Defining biodiversity

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M. Soulé found it shocking that "... we are still trying to define biological diversity after all of the efforts of the Office of Technology Assessment and E.O. Wilson's book, *Biodiversity* ..." (Hudson 1991:75). It is apparent, however, that the term still lacks consistent meaning within the field of natural resource management. It is still defined in different ways by different people as noted by Noss (1990), Cooperrider (1991), Landres (1992), Trauger and Hall (1992), Cloudsley-Thompson (1993), and others. Adams (1994:151) characterized biodiversity as being a widely used term "... having no unified definition."

In addressing the conflicting definitions of biodiversity, Landres (1992:292) stated that "unfortunately, the need is too great and the time too short to be stuck in semantic and turf quarrels." Although conservation cannot be put on hold until a definition of biodiversity is agreed upon, a widely accepted fundamental definition of biodiversity is imperative for effective communication and cooperation within and among different countries, government agencies, disciplines, organizations, and private landowners. Cooperation among these entities has been identified as being necessary for the conservation of biodiversity (Keystone 1991, United Nations 1992, Babbitt 1994, Beattie 1996). Using terms in different ways is one of the major stumbling blocks to reaching agreement in problem solving and decision-making (Lee 1954, Mason and Langenheim 1957). If entities in a planning process view biodiversity in fundamentally different ways, agreement on management objectives and strategies for biodiversity conservation could be impaired.

To reach wider agreement on the meaning of biodiversity and to increase the chance of effective cooperation, a definition of biodiversity is needed that (1) has a sound foundation in semantics and etymology, (2) is consistent with the meanings of other ecological terms, and (3) is not biased toward any particular discipline. With this in mind, I undertook a literature review to locate a sound, objective definition of biodiversity as part of an initial phase of developing a comprehensive management plan for Stillwater National Wildlife Refuge, Nevada, which has the restoration and maintenance of natural biodiversity as one of its overriding goals. Most definitions of biodiversity I reviewed did not meet the above criteria (they generally were inconsistent with the words from which biodiversity was derived); I therefore explored the semantics and derivation of the term. In this paper, I present an objective approach to defining biodiversity that meets the above criteria. The opinions expressed in this paper are my own and do not necessarily reflect those of the U.S. Fish and Wildlife Service.

Range of definitions

Knopf (1992:242) asserted that the definitions of biodiversity are "as diverse as the biological resource." Definitions of biodiversity range in scope from "the number of different species occurring in some location ..." (Schwarz et al. 1976:34) to "... all of the diversity and variability in nature" (Spellerberg and Hardes 1992:1) and "... the variety of life and its processes. It includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, yet ever changing and adapting" (Noss and Cooperrider 1994:5). Table 1 illustrates the wide range of published definitions of biodiversity.

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Table 1. Selected definitions of biodiversity, from least inclusive to most inclusive as determined by the set of components and processes included in each definition and each definition's characterization of diversity, published from 1976 to 1996.

Scope of ecological components and processes	Characterization of diversity	Definition published by:[a]
1. Species	Richness[b]	Schwarz et al. 1976, Stankey 1990, Cloudsley-Thompson 1993, Harms 1994
	Richness and evenness[c]	Art 1993, Cloudsley–Thompson 1993, Lapin and Barnes 1995
	Variety	Sandlund et al. 1992
2. Genes, species (and their activities)	Richness	Erwin 1991, Foster 1992, Spellerberg 1992, Raven 1994
	Variety	Murphy 1988, Koford et al. 1994
3. Genes, species, assemblages	Richness	States et al. 1978, Nat. Wildl. Fed. 1991
	Richness and evenness	Patton 1992
	Variety	Reid and Miller 1989, Raven et al. 1992, Thelander et al. 1994
4. Genes, species (and their activities), assemblages, biotic processes	Richness	Schwarz et al. 1976, Salwasser 1991
	Variety	Norse et al. 1986, Wilcove 1988, Landres 1992, Counc. on Environ. Qual. 1993, Henderson et al. 1993
5. Genes, species, assemblages, ecosystems	Richness	Dasmann 1991, McNeely 1992
	Richness and evenness	Off. of Techn. Assess. 1987, Cooperrider 1991, U.S. Bur. Land Manage. 1991, Spellerberg 1992
	Variety	Counc. on Environ. Qual. 1991, Probst and Crow 1991, Fiedler and Jain 1992, Harris and Silva-Lopez 1992, United Nations 1992, Wilson 1992, Scott et al. 1993, Adams 1994, Allaby 1994, Eisner and Berring 1994, Huston 1994, Meffe and Carroll 1994, Hunter 1996
6. Genes, species, assemblages, ecological processes, and their interactions	Richness	Naiman et al. 1993
	Variety	Wilcove and Samson 1987, Samson and Knopf 1994
7. Genes, species, assemblages, ecological processes, ecological components, ecosystems, and their interactions	Richness	Barker 1993
	Richness and evenness	McNeely et al. 1990, McMinn 1991, Ratliff 1993
	Variety	Keystone 1991, Spellerberg and Hardes 1992, Daniels et al. 1993, West 1993, Noss and Cooperrider 1994, Scott et al. 1995

