World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

A theoretical study to introduce an index of biodiversity and its corresponding index of evenness based on mean deviation

Sudipto Roy [1,*] and Kankana Roy Bhattacharya [2]

[1] *Department of Physics, St. Xavier's College, Kolkata, West Bengal, India.*
[2] *Department of Zoology, Raja Peary Mohan College, Uttarpara, Hooghly, West Bengal, India.*

World Journal of Advanced Research and Reviews, 2024, 21(02), 022–032

Publication history: Received on 19 December 2023; revised on 27 January 2024; accepted on 29 January 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.21.2.0366

Abstract
In the present study, we propose a new biodiversity index and the corresponding index of evenness. These indices are based upon the mean deviation of the number of individuals belonging to a species in a collection of biological organisms. There is an arbitrary parameter in our model whose value can be adjusted to change the sensitivity of any of these two indices to the variations of the population of different species in a sample, caused by various factors. With the help of a hypothetical dataset regarding the populations of six species in six different collections, we have calculated the indices defined in this article and also determined the values of some commonly used indices. It is observed that the changes in the new indices are sufficiently greater than the changes in other indices, due to the changes in the composition of a sample. Loss or gain of species is likely to be better reflected in the values of the new indices compared to the most widely used indices of biodiversity and evenness. We have shown the effect of variation of the parameter that controls the efficiency of the new indices. The characteristics of the new indices and their comparison with the other indices have been depicted graphically.

Keywords: Ecology; Biodiversity index; Evenness index; Biodiversity conservation; Species richness; Relative abundance; Shannon index; Simpson index; Mathematical biology

1. Introduction

In forestry, biodiversity and its preservation are among the issues of highest importance and they are connected to various disciplines of science [1]. The word, biodiversity, generally stands for the variety of life forms on earth, and there are mainly three levels to which this diversity is associated, which are species, genetic and ecosystem diversities [2]. The term, biodiversity, is often used to refer to the diversity of species, describing the collection of plant and animal species in an area [3]. A rich species composition, in forest communities, is found to prevent severe phytopathological and entomological attacks [4], since these organisms mostly play the roles of hosts of specific species. Diversity of plant species in a forest area becomes the habitat for a wide range of animals, especially various species of birds [5]. Biodiversity includes two important features: richness and evenness [6]. Richness in a given area is often measured by the number of different species present in that area, while *evenness* represents the uniformity of distribution of individuals among these species [2]. Thus, for a complete analysis of biodiversity, we need detailed information (data) regarding the total number of species, total number of individuals and the proportion of each species in the area or community being analyzed. For a comparison of two samples (collections of organisms), each having the same number of individuals and the same number of species, biodiversity depends upon the distribution of individuals among species. This is the reason why the relative proportions of different species in a collection is required as an important input for biodiversity analysis. One widely uses the indices of biodiversity to summarize the variations in the populations of different species, to find the loss or gain in biodiversity and thus measures the progress towards the targets based on

* Corresponding author: Sudipto Roy; email: roy.sudipto@sxccal.edu

the policies regarding conservation [7]. For example, biodiversity indices are used to assess threatened species [8], design protected areas [9], manage land and forest resources [10] and implement fire management [11]. It is essential to find the sensitivities of the biodiversity indices to the data, conservation values, and models for the purpose of environmental decision making. Although there has been a lot of progress on choosing appropriate indices of biodiversity for different management targets [12, 13], we still do not have much guidance available to the scientists and the fire managers on the ways towards the quantification of biodiversity indices. It has been found that about 52% of the total forests on earth are in tropical regions and they are regarded as the most important regions as far as biodiversity is concerned [14, 15]. Biodiversity is a structural feature in dynamic and complex forest ecosystems [16]. Species diversity generally decreases with increasing latitude [17]. Human activities of various types and several natural factors contribute to the changes of local and regional diversity [18-20]. These factors include climate change, change of land and sea use, pollution, invasive species and lots of conservation activities meant for the restoring biodiversity.

The functioning of the ecosystem is adversely affected by the loss of biodiversity and it may ultimately lead to a collapse of the ecosystem [21]. For the quantification of species biodiversity in ecosystems, there are several examples of how different indices can be used in scientific literature [22-24]. These indices can be employed to determine changes in biodiversity caused by several factors such as climate change, acidification, ocean warming, loss of habitat and also to find the impact that fisheries have on marine ecosystems [25]. Several indices are generally used for assessing biodiversity [26], because restricting the study to a single index can lead to erroneous conclusions.

