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WHAT IS THE APPROPRIATE MEASURE FOR ASSESSING BIODIVERSITY? AN ANALYSIS

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Abstract: Investigations on biodiversity have gained momentum in view of its importance and the funding support by various agencies. As ecologists have devised a huge range of indices and models for measuring diversity, there is confusion in selecting one over the other. The widely used diversity index is Shannon-Wiener diversity index. As various log bases are used in its calculation and inconsistencies in their use besides sample size dependence, there are difficulties in comparing the results of one study with the other straightaway. Moreover the Shannon and other conventional indices such as Margalef richness index, Simpson diversity etc. are fraught with many disadvantages. This article evaluates the efficiency of these conventional indices vis-à-vis newly introduced diversity indices with a set of hypothetical data besides works done by investigators and suggests the appropriate measure for the assessment of diversity.

Keywords: Biodiversity, assessment, taxonomic relatedness, biodiversity index

INTRODUCTION

Biodiversity has been described as the biology of numbers and difference (Gaston, 1996). Biological Diversity (Biodiversity) is the central tenet of nature and one of its key defining features (Anon., 2002). As biodiversity forms the basis for the very survival of species (including Man) and ecosystems, it remains as one of the central themes of ecology since many years. However after the Rio's Earth Summit in 1992, it has become the main theme not only for ecologists, but the whole biological community, environmentalists, planners and administrators. As many countries including India are signatories to the Convention on Biological Diversity (CBD), each nation has the task of recording all the species of microbes, plants and animals occurring in their respective countries, assess the biodiversity and evolve suitable management strategies for conserving the biodiversity which is often described as the 'Living Heritage of Man'

Why to assess biodiversity?

There are mainly three reasons why biodiversity should be assessed. The mangroves have been mindlessly cleared for various reasons. Coral reefs have been ruthlessly mined. The fishery resources have been overexploited. Many other organisms have been exterminated for ornamental and medicinal purposes. Due to industrial development and large scale use of pesticides and insecticides in agriculture, the pollution load has increased in the estuaries, backwaters, mangroves and seas and there has been widespread degradation of these habitats. In this backdrop, measures of diversity are frequently seen as indicators of the wellbeing of ecological systems. Secondly, despite changing fashions and preoccupations, diversity has remained the central theme of ecology. The well documented patterns of spatial and temporal variations in diversity which intrigued the early investigators of the natural world continue to

stimulate the minds of ecologists today. Thirdly, considerable debate surrounds the measurement of diversity. It is mainly due to the fact that ecologists have devised a huge range of indices and models for measuring diversity. So, for the various habitats and situations, the variety of diversity indices available have to be tried and their suitability evaluated (Magurran, 2004).

Which measure is good for biodiversity assessment?

Many suggest the use of species richness as a measure (iconic measure) of diversity. Richness means strait forward count of number of species. No doubt it is relatively a simple measure, used successfully in many studies and is one of the components of diversity. However, it does not measure the variety. That way diversity measures are often more informative than species counts alone. Investigators often want to find a means of quantifying Darwin's proportional numbers and kinds in a single statistic. Diversity is traditionally taken to be a function of both richness and evenness. In other words it is a combination of both richness and abundance. Less even communities are less diverse than their richness alone. There are swathe of measures which make use of both richness and evenness in the calculation of diversity and it is difficult to evaluate which method is appropriate in what circumstances. Selection of a diversity measure based on whether it fulfills certain functions or criteria is more scientific. Diversity measures are selected in relation to four criteria namely: 1. Ability to discriminate between sites, 2. Dependence on sample size, 3. What component of diversity is measured and 4. Whether the index is widely used and understood (Magurran, 1988). The best way suggested is to evaluate the performance of various indices on a range of data and to select the best one. This communication does exactly this (ability to discriminate etc.) and suggests a more realistic measure of diversity.

METHODS (CONVENTIONAL)

Diversity indices are synonymous with ecological quality. Two types of diversity measures are there namely, parametric and non-parametric. The parametric and non-parametric indices discussed in this paper included the following:

Parametric methods

Log series (a) index: It is used to calculate diversity for a normally distributed population. This method is very widely used because of its good discriminating ability. This index is less affected by the abundances of the commonest species.

