ESTIMATING COMPONENTS OF PLANT COMMUNITY DIVERSITY ON MINED LANDS[1]

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Abstract.--Techniques suggested to date for estimating plant community diversity on mined lands have focused on intracommunity (alpha) diversity, largely ignoring intercommunity (beta) and landscape (gamma) diversity. These techniques have traditionally lacked any formal procedure for expressing sampling variability in the resulting diversity estimates. Jackknife methods now exist, however, which not only estimate alpha, beta and gamma diversity, but provide confidence intervals for these estimates as well. These methods are dependent upon an <u>a priori</u> identification of plant communities, which poses a potential problem on mined lands where the redeveloping plant communities may be so spatially interspersed as to preclude immediate identification. A method which combines non-hierarchical clustering of quadrat data with the jackknife estimates of diversity is presented as a technique for the evaluation of the three components of plant community diversity on mined lands. The feasibility of the approach is demonstrated with a sampling of native reference vegetation adjacent to a southwestern Wyoming coal strip mine.

INTRODUCTION

The evaluation of diversity is perhaps the most difficult challenge in the assessment of revegetation success on surface-mined lands. Techniques suggested to date for estimating plant community diversity have focused on intra-community (alpha) diversity, largely ignoring intercommunity (beta) and landscape (gamma) diversity, even though many papers have identified the need to create or maintain diverse habitats on mined lands (Karr 1968, Allaire 1979, Tyus and Lockhart 1979, Steele and Grant 1982, Emrich 1983). In addition, these techniques typically lack any formal procedure for expressing sampling variability in the resulting diversity estimates, though bond release criteria should ideally be defined on a statistical basis (Chambers 1983).

A robust bias reduction technique introduced by Quenouille (1956) and termed "jackknifing" by J.W. Tukey provides a means of estimating the central tendency and variance of a parameter independently of traditional parametric theory (Efron 1982). The technique reduces bias and allows parametric-like inference even in cases where the distributional properties of the variate are unknown (Gregoire 1984).

Zahl (1977) applied jackknifing methods to obtain estimates of diversity index sampling error. Routledge (1980) examined the bias-reducing properties of the jackknife method of estimating diversity with quadrat samples, and included a procedure for the calculation of confidence intervals for the diversity estimates. Routledge (1980) demonstrated that his jackknife estimator of diversity satisfied Jones' (1974) specification that the estimator must be a function of all the sample stratum means. Routledge's (1984) equations are derived from Jones' (1974) equations for first-order estimations, but incorporate the assumption that the number of quadrats sampled in a community is very much smaller than the total number of quadrats potentially sampled.

Routledge (1984) combined the jackknifing approach with Whittaker's (1972) hierarchical concept of diversity, providing a method for obtaining confidence interval estimates of alpha, beta and gamma diversity. In addition, Routledge (1984) demonstrated that the Shannon index's extreme sensitivity to rare species abundances

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leads to substantial bias in the jackknifed estimates, while Simpson's index has negligible bias. Heltshe and Forrester (1985) also determined the jackknife estimate of Simpson's index to be unbiased using quadrat samples.

The application of Routledge's (1984) technique to mined land assessment requires some modifications, however. The technique retains Whittaker's original idea that species turnover (beta diversity) occurs along elevational gradients. While Whittaker demonstrated that this was the case for an eastern hardwood community, it is unlikely that this assumption will hold for surface-mined lands. Therefore, some other a priori identification of the pattern of species distribution is necessary to employ Routledge's methods.

If we assume that the vegetation itself is the most appropriate expression of habitat (Daubenmire 1968, Gauch 1982), then we may use quadrat information to provide estimates of the plant communities present in a reclaimed area for input into the jackknifing calculations. Redeveloping plant communities may be identified subjectively, which poses a potential problem on mined lands where communities may be so subtle or spatially interspersed as to preclude immediate identification. Cluster analysis, however, provides a more objective alternative for the identification of plant communities from quadrat data, and can provide the non-hierarchical classification of quadrats necessary for the jackknifing approach. However, in order to jackknife estimates of diversity and variance, we must assume that the number of quadrats allotted to a cluster by the classification algorithm is proportional to the total number of quadrats in the community defined by the cluster. This is not an unrealistic assumption if quadrats are random samples in the landscape.

MATERIALS AND METHODS

To demonstrate the technique, data from a native reference area near a mine in southwestern Wyoming were obtained. The data consisted of weight estimates for all plant species within 121 one meter square permanent quadrats within a fenced, undisturbed area one hectare in size. The analysis was performed on three consecutive years' data (1982-1984).

As in all attempts to estimate plant community parameters from quadrat samples, it is necessary to establish the relationship between the size and distribution of plant communities within the study area and the sampling design and intensity necessary to adequately characterize the parameter in question. In the case of diversity, quadrat size must be smaller in magnitude than the smallest community considered, otherwise characteristics of the patch in question will be washed out by information from the surrounding matrix. Further, quadrat number must be demonstrated to adequately characterize diversity within the communities potentially present in the study area, at least those communities identifiable at the scale of the investigation. The choice of this scale is necessarily a subjective one.

For example, in the hectare of native vegetation used to demonstrate this technique, vascular plant communities were apparently distributed on a scale of tens of meters. On this basis, meter square quadrats were chosen for sampling. The minimal number of these quadrats necessary to characterize a community at this scale was determined by inspection of species-area and diversity-area curves.

