Great Basin Naturalist

Volume 49 | Number 3 Article 3

7-31-1989

Comparison of regression methods for biomass estimation of sagebrush and bunchgrass

Robin J. Tausch
University of Nevada, Reno

COMPARISON OF REGRESSION METHODS FOR BIOMASS ESTIMATION OF SAGEBRUSH AND BUNCHGRASS

Robin J. Tausch[1]

ABSTRACT.—Regression analyses for plant biomass estimation from physical measurements of individual plant dimensions that are nonlinear have generally used some form of the allometric equation. Use of this equation has most often involved logarithmic transformation of the variables (power regression). Transformation, however, introduces systematic bias into the analyses. Power regression was compared with a bias correction technique and with nonlinear regression for the prediction of the total foliage biomass (phytomass). Crown volumes of one sagebrush and one perennial grass species were used for these evaluations. The bias correction factor was uniformly applied to all the predicted values from power regression. Nonlinear regression avoided this bias by not requiring logarithmic transformation. It was also consistently less variable than either power regression or the correction factor method in estimating actual total phytomass by the allometric equation and equivalent or better in accuracy. The correction factor technique consistently gave the poorest predictions of the methods evaluated. Standard linear regression worked as well for the bunchgrass as the best method based on the allometric equation. Predictions were generally better when sample sizes used to derive the regression equations represented the range of plant size and variability in the data for which the phytomass was estimated.

Biologists often find it necessary to estimate the biomass or productivity of plant species on specific land areas (Payandeh 1981). Because biomass is difficult and expensive to collect, it is often estimated based on regression relationships between biomass and physical measurements of the individual plants (Tausch 1980, Tausch and Tueller 1988). Because these relationships are generally nonlinear, logarithmic transformation of the variables (power regression) has traditionally been used (Sprugel 1983). Transformation greatly simplifies the calculations because standard least-squares techniques for linear regression can be used. Systematic bias, however, is introduced into the results (Baskerville 1972, Payandeh 1981, Lee 1982, Sprugel 1983). Transformation also results in difficulties in evaluating the usual measures of goodness of fit (Payandeh 1981, Chiyenda and Kozak 1982).

Several techniques for correcting the bias introduced by transformation have been proposed, but two have been the most commonly applied. The first is an upward correction factor uniformly applied to all the predicted values from power regression (Lee 1982, Sprugel 1983). Second is the use of nonlinear regression not requiring logarithmic transformation of the data values (Payandeh 1981, Chiyenda and Kozak 1982). Any correction method should be simultaneously applied along with power regression. The results should be compared using independent data to test for the presence and correction of bias (Schlaegel 1981, Brand and Smith 1985).

Tests for bias correction have focused on the estimation of the weight of individual plants. When these tests are used by biologists, however, individual plant weights are often summed for determination of total plant weight on an area basis. The objectives of this study were to compare the standard power regression with corrected power and with nonlinear regression for estimating the total phytomass on sample sites. Total phytomass was estimated from crown volume for one sagebrush and one perennial grass species.

STUDY SITE DESCRIPTION

The study site is in a sagebrush-bunchgrass community located on the east flank of the Needle Range, southwestern Utah, at an elevation of 2,000 m. Topographically, the site is on a nearly level, occasionally dissected, relict fan-piedmont (Peterson 1981). The site slopes two degrees east-northeast. Low sagebrush (*Artemisia arbuscula* Nutt.) is the dominant shrub species, and squirreltail (*Sitanion*

[1]Department of Range, Wildlife, and Forestry, University of Nevada at Reno, 1000 Valley Road, Reno, Nevada 89512. Present address: Intermountain Research Station, USDA Forest Service, 920 Valley Road, Reno, Nevada 89512.

hystrix [Nutt.] J. G. Smith) is the most abundant bunchgrass. A soil profile on the site has a 24-cm deep A horizon over an argillic horizon. A calcium-carbonate cemented Bkm horizon starts at 38 cm and extends to 50 cm. The soil is a fine-loamy, mixed, frigid Xerollic Palegrid. There was no evidence of grazing at the time of sampling (Tausch 1980).

