DIVERSITY AND BIODIVERSITY: THE DIFFERENCE[1]

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Abstract. The concept of biodiversity embraces the kinds, variety and number of living things, the ways in which they are organized, the environments that support them, and related human values. Diversity is a more limited suite of measures and concepts that is related to species richness and abundance distributions. While diversity can be quantified by single number indices, biodiversity must be examined as a suite of qualities, some of which can be quantified. In fact, biodiversity has become a buzzword with many meanings. Before a meaningful discussion or evaluation of biodiversity can be conducted, we need to define the: (1) types of diversity that are relevant, (2) scales at which they are relevant, and (3) social stakes, stakeholders and values involved. For the latter, human values become important. This paper explains the difference between diversity and biodiversity, why it is important, and how different methods for evaluating diversity affect biodiversity values. A case study is used to examine inventory diversity, richness, abundance distributions, and the human values and stakes related to the reclaimed Fonde mine in Kentucky at the scale of the mine and in the context of statewide flora. Two evaluation methods (complete inventory and sample plot) affect biodiversity values differently.

Additional Key Words: land reclamation, values, social stakes, stakeholders

Introduction

Diversity and biodiversity are two terms in mined-land reclamation that are used frequently and perhaps overused. Both remain undefined in U.S. Federal reclamation law and regulations, though there are many definitions in use among biologists and ecologists, scientists in other disciplines, and the public. Both diversity and biodiversity include multiple, important concepts, so each should be retained in reclamation law, science, and practice. It is not uncommon for two sides to talk past one another when discussing biodiversity, particularly when each side is using different definitions.

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Both diversity and biodiversity therefore should be defined explicitly before they are discussed in a substantive way.

In this paper, I explain the difference between diversity and biodiversity, why it is important, and how two methods (complete inventory and sample plot) for evaluating diversity affect biodiversity values differently. I also describe the different types of diversity and its components (species presence and abundance), use of diversity and similarity indices, evaluation of diversity, and show how biodiversity relates diversity to both scale (from gene to habitat to landscape to world) and to human values associated with social stakes and stakeholders. A case study is used to examine the diversity and biodiversity of a reclaimed surface mine.

Diversity

Types

There are many different kinds of ecological diversity described within the ecological literature. Most often, diversity refers to species richness but it also can be applied to other taxonomic levels (taxa), for example, genera or families of plants or orders of insects. Diversity can apply to functions, guilds or functional groups, i.e., cryptophytes, nitrogen fixers, and cool- and warm-season grasses. Ecologists also recognize structural diversity, habitat diversity, differentiation diversity (heterogeneity), and several kinds of pattern diversity. In short, diversity is associated with anything that is ecologically meaningful.

Components

The concept of diversity can include the number of kinds of organisms (richness), and their relative abundance, evenness of distribution, rarity, or dominance in a community.

Richness. Richness, most often referring to species richness, is the most common and straightforward measure of diversity. It is highly affected greatly by size of inventoried area, number of samples, sample size, and requires context for its evaluation. Context for species richness can be obtained in two ways: richness compared to reference areas or relative richness based on regional standards. Richness of reclaimed land vs. that of reference areas is a valid comparison so long as the tracts being compared are comparable in size. It is well known that larger areas generally have greater species richness and that this relationship is nonlinear, usually taking the form of the power function (log-species:log-area)

$$S = cA^z \qquad \text{or} \qquad \log S = \log c + z(\log A) \tag{1}$$

or the exponential function (species:log-area)

$$S = k + c(\log A) \tag{2}$$

where S = species richness, A = area, and c and k are constants derived from linear regression. This nonlinear species-area relationship makes

$$S/A \tag{3}$$

a wholly invalid statistic for comparison. If species richness via complete inventory of a reclaimed area is known, its relative richness (S_R) to a regional standard can be calculated from a species-area curve such as in Figure 1 (Wade and Thompson 1991). Regional species-area curves can be used to provide the model for relative richness of an area of any given size such that

$$S_R = S_O/S_E \tag{4}$$

where S_R = relative species richness, S_O = species richness as observed, and S_E = species richness expected from use of a regional species-area model.

