MEANINGFUL MEASUREMENT OF REVEGETATION DIVERSITY[1]

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Abstract. In revegetation, the glitzy concept of diversity, once so promising, now lies tarnished if not discarded due largely to the unjustified use of the species as the fundamental unit of diversity. The species can be used to measure floral diversity, but no one knows what functional attributes, if any, accompany floral diversity. Thus, most diversity requirements for revegetation are arbitrary as well as indefensible. Can anyone demonstrate that an assemblage with one or two or five percent blue flax or yarrow is superior to one lacking weeds? To convince people that it matters, diversity must be linked with land use and postmine utility. For some postmine land uses, such as most ranching operations, diversity hardly matters. If wildlife habitat is the postmine land use, the time has come to return to the spirit of the original, breathtaking works relating vegetation to wildlife use. Measurements should focus on community structure and physiognomy, which can be used to define revegetation diversity. Within plant communities, the appropriate focus should be structure, with genuinely different and approximately equally different growth-forms or synusiae replacing the focus on species. The usual planimetric measurement of plant cover could be augmented with horizontal measurements -- a more realistic way to view wildlife habitat for many species. At the landscape scale, the focus should be the relative proportion and interspersion of physiognomic types in a landscape. Proportion can be measured by – what else – a proportional abundance index. Interspersion could be indexed using number of units in an area, average size or circumference, etc. The area evaluated should be large enough to consider the needs and preferences of mobile wildlife species, including temporal considerations, as well as specific requirements for less wide-ranging wildlife.

Additional Key Words: land use, structure, synusiae, physiognomy, wildlife.

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Papers about species diversity -- particularly most of those from the 1980s and 1990s -- rarely reach conclusion. They perpetuate controversies.
M. Rosenzweig (1995)

Introduction

Diversity is properly one goal of most coal and hardrock revegetation, but its measure leaves room form improvement. I am convinced that those approaches restricted to focusing on plant species (e.g., number, density, or proportional abundance) fail to capture the essence of diversity of vascular plants and plant communities. Indeed, it is questionable whether they measure anything important at all, being merely descriptive. If wildlife habitat is an objective, however, animal species may be valid as the dependent variable, e.g., the richness and abundance of wildlife species present seasonally in revegetation types.

Certainly descriptions remain important -- one can hardly imagine discovering functional attributes of diversity without good descriptions. But ultimately function must be convincingly demonstrated, and I am unaware that volumes of coal revegetation monitoring data have proven any general functions attributable to floristic diversity. For critical issues such as bond release, diversity requirements cannot be capricious and should be defensible in court, if necessary.

In Montana, coal reclamation defines diversity as the number of species with >1% relative cover in three select growth-forms[3]: native perennial warm- and cool-season graminoids and native perennial forbs.[4] The scale is strictly within the community or community type. Ignored are the two cornerstones of most species diversity evaluations: a count of species and calculation of proportional abundance. More importantly, no relation of diversity to land use is recognized. The rationale for selecting three growth-forms and ignoring others isn't given, but it suggests that all growth-forms currently in use were not created equal.

Diversity objectives and requirements seem to stand apart from other coal revegetation objectives. Although they are not alone in this, it gives the impression that revegetation objectives are a set of unrelated requirements, a sort of anti-ecosystem view. Function should be

[3]Merriam-Webster's Collegiate Dictionary, 10th ed., hyphenates life-forms. By extension, we are hyphenating growth-forms.

[4]The coal industry/legislature are currently rewriting Montana's coal reclamation law, and it appears that the new definition may be two or more species, native or introduced.

the tie that binds these requirements, but can anyone say how the number of species in three select herbaceous growth-forms relates to postmine utility or land use?

This paper briefly explores alternative ways of evaluating the diversity of mine revegetation. We must explain what benefit or function will be provided by diversity. In doing so, conflicts may arise when we consider various scales and postmine land uses. To expect all objectives to be met on each acre is unrealistic. For example, a different diversity is appropriate for livestock grazing versus wildlife habitat, and for one type of wildlife versus another. In some instances, diversity among communities may take precedence over diversity within communities, or vice-versa. But first, we have to consider the limitations of current approaches that focus solely on species.

Limitations of Using the Species in Diversity Evaluations

Kuchler (1967) said that the following statements are true worldwide:

1. *All plant communities consist of life-forms.*
2. *All plant communities consist of species*.