METHODS

Data-collection Methods

All data used were collected on a single sample area. This concentrated the analysis on variation among the individuals of each species on the site. The 8-m-wide by 20-m-long sample area was divided into 10 subplots, each 4 m on a side (16 m^2). The entire area was sampled in 1 × 2-m microplots with eight microplots per subplot. All low sagebrush and squirreltail bunchgrass plants with their trunk or basal area half or more in a microplot were sampled. Each shrub was measured for its longest crown diameter, the diameter perpendicular to the longest, and its crown height. Crown height was the longest vertical measure of the portion of the crown containing green foliage. The green foliage (phytomass) was individually collected for each shrub.

Squirreltail plants were individually measured for the longest diameter of their basal area, the diameter perpendicular to the longest, and culm height (Johnson et al. 1988). Grass phytomass was also collected by individual plant. A total of 474 low sagebrush and 122 squirreltail bunchgrass were sampled.

Crown volume for the shrubs was computed using the formula for one-half of an ellipsoid (Tausch 1980). Crown volume for the grass plants was computed with the formula for the volume of a cylinder using the basal area and the average culm height. This is the shape for bunchgrass that generally gives the best results (Johnson et al. 1988).

Analysis Methods

Nonlinear regression analyses were based on the allometric equation ($Y = aX^b$). For power regression both the X and Y variables were logarithmically transformed before analysis by linear regression (Payandeh 1981). Results from power regression were converted back to arithmetic form (antilogarithms) for most of the additional analyses. For nonlinear regression the parameters a and b were determined by an iterative technique. The correction factor (CF) for power regression was based on the square of the standard error of the estimate (SEE^2) computed from logarithmically transformed data (Sprugel 1983). The CF equaled the exponential of the SEE^2 divided by two ($CF = \exp[SEE^2/2]$). The CF, a number greater than 1.0, was then multiplied by all the estimated phytomass values before summing for the total phytomass.

Schlaegel (1981) recommended that several statistics be used when comparing biomass estimation equations. A coefficient of determination (r^2) and a standard error of the estimate were computed to compare the regression results. Also computed was a relative deviation. This was the difference between the estimated total phytomass and the actual total divided by actual total phytomass (%). Confidence limits for the relative deviations were computed using the chi-square technique from Freese (1960). The first two statistics permitted comparisons of the variability of the estimates by the different regression models. The last two were comparisons of how close the estimates were to the actual sampled total phytomass. All four statistics were computed from untransformed data as recommended by Payandeh (1981) and Brand and Smith (1985).

Ten data or equation sets were used to compute the crown volume to phytomass regression tests for low sagebrush. Data from 2 randomly selected subplots out of the 10 were combined for each equation set. Regression equations from each equation set were used to estimate total phytomass for the combination of the remaining 8 subplots (test sets) not used to derive each equation. Ten random groups of 4 subplots each were used in the equation sets to compute the crown volume to phytomass equations for the squirreltail bunchgrass. The resulting 10 regression equations were used to estimate the total phytomass for the combination of the 6 remaining subplots (test sets) associated with each of them. The random selections provided 10 estimates of total phytomass for each species using independent test sets (groups of 8 or 6 combined subplots, respectively).

TABLE 1. Sample size, maximum crown volume, and average foliage density in the plant crowns for *Artemisia arbuscula* in 10 equation sets (pairs of subplots randomly selected from 10) and in 10 test sets (combined 8 remaining subplots) associated with each equation set.