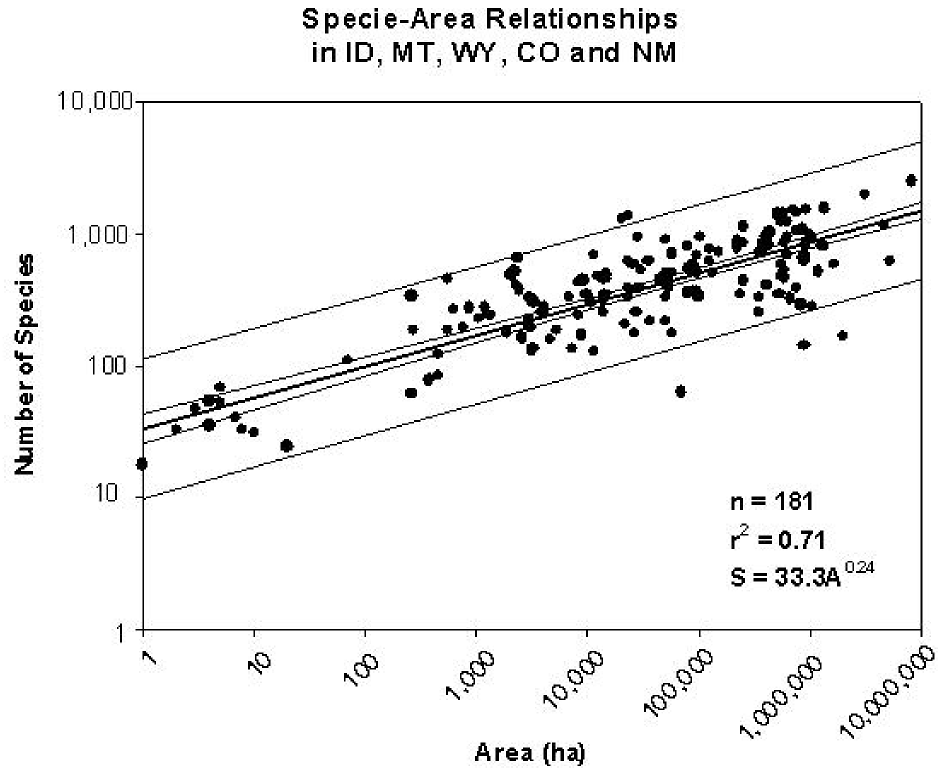

Figure 1. Species-area curve for Idaho, Montana, Wyoming, Colorado, and New Mexico based upon vascular plant inventories of defined areas. The outer confidence interval is the 95-percent confidence interval for prediction of species richness; the inner confidence interval is the 95-percent confidence interval for the mean.

A weakness with richness as an index of diversity is that it conveys no other information, such as how many kinds are expected to be found in an area, the proportion of exotic species, the relative abundance of native and exotics, and their evenness of distribution, dominance and rarity. The proportion of exotics in a flora and the relative abundance of the component species are relevant and should also be evaluated and reported along with richness.

Species abundance. Species abundance is a common concern, and its measures include evenness, dominance, commonness, and rarity. Relative species abundance often is represented graphically as in Figure 2.

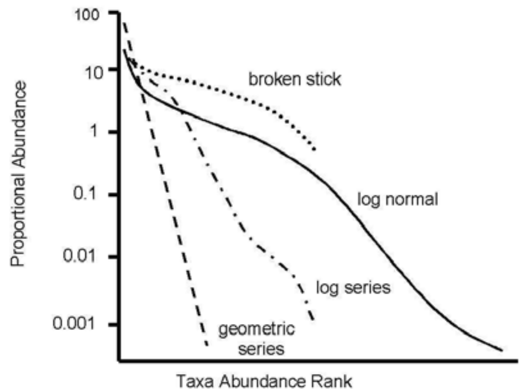

Figure 2. Four species abundance models.

The *broken stick* abundance distribution is characterized by the number of species present. Species are distributed with high evenness, and abundance is due to even distribution of resources. Such a plant distribution on reclaimed land typically would be the result of a single, recently applied seed mix that has developed into an initial community within which competition and environmental winnowing of species had not progressed to a significant degree. Therefore, dominance is low and there are few or no rare species. This is a nonequilibrium, unnatural community, and its abundance distribution will be altered as increased interspecies competition results in certain species being reduced or eliminated, others gaining dominance, and invasive species becoming established with a portion prospering over time. The *geometric series* abundance distribution results when a several dominant species preempt a high proportion of limiting resources. Species richness and evenness are low, dominance is high, and there are few rare species. Propagules tend to arrive at regular intervals. Among plant communities, this distribution is unnatural and denotes a nonequilibrium condition.

