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Predicting Utilization of Forage Species on Great Basin Desert Winter Range

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PREDICTING UTILIZATION OF FORAGE SPECIES ON GREAT BASIN DESERT WINTER RANGE

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HIGHLIGHT

One of the principal mechanisms operating in any grazing management program is the differential utilization of forage species. An ability to predict this differential utilization pattern, prior to the application of a grazing program, would allow more accurate prejudgment of the program's expected success. A predicting scheme is discussed, along with an actual application of this scheme to prediction of utilization of forage species by sheep on Utah winter range.

INTRODUCTION

Considerable attention has been given through the years to the effects of utilization on range plants. The role of differential forage utilization by domestic livestock in causing floristic changes is widely recognized. Little attention, however, has been given to understanding or predicting these patterns of utilization among individual range plant species.

One notable exception has been the work of Hutchings and Stewart (1953) in studying grazing by sheep on Utah winter range. Some fundamental patterns of utilization were observed in their studies. For example, their data suggested that the percent utilization of the various plant species varied with their relative production values; the utilization of a given species tended to increase with a decrease in its relative production. Other factors that seemed to affect relative utilization were growth conditions for the herbage, floristic composition of the community, grazing intensity, and phenophase of the plants when grazed. Holmgren and Hutchings (1971) have discussed the responses of salt desert shrub communities to these utilization patterns.

In theory, if the utilization of each plant species in a range plant community was predictable, and if the effects of such utilization were known for each plant species, then, as regards floristic composition, a range manager would have as much prior assurance of the expected success or lack of success of a proposed grazing program as it is reasonably possible to have. This paper describes a method of predicting this differential pattern of utilization among range plant species by domestic livestock. The specific examples given herein are for sheep on Utah winter range, but the principles are applicable to other range types, other seasons of grazing, and other classes of livestock.

THE BASIC EQUATION AND ITS USE

The basic equation relating utilization of individual plant species to utilization of total forage is as follows:

$$\text{Util. of Species ``A''} = \text{Util. of Total Forage}^{\left[\left(\text{Relative Abundance of Species ``A''}\right)^{(X)}\right]}$$

An example substituting real numbers can demonstrate the equation's use. Consider a situation where species "A" constitutes 35% of the total available current annual yield, and where total community forage utilization is to be 45% of the total available current annual yield. The basic equation would then, after substitution, become:

$$\text{Util. of Species ``A''} = .45^{[.35^{(X)}]}$$

THE "X" PARAMETER

The "X" is an empirically derived parameter that plays a critical role in the predicting scheme. Because of its importance, it will be considered here in detail.

For each of the "n" forage species in a community there is an appropriate "X" value ($X_1, X_2, \ldots, X_n$). Basically, X is an indication of the relative palatability or non-palatability of a plant species within a community. It is helpful to consider its effect in the two equations above.

On inspection, when X = 0, the utilization of species "A" will be identical to the utilization of total forage. This is because .35 raised to the power of 0 equals 1, and .45 raised to the power of 1 is equal to .45. Similar reasoning shows that, when X is greater than 0, the utilization of species "A" will be greater than the value for total community utilization, and when X is less than 0, the utilization of species "A" will be less than total community utilization. The value of X, then, whether positive, zero or negative, is an absolute indication of whether species "A" is a preferred or a non-preferred forage species in the community. The higher the X value for a given species, the more it is preferred in that community (Fig. 1).

It should also be pointed out that X is a relative value rather than an absolute. It indicates, in any given plant association, the relative utilization to be expected for a plant species. It is meaningless in a single-species plant community, which can be seen by substituting the value of 1.0 into the relative abundance term. When the relative abundance is 1.0 (the species comprises 100% of the community), the value of X has no effect on the result of the equation.