Group number	Equation sets (2 subplots)			Test sets (8 subplots)		
	Sample size	Maximum crown volume (dm^3)	Average foliage density (g/dm^3)	Sample size	Maximum crown volume (dm^3)	Average foliage density (g/dm^3)
1	46	29.15	4.50	428	65.60	4.98
2	63	65.60	4.57	411	37.90	4.97
3	110	30.63	5.34	364	65.60	4.81
4	100	14.93	5.44	374	65.60	4.81
5	138	30.63	5.54	336	65.60	4.73
6	118	16.89	5.83	356	65.60	4.69
7	117	65.60	5.15	357	37.90	4.81
8	50	65.60	4.68	424	37.90	4.94
9	121	29.15	4.94	353	65.60	4.89
10	77	37.90	4.34	397	65.60	5.08

Sample sizes were selected to be adequate for the site and to reflect the relative abundance of each species. Standard linear regression was also used with the bunchgrass data. Averages and standard deviations were computed for the r^2, standard error of the estimate, and the relative deviations for each combination of regression equation and species. Interpretation of the results included comparison of the densities of individual plants in the equation sets with the densities in the test sets used for each estimation. The ranges in crown volume and average foliage density in the plant crowns were also compared within and between the predicting and predicted data sets.

RESULTS AND DISCUSSION

Low sagebrush sample sizes for the 10 equation sets of random pairs of plots ranged from 46 to 138 individuals (Table 1). Sample sizes for the test sets of the combination of 8 remaining subplots associated with each equation set all exceeded 300 individuals. The largest maximum crown volume in the equation sets was about four times the smallest crown volume. In the test sets the smallest of the maximum crown volumes was more than half as large as the largest sampled. Maximum crown volume was less in the equation sets than in the test sets for 7 of the 10 pairs. Equation sets and test sets had a similar range in average foliage density in the plant crowns (Table 1). Squirreltail had sample sizes in the equation sets (4 plots) ranging from 33 to 66 individuals (Table 2). In the test sets sample sizes were generally, but not always, higher than the number of individuals in the equation sets. Maximum squirreltail crown volumes in both the equation sets and the test sets had similar 2:1 ranges in size. Equation set values were less than test set values in 6 of the 10 pairs. The range in foliage density was also similar between sets (Table 2). The r^2 values for the low sagebrush equation sets were usually less for nonlinear regression than for power regression results (Table 3). Coincidentally, standard error of the estimates for low sagebrush was consistently less for nonlinear regression. The value of regression parameter b was consistently higher for power regression than for nonlinear regression (Table 3).

Squirreltail bunchgrass regression results for the equation sets showed the same pattern as sagebrush but with a generally lower level of precision (Table 4). This appeared to be related to the lower sample size of the less abundant species. The relative increase in r^2 between power regression and nonlinear regression, however, was considerably larger than for sagebrush. The regression parameter b was larger for nonlinear regression than power regression, the opposite of the results for sagebrush. The regression parameter b for the nonlinear analysis results for squirreltail averaged very close to 1.0. Because of this, standard linear regression analysis was also used to derive prediction equations from the

TABLE 2. Sample size, maximum crown volume, and average foliage density in the plant crowns for *Sitanion hystrix* in 10 equation sets (groups of 4 subplots randomly selected from 10) and in 10 test sets (combined 6 remaining subplots) associated with each equation set.

Group number	Equation sets (4 subplots)			Test sets (6 subplots)		
	Sample size	Maximum crown volume (cm^3)	Average foliage density (g/dm^3)	Sample size	Maximum crown volume (cm^3)	Average foliage density (g/dm^3)
1	66	318.1	18.5	56	192.4	15.2
2	50	164.9	17.1	72	318.1	17.0
3	45	318.1	16.9	77	164.9	17.3
4	44	164.9	16.8	78	318.1	17.1
5	42	192.4	15.6	80	318.1	17.8
6	54	164.9	15.9	68	318.1	17.5
7	52	192.4	14.8	70	318.1	18.2
8	54	318.1	18.0	68	164.9	15.3
9	52	318.1	17.2	70	164.9	16.8
10	33	164.9	15.4	89	318.1	17.6

TABLE 3. *Artemisia arbuscula* crown volume to phytomass allometric regression analysis equations ($Y = aX^b$) by two methods for data for 10 equation sets, each composed of 2 randomly selected subplots.