Data for each year were first subjected to cluster analysis to identify the pattern of plant communities. CLUSTAR (Romesburg and Marshall 1984) was selected as the clustering program. Because the input data matrix of quadrats by species contained a large number of zero values, the Bray-Curtis coefficient was used to determine similarity on the basis that this index ignores joint absences (Clifford and Stephenson 1975).

Jackknife estimators of the three components of diversity were calculated based on the estimator of Simpson's index of concentration as it appears in Routledge (1980) and additional formulae in Routledge (1984). Variance estimators of alpha, beta, and gamma diversity were based on Routledge (1984). The distribution of jackknife pseudovalues converges to normal for these diversity estimators with increasing sample size; but because the number of clusters in a data set may be small, the variance estimators may be biased. The distributions of all three components of diversity were tested for normality with the one-sample Kolmogorov-Smirnov goodness of fit statistic for the intrinsic hypothesis (Sokal and Rohlf 1981).

Although beta is defined as the quotient of gamma over alpha and so might not be independent of alpha and gamma, Routledge (1984) proved that alpha, beta, and gamma are distributed asymptotically multivariate normal. However, for small sample sizes like ours, the asymptotic joint distribution may not be achieved. As an alternative, beta was also calculated as the quotient of the jackknife gamma over the jackknife alpha, and its variance approximated as a function of the variances and covariance of the jackknife gamma and alpha diversities (Mood et al. 1974).

For the purposes of comparison, the three components of diversity were calculated according to Whittaker's (1972) original method.

RESULTS

Jackknife statistics for the three components of diversity for the three years of data appear in table 1 along with the values for these same parameters calculated according to Whittaker's methods.

Table 1--Components of species diversity for a native reference area as calculated by (A) Whittaker's original methods and (B) jackknife method, with 95% confidence intervals.

Year		A (Whittaker)	B (jackknife)	95% C.I. (jackknife)
1982				
	alpha	2.16	2.26	2.00, 2.60
	beta	1.68	1.77	1.59, 1.95
	gamma	3.63	4.10	3.46, 5.03
1983				
	alpha	2.41	2.42	2.16, 2.74
	beta	1.75	1.74	1.50, 1.99
	gamma	4.22	4.26	3.80, 4.85
1984				
	alpha	3.27	3.14	2.31, 4.91
	beta	1.42	1.57	1.30, 1.85
	gamma	4.65	4.96	3.65, 7.74

Only in 1982 did we fail to reject ($p > 0.05$) the hypothesis of normal distribution of cluster pseudovalues for all three diversity components. In 1983, normal distributions of gamma and beta were rejected, as were the alpha and gamma pseudovalues for 1984. Thus, we might suspect that some of the variance estimates are biased. Heltshe and Forrester (1985) showed that the estimates of standard error for Simpson's index for sample sizes of similar magnitude to that of this study were either unbiased or slightly underbiased. These obsevations imply that slight deviations from normality may not significantly affect the estimation of diversity sampling variance.

The jackknife estimates for beta diversity variance were in all cases smaller than the beta estimates based on the variances of alpha and gamma diversities, though the latter were quite similar and in all years fell within the jackknife 95 percent confidence intervals.

For illustration, we assumed that no variance estimate was overly biased and tested the hypothesis of equality of diversity components with Student's t at a 0.05 significance level. Each yearly alpha estimate was significantly different from every other year; alpha diversity steadily increased from 1982 to 1984. No yearly gamma estimate was shown to be significantly different from any other year. Beta diversity in 1982 was not significantly different from beta diversity in 1983, but both were significantly greater than beta diversity in 1984.

DISCUSSION

Regardless of the calculation method, the components of diversity are estimates from sample data, not the true values. As such, there is sampling variability associated with the estimates. The jackknife estimates for diversity are all quite close to the estimates derived from Whittaker's approach, the latter in all cases falling within the jackknife 95% confidence intervals. However, the latter approach does not allow between-site or between-year comparisons which incorporate sampling variability information. The value of the jackknife technique lies in its ability to quantify the variance of the diversity index estimates and so to permit construction of confidence intervals and testing of hypotheses.

It should be noted that the landscape diversity will increase with the size of the study area. To employ any estimate of diversity for the purposes of comparison, the areas sampled should be equivalent.

The jackknifing method presented in this paper may also be used to evaluate diversity of life form classes as well as species. The method is also appropriate for data based on dominance parameters other than aboveground phytomass, e.g. cover or density.

Successful reclamation restores ecosystem function as well as structure and, ideally, reclamation criteria should consider both of these aspects. Any procedure based on an index of structure, such as species diversity (or similarity), does not necessarily evaluate function. Further, any structural index will fail to adequately characterize the contribution of a given species to ecosystem function if the magnitude of that function is not proportional to the dominance parameter for that species used to evaluate structure. For example, a nitrogen-fixing forb critical to the nutrient cycling of an ecosystem may have a very low relative importance when expressed as phytomass or cover, and thus its small contribution to a diversity or similarity index may underestimate that species' functional importance to the system.

Unfortunately, we have yet to define the roles that a given species plays in ecosystem function. Function may be approximated by reorganizing the data to life forms, but most such schema are based on structural attributes, which may or may not be correlated with function. Until functional relationships on mined lands are better defined and quantified, we are limited to the consideration of structural attributes and synthetic concepts such as species (or life form) diversity. The method for the evaluation of diversity presented in this paper was formulated for the purpose of estimating on an ecologically appropriate and statistically sound basis a single, synthetic, structural criterion of revegetation success.

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