The value of X for any species in a given association is more than simply a function of the associated species, however. Certain weather patterns can render a species either more or less palatable than "usual." The X value can even change as a function of total forage utilization. The morphology of shadscale (*Atriplex confertifolia*), for

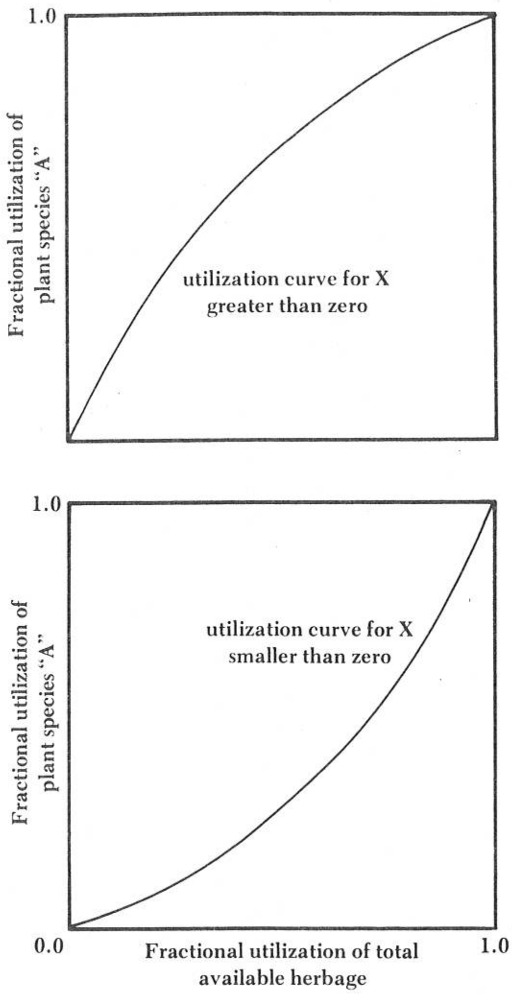

Figure 1. Utilization curves showing the effect of the "X" parameter in the predicting equation. When X is greater than zero, fractional utilization of the plant species is greater than utilization of the total available herbage. When X is less than zero, fractional utilization of the plant species is less than utilization of the total available herbage. When X is exactly zero, a straight diagonal line is produced and fractional utilization of the plant species is identical to utilization of the total available herbage. Thus, a positive X indicates a relatively heavily utilized forage species, and a negative X indicates a relatively lightly utilized species.

example, is such that the first 20% of new growth is both palatable and readily available to the grazing animal. While forage utilization for the community remains below about 20%, the X value for shadscale remains positive in most associations. The remainder of shadscale's growth, however, is protected by spines, and in spite of the fact that total community utilization may rise well above 20%, the utilization of shadscale usually does not. At this point, the X value for shadscale becomes negative (Fig. 2).

The foregoing is only to demonstrate that the X value for any given species can be expressed as a complex function of many different factors. For many salt desert plant species, however, a substantial part of the variability in the value of X is accounted for as a function of only four principal variables: (1) the relative abundance of the species in the community; (2) the total forage utilization in the community; (3) the precipitation prior to and during the growth of the plant; and (4) the associated species in the community.

A regression analysis including the above factors, as they affect the value of the X parameter for each plant species, is required to complete the equation system which then consists of one equation for each plant species. Each equation contains, within the X exponent, a series of regression-derived coefficients that predict the value of X, and thus, the relative fractional utilization for the plant species, under a variety of situations.

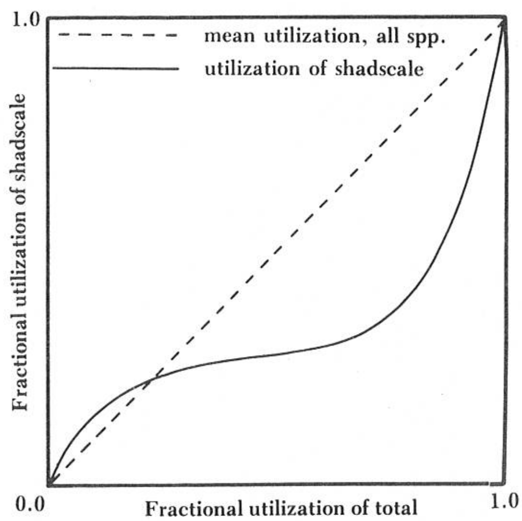

Figure 2. Representative utilization curve for shadscale. While total community utilization remains below about 20%, shadscale is frequently a preferred forage species. The remainder of the plant is protected by spines and little more is utilized until total community utilization becomes extremely high. Thus, the X parameter can be positive under light utilization, but can become negative as utilization becomes heavier.

