleta grass. The chi-square test for association of these two species shows that they were associated negatively on each range condition (Table 4). The frequency of each species was greater on poor range than on good range. This was more pronounced for yellowbrush than for galleta grass. The data in Table 4 may be misleading since it might appear that the two species have a tendency to be associated positively on poor ranges when comparing the changes in occurrence for the two range conditions.

The absence of both species on only 3 plots on poor range compared to 18 plots on good range indicated that at least one or both species were more plentiful on the poor range. Likewise, they appeared together a greater number of times on poor range as might be expected because both were actually more plentiful. Regardless of apparent changes from good range to poor range, these two species were negatively associated.

Indian ricegrass and galleta grass. The chi-square values for association between these two species were significant for data collected over both ranges and for frequencies within each range condition (Tables 2 and 4). The coefficients of interspecific association (Table 4) show that the association was negative in both good and poor range condition. The degree of negative association was much greater on poor range than on good range.

Indian ricegrass increased in occurrence on good range, whereas galleta grass increased on poor range (Table 4).

Plant Indicators of Range Condition. Yellowbrush and galleta grass increased on poor range compared to good range areas. However, the chi-square test for association shows that only yellowbrush was significantly associated with changing range condition (Table 3). Therefore, the presence of yellowbrush can be used as a reliable indicator of range trend under the conditions of this study.

Winterfat and Indian ricegrass increased on good ranges. Chi-square values show that the association of winterfat with range condition approached significance ($p<.05$) and the association of Indian ricegrass and range condition was highly significant ($p<.01$). Therefore, a decrease in the presence of these two species could be used as an indicator of range trend.

The reasons for plant association—positive or negative—are not always obvious; to obtain an

Table 4. Observed and expected frequencies for five species in all paired combinations on both good and poor range along with chi-square and coefficients of interspecific association (C).

Species combinations[1]		Letter identification of cells[2]	Observed frequency (0) good	Observed frequency (0) poor	Expected frequency (E) good	Expected frequency (E) poor	$(O-E)^2/E$ χ^2 good	$(O-E)^2/E$ χ^2 poor	C good	C poor
Winterfat	Yellowbrush									
0	0	d	23	11	29.42	17.77	1.40	2.58		
0	1	b	49	76	42.58	69.23	.97	0.66		
1	0	c	53	27	46.58	20.23	.88	2.27		
1	1	a	61	72	67.42	78.77	.61	0.58		
							3.86 *	6.09 *	—.2182	—.2303
Winterfat	Indian ricegrass									
0	0	d	23	49	30.58	55.19	1.88	0.69		
0	1	b	49	38	41.42	31.81	1.39	1.20		
1	0	c	56	69	48.42	62.81	1.19	0.61		
1	1	a	58	30	65.58	36.19	.88	1.06		
							5.34 *	3.56	—.2479	—.1711
Winterfat	Galleta grass									
0	0	d	29	24	22.84	23.39	1.66	.01		
0	1	b	43	63	49.16	63.61	0.77	.00		
1	0	c	30	26	36.16	26.61	1.05	.01		
1	1	a	84	73	77.84	72.39	0.49	.00		
							3.97 *	.02	+.1253	+.0096
Yellowbrush	Indian ricegrass									
0	0	d	42	33	32.28	24.11	2.93	3.28		
0	1	b	34	5	43.72	13.89	2.16	5.69		
1	0	c	37	85	46.72	93.89	2.02	0.84		
1	1	a	73	63	63.28	54.11	1.49	1.46		
							8.60 **	11.27 **	+.2223	+.6401
Yellowbrush	Galleta grass									
0	0	d	18	3	24.11	10.22	1.55	5.10		
0	1	b	58	35	51.89	27.78	0.72	1.88		
1	0	c	41	47	34.89	39.78	1.07	1.31		
1	1	a	69	101	75.11	108.22	0.50	0.48		
							3.84 *	8.77 **	—.2533	—.7063
Indian ricegrass	Galleta grass									
0	0	d	17	12	25.06	31.72	2.59	12.26		
0	1	b	62	106	53.94	86.28	1.20	4.51		
1	0	c	42	38	33.94	18.28	1.91	21.27		
1	1	a	65	30	73.06	49.72	0.89	7.82		
							6.59 *	45.86 **	—.3216	—.6217

[1]Figures 0 and 1 represent absence and presence in plots for species above them in each case, respectively.
[2]This column identifies the cells by letter in each 2 x 2 contingency table for calculating χ^2 or the coefficient of interspecific association (C).
*Indicates significance at the .05 level of probability.
**Indicates significance at the .01 level of probability.

adequate explanation, a detailed analysis of the habitat complex and growth requirements of the individual species may be necessary.

Summary

During the fall of 1958 a study of fence-line contrasts displaying good and poor range condition in the Escalante desert in southern Utah was conducted to determine if plant species were distributed independently or if they were associated with one another and with condition of the range.

In each of 31 separate fence-line contrasts, 6 plots, in each of five different sizes, 1 x 5-, 2 x 5-, 3 x 5-, 4 x 5-, and 5 x 5-foot, were located an equal distance apart on grid lines on each side of the fence.

The four abundant species studied were winterfat, yellowbrush, Indian ricegrass, and galleta grass. Only the presence or absence of each of the four species was recorded in each plot.

Chi-square tests and coefficients of interspecific association were used to determine independence and degree of sociability.

Plot sizes of 1 x 5 and 2 x 5 feet were considered too small because plant association tended to be negative and less abundant species appeared in fewer than

30 percent of the plots. Plot sizes 3 x 5, 4 x 5, and 5 x 5 feet gave about equal number of positive and negative associations and no material difference in analysis was found among the three sizes.

Presence of yellowbrush was significantly associated with poor range conditions and presence of winterfat and Indian ricegrass was significantly associated with good range condition.

Winterfat and yellowbrush, winterfat and Indian ricegrass, yellowbrush and galleta grass, and Indian ricegrass and galleta grass were negatively associated on both good and poor range. Winterfat and galleta grass and yellowbrush and Indian ricegrass were positively associated on both good and poor range.

LITERATURE CITED

Cole, L. C. 1949. The measurement of interspecific association. Ecology 30: 411-424.