[a] References appear in the literature cited.
[b] Richness: the number of different types of items (e.g., species, communities) within an area.
[c] Evenness: the relative abundance of different types of items in an area (i.e., evenness in abundance of species).

Building an objective and sound definition of biodiversity

In my review of 85 definitions of biodiversity and related literature, I did not come across a formal semantic basis for the meaning of biodiversity, although I did encounter the rationale behind specific aspects of its meaning (Noss 1990, Angermeier 1994). The most common basis for published definitions of biodiversity appears to be other published definitions of the term. For example, the definition of biodiversity put forth by the Office of Technology Assessment (1987) appears to be the most widely cited basis for other published definitions (Wilcove 1988, McNeely et al. 1990, Noss 1990, Cooperrider 1991, Raven et al. 1992, Scott et al. 1995). However, the Office of Technology Assessment did not explain why they defined the term as they did, nor did they cite any supportive documentation. One problem with relying solely on authoritative sources for definitions of biodiversity is that different authorities have defined the term in fundamentally different ways (Table 1), i.e., nearly any view of biodiversity can be supported in this way. It is in such cases that Mason and Langenheim (1957) asserted that it becomes mandatory to analyze the foundations of a term. Without a logical, objective basis for defining biodiversity, it is unlikely that disagreements about its meaning will be resolved. The purpose of this paper is to put forth such a logical and objective basis. I used the following 5 approaches, based on methods described by Borsodi (1967), Tibbetts and Moake (1969), and Sherman and Johnson (1990), to construct what I believe is an objective and sound definition of biodiversity.

Definition based on derivation

The term biodiversity was derived from the root word "diversity" as modified by the prefix "bio-." Although words in the English language do not always reflect the exact meanings of the words from which they were derived (Laird 1981, Room 1986), that is the intent of the derivation process (Monson 1968, Laird 1981, Hurford and Heasley 1983). This principle provides a sound basis for defining terms, and, in the case of biodiversity, it would maintain consistency with other biological terms (e.g., biological community, biotic factors). Using such a foundation to define biodiversity would address inconsistencies among disciplines regarding the meaning of biodiversity because many of the disagreements can be traced back to departures from the meaning of the term biological, and to some extent, diversity (Table 1).

Basing the definition of biodiversity on the words from which it was derived is accomplished easily in regard to the prefix bio- because there appears to be broad agreement regarding the meaning of bio-, or biotic or biological. Bio- was derived from the Greek word bios, meaning life (Partridge 1966, Soukhanov et al. 1988, Gove et al. 1993). Biological and biotic are terms that refer to life, living organisms, assemblages of living organisms, and the activities and interactions of living organisms (Keeton 1967, Barret et al. 1986, Mader 1990, Ricklefs 1990, Allaby 1994). Once an organism dies, it is no longer considered biological. At this point, it is considered to be an abiotic, or nonliving, part of the environment (Keeton 1967, Odum 1971, Thomas 1979, Mader 1990, Allaby 1994). The scope of the term biological can be further understood in the context of components and processes that are considered biological.

Defining the base word of biodiversity (i.e., diversity) is more difficult because it continues to be defined in several fundamentally different ways. In definitions of biodiversity, diversity has been characterized as: (1) the number of different types of items, (2) the number of different types of items and their relative abundance, and (3) variety (Table 1). Characterization of diversity in discussions of biodiversity has also included structural complexity (Noss 1990, Henderson et al. 1993, Huston 1994). The following discussion addresses diversity in more detail.

