United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-382

June 1988

Relative Suitabilities of Regression Models in Electronic Analysis of Riparian Vegetation

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ABSTRACT

By regressing actual green vegetation weights against capacitance meter outputs, the linear model more frequently explained a greater proportion of the variance in vegetation weights than did the logarithmic model. Examination of the residual plots, however, indicated that there may often be a problem of nonconstant variance. While the linear model should ordinarily be used for predictions of green vegetation weights, sometimes a more extensive analysis is necessary to determine the appropriate model. The R^2 *values and Furnival's Index indicated a better fit for the logarithmic model. Comparisons using* R^2 *values and Furnival's Index should be used cautiously.*

KEYWORDS: herbage meter, linear, logarithmic, nonconstant variance

Increases in labor costs are continually increasing the need to develop less labor-intensive means of conducting analyses of rangeland vegetation. One device that has recently gained widespread attention for this purpose is the electronic capacitance meter, which allows quick, efficient, and nondestructive estimation of forage production (or biomass) based on the direct relationship between vegetation weight and capacitance (Fletcher and Robinson 1956; Neal and Neal 1973). These meters are simple to use, allow rapid sampling of an area because only a small, separate sample of representative vegetation need be clipped and weighed, and are useful under a variety of rangeland conditions (Currie and others 1973; Morris and others 1976; Neal and others 1976; Platts and Nelson 1983).

Use of the electronic capacitance meter depends upon the relationship between vegetation weights (green or dry weight) and electronic capacitance as measured by the meter. Double-sampling techniques (Cochran 1963) have been used to establish a relationship between the small clipped and weighed secondary samples and the unweighed primary sample. A linear regression model has typically been used to describe the relationship between vegetation weight and electronic capacitance and has generally provided an adequate description (Back and others 1969; Neal and Neal 1973; Platts and Nelson 1983). Recently, some researchers (Terry and others 1981) have suggested that taking a logarithmic transformation of both vegetation weight and electronic capacitance and fitting a linear regression model to these transformed variables may result in increased precision. This model is nonlinear in the original units and will be referred to as the logarithmic model, whereas the model using untransformed variables will be referred to as the linear model.

Much of the work supporting use of the logarithmic model consists of a comparison of coefficients of determination (R^2), a questionable procedure whose indiscriminate use is discouraged by many writers. Draper and Smith (1981), for example, state that adjusted R^2 values (adjusted for different degrees of freedom) may be used to compare equations from different sets of data, but only as an initial gross indicator. Rodriguez (1982) states that caution should be used in judging the explanatory power of a nonlinear fit when transformations are involved. Additionally, most studies were conducted in limited areas on similar vegetation, precluding evaluation of their generality.

We have successfully used electronic capacitance meters in riparian vegetation since 1979 and have assembled an extensive data base from a variety of geographic and riparian settings in the Intermountain West and under

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extremely variable climatic conditions. This data base was used to examine the relative merits of the two models, one using untransformed variables and the other using logarithms of both variables. Comparison of these regression models will help (1) determine the relative precision of each for estimating vegetation weights from meter readings, (2) determine which is the more generally applicable relationship, and (3) help investigators choose the more appropriate model under local conditions.

STUDY AREAS AND METHODS

We conducted herbage meter studies in three river drainages in south-central Idaho, two in northeastern Nevada, and two in northeastern and south-central Utah. The study areas in Idaho were in forested meadows of the Rocky Mountain Forest Province (Bailey 1980) and were characterized by well-developed riparian zones. The study areas in Nevada and Utah were in the Great Basin on the perimeter of the Intermountain Sagebrush Province (Bailey 1980) and were characterized by narrow, poorly developed riparian zones into which xerophytic vegetation has frequently invaded.