The *log series* abundance distribution is characterized by several abundant species, several species of common abundance, and more rare ones. As with the broken stick and geometric series the total number of species is low. Dominance is high and evenness is low in relation to the broken stick and geometric series. One or several environmental factors govern species abundances. Over time through successional processes, the log series tends to grade into the lognormal distribution (Magurran 1988).

The *lognormal* distribution has relatively few abundant species, somewhat more intermediate ones, and the majority of species are rare. Ugland and Gray (1982) propose that in a lognormal distribution, about 10 percent of species will be abundant, 25 percent will have intermediate populations, and 65 percent will be rare. Species richness is high, and dominance and evenness are moderate The lognormal distribution is associated with a large number of species affected by many independent habitat variables that interact to influence abundances. Communities with lognormal abundance distributions tend to be in equilibrium. A lognormal distribution is common in rich natural plant communities and among other groups of similar taxa, e.g., birds and insects. In land reclamation or restoration, a lognormal distribution of species in rich plant communities on the site would be one indicator of success from an ecological point of view.

Diversity Indices

Diversity generally is considered as being greatest when many taxa are evenly abundant. Richness and abundance values are frequently combined into complex indices of ecological diversity. Increasing richness or evenness increases the index value; complex diversity indices vary with respect to the effects of taxonomic abundance on the index value. Shannon's index of diversity is sensitive to the number of rare taxa that constitute a large proportion of the taxonomic richness in communities with lognormal distributions. Simpson's index is more sensitive to change in the number of the most common taxa; it is a measure of dominance. The reciprocal of Simpson's index is a measure of evenness.

Diversity indices often are credited with a qualitative meaning relative to an ecosystem's stability, resiliency, or health. However, some ecologists, myself included, are critical of compound diversity indices due to their loss of information. For example, two areas may have nearly identical diversity-index values but comprise different sets of species. Also, a change in index values does not reveal changes in richness or relative abundance or both. I suggest that separate handling and evaluation of the component factors in diversity (taxonomic richness, relative abundance, dominance, evenness) is preferable. Most people understand multiple concepts of quality related to reclamation, though in the United States, a strong legalistic culture seems to dictate that measures of quality and success be reduced to a single or as few numbers as possible with a binary interpretation: acceptable or unacceptable reclamation.

Similarity Indices

Within a biotic region, experience with data and indices can be used to specify reclamation standards without recourse to reference areas specific to each mine. However, local reference areas reflect local conditions that regional standards do not. The basic assumption is that if suitable reference areas are available, a reclaimed or restored area with similar richness and abundances will have similar ecological qualities and functions.

The similarity of species composition based upon presence-absence data can be measured using Sørenson's and Jaccard's indices of similarity (Magurran 1988). Sørenson's index

$$IS_S = 2c/(F_1 + F_2) \tag{5}$$

shows the mean proportion of the species (c) in Flora 1 that are also present in Flora 2 and vice versa. Jaccard's index

$$IS_J = c/(F_1 + F_2 - c) \tag{6}$$

shows the proportion of all taxa that are common to both (the core taxa). Jaccard's index always returns a lower value than does Sørenson's (except at 0.0 and 1.0), and Jaccard's index changes nonlinearly with change in taxa in common.

Sørenson's and Jaccard's indices are based on presence/absence only; they do not consider similarity/dissimilarity of species abundances. Chambers and Brown (1983) suggested that Spearman's rank correlation of species abundances in two areas is useful. I find that the pairing of Sørenson's index and Spearman's rank correlation of species in common accurately describes compositional similarity of two areas and is effective in tracking compositional changes within one area over time.

Evaluating Diversity

Field-study methods may have a significant effect on the evaluation of diversity. In most natural systems, several species are abundant but most are common to rare, and their abundance follows the lognormal distribution (Fig. 2) (Magurran 1988). About 10 percent of species are abundant, 25 percent are common, and 65 percent are rare (Ugland and Gray 1982). If a five-category abundance notation is used, most species abundances are occasional, infrequent, or rare (Fig. 3). This variation has an adverse effect on the results from sampling studies.

Sampling captures abundant and frequent species but increasingly misses occasional, infrequent, and rare species (Fig. 4). In fact, it is common for sampling studies to miss half or more of the species in a study area (unpublished data). Therefore, species richness used as a diversity index is suspect if it is derived from sampling. Richness of plots is sometimes used as an indicator of richness of the study area, but the assumption that plot studies capture equivalent proportions of total species richness does not necessarily hold true if a reclaimed area is being compared to a reference area with a different abundance distribution of the same species richness. If a similar pair of reference and reclaimed areas is evaluated using sampling methods, abundant and frequent taxa will be included in both data sets, but a large proportion of the infrequent and rare species captured will be different. Because of this disparity, both Sørenson's and Jaccard's indices of similarity will be lower than the true values for the entire areas. Sampling studies are useful for some applications and for addressing questions related to species associations, communities, and habitat variation, but they are weak with respect to questions regarding the similarity of floras and faunas.

