Species and Biological Diversity - Choices of Diversity Indices and their Potential Consequences for Nature Conservation

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Abstract

As there currently are not so many known studies which directly evaluate how diversity indices have been used in different contexts, following literature study was made with the purpose of investigating how three of the most commonly used diversity indices (including Shannon-Wiener's and Simpson's Indices as well as a certain index measuring taxonomic diversity) are representing different categories of species in scientific reports and articles through an environmental scientific point of view.
In order to find a possible explanation to the potential relations between the individual choice of diversity index as well as the substantial conservation of species and biological diversity in general, 50 reports and articles, which all had in common that they had species or biological diversity as their main topic as well as which included the use of any of the diversity indices chosen in this study, were randomly chosen through a single sample. While the results obtained from the following analysis of this study revealed Shannon-Wiener's Index being the most commonly used one of the three indices, and that insects and other invertebrates are the most prominent types of totally eight identified groups of organisms, it is suggested that more data is still needed in further order to uncover how the use of those indices may have varied over a wider amount of time as well as how the within article-type distribution of the different indices may vary in articles about nature conservation in relation to other reports and articles treating other topics of ecology.

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Introduction

Background

Species and *biological diversity* have always been some of the most frequently used evaluation measures for biotic communities in the general biological monitoring work (Hill et al., 2011), sometimes to the degree that it has been used as "indicators of the wellbeing of ecological systems" (Magurran, 1988). However, due to the fact that the term *diversity* alone is of ambiguous nature and can be interpreted in many different ways, many authorities have occasionally tried coming up with a universal definition of *biodiversity* during the latest decades (Peet, 1974). At one point, the term was for example coined by the United Nations Environment Programme (UNEP) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems" (Magurran, 2004; Miller & Spoolman, 2012).

Diversity Indices

Working as one of the main gears inside the vast machinery of environmental science, *biodiversity* – both directly and indirectly - plays a pivotal role within many research areas - often linked to other terms such as *ecosystem service*, *indicator species*, *signal species*, *keystone species* and *sustainable development* (Wheeler et al., 2012). As a result, many attempts have been made during the latest six decades in order to comprehensively uncover and define the fundamental causes to variation between, and in some cases also within species in ecological systems (Peet, 1974). Those attempts have further come to give rise to one special and, within the many topics of conservation biology, commonly used type of tools in terms of certain mathematical models collectively known as *diversity indices* (Sodhi & Ehrlich, 2010). Those indices; of which some are the main subjects of this study, are often used in order to estimate values for variation among species in these systems and thus obtain substantial values for the biodiversity within a chosen site or sample (Hill et al., 2011). While some diversity indices tend treating all species living in a certain habitat as equal, other indices exclusively treat only certain species in the same habitat, depending on what is of relevance for the chosen study in question (Ricotta, 2004).
Below follows a description of some of the most commonly used indices.

Shannon-Wiener's and Simpson's Indices

Examples of diversity indices, which both tend treating all species living within the same area as equal in a certain biotic community, are two indices known as *Shannon-Wiener's* ($H' = -\Sigma(n_i/N) * log(n_i/N)$) and *Simpson's Diversity Indices* ($D = 1 - \Sigma(n_i/N)^2$), where n_i is the abundance of the *i*-th species in an area and N the total number of said species living in the same area (Gotelli & Graves, 1996; Heip et al., 1998; Oksanen, 2015). Generally seen as sophisticated forms of simple diversity indices measuring *species* and *habitat richness*, which sometimes could be described as the "most intuitively simple measures of diversity", those indices are two of the most commonly used ones in the general ecological work (Hill et al., 2011); also known as two of the so-called "traditional diversity indices" (Desroachers & Anand, 2004). Akin to the basic measures for *species richness*, which tend weighing all species equally with no concern about their functional or phylogenetic differences and properties, Shannon-Wiener's and Simpson's Diversity Indices are both designed to measure α-diversity (Sodhi & Ehrlich, 2010); which in turn is defined as diversity within one habitat; also known as *point diversity* (Rosenzweig, 1995). What in turn also distinguishes those indices from other more basic indices is the fact that they not only measure *species richness*, but also incorporate *evenness* within communities, which furthermore is defined as the variation between species in their relative frequency (Peet, 1974). As a result of this fact, the both indices are sometimes also alternatively termed as so-called *heterogeneity indices* (Desroachers & Anand, 2004). Both indices in turn differ from each other in the way that while the results obtained from Shannon-Wiener's Index appears being notably sensitive to species with low frequency, the results obtained from Simpson's Index are not as they are overall based on squared frequency values (Peet, 1974). As a result of this fact, species with low frequency often tend to be barely represented in the obtained values from Simpson's Index, which in turn may have some impact on the study, largely depending on its main purpose in question (Hill et al., 2011).