The present article describes a study which may be regarded as a continuation of an investigation carried out earlier on biodiversity indices where we proposed a biodiversity index and the corresponding index of evenness [27]. These indices were defined in terms of the standard deviation of the number of members of a species present in a collection of biological organisms. In was shown that these indices were more sensitive than some widely used indices (Shannon-Wiener diversity index, Simpson diversity index and their corresponding evenness indices) to the changes in species abundance (n_i) in the collection. In the present study, we have used the mean deviation of n_i values in a sample to define a new biodiversity index and its corresponding index of evenness. There is an arbitrary parameter (denoted by α), in the expressions for the new indices, which controls the sensitivity of the indices to the composition of a sample. Based on a hypothetical dataset we have calculated these indices and also the values of various other indices. For a comparison between the newly defined indices and the older ones, in terms of their sensitivity to the changes in sample composition, we have depicted their behaviors graphically. The new indices (denoted by K' and $E_{K'}$) are found to be more efficient than the other indices discussed in the present article.

2. Some Indices of Biodiversity and Evenness: An analysis

Shannon-Wiener diversity index (H') is one of the most commonly used theoretical tools to measure biodiversity [28]. It is given by,

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \tag{1}$$

In equation (1), p_i is the proportion of the i^{th} species in a sample (i.e., a collection of biological organisms), which is also referred to as the *relative abundance* of the i^{th} species. The symbol S denotes *species richness*, which is defined as the number of species present in the sample. When different species are present in a sample in equal proportions, which is an extremely rare case, we have, $p_1 = p_2 = p_3 = \cdots = p_S = 1/S$. In this case, no species dominates in the sample over the others, resulting in the maximum diversity for the collection. Substituting $p_i = 1/S$ in equation (1) for all values of i, we get $H' = H'_{max} = \ln S$. The theory of Shannon-Wiener diversity index (H') has its origin in information theory and it represents the degree of difficulty or uncertainty in predicting the species to which a randomly chosen organism belongs [29]. The larger the diversity, the greater would be the difficulty in predicting the identity of a member of the sample.

Like Shannon's index, Simpson's diversity indices are also very widely used. These indices, denoted by the symbols D_1 and D_2 in this article, are expressed as [30, 31],

$$D_1 = 1 - \sum_{i=1}^{S} {p_i}^2 \tag{2}$$

$$D_2 = \frac{1}{\sum_{i=1}^{S} {p_i}^2} \tag{3}$$

We know $\sum_{i=1}^{S} p_i = 1$, since p_i is the fraction of the total number of individuals in a sample represented by the i^{th} species. Simpson's original index ($\lambda = \sum_{i=1}^{S} {p_i}^2$) serves as an index of dominance of one or more species among all members in a collection of biological organisms [32]. The value of λ depends more on the existence of species having higher values of relative abundance (p_i) in a sample in comparison to other species. The larger the dispersion between the p_i values, the larger would be the value of λ. Being a complement of λ, D_1 represents the probability that two randomly chosen individuals are of two different species [33]. D_2 is the reciprocal of Simpson's original index (λ) and closely related with D_1 [30]. D_2 is more widely used among these two indices [29]. When different species are present in a sample in equal proportions, we have, $p_1 = p_2 = p_3 = \cdots = p_S = 1/S$. Under this rare situation, both D_1 and D_2 attain their maximum values, which are, ${D_1}_{max} = 1 - 1/S$ and ${D_2}_{max} = S$ respectively. Following the concept of Simpson index, one may define a new diversity index (D), such as, $D = \frac{1}{\sum_{i=1}^{S} {p_i}^m}$ with $m > 2$. The larger the value of the parameter m, the smaller would be the contribution of the less dominant species of the sample to the summation $\sum_{i=1}^{S} {p_i}^m$. The root-mean-square of p_i values may be expressed as, $p_{rms} = \sqrt{\frac{1}{S}\sum_{i=1}^{S} {p_i}^2}$. Using this relation, the indices D_1 and D_2 can be expressed as, $D_1 = 1 - S\, {p_{rms}}^2$ and $D_2 = \frac{1}{S\, {p_{rms}}^2}$ respectively. Using equations (1) and (2), the relation between D_1 and D_2 is obtained as, $D_1 = 1 - \frac{1}{D_2}$.

Evenness in a collection of biological organisms is a measure of the closeness of p_i values for different species in the collection. It has its highest value when different species are present in equal proportions in the sample. The equitability of distribution of individuals in a sample enhances both diversity and evenness. Dominance of one or two species over others reduce the degree of both diversity and evenness in a collection of organisms. Each evenness index is based on a diversity index, since it inherently possesses the aspects of both richness and evenness.

