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Assessing diversity indices for the macroinvertebrates in the tidal mudflat of Hana Char in the Sunderbans, WB, India

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Abstract

Shannon-Wiener diversity index is undoubtedly the best choice for the estimation of diversity indices of a particular ecological community among several such conventional indices like Margalef index or Magurran index used by the researchers in the field of applied forest ecology, marine ecology, or brackish water ecology in the estuarine environment though the Margalef index and Magurran index categorically state about species richness indices sensitive to abundance based sampling of species. And after application of all these indices for the estimation of diversity index for the macro-invertebrates identified and sampled at a tidal mudflat of Hana Char in the estuarine environment of the world famous mangrove ecosystem of the Sunderbans, the obtained values show completely different results like the values of Shannon-Wiener diversity index 0.74, Margalef diversity index 1.066, and Magurran diversity index 0.30 because of their sensitiveness to the presence-absence based data and abundance based data of the sample populations. For obtaining such different diversity indices values, a thorough literature search has been conducted for finding a modified combined form or reformulated version of the Margalef diversity index and the Magurran diversity index that will be befitted for the better interpretation of the diversity indices in broader aspects and shows similarity in values with that of the Shannon-Wiener Index. Finding out no such scientific literatures related to the combined formulas of these indices, an attempt has been taken to reformulate the diversity indices measurement combining and modifying both Margalef diversity index and Magurran diversity index which are well-known as species richness indices in the field of applied ecology. The estimated value 0.72 for the macroinvertebrates of Hana Char applying the modified and reformulated version for measuring diversity indices is remarkably close to the value 0.74 obtained from the Shannon-Wiener diversity index which might be used for the estimation of diversity indices in a particular ecological community and might be compared with the index's values of the Shannon-Wiener index.

Keywords: Shannon-Wiener diversity index, Margalef species richness index, Magurran species richness index, Reformulated diversity index.

Introduction

Hana Char, a tiny island of only 0.7sq km area, lies between Latitude 22.227971^{0}N and Longitude 88.745971^{0}E under Basanti Police Station of South 24 Parganas district of West Bengal, India. The island is almost resembling the Greek letter delta (Δ) and it forms on the riverbed of Pathankhali Nadi (river), a branch of the Hogol river near Hogolduri village which is situated about 5km away from the Basanti Police Station of South 24 Parganas district in West Bengal. Pathankhali Nadi is locally known as Hana river and the newly emerged island on the riverbed of Hana river is called Hana Char by the local inhabitants. The tiny island is almost young in origin and emerged from a tidal shoal only 50 years back as reflected in the toposheet (no. 79B/16) published by the Survey of India in 1969. The toposheet map of 1969 shows Hogol River, a branch of Matla River, related to a tidal inlet namely Pathankhali Nadi at right angles. The tidal inlet containing a tidal shoal in the riverbed was in the stage of formation of an island. Initially terrigenous mud eroded from the left bank of Pathankhali Nadi settled upon the tidal shoal and accumulated sands at the riverbed. Thereafter, accretion was in progress by the sediments carried by the tidal current with the process of sedimentation through suspension during slack water condition during the transitional period of flood and ebb tide. At present, Hana Char is almost covered with the mangroves vegetation which is a rich habitat for the macro invertebrates of different species.

Species richness is simply a count of species living in a certain location indicating the number of different species as the representatives in an ecological community, whereas the number of species and their abundances of each species in a particular ecological community is the species diversity[1-5]. Species richness never reveals the accountability of species abundances or relative abundance distribution of the species in the ecological community. Occurrences of common or rare species relative to other species in an ecological community is referred to as the relative species abundances. A quantitative measure of different types of individuals in a dataset and their phylogenetic relationships among each other including distributions of all types of individuals such as divergence, evenness, or richness is referred to as diversity index[6-16]. Estimation of such diversity indices of the macroinvertebrates at the mudflat of Hana Char in the estuarine environment of the Sunderbans is the objective of the present study.