Complete inventories, though seldom practiced on reclaimed lands, offer some advantages. Values for species richness, relative richness, compositional similarity (Sørenson's and Jaccard's indices), and beta diversity (differences related to environmental gradients or among habitats) at the land unit scale can be accurate if the inventory is complete and accurate. However, complex diversity indices based upon richness and abundance have not been developed for inventory studies.

Measures of diversity and their usefulness based on plot and inventory data are included in Table 1.

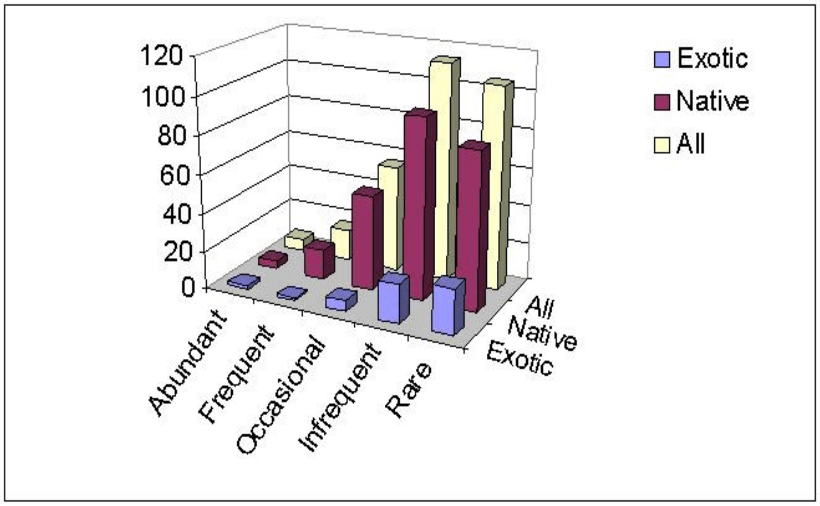

Figure 3. Distribution of species abundance categories; data are from the Fonde Surface Mine Demonstration Area, Bell County, Kentucky.

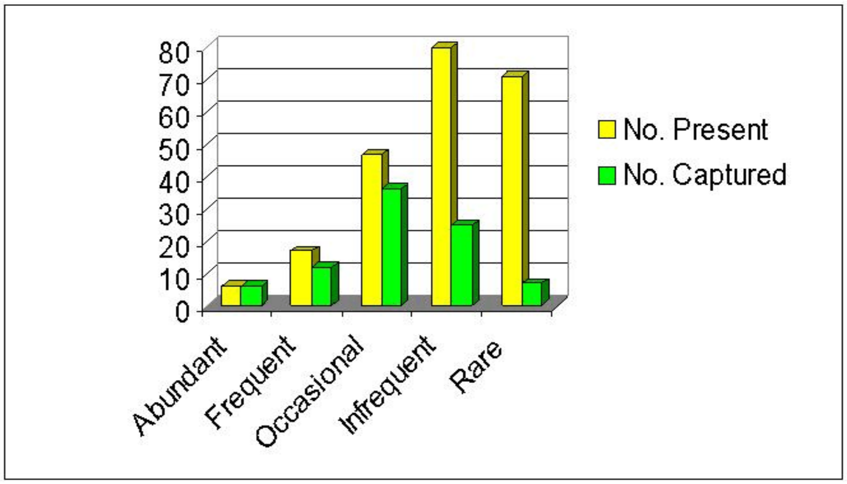

Figure 4. Species capture by complete inventories versus plot studies; data are from a complete inventory of the Fonde surface mine.