One of the evenness indices, called the Pielou's index, is given by [34],

$$E_P = \frac{H'}{H'_{max}} = \frac{H'}{\ln S} \tag{4}$$

Another measure of evenness, known as Buzas & Gibson's evenness, is given by [35],

$$E_{BG} = \frac{e^{H'}}{e^{H'_{max}}} = \frac{e^{H'}}{S} \tag{5}$$

Based on the diversity index D_1 (of eqn. 2), an index (E_{S1}) for evenness can be defined as,

$$E_{S1} = \frac{D_1}{{D_1}_{max}} = \frac{1 - \sum_{i=1}^{S} {p_i}^2}{1 - 1/S} \tag{6}$$

An evenness index (E_{S2}) has been defined as a function of D_2 (of eqn. 3) [31]. It is expressed as,

$$E_{S2} = \frac{D_2}{{D_2}_{max}} = \frac{1/S}{\sum_{i=1}^{S} {p_i}^2} \tag{7}$$

In accordance with the definitions, the maximum value, for each of the evenness indices discussed above (eqns. 4-7), is unity.

There are simple diversity indices defined in terms of species richness (S) and sample size (N) only. Two among them are Margalef index [36], and Menhinick index [37], which are represented by the following two equations (eqns. 8 & 9) respectively.

$$D_{mg} = (S - 1) / \ln(N) \tag{8}$$

$$D_{mn} = \frac{S}{\sqrt{N}} \tag{9}$$

Proper quantification of biodiversity cannot be expected to be achieved with the help of these indices (D_{mg} and D_{mn}), because they are not dependent upon the intricacies of the distribution of individuals among different species in a collection of organisms. The values of p_i of different species in a sample play an important role in determining its diversity. There can be a large number of combinations of the p_i values (satisfying the relation $\sum_{i=1}^{S} p_i = 1$) corresponding to a single combination of values for species richness (S) and the sample size (N).

3. Our Previously Defined Indices of Biodiversity and Evenness

In one of our previous studies, we defined a biodiversity index and its corresponding index of evenness [27]. These two indices are given below.

$$K = \frac{S}{1+\sigma_n} \tag{10}$$

$$E_K = \frac{K}{K_{max}} = \frac{K}{S} = \frac{1}{1+\sigma_n} \tag{11}$$

In the above equations, σ_n stands for the standard deviation of n_i (*species abundance*) which denotes the number of individuals of the i^{th} species in a sample. It was shown in that study that the indices represented by equations (10) and (11) are more sensitive than the indices described in Section-2, to changes in the values of n_i [27].

4. New Indices of Biodiversity and Evenness

We propose a new biodiversity index (K'), represented by the following equation.

$$K' = \frac{S}{1+(M_n)^{\alpha}} \tag{12}$$

where M_n is the mean deviation of the n_i values (species abundance) from their mean and α is an arbitrary parameter which determines the sensitivity of K' to the value of M_n.

The mean deviation, M_n, is given by,

$$M_n = \frac{1}{S}\sum_{i=1}^{S}|n_i - \bar{n}| \tag{13}$$

where $\bar{n}$ is the mean of the n_i values which is expressed as,

$$\bar{n} = \frac{1}{S}\sum_{j=1}^{S} n_j = \frac{N}{S} \tag{14}$$

Substituting equation (13) into equation (12) we get,

$$K' = \frac{S}{1+\left(\frac{1}{S}\sum_{i=1}^{S}|n_i-\bar{n}|\right)^{\alpha}} \tag{15}$$

If a sample contains the same number of individuals of all species present, we get $M_n = 0$ as per equation (13), leading to $K' = K'_{max} = S$, as per equation (12).

Based on the relation $p_i = \frac{n_i}{N}$, it can be shown that,

$$M_n = NM_p \tag{16}$$

where M_p is the mean deviation of the p_i values (relative abundance) from their mean, which is given by,

$$M_p = \frac{1}{S}\sum_{i=1}^{S}|p_i - \bar{p}| \tag{17}$$

where $\bar{p}$ is the mean of the p_i values which is expressed as,

$$\bar{p} = \frac{1}{S}\sum_{j=1}^{S} p_j = \frac{1}{S} \tag{18}$$

Since p_j denotes the proportion of the j^{th} species in the sample, we have $\sum_{j=1}^{S} p_j = 1$.