Taxonomic Diversity Indices

Unlike the traditional diversity indices such as the Shannon-Wiener's and Simpson's Indices, which have been described as "summarizing information about the relative abundance of species in an area without regard to differences between species", taxonomic diversity indices instead are based on the phylogenetic distinctness within communities (Ricotta, 2004). By calculating values for the taxonomic diversity and the taxonomic distinctness of species within a certain area or even a sample (*Fig. 1*), it thus is possible obtaining values even without the need of knowing the total number of individuals in for example a certain habitat or sample (Kaiser et al., 2011).

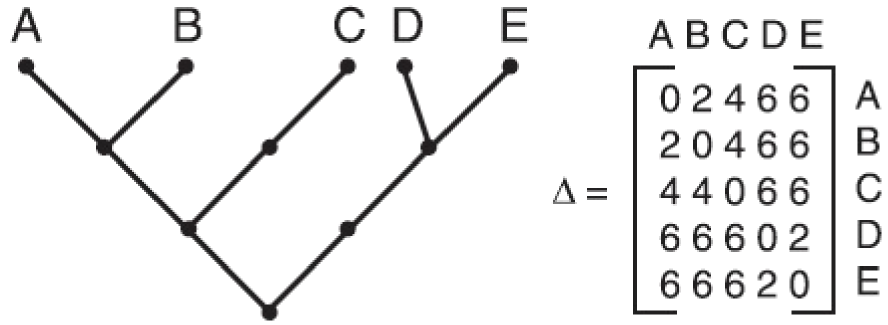

Fig. 1: An artificial taxonomic tree along with the resulting species distance matrix (Δ) showing how taxonomic distances are measured (Ricotta, 2004). In this case, in the matrix (Δ) has a total path length of 96 and a total number of linkages of 20, which in this case brings a value for the taxonomic distinctness (Δ*) as 4.8. Note that every point in the taxonomic tree are representing different hierarchical linkages which may include units such as, and in this case following order: *Order*, *Family*, *Genus* and eventually the most basic of all those units; *Species* (depicted as A, B, C, D and E in this example), depending on how closely or remotely related the species in the area or the sample in question are to each other. These units in turn could be determined either through an existing taxonomic classification or, if more accurate values are desired, through DNA-analyses with the aid of modern molecular methods (Benton, 2000; Evans & Sullivan, 2012; Zhou et al., 2012). In this case it is also good to know that the more to each other remotely related species there can be found in the same area, the higher gets the value of taxonomic diversity for said area. By for example using DNA-analyses in order to classify species found in a certain area, even more accurate results thus could theoretically be obtained in favor for the substantial conservation of species in said areas, regardless their frequencies.

As a result, the taxonomic diversity (Δ) thus could be defined as "the average path length between every pair of individual organisms identified within a sample" (Kaiser et al., 2011), implying that individuals derived from for example the same genus tend to have "a shorter average path length (measured as the *Euclidean distance* (Desroachers & Anand, 2004)) compared to individuals from the same family" (Kaiser et al., 2011). With that, it is also possible calculating a value for the taxonomic distinctness (Δ*) by dividing the total path length by the total number of linkages in the obtained matrix (*Fig. 1*) (Kaiser et al., 2011).

Aims

As there currently are not many known studies which consistently evaluate how diversity indices have been used in different contexts (including choice of index, trends over time, choice of species et cetera), the aims of this literature study thus are investigating how the aforementioned diversity indices are representing different categories of species in scientific reports and articles from an environmental scientific point of view. Another purpose of this study is also comparing those diversity indices and their degree of public occurrence in relation to each other. This part of said study may include certain moments of more utilitarian character; in this case in terms of statistical presentations, with further derivation from the chosen diversity indices and available data related to said mathematical models, largely depending on the availability of said data in question.