Table 1. Some measures of diversity and their usefulness with data from plot and inventory studies

Measure of diversity	Sample study	Inventory study
Species richness and relative richness	Can be 20-80 percent low	Can be highly accurate
Abundance distribution	Fine-grained, forms can be statistically tested: Log series Lognormal series Geometric Broken stick	Coarse grained, categorical, can be useful
Dominance	Berger-Parker	None developed for class data
Complex indices Richness + abundance	Shannon Index (emphasis: richness and rare taxa) Simpson Index (emphasis: abundances of common taxa) Shannon evenness (emphasis: evenness of taxa distribution)	None developed for class data
β diversity	using transects: Whittaker's β_W Cody's β_C	Using defined areas: 1 - IS_J 1 - IS_S
Compositional similarity		
Jaccard's index IS_J	Commonly used Samples yield lower values	Good, yields true proportion of core taxa
Sørenson's index IS_S	Commonly used Samples yield lower values	Good, yields true unit-wise proportional similarity
Sørenson's quantitative index	Commonly used	Not valid with presence/absence or categories
Correlation of abundances	Spearman's rank correlation of continuous abundance data without test of significance	Spearman's rank correlation of binary, category, or continuous abundance data without test of significance

The strengths and weakness of various diversity indices should be considered before a particular index is chosen. Different tracts of mined lands are reclaimed or restored for different reasons. If managing grazing lands with a large variety of abundant forage species is the goal, Simpson's index or its reciprocal might be the most appropriate because it emphasizes changes among the most

abundant species (rare species have little importance in grazing management). If the goal is restoration to natural conditions (high richness and log normal distribution) in a moderate environment, Shannon's index might be the better choice as it places greater emphasis on changes among the rarer species. Other diversity indices might be selected for their strengths and sensitivities relative to reclamation goals, expected land uses, or desired community compositions. Indices that emphasize species richness tend to agree on the relative ranking of diversity of several areas
(Magurran 1988). Indices that emphasize evenness or dominance also tend to be in agreement, though they can return rankings that differ from the richness group. See Magurran (1988) for a detailed discussion of advantages of numerous diversity indices.

Biodiversity

Biodiversity is a more complex topic than diversity and is unique in that no single summary value can be assigned to it. Because it is multifaceted, biodiversity presents a multidimensional problem for binary thinkers, that is, those agencies who categorize reclamation or restoration results as "adequate" or "inadequate."

Biodiversity can include eight types of diversity and is inextricably related to human values – it means what we want it to mean. Scale is an integrating factor for both diversity types and related human values. Figures 5-6 show at which levels of scale different types of diversity and human values may be valid concerns (Wade and Tritton 1997).

Inventory diversity is the number of different kinds and the abundance of each kind. This is sometimes characterized as alpha (α) diversity (local) and gamma (γ) diversity (landscape) (Magurran 1988). We can consider inventory diversity at any level from the gene to the biome. In the case of surface mines, we would be evaluating species composition at and below the mine level of scale, and the mine itself in the context of higher levels of scale. For example, we could ask:

- What is the genetic diversity among *Lirodendron tulipifera* on a reclaimed mine?
- How many planted species are present?
- What proportion of the entire Kentucky flora is present on this mine?