Equation set number	Power regression				Nonlinear regression			
	a	b	r^2	Standard error (g)	a	b	r^2	Standard error (g)
1	0.0238	0.823	0.90	7.68	0.0939	0.670	0.96	5.22
2	0.0216	0.833	0.92	9.09	0.0454	0.751	0.94	7.43
3	0.0253	0.815	0.90	5.91	0.0336	0.786	0.90	5.87
4	0.0217	0.832	0.86	5.30	0.0543	0.725	0.87	5.06
5	0.0227	0.835	0.94	4.54	0.0378	0.776	0.95	4.27
6	0.0239	0.831	0.90	5.39	0.0261	0.821	0.90	5.39
7	0.0248	0.829	0.90	8.45	0.0606	0.726	0.96	5.51
8	0.0328	0.795	0.93	9.24	0.0664	0.716	0.96	7.10
9	0.0235	0.826	0.90	6.23	0.0757	0.691	0.94	4.78
10	0.0309	0.782	0.81	9.85	0.1039	0.651	0.84	9.12
mean	0.0251	0.820	0.90	7.17	0.0598	0.731	0.92	5.98
S.D.	0.0038	0.018	0.037	1.92	0.0257	0.053	0.042	1.48

10 equation sets (Table 5). Linear regression had an average r^2 and standard error very similar to nonlinear regression.

Low Sagebrush Predictions

Nonlinear regression averaged a higher r^2 and a lower standard error of the estimate than either power or corrected power regression when predicting the test sets (Table 6). The variabilities for the r^2 and standard error values were also less for nonlinear regression. Nonlinear regression had an average relative overestimate of actual total phytomass (+6.8%) that was about 75% larger than the results of power regression (+3.9%). Corrected power regression had an average relative overestimate over twice that of power regression. Where average foliage densities for the equation sets were greater than for the test sets, the predictions generally had larger total phytomass overestimates than when they were less. This was modified by differences in the range in crown volume between equation and test sets.

Although power regression had a closer estimate of actual low sagebrush phytomass, both the maximum underestimate (−9.6%) and overestimate (+14.2%) exceed the same values for nonlinear regression (−2.0% and +13.0%, respectively). Based on the methods of Freese (1960), power regression predicted total phytomass within 10.4% of the actual

TABLE 4. *Sitanion hystrix* crown volume to phytomass allometric regression analysis equations ($Y = aX^b$) by two methods for data for 10 equation sets, each composed of 4 randomly selected subplots.

Equation set number	Power regression				Nonlinear regression			
	a	b	r^2	Standard error (g)	a	b	r^2	Standard error (g)
1	0.0361	0.785	0.72	0.061	0.0157	1.03	0.90	0.036
2	0.0349	0.759	0.67	0.279	0.0245	0.89	0.73	0.250
3	0.0376	0.783	0.75	0.687	0.0100	1.10	0.89	0.447
4	0.0508	0.667	0.67	0.335	0.0164	0.99	0.80	0.259
5	0.0421	0.731	0.80	0.301	0.0239	0.89	0.86	0.257
6	0.0486	0.626	0.57	0.250	0.0235	0.87	0.67	0.216
7	0.0376	0.720	0.77	0.242	0.0221	0.88	0.84	0.202
8	0.0382	0.801	0.80	0.573	0.0162	1.02	0.90	0.416
9	0.0319	0.812	0.76	0.644	0.0114	1.08	0.91	0.400
10	0.0324	0.786	0.79	0.326	0.0206	0.93	0.85	0.277
mean	0.0390	0.747	0.73	0.370	0.0184	0.97	0.84	0.276
S.D.	0.0064	0.061	0.07	0.200	0.0053	0.09	0.006	0.121

TABLE 5. *Sitanion hystrix* crown volume to phytomass linear regression analysis equations ($Y = a + bX$) for data for 10 equation sets, each composed of 4 randomly selected subplots.