Four questions that might be of relevance in this case thus could be defined as following points below:

- *Which of the described types of diversity indices are the most commonly used and why?*
- *On which types of species are those diversity indices mostly used?*
- *How has the use of the indices varied over the latest two decades?*
- *What is the within article-type distribution of the different indices?*

Methodology

Approach

This report will, as mentioned above, primary include a consistent and empirical literature study with derivation from earlier studies, including relevant articles found in books and other similar material as well as from reports retrieved from the database and the search engine known as Web of Science: Core Collection and Google Scholar, respectively.
As another of the main purposes of this study is investigating how the in this study chosen and described diversity indices are used and scientifically represented through a series of statistical analyses, 50 published scientific reports and articles in turn will be randomly picked and analyzed in order to properly answer the in this study formulated questions through a so-called statistical sampling during the search for relevant articles.
Keywords which consequently might be of most relevance for this case will thus primarily include the terms “diversity index”, “species diversity index” and variations of those words, as well as the terms “Shannon-Wiener”, “Simpson” and “taxonomical distinctness” and variations of those words to further restrict the search for those articles.
Both the obtained numbers and the calculated and percental equivalents of reports and articles treating Shannon-Wiener’s Index, Simpson’s Index, and taxonomic diversity will then be transferred to a bar diagram in order to further display the number of sampled articles for each index.
At the same time as the reports and articles used in this study are sampled, they will also be skimmed through one more time in order to determine which types of species which ideally may be represented for each of the in this case studied indices.
As another aim with this study is investigating how the three different indices are distributed in articles concerning nature conservation in relation to other articles having other aspects of ecology as their main topic, all articles will be skimmed through once again in order to determine whether which of those that have either ecology or nature conservation as their main topics, respectively.
The obtained numbers for the two different categories of journals will then be transferred to another circle diagram in order to display which journal category that in this case is the most prominent for each diversity index.

Restrictions

This report will, as aforementioned, only focus on three of the most commonly used types of diversity indices; in this case traditional diversity indices, such as Shannon-Wiener's Index, Simpson's Index as well as the taxonomic diversity index commonly used in order to calculate values for the taxonomical distinctness within an area, which mainly focuses on the phylogenetic relationship between species in general.

Results

In order to answer the four questions back in the *Introduction* of this study, 50 randomly and manually picked reports and articles (references to those are found back in *Appendix*), which all had in common that they had *species* or *biological diversity* as their main topic, were retrieved from the database and the search engine known as Web of Science: Core Collection and Google Scholar, respectively, and skimmed through in further order to determine which of the chosen diversity indices that had been used in each study. If some of the reports appeared applying two or three indices, they were counted as for example treating both Shannon-Wiener's and Simpson's Index (*Fig. 2*).