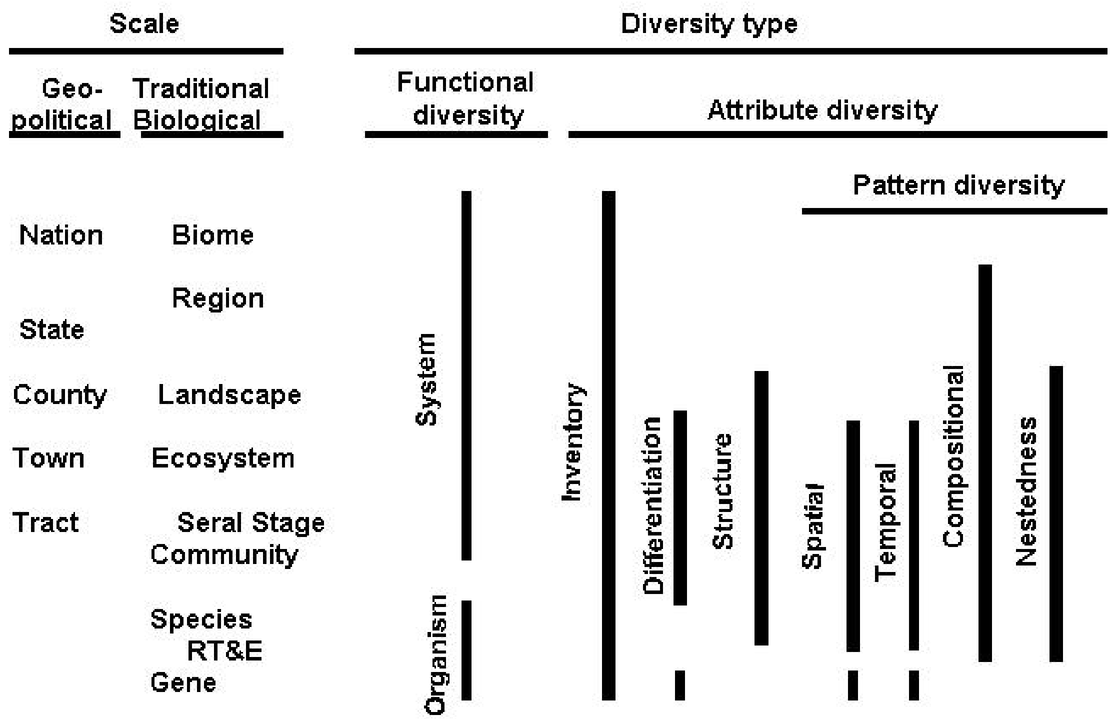

Figure 5. Relationships of diversity types to scale (after Wade and Tritton 1997).

Species richness is not the only component of inventory diversity that should be considered. Evenness might be more important than richness by some measures, and the presence of one or several rare, threatened, or endangered species might even be more important than that area's species richness or evenness. The weight given to richness, evenness, and rarity are value related and are discussed elsewhere.

Differential diversity describes the amount of differentiation present on a mine: how dissimilar among themselves are the habitats and communities within the mine boundaries. At the genetic level one might ask, How much genetic differentiation has been exhibited on the mine? This could include degrees of metal tolerance or polyploidy among varieties of sage brush (*Artimesia* spp.), important considerations in the western United States.

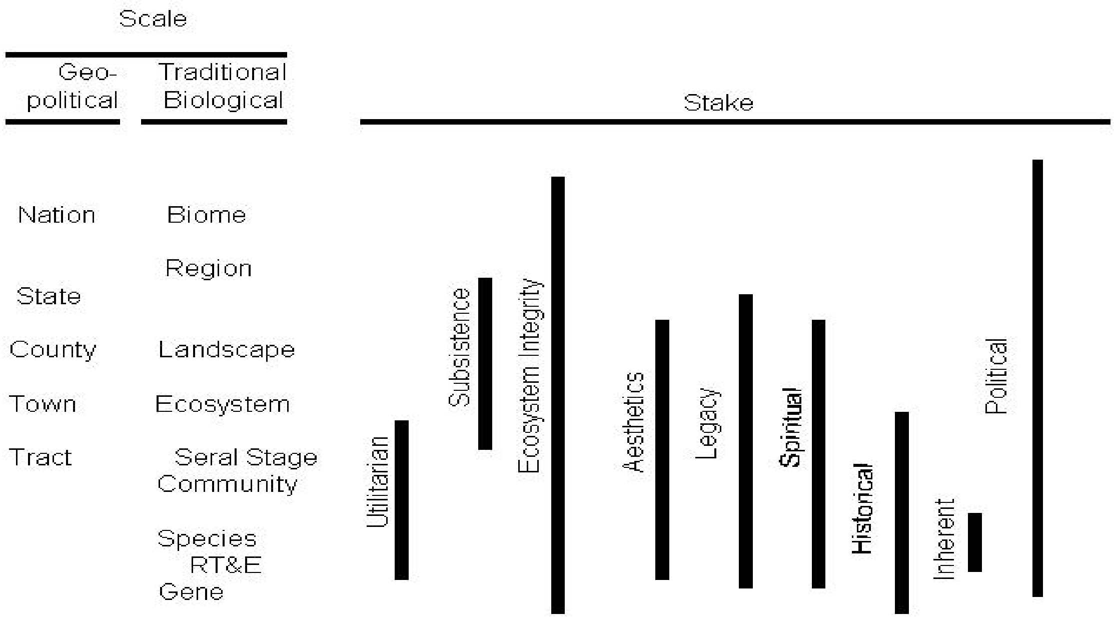

Figure 6. Relationships of social stakes and stakeholders to scale (after Wade and Tritton 1997).

Structural diversity is concerned with the types of physical structure contributed by plant species, habitat features, and even the topographic structure of the entire mine in the greater context of the landscape around it.

Functional diversity is truly multifaceted as it describes the role of species (nitrogen fixation, warm or cool season grass, wildlife food source, etc.) on the mine, and even the differential function of genotypes among them. It can be used to describe the functions of different habitats and communities within the mine, as well as the function of the mine and its influences at higher levels of scale, for example, as a source of clean or polluted water, or products extracted from the mine after reclamation and the area's return to productive agriculture.

