Species diversity or biodiversity?

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Abstract

Species diversity and biodiversity are widely used terms in ecology and natural resource management. Despite this, they are not easily defined and different authors apply these terms with varying connotations. The term biodiversity, in particular, has the dubious honour of being widely used but rarely defined. Is it simply the number of species or is it something more? Here I consider what these terms might really mean and their value. I also briefly discuss the rationale for studying and protecting species diversity or biodiversity.

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1. Introduction

When considering the basic structure of biological systems such as communities or ecosystems, two fundamental parameters are the number of species and the number of individuals within each of these species. Ecologists have studied the inter-relationships between these in considerable depth over many decades (e.g. Fisher 1943; MacArthur, 1957; Hurlbert, 1971; May, 1975; Sugihara, 1980), and in doing so have primarily been concerned with what they call species diversity. More recently, a concept known as biodiversity has been rapidly gaining prominence in political, management, public, and scientific arenas (DeLong, 1996; Williams in press). There has been considerable confusion, however, as to what exactly is meant by biodiversity, and its connection to more traditional concepts such as species diversity is unclear. In this paper I discuss both concepts, identify possible commonalities and differences, and consider their usefulness.

2. Species diversity: what is it and how do we measure it?

Traditionally, ecologists have been concerned with the concept of ecological diversity. Species diversity is the most commonly used representation of ecological diversity, but it is not the only measure. Niche width and habitat diversity are also key components of ecological diversity. Niche width describes the availability of resources to an organism (or taxon) over spatial and temporal scales. It is the breadth or diversity of resources used by an individual/taxon (Magurran, 1988). Habitat diversity measures the structural complexity of the environment (Mumby, 2001). I will primarily focus on species diversity, but it should be noted that many of the methods used to define species diversity are also applicable to a degree to niche width and habitat diversity. The concepts of niche width and habitat diversity are of utmost importance for understanding ecosystem function.

Ecologists have found species diversity difficult to define and measure, and this may in fact reflect the possibility that it is a 'non-concept' (Hurlbert, 1971). In general, there have been two approaches to measuring species diversity, both of which incorporate information on the number of species (species richness) and the relative abundances of individuals within each species (species abundance). One method has been to construct mathematical indices broadly known as diversity indices; the other involves comparing observed patterns of species abundance to theoretical species abundance models.

Many commonly used diversity indices are derived from information theory, such as grammatical diversity in manuscripts (e.g. Margalef, 1958; Shannon, 1948; Shannon...
and Weaver, 1949). The similarities between artificial information sets, such as letters or words on a page, and natural communities have not been determined, rather only assumed or at best, implied (Hurlbert, 1971). Species diversity indices take two aspects of a community into account, namely species richness and evenness or equitability (the distribution of abundance among the species). Different diversity indices apportion different relative weights to these properties, and the definition of evenness itself varies. Justifications for these ‘weightings’ are largely subjective, and consequently diversity indices do not have clear ecological meaning. Such limitations can be seen mathematically as well. May (1975) pointed out that diversity indices are simply moments of the full \( S(N) \) distribution, where \( S \) is the number of species and \( N \) is the total number of individuals. Considering this, he suggested that the variance of the distribution would be a sensible measure of diversity. He also propounds that if a diversity index is to be used, then a variance-based index is preferable (i.e. one that includes \( \sum(N_i/N)^2 \), where \( N_i \) is the number of individuals in the \( i \)th species).

Perhaps the most meaningful but seldom used index, not a diversity index sensu stricto, is PIE (probability of interspecific encounter), which attempts to calculate, for a hypothetical individual, the proportion of encounters that will be with another species (Hurlbert, 1971).

\[
\text{PIE} = \left[ \frac{N}{N-1} \right] \left[ 1 - \sum \left( \frac{N_i}{N} \right)^2 \right]
\]

where \( N \) and \( N_i \) are as defined above. PIE assumes that each individual within a community can encounter or interact with every other individual, an assumption that would not hold true in reality. Nonetheless, this simple index has a clear ecological interpretation. In high PIE communities, there would be less reliance by species on random processes in searching behaviour. For example, it is uncommon for plant species in high PIE communities such as tropical rainforests to breed by the random method of wind dispersal of pollen (Hurlbert, 1971). It should be noted that Simpson’s (1949) index is closely related to PIE.

Describing species diversity as a single value compromises much of the detailed structure of a community. Theoretical rank-abundance models provide a more complete picture of community structure (May, 1976). These include, among others, the log normal distribution (Sugihara, 1980), the geometric series (Motomura, 1932; May, 1975), the logarithmic series (Fisher et al., 1943), and MacArthur’s broken stick model (MacArthur, 1957; Webb, 1974; May, 1975). The geometric series and the broken stick describe the respective opposing extremes where a community is dominated by a few species and where species are equally abundant. The log series and the log normal describe intermediate situations, with the former being closer to geometric and latter to the broken stick. A pragmatic limitation of such models is that they are not always amenable to comparisons between communities: the one model may not adequately describe all communities.

Species diversity, or other forms of diversity for that matter, can be partitioned across spatial scales. Whittaker (1960, 1977) defined a hierarchical system whereby point diversity is the diversity within a microhabitat, \( \alpha \) diversity is that within a homogenous habitat, \( \gamma \) diversity is that within landscape level units such as islands, and \( \varepsilon \) diversity describes diversity at the scale of biogeographical regions. This multilevel diversity is also called inventory diversity.

