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Measuring species diversity for conservation biology: incorporating social and ecological importance of species

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ABSTRACT A new Importance-Diversity Index is proposed as an enhancement to the traditional Shannon diversity index. The proposed index incorporates an importance weight to each species of organisms found in an ecosystem. The importance weights are derived from four (4) main domains deemed important in conservation biology, namely: (1) species endemicity, (2) economic utility, (3) functional role in the ecosystem, and (4) risk status of the species (threatened or endangered). Scenario simulations show that the new index aids in conservation decisions particularly in cases where the Shannon's indices of the ecosystems are equal or near equal or even in situations where the Shannon's index clearly identifies a site but the relative importance of the species found in other sites is heavier.

KEY WORDS Conservation biology; diversity-importance index; diversity index; Shannon Index.

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INTRODUCTION

Current competing uses of finite resources vis-a-vis protection of biological diversity has forced society to make difficult decisions in balancing species conservation and economic development. Given this situation, conservation biology has been in the forefront in the protection of biological resources, ecosystems and habitat against pressures imposed by economic progress and urbanization which often results into reduction of biological diversity. Furthermore, decisions with regard conservation prioritizations depend on the biodiversity of the area.

Several measures of biodiversity have been proposed and used with varying applications depending on the level and scale of diversity. One of the most commonly used measures of biodiversity is the Shannon Index (Spellerberg & Fedor, 2003), wherein both the species richness (i.e. number of species) and species abundance (i.e. number of individuals within the same species) are incorporated in the function. High Shannon Index value (highly diverse areas) are prioritized, less diverse areas are less prioritized or converted to other economic uses.

Such mind set is acceptable if we assume that all species present in the area do not have additional importance values. However, there are species that are endemic (or rare), some are classified as either endangered or threatened, and others play important functions in the ecosystem (e.g. keystone species). Duelli & Obrist (2003) identified these as among the concordant indicators representing three value systems, namely, conservation, ecology, and biological control. These values should be given considerations in measuring indices for conservation biology. On the other hand, the Shannon Index, as like most other indices of diversity existing to date, treats species equally and does not incorporate these "important values". Hence, the Shannon Biodiversity Index is not designed to detect the presence of endemic (or rare) species nor is it sensitive to species that are classified as threatened or endangered. Consideration for "additional values" is imperative if we are to meaningfully protect our biological resources.

This paper proposed a new index which incorporates "importance values" in measuring diversity index for conservation of biological resources and habitats. It has immense policy implications particularly in making sure that species that have values, which are otherwise not being considered in other indices, be given priority for protection and conservation.

The Shannon's Diversity Index

A popular diversity index used in Biology is the Shannon's Index given by:

1) $$H = -\sum_{i=1}^{R} P_i \ln P_i$$

where P_i is the proportion of individuals found in an ecosystem and R is the number of individual types. The index, therefore, takes into a count both abundance and richness (R) in the competition. To maximize H, we can either increase R or make the distribution of the individual types more even e.g. $P_i = 1/R$ for all i. Thus:

2) $$H_{max} = -\sum_{i=i}^{R} \frac{1}{R} \ln \frac{1}{R} = \ln R$$

Where H tends to infinity as $R \rightarrow \infty$. High values of H indicate higher biodiversity while low values of H reflect the opposite situation. As such, (1) is often used as a criterion for determining which of several competing ecosystems need to be protected (conserved) and which can be developed. Ecosystems that have high biodiversity (H) are often declared as protected areas for conservation purposes. The general equation of diversity is often written in the form:

$$^{q}D = \left(\sum_{i=1}^{R} p_i^{q}\right)^{1/(1-q)}$$

The term inside the parentheses is called the basic sum. Some popular diversity indices correspond to the basic sum as calculated with different values of q. For diversity of order one, an alternative equation is:

$$^{1}D = exp\left(-\sum_{i=1}^{R} p_i \ln p_i\right) = exp\,(H')$$

where H' is the Shannon's index as calculated with natural logarithms.

Nonetheless, it is quite possible that an ecosystem, say A, has lower Shannon's index than another ecosystem, B, yet A is the habitat of "important" biological species endemic in it. In this case, it may be preferable to protect A than B despite the higher Shannon's index of the latter than the former. An index that incorporates the notion of "importance" is, therefore, a necessary tool for conservation biology.

A Model for Importance Values

In this Section, we define the notion of relative importance (I_j) of the j^{th} species. (j = 1, 2, …, R) found in an ecosystem. Conservation biology literature (Hurlbert, 1971; Duelli & Obrist, 2003; Spellerberg & Fedor, 2003; Jiang & Yin, 2013;) suggests four (4) domains of relative importance, namely: (1) Species endemicity, (2) Economic importance, (3) Functional Role, and (4) Species risk status (threatened or endangered).

Species endemicity refers to a situation where a particular species of biological organism can only be found in a particular habitat and nowhere else. Species' economic importance refers to the economic utility of the species. The species' functional role in the ecosystem alludes to specific biological function of the organism viz. whether or not it is a keystone species. Finally, the risk status of the species refers to its being a threatened or an endangered species which necessitates protection and conservation.

The domains are assigned individual weights, W_j, for the j^{th} domain. A relative importance I_j score for the j^{th} species is obtained from:

3) $$I_j = W_1 + W_2 + W_3 + W_4$$

where:

$$0 \leq I_j \leq 1, \quad 0 \leq W_j \leq 1$$

Domain	Relative Importance
1. Species endemicity	0.50
2. Economic utility	0.20
3. Ecosystem Function	0.20
4. Risk Status (threatened/endangered)	0.10
Total	**1.00**

Table 1. A priori relative importance weights.