Q statistic: It is an innovative approach to diversity measurement. It takes in to consideration the distribution of species only and does not entail fitting a model like the above index. It measures inter-quartile slope of the cumulative species abundance curve and provides an indication of the diversity of the community.

Non-parametric indices

Shannon-Wiener Index: It is a benchmark measure of biological diversity and denoted as H'. It is a widely used measure of diversity index for comparing diversity between various habitats (Clark and Warwick, 2001). Shannon and Wiener independently derived the function which has become known as Shannon index of diversity. It is often wrongly called as Shannon and Weaver index because the original formula was published in a book by them (Shannon and Weaver, 1949). It is derived from information theory – on the rationale that diversity or information in a natural system can be measured in a similar way to the information contained in a code or a message. This indeed assumes that individuals are randomly sampled from an infinitely large population. The index also assumes that all the species are represented in the sample. The value of Shannon diversity is usually found to fall between 1.5 and 3.5 and only rarely it surpasses

4.5. It has been reported that under log normal distribution, 10^5 species will be needed to produce a value of Shannon diversity more than 5. It is used extensively in pollution research.

Expected H' (EH'): It is being used as an alternative to H'. It is equivalent to the number of equally common species required to produce the value of H' of the sample.

Maximum Shannon diversity (H_{max}): The observed diversity (H') is always compared with maximum Shannon diversity (H_{max}) which could possibly occur in a situation where all species are equally abundant.

Brillouin Index (HB): This index is used instead of Shannon index when diversity of non-random samples or collections is being estimated. For instance, fishes collected using the light produce biased samples since all the fishes are not attracted by light. Brillouin index is used here to calculate the diversity of fishes collected by gears which use light for fishing. It is denoted as HB.

McIntosh's Measure of Diversity: Mcintosh proposed that a community could be envisaged as a point in an S dimensional hyper volume and that the Euclidian distance of the assemblage from the origin could be used as a measure of diversity. This index is denoted as U. The demerit of this index is that it is influenced by evenness.

The performance of the above indices was evaluated against the following recent methods.

Recently introduced indices: Warwick and Clarke (1995) based only on the topology ('elastic shape') of a phylogenetic tree introduced the following measures incorporating the taxonomic relatedness of species in their calculation:

Taxonomic Diversity (Δ): Δ is an index of taxonomic diversity as it is empirically related to the Shannon's species diversity H' but has an added component of taxonomic separation. It is defined simply as the average (weighted) path length between every pair of individuals.

Taxonomic distinctness (Δ*): It is defined as Δ divided by the value it takes when the hierarchical tree has the simplest possible structure, that of all species belonging to the same genus.

Average taxonomic distinctness(Δ+): It is the average taxonomic distance apart of all its pairs of species.

Total taxonomic distinctness (sDelta+): It is the average taxonomic distance from species i to every other species, summed over all species.

Phylogenetic diversity (sPhi+): It is simply a cumulative branch length of the full tree.

Average phylogenetic diversity index (Phi+) : It is the total tree length divided by the total number of species.

Unlike most other diversity measures, these indices do not involve systematic bias of low sample size. This is considered to be a desirable property for any index. These indices are also demonstrated as the most robust and sensitive indices of community perturbation (Hall and Greenstreet, 1998).

RESULTS AND DISCUSSION

Consider two hypothetical islands, each with only 2 species of vertebrate animals in equal abundance: 2 birds in one case, and a bird plus a mammal in the other. As the number of species and abundance are equal, both the islands will have only the same diversity. However, intuition tells us that a bird plus a mammal represents more biodiversity than does two birds (Purvis and Hector, 2000). Conventional indices cannot discriminate the diversity of the above islands. This is becoming apparent with the following example:

This example involves 2 samples collected from unit areas in 2 forests (forests 1 and 2). In each forest 12 species have been recorded (Table 1). In the first forest all the 12 species were represented by 30 trees each and the total is 360 trees (no community consists of species of equal

abundance and thus it is a hypothetical/artificial data designed to explain a point). In forest 2 also, 12 species were recorded and the total number of trees is again 360. However, in this forest, one species (C) was found dominant (represented by 300 trees) and other species represented by few trees (9 species by 5 trees and the remaining 2 species respectively by 7 and 8 trees). From the results it is clear that the diversity is on the higher side in forest 1 and less in forest 2. Shannon index is able to differentiate the diversity in two forests in the absence of taxonomic information. In this example log 2 was used for calculating the Shannon index. There is a problem in the usage of this index as three log bases (log 2, natural logarithm and log 10) are used for calculating this index.

