MEASUREMENT OF QUANTITATIVE SPECIES DIVERSITY ON RECLAIMED COAL MINE LANDS: A BRIEF OVERVIEW OF THE WYOMING REGULATORY PROPOSAL[1]

by

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Abstract: The Wyoming Land Quality Division (LQD) Coal Rules and Regulations require mine operators to specify quantitative procedures for evaluating postmining species diversity and composition. Currently, permit commitments range from deferring to commit to a quantitative procedure until some future date to applying various similarity/diversity indices for comparison of reclaimed lands to native vegetation communities. Therefore, the LQD began trying to develop a standardized procedure to evaluate species diversity and composition, while providing operator flexibility. Review of several technical publications on the use of similarity and diversity indices, and other measurement techniques indicate that a consensus has not been reached on which procedure is most appropriate for use on reclaimed mine lands. In addition, implementation of many of the 'recommended' procedures are not practical with regards to staff and data limitations. As a result, the LQD has developed an interim procedure, based on site-specific baseline data, to evaluate postmining species diversity and composition success with respect to bond release requests. This paper reviews many of the 'recommended' procedures, outlines some of the pros and cons, and provides a specific example of how the proposed interim procedure was applied to an actual coal mine permit. Implementation of this or a similar procedure would allow for site-specific standardization of permits and regulatory requirements, thus reducing review time and reducing some of the subjectivity surrounding a component of the Wyoming bond release requirements.

Additional Key Words: diversity indices, similarity indices, bond release criteria, technical standard.

Introduction

The Wyoming Land Quality Division (LQD) Coal Rules and Regulations (R&R) state "The Administrator shall specify quantitative ...procedures for evaluating postmining species diversity and composition." The regulations also suggest operators commit to "a direct qualitative comparison of the life-forms of the premining and postmining communities using an appropriate index of similarity or other assessment method agreeable to the LQD." The requirement to measure and obtain adequate species diversity and composition, as written in the rules and regulations, is very subjective. However, the Federal statutes provided in the 1977 Surface Mining Control and Reclamation Act (SMCRA)and Federal rules, 30 CFR § 816.111 and § 816.116 may be used to understand the intent of the State requirements.

The LQD has developed a standardized procedure, based on site specific baseline data, to evaluate species diversity and composition. This proposed procedure meets the regulatory requirements for species diversity and composition, while offering the operator some flexibility to achieve bond release. Using the site specific standardization all operators will be required to meet a similar set of criteria for determining reclamation success. In addition, use of this procedure would essentially create a quantitative technical standard for composition and diversity, and not an unknown target inherent in the use of various indices.

The following terms are defined to ensure an understanding of key parts of this discussion:

- **Species composition** is defined as "number, kinds, amount and quality of species" (LQD R&R, 1996);

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- **Species diversity** is defined as "number of species per unit area" (LQD R&R, 1996).

- **Richness** is defined as the total number of species, genera or lifeforms sampled (Prodgers and Martin, 1996).

- **Density** is defined as the average number of species, genera or lifeforms per plot (Prodgers and Martin, 1996) and "the number of individuals per unit area" (LQD R&R, 1996).

- **Abundance** is defined as an arbitrary estimated range in numerical values which expresses plentifulness or scarcity of a species, lifeform, etc. (Bonham, 1989).

Bond Release Criteria and Quantification of Species Diversity and Composition

The primary purpose of creating a diverse reclaimed area is to produce a functioning community that will meet all necessary (or required) postmine land use(s). Both structure and species diversity are important considerations for reclamation (Allen, 1990). Structural diversity can be defined by the patchiness and vertical distribution of species, lifeforms, and/or communities.

By developing diverse reclaimed communities, an operator increases the likelihood of supporting a wider range of animal species and land uses. Diverse reclaimed lands provide a relatively stable, broad based vegetative community capable of withstanding a variety of environmental impacts. Such environmental impacts might include overgrazing, a change in dominant faunal species use, climatic changes (i.e., droughts, flooding, extreme temperature fluctuations, etc.), etc. Creation of a diverse reclaimed community within the first five to ten years may reduce the length of or eliminate early seral stages of succession, thus shortening the time it takes a reclaimed community to stabilize.

The state regulations regarding species diversity and species composition are open for broad interpretations both by industry and the regulatory authority (LQD). Administrative interpretation of the specific regulations and how to apply specific bond release criteria to meet the regulations have not always been consistent through time. Changes in staff, regulatory attitude, development of new regulations, and the evolution of reclamation science have all impacted past requirements for reclaimed area species diversity and composition.