Substituting equation (16) into equation (12) we get,

$$K' = \frac{S}{1+(NM_p)^{\alpha}} \tag{19}$$

Substituting equation (17) into equation (19) and then using equation (18), we get,

$$K' = \frac{S}{1+\left(N\bar{p}\sum_{i=1}^{S}|p_i-\bar{p}|\right)^{\alpha}} \tag{20}$$

Equation (20) expresses K' in terms of the proportions (p_i) of different species in the sample.

Based on our proposed diversity index (K'), we define the following evenness index $(E_{K'})$.

$$E_{K'} = \frac{K'}{K_{max}} = \frac{K'}{S} \tag{21}$$

Using equation (12) in equation (21), one obtains,

$$E_{K'} = \frac{1}{1+(M_n)^{\alpha}} \tag{22}$$

Substituting equation (13) into equation (22) we get,

$$E_{K'} = \frac{1}{1+\left(\frac{1}{S}\sum_{i=1}^{S}|n_i-\bar{n}|\right)^{\alpha}} \tag{23}$$

Substituting equation (20) into equation (21) we get,

$$E_{K'} = \frac{1}{1+\left(N\bar{p}\sum_{i=1}^{S}|p_i-\bar{p}|\right)^{\alpha}} \tag{24}$$

Equation (24) expresses $E_{K'}$ in terms of the proportions (p_i) of different species in the sample.

According to equation (22), the maximum value of evenness $(E_{K'})$ is 1 (corresponding to $M_n = 0$), which is similar in behavior to the indices expressed by equations (4-7). It varies in the range which can be expressed as, $0 < E_{K'} \leq 1$.

Consider two samples A & B, each having $S = 3$. In Sample-A: $n_1 = 555$, $n_2 = 600$ and $n_3 = 645$. In Sample-B: $n_1 = 540$, $n_2 = 600$ and $n_3 = 660$. Here, $M_n = 30$ & 40 for Sample-A & Sample-B respectively, as per equation (13). The values of the diversity index K' for the samples A and B, as per equation (12), are 0.097 and 0.073 respectively, for $\alpha = 1$. As per equation (22), the values of $E_{K'}$ are 0.032 and 0.024 respectively for $\alpha = 1$. Although A & B have same species richness (S), sample B has larger M_n value, resulting in a smaller value of K' for B. Consider a third sample C with $S = 5$ which contains: $n_1 = 550$, $n_2 = 575$, $n_3 = 600$, $n_4 = 625$, $n_5 = 650$. For this sample, $M_n = 30$, $K' = 0.161$ and $E_{K'} = 0.032$. Samples A & C have the same values for M_n while C has a greater value of S, leading to a larger value of K' for C. But $E_{K'}$ is the same for them since $E_{K'}$ is independent of S as per equation (22).

The ratio $M_n/\bar{n}$ is called the *coefficient of mean deviation* (C_V) in statistical parlance. Thus, $M_n = \bar{n}C_V = (N/S)C_V$ where C_V is a measure of dispersion in the values of n_i relative to $\bar{n}$. In terms of C_V, equations (12) and (22) can be expressed as equations (25) and (26) respectively, as given below.

$$K' = \frac{S}{1+[(N/S)C_V]^{\alpha}} \tag{25}$$

$$E_{K'} = \frac{1}{1+[(N/S)C_V]^{\alpha}} \tag{26}$$

Equations (25) and (26) show that the new indices (K' and $E_{K'}$) can be expressed as functions of three parameters related with a collection of organisms, which are N, S and C_V.

5. Results and Discussion

For the calculation of indices, we have used a hypothetical dataset (represented by Table 1) regarding the populations of six species, in six different samples.

The values of various indices of biodiversity, based on the data in Table 1, have been listed in Table 2. The values of several evenness indices, based on the data in Table 1, have been listed in Table 3. Calculations of all these indices have been carried out using the definitions given in Sections 2-4 of this article. The total number of biological organisms (N) in each of the six samples is 36. Their distribution (among six species) is different for different samples.

Table 1 A hypothetical dataset for 6 samples, each having $\boldsymbol{N = 36, S = 6}$

	Sample No.					
Species abundance (n_i)	***1***	***2***	***3***	***4***	***5***	***6***
n_1	6	7	8	9	10	11
n_2	6	5	4	3	2	1
n_3	6	7	8	9	10	11
n_4	6	5	4	3	2	1
n_5	6	7	8	9	10	11
n_6	6	5	4	3	2	1

Table 2 Values of biodiversity indices based on Table 1

	Sample No.					
Diversity Indices	***1***	***2***	***3***	***4***	***5***	***6***
H'	1.792	1.778	1.735	1.661	1.549	1.385
D_1	0.833	0.829	0.815	0.792	0.759	0.718
D_2	6.000	5.838	5.400	4.800	4.154	3.540
K	6.000	3.000	2.000	1.500	1.200	1.000
K' (for $\alpha = 2$)	6.000	3.000	1.200	0.600	0.353	0.231

As we move across Table 1 from left to right (i.e., from Sample-1 to Sample-6), the uniformity of distribution of individuals among different species decreases. Table 1 has been so constructed that, the dispersion of species abundance (n_i) increases with the *sample number* (i.e., the serial number of a sample in the table).