Table 1. No. of trees belonging to various species in plots sampled in two forests (1 and 2)

Species	Forest 1	Forest 2
A	30	5
B	30	5
C	30	300
D	30	5
E	30	5
F	30	5
G	30	5
H	30	5
I	30	5
J	30	5
K	30	7
	30	8
Total no. of species	12	12
Total no. of trees	360	360
Shannon diversity	3.585	1.223
Brillouin diversity	3.474	1.145

Table 2 presents the results of Shannon-Wiener diversity calculated using the 3 log bases. Let us assume that Scientist A is calculating the Shannon diversity of forest 2 using log 2 and reports the results as 1.223. However, he is forgetting to indicate the log base he used (perusal of literature showed results of Shannon index without log base in most instances). Later let us again assume that scientist B is calculating the Shannon diversity for forest 1 and uses log 10 which is easy to obtain. He arrives at the result of 1.079. Now he is trying to compare his result with the earlier result of scientist A. As 1.079(log10) is lower than 1.223(log2), scientist B concludes that forest 1 is less diverse than forest 2. How misleading it is (Shannon diversity for forest 1 calculated using log 2 is 3.585-larger than 1.223 of forest 2. As scientist A has not mentioned the log base he used, this mistake is creeping in.

Brillion index always produces a lower value than Shannon as it describes a known collection about which no uncertainty is there (Table 3). Shannon by contrast calculates the diversity of sampled/unsampled portion of community. The above example explains this fact well.

Table 2. Shannon-Wiener diversity values calculated using different log bases for the two forests

Log base	Forest 1	Forest 2
H'(ln)	2.485	0.847
H'(log 2)	3.585	1.223
H' (log10)	1.079	0.368

Table 3. Shannon and Brillouin diversity values calculated for the two forests

Diversity index	Forest 1	Forest 2
Shannon-Wiener index(log2)	3.585	1.223
Brillouin index	3.474	1.145

Shortcomings of the conventional methods

Magurran (2004) has listed the following demerits of the conventional indices. Log series

(α) index may not give accurate results when the population studied is not following the log series distribution model. The widely used Shannon-Wiener diversity index is called a dubious method with no direct biological interpretation. However, it is regarded as a notoriously popular method. It is influenced very much by the sample size and is weighted slightly towards species richness. It is often used for historical reasons to compare data collected presently with earlier. In the calculation of this index various log bases are used. It is of course essential to be consistent in the choice of log base when comparing diversity between samples. As many investigators have not indicated the log base they used in past and continue to do so, effective comparison with the earlier results is often difficult.

All these indices are heavily influenced by the sample size. As a result, indices with similar effort can only be compared. Moreover quantitative data are required for the calculation of these indices. With qualitative data (historical data in most instances are qualitative only (+ or -), indices cannot be calculated and compared with the present quantitative data. Moreover these indices do not reveal the higher level diversity (generic and above)-show only the species level diversity. Lastly these indices do not have the statistical framework for testing departure from the normal distribution. In this background no conventional measure appears to be foolproof for assessing diversity.

What is the way out for correctly measuring diversity?

To overcome the demerits elaborated above, the newly introduced diversity indices were used. The efficiency of the newly introduced indices vis-à-vis conventional indices has been tested presently for a set of data (again hypothetical) given in Table 4. The diversity values calculated are given in Table 5. In both the stations, 12 species of fishes were recorded and the total number of fishes collected was 360 each (as before). In station 1, the 12 species belonged to 12 genera, 12 families, 12 orders and 2 classes. In station 2, the 12 species belonged to 4 genera, 4 families, 3 orders and 1 class. That way the taxonomic breadth in station 1 was more. The conventional indices calculated for the above data such as Fisher a, H' (log2), Max.H', EH', HB', N1, Q statistics and Macintosh did not differentiate diversity in the two stations and showed one and the same values. However, the values representing new indices such as taxonomic diversity (Δ), taxonomic distinctness (Δ*), average taxonomic distinctness (Δ +), total taxonomic distinctness (sDelta+), total phylogenetic diversity (sPhi+) and average phylogenetic diversity (Phi.+) were higher in station 1 and lower in station 2 reflecting well the taxonomic breadth (Figs. 1, 2).