Currently, and in the past, permit commitments to quantitatively measure species diversity and/or composition have included diversity indices, similarity indices, direct composition comparisons between the seed mixtures and a reclaimed area, direct comparison of a specific number of species or life-forms present on a reclaimed area at various levels of cover (i.e., similar to setting a standard), or deferring commitment to a future date. Still other operators proposed not to measure species diversity/composition quantitatively, noting that attainment of postmine land use goals (generally livestock grazing and interim wildlife use/grazing) in conjunction with a species list was evidence enough to prove adequate species diversity and composition (i.e., if an area could sustain grazing at some pre-determined level then species diversity and composition would be successful).

Inconsistency in and evolution of regulatory interpretation, and the wide range of procedures proposed by industry, have made the evaluation of species diversity and composition extremely confusing, both for industry and regulators. What constitutes and how to adequately measure/evaluate species diversity and community composition have been large unknown factors in reclamation. With more mine operators requesting the release of their reclaimed areas from bonding responsibilities, the LQD needs to develop an acceptable and consistent method of evaluating species diversity and composition.

Quantitative Measurements

Direct Measures

Various researchers have proposed different methods to measure species diversity on reclaimed mine lands. Some of the basic concepts are overviewed below. For more in-depth descriptions of methods and procedures the specific references should be reviewed.

Inventory diversity could (and does) include the number of species, rare species, community or habitat types, or ecosystems and the quantity of each (Wade, 1996). Lists or counts, and richness might be considered types of inventories.

Wade and Thompson (1993) used species richness (number of species present) to measure species diversity and composition for pre-1977 reclamation in eastern Kentucky. A correlation matrix was developed for each reclaimed site and compared to the expected species richness of native areas of the same size. These expected species richness values were derived from combined regional/local floras developed for native vegetation types.

To properly evaluate species richness, sampling would need to be performed in each season. In addition, using plot or sample locations provides incomplete lists. To accurately identify all species present, a complete inventory of the area would need to be performed. Complete inventories are more time consuming and more expensive than limited sampling events.

Development of a "flora", defined as "an inventory of the plants of a definite area" (Palmer et al., 1995), could also be used to evaluate diversity and composition of reclaimed sites. Floras developed independently for each reclaimed community provide a more accurate description of vegetation composition than developing a flora for all reclaimed areas combined. Palmer et al. (1995) proposed a comprehensive list of standards needed to develop a flora. Some of the information needed for developing floras include locations, environmental data, taxonomic scope, voucher specimens, botanical collection efforts, abundance information, origins, checklists, context to other work and summary statistics.

Function should also be considered when assessing diversity. Functional diversity could include the function of a gene or species, also the functions of communities, habitats and ecosystems (Wade, 1996). Aspects of functional diversity include on-site and off-site effects, cumulative effects, organizational stability and resilience, water storage and yield, permanent and transient habitat for faunal species, productivity, economic factors, and other human related uses and attributes (Wade, 1996).

Structural measurements are preferable because they are usually faster and less complicated to measure than to quantify functioning, and they are the types of measurements that are legally required (Allen, 1990). Table 1 outlines the relationship of the structural measurement to anticipated functional needs.

Some researchers recommend the use of lifeforms rather than species to evaluate reclaimed area diversity and composition (White and Keammerer, 1985). Much of the work on the lifeform level has been performed with similarity indices. Working with lifeforms reduces identification problems and strengthens statistical evaluations by reducing the number of categories available relative to using species.

[1]Table 1. Functional Measurements Commonly Used to Determine Success, and the Functional Measurements Needed

Structural Measure	Functional Need
Production	Productivity
Density	Mortality & Reproduction
Richness caused	Potential functional loss by missing species
Seasonal Variety of Species	Changes in function caused by absence of some phenologies
Number of Lifeforms	Changes in function caused by absence of some lifeforms
Indices of Diversity, Similarity	More specific information on species composition, and relationship to functioning
Production, Density during 2-3 years	Long-term stability

[1] (Allen, 1990)

Abundance measures of species and lifeforms would include evenness, frequency, cover, biomass, density and abundance ratings or scales given to density of colonies, lifeforms or species. Cover, density and biomass measurements can be used as a basis for developing (i.e., using data from sample locations) diversity and composition.