All other things being equal, which they seldom are, a diverse assemblage is likely to be more resistant or resilient to stress or disturbance than a less diverse one. Likewise, diverse vegetation is likely to provide food, shelter, or some kind of habitat for a broader array of wildlife, or in more seasons, than a simple assemblage. The question is, a diverse assemblage of what?

The usual answer is: species -- but not because it has been proven or is self-evident that the species is the proper focus of vegetational diversity. The species is the fundamental unit of flora, of plant taxonomy. Subtly, with little if any critical appraisal, it has become the default unit for diversity measurements and calculations. Consider the following examples of how the focus gravitates to species, contradictions notwithstanding.

A book on mammalian diversity (Wilson et al*.,* 1996) begins by defining biodiversity as “the variety of life forms, the ecological roles they perform, and the genetic diversity they contain,” citing Wilcox (1984). In the next paragraph, the authors say that the first step in “assessing” biodiversity is to estimate diversity, parenthetically adding, “e.g., with respect to species richness.” The shift is made from parenthetical example to dogma in the third paragraph: species diversity is the measure of community diversity. None of the three scales of diversity they recognize (genetic, community, and ecosystem) use life-forms. One wonders why they cited Wilcox if they were going to ignore him. Another example comes from Magurran (1988) in a book titled Ecological Diversity and Its Measurement. In the second paragraph, she said that diversity has two components: the variety and relative abundance of species.

The thoughtful reader is probably still pondering Wilcox, who no doubt carefully selected the term "life-form" when defining biodiversity. A plant ecologist will wonder whether, in Kingdom Plantae, he should use Raunkiaer's system (1934), which is based on the location of perennating buds. His scheme is enduringly popular (e.g., Lincoln et al. (1998) still use it to define life-form[5]), although few today are familiar with the classical Greek terminology. Perhaps the most important thing to realize is that the number of life-forms is few; six are commonly recognized for vascular plants, with four subdivisions of *phanerophyta* (trees and the taller shrubs) based on mature height. The number of species is vast in comparison. It is worth noting that in Raunkiaer's classification, all the perennial herbs usually seeded in revegetation would fall into *geophyta* (tubers, bulbs, rhizomes) or *hemicryptophyta* (herbs with renewal buds at the soil surface), with grasses and forbs undistinguished.

Barbour et al. (1980) said that life-forms can be defined based on attributes such as size, life span, degree of woodiness, morphology, leaf traits, and phenology. I see no reason why other criteria should not be used if the distinction is useful in evaluating some facet of diversity. For example, if birds or bears are of interest, those plants producing edible fruits would make a useful class. Following Daubenmire (1968, p. 62), I prefer "growth-form" as a plastic term for groupings of plants that avoids confusion with a fixed system such as Raunkaier's life-forms, but it seems that life-form can take on a number of meanings.

It has long been know that species are not equally different or equally important. This is the main shortcoming of using flora to evaluate diversity. For more meaningful measurement/ calculation of diversity, we need to assign each plant species to groups, call them growth-forms or life-forms, that differ more or less equally or at least in really important ways.

[5]Kuchler (1967) credits Warming with coining the term without identifying where. His Oecology of Plants, the first plant ecology text, came out in 1909; Daubenmire (1968) said that Raunkiaer developed his life-form classification between 1903-1907.

For this, one needs a frame of reference, and value judgments must be made. If wildlife habitat is an important objective, one must know the habitat requirements for important species throughout the year, and perhaps their special needs in years of unusual weather, etc. It takes an intimate knowledge not only of flora and vegetation, but also of wildlife to build this framework. This task is best left to regulators because a shift in paradigm can only come about if they are invested. Creating a new diversity paradigm will require a certain amount of verve and is, perhaps, unlikely.

How Does Diversity Matter?

The current paradigm is that diversity is self-evidently a GOOD THING, and that the species is usually the correct unit for measuring diversity. But diversity is a descriptive concept, not a fundamental attribute of plant communities as is primary production. It is no wonder that no one has much faith in the plethora of diversity calculations in use.

For diversity to be meaningful and important in revegetation, we have no choice but to state explicitly what advantage we think it confers. That depends on the postmining land use. In Montana, where I work, this is usually livestock grazing and/or wildlife habitat.

