

## Ecological Diversity Indices: Any Hope for One Again?

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### Abstract

The problem of answering the dual question of how many species exist on the earth's surface and why are there more species in some areas than others has intrigue ecologists for some time as it raises fundamental issues concerning speciation, adaptation and evolution. Diversity has recently become a popular term for the variety of the organism at different spatial scale. Its measurement has equally generated a heated argument as authors vary in this respect. This paper critically evaluates the various indices used in measuring diversity. The general position of this paper is that despite the multiplicity of opinion on the devices for measuring diversity, one fundamental point is that any technique, which is deemed to carry the time, must encompass species richness as well as their distribution in space.

**Key Words:** Ecology, Diversity, Species, Evenness, Richness

### Introduction

According to Ludwig (1988), the concept of species diversity in community ecology has been intensely debated by ecologist over the years. Infact, Hulbert (1971), went as far as suggesting that diversity was properly best described as a 'non concept' because of the many semantic, conceptual and technical problems associated with its use. In spite of the debated and numerous cautionary remarks put forward by many regarding its use, this concept has remained popular among ecologists.

A diversity index is a quantitative measure that reflects how many different types (such as species) that are in a dataset, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among these types. The value of a diversity index increases both when the number of types increases and when evenness increases. For a given number of types, the value of diversity index is maximised when all types are equally abundant (Rosenzweig, M. L. (1995). When diversity indices are used in ecology, the types of interest are usually species, but they can also be other categories, such as genera, families, functional types or haplotypes. The entities of interest are usually individual plants or animals, and the measure of abundance can be, for example, number of individuals, biomass or coverage. In demography, the entities of interest can be people, and the types of interest various demographic groups. In information science, the entities can be characters and the types the different letters of the alphabet. The most commonly used diversity indices are simple transformations of the effective number of types (also known as 'true diversity') but each diversity indices can also be interpreted in its own right as a measure corresponding to some real phenomenon. On the whole, diversity indices provide more information about community composition than simply species richness (number of species present); they also, take the relative abundances of different species into account. Based on this fact, diversity indices therefore depend not only on species richness but on the evenness, or equitability, with which individuals are distributed among the different species (Magurram, A. E. (1988).

The diversity of organisms, the measurement of diversity, and hypotheses about the causes of diversity have long interested ecologists. Exploring the natural forest, making list of species, hunting rare species, and posing questions such as why a species is present, rare or abundant at some sites but not at others is fundamental to forest ecologist. The study of diversity may also involve a range of foci from genes to ecosystems. It becomes clearly intertwined with theoretical and practical questions related to ecosystem productivity and conservation. Numerous questions arise here: is species diversity a product of a site and its physical attributes? Is it a product of biotic interactions of

competition and mutualism within the community residing on that site? Are ecosystems with many species more or less stable than those few? How do we best identify and preserve the variety of organisms and ecosystems that exist locally, regionally and globally? From all indication, we too little about the genetic, species and ecosystem aspect of diversity and their causes (Barnes et al 1997), it is therefore no surprise as Solbrig (1991), categorically stated that scientists generally have a very rudimentary knowledge of biodiversity and as such are finding it difficult to understand the earths biota. This is because the issue of measuring what constitute diversity has been adequately addressed.

Generally, in the study of species diversity, one of the key issues that have called for concern is the determination of what constitutes diversity and how this can be measured. From the various opinions that have emerged in this subject matter, there seems to be consensus that species diversity can be analysed in terms of species richness,, rarefaction and diversity indices (Walker, 1989). It is the intention of this paper therefore to examine critically the practicality or functional of these indices in the measurement of diversity in any ecological context.

## Measuring Diversity

### Species Richness

The simplest way to measure species diversity is to count the number of species present in a designated area. This number or species richness is the oldest, most fundamental, and perhaps the least ambiguous of the diversity measurements (Peet, 1974). It depends on the area sampled, so richness is often express as number of species per unit area. Richness varies with size of the area sampled. In an area of homogenous composition, such as a single ecosystem type with the relatively micro topographic variation relatively small gaps or disturbance features and uniform climate, richness will increase with increasing size of sampled area up to a point where all or almost all, species have been captures in the sampled. At this point increasing the sample size results in no increase in species number (Barnes, 1997). Thus, in determine the richness for a given ecosystem by measuring sample plots within it, it is important to use a plot size large enough to encompass most of the species. In essence, this total number is very difficult to determine for most major groups of organisms in an area like a large forest. Furthermore, as the sampled area expands beyond a single local ecosystem, environmental heterogeneity increases, and different ecosystem with different species are included in the sample. Therefore, to attain a reliable estimate of diversity of species for a given ecosystem, it is important to recognize that ecosystem's boundaries.