Chambers (1983) noted that direct, statistical measures of the values reflecting species importance (production, cover, or density) between reference and revegetated areas would appear to be a logical method for assessing diversity. "Spearman's rank correlation test coefficient provides a nonparametric statistical measure of the similarity between two areas, reflected by the relative importance of the various species or lifeforms within the two areas" (Chambers, 1983). However, she qualified the limitations of these methods for evaluating mined lands:

- Rank correlation tests provide only a relative comparison of species or lifeform apportionment, because ranking values are used instead of actual importance measures; and

- Tests of independence between two different areas do not directly evaluate differences in species or lifeform numbers or identities. Large differences in species or lifeform composition between the two areas greatly decreases the validity of the test.

Evenness can be defined as the distribution of species or lifeforms throughout a defined area (community), depending on the level of evaluation performed (or required) (Larson, 1980). Frequency is expressed in the number of times a particular species or lifeform occurs in the total number of plots (Cook and Bonham, 1977). Frequency of occurrence is often averaged across all samples per reclaimed vegetation type or community.

Calculating abundance of species provides a more precise description of the composition and structural diversity of a reclaimed area than simply using lifeforms. Collection of species data is more time consuming and may require more sampling to attain sample adequacy. Lifeform data is generally easier to use in statistical analyses, because of lower variability associated with the number of categories in which sample data can be placed.

Indirect Measures

Species diversity can be measured by alpha, beta and gamma diversity (Allen, 1990). Hatton and others (1985) stated estimating plant community diversity on mined lands has historically focused on intracommunity or within-habitat (**alpha**) diversity, largely ignoring intercommunity or between habitat (**beta**) and landscape diversity or the sum of the diversity of all the patches (**gamma**). Alpha diversity is typically measured by enumerating species richness and evenness with a habitat, patch or homogenous land unit (Allen, 1990). Beta and gamma diversity incorporate concepts of species and structural diversity (Whittaker, 1975). Whittaker (1972) classified gamma diversity as the species diversity for a range of habitats.

Prodgers and Keck (1996) state that determining beta diversity floristically is inappropriate in revegetation. They felt that environmental differences between fields are minor and random; and even if a unifying habitat gradient existed, the recentness of planting/seeding would overshadow any gradient distinctions in vegetation composition.

Prodgers and Keck (1996) also state that community structure (physiognomy) of reclamation rather than composition of the various reclaimed communities is the appropriate focus for assessing gamma diversity. Gamma diversity can be considered high if the landscape contains many dissimilar patches (Allen, 1990). Thus it addresses horizontal structure, but not necessarily vertical structure. Daubenmire (1968) defined **physiognomy** as "the gross appearance of a kind of vegetation, ignoring its taxonomic composition." The concept of physiognomy would require the use of an abundance measurement or rating system for quantification.

Hatton and others (1985) presented a method to measure all three types of diversity (alpha, beta and gamma) on reclaimed mined lands, however, there were qualifications and limitations to the application of their method. These qualifications include:

- A large number of production samples (121 one meter square quadrats) were collected on a small (one hectare), native area;
- A relationship between the size and distributions of plant communities, and the sampling design and intensity (which can be a subjective choice) necessary to adequately characterize the parameter in question must be established;
- Selection of the appropriate analyses technique ("cluster" and "jackknifing"); and
- Collection of multiple years worth of data.

Most of these qualifications are unrealistic for mine operators. The high number of samples on small study areas make this procedure cost prohibitive. In addition, most operators and regulators do not have the statistical background and knowledge to implement the statistical (cluster and jackknifing)techniques.

The two primary statistical (indices) procedures that have been proposed by Wyoming operators to measure diversity (comparing a reclaimed area to native vegetation communities) are the Shannon-Weiner (Shannon and Weaver, 1963; Pielou, 1975) and Motyka (Steward, 1983) tests.

Alpha diversity can be measured using various indices such as the Shannon-Weiner diversity index or Simpson's index (Allen, 1990). Chambers (1983) outlined several concerns (primarily dealing with issues of scale or where to draw the boundaries of the community) pertaining to the use of diversity indices:

- They were devised for use with numbers of individual species and assume that all individuals are equal;

- They are statistically comparable only if based upon numbers of individual species and even then, their comparability is questionable;

- Index values obtained from different communities are not directly comparable, and individual index values cannot be reapportioned to 100% as has been suggested for the Shannon-Weiner index;

- When examining two different communities, diversity indices do not reveal changes in the apportionment of individuals among species or in the identity of species; and

- All diversity indices that contain a term for species number are sample-size dependent and two populations are comparable by these measures only when the sample sizes are identical.

Some researchers have questioned what these indices actually measure (Chambers, 1983). Most people do not understand what the values mean. In addition, how do you compare two index values? What does 80% of an index value mean in terms of richness and distribution?