Equation set number	Linear regression			
	a	b	r^2	Standard error (g)
1	0.0070	0.0183	0.90	0.358
2	0.0733	0.0141	0.74	0.247
3	−0.0141	0.0171	0.89	0.455
4	0.0666	0.0145	0.81	0.254
5	0.0838	0.0134	0.86	0.254
6	0.0951	0.0115	0.70	0.207
7	0.0866	0.0118	0.85	0.195
8	0.0243	0.0175	0.90	0.416
9	−0.0133	0.0175	0.90	0.405
10	0.0454	0.0141	0.85	0.277
mean	0.0455	0.0150	0.84	0.307
S.D.	0.0418	0.0025	0.070	0.0942

at the 10% significance level. For nonlinear regression it was 11.4%, a difference much smaller than for the average of the overestimates. The greater precision of nonlinear regression resulted in estimates generally equivalent to those for power regression. The potential for extremes in over- or underprediction were also less for nonlinear regression. For corrected power regression, the confidence limit for the relative deviations was 14.0% of the actual at the 10% level of significance. The total range in the r^2 values for nonlinear regression (.84–.92) was just over half that of power regression (.78–.93) and less than half that of corrected power regression (.75–.94). Similar results occurred for the standard error of the estimate. The more representative the equation set was of the full site, the better the predictions generally were.

Squirreltail Bunchgrass Predictions

Test estimations of total squirreltail phytomass based on the allometric equation (Table 7) were more variable than those for low sagebrush (Table 6). Like the low sagebrush results, the least variability was with nonlinear regression. Unlike sagebrush, the best average accuracy for an average allometric estimate of total sampled squirreltail phytomass was with corrected power regression. Although the average for the relative deviations was the lowest for corrected power regression, its range of variation was greater than for either nonlinear regression or power regression. Nonlinear regression predicted total phytomass within 21.9% of the actual at the 10% level of significance. For corrected power regression it was 30.6% and for power regression it was 33.9% of the actual. The reduced variability for nonlinear regression resulted in the best predictions of squirreltail phytomass by the allometric equation. Differences in average foliage density between the equation sets and test sets (Table 2) were significantly correlated ($r = .94$, $P \leq .01$) with the relative deviations in the predictions (Table 7). When foliage density in the equation set was greater than or less than the test set, the test set was proportionally over- or

TABLE 6. Comparison of three allometric regression methods for determination of *Artemisia arbuscula* phytomass from crown volume. Equations were derived from combined data for equation sets of 2 random subplots (Table 3) out of 10 and used to estimate total phytomass for test sets of the combination of the remaining 8 plots.

Equation set number	Power regression			Corrected power regression			Nonlinear regression		
	r^2	Standard error (g)	Rel. dev. of total from act.	r^2	Standard error (g)	Rel. dev. of total from act.	r^2	Standard error (g)	Rel. dev. of total from act.
1	0.88	7.01	0.0067	0.87	7.38	0.0410	0.90	6.47	0.0661
2	0.87	6.82	−0.0060	0.84	7.73	0.0765	0.90	6.06	0.0331
3	0.89	7.08	0.0076	0.87	7.74	0.0577	0.86	8.01	0.1158
4	0.89	7.45	−0.0045	0.87	8.21	0.0513	0.92	6.45	−0.0198
5	0.82	9.28	0.0952	0.79	10.13	0.1357	0.88	7.63	0.0819
6	0.83	9.14	0.1183	0.79	10.13	0.1626	0.84	8.89	0.1198
7	0.78	8.85	0.1417	0.75	9.55	0.1785	0.87	6.87	0.1299
8	0.85	7.26	0.1007	0.83	7.80	0.1372	0.88	6.61	0.1350
9	0.88	7.59	0.0254	0.86	8.06	0.0596	0.90	6.67	0.0295
10	0.93	5.54	−0.0955	0.94	5.22	−0.0438	0.91	6.26	−0.0086
mean	0.86	7.60	0.0390	0.84	8.19	0.0863	0.89	6.99	0.0683
S.D.	0.041	1.174	0.0730	0.052	1.470	0.0676	0.0234	0.8983	0.0575

TABLE 7. Comparison of three allometric regression methods for determination of *Sitanion hystrix* phytomass from crown volume. Equations were derived from combined data for equation sets of 4 random subplots (Table 4) out of 10 and used to estimate total phytomass for test sets of the combination of the remaining 6 plots.