Sampling in the Idaho study areas almost exclusively included riparian vegetation, chiefly willows (*Salix* spp.), sedges (*Carex* spp.), and tufted hairgrass (*Deschampsia intermedia*). When nonriparian vegetation reached the water's edge, we included in the samples such species as Idaho fescue (*Festuca idahoensis*) and timber danthonia (*Danthonia intermedia*). Because riparian zones in the Great Basin study areas were relatively narrow, such terrestrial species as cheatgrass (*Bromus tectorum*) and big sagebrush (*Artemisia tridentata*) were frequently included in the sample with the typical riparian willows, sedges, and grasses. No attempt was made to determine the actual species composition of the samples. The above merely describes the difference in character between the geographic locations.

We measured sample plots using either a Neal Electronics[2] Model 18-2000 or 18-3000 electronic capacitance herbage meter. We determined vegetal capacitance of each sample plot by taking the average of three successive readings on the plot. Vegetation included in the sample was selected to provide a wide distribution of capacitance-weight points for fitting the regression models. The overall sample design was a double-sampling scheme (Cochran 1963) and is discussed in detail in Platts and others (1987) and Platts and Nelson (1983). Sample size varied with the size of the primary sample, with approximately one weighed sample plot for every four or five biomass sample plots.

Green vegetation weights (in grams) were regressed against meter readings (dimensionless) according to the linear model:

$$Y = a_1 + b_1X \qquad (1)$$

where:

Y = predicted green vegetation weight
X = meter reading
a_1 = intercept
b_1 = slope

and according to the logarithmically transformed model:

$$\mathrm{Ln}(Y) = a_2 + b_2\mathrm{Ln}(X) \qquad (2)$$

where:

$\mathrm{Ln}(Y)$ = natural log of predicted green weight
$\mathrm{Ln}(X)$ = natural log of meter reading
a_2 = intercept of the transformed data model
b_2 = slope of the transformed data model.

Zero points, corresponding to calibration of the machine to no-yield conditions, were eliminated in both regressions. This represents a departure from usual methods (Platts and Nelson 1983).

The primary measure used to assess the relative precision of each regression model for describing the relationship between meter readings and vegetation weights was the sum of the squared deviations from regression (SSD). These were calculated by determining the values from each predictive model, subtracting these predicted values from the actual values, and squaring the differences. Finally these squared differences were added to obtain a total for each sampled area. This is a natural measure of how well a model can predict, and we feel it is the most informative and appropriate.

Calculating SSD was straightforward for the linear model, but the logarithmic model required a retransformation back to the original units. A direct retransformation by antilogs results in biased estimates, and we used a correction formula recommended by Baskerville (1972) to correct this bias. (This correction was not large, however, and the results from the direct retransformation produced similar results.) The smaller the sum of squared deviations from regression, the better the fit.

The residuals were also examined to determine whether one of the assumptions of linear model fitting was violated, namely the assumption of constant variance. This was done by plotting the residuals against the predicted values. If the variance was not constant, it was expected to increase as the green vegetation weight became larger. Consequently, the plots of the residuals from the untransformed data were examined to determine if the absolute value of the residuals increased for larger values of predicted green vegetation weights. The plots obtained from the transformed model were compared with the plots from the untransformed model to determine if the residuals were more uniform throughout and also to see if the absolute values of the residuals in the transformed model decreased as the expected values increased. If they did decrease, then transformations actually caused a nonconstant variance to occur when it was approximately constant before transformation.

Other comparisons of the two models included here are (1) coefficients of determination, R^2, and (2) Furnival's Indices (Furnival 1961). These are included only because they have been widely used by other researchers and it is

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

of interest to evaluate the validity of these methods. Coefficients of determination do not directly measure the fit of the regression relationship to the data. Rather, they measure the proportion of variation in the response variable that can be attributed to its regression on the explanatory variable. Consequently, higher R^2 values indicate a better explanation of variation in the response variable, but comparison of R^2 values from models having different dependent variables (even when the difference results from transformation) is discouraged.

Furnival's Index (I) is an attempt to allow comparisons of residual errors among regression models when the dependent variables differ. It adjusts the standard errors to facilitate these comparisons. From the linear model, I is identical to the standard error of estimate, but from the logarithmic model, I is calculated as:

$$I = (S_{Y \cdot X}) \times (e^{Y}) \tag{3}$$

where:

$S_{Y \cdot X}$ = the standard error of estimate

e^{Y} = the antilog of the natural logarithm of the mean vegetation weight.