In Table 2, each of the five diversity indices is found to decrease in the direction in which the uniformity of distribution gets reduced (i.e., in the direction from Sample-1 to Sample-6). In this table, K' values have been calculated for $\alpha = 2$.

In Table 3, the value of each of the six evenness indices is found to decrease (from 1 to gradually smaller values) in the direction in which the uniformity of distribution decreases (i.e., in the direction from Sample-1 to Sample-6). In this table, $E_{K'}$ values have been calculated for $\alpha = 2$.

The reason for not choosing $\alpha = 1$ for K' and $E_{K'}$ in Tables 2 & 3 respectively is that their values, for $\alpha = 1$ (listed in Tables 4 & 5), are the same as our previously defined indices (K and E_K).

The values of the indices proposed by us in the present study, for diversity and evenness measurements (i.e., K' & $E_{K'}$ respectively), are found (in Tables 2 & 3) to be reduced by a sufficiently greater amount, compared to the other indices, as the distribution of individuals (among species) changes from one sample to another in the direction from left to right.

The values of D_{mg} and D_{mn} are 1.395 and 1, respectively, as per equations (8) and (9) respectively, for all samples considered here.

In Table 4 we have listed the values of K' for each of the six samples (listed in Table 1), for five different values of the parameter α. The change of value of the index in the direction from left to right (i.e., from sample no. 1 to sample no. 6) is greater for larger values of the parameter α.

Table 3 Values of evenness indices based on Table 1

	Sample No.					
Evenness Indices	***1***	***2***	***3***	***4***	***5***	***6***
E_P	1.000	0.992	0.968	0.927	0.865	0.773
E_{BG}	1.000	0.986	0.945	0.877	0.785	0.666
E_{S1}	1.000	0.994	0.978	0.950	0.911	0.861
E_{S2}	1.000	0.973	0.900	0.800	0.692	0.590
E_K	1.000	0.500	0.333	0.250	0.200	0.167
$E_{K'}$ (for $\alpha = 2$)	1.000	0.500	0.200	0.100	0.059	0.038

Table 4 Values of $\boldsymbol{K'}$ for different values of $\boldsymbol{\alpha}$

	Sample No.					
Value of $\boldsymbol{\alpha}$	***1***	***2***	***3***	***4***	***5***	***6***
1	6.000	3.000	2.000	1.500	1.200	1.000
1.5	6.000	3.000	1.567	0.968	0.667	0.493
2	6.000	3.000	1.200	0.600	0.353	0.231
2.5	6.000	3.000	0.901	0.362	0.182	0.105
3	6.000	3.000	0.667	0.214	0.092	0.048

Table 5 Values of $\boldsymbol{E_{K'}}$ for different values of $\boldsymbol{\alpha}$

	Sample No.					
Value of $\boldsymbol{\alpha}$	***1***	***2***	***3***	***4***	***5***	***6***
1	1.000	0.500	0.333	0.250	0.200	0.167
1.5	1.000	0.500	0.261	0.161	0.111	0.082
2	1.000	0.500	0.200	0.100	0.059	0.038
2.5	1.000	0.500	0.150	0.060	0.030	0.018
3	1.000	0.500	0.111	0.036	0.015	0.008

In Table 5 we have listed the values of $E_{K'}$ for each of the six samples (listed in Table 1), for five different values of the parameter α. It is evident that larger values of the parameter α cause greater change in the index value, as the *sample number* increases.

It should be noted that, if we reshuffle the values of n_i along any column in Table 1, the values of the indices (as listed in Tables 2-5), corresponding to the sample represented by that column, won't change, according to the mathematical expressions for these indices given in Sections 2-4 of this article.