A TEST OF THE EQUATION SYSTEM

METHOD

One test of the equation system, using historical utilization data, will be discussed, although several tests have been run for various seasons of grazing and under many conditions and stocking pressures.

The U.S. Forest Service has, since the mid-1930's, conducted long-term grazing experiments with sheep on Utah winter range that is similar to some 65 million acres of Intermountain rangeland. Hutchings and Stewart (1953) have discussed, in some detail, the results of the experiments as of 1953. Part of the information collected during this period was utilization of plant species by sheep under several experimental treatments covering a range of vegetational associations. The Forest Service graciously made these data available to the authors for their use in the development of this predicting technique. The data were subdivided for this exercise. Some were used to develop the equations and parameters, and others to test them.

Six experimental pastures at the Desert Experimental Range, near Milford, Utah, provided the data for this test. All six were considered "early-grazed" pastures, being grazed between about October 1 and early the following February, each year. Three of the six pastures were used to develop equation parameters for each plant species; these are referred to as "data-base" pastures in this exercise. The other three pastures were used to validate the equations after parameter development was complete, and are referred to as "validation" pastures.

PARAMETER DEVELOPMENT

Thirteen species or plant groups were studied in each pasture. For each species studied, the three data-base pastures provided 24 utilization values, covering eight separate years, under a multiplicity of plant associations and weather conditions. Each of the 24 utilization values was substituted, along with appropriate relative abundance and total utilization values, into the predicting equation. The only part not substituted for was the value of X in each case. The X value was obtained by solving the equation. When all 24 X values were known, regression analysis of the variables affecting X was made. Five specific variables were included in the regression analysis of X. They were (1) utilization of total available forage, (2) relative abundance of the plant species in question, (3) total precipitation for the previous winter (October through March), (4) total precipitation for April through June prior to the grazing season, and (5) total precipitation for July through September prior to the grazing season.

Table 1 presents coefficients, derived from the regression analysis, for the determination of X values for the 13 plant groups studied in Pine Valley.

Table 1. Regression-derived coefficients for the determination of the value of "X". These are most appropriate for early-winter grazing by sheep at the Desert Experimental Range

Species	"X" = this constant	+ this coeff. x previous winter precip.	+ this coeff. x previous Apr-Jun precip.	+ this coeff. x previous Jul-Sep precip.	+ this coeff. x total forage utiliz'n	+ this coeff. x species relative abundance	+ a small adjustm't for plant associat'n
Atriplex confertifolia (shadscale)	0.074	0.164	0.052	-0.044	-1.257	-1.227	(?)
Eurotia lanata (winterfat)	0.282	-0.054	0.040	0.020	0.751	-0.566	(?)
Artemisia spinescens (budsage)	-0.073	0.098	-0.012	0.058	-0.280	-2.490	(?)
Chrysothamnus spp. (rabbitbrush)	0.253	-0.137	0.002	-0.022	0.031	-1.512	(?)
Ephedra nevadensis (nevada ephedra)	-0.547	0.053	0.022	0.016	0.576	-0.020	(?)
Other shrubs	-0.109	-0.093	0.012	0.053	0.234	-0.463	(?)
Hilaria jamesii (galleta)	0.369	-0.021	-0.071	-0.037	0.296	0.313	(?)
Orysopzis hymenoides (indian ricegrass)	0.212	0.016	-0.003	0.015	0.716	0.290	(?)
Sporobolus spp. (dropseed)	0.978	-0.010	-0.101	-0.129	-0.360	-3.135	(?)
Other grasses	-0.193	-0.022	0.033	-0.046	0.453	2.267	(?)
Salsola kali (russianthistle)	-0.341	0.033	0.035	-0.001	0.197	0.336	(?)
Sphaeralcea grossulariaefolia (globemallow)	-0.052	0.090	-0.052	0.067	1.279	-3.020	(?)
Other forbs	0.197	0.011	-0.065	0.029	-0.634	-4.654	(?)