For livestock grazing, assuming water is usefully present, revegetation could diversify a particular operation by providing a specific type or season of forage, or by overcoming some limitation to the operation. It could provide early-season forage, or hay, or perhaps something we cannot realistically create in a decade such as a calving pasture.

On millions of acres in the west, native plant communites have been replaced with very simple communities, sometimes monocultures, of introduced species. Botanists may lament this conversion; it is anathema to what we think of as diversity and demonstrates that the cow has historically been valued much more highly than native plant communities; but it remains a fact. It is done for utility, and utility is an important goal of coal revegetation and indeed most revegetation. The point is that species and vegetational diversity are all but irrelevant to one important postmine land use. A stand of alfalfa with crested and intermediate wheatgrasses pleases the cow and can be hayed in good years. For shade, a billboard is as good as a stand of trees. Wildlife also use tame pastures within the context of a habitat mix. Diversity requirements for livestock should be easily defined and met.

The other common postmine land use is wildlife habitat. This vague concept was written into many coal permits in Montana, but a particular species or season of use is rarely mentioned. The permits I am familiar with don't mention grouse leks, or antelope calving areas, or critical mule deer habitat. On its face, "wildlife habitat" is meaningless…or all-encompassing, depending on interpretation. (Oh, the promises that are made to get a permit!) Worst of all, from a bond-release perspective, it is subject to evolving interpretation by a changing set of mine personnel and regulators.

Wildlifers usually approach vegetation in a way that botanists find maddeningly sloppy. Instead of identifying a big sagebrush/bluebunch wheatgrass type and a big sagebrush/western wheatgrass type and a silver sagebrush/western wheatgrass type, they recognize some nebulous thing called "sage--grass." Perhaps they do so because they know that habitat selection by many mobile species is not very precise, that community structure and physiognomic type are more relevant than floristic nuance, and that critical use may have more to do with which slope is snow-free and which is drifted than the species composition of structurally similar vegetation.

To evaluate or design diverse revegetation for wildlife habitat, someone must identify the species or group they hope to favor. We have to consider not just forage/browse/fruits in all seasons, but also thermal cover and escape cover and perching sites and wetlands. Within the community, the focus is structure as well as food. In the landscape, the focus is the mix of physiognomic types. This is the grist for our diversity mill.

Scale and What to Measure

Structure refers to the measured and described elements of physiognomy. Sometimes structure is synonymous with the height of synusiae[6], but its definition can be broader and incorporate

[6]Or synusias if you like. The term was coined by Gams (1918 as cited in Kuchler, 1967). Apparently synusia (sing.) is meant to be feminine, so the plural would be synusiae, but synusias may be acceptable.

layers. (Synusia are groups based on life-forms, the position of perennating buds, whereas layers are based on mature height.) Structure refers to the pattern of life-forms (and some would say layers) in a phytocenose, especially with regard to their height and density or coverage within each individual synusia (Kuchler, 1967, p. 20).

Zobel et al. (1976), in their study of Oregon forest communities, found that the abundance of each stratum had its own pattern in relation to the environment. Trees were centered in moderate environments, decreasing toward the extremes, especially the dry one. Shrubs were most common in dry stands, lowest in cold communities. Herbaceous plants were somewhat more common in high mesic stands. The lesson for us is not the particulars but the fact that abundance of a particular synusia, hence structural diversity, can vary independently within a single physiognomic type, i.e., coniferous forests.

Structure can be evaluated the usual way (e.g., using plant cover) by stratifying data by life-form. However, the usual planimetric measurement of cover may be less appropriate than a horizontal approach. Cover can be measured using a visual obstruction method such as the Robel-Pole or cover-board method. Both are described in a 1996 USDA-USDI publication. Again, required density would be regressed on cover.

As hinted before, woody plants may have to be subdivided into several classes. For example, sagebrush is a nanophanerophyte, chokecherry is a microphanerophyte, and box elder is a mesophanerophyte. Members of each subdivision collectively form a synusia. This of course is for mature plants in reference communities or the premine landscape. In the early stages of revegetation, plants are immature and short. By regressing density on cover in mature communities, the appropriate revegetation densities can be determined -- realizing that a reference community of woody plants can be an artifact of sorts resulting from decades or centuries of certain land use practices, such as fire exclusion and cattle grazing. Numerous woody age classes may be present, including sometimes a large senescent component that cannot be replicated in a bond-release time frame. Anticipated mortality of woody plants also must be considered in picking a density target.