Based on the above limitations a good number of indices have been proposed to measure species richness. Two historically well known richness indices are as follows:

- i. The Margalef (1958) index which is represented by:

$$R1 = \frac{S-1}{\ln(n)} \dots \dots \dots (1) \text{ and}$$

- ii The Menhinick (1964) index which is represented by:

$$R2 = \frac{\sqrt{S}}{N} \dots \dots \dots (2)$$

Where in the both equations, R1 and R2 refer to Richness Indices, S is the total number of species in the community and 'n' in the total number of individuals observed.

It must be emphasized here that before drawing conclusion on any study, we must recognize that the use of R2 (Menhinicks index) presupposes that a functional relationship exist between 'S' and 'n' in the community and is in fact given by:

$$S = \frac{\sqrt{n}}{K} \dots \dots \dots (3)$$

Where K is constant and this must hold or R2 will vary with samples containing different values of 'n' and consequently communities cannot be compared. Peer (1974) points out that if these assumptions fail to hold the

richness index will vary with sample size in some unknown manner. Consequently, these indices are only used when the assumptions of equal sample size are met.

An alternative to richness indices is to use direct counts of specie numbers in samples of equal size not only is this a vary simple procedure, it also avoid some of the problems of using indices of the type described above. In situations where sample sizes are not equal, statistical method known as rare-fraction may be used to allow comparisons of species numbers between communities (Hurlbert, 1971, Sanders, 1968). In order to put this index in operation it is assumed that sample size biases or sampling differences, between communities can be overcome by some underlying sampling model that applies to all communities concerned.

An example of such a model is that of Hurlbert (1971). He shows that the number of species that can be expected in a sample of 'n' individuals denoted to be E (S<sub>n</sub>) drawn from a population of 'n' total individuals distribution among 'S' species.

$$E(S_n) = \sum_{i=1}^S \left\{ 1 - \left[ \frac{N-n}{N} \right]^n \right\} \quad \text{-----(4)}$$

Where n<sub>i</sub> is the number of individuals of the species. In other words, this question compute the expected number of species in a random sample of size 'n' as the sum of the probabilities that each specie will be included in the sample.

In the views of Hurlbert (1971) rarefaction methods are preferred over the simple richness indices only when community sample size differ. However, Peet, (1974), shows that for two communities possessing very different number of species and relative abundances, rarefaction may predict that both communities have same number of species at small sample size. Thus, this method is only used when it is assumed that the communities being studied do not differ in their species individual relationship (Peet, 1974).

Various studies have used the richness indices in the analysis of species diversity. For example Bruening et al (1982) study of the analysis of floristic and morphologic forest community structure in the Borean 'Keranges' and the Amazonia Caatinga, indicated surprising consistent patterns. The same situation occurred in the comparison between mixed dipterocarp – bearing forest, Keranges and Montanes forest in China. The conclusions of these comparisons with respect to diversity were that tree species richness in pristine forest is primarily controlled by site factors (soil properties). The evenness of species mixture, or the values of any the diversity indices, were seen to be closely of vegetation and soil or to the phases of recovery after disturbance, than to site.

The values of the McIntosh index (Greig-Smith, 1983) which was for used for comparison, vary within a community and the differences between communities were so small that limited its usage for analysis on small scales as it is for global and broad comparisons (Brueing, 1989).

**Evenness**

Evenness refers to how the species abundance (or example, the number of individual, biomass, cover etc are distributed among the species. When all species in a sample are equally abundant, it seems intuitive that an evenness index should be maximum and decrease towards zero as the relative abundance of the specie diverges away from evenness. Hulbert (1971) noted that evenness has this property if it can be represented either as:

$$V1 = \frac{D}{D_{max}} \quad \text{.....(5)}$$

Or as 
$$\frac{D - D_{min}}{D_{max} - D_{min}} \quad \text{.....(6)}$$

Where D is some observed diversity index and D<sub>min</sub> and D<sub>max</sub> are the minimum and maximum values, respectively, that D can obtain. In an attempt to qualify the evenness component of diversity a number of indices have been proposed. A good example is pielow's (1975), index which is expressed mathematically as:

$$E1 = \frac{H1}{\ln(s)} = \frac{\ln(N1)}{\ln(NO)} \dots \dots \dots (7)$$

Where H is expressed relative to the maximum value that ‘H’ can attain when all of the species in the sample are perfectly even with one individual per species. Another index of evenness used as a measure of diversity is that proposed by Sheldon (1969) who initiated an exponential form of E1 above as an evenness index, it has the form

$$E2 = \frac{eH1 - N1}{S - No} \dots \dots \dots (8)$$

Where No is the number of all species in the area (regardless of their abundance), N is the number of very abundant species and ‘H’ is the average uncertainty per species in an infinite community made up of S species.