White and Keammerer (1985) cite a 1983 WDEQ-LQD memo on species composition and diversity that proposes the use of indices calculated between affected area vegetation types and corresponding non-affected, native areas (i.e., a similarity index). An 80% similarity (using lifeform groupings for the calculations) was suggested as a reasonable level of postmining similarity between affected (baseline) and reclaimed areas. They reported inherent internal mean similarity varied from low to high based on the use of species, nine lifeform categories and four lifeform categories, respectively. White and Keammerer (1985) concluded the use of eight to nine lifeform categories would provide the appropriate level of detail for revegetation evaluation of similarity.

If species richness and evenness need to be evaluated, Motyka and others (1950), Bray and Curtis' (1957) version of Sorensen's index and/or Spatz' (1970) version of Jaccard's index have a good potential for the comparison of two communities (Chambers, 1983). However, Chambers stated "the value of similarity indices for the assessment of mined land alpha diversity has not yet been tested." She suggested that one method for obtaining a realistic "acceptable" index value would be to sample replicate areas within the representative non-affected, native area and compute the similarity index for the replicates. A slightly lower value than this computed "inherent similarity value" for the representative non-affected, native area could then be used as the minimum similarity value to compare revegetated areas.

Calculation of the "inherent similarity value" requires repeated sampling. Most mining operations sampled the permit area vegetation types to the maximum number of samples required (30-50), and sometimes sampling did not meet regulatory adequacy. Multiple sampling episodes within a single growing season do not account for the effects of environmental extremes. In addition, sampling through several years generally takes place during the peak season of phenological development and thus may not account for the seasonal variations in composition. Those areas that have been repeatedly sampled through multiple years have not had the "inherent similarity values" computed. Baseline sampling for new applications follow similar patterns of maximum sampling and sampling adequacy.

Prodgers and Keck (1996) noted "Mining and reclamation destroy plant habitats, and regulations limit diversity strategies, making similarity an impossible goal. Further, there is a contradiction in comparing the "diversity" of two communities without ever having measured it. Finally, a similarity index seems best suited to measuring beta diversity where composition keys to habitat factors."

Some disadvantages of using non-affected native areas for assessing or evaluating reclaimed area success include:

- These areas are generally small and broad assumptions must be made regarding the ability of these sites to adequately represent the vegetative variability of a much larger affected area;

- Accuracy of community mapping which can be dependent on base mapping scale, level of community homogeneity performed or required, costs, etc;

- Assumptions that variations in the non-affected native area will be parallel to variations in the affected area;

- Potentially large number of samples needed to obtain sample adequacy;

- Changes in the mine plan which might impact these non-affected native areas;

- Infestations of pest species or disease; and

- Disturbance history differences.

Some advantages to using non-affected native areas for assessing or evaluating reclaimed area success include:

- Quantitative vegetative bond release parameters are based on dynamic, non-affected vegetation communities rather than arbitrary numbers or standards;

- If baseline statistical analysis is preformed between the non-affected and affected native areas then initial sample variability has been addressed; and

- Relative ease of statistical calculations and comparisons to be performed.

When originally proposed, the comparison of species seeded with those in the reclaimed environment seemed like a logical technique for the evaluation of species diversity or composition. However, many of the seed mixtures used by the mining industry were (and commonly still are) dominated by cool season perennial grasses (predominately wheatgrass species). Introduced, highly competitive cool seasons species are also common on older reclaimed areas. Evaluation of species/lifeform "success" using this comparative procedure amounts to a technique of quality control of seeding (Wade, 1997).

Operators commonly state in their permits that competitive seed mixture species will act as primary successional (early seral) species and the other lifeforms (warm season perennial grasses, perennial forbs and woody species) and later seral species will eventually invade the reclaimed sites. Permits often quoted various scientific sources which substantiated this invasion theory. However, much of the 'early' scientific research and data collection were performed on reclaimed disturbed range sites and not drastically disturbed mined lands.

Large scale mining affects on reclamation are well documented, but basically the overall effect is the homogenization of most non-climatic, environmental elements influencing plant establishment. Reclaimed areas seeded before 1990 tend to be less diverse than more recently reseeded areas (Schladweiler and Vance, 1995; Prodgers and Martin, 1996). This difference is due primarily to the content and quality of the seed mix with some influences of the seeding method (i.e., broadcasting versus drilling, direct topsoil application, multiple seeding techniques, spring versus fall, etc.). Prodgers and Martin (1996) concluded competitive dominance of early seral species inhibits invasion of species, even the later seral stage species. They also noted reestablishment of uniform habitat as a reason for low levels of reclaimed area diversity. As epitomized in the title of their 1996 paper, "*What You Seed Is What You Get,*" older reclamation, some approaching or exceeding the minimum bond release period (i.e., 10 years), tends to be composed of only a few genera and structural composition is homogenesis.