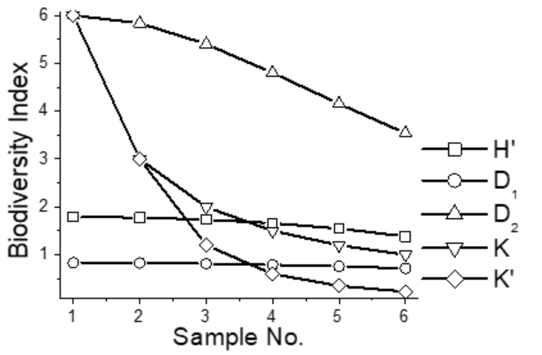

Figure 1 Plots of biodiversity indices versus sample number, based on Table 2

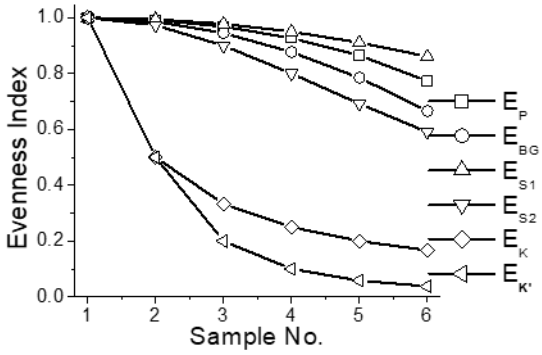

Figure 2 Plots of evenness indices versus sample number, based on Table 3

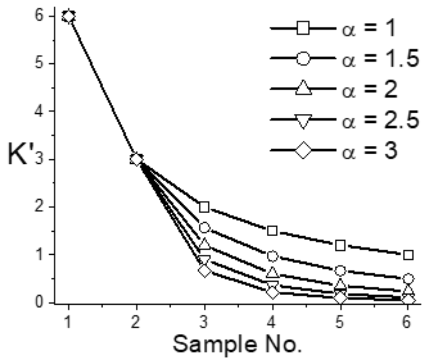

Figure 3 Plots of the new biodiversity index ($\boldsymbol{K'}$) versus sample number for five values of the parameter $\boldsymbol{\alpha}$, based on Table 4

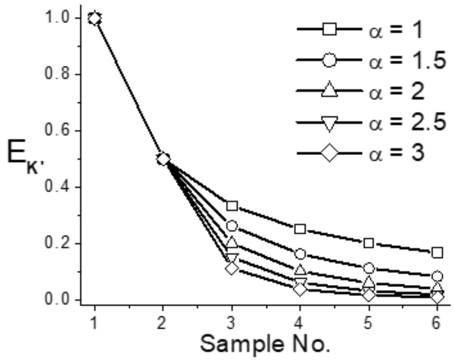

Figure 4 Plots of the new evenness index ($\boldsymbol{E_{K'}}$) versus sample number for five values of the parameter $\boldsymbol{\alpha}$, based on Table 5

In Figure 1, we have plotted the biodiversity indices as functions of the sample number, based on the data of Table 2. As the sample number increases (from 1 to 6), the uniformity of distribution of individuals among different species decreases, as evident from Table 1. The change in the new biodiversity index (K'), with sample number, is the largest among all indices of biodiversity discussed in the present study.

In Figure 2, we have plotted the evenness indices as functions of the sample number, based on the data of Table 3. As the sample number increases (from 1 to 6), the uniformity of relative proportions of different species decreases, as evident from Table 1. The change in the new evenness index ($E_{K'}$), with sample number, is the largest among all indices of evenness discussed in the present study.

In Figure 3, we have plotted the new biodiversity index (K') as a function of the sample number for five different values of the parameter α, based on Table 4. As the sample number increases, K' decreases for each value α. Larger values of α cause a faster fall in K' as the sample number increases.

In Figure 4, we have plotted the new evenness index ($E_{K'}$) as a function of the sample number for five different values of the parameter α, based on Table 5. As the sample number increases, $E_{K'}$ decreases for each value α. Larger values of α cause a more rapid fall in $E_{K'}$ as the sample number increases.

Figures 3 and 4 show that, for the larger values of α, both indices (K' and $E_{K'}$) undergo greater changes as we go from one sample to another with smaller biodiversity. It implies that the value of α is a measure of sensitivity, of these newly defined indices, to the changes in the distribution of individuals among different species in a collection of biological organisms. Thus, the efficiency of any of these two indices (K' and $E_{K'}$), in terms of its sensitivity to the sample composition, can be enhanced by increasing the value of the parameter α.