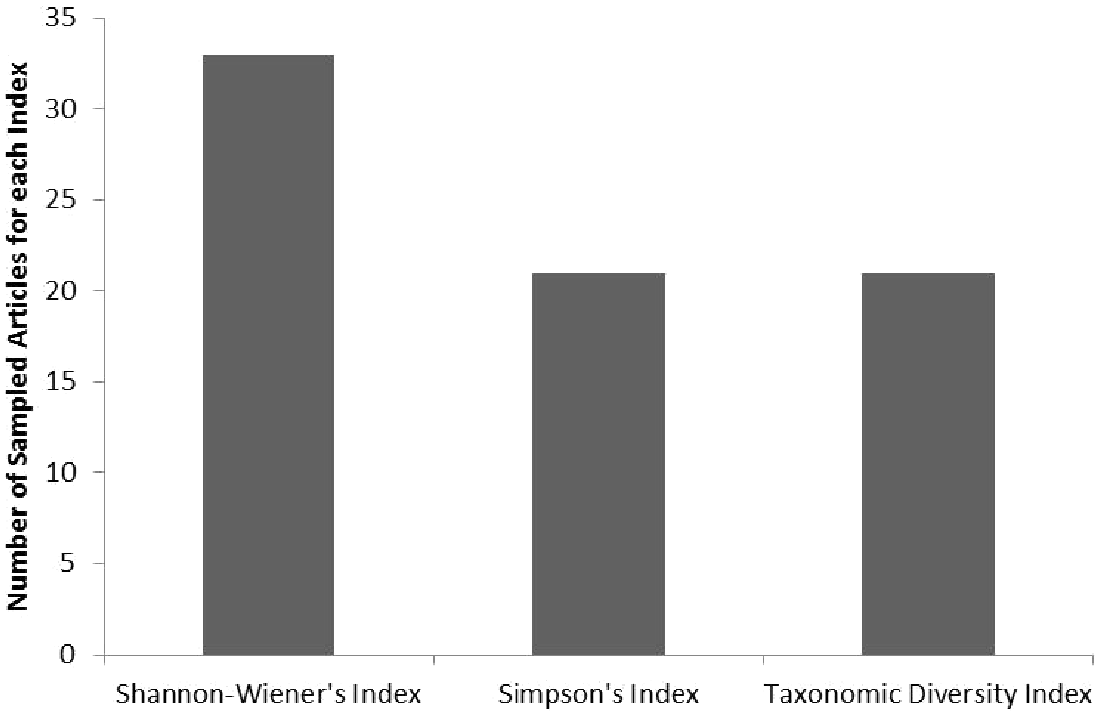

Fig. 2: Bar diagram displaying the total numbers of occurrences for each index in relation to the total number of the in this study sampled articles.

Shannon-Wiener's Diversity Index, was used in 33 (66 %) of the sampled articles, whereas Simpson's Diversity Index and the Taxonomic Diversity Index were used in 21 (42 %) of the sampled articles each. Through the qualitative analysis, eight different categories of organisms were also determined, with further derivation from the species mentioned in each of the randomly picked reports and articles. Those categories were identified as *Plants*, *Fungi*, *Insects*, *Other Invertebrates*, *Fish*, *Amphibians*, *Birds* and *Mammals* (*Fig. 3*).

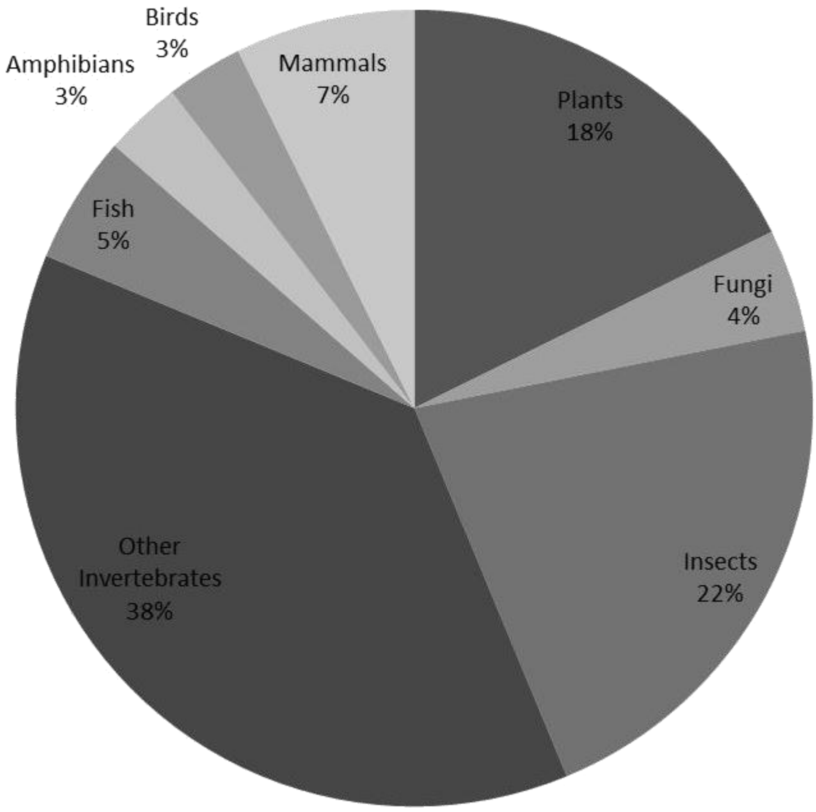

Fig. 3: Circle diagram representing the percental rates for all eight groups of species identified in some of in this study used reports and articles in which all the in this study chosen indices appear having been used.

In an attempt to uncover how the use of the chosen diversity indices may have varied during the currently latest twenty years (starting year 1997), a surface diagram was also plotted in order to visualize how the choices of the three indices may have varied over time; based on dates of publication (*Fig. 4*).