Prior to the survey, a relative importance table is constructed such as typically illustrated in Table 1.

The weights assigned to the domains reflect the researchers' bias and are inherently subjective. Thus, an environmental economist would probably assign higher weight to domain 2 while a conservationist would perhaps give greater weight to (1), (2), (3) and (4).

A perfectly unbiased weight assignment assigns equal score to each domain viz. 0.25.

A Diversity-Importance Index

Let there be R types of organisms (species, genera etc.) in an ecosystem. The proportions of each type of organisms are given by $P_1, P_2, \ldots, P_R$. To each type of organisms, we assign relative importance weight $I_1, I_2, \ldots, I_R$. Let:

4) $q_j = P_j I_j^{P_j}$, $j = 1, 2, \ldots R$

The equality in (4) is defined as the "basic diversity-importance information number (DIIN)." Note that $0 \leq q_j \leq 1$.

Further, q_j incorporates both the diversity measure (P_j) and the importance measure (I_j). Using q_j, we define the Diversity-Importance Index as:

5) $DI = -\sum_{i=1}^{R} q_j \ln q_j$.

or:

6) $-\sum_{i=1}^{R} (P_j I_j^{P_j}) \ln (P_j I_j^{P_j})$, $\sum_j P_j = 1$

Equation (6) can be written in a more symmetric fashion as:

7) $DI = -\sum_{i=1}^{R} I_j^{P_j} P_j \ln P_j - \sum_{i=1}^{R} I_j^{P_j} P_j^2 \ln I_j$

Since $0 \leq Pj \leq 1$, $0 \leq Ij \leq 1$, it follows that $DI \geq 0$. Equation (7) is maximized when $Pj = 1/R$ and $Ij = 1/R$ for all j.

In this case, (7) becomes:

$$DI_{max} = \left(\tfrac{1}{R}\right)^{\frac{1}{R}} \ln R \left[1 + \tfrac{1}{R}\right]$$

and:

$\left(\tfrac{1}{R}\right)^{\frac{1}{R}} \rightarrow 1$ as $R \rightarrow \infty$, hence $DI_{max} \rightarrow \infty$.

The function (8) monotonically increases with increasing richness R and uniformly equal importance values. That is, an ecosystem that is diverse with equally important species composition will have high DI values.

Scenarios and Illustrative Examples

A maximum of five (5) species (R = 5) are observed in two (2) sites A and B. The purpose of the environmental assessment is to decide on which site to protect and which site is open for development.

Three (3) experts were asked to construct the Relative Importance Table (RIT). The experts' ratings were averaged out to produce the RIT as shown in Table 2.

Domain	Weight
1. Species endemicity	0.40
2. Economic utility	0.30
3. Ecosystem Function	0.20
4. Risk Status	0.10
Total	**1.00**

Table 2. Relative importance table.

Scenario 1: Equal Shannon's Diversity Index

In this scenario, the traditional Shannon's Index are equal for the two (2) sites (sites A and B) but the Diversity-Importance Indices are different.

A specific illustrative numerical example is given in Table 3.

Species	IV	Pi (A)	Pi (B)
a	0.40	0.25	0.00
b	0.20	0.25	0.25
c	0.20	0.25	0.25
d	0.15	0.25	0.25
e	0.05	0.00	0.25
Total	**1.00**	**1.00**	**1.00**
DI Index		**1.20871**	**1.13997**
H Index		**1.38629**	**1.38629**

Table 3. Illustrative Example for equal Shannon index.

Since the Shannon index of two sites A and B are the same, traditional conservation principles will not be able to decide which site to conserve and which site to develop. However, since the Diversity-Importance (DI) index of site A is greater than that of site B in this case, this means that it makes more sense to conserve site A. Species a which has the highest importance value is not found in B but is found in A. Moreover, species e which is of least importance is absent in A but found in B.

Scenario 2: Unequal Shannon's Diversity Index

In this scenario, the Shannon's indices are unequal for the two sites which would have led to a decision to choose the site with greater H index for conservation, shown in Table 4.

Species	IV	Pi (A)	Pi (B)
a	0.40	0.40	0.20
b	0.30	0.20	0.20
c	0.10	0.10	0.20
d	0.10	0.15	0.20
e	0.10	0.15	0.20
Total	1.00	1.00	1.00
DI Index		1.08585	1.07449
H Index		1.20323	1.28755

Table 4. Unequal Shannon index.

The traditional conservation choice would be site B because of its higher Shannon index (H=1.28755). However, species a which has the highest importance value is found in greater abundance in site A than in site B. For this reason, it makes more practical sense to protect site A than site B as evidenced by the higher DI value of DI =1.085853 for the former site than the corresponding DI value for the latter site which is DI =1.07449.

Scenario 3: Equal Importance Values

If the species are of equal importance, then the decision criterion reduces to a decision based only on the Shannon index; see Table 5 for a typical situation.

Species	IV	Pi(A)	Pi(B)
a	0.20	0.40	0.20
b	0.20	0.30	0.20
c	0.20	0.10	0.20
d	0.20	0.10	0.20
e	0.20	0.10	0.20
Total	1.00	1.00	1.00
DI Index		1.05951	1.11983
H Index		1.18823	1.28755

Table 5. Species with equal importance value.

As expected, the Shannon diversity index is higher for site B than for site A. The DI index likewise is higher for B than for A.

In conclusion, the proposed Diversity-Importance Index is an important aid to conservation biologists in situations when the Shannon Diversity Index (based only on abundance and richness) provides ambiguous or impractical results.

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