How much cover of a life-form or synusia is needed to provide a structure suitable for various wildlife species? An approach based on the habitat needs of some target species or group of wildlife is superior to an approach based on reference stands. The structural diversity of a community or physiognomic type can be evaluated by enumerating the structural elements (e.g., life-forms, synusiae), calculating a proportional abundance index, and regressing them on the chosen measure of wildlife abundance.

By now it should be clear why the definitions of life-forms are so critical, and why they should differ in important ways and be approximately equally different. It will not do to recognize a half-dozen herb life-forms and one or two woody life-forms because the addition of one woody life-form can dramatically change wildlife suitability, e.g., perching sites, security cover, etc.

How important is structure? In one of the keystone papers from the halcyon days of diversity, MacArthur (1964) demonstrated that avian species diversity was correlated with plant community structure, basically the proportional abundance of three structural classes: herbs, shrubs, and trees. It was a remarkable paper in many respects, including the fact that it contained just nine citations, two of them atlases of birds. He distilled his approach in a 1965 paper:

> The experimental procedure is this: some measures of habitat complexity are guessed; to see which, if any, of these measures is responsible for the local bird species diversity it is sufficient to see, for a variety of bird censuses in a variety of different habitats, which habitat diversity measure is closely correlated with the bird species diversity. More precisely, a multiple regression of bird species diversity is calculated against all of the measures of habitat diversity which might be supposed to regulate the diversity of birds.

I included this quote not to make my own writing style look good by comparison, but to remind us that useful things are known about diversity. One is the importance of vegetational structure to animal diversity. Another is that Shannon's index was usefully applied to both the independent variable (foliage height diversity) and the dependent variable (bird species diversity). Johnson (1970) correctly predicted that it would be one of information theory's few productive contributions to ecology. MacArthur (1965) summarized the main points as 1) there is a simple structural component to within-habitat (animal) species diversity, and 2) the linear regression equation holds for a large geographic area, i.e., at least much of the United States. He soon expanded it to Puerto Rico and Panama (MacArthur et al., 1966). Recher (1969) added Australia. The relationship has been demonstrated on at least three continents (Rosenzweig, 1995).

The 1966 article also showed that the greater the bird diversity, the more habitats they recognize in structurally identical vegetation. This led the way to concepts of niche packing and resource partitioning. Can anyone think of a recent paper on (probably species) diversity so rich in ecological insight and so downright exciting?

If a particular type of wildlife habitat is the goal, structure may not suffice and particular plant species may define the habitat. One thinks of the sage grouse and sagebrush, or any number of frugivorous birds and the fruits of shrubs and trees. But in general, structure is the paramount vegetational attribute for wildlife.

Structure is a within-community attribute. At a larger scale that encompasses aggregates of fields, an entire permit area, or a larger area including undisturbed vegetation outside the mine, the focus should be the interspersion of physiognomic types relative to wildlife needs. Delineation of this universe is subjective, but it should be large enough to meaningfully evaluate the habitat needs and preferences of mobile wildlife.

In physiognomy, the emphasis rests on the appearance of vegetation, regardless of its floristic composition. It refers to the overall appearance of a phytocenose (Kuchler, 1967). Daubenmire (1968) similarly defined it as the gross appearance of a kind of vegetation, ignoring its taxonomic composition. Daubenmire listed what he considered to be standardized physiognomic types. In Montana, we might recognize forests, woodlands, scrub, grassland, meadow, and steppe, the last further divided into meadow-steppe, shrub-steppe, and true steppe. Barbour et al. (1980) said physiognomy is the outer appearance of vegetation and that both life-form and architecture contribute to it.

In Montana coal reclamation, the postmine revegetation distribution map indicates the location, extent, and interspersion of physiognomic types. Regulators require that the acreage of each type must approximate the premine extent, not because the premine condition is particularly great for some specified purpose, but because restoration is the Montana ideal and it doesn't require explicit justification. (Some coal companies are rebelling and the law in now being changed.) I suggest that the extent, interspersion, etc. of types should be based on the postmine land use, and if that use is "wildlife habitat," someone must define exactly what it means. The relative roles of livestock and wildlife must likewise be stated explicitly and reconciled.

Extent and interspersion of physiognomic types can be summarized by the number of units/ type and average size, or better yet average circumference. Of course, the versatile relative abundance index can also be applied to the percentage of each type.