There are four kinds of *pattern diversity*: *spatial* describes diversity that repeats itself across space, e.g., valley-slope-ridge-slope-valley in a landscape; *temporal* includes changes through time such as progression through seral stages; *compositional* relates to spatial differences in species composition; and *nestedness* is the tendency for collections of species or habitats to be predictable, nested subsets of the greater number of those available in the region.

Human Values and Biodiversity

We cannot ignore human values, the needs of society, or intrinsic values when we discuss or evaluate biodiversity. Such values are central to discussion about the value of species richness, evenness, and rarity. The perceived values of biodiversity define society's stakes or interests in it.

Utilitarian values or social stakes are related to what can be extracted, removed, and used from a reclaimed mine. Examples include water yield, pole and sawtimber, and agronomic crops.

Subsistence values are related to utilitarian values but differ in applicable scale. Subsistence is the ability to make a living entirely on reclaimed mine lands.

Ecosystem integrity is one of the most important characteristics in mined land reclamation, and can be linked to anything from genetics to land units. Genetic variability among *Artimesia* can effect the persistence of that keystone species on a mine. A large mine with failed reclamation can affect water quality to a long distance from the mine itself. Sediments can choke rivers and contribute to flood severity at great distances. Some effects of reclamation failures across a region have long-distance cumulative effects.

Aesthetic, spiritual, and historical stakes related to a mine are largely self explanatory.

Legacy stake is concerned with other human values – do we wish to leave these values for our children?

Inherent stake concerns a species's "right" to exist and also with conservation values. Does a species or unique community have inherent value apart and beyond that which society placeson it? Does a tree have legal standing (Stone 1996)? The evaluation of inherent stake(s) is closely associated with ethics and ethical values.

Political stakes as related to mined lands and their reclamation and quality are particularly important. Whether or not we admit it, many reclamation decisions are based more on political than on ecological considerations, and the political stakes with respect to social values and their stakeholders can be great.

Biodiversity of a Reclaimed Surface Mine: A Case Study

Evaluating biodiversity on mined land is partially an application of summary statistics and partially one of human values. Like diversity, the perceived biodiversity value of a mine can be effected by the study methods applied to it. As an example of biodiversity evaluation, consider the 7.3-ha Fonde Surface Mine Demonstration Area in Bell County, Kentucky. For this discussion, biodiversity includes inventory plant diversity at the scale of the mine but also in the context of the statewide flora (Table 2). Structure of the mine is considered at the scale of the mine and in the context of the surrounding landscape. Function is considered in the context of its contribution of acid-mine drainage to local streams, its provision of specialized habitats and potential products for human use, and its value as scientific information.

The Fonde mine was reclaimed in 1965 with the goal of demonstrating state-of-the-art reclamation under state regulations in place at that time. After mining, it was graded to control surface runoff and acid-mine drainage. Thirty-one species were planted in different communities based on spoil qualities, desired plant community function, and potential forest products. A complete floristic inventory and vegetation study on the mine were conducted (unpublished data); of the mine's reclamation and development are discussed in Wade et al. (1986) and Wade and Halverson (1988).

A summary of inventory biodiversity on the Fonde mine (Table 2) shows after 25 years the mine contained 299 species, about 9.5 percent of the 3,242 taxa in the Kentucky (Browne and Athey 1992). This floristic richness is about 88 percent of what might be expected in an undisturbed area of the same size (Wade and Thompson 1991). One species on the mine, *Scirpus fluviatilis,* is listed as threatened in Kentucky.

The highwall and bench of the mine and water control structures such as the sediment pond there provide habitat not previously available in the immediate area. Soils on much of the mine are deeper than those in the up- and downslope forests. Pine plantations on the mine provide vegetative structure not generally available on the surrounding slopes.

Table 2. Biodiversity of the 7.3-ha Fonde Demonstration Area

Attribute	Inventory	Plots
Number of taxa	299	86 (29%)
Relative richness (%)	88	25

Proportion of Kentucky flora (%)	9.5 %	2.7
Number of native taxa	246 (82%)	80 (93%)
Number of exotic taxa	53 (18%)[a]	6 (7 %)
Threatened species	*Scirpus fluviatilis*	none

[a] Proportion of exotic species in the state of Kentucky flora is 15.5 percent (Browne and Athey 1992).

Functionally, the Fonde mine differs somewhat from surrounding unmined lands. The eastern portion releases acidic surface drainage after storm events, but most water falling onto the mine or intercepted from upslope drainage is retained there. Sediment export is now well controlled. There is potential for polesize timber and later for sawtimber, for human use, but this is differs little from the surrounding forests. The method of reclamation and the scientific studies on this mine give it a value (information) that is greater than that of other mined areas in the region.