Despite the multiplicity of the indices of evenness as a measure of diversity, it should be noted that an evenness index should be independent of the number of species in the sample. Intuitively, it would seem reasonable that, regardless of the number of species present, an evenness index should not be change. This is because most of the indices of evenness are strongly affected by species richness. The addition of one rare species to a sample that contains only a few species (low S) greatly changes the value of some indices of evenness especially that equation 7.

For the purpose of illustration, let us consider a hypothetical case: A young researcher sampled two different fields in the tropical rainforest. The sample from the first field consists of 300 *Daniella Ogea*, 335 *Lophira alata* and 365 *Mamea africana*. The sample from the second field comprises 20 *Daniella Ogea*, 49 *Lophira alata* and 931 *Mamea africana* (see the table below). Both samples have the same richness (3 species) and the same total number of individuals (1000). However, the first sample has more evenness than the second. This is because the total number of individuals in the sample is quite evenly distributed between the three species. In the second sample, most of the individuals are *Elaeis guinensis*, with only a few *Daniella ogea* and *Mamea africana* present. Sample 2 is therefore said to be less diverse than sample 1.

Tree species	Number of individuals	
	Sample 1	Sample 2
<i>Daniella Ogea</i>	300	20
<i>Lophira alata</i>	335	49
<i>Mamea Africana</i>	365	931
<u>Total</u>	1000	1000

One of the studies, which have utilized the evenness indices as a measure of diversity, is that of Zahl (1977). He collected data on the total basal area of 20 trees in the Harvard Research Forest, Petersham, Massachusetts, during 1956, 1960, and 1975. This objective was to study patterns of changes in diversity with forest regeneration, since the forest was cut cover in 1951 and then left undisturbed. Thus, applying the Pielou (1975) index of evenness, the result of his study revealed that there was a decrease in evenness from 1956 to 1975 (0.65 – 0.55).

**Diversity Indices**

Diversity indices incorporated both species richness and evenness into a single value. Accordingly, Peet (1974), terms this ‘heterogeneity’ index. One of the biggest obstacles to overcome in applying the diversity index is interpreting what this single statistics actually means. For example, in some cases a given value of a diversity index may result from various combinations of species richness and evenness (Ludwig 1988). In other words, the same diversity index value can be obtained for a community with low evenness. It follows, then that if one is given just the value of a diversity index, it is impossible to say what the relative importance of species richness and evenness is.

Inspite of such problems, ecologist commonly employ the diversity in their research, often ignoring some well known problems. One of the indices of diversity is the Simpsons (1949) index. It has the form:

$$X = \sum P1^2 \dots \dots \dots (9)$$

Where  $P_i$  is the proportional abundance of the  $i$ th species given by:

$$P_i = \frac{n_i}{N}, \quad i = 1, 2, 3, \dots, s$$

Where  $n_i$  is the number of individuals of the species and  $N$  is the known total number of individuals for all species in the population. The value of this index varies from 0 to 1, giving the probability that two individuals drawn at random from a population will belong to the same species or different species. Another version of the formula is given below.

$$D = \frac{\sum n_i(n_i - 1)}{N(N - 1)} \dots \dots \dots (10)$$

Or

$$D = \sum (n_i / N)^2 \dots \dots \dots (11)$$

Where  $n_i$  = the total number of organisms of a particular species,  
 $N$  = the total number of organisms of all species.

The value of  $D$  ranges between 0 and 1. With this index, 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of  $D$ , the lower the diversity. This is neither intuitive nor logical, so to get over this problem,  $D$  is often subtracted from 1 to give what we call Simpson's index of diversity ( $1-D$ ). The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity. This makes more sense. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species.

Another way of overcoming the problem of the counter-intuitive nature of Simpson's Index is to take the reciprocal of the Index. The value of this index starts with 1 as the lowest possible figure. This figure would represent a community containing only one species. The higher the value, the greater the diversity. The maximum value is the number of species (or other category being used) in the sample. For example if there are five species in the sample, then the maximum value is 5.

The name 'Simpson's Diversity Index' is often very loosely applied and all three related indices described above (Simpson's Index, Simpson's Index of Diversity and Simpson's Reciprocal Index) have been quoted under this blanket term, depending on author. It is therefore important to ascertain which index has actually been used in any comparative studies of diversity.