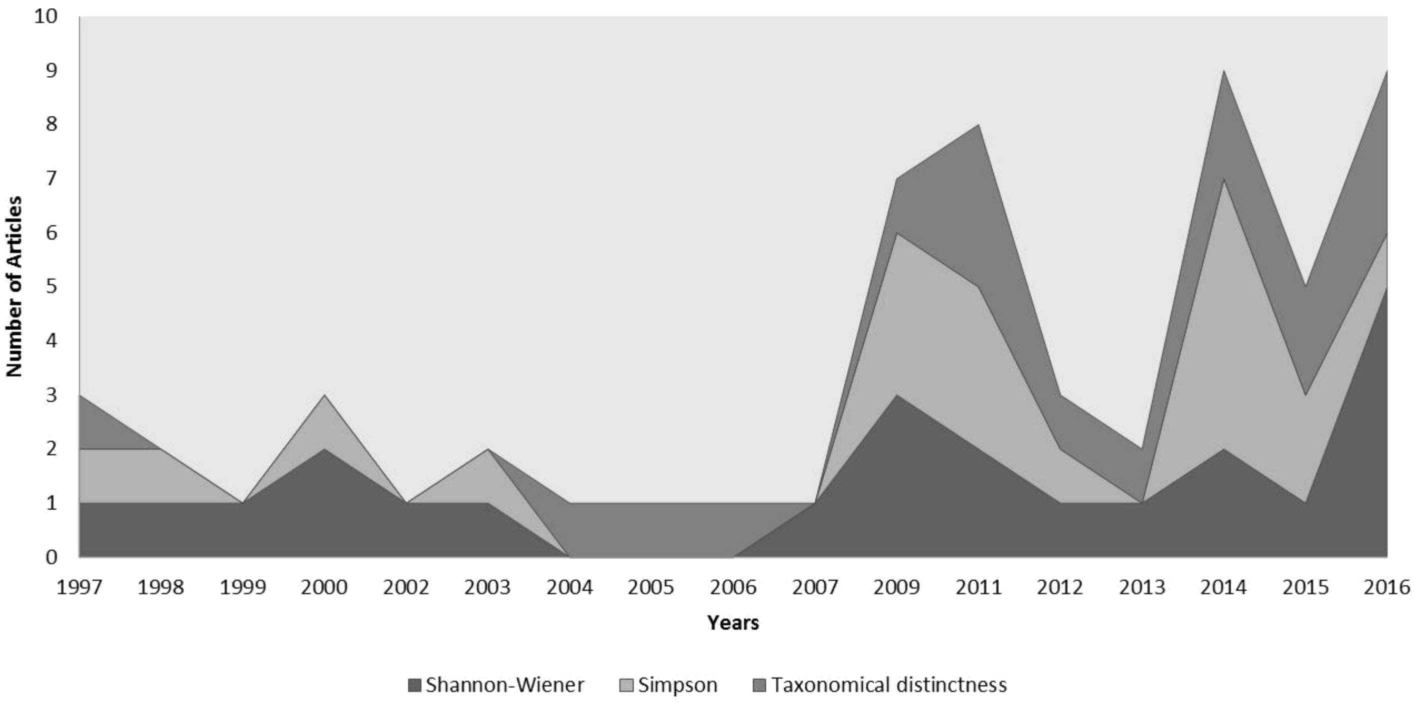

Fig. 4: Surface diagram displaying how the use of in this study three chosen diversity indices have varied during the latest 20 years; further based on the number of sampled reports applied to this study as well as on their dates of publication.