An example will demonstrate the use of these coefficients in determining the utilization of shadscale. Assume, for this example, that the previous winter's precipitation was 3 in., that the April through June precipitation was 2 in. and that the July through September precipitation was 1 in. No correction will be made for plant association. If shadscale comprises 35% of the total available current annual yield, and total community utilization is to be 45%, the X value is calculated as follows:

$$X = .074 + .164(3) + .052(2) - .044(1) - 1.257(.45) - 1.227(.35) = -0.369$$

The equation predicting the utilization of shadscale then becomes:

$$\text{Util. of shadscale} = .45^{[.35^{(-0.369)}]} = .45^{[1.47]} = .31$$

Thus, under these conditions, although the total community utilization is 45%, the utilization of shadscale is only 31%. It should be emphasized that the parameters in Table 1 are specific to early-winter grazing by sheep at the Desert Experimental Range; late-winter grazing produces somewhat different parameters, as, of course, does grazing by other classes of livestock.

THE TESTING PROCEDURE

After determining parameters for the equations and prior to their use in predicting independent data, an interim step was taken; this was to use them in duplicating the utilization values on the data base pastures themselves. This was done principally to provide a convenient point of reference from which to judge the independent validation attempt. When this interim procedure was accomplished, the equation system was then applied to the independent data from validation pastures.

Both applications of the equation system were conducted in an identical manner. For each year and each pasture, preconditions for the grazing were substituted into the equations, which were then solved for the species-specific utilization. For simplicity, a digital computer program was written to operate the equation system. Data were provided to the program on total community utilization, relative abundance of the species and precipitation; the appropriate parameters were incorporated intrinsically within the program. In this manner, a utilization value for each plant species, for each pasture and for each year was obtained.

A check showed that in any given pasture, for each year predicted, the first utilization values so obtained did not equate to the proper total community utilization value. That is, even though total community utilization of, for example, 45% was used in each species equation, the weighted sum of the individual utilization values obtained did not equal 45%. This variance arose, as it always will, as a result of differences in associational relationships among the species from those existing in the data-base pastures from which parameters were developed. One could, for an extreme example, be predicting utilization for a community with just two plant species, even though the parameters for the two species were developed based on much more complex communities. If both species are highly palatable, they may both have X values greater than zero. In this case, the first utilization values obtained would result in total utilization that was too high. To compensate for this kind of variance, an adjustment was made to each X exponent by adding an appropriate small positive or negative constant, identical for all species. The predicting process was then repeated and further adjustments made until proper total utilization was obtained to sufficient accuracy, in this case, to the fourth decimal place.

When all predictions were made, each was compared with its corresponding actually measured value. The comparisons, along with an analysis of their accuracy, follow.

RESULTS

Table 2 is a sample of predicted values for one of the data-base pastures with corresponding actually measured utilization values. A total of 312 predicted values from the data-base pastures and 312 from the validation pastures were compared with actual values. The comparison took several forms.

When each of the 312 predicted utilization values is divided by its corresponding actual value, a distribution of 312 "accuracy factors" is obtained, centering around a value of 1.0. The higher the proportion of values found in the vicinity of 1.0, the more accurate the prediction. Figure 3 depicts the distribution of accuracy factors, for both the data-base pastures and for the validation pastures. For the data-base pastures, where more accuracy is expected, 164 out of 312 total predicted values fell within the range of 0.8 times the actual value and 1.2 times the actual value. For the validation pastures, the accuracy factors are somewhat more broadly distributed. Nonetheless, 130 out of 312 still fell in the same range (Fig. 3).

Table 3 shows the 90% confidence intervals placed around each predicted value. The interpretation of the table factors is that, about 90% of the time, the actual value should fall within the range of the predicted value plus or minus the table value times 100%.