Definition by classification

A classification definition (or logical definition) consists of 2 parts: class (or genus) and differentia (or species; Borsodi 1967, Hayakawa 1978, Sherman and Johnson 1990). The class indicates a classification or group that includes the term, and the differentia distinguishes the term being defined from all other members of that class. The value of this approach is that it places the term of interest into a class with which readers are already familiar and eliminates ambiguity by differentiating it from other terms in this class (Mudd and Sillars 1979). As an example, a bucket is a type of domestic carrying utensil (class) that is deep and round, has a curved handle, and is used for carrying fluids, especially water and milk (differentia; Tibbetts and Moake 1969). In the case of biodiversity, the class is denoted by the root word (diversity) and the differentia is determined by the prefix (bio-). As the meaning of bio- is discussed in other sections, I concentrate in this section on the class to which biodiversity belongs.

Biodiversity is a type of diversity. Other terms that fall within the class of diversity include geologic diversity, cultural diversity, economic diversity, etc. However, because there is widespread disagreement regarding the meaning of diversity in the ecological literature (McIntosh 1967, Hurlbert 1971, Solomon 1979; Table 1), specifying that biodiversity is a type of diversity (e.g., biodiversity is the diversity of ...) may contribute little to a natural resource professional's understanding of biodiversity. Many of the disagreements about the meaning of diversity may occur because a class has not been designated for diversity (e.g., state, attribute, measure, index) in defining the term. Hayakawa (1978:205) argued that the class is a major component of the fundamental meaning of a word and surmised that "Most intellectual problems are ultimately problems of classification and nomenclature." Two decades ago, Peet (1974) and Solomon (1979) pointed out that diversity lacked a fundamental definition. Because variety and diversity have similar meanings in common usage, using the term "variety" to designate the class to which biodiversity belongs may also be insufficient.

Therefore, exploring the classification of diversity is necessary to determine the class to which biodiversity belongs. Diversity has been treated in 2 main ways: (1) as a state or attribute and (2) as a measure or index (of a state or attribute). Standard dictionaries have classified diversity as a state, condition, or quality (Flexner and Hauck 1987, Soukhanov et al. 1988, Gove et al. 1993). In the ecological and natural resource management literature, Pielou (1977), Ricklefs (1979), Thomas (1979), and others have treated diversity as a 1- or 2-dimensional attribute of a community (e.g., diversity is "the number of ..." or "the number and relative abundance of ..."). More recently, it has been defined as a measure or index of those attributes; e.g., diversity is a "measure of ..." (Walker 1989, Fiedler and Jain 1992, Koford et al. 1994, Noss and Cooperrider 1994). Thus, a shift in the fundamental classification of diversity appears to be taking place because ecologists did not clearly designate the class of the term when it first came into popular use in the 1960s and 1970s.

The term biodiversity is immersed in the same confusion. One advantage with respect to clarifying the meaning of biodiversity is that most definitions of the term still treat it as a state or attribute, in contrast to a *measure of* a state or attribute. However, references to biodiversity being a measure have already appeared (e.g., Cloudsley-Thompson 1993). Furthermore, operational definitions of biodiversity (referenced by Probst and Crow 1991, Angermeier 1994) may provide impetus to define biodiversity in quantitative terms as Hunter (1996) recommended.

All but 1 (Cloudsley-Thompson 1993) of the 85 definitions of biodiversity that I reviewed treated biodiversity as a state or attribute, .e.g., "biodiversity is the variety of ..." or "variety and variability of ..." (Keystone 1991, Salwasser 1991, Scott et al. 1993, Noss and Cooperrider 1994). From this standpoint, biodiversity is classified as a type of variety, which in turn is classified by standard dictionaries as a state, condition, or quality (Soukhanov et al. 1988, Gove et al. 1993). When diversity is used in a similar manner in defining biodiversity (e.g., "biodiversity is the diversity of life;" Norse et al. 1986, Wilcove 1988), it falls into a similar classification because diversity, in common usage, also is classified as a state, condition, or quality.

Other definitions of biodiversity classified the term as a state or attribute, but they limited the scope of the attribute to explicit, quantifiable dimensions; e.g., "biodiversity is the number of ..." or "the number and relative abundance of ..." (Off. Technol. Assess. 1987, Erwin 1991, Spellerberg 1992, Art 1993). This emphasis on numeric characterization of biodiversity, along with arguments in favor of quantitative, operational definitions of biodiversity and criticisms of nonquantitative definitions (Trauger and Hall 1992, Angermeier 1994, Hunter 1996), may signal a potential shift in the classification of the term by some groups from an attribute to a measure of an attribute. This shift in the basic meaning of biodiversity can be prevented by agreeing on a fundamental definition of biodiversity that explicitly identifies the class to which the term biodiversity belongs, thereby avoiding some of the classification problems that have arisen in defining the term diversity.