6. Conclusion

In the present article we have defined a new index (K') to measure biodiversity and a corresponding index ($E_{K'}$) to measure evenness. These indices are sufficiently easy to calculate. Using a hypothetical dataset, we have shown that, these new indices are more sensitive, than some commonly used indices, to changes in relative proportions of different species in a community. We have shown the variations of different indices graphically where it is found that the changes in the values of new indices (K' and $E_{K'}$), due to the changes in the populations of different species in a sample, are much greater compared to the changes of some of the commonly used indices. The efficiencies of K' and $E_{K'}$, as measures of biodiversity and evenness respectively, are found to be greater than the indices (K and E_K) that we defined in one of our previous investigations in the same field [27]. There is a parameter (α) in the expressions for the new indices, which can be increased or decreased, as per requirements, to enhance or reduce, respectively, the sensitivity of the indices to the changes in the numbers of individuals of different species present in a collection of biological organisms. Loss of organisms of any species is expected, therefore, to be better reflected in the values of the new indices. In the hypothetical dataset of Table 1, there is no specific reason for choosing 6 samples, each having 36 individuals divided into 6 species. One may choose any number of samples in a hypothetical dataset, each having just any number of individuals divided into any number of species. We have kept the same sample size (N) for each sample and the same number of species (S) for each of them. The reason for this is connected to our objective for this theoretical study which is to examine how the values of the indices are affected as one varies the values of n_i (species abundance) without changing the sample size ($N \equiv \sum_{i=1}^{S} n_i$) and species richness ($S$, i.e., the total number of species in a sample). Instead of using a hypothetical dataset, one may use a real dataset (i.e., a set of data collected by counting the number of species and also the number of organisms of each species in an area or community) to calculate the indices of biodiversity and evenness (K' and $E_{K'}$) introduced in the present article and compare their values with the most commonly used indices. According to a study by Buzas and Hayek, the *species richness* (S) depends upon the total number of individuals (N) in a sample [38]. We have plans to examine, in our future investigations, how the values of K' and $E_{K'}$ change as the sample size (N) varies.

Compliance with ethical standards

Acknowledgement

The authors are grateful to numerous researchers whose works have inspired them to carry out a theoretical study whose findings have been described in the present article.

Disclosure of conflict of interest

There is no conflict of interest pertaining to this article.

References

[1] Gross M. How can we save forest biodiversity?. Current Biology. 2016 Nov 21;26(22):R1167-70.

[2] Swingland IR. Biodiversity, definition of. Encyclopedia of biodiversity. 2001 Jan 1;1:377-91.

[3] Lakićević M, Srđević B. Measuring biodiversity in forest communities–a role of biodiversity indices. Contemporary Agriculture. 2018;67(1):65-70.

[4] Freer-Smith PH, Webber JF. Tree pests and diseases: the threat to biodiversity and the delivery of ecosystem services. Biodiversity and Conservation. 2017 Dec;26(13):3167-81.

[5] Zhao Q, Mason TH, Azeria ET, Le Blanc ML, Lemaître J, Barnier F, Bichet O, Fortin D. Robust predictive performance of indicator species despite different co-occurrence patterns of birds in natural and managed boreal forests. Forest ecology and management. 2017 Aug 1;397:108-16.

[6] Stirling G, Wilsey B. Empirical relationships between species richness, evenness, and proportional diversity. The American Naturalist. 2001 Sep;158(3):286-99.

[7] Nicholson E, Collen B, Barausse A, Blanchard JL, Costelloe BT, Sullivan KM, Underwood FM, Burn RW, Fritz S, Jones JP, McRae L. Making robust policy decisions using global biodiversity indicators. PloS one. 2012 Jul 18;7(7):e41128.

[8] Butchart SH, Stattersfield AJ, Bennun LA, Shutes SM, Akçakaya HR, Baillie JE, Stuart SN, Hilton-Taylor C, Mace GM. Measuring global trends in the status of biodiversity: Red List Indices for birds. PLoS biology. 2004 Dec;2(12):e383.

[9] Loh J, Green RE, Ricketts T, Lamoreux J, Jenkins M, Kapos V, Randers J. The Living Planet Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society B: Biological Sciences. 2005 Feb 28;360(1454):289-95.

[10] Herrando S, Brotons L, Guallar S, Quesada J. Assessing regional variation in conservation value using fine-grained bird atlases. Biodiversity and conservation. 2010 Mar;19(3):867-81.

[11] Giljohann KM, McCarthy MA, Kelly LT, Regan TJ. Choice of biodiversity index drives optimal fire management decisions. Ecological Applications. 2015 Jan;25(1):264-77.

[12] Buckland ST, Magurran AE, Green RE, Fewster RM. Monitoring change in biodiversity through composite indices. Philosophical Transactions of the Royal Society B: Biological Sciences. 2005 Feb 28;360(1454):243-54.