Summary

In the context of mine reclamation, revegetational diversity must be related to postmine utility and land uses. The relative roles of livestock versus wildlife habitat, or other potentially conflicting postmine land uses, should play a central role in planning revegetation distribution.

If livestock habitat is the primary land use, simple plant communities may suffice, and elaborate diversity measurements and requirements are inappropriate. Revegetation in this case should provide missing or limited elements for the livestock operation.

Wildlife habitat is too vague to be useful as a land use designation -- it must be more precisely defined, and the needs of target species must be known. Within the community, habitat components are structure- and food-oriented. Structure is evaluated by layers or life-forms organized into synusiae. Carefully defined life-forms or growth-forms are appropriate units for evaluating vegetational (not floristic) diversity. Measurements stratified by plant species are useful only insofar as they help inventory structure.

The density of woody plants required in revegetation can be determined by first determining the cover of structural components associated with valuable wildlife habitat for target species, then regressing cover on density. The regression equation could be used to determine the density of woody plants within a synusia desirable for certain wildlife. Initial densities may have to be considerably higher, depending on the typical woody plant mortality in a particular setting.

At a larger scale, the mix of physiognomic types in a landscape large enough to incorporate the needs and preferences of mobile wildlife (where appropriate) is the measure of diversity. A diverse landscape is one in which important physiognomic types are interspersed to favor select wildlife species.

Literature Cited

Barbour, M. G., J. H. Burk and W. Pitts. 1980. Terrestrial plant ecology. The Benjamin/Cummings Pub. Co., Menlo Park, CA. 604 pp.

Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. Harper and Row, N.Y. 300 pp.

Johnson, H. 1970. Information theory in biology after 18 years. Science 168: 1545-1550.
http://dx.doi.org/10.1126/science.168.3939.1545

Kuchler, A. 1967. Vegetation mapping. The Ronald Press Co., New York, NY. 472 pp.

Lincoln, R., G. Boxshall and P. Clark. 1998. A dictionary of ecology, evolution, and systematics. 2nd ed. Cambridge Univ. Press, Cambridge, MA. 361 pp.

MacArthur, R. 1964. Environmental factors affecting bird species diversity. Am. Nat. 98: 387-397. http://dx.doi.org/10.1086/282334

MacArthur, R. 1965. Patterns of species diversity. Biol. Rev. 40: 510-533. http://dx.doi.org/10.1111/j.1469-185X.1965.tb00815.x

MacArthur, R., H. Recher and M. Cody. 1966. On the relation between habitat selection and species diversity. Amer. Nat. 100 (913): 319-325. http://dx.doi.org/10.1086/282425

Magurran, A. 1988. Ecological diversity and its measurement. Princeton Univ. Press, Princeton, NJ. 179 pp. http://dx.doi.org/10.1007/978-94-015-7358-0

Raunkiaer, C. 1934. The life forms of plants and statistical plant geography; being the collected papers of C. Raunkiaer. Clarendon Press, Oxford, Eng. 632 pp.

Recher, H. 1969. Bird species diversity and habitat diversity in Australia and North America. Amer. Nat. 103:75-80. http://dx.doi.org/10.1086/282583

Rosenzweig, M. 1995. (Reprinted w/corrections 1997.) Species diversity in space and time. Cambridge Univ. Press. Cambridge-New York. 436 pp.

USDA-USDI. 1996. Sampling vegetation attributes. 163 pp. BLM/RS/ST-96/002+1730. 163 pp.

Wilcox, B. A. 1984. In situ conversion of genetic resources: determinants of minimum area requirements. p. 639-647. *In* J. A. McNeely and K. R. Miller (eds.) National

Parks, Conservation and Development: The Role of Protected Areas in Sustaining Diversity. Smithsonian Institution Press, Wash., DC.

Wilson, D. E., J. D. Nichols, R. Rudran and C. Southwell. 1996. Introduction, Chapter One. p. 1-7. *In* D. E. Wilson, et al. (ed.) Measuring and Monitoring Biological Diversity; Standard Methods for Mammals. Smithsonian Institution Press, Wash., DC.

Zobel, D., A. McKee, G. Hawk and C. Dyrness. 1976. Relationships of environment to composition, structure, and diversity of forest communities of the central western Cascades of Oregon. Ecol. Monogr. 46: 135-156. http://dx.doi.org/10.2307/1942248