Depositional Environment: Hana Char is characterized with the clayey-silt dominated mudflat at its periphery restricted to the mesotidal estuarine environment of the Sunderbans. Sedimentation pattern at Hana Char is controlled by the influence of flooding and the ebbing phase of the tidal cycle. Each tidal cycle produces a cyclic sequence of sand and mud and that sequence leads to the arrangement of four distinct strata citing periodic states of tidal rise and fall[17]. Higher velocities of ebb and flood currents accelerate accumulation of sands whereas deposition of mud consisting of silt and clay takes place from suspension in the slack water condition. Depositional process in this tide dominated environment depends on the phenomenon of time velocity asymmetry where maximum flood current velocity occurs before achieving mid tide and maximum ebb current observed much later the ebb when water starts to recede[18]. In shallower water depths, particularly at less than 5m depth of east and north directions of Hana Char, the speed differential increases rapidly with a corresponding increase in the tidal distortion. In these circumstances the distortion becomes so pronounced that the front of the tide is vertical, much like the front of a breaking wave in the mudflat. The discharge volume through this tidal channel on the flooding tide closely matches the discharge volume on the ebbing tide, the inequality between the flood and ebb durations must produce a velocity-magnitude asymmetry between the tidal currents[19]. Tidal mudflat of this tiny island Hana Char contains many infaunal organisms like macro-invertebrates that produce bioturbation. Bioturbation features are visible in the upper portion of the tidal flat at the western part of the island that lacks presence of vegetation and in the relatively low physical energy condition. Formation of flaser bedding results in accumulation of pellets left by the infaunal organisms like macroinvertebrates in the mudflat of Hana Char.

Figure-1: Formation of dome-shaped bioturbation structures by the *Thalassina anomala* scattered around the mudflat of Hana Char of the Sunderbans.

Materials and methods

Hana Char, a tiny island, emerged on the riverbed of Hana river, is mapped, and the areas of the island have been measured using measuring tapes. Mudflat of the Hana Char located at its southern part is only exposed after the recession of water during ebb tide where sampling and collection of the macroinvertebrate species are possible only during that period. Categorically, one of each individual species of the macroinvertebrates are collected and preserved in 4% formalin solutions. The arthropods are preserved in the 60% alcohol as their chitinous exoskeleton comprising calcium carbonate reacts with the formalin solutions. The collected and preserved macroinvertebrates are sent to the Zoological Survey of India for proper identification. The macroinvertebrates of Hana Char are characterized with the brackish water origin and these species prefer mangrove swamp and marshy areas as their natural habitat. Individual species of these macroinvertebrates and their total numbers of presence in the mudflat are carefully sampled following the presence-absence based method of sampling.

The burrow-dwelling macroinvertebrates like *Thalassina anomala* are sampled by counting their dome-shaped bioturbation structures without destroying their habitat that might hamper the ecological balance of the community structure of Hana Char of the Sunderbans (Figure-1). About 8 individual species of macroinvertebrates are properly identified and their total number of occurrences are 710 at the mudflat that are enlisted in the inventory for such a tiny island like Hana Char.

Determination of Species Diversity Indices: Bioturbation structures forming macro-invertebrates at the mudflat of Hana Char are identified and sampled during the survey and the diversity indices of sampled biota are estimated using tools and formulas of different diversity indices measuring methods like Shannon-Wiener diversity index, Margalef diversity index, and Magurran diversity index.

The biodiversity of identified macro-invertebrates of Hana Char is estimated using the formula of Shannon-Wiener Index (Table-1). The Shannon-Wiener Index is a commonly used measure among other diversity indices as the Shannon-Wiener Index is a comparatively better way of representing biodiversity, species diversity, species richness, evenness etc[20-26]. The measures of variability cannot be used in calculation of Shannon's index of diversity because there is no mean or median, or measures of variations for categorical data for the species[27]. Shannon's diversity index can be calculated for a random of observation which is defined as

$$H' = \log n - \frac{1}{n}\sum_{i=1}^{s} n_i \log n_i$$

Where n is the number of observations from the sample in the i (species) of S categories and n = $\sum_{i=1}^{n} n_i$ is the sample size. An equivalent formula is,

$$H' = -\sum_{i=1}^{s} \frac{n_i}{n} \; ln \; \frac{n_i}{n}$$

Where: $\frac{n_i}{n}$ is the proportion of observations in the ith of S categories; n_i is the number of individuals, and N is the total number of species. The diversity (D) is estimated using the formula,

$$D = 1 - \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$$

The maximum value of *H*' occurs when all categories have the same number of observations. Relative diversity i.e., evenness or homogeneity is measured using the formula,

$$E = \frac{H'}{log\, S} = \frac{H'}{Hmax}$$

Shannon-Wiener Index and the species diversity index of Hana Char are estimated applying the stated equations of the statistical methods using Excel's data analysis tool.

Another two important diversity indices are Margalef diversity index and Magurran diversity index[28-31]. The Margalef diversity index can easily be calculated with the following formula using the sampled data of macroinvertebrates collected from the mudflat of Hana char.

$$D = \frac{S-1}{ln\, N}$$

Where S is the number of species, and N is the total number of individuals in the sample.