Overlaying the concepts of diversity, species or habitat, described above is the idea of differentiation diversity. This describes the degree of change in diversity over space, such as along a transect or between habitats. Whittaker (1960, 1977) outlined three spatial-levels of differentiation diversity that correspond to his inventory diversity: pattern diversity, \( \beta \) diversity, and \( \delta \) diversity. Of these, \( \beta \) diversity is the most commonly measured (Vellend, 2001; Crist et al., 2003), and it describes change in diversity along a transect or the difference between habitats.

3. Biodiversity: what is it and how do we measure it?

There are currently many definitions of biodiversity and most are vague, which probably reflects the uncertainty of the concept. Some consider it to be synonymous with species richness (Marc and Canard, 1997; Heywood, 1998), others see it as species diversity (Bond and Chase, 2002), whereas many propound a much broader definition such as the ‘full variety of life on Earth’ (Takacs, 1996). NRE (1997) distinguish between native and introduced species, and others have put extra emphasis on threatened species (Brockerhoff et al., 2001). DeLong (1996) reviewed and assessed a large number of definitions of biodiversity. The International Convention on Biological Diversity (2003) uses the following definition:

“Biological diversity” [biodiversity] means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

One way to gain an appreciation of the word’s most widely accepted meaning is to consider its evolution. In 1980 the term biological diversity was used to describe what was presumably species richness (Lovejoy 1980). In the same year, Norse and McManus (1980) used this terminology to describe a concept that incorporated both ecological diversity and genetic diversity. In 1981 the US Strategy Conference on Biological Diversity was held. In 1985 the National Forum on BioDiversity took place, and the use of the contracted form of the term in the proceedings of this conference probably initiated its widespread use...
(Harper and Hawksworth, 1994). Ghilarov (1996) noted that the word biodiversity was originally used in political debate rather than science. But scientists soon adopted it to secure research funding. In particular, it seemed to provide a justification for disciplines such as systematics, which traditionally had difficulty convincing funding bodies of the value of their work. This somewhat disingenuous origin in the scientific literature is probably responsible for the current ambiguity of the word, especially its synonymous treatment with ecological diversity, species diversity, and species richness.

There are many ways of measuring biodiversity. Clearly, the indices and models described earlier are applicable if we consider biodiversity to be synonymous with species diversity. However, metrics that accommodate a broader definition of biodiversity have also been developed (summarised in Williams 2004). For example, ‘habitat hectares’ is an index that combines vegetation area with its ‘quality’ (Parkes et al., 2003). The index is primarily designed for the management of agro-ecosystems. Quality parameters include canopy cover, the number of large trees, number of logs, patch size and proximity to a stand of native vegetation. The Biodiversity Benefits Index (BBI) is an extension/modification of the habitat hectares index (Oliver and Parkes, 2003). Neither of these metrics have strict ecological meanings (c.f. Hurlbert’s PIE). The weights assigned to the various components are purely subjective in the sense that they do not represent actual ecological processes, and the statistical distributions associated with each component are not considered. Moreover, as noted by Williams (2004), the ecological significance of the mathematical manipulations applied to components, summation for habitat hectares and multiplication for BBI, used to obtain the metric are not explained or justified.

4. Justifications for protecting species diversity or biodiversity

The study of species diversity, or at least species richness, gives ecologists insights into the stability of communities (Walker, 1988). The relationship between species diversity/richness and community stability is quite complex. Stability can be defined as the ability of a system to recover to an equilibrium state after disturbance, or simply persistence of the system (May, 1976). The diversity-stability hypothesis asserts that species vary in their traits, and that in a highly diverse (species rich) system there will be some species that can compensate for the loss of others after disturbance (Elton, 1958; Pimm, 1984). Thus, species rich systems are more likely to be considered stable. The species (functional) redundancy hypothesis, on the other hand, propounds that in most ecosystems there are several species that fulfil very similar functions, and thus loss of some of these would have little impact on the system as a whole (Walker, 1988). There is empirical evidence supporting both the diversity-stability (Tilman and Downing, 1994) and species redundancy (Bellwood et al., 2003) hypotheses. Mathematical reckoning has demonstrated that the stability of any system increases with the complexity (i.e. number of components) only until a critical point is reached, at which the system becomes unstable (Gardner and Ashby, 1970; May, 1972).

Species diversity has often been discussed in relation to ecosystem functioning. But here we run into a further problem—how do we define ecosystem functioning? One definition is simply the total production of organic matter or consumption of carbon dioxide, whereas another includes the synthesis of all compounds that the organisms of a community contain (Ghilarov, 2000). Furthermore, the relationship between species diversity and ecosystem functioning appears to change over different spatial scales (Bond and Chase, 2002; Jonathan, 2002).

Ghilarov (2000) has argued that more emphasis should be put on the intrinsic worth of biodiversity as a rationale for valuing it. He states that “if biodiversity has intrinsic value it could in principle be ‘useless’ for human needs or for ‘ecosystem functioning’.” This is an important argument, as it removes the anthropocentric theme that underlies many justifications for protecting biodiversity. There is a danger that the public or industry will have a suspicious opinion of biodiversity if its benefits are mostly expressed in terms of reimbursements to humans. Such (perceived) benefits are likely to be indirect or even non-existent, and this could lead to a devaluing or mistrust of biodiversity. People need to be aware of issues such as the uniqueness of species, the right of species to exist, and the irreversible nature of extinction.

5. Conclusion

Species diversity can be a useful tool for the ecologist, but one must be clear as to the particular definition and measure being used. Biodiversity, on the other hand, is an unclear concept, and its value to the ecologist is questionable. Nonetheless, it is well entrenched in the world of environmental management and policy, and it may be that it is a useful tool from a sociological and political perspective, even if it does have substantial theoretical limitations. Ultimately, if biodiversity plays a key role in minimising anthropogenic impacts on nature, then it is indeed valuable as a word and concept.

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References