As with standard errors of the estimate, lower values of I indicate a better fit between the model and the observed data.

Neither R^2 nor Furnival's Index directly measures how well a model predicts.

RESULTS

Results of the study indicate a need for careful consideration of the merits of each model before making a selection of their use.

Sums of Squared Deviations

An examination of the sums of the squared deviations from the regression model showed a clear superiority of the linear model over the logarithmic model. The data from the locations in Idaho resulted in 40 out of 52 (or 77 percent) linear regressions having a lower SSD than the logarithmic regressions. In the more arid regions of Utah and Nevada, the results were even more favorable for the linear model. Here 23 out of 27 (or 85 percent) linear regressions resulted in lower SSD than using the logarithmic model. Contingency table analyses of these results indicate significantly more favorable results ($p<0.01$) for the linear model in both geographic regions.

Residual Plots

The results from the examination of the residual plots were ambiguous. Admittedly, examining these plots was somewhat subjective, and more data points from some locations would have helped. Nevertheless, 25 out of 52 locations in Idaho appeared to produce more uniform residual plots. In the Great Basin this number was 12 out of 27. Thus, in almost half of the cases, the log transformation seemed to help correct for nonconstant variances. On the other hand, in over half the cases it appeared that a correction was unnecessary. This ratio was about the same in Idaho as in the more arid locations in the Great Basin.

Coefficients of Determination

When the R^2 values were examined, there were only 12 out of 52 (or 24 percent) cases in Idaho where the linear model had higher R^2 values than the logarithmic model. This is opposite of what was found by examining the sums of squared deviations. In the Great Basin, however, 15 out of 27 (or 50 percent) showed higher R^2 values for the linear models. (Mean values are presented in table 1.) However, the differences in the means of the coefficient values were not found to be significant. The logarithmic model appeared to provide the better fit in Idaho based on this criterion, whereas the linear model seemed more suitable in the Great Basin sites. There also appeared to be a difference in fit that was related to the year of sampling.

The proportion of logarithmic R^2 values exceeding the linear R^2 values was tested to determine if this value differed from 0.5. The proportion of cases in Idaho was significantly greater than 0.5 ($p<0.01$), but the proportion of cases in the Great Basin was not significantly different from 0.5 ($p<0.05$). It should be recalled that comparison of R^2 values for different dependent variables is discouraged and that these were made for comparison with the work of other researchers. Nevertheless, the results of the R^2 values were opposite of what was expected after examining the SSD for both locations, and particularly for locations in Idaho.

Table 1— Mean linear and logarithmic model coefficients of determination (R^2) by geographic region and year of sampling

Study areas	Mean R^2											
	1979		1980		1981		1982		1983		Total	
	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log
Idaho	0.70	0.78	0.83	0.84	0.74	0.82	0.86	0.89	0.74	0.86	0.78	0.84
Great Basin	.90	.69	.83	.83	.81	.78	.85	.87	.78	.80	.83	.80
Combined	.76	.75	.83	.84	.77	.81	.86	.88	.76	.84	.79	.83

Table 2—Mean linear and logarithmic model values of Furnival's Index (I) by geographic region and year of sampling

Study areas	Mean I											
	1979		1980		1981		1982		1983		Total	
	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log
Idaho	33.9	20.0	20.0	13.5	27.7	21.7	33.2	25.8	25.4	17.4	27.9	19.6
Great Basin	15.6	19.2	43.3	34.0	7.2	8.2	29.2	16.6	28.2	19.4	24.2	28.3
Combined	28.7	19.8	26.2	19.0	20.4	16.9	31.6	22.0	26.4	18.1	26.6	19.2

Furnival's Index

Furnival's Index (1961) has also been used by other researchers to compare models (Terry and others 1981). The purpose of this index (I) is to adjust the standard errors of regression models with different dependent variables to allow comparison among them. The model producing a lower value of I would be interpreted as the model that best fits the data.