Magurran diversity index is calculated through the estimation of species richness index using the following formula stated by Magurran[28,29].

$$\text{Magurran diversity index} = \frac{S}{\sqrt{N}}$$

Results and discussion

Measuring diversity indices using methods of Shannon-Wiener index is widely acceptable to the researchers in the field of applied ecology where the range of richness index is observed species to species distribution. Shannon's entropy and evenness also reflect richness and distribution[32-35]. High level of Shannon's entropy means even distribution[36-44]. Species like the *Thalassina anomala* are dominant at Hana Char mudflat, and that species has dominance-richness and reduces the distribution of species. The richness focuses on the amount, evenness focuses on distribution, but the range remains the same.

For assessing biodiversity, the number of species is considered as the main criteria where the number of species in a unit area i.e., species diversity and the number of species per number of individual species i.e., numerical species richness have been used extensively in the field of brackish water or marine ecology[45-52]. Both indices have been used for measuring species richness representing the same phenomenon of biodiversity. Species sampled at Hana char have been identified properly in a large-scale survey for maintaining the degree of sampling accuracy and for measuring the differences between taxonomic relationships, phylogeny (evolutionary history), and function of the sampled species. The number of species sampled at the mudflat of Hana Char has been analyzed choosing Shannon-Wiener index, Margalef species richness index, and Magurran species richness index for their ease of calculation and extensive uses[53-55].

Table-1: Calculation of Shannon-Wiener index and diversity index using Excel's data analysis tools.

Name of the macro-invertebrates	Number of species	H' calculation	D calculation
Thalassina anomala	292	-0.36542	0.168799539
Pelocoetes exul	6	-0.04034	5.95959E-05
Uca acuta	54	-0.19594	0.005685453
Virgularia sp.	2	-0.01654	3.97306E-06
Ocypode macrocera	17	-0.08936	0.000540337
Telescopium telescopium	95	-0.26913	0.017739725
Cerithidea cingulata	141	-0.32102	0.039214128
Coenobita cavipes	103	-0.28006	0.020870498
S = 8	N = 710	H' = 1.577815	D = 0.747086752

Shannon-Wiener index: The estimated Shannon-Wiener's index is 1.577815 and the value in exp (1.577815) is 4.84435931368 that indicates a community with Shannon-Wiener index of 1.577815 has an equivalent diversity as a community with about 5 equally common macroinvertebrate species (Table-1). And these 5 equally common macroinvertebrate species are *Thalassina anomala, Cerithidea cingulata, Coenobita cavipes, Telescopium Telescopium* and*Uca acuta* identified in the mudflat of Hana Char of the Sunderbans.

Considering the value of Shannon-Wiener's index 1.577815, evenness (E) or relative diversity is calculated using the following formula,

$$E = \frac{H'}{log\, S} = \frac{H'}{Hmax}$$

$$E = \frac{1.577815}{log(8)} = \frac{1.577815}{0.903089} = 1.7471$$

$$= 1.75$$

The value 1.75 reveals the relative diversity of species identified in the mudflat of Hana Char of the Sunderbans.

Margalef diversity index: The Margalef diversity index can easily be calculated with the following formula using the sampled data from the Table-1.

$$D = \frac{S - 1}{ln\, N}$$

Where S is the number of species, and N is the total number of individuals in the sample.

Results will become different if densities are used for the estimation of Margalef diversity index instead of total numbers. Margalef diversity index of the macro-invertebrates identified at Hana Char will become,

$$D = \frac{S-1}{ln\, N} = \frac{8-1}{ln\, 710} = \frac{7}{6.56526} = 1.066$$

A log normal species distribution results in geometric distributions of ecologically relevant communities. Thus, by extension, the Margalef index applies to log normal species distribution. As Margalef index, a good index of diversity, is followed by replication principle and independent of the sample size, so, the effective number of species is to be used. Sometimes, Margalef index formula D = (S -1)/log(N) is used by the researchers but they are calculating log value rather *ln* value. There is a difference between log and *ln* as log is defined for base 10 and *ln* is denoted for base e; *ln* is a natural logarithm that can be referred to as the power to which the base 'e' that has to be raised to obtain a number called its log number.

Magurran diversity index: Magurran diversity index is calculated using the data of macroinvertebrates sampled at Hana Char (Table-1) through the estimation of species richness index following the formula as propounded by Magurran[28].

$$\text{Magurran diversity index} = \frac{S}{\sqrt{N}}$$

$$= \frac{8}{\sqrt{710}} = 0.30$$

Magurran[28] states the range of values calculated for the diversity index – i) H' ≥ 3 means low species diversity, ii) 1 < H' < 3 means moderate species diversity, and iii) H' > 3 means high species diversity.