The efficiency of the newly introduced diversity indices became clear from the above (hypothetical) data. How these indices will behave under field conditions? It was checked with the help of works carried out on diversity using these indices. Ajmalkhan *et al.* (2004) compared the diversity of brachyuran crabs in two mangroves (natural and artificial) using the conventional and the new indices (Table 6). The Shannon diversity, Margalef and Simpson reflected the trend noticed in the number of species. The taxonomic diversity also showed the above trend. However the taxonomic distinctness index and average taxonomic index did not (the differences are not that distinct as the above indices). Clarke and Warwick (2001) mentioned that they are size independent and are attributed to reflect the taxonomic breadth of the biota. For stations I-IV, where the number of species was in the range of 16-30species (number of genera-12-18 and number families 4-5), the taxonomic distinctness and average taxonomic distinctness were in the ranges of 86.51-87.85 and 87.20-89.33 respectively. However, in stations V-VII, where the number species was only in the range of 5-8 (number of genera-4-6 and family only 2), the above indices were in the ranges of 81.32-

Table 4. Abundance of fishes recorded in two stations

Name of species	Station 1	Station 2
Raja radiata	30	30
Raja naevus	0	30
Raja undulata	0	30
Raja clavata	0	30
Raja microocellata	0	30
Raja brachyura	0	30
Raja montagui	0	30
Torpedo marmorata	0	30
Torpedo nobiliana	0	30
Scyliorhinus canicula	0	30
Scyliorhinus stellaris	0	30
Mustelus mustelus	0	30
Anguilla anguilla	30	0
Gadus morhua	30	0
Lophius piscatorius	30	0
Gasterosteus aculeatus	30	0
Hippocampus ramulosus	30	0
Capros aper	30	0
Gobius niger	30	0
Diplecogaster bimaculata	30	0
Solea solea	30	0
Taurulus bubalis	30	0
Mola mola	30	0

83.07 and 80.95-84.13 respectively. But the total taxonomic distinctness (1400-2616.09 in stations I-IV and 416.67-588.89 in stations V-VII) and total phylogenetic diversity (1100-1733 in stations I-IV and 368-500 in stations V-VII) clearly brought out the wide variations in the crabs diversity between the two mangroves. However, Warwick and Clarke (1995) pointed out that phylogenetic diversity is unsuitable for biodiversity assessment as it is a total rather than an average property and as new species is added to the list, it always

Table 5. Diversity of fishes in stations 1 and 2

Diversity measures	S1	S2
S	12	12
N	360	360
d	1.87	1.87
J′	1	1
Fisher a	2.39	2.39
H′(log2)	3.59	3.59
Max.H′	3.59	3.59
E H′	1.6	1.6
HB′	2.41	2.41
N1	12	12
Q stat.	0	0
Macintosh	0.75	0.75
Delta(Δ)	76.6	53.76
Delta*(Δ*)	83.33	58.48
Delta +(Δ+)	83.33	58.49
sDelta+	1000	701.82
sPhi+	1000	480
Phi.+	83.33	40

increases (has dependence on sampling effort. But the other one Total taxonomic distinctness is having the average property. Therefore it can be used for biodiversity assessment as it is sample independent and truly reflects the taxonomic breadth of the samples.