To calculate Simpson's Index for a particular area, the area must first be sampled. The number of individuals of each species present in the samples must be noted.

As an example, let us work out the value of  $D$  for a single quadrat sample of upper storey vegetation in a pristine forest.

Species	Number (n)	n(n-1)
<i>Terminalia superba</i>	4	4
<i>Kaya ivorensis</i>	16	112
<i>Ceiba pentandra</i>	2	0
<i>Cola acuminata</i>	2	0
<i>Garcinia manii</i>	6	12
Total (N)	30	128

Putting the figures into the formula for Simpson's Index

$$D = \frac{\sum n(n-1)}{N(N-1)} \dots\dots\dots(12)$$

$$D = \frac{128}{30(29)}$$

$$D = \frac{128}{870}$$

D = 0. (Simpson's Index).

Then:

In this case Simpson's Index of Diversity  $1 - D = 0.9$ , while the Simpson's Reciprocal Index  $1 / D = 10$

These 3 different values all represent the same biodiversity. It is therefore important to ascertain which index has actually been used in any comparative studies of diversity. A value of Simpson's Index of 0.9, is not the same as a value of 0.9 for Simpson's Index of Diversity.

Simpson's Index gives more weight to the more abundant species in a sample. The addition of rare species to a sample causes only small changes in the value of D.

Another index of diversity is the Shannon and Weiner (1949) index of diversity. This index is based on information theory and is a measure of the average degree of uncertainty in predicting to what species and individual a chosen at random from a collection of species and individuals will belong. It is represented by the formula:

$$H_i = - \sum_{i=1}^s (p_i \ln p_i) \dots\dots\dots (13)$$

Where H is the average uncertainty per species in an infinite community made up of 'S' species with known proportional abundance  $p_1 p_2 p_3 \dots p_s$ . That have made it a popular measure of species diversity, (1)  $H_1 = 0$  if and only if there is one species in the sample, and (2) is maximum only when all S species are represented by the same number of individuals, that is perfectly even distribution of abundance. Thus, the value of 'H' ranges from zero to one.

From the ongoing discussion, it could be inferred that the problem of conceptualizing and measuring diversity has been of continuous concern to ecologist. This is because diversity could be taken to mean different things to different people. That notwithstanding, diversity has become an important field of study in biogeography as human society tried to measure and mitigate its adverse impacts on the biophysical environment. The assessment of such

impact is made difficult by the lack of many long-term data sets which could enable conclusions to be drawn. Hence, evolution of these measure of diversity have emerge to answer the question to some of these unresolved issue as it has to do with determining the stock of species and their evenness of distribution in space.

In all ramification measure of diversity must catch not only the number of entities by which two samples differ but also the relative abundance of each kind in a sample. One complication is the size of the sample and the area over which it is taken. Because individuals and species are neither equally abundant nor distributed regularly over space, it is found that as sample size or area sampled increases, the number of species in a sample increases and thereby changes the values of whatever diversity measure that is used (Kumar, 1996). Thus, a good measure of diversity must recognize this situation.

It should be understood that the number of individuals of each genotype, phenotype or species in a community varies from those that are very abundant to those that are represented by very few individuals. The distribution of frequency of individuals in a sufficiently large random sample usually follows a log normal distribution. It is in this respect that the Shannon Weiner index of diversity stands with a high shoulder above the others because it takes all the afore-mentioned variables into consideration in the measurement process. It is therefore suffice to conclude in this paper that based on observation of the inherent characteristics of this index; the future seems promising for it.

## Conclusion

In sum, indices of diversity vary in computation and interpretations, and it is appropriate to compare diversity measured by one index with that measure by another. The values will definitely vary depending on other organisms or circumstance under consideration. However, given reasonable standardization, when multiple indices are computed for the same data, they tend to be correlated. That is, the sampled areas tend to be ranked similarly in diversity as measured by various indices. Given that agreement is not complete, however, studies using diversity indices should use indices sensitivity to the factors of interest in the study. As a matter of fact, it is worth pointing out here that in order to arrive at a definite diversity value for any species or community using any of the indices, there are so many factors that may come into play. Some may be external such as size of the habitat, spatial patchiness, harshness of habitat, predictability of change in the habitat, disturbance in the habitat and isolation of a habitat. On the otherhand, the internal factors include, the age of a community type, primary productivity of a community, community structure and competition. In all ramifications, these two forces combine to produce the identity of species evident in any community

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