Definition by listing characteristics, properties, qualities, and parts

Another way of delineating the meaning of a term is to list its characteristics, properties, qualities, and parts (Borsodi 1967, Sherman and Johnson 1990). Noss (1990) suggested that this approach to defining biodiversity was more useful than a sentence definition. A benefit of this approach is that it helps readers to recognize the full scope of the term (Sherman and Johnson 1990).

Noss (1990) recognized 3 main attributes of biodiversity: composition, structure, and function. Composition addresses the identity and richness of biotic components, and the relative amount (e.g., abundance, cover, biomass) of each (Noss 1990, Samson 1992). Biotic components of ecosystems include genes, organisms, family units, populations, age classes, species and other taxonomic categories, trophic levels of animals (e.g., herbivores, predators), animal guilds and assemblages, plant communities, and interacting assemblages of plants, animals, and microorganisms (i.e., biotic communities; Curtis 1979, Barret et al. 1986, Mader 1990, Ricklefs 1990). The ecological components listed in the first 4 categories of Table 1 would be considered biological. Abiotic components, which are not included within the scope of biodiversity, include geologic formations, rocks, soil, water, detritus, plant litter, and snags (Odum 1971, Curtis 1979, Thomas 1979, Mader 1990, Ricklefs 1990).

Structural attributes of biodiversity refer to the various vertical and horizontal elements of a community or landscape (Noss 1990, Samson 1992) and the organizational levels of plant and animal populations and assemblages (Krebs 1978, Hunter 1996). Considering only biotic, vegetative components of a landscape, horizontal structure consists of the size, shape, and spatial arrangement and juxtaposition of different plant communities; vertical structure consists of the foliage density and height of different vegetation layers (Toth et al. 1986, Noss 1990). Structure can also refer to population, age and trophic structure, and other levels of community organization (Krebs 1978, Ricklefs 1979, Bailey 1984, Hunter 1996). Incorporating structure into the scope of biodiversity would provide a link to other concepts, such as habitat diversity, of which vegetation structure is a major component (Toth et al. 1986, Morrison et al. 1992, Patton 1992, Anderson and Gutzwiller 1994), and the plant community concept, of which vegetation structure is an important differentiating attribute (Küchler 1988, Zonneveld 1988). Structure may have been left out of most definitions of biodiversity because the concept of biodiversity evolved from the concept of ecological diversity, which primarily focused on species diversity (Pielou 1975, Grassle et al. 1979, Hair 1980). Interestingly, Peet (1974) asserted 20 years ago that measurements of diversity should not preclude structural diversity even though the term is most often used in reference to species diversity. Magurran (1988) also noted that diversity can be used in reference to niche width and structural complexity of habitats.

Biotic functions include processes such as herbivory, predation, parasitism, mortality, production, vegetative succession, nutrient cycling and energy flow through biotic communities, colonization and extinction, genetic drift, and mutation (Ricklefs 1979, Mader 1990, Noss 1990). Biotic processes can be addressed in terms of the identity and number of different types of processes as well as the rate (e.g., predation rate) at which each process operates. Ecological processes such as water cycling, wind, soil erosion, earth quakes, and fire are not biotic (Ricklefs 1979, Barret et al. 1986, Mader 1990), and, therefore are not encompassed within the scope of biodiversity.

Diversity of biotic components and processes can be observed at many biogeographic scales from microsites and larger-scale landscape elements (e.g., vegetation types, habitat types, range sites) to regional landscapes, biomes, continents, hemispheres, and the entire biosphere (Noss 1990, Huston 1994, Hunter 1996). Although these are scales at which biodiversity can be observed, they are not necessarily scales of biodiversity because most include abiotic (e.g., geological) features. Biodiversity can be observed at several organism-based scales, including individual organisms, populations, species, and assemblages (e.g., guilds, plant communities), which themselves can be observed at various biogeographical scales.

Definition by comparison and contrast

The purpose of this section is to compare and contrast the meaning of biodiversity with other, related ecological terms. As noted by Sherman and Johnson (1990), the full meaning and exact limitations of a term might not be realized until it is compared with similar terms. In contrasting biodiversity with other terms, I argue in favor of defining biodiversity so as to be consistent with standard meanings of the terms from which it was derived.