Raja (2010) studied the diversity of macrobenthos at various depths (30, 50, 75, 100, 150 and 200 m) in the continental shelf off Singarayakonda in Andhra Coast. He recorded 48 species at 30m depth and 26 species at 50m depth. The Shannon diversity values recorded were 5.38 and 4.58 at the above depths respectively (Table 7). However, the taxonomic distinctness value was higher at 50m depth (87.11) where comparatively less number of species, genus, family and order were reported (Table 8) and lower at 30m depth (81.77) where higher number of species was recorded. Do these indices also fail? Warwick and Clark (1995) who introduced these indices pointed out that these indices vouch for the taxonomic breadth

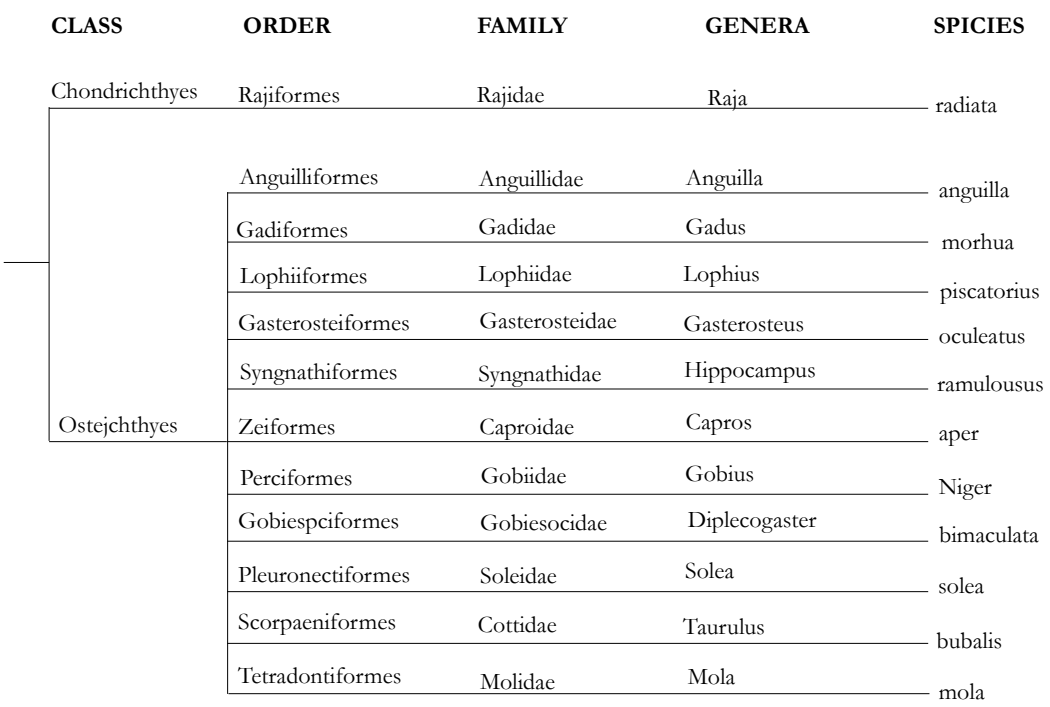

Figure 1. Taxonomic tree for station 1

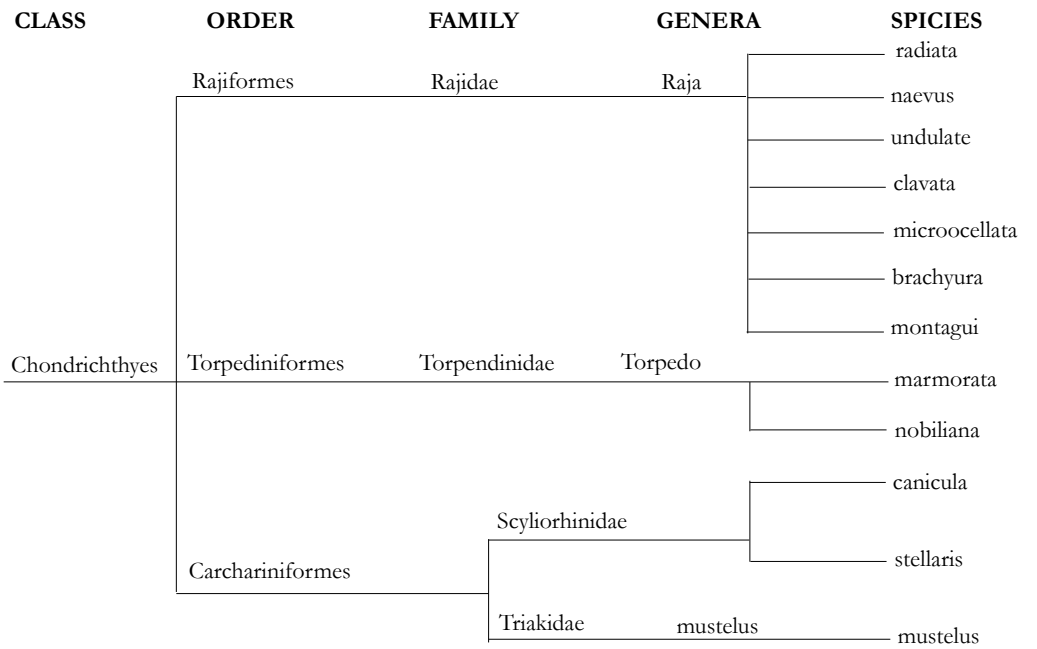

Figure 2. Taxonomic tree for station 2

Table 6. Diversity of brachyuran crabs in Pitchavaram (stations I-IV) and Vellar (stations V-VII) mangroves (Ajmalkhan *et al.*, 2004).

Stations	S	N	d	J'	H'(log2)	Lambda'	1-Lambda'	Delta	Delta*	Delta+	sDelta+	Phi+	sPhi+
I	16	71	4.44	0.95	3.81	0.05	0.95	82.61	86.99	87.50	1400.00	68.75	1100
II	30	82	7.79	0.96	4.69	0.02	0.98	84.95	87.06	87.20	2616.09	57.78	1733
III	21	65	5.83	0.95	4.16	0.04	0.96	83.33	86.51	86.83	1823.33	61.90	1300
IV	26	78	6.75	0.97	4.56	0.02	0.98	85.81	87.85	89.33	2322.67	60.26	1568
V	7	27	2.41	0.93	2.62	0.11	0.89	72.12	81.32	84.13	588.89	71.43	500
VI	8	40	2.56	0.92	2.77	0.11	0.89	72.42	81.37	80.95	647.62	62.50	500
VII	5	33	1.61	0.95	2.20	0.16	0.84	69.67	83.07	83.33	416.67	73.33	368

Table 7. Diversity of macrobenthos in continental shelf off Singarayakonda (Raja, 2010)

Depth	S	N	d	J'	H'(log2)	1-Lambda'	Delta	Delta*	Delta+	sDelta+	Lambda+	sPhi+
30m	48	289	8.29	0.88	4.91	0.96	78.56	81.77	83.33	4000	432.86	2520