In essence, we know we can reestablish a few highly competitive species, but evaluation (or proof) of adequate species diversity and diverse community structure is more complicated than performing a one to one comparison of the major (competitive) species used in a seed mix to those found in a reclaimed area.

Another method proposed by some operators to quantitatively measure species diversity and composition, commits reclaimed areas to contain specific lifeforms or species to predetermined cover levels. Again, these lifeforms are usually determined by the seed mixture that will be applied to the reclaimed site, with little consideration for native community composition, function and rare or non-abundant species. Some problems with this method are explained by reviewing the following example of a typical permit commitment.

The permit commits to reestablishing the following lifeforms at the predetermined cover levels:

3 Perennial Cool Season Grass Species at minimum 5% relative cover;
1 Perennial Warm Season Grass Species at minimum 5% relative cover;
1 Perennial Forb (or Shrub) Species at minimum 5% relative cover; and
No one species will exceed 25% relative cover.

This "specific" commitment usually applies to all reclaimed vegetation communities. This evaluation method does not take into consideration that operators are required to plan for a variety of reclaimed communities or habitats (i.e., a combination of beta and gamma diversity elements). Instead it merely ensures that at least five different species (and theoretically as few as 3 genera) will be present at a minimum of 5% relative cover in the postmining environment of the entire reclaimed permit area. Again, this may be more of a measure of seeding technique quality control. This method also requires a high degree of regulatory input into the seed mixture and all associated reclamation/revegetation techniques.

Statistical Considerations

Probably the most important item needed for proper statistical analysis is the attainment of sample adequacy. Without meeting sample adequacy any statistical analysis is meaningless. Sample adequacy tests (Cochran's, the WDEQ-LQD method, etc.) are based on the assumption of normal distribution of sample values. In Wyoming, tests for normality have not be performed on baseline vegetation data. The LQD R&R set a minimum and maximum limit for the number of samples in both the non-affected, native area (5-30), and proposed affected (baseline) and reclaimed areas (7-50) for cover and production measurements. However, the establishment of a maximum sample size has not been approved by the OSM, because it has not been proven to be a statistically valid sampling technique. Therefore, the LQD currently requires sampling for bond release purposes, to be performed to adequacy.

Sampling annually or at least at regular intervals in a non-affected, native area allows for the tracking of vegetation variation (i.e., trend development and/or analysis). Vegetation cover, production and composition may be highly variable on an annual basis in response to variation in the distribution and amount of precipitation (Kunkel and Hinzel, 1983). In addition, different species respond differently to climatic events as a result of physiological and morphological adaptations, thus subtle differences in composition may result in quite distinct differences in plant community responses within relatively short time periods (Kunkel and Hinzel, 1983).

The choice of sampling methods (and parameters) is dictated by the objectives, the vegetation type, the vegetation characteristics to be measured, and financial and technical resources (Bonham, 1989). Species compositional changes can be determined through sampling of randomly located permanent sample locations or sample locations randomly located prior to each sampling event. Measurements for vegetation monitoring requires a high level of accuracy and repeated measurements. Modeling may be a viable solution to actual sampling constraints, but it is recommended that modeling be combined with actual field data for more accurate results (Bonham, 1989).

When the homogeneity of the area to be sampled is referred to, not only is the vegetation and community considered, but the distribution of the parameter (within the community) to be measured (i.e., vegetation cover, production, density) and the level for which this parameter needs to be evaluated (i.e., species, genera, lifeform, etc.) must be considered. All levels of homogeneity must be considered prior to developing a sampling regime.

Parametric statistical evaluations performed on baseline vegetation and bond release comparisons require normally distributed sample means, medians, variances, etc. The LQD regulations require only the statistical comparison of the vegetation cover, total cover and total biomass between the non-affected, native area and the reclaimed site, using a t-test. T-tests are performed at an $\alpha = 0.2$ and a confidence level of 80%.

In general, it is rare that biological sampling at the level required in the LQD R&R produce normally distributed data sets. Alternate sampling techniques (non-parametric) and technical standards can be developed for these and other parameters, but to date technical standard development remains in the planning stage for all parameters except subshrub/shrub density.