Species richness and species diversity. Wilcove and Samson (1987), Noss (1990), Probst and Crow (1991), and Noss and Cooperrider (1994) argued that biodiversity does not equate to the number of species in an area; it is more than this. The term for the number of species in an area is species richness (Fiedler and Jain 1992, Koford et al. 1994, Noss and Cooperrider 1994), which is only one component of biodiversity. Biodiversity also is more than species diversity (simply called diversity by some authors), which has been defined as the number of species in an area and their relative abundance (Hurlbert 1971, Pielou 1977, Fiedler and Jain 1992, Koford et al. 1994). Species diversity also is only one component of biodiversity.

Ecological diversity. Biodiversity, according to the definition of biological, does not include the diversity of abiotic components and processes. It is inaccurate, in a definition of biodiversity, to identify ecological processes, ecosystems, ecological complexes, and landscapes as components of biodiversity as many definitions have done (categories 5–7, Table 1). This is because the term ecological, as used in the sense of ecological system (ecosystem), encompasses both biotic and abiotic components and processes (Thomas 1979, Ricklefs 1990, Gove et al. 1993, Noss and Cooperrider 1994). As such, ecological diversity is a more appropriate term for definitions that include diversity of ecological processes and ecosystems (Naiman et al. 1993).

Noss (1990:356), however, argued that ecological processes should be included in the definition of biodiversity, reasoning that "... although ecological processes are as much abiotic as biotic, they are crucial to maintaining biodiversity." Similarly, a U.S. Bureau of Land Management advisory group included ecological processes in their definition of biodiversity in response to criticism that the Office of Technology Assessment's (1987) definition did not consider form and function (Cooperrider 1991). Whereas ecological processes are often cited as being crucial to maintaining biodiversity (Reid and Miller 1989, Noss and Cooperrider 1994, Samson and Knopf 1994), this does not warrant the inclusion of ecological processes into the meaning of biodiversity. Reid and Miller (1989), Agarwal (1992), and Brussard (1994) distinguished between biodiversity and the processes and ecological diversity that maintain it. Including ecological processes as part of biodiversity because they are important to maintaining biodiversity equates to including potable water and airborne oxygen as components of a human being because they are necessary for the survival of human beings. It confuses definition with functional relationships.

Defining biodiversity using the standard meaning of biological would provide consistency with other biological terms such as biotic community, biomass, and biological control. For instance, a biotic community, or community, generally is defined as an assemblage of populations of organisms in a given area (Dasmann 1964, Krebs 1978, Burger 1979, Noss and Cooperrider 1994). The area occupied by a particular biotic community can range from a hollow in a tree to the entire biosphere (Odum 1971, Krebs 1978, Noss and Cooperrider 1994). If the basic meaning of biological is retained in the term biodiversity, then biodiversity equates to the diversity within and among biological communities. This creates a useful link between the 2 concepts and reduces confusion with ecological-based terms (e.g., ecosystem, ecological process). For instance, an ecosystem generally is defined as a biological community and its abiotic environment (Dasmann 1964, Krebs 1978, Fiedler and Jain 1992, Noss and Cooperrider 1994). Biodiversity is therefore a component of ecosystem or ecological diversity.

Native biodiversity. Whereas some authors have emphasized or limited the meaning of biodiversity to that of native biodiversity (Wilcove and Samson 1987, Murphy 1988, Samson and Knopf 1994, Angermeier 1994, Noss and Cooperrider 1994), others have included human alterations of biological communities in the scope of biodiversity (McNeely et al. 1990, Dasmann 1991, Pimentel et al. 1992, West 1993, Bryant and Barber 1994). Most definitions, however, do not distinguish between native and artificial diversity. For instance, I know of only 1 definition that limits the meaning of biodiversity to that which is native: "the variety of life and the ecological processes native to a particular landscape" (Samson and Knopf 1994:367). Conversely, I am aware of only 1 definition of biodiversity that specifically includes human-caused diversity: "The term *biodiversity* refers to the totality of species, populations, communities, and ecosystems, both wild and domesticated, that constitute the life of any one area or the entire planet ... it specifically includes cultural modifications of the natural world" (Dasmann 1991:8).