50m	26	108	5.34	0.90	4.23	0.94	81.73	87.11	86.52	2250	402.99	1520
75m	19	99	3.92	0.88	3.73	0.92	77.14	84.02	82.11	1560	416.62	1220
100m	18	125	3.52	0.76	3.18	0.84	64.10	76.68	85.36	1536	397.42	1120
150m	21	179	3.86	0.93	4.09	0.94	74.22	79.14	86.00	1806	457.33	1140
200m	12	58	2.71	0.85	3.06	0.86	66.12	76.59	86.06	1033	411.75	800

of diversity in areas sampled. Somerfield et al. (2008) pointed out that these indices are weakly related to species richness. However, only the total taxonomic distinctness (4000 & 2520) and the phylogentic diversity indices showed wide variations in the above depths (30 & 50m). As phylogenetic diversity is having the demerit of being total and linked to species richness, the total taxonomic distinctness which is having the average property appears to be the suitable measure for biodiversity assessment.

For assessing the diversity, conventional index as Shannon and Wiener is still used extensively besides others. However, it is very much influenced by the sample size. Moreover, it measures only the species level diversity. The diversity indices introduced by Warwick and Clarke (1995) are attributed to have no such demerits and have taxonomic relatedness. The suitability of these indices vis-à-vis conventional indices with their ability to discriminate situations was tested using both hypothetical data and with field data collected. Among all the indices, the total taxonomic distinctness is found to have the ability to discriminate between situations. It shows clearly the taxonomic breadth and in addition allows species inter-relatedness. Therefore it is suggested that for biodiversity assessment, this index may be used in future. As taxonomic information is an input, the use of this index in biodiversity monitoring will generate interest in taxonomy which is slowly waning.

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