Several other researchers (Hatton and other, 1985; Magurran, 1988; Pielou, 1986; Prodgers and Keck, 1996) have proposed the use of similarity and/or diversity indices to compare reclaimed area to native areas after "jackknifing" the data sets. The jackknife procedure is a parametric technique used to reduce bias in estimates of population statistics (Sokal and Rohlf, 1981). The procedure also provides standard errors for the population statistics that can be used to calculate t-tests and confidence intervals. However, these methods usually require multiple sample sets and sample sizes larger than those sampled by most mines.

Prodgers and Keck (1996) conclude that with the use of "jackknifing" techniques, equations to estimate variance and calculate the "t" to test for the difference between samples, can be used in conjunction with the Shannon Index in reclamation. They also state "if all else fails, technical standards can set the necessary level for the Shannon values."

Almost all of these proposed statistical methods require more than a basic knowledge of statistics, in some cases, the applications are very complicated and require precise interpretations. At this time, neither the LQD nor most mining operations regularly employ staff with the required level of statistical knowledge. Therefore, until these various formulae can be simplified and specific methods approved by the LQD and OSM, it is not likely that complicated similarity indices, diversity indices, resampling, jackknifing, or other non-parametric statistical methods will be used for the measurement or release of species diversity and composition bond criteria.

Current State Interpretations and Requirements

The LQD R&R require "the postmining plant communities have sufficiently diverse species composition (numbers and types of individual species and lifeforms) and sufficient species diversity (a measure of the variability of the species composition) to support the postmining land uses." The reclamation plan should include a discussion of projected species composition and species diversity, and the ability of the species to support the postmining land uses. The composition of reclamation seed mixes and/or special plantings, known species characteristics and lifeform distribution should form the basis of this discussion. The reclamation plan should also include a conceptual outline of how species diversity and composition will be evaluated when bond release is requested. This outline should include:

- A discussion of the reclaimed community species and their ability to support and maintain the postmining land uses;
- The role of these species in secondary succession;
- A direct qualitative comparison of the species composition of premining and postmining communities;
- A direct qualitative comparison of the lifeforms of premining and postmining communities using an appropriate index of similarity or other assessment method agreeable to the LQD.

The LQD "shall specify quantitative ...procedures for evaluating postmining species diversity and composition" (LQD R&R, 1996). The LQD allows for species diversity and species composition to be compared to non-affected areas (more than one native area option) or technical standards. With this in mind the regulations also note that "an index of similarity (Mueller-Dombois and Ellenberg, 1974) may be used to compare the premining and postmining communities. However, such indices should not constitute the sole criterion for evaluation of species diversity."

In addition, the LQD requires a species list to be compiled for each postmine community. The LQD has also required the operator to provide some evaluation of each of these species abundance by community.

To date, no final Wyoming State Program (post-SMCRA), coal mine reclamation has been released from final bonding requirements. It is therefore hard to assess both the adequacy of the method (i.e., comparison to native areas or technical standards) and/or the adequacy of revegetation relative to the agreed upon method of evaluation.

Procedure Proposed by the Wyoming LQD

It became apparent during the late 1980's that many operators were not voluntarily addressing reclaimed land monitoring and bond release criteria for species diversity and composition. In addition, it was felt some of the methods that had been proposed may not return the land use value to a level equal to or greater than the premine conditions. Therefore, it became necessary for the LQD to develop an alternate method to assess a reclaimed site's quantitative species diversity and composition.

The LQD procedure summarizes all the vegetation cover data collected on native areas at a specific mine site, by premine vegetation community. Cover data is collected for all lifeforms and reported on the species level. Biomass data collection is limited to herbaceous lifeforms and density data collection is limited to shrubs and half-shrubs. Thus cover data was chosen to develop the quantitative species diversity and composition criteria. **Major species** are defined by the LQD R&R as a species "having relative cover equaling or exceeding two (2) percent." Baseline vegetation cover information (all native vegetation community cover data) is reviewed, and all "major species" are identified and grouped into one of the following lifeform categories:

Perennial Cool Season Grass;
Perennial Warm Season Grass;
Perennial Grass-Like (Sedges, Rushes, etc.);
Pereunial/Biennial Forb;
Perennial Sub-Shrub;
Perennial Shrub;
Succulent; and
Annual Forbs and Grasses

Total relative cover and total number of species by lifeform, are also used to develop the site specific standard. The regulations require baseline climatic data, including precipitation data, to be sampled prior to and during baseline vegetation sampling. This climatic data is compared to long term averages to determine if a year's weather patterns fall within normal or abnormal ranges. Potential climatic influences are then (arbitrarily) factored into the lifeform assessment. In addition, the time of the year sample information was collected and the species lists developed for each native community are taken into consideration.