The results from this index were more dramatically in favor of the logarithmic model than were comparisons of R^2. In Idaho 42 out of 52 (or 81 percent) produced higher indices for the logarithmic model, and in the Great Basin only 18 out of 27 (or 67 percent). Again, these results were unexpected after examining the SSD values.

Also of interest is the fact that Furnival's Index indicated that the transformed model was better 13 times in 79 cases. However, we found no evidence from the SSD's, residual plots, or the scatter diagrams of the original data to support this result.

Table 2 shows average values of I for both regression models by year and geographic location. Overall values of I were significantly lower ($p<0.001$) when data were fitted to the logarithmic model. In only two cases did the linear model produce lower I values: Great Basin in 1975 and 1981. It is interesting that these two exceptional incidents occurred in the more arid Great Basin study areas, and during two unusually dry years.

DISCUSSION

For most of the conditions under which we have used the electronic capacitance meter with double-sampling, the linear regression model provided a more accurate means of predicting green weights based upon the SSD. Each squared deviation measures how far the predicted value deviates from the observed value, and their sum provides an overall measure of how far the model predictions deviate from observed values. The sum of squared deviations from the regression model is a clear, natural, and powerful measure of how well the model predicts and was considered as the overriding criterion for determining which regression model provided better predictions.

However, the assumption of a uniform variance is also extremely important in model fitting. Examination of the residual plots indicated that this was a problem in about half the cases that we examined. A logarithmic transformation of the data can sometimes be used to help correct this problem. Our results are thus somewhat ambiguous, and it may often be difficult to determine which model should be used. Under ordinary circumstances, when a quick prediction of vegetation weight is wanted, we see little advantage in using the logarithmic model because it is more complicated conceptually and more difficult to compute. In addition, when transformations are used, direct retransformations result in biased predictions requiring the use of correction factors.

In some situations an extensive analysis to determine the appropriate model may be justified. Under these circumstances we recommend a careful examination of the data using scatter plots of both the data and the residuals as well as examination of the SSD. It may be important to determine what transformation corrects for a nonconstant variance, and after transformation if a linear model fits the transformed data, or if a nonlinear model is indicated. This procedure can become rather complicated and will not be discussed at length here.

Interestingly, the linear model worked better in arid regions than in wetter areas and in drier years. On the other hand, the logarithmic model produced its best results in wetter regions and in wetter years. Thus, weather conditions may influence the shape of the curve and influence the choice of the more appropriate model.

Investigators should always retain the responsibility of comparing the fit of both models to their data and selecting the more appropriate one.

Comparison of coefficients of determination (R^2) derived from each model is not a recommended procedure because the dependent variables are not identical. This method has often been used, but our results verify that it is nothing more than a rough indicator. Even so, we expected the R^2 values to produce the same general results as the sums of the squared deviations. When the magnitudes of the R^2 values were examined, however, they showed no clear-cut superiority for the logarithmic model, although the logarithmic model produced higher values of R^2 more frequently. Thus, based on the comparison of R^2 values, we would have little reason to reject use of the linear model for most routine analyses.

An examination of the values obtained from Furnival's Index implied a clear superiority of the logarithmic model over the linear model. This was a result of the magnitudes of the I values as well as the fact the I values were generally lower for the logarithmic model. Again we expected Furnival's Index to produce the same results as the SSD, and our results were surprising. These results—and the 13 cases where Furnival's Index indicated a transformation and other analyses indicated a transformation was unnecessary—suggest a careful reexamination of routine use of this index.

The question of the significance of sampling riparian vegetation needs further evaluation. Vegetation moisture may likely have an effect on the relative suitability of the two models because the logarithmic model tended to be more effective in the wetter study areas of Idaho. Certainly, this would indicate that plant phenology may have a bearing on model selection, as may the range type (for example, riparian or upland range). We are currently considering studies that will help answer these questions. Meanwhile, the choice of which model to use requires careful thought and analysis.

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