Coefficients of determination were computed for each species, and for each overall application of the equation system. These are presented in Table 4.

Table 2. A comparison between actual and predicted values on one of the heavily-grazed, early-season, data base pastures, for selected years

		1939	1941	1942	1943	1944	1945	1946	1958
Shadscale	Predicted	0.22	0.19	0.25	0.28	0.21	0.29	0.25	0.14
	Actual	0.22	0.19	0.25	0.27	0.25	0.25	0.26	0.09
Winterfat	Predicted	0.55	0.51	0.61	0.72	0.56	0.51	0.60	0.53
	Actual	0.57	0.51	0.66	0.74	0.60	0.51	0.58	0.53
Budsage	Predicted	0.58	0.39	0.53	0.49	0.33	0.46	0.61	0.15
	Actual	0.76	0.38	0.65	0.57	0.37	0.43	0.61	0.11
Rabbitbrush	Predicted	0.07	0.06	0.11	0.36	0.31	0.00	0.13	0.35
	Actual	0.23	0.22	0.10	0.21	0.20	0.02	0.16	0.32
Nevada ephedra	Predicted	0.10	0.02	0.20	0.33	0.12	0.12	0.38	0.02
	Actual	0.16	0.13	0.30	0.15	0.24	0.41	0.28	0.00
Other shrubs	Predicted	0.21	0.13	0.18	0.29	0.25	0.02	0.42	0.17
	Actual	0.28	0.24	0.17	0.22	0.20	0.13	0.38	0.26
Galleta	Predicted	0.42	0.64	0.53	0.82	0.73	0.63	0.65	0.45
	Actual	0.30	0.63	0.43	0.72	0.73	0.92	0.57	0.40
Indian ricegrass	Predicted	0.83	0.82	0.87	0.92	0.90	0.87	0.94	0.75
	Actual	0.83	0.88	0.79	0.92	0.97	0.92	0.92	0.74
Dropseed	Predicted	0.12	0.48	0.28	0.45	0.52	0.67	0.33	0.26
	Actual	0.07	0.40	0.26	0.49	0.29	0.88	0.39	0.43
Other grasses	Predicted	0.21	0.11	0.32	0.48	0.29	0.20	0.25	0.19
	Actual	0.37	0.15	0.10	0.37	0.45	0.83	0.11	0.37
Russianthistle	Predicted	0.10	0.00	0.22	0.04	0.00	0.08	0.29	0.09
	Actual	0.11	0.27	0.30	0.00	0.00	0.55	0.34	0.13
Globemallow	Predicted	0.84	0.89	0.88	0.97	0.96	0.93	0.96	0.79
	Actual	0.91	0.90	0.92	0.99	0.98	0.91	0.91	0.80
Other forbs	Predicted	0.06	0.19	0.04	0.37	0.05	0.03	0.23	0.06
	Actual	0.15	0.28	0.00	0.68	0.00	0.22	0.38	0.34

Table 3. Ninety-percent confidence intervals around predicted values of utilization on early-grazed pastures. The interval is equal to the predicted value plus or minus (table value times predicted value)

Species	90% Confidence Interval	
	Data Base Predictions	Validation Predictions
Shadscale	0.22	0.38
Winterfat	0.13	0.26
Budsage	0.27	0.93
Rabbitbrush	42.68	91.19
Nevada ephedra	3.11	27.86
Other shrubs	2.34	42.43
Galleta	0.49	0.43
Indian ricegrass	0.16	0.22
Dropseed	0.38	0.46
Other grasses	3.58	7.26
Russianthistle	103.52	35.43
Globemallow	0.21	0.37
Other forbs	2.48	2.54

Table 4. Coefficients of determination ("R-squared" values) between actual and predicted values on early-grazed pastures

Species	Coefficients of Determination	
	Data Base Pastures	Validation Pastures
Shadscale	0.75	0.65
Winterfat	0.83	0.72
Budsage	0.83	0.65
Rabbitbrush	0.40	0.55
Nevada ephedra	0.39	0.19
Other shrubs	0.63	0.14
Galleta	0.70	0.86
Indian ricegrass	0.74	0.75
Dropseed	0.84	0.73
Other grasses	0.32	0.09
Russianthistle	0.27	0.09
Globemallow	0.57	0.54
Other forbs	0.19	0.35

