Method Article

Within-forest stand (or formation, or plot) and between-forest stand (or formation, or plot) biodiversity indices

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A B S T R A C T

The idea of entropy, which has its roots in information theory and proposes that one may measure the degree of uncertainty associated with the prediction of bits and pieces of information, has been widely used by biologists and ecologists for decades to define biological diversity. For ecologists, the core of the issue is whether or not two species’ distribution taken from the same habitat are the same or distinct. The Shannon index and Simpson diversity are well-known in ecology; however, the non-linearity of these indices may cause a misinterpretation of the underlying diversity, as shown by Lou Jost (2006) and others. Applying the proposed template, one can:

• calculate several biodiversity indices,
• compare two different forest stands (or formations, or plots), or two different profiles in two different times, for the same forest stand (or formation, or plot), in terms of biodiversity.

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A R T I C L E   I N F O
Method name: Within-stand (or formation, or plot) and between-stand (or formation, or plot) biodiversity indices
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Specifications table

| Subject area:                        | Environmental Science                  |
|--------------------------------------|----------------------------------------|
| More specific subject area:          | Silviculture, Forest Biometry          |
| Name of your method:                 | Within-stand (or formation, or plot) and between-stand (or formation, or plot) biodiversity indices |
| Name and reference of original method: | Not Applicable                         |
| Resource availability:               | StandBiodiversityIndices.xlsx           |

Method details

In our template, eleven (11) biodiversity indices are calculated:

| No | Index                     | Formula                                                                 | Meaning                                      | Reference |
|----|---------------------------|-------------------------------------------------------------------------|----------------------------------------------|-----------|
| 1  | Richness                  | \( R = \text{number of categories, or types, or classes.} \)             | The larger the \( R \), the greater the diversity. | [1]       |
| 2  | Shannon Entropy           | \( H = - \sum_{i=1}^{g} p_i \ln p_i \), \( p_i \): proportional abundance of the \( i \)-th category. | The larger the \( H \), the greater the diversity. | [4]       |
| 3  | Shannon equitability      | \( H' = \frac{\sum_{i=1}^{g} p_i \ln p_i}{\ln \lambda} \)                | The closer \( H' \) is to 1, the greater the variety. | [5]       |
| 4  | Simpson Dominance         | \( \lambda = - \sum_{i=1}^{g} p_i^2 \)                                | The closer \( \lambda \) is to 1, the greater the variety. | [6]       |
| 5  | Simpson Dominance Unbiased (finite samples) | \( \lambda' = \frac{\sum_{i=1}^{g} n_i(n_i-1)}{n(\sum_{i=1}^{g} n_i-1)} \), \( n_i \): number of observations of the \( i \)-th category, \( N \): total number of observations. | The closer \( \lambda' \) is to 1, the greater the variety. | [6]       |
| 6  | Gini-Simpson              | \( GS = 1 - \lambda \)                                                | The closer \( GS \) is to 0, the greater the variety. | [1]       |
|    | Note: \( \lambda \) equals the probability that two observations taken at random (with replacement) belong to the same category. GS equals the probability that the two observations belong to different categories. |                                               |           |
| 7  | Gini-Simpson unbiased (finite samples) | \( GS' = 1 - \lambda' \)                                               | The closer \( GS' \) is to 0, the greater the variety. | [1]       |
| 8  | Gini-Simpson equitability | \( GSE = \frac{GS}{1-\lambda} \)                                       | The closer \( GSE \) is to 0, the greater the variety. | [1]       |
| 9  | Berger-Parker Index       | \( BP = \max p_i \)                                                   | The closer \( BP \) is to 0, the greater the variety. | [7]       |
| 10 | Hill Numbers – True Diversity | \( qD = \left( \sum_{i=1}^{g} p_i^q \right)^{\frac{1}{q}} \), \( q \): order of Diversity \( D \). When \( q=0 \), we take into account Richness only. When \( q=\infty \), we take into account abundance only. | The larger the \( qD \), the greater the diversity. | [1]       |
| 11 | Rényi Entropy             | \( qH = \ln qD \)                                                     | The larger the \( qH \), the greater the diversity. | [8]       |
In this context, we are thinking about biodiversity assessment at the forest stand, formation, or plot levels. When we talk about a forest stand, we're referring to an area occupied by trees and other vegetation which have some common characteristics to be considered as a single entity. Formation is a cluster of trees that can vary greatly in area (from a small to a very extensive area). A plot is an area which defines a sampling unit.