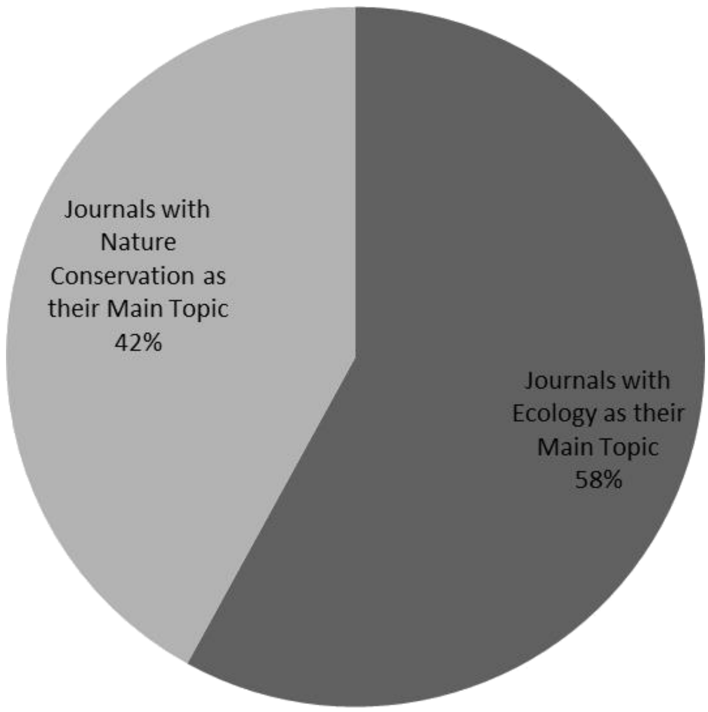

Fig. 5: Circle diagram representing the percental rates for all reports and articles used in this study, which all treat the subjects of either nature conservation or any other aspect of ecology.

Discussion

When looking at the bar diagram displaying the total numbers of occurrences for each index in relation to the total number of the in this study sampled articles (*Fig. 2*), it appears that Shannon-Wiener's Diversity Index was the most used of the three indices; which makes sense as this index, as aforementioned back in the *Introduction*, has been described as one of the most commonly used ones in general ecological work (Hill et al., 2011). Another reason to this may be the fact that Shannon-Wiener's Index being sensitive to species with low frequencies unlike Simpson's Index (Peet, 1974), which instead tends diminishing such species and also their potential importance to areas in which they may be located. Consequently, it is possible to assume that those facts are the reasons to why Shannon-Wiener's Index is the most commonly used type of the in this study three indices.

Furthermore, it also appeared that of all the eight groups of species identified through this study, two groups; *Insects* and *Other Invertebrates*, had the highest percental rates of all said groups. By further comparing the previously obtained circle diagram in *Fig. 3* against the one in *Fig. 6* below, one could also see that those groups in both cases are ranging from being overrepresented in studies involving diversity indices to being heavily represented as they actually are in reality. This also makes sense as insects and other species of invertebrates in fact are known being among the most diverse groups of all known organisms (Burnie; Smithsonian Institution, 2011); in further direct comparison to the majority of the in this study smaller and identified groups of species such as the groups including species of amphibians, birds and mammals, which of those in this case are notably more represented in studies involving diversity indices in direct comparison to the fact that they still are comparatively among the smallest groups of known organisms in the world.