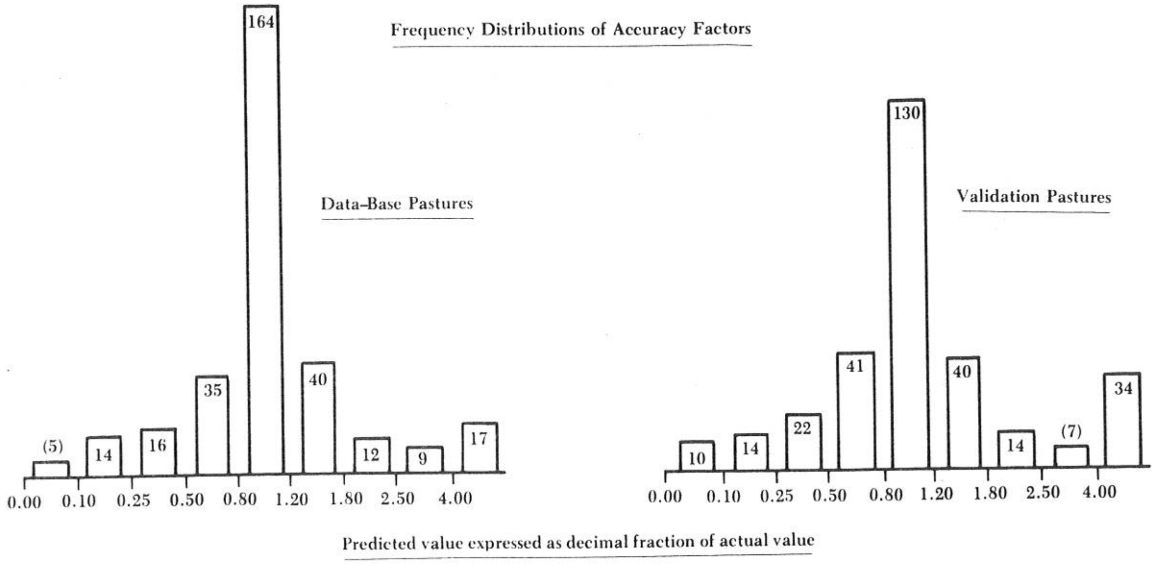

Figure 3. Frequency distributions of accuracy factors, obtained by dividing the predicted utilization value by its corresponding actual value in each instance.

DISCUSSION

Utilization values for certain species are predicted with much less accuracy or precision than for others. The problem lies partly with the data on which the parameters were estimated. In the data-base pastures, rabbitbrush, ephedra, Russian thistle, globemallow, and the categories "other shrubs," "other grasses " and "other forbs" were all quite sparse, and frequently not present at all. Even small absolute error in measurement introduces great relative variability into such measurements. In several instances, records of plant growth showed certain species to be completely absent from the pastures; nonetheless, utilization values were still recorded for them. Because the authors wanted to avoid manipulation of the data in any way prior to analysis, such inconsistencies could not be excluded. Fortunately, the very paucity of these species renders such errors quite tolerable; if the presence of a species is so small as to be almost unmeasurable, one probably does not care whether it is utilized at a rate of 100% or 0%.

For certain applications, the manager may be interested in long-term utilization averages for a species rather than in year-to-year utilization values. If so, he need only substitute long-term average precipitation values into the equations. Over a large number of years, such a simplification introduces little additional error.

Other unpublished tests show that the equation system works well for other subsets of the species mentioned in the example given. Obviously, however, for site locations other than the Desert Experimental Range, the specific parameters developed for these 13 plant categories may be either partly or almost completely inappropriate. Ideally, parameters should be developed on a site-specific basis. This is not practical in many cases, however, in which case these parameters, or, preferably, others developed for a nearby site or for a site with a similar plant community can be used as the best available approximation in predicting utilization.

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