The proposed template can be applied to an individual forest stand (or formation, or plot), to assess its diversity with eleven (11) indices, and three graphs (Diversity Profile, the Proportional Distribution and the Proportional Abundance); this is called within-forest stand diversity.

The template can be applied also for comparing two different profiles in two different times for the same forest stand (or formation, or plot) (another case of within-stand diversity), or for comparing two different profiles in the same time for two different stands (or formations, or plots - between-stand diversity), applying z-test. In such situation, a graph comparing the two different profiles is provided.

Instead of categories (or types, or species) of a qualitative variable, one can have classes of a quantitative variable (columns E in RawDataA and RawDataB spreadsheets, columns B in DiversityDataA and DiversityDataB spreadsheets).

Applying the proposed template, one can have:

- Max of 20 different categories or types or species or classes.
- Max of 2000 records.
- Max of 3 factors per record.
- The average of the quantitative variable per category or type or species, if applicable.
- Calculation of eleven (11) biodiversity indices.
- Graphs of the Diversity Profile, the Proportional Distribution and the Proportional Abundance.
- Statistical comparison of two different profiles in two different times, for the same forest stand, or formation, or plot (within-stand diversity), or comparison of two different forest stands, or formations, or plots (between-stand diversity), applying z-test.
- Graph of the Diversity Profiles Comparison.

In the following example (pseudo-data), the 11 biodiversity indices for forest stands A and B, and their graphs (Diversity Profiles, Proportional Distributions and Proportional Abundances) are produced, while their Diversity Profiles are compared. We suppose that we have 16 plant species (from A to P), either for two different stands (A and B), or two different times (A and a later time B) for the same forest stand. Number of observations is the number of plants counted for each species. In our pseudo-data example, the comparison of A and B, in terms of species’ biodiversity, is statistically insignificantly smaller in B.

We note that:

Instead of a qualitative variable (plant species in our example), one can use a quantitative variable (e.g. tree diameter), after classifying it into classes.

The order q refers to the richness and abundance that constitute the biodiversity. When q = 0, we take into account richness only (i.e. the number of classes / categories / types / species etc.). As q increases, abundance (i.e. the number of observations per class / category / type / species etc.) has an impact on biodiversity.
| No | Category of 1 Type of Species | Number of Observations | Proportion of Class A | Order 1 | 2 | 3 | 4 |
|----|-------------------------------|------------------------|----------------------|---------|---|---|---|
| 1  | 1                            | 10                     | 0.64                 | 0.90    | 0.00 | 0.00 | 0.00 |
| 2  | 2                            | 8                      | 0.75                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 3  | 3                            | 4                      | 0.93                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 4  | 4                            | 2                      | 0.80                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 5  | 5                            | 1                      | 0.85                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 6  | 6                            | 2                      | 0.85                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 7  | 7                            | 4                      | 0.91                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 8  | 8                            | 1                      | 0.88                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 9  | 9                            | 5                      | 0.96                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 10 | 10                           | 2                      | 0.88                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 11 | 11                           | 1                      | 0.85                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 12 | 12                           | 1                      | 0.80                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 13 | 13                           | 2                      | 0.85                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 14 | 14                           | 3                      | 0.91                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 15 | 15                           | 4                      | 0.96                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 16 | 16                           | 2                      | 1.00                 | 0.00    | 0.00 | 0.00 | 0.00 |

Stand (or formation, or plot) B

| No | Category of 1 Type of Species | Number of Observations | Proportion of Class A | Order 1 | 2 | 3 | 4 |
|----|-------------------------------|------------------------|----------------------|---------|---|---|---|
| 1  | 1                            | 20                     | 0.13                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 2  | 2                            | 10                     | 0.12                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 3  | 3                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 4  | 4                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 5  | 5                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 6  | 6                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 7  | 7                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 8  | 8                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 9  | 9                            | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |
| 10 | 10                           | 10                     | 0.11                 | 0.00    | 0.00 | 0.00 | 0.00 |