Angermeier (1994:602) argued that "the absence of a 'native' criterion within the definition [of biodiversity] severely compromises biodiversity's utility as a meaningful biological concept," reasoning that native biodiversity is more valuable than artificial diversity and should be the primary focus of conservation efforts. Conservation of native biodiversity appears to be the theme of biodiversity conservation texts (Wilson and Peter 1988, Meffe and Carol 1994, Noss and Cooperrider 1994, Hunter 1996).

Conversely, Oldfield and Alcorn (1991) and Götmark (1992) argued that an important component of biodiversity is maintained by traditional farming techniques. In the context of conserving biodiversity, Reid and Miller (1989), McNeely et al. (1990), Bryant and Barber (1994), discussed the importance of genetic diversity within species of cultivated plants. Biodiversity within agricultural crops was described by Stewart (1990), Altiere (1994), and Swift and Anderson (1994) as being important to pest management in agroecosystems and to sustainable agriculture. Pimentel et al. (1992) also discussed the conservation of biodiversity in agricultural systems. In his discussion of biodiversity on western rangelands, Laycock (1994) included native and nonnative aspects of plant-community ecology.

Applying Tibbetts and Moake's (1969) "reality check" and Mason and Langenheim's (1957) "truth-conditions" to the definition of biodiversity reveals that biodiversity does not equate to native biodiversity. Tibbetts and Moake (1969:79) suggested that the following question be asked when defining a term: "Am I telling the truth about this word?" They provided the following examples of unrealistic definitions: a monarchy is a "contemporary government ruled by a king for his own selfish purposes" and a fraternity is "a snob co-op." In both cases, the definitions were swayed by biases of the writer. Limiting the scope of biodiversity to that which is native because of a value judgment about the importance of native biodiversity would allow any number of other biases to be built into the definition of the term. I do not wish to downplay the importance of maintaining native biodiversity. However, if native biodiversity is the intended meaning, the term native biodiversity should be used.

Limiting the scope of biodiversity to that which some disciplines or groups consider native would invite miscommunication and controversy, and, consequently, would hinder interdisciplinary agreement. This in turn could hamper interdisciplinary cooperation in conservation efforts.

Definitions and designators. Another way of evaluating definitions of a term is to write out the definitions and assess whether other terms may be more appropriate for the definitions (Borsodi 1967). Borsodi (1967:40) recommended abandoning definitions based on common usage, which he contended "is never a common one because there are usually dozens of usages in common use." He recommended replacing this approach with recommended designators (terms) for each of the common usages. A benefit of this approach is that the meanings and concepts contained in the definitions are not necessarily abandoned; more appropriate terms simply replace the inadequate term currently used to designate the definitions. The following published definitions of biodiversity provide a starting point for this exercise. Following each definition, I assign what I believe to be a more appropriate term, or designator, for each definition.

"... the number of different species occurring in some location or under some condition such as pollution" (Schwarz et al. 1976:34)

≈ species richness

"The number and relative abundance of all of the species within a given area" (Art 1993:63,511)

≈ species diversity

"... the variety of life and the [biotic] processes native to a particular area" (Samson and Knopf 1994: 367, modified)

≈ native biodiversity

"... includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, yet ever changing and adapting" (Noss and Cooperrider 1994:5)

≈ ecological diversity

"... all of the diversity and variability in nature" (Spellerberg and Hardes 1992:1)

≈ ecological diversity

This approach would foster a more consistent use of ecological terms and would resolve some of the concerns raised by Angermeier (1994) and Noss (1990). For example, the biodiversity concept described by Angermeier (1994) does not include artificial diversity; changing the name to "native biodiversity" would provide a designating term that would more accurately reflect the intended meaning of that concept and allow the meaning of biodiversity to remain intact. Using the term ecological diversity to designate definitions that include ecological processes would permit the concept of biodiversity described by Noss (1990) and Samson and Knopf (1993), which includes ecological processes, to be maintained while not altering the meaning of biodiversity.

Definition by operation

Operational definitions state what something does, how it works, or what to do to bring the term being defined within the range of one's experience (Borsodi 1967, Tibbetts and Moake 1969, Hayakawa 1978). For instance, a bucket is "a round, deep container, hung from a curved handle, *that is used for carrying water, milk, etc.*," (Tibbetts and Moake 1969:76). Tibbetts and Moake surmised that an operational definition is valuable because it provides a practical check on the reality or truth behind a definition. Assuming that what something does can include the value of something, biodiversity has been identified as important for ecosystem health, medicinal values, agricultural purposes, and aesthetic and recreational values (Wilson 1992, Bryant and Barber 1994, Noss and Cooperrider 1994). Depending on the audience, referring to 1 or more values of biodiversity in the definition of biodiversity may be appropriate.