The human values and social stakes associated with the Fonde mine are not exceptional, but it is instructive to consider them (Table 3). The aesthetic, subsistence, legacy, historical, and political stakes of the mine are different from those that might be attached to the adjacent unmined forest. Mined sites of this vintage and form are common in Appalachia. The Fonde mine probably carries no inherent value except for the information value that is derived from the scientific study of this mine.

At the scale of plant species, I believe that the population of the threatened *Scirpus fluviatilis* has inherent value. Does *S. fluviatilis* confer inherent value to the Fonde Demonstration Area? Should this reclaimed mine be protected for its biodiversity/conservation value? I believe that conservation value of *S. fluviatilis* supersedes renovation of this mine to greater conformity to the Surface Mine Control and Reclamation Act of 1977 or other uses.

A plot study conducted at Fonde Demonstration Area at the same time as a complete inventory captured 86 species or 28.8 percent of those present on the mine (Table 2). The plot study, as is commonly the case in mine studies, was restricted to the most widespread habitats: mixed hardwoods, pine, black locust plantations, and the unplanted area. These areas contained 221 taxa, 39 percent of which were captured in the plots (Fig. 4). Plots missed most of the occasional,

Table 3. Human values and stakeholders in biodiversity of the Fonde mine

Values	Social Stakes
Utilitarian	• Hardwood and softwood pole timber, future sawtimber • Several herbaceous medicinals • Wildlife (hunting).
Subsistence	• None (area too small.)
Ecosystem Integrity	• Sediment control adequate. • Modest acid drainage after storms • Ecosystem processes well developed
Aesthetics	• Negative to most people (appears unnatural)
Legacy	• Little or no value to most people • Significant research value to those who study mined-land reclamation and succession because of the records kept of reclamation procedures and the subsequent information on ecosystem development
Spiritual	• None known
Historical	• Example of state-of-the-art reclamation at the time of its creation
Inherent Value	• As a mined site, probably none • *Scirpus fluviatilis* is threatened in Kentucky
Political Value	• Illustrates that reclamation to a species-rich area is possible; may have future influence on law and regulations

infrequent, and rare species (the majority of these areas' flora) so that, as expected, number of taxa, relative richness, and the mine's proportion of the Kentucky flora are low. Sampling did not capture the true proportion of nonnative taxa on the mine as most of these also were among the lower abundance classes (Fig. 4). *S. fluviatilis* was captured in the pond area outside the sampled areas.

These results point out the shortcomings of sampling studies for floristics descriptions and biodiversity evaluation. The tendency of species abundance to be lognormally distributed with less frequent species not being captured degrades the ability of plot data to be applied in this way. However, plot studies yielded quantitative data that well described the mine communities. These studies yield fine-grained data that are useful for community analysis and description that inventories with presence-absence or abundance class data cannot match. However, the coursegrained data of inventories are more effective in addressing quetions related to floristics. It is clear that for serious evaluation of diversity and biodiversity, both sampling and inventory studies on the same mines are desirable.

Summary

The concepts of diversity and Biodiversity are useful in reclamation, though each must be defined explicitly before use. Diversity requires definition as to type and context for index values. Any discussion or evaluation of biodiversity requires definition that includes: type(s) of diversity, values and stakeholders, and applicable levels of scale.

Evaluation of biodiversity of mined lands is value driven. There are no simple indices for biodiversity, and evaluation must be point by point among the multiple dimensions of biodiversity. Species richness and abundances should be evaluated in the context of local and regional norms. Special values can be assigned to rare species or communities. Differentiation is important at the genetic, community, ecosystem, and landscape levels, each of which includes different metrics for evaluation. Measures of structure vary among levels of organization from species to landscape. Each function that can be identified for genes, species, communities, ecosystems, or landscape units has separate measures. There are many measures and indices for evaluating pattern diversity. For each of these dimensions of biodiversity, a metric must be chosen and meaningful standards must be set. Human needs, social values, and ethics govern these choices.

The study methods used to evaluate diversity and biodiversity can affect the quantitative results achieved. Plot studies and complete inventories may produce equivalent results in process-related studies, but also different results when applied to floristics. Plot studies undercount species richness, miss the majority of rarer species, including those of special concern, and underestimate indices of similarity. Results of both inventory and plot-study methods need to be applied and interpreted with care.

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