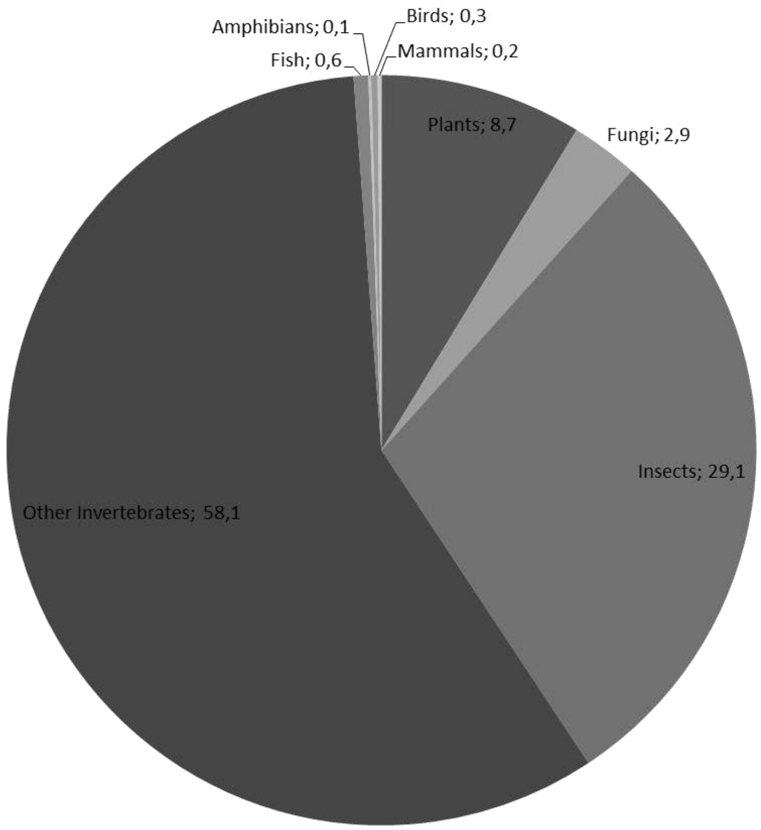

Fig. 6: Circle diagram representing the percental values for the globally known numbers of species of organisms belonging to the in this study identified groups. The values are based on the actual estimated numbers of those living organisms known today; in this case only covering certain groups of species identified throughout the various rapports used in this study (Burnie; Smithsonian Institution, 2011).

Further looking at the timeline over how the use of in this study three chosen diversity indices have varied during the latest twenty years in *Fig. 4*, said timeline did not show any significant trend in increased uses for any of the in this study investigated diversity indices. This includes the certain taxonomical index used in order to obtain values for taxonomic distinctness, considering the fact that this type of index lately has been more and more applied over the years thanks to the gradually increased use of DNA-samples (Benton, 2000). The reason to this may further be found in either the fact that the applied timespan (in this case based on the most common dates of publication of in this study used articles) is too short or that certain methods may have been used in earlier articles not applied to this timeline.

Furthermore, when also looking at the nature preservative aspects of this study, it appeared that only 42 % of all reports and articles also coincidentally appeared treating species which often are playing pivotal roles for the well-being of the ecological systems in which they are found (*Fig. 5*). Most of those reports in this case also treated measures of species diversity among insects and other invertebrates through an environmental preservative perspective; including species of pollinators such as bees (*Hymenoptera; Apoidea*) and bumblebees (*Bombus*), species important for soil function; including springtails (*Collembola*), as well as species of predators working either as bioindicators of freshwater ecosystems or even as providers of pest control in agricultural landscapes; such as spiders (*Araneae*), dragonflies (*Odonata*) and carabid beetles (*Coleoptera; Carabidae*) (Borchard et al., 2014; Birkhofer et al., 2015; Gunnarsson & Federsel, 2014; Le Féon et al., 2016; Menta et al., 2009; Sharma & Rawat, 2009; Sodhi & Ehrlich, 2010; Tomkiewicz & Dunson, 1977; Whalen & Sampedro, 2009). Those reports also treated some species belonging to the minor groups important for nature conservation as well; including case studies for example concerning birds and their role in seed dispersal, certain species of large land mammals and their importance to natural landscapes through their defined maintenance of "critical ecosystem services and thus their increasing of ecosystem resilience by connecting habitats and ecosystems as they move between them" (Oindo et al., 2003; Sodhi & Ehrlich, 2010) as well as the mutually symbiotic relationship between species of mycorrhizal fungi and most plants (Aguilera et al., 2014; Whalen & Sampedro, 2009). As there are not so many known studies which directly evaluate how diversity indices have been used within different contexts; including choice of index, trends over time, choice of species et cetera, it is possible to assume this might be the reason why fewer than half of all analyzed articles appeared treating diversity indices from a direct environmental preservative perspective.

Although it appeared being possible to answer some questions, this study is certainly not free from potential limitations and flaws; including the fact that only 50 articles restricted to a certain time-span were used. The reason to this choice of time-span was chosen was simply because most of the in this case randomly chosen articles appeared during the analyses having been published between the years 1997 to 2016, which in turn might have some limiting impact on this part of the entire study. Furthermore, although the results obtained from this single sample may not entirely explain the causes to the individual choice of diversity indices, they still display a quite good view of how the data could be treated. However, as a consequence of the many apparent limitations in this study, it is suggested that more data is still needed in order to comprehensively detect the fundamental causes and connections to the individual choice of diversity index properly.

Conclusion

Although this study confirmed that Shannon-Wiener's Diversity Index is the most common of the three diversity indices in the in this study used articles and journals as well as that insects and other invertebrates are the most studied groups of species based on said articles, more data is still needed in order to uncover how the use of those indices may have varied over a wider amount of time and in relation to other, more nature preservative aspects.

Acknowledgement

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Appendix

Following appendix includes a list over all sampled articles used in this study.

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