Equation set number	Power regression			Corrected power regression			Nonlinear regression		
	r^2	Standard error (g)	Rel. dev. of total from act.	r^2	Standard error (g)	Rel. dev. of total from act.	r^2	Standard error (g)	Rel. dev. of total from act.
1	0.83	0.264	−0.0213	0.81	0.282	0.1573	0.67	0.368	0.1698
2	0.64	0.692	−0.2898	0.73	0.597	−0.1649	0.83	0.474	−0.1075
3	0.72	0.278	−0.0250	0.72	0.280	0.1167	0.73	0.276	−0.1477
4	0.58	0.720	−0.2758	0.66	0.648	−0.1624	0.86	0.410	−0.0988
5	0.65	0.631	−0.2254	0.72	0.565	−0.1149	0.81	0.472	−0.1573
6	0.39	0.929	−0.4526	0.50	0.844	−0.3539	0.74	0.611	−0.2608
7	0.54	0.789	−0.3778	0.64	0.700	−0.2712	0.74	0.588	−0.2715
8	0.62	0.254	0.2090	0.47	0.300	0.3609	0.49	0.296	0.1263
9	0.73	0.289	−0.0827	0.74	0.285	0.0042	0.70	0.305	−0.0725
10	0.68	0.586	−0.2528	0.76	0.510	−0.1028	0.83	0.428	−0.1466
mean	0.64	0.543	−0.1794	0.67	0.501	−0.0531	0.74	0.423	−0.0967
S.D.	0.120	0.251	0.1978	0.111	0.204	0.2151	0.1090	0.117	0.1444

underestimated. Linear regression gave results for squirreltail better than any of the allometric-based methods (Table 8). It had the lowest average relative deviation and predicted total phytomass within 20.4% of actual at a 10% significance level. Squirreltail could also be analyzed by subdividing it into two parts. This would separate the nonlinear relationship of the smallest plants from the linear relationship of the larger plants. Each group could be analyzed separately to improve the estimation of the smallest plants.

CONCLUSIONS

Differences in total phytomass estimation between the evaluated regression methods stem from the usually skewed distribution of plant sizes on a site. The more abundant, smaller plants generally had denser crowns with more phytomass per unit of crown volume than the larger plants. Logarithmic transformation of the data for power regression decreased the values for larger plants more than for the smaller ones in a regression analysis. This gave the smaller plants with their denser crowns greater weight. In nonlinear regression the larger plants contributed to the analysis results more in proportion to their size. These differences were evident in the consistently larger values of the regression

TABLE 8. Linear regression prediction of *Sitanion hystrix* phytomass from crown volume. Equations were derived from combined data for equation sets of 4 random subplots (Table 5) out of 10 and used to estimate total phytomass for test sets of the combination of the remaining 6 plots.

Equation set number	Linear regression		
	r^2	Standard error (g)	Rel. dev. of total from act.
1	0.66	0.375	0.2150
2	0.85	0.443	−0.0737
3	0.73	0.275	−0.0377
4	0.86	0.419	−0.0594
5	0.83	0.449	0.1207
6	0.76	0.583	−0.2292
7	0.76	0.568	−0.2418
8	0.47	0.301	0.2116
9	0.69	0.310	0.0126
10	0.84	0.410	−0.1310
mean	0.74	0.410	−0.0213
S.D.	0.12	0.106	0.1632

parameter *b* in power regression results than in nonlinear regression results for sagebrush. Previous tests of the use of the correction factor (Baskerville 1972, Lee 1982) have been based on populations of individual plants that have generally been well distributed over the size range of the data. Greater numbers of smaller plants is more generally the rule in typical western shrub communities. When low sagebrush data were analyzed with power regression, the result was a general overestimation of the phytomass of the larger plants. This usually more than compensated for any underestimation of the smaller plants by logarithmic transformation bias. In closed-stand, pinyon-juniper woodlands the largest trees contributed more to the total phytomass on a site (Tausch and Tueller 1988) than they did for low sagebrush in this study. With the greater importance of the larger plants, the average overestimation of total phytomass by crown volume with power regression was 35.3%. Average overestimation from nonlinear regression was only 5.7%. The overestimation by power regression was increased, and by nonlinear regression decreased, compared to low sagebrush.