[13] Van Strien AJ, Soldaat LL, Gregory RD. Desirable mathematical properties of indicators for biodiversity change. Ecological indicators. 2012 Mar 1;14(1):202-8.

[14] Djuikouo MN, Doucet JL, Nguembou CK, Lewis SL, Sonké B. Diversity and aboveground biomass in three tropical forest types in the Dja Biosphere Reserve, Cameroon. African Journal of Ecology. 2010 Dec;48(4):1053-63.

[15] Holdridge LR, Tosi Jr JA. Tropical Science Center: San jose, Costa Rica. Life Zone Ecology; Tropical Science Center: San Jose, Costa Rica. 1967.

[16] Monarrez-Gonzalez JC, Gonzalez-Elizondo MS, Marquez-Linares MA, Gutierrez-Yurrita PJ, Perez-Verdin G. Effect of forest management on tree diversity in temperate ecosystem forests in northern Mexico. Plos one. 2020 May 18;15(5):e0233292.

[17] Hooper DU, Chapin III FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological monographs. 2005 Feb;75(1):3-5.

[18] Pereira HM, Navarro LM, Martins IS. Global biodiversity change: the bad, the good, and the unknown. Annual Review of Environment and Resources. 2012 Nov 21;37:25-50.

[19] Moreno-Mateos D, Barbier EB, Jones PC, Jones HP, Aronson J, López-López JA, McCrackin ML, Meli P, Montoya D, Rey Benayas JM. Anthropogenic ecosystem disturbance and the recovery debt. Nature communications. 2017 Jan 20;8(1):14163.

[20] Moreno-Mateos D, Alberdi A, Morriën E, van der Putten WH, Rodríguez-Uña A, Montoya D. The long-term restoration of ecosystem complexity. Nature Ecology & Evolution. 2020 May;4(5):676-85.

[21] Bland LM, Rowland JA, Regan TJ, Keith DA, Murray NJ, Lester RE, Linn M, Rodríguez JP, Nicholson E. Developing a standardized definition of ecosystem collapse for risk assessment. Frontiers in Ecology and the Environment. 2018 Feb;16(1):29-36.

[22] Whittaker RH. Evolution and measurement of species diversity. Taxon. 1972 May;21(2-3):213-51.

[23] Chao A. Species richness estimation. Encyclopedia of statistical sciences. 2005;12:7907-16.

[24] Gamfeldt L, Lefcheck JS, Byrnes JE, Cardinale BJ, Duffy JE, Griffin JN. Marine biodiversity and ecosystem functioning: what's known and what's next?. Oikos. 2015 Mar;124(3):252-65.

[25] Kaiser MJ. Marine ecology: processes, systems, and impacts. Oxford University Press, USA; 2011 Jul 21.

[26] Daly AJ, Baetens JM, De Baets B. Ecological diversity: measuring the unmeasurable. Mathematics. 2018 Jul 10;6(7):119.

[27] Roy S, Bhattacharya KR. A New Biodiversity Index and the Corresponding Index of Evenness: A Simple Theoretical Analysis. *Brainwave: A Multidisciplinary Journal*. 2023 September, 4(3): 445-453.

[28] Shannon CE. A mathematical theory of communication. The Bell system technical journal. 1948 Jul;27(3):379-423.

[29] Magurran AE. Measuring biological diversity. Current Biology. 2021 Oct 11;31(19):R1174-7.

[30] Simpson EH. Measurement of diversity. nature. 1949 Apr 30;163(4148):688-.

[31] Morris EK, Caruso T, Buscot F, Fischer M, Hancock C, Maier TS, Meiners T, Müller C, Obermaier E, Prati D, Socher SA. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecology and evolution. 2014 Sep;4(18):3514-24.

[32] Odum EP, Barrett GW. Fundamentals of ecology. Philadelphia: Saunders; 1971 Jan.

[33] McCune B, Grace JB. Analysis of ecological communities. 2002.

[34] Pielou EC. The measurement of diversity in different types of biological collections. Journal of theoretical biology. 1966 Dec 1;13:131-44.

[35] Buzas MA, Gibson TG. Species diversity: benthonic foraminifera in western North Atlantic. Science. 1969 Jan 3;163(3862):72-5.

[36] Margalef R. Temporal succession and spatial heterogeneity in natural phytoplankton.

[37] Menhinick EF. A comparison of some species-individuals diversity indices applied to samples of field insects. Ecology. 1964 Oct;45(4):859-61.

[38] Buzas MA, Hayek LA. On richness and evenness within and between communities. Paleobiology. 2005;31(2):199-220.