For example, sampling may have occurred in mid-August during a relatively dry summer. Perennial forbs may not have been prevalent during cover sampling, but several species may have been noted in the species list, which accompany the baseline vegetation survey. With some limited knowledge of the vegetation communities of the general area, importance of the perennial forb lifeform component could be factored into the quantitative species diversity standard.

Baseline vegetation data for all coal mine permits was sampled one to two years prior to submittal of the permit application. Due to the expansion of mining, and therefore mining permits, some permits contain additional baseline studies for these permit amendment areas. Multiple years of baseline cover data can be summarized and used to develop the quantitative species diversity standard, thus incorporating some, environmental variation.

An example of summarized vegetation baseline cover information is presented in Tables 2 and 3. Table 2 displays the number of major species in each of the first six lifeform categories (succulents and annual species were not used in this example) by premine vegetation type. Table 3 displays the relative cover composition for each lifeform category by premine vegetation type, as defined by the operator (excluding succulents, but including a combined category for all annual species). These data were developed from one year of baseline cover data at one particular mine.

Table 4 displays the evaluation criteria developed to assess species composition and diversity in the various revegetated areas. This table was developed using 1988 baseline data, adjacent mine data, and summarization of the data included in Tables 2 and 3. Adjacent mine data was used because 1988 was considered a drought year, therefore the operator and the LQD deemed the vegetation baseline data was not entirely representative of the same vegetation types under more normal climatic conditions (i.e., long-term precipitation average).

The example presented (Table 4), is a first attempt at using the proposed quantitative species diversity and composition standard. Thus these original efforts were somewhat of a best guess at reasonable reestablishment of lifeforms. In general, it was thought that reestablishing approximately 80% of the premine major species by lifeform would be adequate.

The relative cover ranges for each lifeform are broad to account for seasonal extremes in relative cover. Low relative cover minimums for shrubs in the upland and shrub grassland reclaimed communities reflect the relatively low expected cover of native shrubs early in succession. Shrub density is considered a more valid method to evaluate reestablishment of certain shrub species during early stages of reclamation (10-20 years in age). The high of 20% relative cover for annual grasses and forbs reflects the cyclic nature of those two lifeforms and succession on disturbed sites. In more typical years, relative cover of all annual species should not exceed 10% in 10-year-old reclamation. If relative cover of annuals exceeds 10%, the permit commits to comparing the reclaimed area to the specified non-affected, native area to determine similarity. The important species (S) value in the reclaimed shrub grassland reflects the premine relative cover values for the shrub and subshrub lifeforms in the Big sagebrush and Silver sagebrush communities.

Most of the criteria developed in Wyoming have been done during major permit reviews, and thus completed under regulatory time constraints. The evaluation criteria should be refined over time, as needed, with the inclusion of additional baseline sampling data. Refinement will generally take place during major permit revisions or if the permit is determined to be deficient. It should again be qualified that the example, presented in Tables 2 through 4, was the first evaluation criteria developed using this procedure.

Discussion and Conclusions

Gamma diversity in Wyoming reclaimed mined lands is partially being addressed, holistically, by requesting the mine operators to replace approximate premine acreage of the various general vegetation types (i.e., shrublands, grasslands, woodlands, etc.). This type of diversity is accomplished through the requirement of variable topographies, replacement of premine topographic features, multiple seed mixtures and various

Table 2. Number of Major Species (>2% Relative Cover) by Lifeform from 1988 Baseline Data

	PREMINE VEGETATION TYPES					
LIFEFORM	Grassland	Big Sagebrush	Silver Sagebrush	Rough Breaks	Riparian Bottomland	Tame Pasture
Cool Season Grass	3	5	4	3	3	4
Warm Season Grass	3	1	0	2	2	0
Grass-Like	2	1	1	1	6	0
Perennial Forb	0	0	0	2	1	0
SubShrub	1	0	0	1	0	0
Shrub	0	1	1	2	0	0