In a different context, Noss (1990:356) characterized an operational definition as one that is responsive to real-life management and regulatory questions, adding that such a definition is unlikely to be found for biodiversity. Trauger and Hall (1992) and Angermeier (1994) referred to an operational definition in a similar way, and Hunter (1996) suggested that a quantitative definition is needed for monitoring biodiversity and developing management plans. Landres (1992), on the other hand, asserted that confounding of definition and application is partly to blame for the confusion over how biodiversity concepts can be practically implemented. There appears to be confusion between the definition of biodiversity and the management objectives for its conservation and measure. Attempts to limit the fundamental meaning of biodiversity so that it is more practical to measure, and thus manage, contribute to this confusion.

One of the biggest challenges facing managers who are developing biodiversity conservation plans is quantifying biodiversity, a process necessary to describe baseline conditions, formulate management objectives, and monitor the effects of management actions. If the need to quantify biodiversity drives the fundamental meaning of biodiversity, the definition may be limited to that which can be readily measured given current understanding and technologies. This definition of biodiversity could change over time and space as ideas, technology, and resources for measuring diversity change. To ensure that the need to measure biodiversity does not drive the meaning of the term and change its fundamental meaning, as has been the case for the term diversity (Peet 1974, Solomon 1979), an operational "clause" (Tibbetts and Moake 1969) should be added to the definition of biodiversity. For instance, a definition of biodiversity that is more responsive to management, but that does not compromise the fundamental meaning of the term might be framed as: "biodiversity is ..., as measured in terms of ..." This approach provides a link to management while distinguishing between what biodiversity is (a state or attribute) and how it is measured. It also allows the operational clause to be adjusted over time without changing the fundamental meaning of the term.

An operational clause, then, can list the known measurable attributes of biodiversity. The biodiversity of an area could be described and measured in terms of the identity and number of all species (plants, animals, and microorganisms) and their interactions, species' assemblages (e.g., plant communities, animal guilds), the quantity and structure of each, and the genetic variation contained therein (Noss 1990, Hunter 1996). One may argue that biodiversity in its entirety cannot be measured in a real-world situation. I agree. It should also be recognized that biodiversity cannot, in all of its complexity, be measured fully in terms of the number of bird and mammal species and their relative abundances in an area. The diversity of bird and small mammal species is only a partial measure of biodiversity.

Tibbetts and Moake (1969) asserted that definitions must be realistic, but the realism they addressed is a matter of accuracy and honesty (e.g., not swayed by personal opinion), not a matter of utility. The purpose of a definition is to convey the meaning of a word (Tibbetts and Moake 1969, Gove et al. 1993, Crystal 1995). A definition of biodiversity should portray the full scope of what the term means, not just what can be measured and managed. In contrast, monitoring or management objectives must be attainable to be effective (Crowe 1983, Coughlan and Armour 1992). It is during the formulation of objectives that components of biodiversity are narrowed to a set which can be measured and managed. Objectives to achieve biodiversity goals may have to address a small subset of biodiversity components and processes to be practical for management and monitoring. These management objectives should be developed with an understanding of the full scope of biodiversity. Recognizing the distinction between a definition and management objectives should reduce the confusion between the meaning of biodiversity and the objectives for achieving biodiversity goals.

Recommended definitions of biodiversity

Recognizing that the appropriateness of a particular definition depends on the audience, I suggest several possible definitions that are consistent with my findings. I begin by presenting a definition that summarizes the results of the previous sections and a short discussion of the definition. I then present several other definitions that are consistent with the findings of this paper.

> Biodiversity is a state or attribute of a site or area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of genetic diversity and the identity and number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount (e.g., abundance, biomass, cover, rate) and structure of each. It can be observed and measured at any spatial scale ranging from microsites and habitat patches to the entire biosphere.

This definition is consistent with the meanings of the terms from which biodiversity was derived (i.e., diversity and biological). In the first sentence, I identified the class to which biodiversity belongs (i.e., state or attribute) and differentiated it from other states or attributes of a site or area. The first sentence identifies the fundamental meaning of the term. In the second sentence, I identified broad categories of measurable biotic components and processes (e.g., genes, species). The first 2 sentences were structured to maintain clear distinction between what biodiversity is and how it can be measured. In this way, the measures of biodiversity may be adjusted over time without altering the fundamental meaning of the term. The clause "... whether naturally occurring or modified by humans" is not absolutely necessary, but the message conveyed by the clause is implied in its absence.