Reformulating Margalef and Magurran diversity indices: As the estimated values of indices show different results, therefore, an attempt has been taken to modify the formulas of Margalef diversity index and Magurran diversity index combining both formulas of indices and the reformulated equation will become,

$$\text{Diversity Index} = \frac{2\,(S+1)}{\sqrt{N}}\frac{S-1}{\ln N}$$

Where S is the number of species, and N is the total number of individuals in the sample.

In the modified diversity index formula, multiplying (S + 1) by 2 is because of the data collected by presence-absence method of sampling is almost the half of the abundance-based method of sampling in the present study area. Again, the number 1 is added with the S value for not including mudskippers, an important species in the present study area that prefer both mudflat and water equally for their habitat or living purposes creating difficulties for sampling. Mudskippers are not enlisted in the inventory of macroinvertebrates as the sampled data in this study (Table 1). For the modified reformulated diversity index, it is to be noted that the range of values calculated for this reformulated diversity index – i) 0 means low species diversity, ii) 0.50 means moderate species diversity, and iii) 1 means high species diversity where the value of diversity index ranges from 0 to 1. For abundance-based data sampling of benthic fauna living in burrows forming dome-shaped bioturbation structures, destruction method is to be applied for data collection that might destroy the ecological balance of the macroinvertebrate community in such a newly built-up tiny tidal island of the Sunderbans.

Diversity index for the sampled macro-invertebrates of Hana Char (Table 1) is calculated using this reformulated equation as following,

$$\text{Diversity Index} = \frac{2\,(S+1)}{\sqrt{N}}\frac{S-1}{\ln N}$$

$$= \frac{2\,(8+1)}{\sqrt{710}}\frac{8-1}{\ln(710)} = 0.72$$

The result comes out to be 0.72 that indicates diversity index of identified and sampled macro invertebrates is lying above the moderate diversity of the species in this ecological community and the value 0.72 is close to the value of Shannon-Wiener's diversity index (0.74) estimated for the macro-invertebrates at Hana Char of the mangrove forests of the Sunderbans using Excel's data analysis tools.

The macroinvertebrates are sampled at Hana Char based on presence-absence data as this method of sampling is less time consuming and easier than that of the abundance data. Collection of abundance data for the macroinvertebrates is rather difficult because of the occurrences of *Thalassina anomala* within 60-80cm depth of the mud layer with the formation of dome-shaped bioturbation structures and they would have been sampled with the method of destruction which is harmful and will destroy ecological balance of an ecological community. For these reasons, the reformulated diversity index and its calculated value is to be interpreted in broader aspects and reveals wider range of values for the ecological community. The modified formula would be considered with such limitations due to lack of abundance data for sampling of macroinvertebrates at Hana Char of the Sunderbans.

The obtained value of diversity index of 0.747086752 is converted into exponentials that is exp (0.747086752) = 2.11 because of a community with diversity index has an equivalent diversity as a community containing equally-common species of exp (*D*), indicating that a community with diversity index of 0.747086752 has an equivalent diversity as a community with about 2 equally-common species. Index value of D includes not only richness, but also evenness of abundance distribution. The value obtained after estimation with the modified reformulated diversity index is converted into exponentials i.e., exp (0.72) = 2.05 that reveals an equivalent diversity as a community with 2 equally-common species indicating closeness to the value of Shannon-Wiener diversity index and the equally-common species are *Thalassina anomala* and *Cerithidea cingulata* of the mudflat of the present study area of the Hana Char in the Sunderbans.

Conclusion

The present work is driven to draw multicomponent aspects of diversity of species like species richness, evenness, and relative abundance by analyzing the macroinvertebrates of Hana Char by using reformulated formulas combined from two main diversity indices by Margalef and Magurran. Margalef described the index as a special case where all species would be uniformly distributed reflecting the index as a concept behind the species area curve[56-61]. Such linear relationship between the number of species and the logarithm of the number of individuals would represent a geometric distribution when the species' abundance is in order, though the reformulated equation shows its uniqueness and standardized version for monitoring diversity indices measurements in the brackish water environment[62]. The estimated data (0.72) after reformulating the Margalef and Magurran indices is close to the data obtained from the Shannon-Wiener index (0.74) and the proposed modified diversity index might be applicable for the calculation of data sampled after presence-absence method of sampling and/or abundance-based method of sampling in an ecological community. The modified reformulated equation for measuring diversity indices is a generalized version of Margalef and Magurran indices that shows similarity with the estimated values of the Shannon-Wiener index.

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