Stand (or formation, or plot) B at a later time, or after treatment

Index

| Order 1 | Order 2 | Order 3 | Order 4 | Average of the Orders |
|---------|---------|---------|---------|----------------------|
| 1       | 1       | 1       | 1       | 1.00                 |
| 2       | 2       | 2       | 2       | 2.00                 |
| 3       | 3       | 3       | 3       | 3.00                 |
| 4       | 4       | 4       | 4       | 4.00                 |

Notes for Order 1

- 1.00: Ongoing treatment
- 2.00: Incomplete treatment
- 3.00: Treatment completed
- 4.00: Treatment completed

Diversity Profiles

- **Alpha diversity**: A measure of species richness, a common metric used to assess biodiversity within a sample.
- **Beta diversity**: A measure of species composition variation, indicating how different communities are from each other. It is often measured using Bray-Curtis similarity.
- **Rarefaction**: A statistical method that allows for comparison of biodiversity across samples that may differ in size.
- **Shannon diversity index**: A measure of diversity that takes into account both species richness and evenness.
- **Simpson diversity index**: A measure of species evenness, with a higher value indicating a more even distribution of species.

Proportional Distribution

- **Proportional abundance**: The proportion of each species relative to the total abundance in the sample.

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Additional information

The concept of entropy, which has its origins in information theory and proposes that one can measure the degree of uncertainty associated with the prediction of bits and pieces of information, has been widely used by biologists and ecologists to define biological diversity for decades. For ecologists, the most important question is whether or not two species’ distribution acquired from the same environment are identical or unique from one another. The Shannon index and Simpson diversity are well-known in ecology; nevertheless, as Jost (2006) and others have shown, the non-linearity of these indexes may lead to a misconception of the underlying diversity.

The preservation and enhancement of forest biodiversity necessitates a careful management of forest species. Any proposed silvicultural treatments require appropriate measurements of biodiversity, in order to evaluate and compare different stands (or formations, or plots), or to assess the evolution of a stand (or formation, or plot) over time; in so doing, forest managers can incorporate appropriate silvicultural interventions to improve the biodiversity of the forest [2,3].

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

In the example, pseudo-data are used to illustrate the application of the excel template.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mex.2022.101919.
References

[1] L. Jost, Entropy and diversity, Oikos. 113 (2) (2006) 363–365, doi:10.1111/j.2006.0030-1299.14714.x.
[2] E. Milios, P. Petrou, K. Pytharidis, A.K. Christou, N-G.H. Eliades, Assessment of how natural stand structure for narrow endemic Cedrus brevifolia Henry supports Silvicultural treatments for its sustainable management, South-east European For 12 (1) (2021) 21–34, doi:10.15177/seefor.21-09.
[3] P. Petrou, E. Milios, Investigation of the factors affecting artificial seed sowing success and seedling survival in Pinus brutia natural stands in middle elevations of central Cyprus, Forests 11 (12) (2020) 1349, doi:10.3390/f11121349.
[4] C.E. Shannon, A Mathematical Theory of Communication, Bell Labs Tech. J 27 (379–423) (1948) 623–656.
[5] C.E. Shannon, W. Weaver, The mathematical theory of communication, University of Illinois Press, 1963.
[6] E.H. Simpson, Measurement of diversity, Nature 163 (4148) (1949) 688, doi:10.1038/163688a0.
[7] W.H. Berger, F.L. Parker, Diversity of planktonic foraminifera in deep-sea sediments, Science 168 (3937) (1970) 1345–1347, doi:10.1126/science.168.3937.1345.
[8] A. Rényi, On Measures of Information and Entropy, in: Proceedings of the 4th Berkeley Symposium on Mathematics, Statistics and Probability, Berkeley and Los Angeles, University of California Press, 1961, pp. 547–561. June – July).