Table 3. Percent Relative Cover by Lifeform from 1988 Baseline Data

	PREMINE VEGETATION TYPES					
LIFEFORM	Grassland	Big Sagebrush	Silver Sagebrush	Rough Breaks	Riparian Bottomland	Tame Pasture
Cool Season Grass	47.3%	28.8%	20.2%	36.2%	27.0%	91.6%
Warm Season Grass	20.2%	3.5%	3.4%	15.6%	15.0%	2.1%
Grass-Like	13.0%	4.0%	24.4%	2.8%	49.6%	0%
Perennial Forb	8.4%	4.3%	2.7%	15.6%	7.8%	2.1%
SubShrub	6.9%	1.6%	0.7%	15.6%	T	2.9%
Shrub	1.9%	55.3%	46.2%	13.9%	T	0.4%
Annual Forb/Grass	1.9%	2.1%	2.2%	0.4%	0.5%	0.5%

Table 4. Evaluation Criteria for Assessing Species Composition and Diversity in Revegetated Areas

	REVEGETATION TYPE											
LIFEFORM	Upland Grassland		Shrub Grassland		Tame Pasture		Streamside Bottomland		Mesic Bottomland		Closed Basin Bottomland	
	RC[1]	S[2]	RC	S	RC	S	RC	S	RC	S[3]	RC	S
Cool Season Grasses	45-75	4	30-70	3	60-95	2	30-70	4	30-60	4	55-85	3
Warm Season Grasses	10-30	1	2-15	0-1	0-5	0	2-20	1	10-50	1	2-20	1
Perennial Forbs	5-30	1	2-25	1	5-50	1	5-30	1	10-40	2	5-30	1
Annual Forbs/Grasses	0-20	0	0-20	0	0-20	0	0-20	0	0-20	0	0-20	0
SubShrubs	1-15	0	0-10	0	0-5	0	0-10	0	0-10	0	2-25	1
Shrubs	2-20	0	5-60	1	0-5	0	0-20	0	0-20	0	0-20	0

reclamation techniques (i.e., application of best available technology depending on the postmine land use, etc.). Specialized seed mixture application based on specific edaphic conditions (Allen, 1990) or topsoiling strategies that reapply variable depths based on location and topography (DePuit, 1984) could be considered reclamation strategies to increase gamma diversity. Original LQD interpretations of the regulations required uniform topsoil/subsoil redistribution depths across all reclamation. However, this interpretation has evolved to allow site specific variations in depth. This revised interpretation and replacement of variable soil depths should stimulate greater alpha, beta and/or gamma diversity.

The LQD's interpretation of the species diversity and species composition regulations leads us to believe that only the qualitative and quantitative measurement and assessment of intracommunity or alpha diversity are required. Regional landscape diversity, distinct from gamma diversity, is generally addressed (or homogenized) in the requirements to return a mined area to Approximate Original Contour and the limitations of a maximum postmine slope. The LQD recognizes the importance of beta and gamma diversity, and supports (and recommends the use of) sound reclamation activities that could enhance them. However, their statistical evaluation is not regulated as a bond release criteria.

Furthermore, Wyoming regulations require at least three (3) interim vegetation monitoring events during the initial 10 year bonding period for all reclaimed areas. This regulation was implemented in an attempt to provide a mechanism by which the LQD and the operator could assess potential problems or trends in revegetation, and provide data to make management and bond release decisions concerning the success of a reclaimed area.

It can be interpreted that most professionals cannot agree on a specific procedure for the evaluation of reclaimed mine land species diversity and species composition. Often times the methods that are proposed are impractical for both the mine operators and the regulator. Mining continues to affect more land every day in Wyoming. The LQD is faced with processing bond release requests and as part of those requests the LQD must make evaluations of reclaimed area species diversity and composition.

Therefore, in an attempt to provide a relatively simple, consistent and flexible procedure to quantitatively evaluate these two vegetation parameters, the LQD developed the procedure discussed in the previous section for this paper. In conjunction with all the other LQD regulatory requirements, use of the LQD procedure allows a mine operator to develop an evaluation technique for quantitative species diversity based on site specific data and to meet the regulatory requirements (as interpreted by the LQD). The LQD procedure also allows an operator to evaluate species diversity and composition, relative to bond release criteria, during interim vegetation monitoring. Reclaimed area trends can be evaluated and management decisions pertaining to various reclamation methods can also be assessed.

The LQD evaluation procedure should be viewed as interim. Based on new research, and the continued review and summary of existing research and technical literature the current procedure may need to be refined. The LQD is considering requesting an additional commitment by operators to include a minimum number of species per lifeform for each reclaimed vegetation community. Based on Tilman and Downing's (1994) and Tilman's (1996) research, the more diverse the community, in terms of species richness, the more resistant and resilient it is to environmental perturbation. In addition, the LQD is currently engaged in a research project to combine and analyze existing regionalized baseline data, which may allow for broader application and/or refinement of this procedure for assessing species diversity and composition.

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