The first sentence is the most important part of the definition. It provides an objective fundamental definition of the term, on which broad agreement should be possible. Reaching agreement on measures of biodiversity also is important, but this cannot be achieved until a fundamental definition of the term is agreed upon. Fundamentally, biodiversity should be viewed as a broad concept just as Odum (1971) argued that the ecosystem concept should be viewed as a broad concept.

Another definition of biodiversity that is consistent with my findings is as follows (operational clauses can be added as needed).

> Biodiversity is an attribute of a site or area that consists of the variety within and among biotic communities, whether influenced by humans or not, at any spatial scale from microsites and habitat patches to the entire biosphere.

At the most basic level, biodiversity can be defined as the variety of life (Norse et al. 1986, Wilcove 1988, Landres 1992). Although this definition is simple and straightforward, it is consistent with the terms from which biodiversity was derived. In fact, variety-of-life can be viewed as a synonym of biological diversity. Biodiversity can also be defined as the variety of life and its processes (Counc. Environ. Quality 1993, Henderson et al. 1993), assuming that life's processes equate to biotic processes. These definitions, which fall under category 4 of Table 1, do not specify that biodiversity is a state or attribute, but the term variety (the designated class to which biodiversity belongs in the definitions) is classified by standard dictionaries as being a state or attribute.

Conclusion

Life is complex, and biodiversity is a word that can, if properly used, convey this complexity. By properly used, I mean adhering to a fundamental definition that is consistent with the meanings of the terms from which biodiversity was derived rather than a definition that is altered to serve particular interests. If 1 discipline or special interest alters the meaning of biodiversity to suit its interests or needs, it leaves the door open for others to do the same—and so the semantic and turf quarrels continue. When it is necessary to communicate a specific type of biodiversity, appropriate adjectives should precede the term. For example, the term native biodiversity should be used when discussing the biodiversity native to an area; by assuming that biodiversity is limited to that which is native will only invite miscommunication and disagreement. Stepping back and taking an honest look at what biodiversity really means could resolve many of the conflicting views of the term.

Properly used also means resisting temptations to tailor the fundamental meaning of biodiversity by narrowing or expanding the scope of its meaning for particular management or monitoring purposes. Tailoring of any sort to fit particular management situations should be reserved for the development of management and monitoring objectives. Although management constraints (i.e., staffing, budget) may limit a certain biodiversity conservation program to managing and monitoring the diversity of several groups of vertebrate species, this does not warrant simplifying the meaning of biodiversity to that of vertebrate species-diversity. Making biodiversity easier to deal with in natural resources management does not necessitate that the fundamental meaning of the term be simplified or expressed in quantifiable terms.

To facilitate communication among the many groups of people using the term biodiversity, definition and application of the term must be kept separate.

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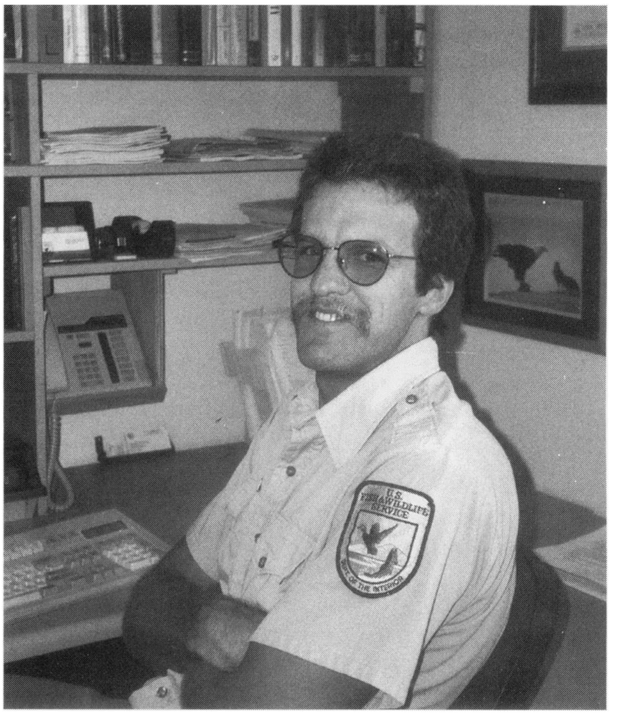

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