For squirreltail, the differences between power and nonlinear regression were the opposite of those for sagebrush. The lower values of regression parameter *b* and the associated greater curvature of the line occurred with power, rather than nonlinear, regression. The result from use of the power regression equation was, first, a small average underestimation of the smaller plants from logarithmic transformation bias. Second, there were larger underestimations of the larger plants from the dominance of the analyses by the smaller plants. Nonlinear regression eliminated the underestimation of the larger plants, but this was partially offset by an increased underestimation of some of the more numerous, smaller plants. An initial decline in the phytomass density with increasing crown volume in squirreltail occurred at a much smaller relative plant size than with sagebrush. The relationship was very nearly constant (linear) for most of the larger plants. Because the larger plants dominated the nonlinear regression analyses, the values of the parameter *b* were very close to 1.0 (Table 7), and linear regression worked as well (Table 8).

The general reduction in phytomass density with increasing plant size for both species could not be exactly matched by the mathematical capabilities of either allometric-based or linear equations. This resulted in either over- or underestimates for at least one part of the regression curve, depending on which regression method was used.

Bias from logarithmic transformation of the data values is a mathematical reality. It is, however, modified by other data characteristics. Particularly important are the differences in the pattern of phytomass density decline with increasing plant size, the distribution of plant sizes, and the sample size differences between data sets. The more the data set used to derive the estimation equations represented the data set being predicted, the better the results.

Nonlinear regression was the better choice for sagebrush despite the greater computation effort involved. It was nearly as accurate and had a much lower variability than the other two allometric-based methods. This lower variability appeared to be related to a better reflection of the crown phytomass density of the more dominant larger plants. The correction factor method should not be used for these types of data because it consistently had the poorest predictions.

ACKNOWLEDGMENTS

This research was done under a grant from the School of Graduate Studies, University of

Nevada at Reno. The author expresses his gratitude to Karen Chen for her help in processing and analyzing the data.

LITERATURE CITED

BASKERVILLE, G. L. 1972. Logarithmic regression in the estimation of plant biomass. Canadian J. For. Res. 2: 49–53.

BRAND, G. J., AND W. B. SMITH 1985. Evaluating allometric shrub biomass equations fit to generated data. Canadian J. Bot. 63: 64–67.

CHIYENDA, S. S., AND A. KOZAK 1982. Some comments on choosing regression models for biomass prediction equations. The Forestry Chron. 58: 203–204.

FREESE, F. 1960. Testing accuracy. For. Sci. 6: 139–145.

JOHNSON, P. S., C. L. JOHNSON, AND N. E. WEST 1988. Estimation of phytomass for ungrazed crested wheatgrass plants using allometric equations. J. Range Manage. 41: 421–425.

LEE, C. Y. 1982. Comparison of two correction methods for the bias due to the logarithmic tranformation in the estimation of biomass. Canadian J. For. Res. 12: 326–331.

PAYANDEH, B. 1981. Choosing regression models for biomass prediction equations. Forestry Chron. 57: 229–232.

PETERSON, F. F. 1981. Landforms of the Basin and Range Province. Nevada Agric. Expt. Sta. Tech. Bull 28, Reno, Nevada. 52 pp.

SCHLAEGEL, B. D. 1981. Testing, reporting, and using biomass estimation models. Pages 95–112 *in* Proceedings of 1981 Southern Forest Biomass Workshop, June 11, 12, 1981, Clemson University, Clemson, South Carolina. USDA Forest Serv. Southern For. Expt. Sta., New Orleans.

SPRUGEL, D. G. 1983. Correcting for bias in log-transformed allometric equations. Ecology 64: 209–210.

TAUSCH, R. J. 1980. Allometric analysis of plant growth in woodland communities. Unpublished dissertation, Utah State University, Logan. 145 pp.

TAUSCH, R. J., AND P. T. TUELLER 1988. Comparison of regression methods for predicting singleleaf pinyon phytomass. Great Basin Nat. 48: 39–45.