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Point of View

Embracing Methodological Issues in Ethnobiology and Overcoming Challenges

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ABSTRACT

This article delves into the evolving landscape of ethnobiology, mainly focusing on integrating quantitative approaches and the hypothetical-deductive method. We highlight the challenges associated with adopting quantitative tools, such as the potential for oversimplification and lack of critical reflection on the principles guiding these methods. We also examine ecological diversity indices, cultural importance indices, sample sufficiency, replication in studies, and the importance of spatial-temporal context in ethnobiological research. We conclude with practical tips to enhance research's validity, reliability, and generalizability, proposing a path forward for the discipline that respects its essence while adapting to the demands of scientific evolution. While this paper broadly addresses ethnobiology, it primarily focuses on Ethnobotany literature, highlighting the field's rapid advancements and its relevance to other areas within ethnobiology.

Keywords: Ethnobotany, Quantitative Methods, Data Replicability, Sample Sufficiency, Spatial-Temporal Analysis, Cultural Importance Indices.

Introduction

For over three decades, there has been a tremendous shift in ethnobiological research from classical studies that primarily result in the helpful identification of species to human societies and their application in subsistence strategies, local livelihoods, and ethnomedicine to studies that have emphasized the development of quantitative methods, complementary to qualitative approaches, that are foundational for hypothesis testing and a greater understanding of the factors that drive human-environmental interactions worldwide (Prance *et al*. 1987; Turner 1988; Phillips & Gentry 1993a; b; Hoffman & Gallaher 2007; Medeiros *et al*. 2011; Gaoue *et al*. 2017; 2021; Albuquerque & Alves, 2024).

The use of quantitative methods has gained momentum and proven to be informative in ethnobiological research while providing necessary frameworks for the theoretical development of the discipline (Moerman 1979; Phillips & Gentry 1993b; Garibaldi & Turner 2004; Albuquerque & Oliveira 2007; Vandebroek & Balick 2012; Gaoue *et al*. 2017; 2021; Hart *et al*. 2017; Seyler *et al*. 2019; Bond & Gaoue

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2020; Coe & Gaoue 2021), a critical and honest assessment of quantitative methods themselves along with their direct links to a given research question or hypothesis that researchers aim to address is essential to their adequate and appropriate use along with their refinement as the discipline continues to evolve and methodological advancements emerge over time.

Like other emerging sciences, ethnobiology is pivotal in its evolution: the challenge of self-examination and advancement in both methods and theories. This process of self-critique is crucial, especially considering integrating quantitative approaches and using the hypothetical-deductive method in ethnobiological research (Gaoue *et al*. 2021). Such strategies represent a notable evolution in the field, reflecting a maturation and a pursuit of greater precision in its conclusions. However, this transition to quantitative and hypothetical-deductive methods also brings challenges and implications that warrant in-depth reflection.

The increasing adoption of quantitative tools began gaining popularity, promising a new era of rigor and generalization in ethnobiological research. However, this enthusiasm for quantitative techniques was not matched by an equally necessary reflection on the principles and premises that should guide these approaches (Ferreira Júnior 2020). This lack of critical reflection might lead to an undue simplification of the complex knowledge systems that Ethnobiology aims to study or to an inappropriate application of quantitative methods that do not consider the cultural and contextual specificities of the studied groups.

Therefore, in this article, we seek to initiate a critical discussion on the challenges faced by Ethnobiology in integrating quantitative approaches and the hypothetical-deductive method, emphasizing the need for well-defined and context-sensitive principles that can guide this approach effectively. Thus, it proposes a path for advancing Ethnobiology, respecting its essence while adapting to the demands of an ever-evolving scientific field. Although this paper addresses Ethnobiology in general terms, the vast majority of examples, references, and cases discussed pertain to Ethnobotany. Among the fields of Ethnobiology, Ethnobotany has advanced most rapidly in the discussions covered in this text. For this reason, nearly everything discussed here results from the research and advancements within Ethnobotany and, in turn, can be widely applied to other fields of Ethnobiology.

Are You Comparing? Then You Need More of the Same

Ethnobiology, throughout its history, has gone through several phases, with I (Utilitarianism) and II (Cognitive Ethnobiology) being considered more descriptive (Clément 1998; Hunn 2007). Around 1970 and 1980, phase III (Ethnoecology) emerged to overcome the limitations of the first phases by understanding the relationships between humans and nature more broadly than just descriptive (Toledo, 1992; Hunn, 2007). Since then, ethnobiology has gone through new phases: phase IV (Indigenous Ethnobiology); phase V (Interdisciplinarity in an Era of Rapid Environmental Change); and VI (Decolonizing Institutions, Projects, and Scholarship) - that changed the object of study and scale but often maintain a descriptive bias (Hunn 2007; Wyndham *et al*. 2011; Nabhan *et al*. 2011; Wolverton 2013; McAlvay *et al*. 2021). The maintenance of this descriptive bias in ethnobiology may be due to a lack of understanding of the importance of replication in finding general patterns or failure to carry it out due to the higher cost of energy, time, and money for more robust research. Moreover, the strong influence of non-naturalistic sciences – social sciences – on ethnobiology may make replication less relevant or challenging to apply due to the nature of their research. For example, for non-naturalistic research groups, such as those taking a phenomenological approach, the emphasis may be more on an in-depth understanding of subjective experiences and meanings, and this difference in perspective may lead to a lower appreciation of replication in specific non-naturalistic research contexts.

Replication is important to improve the generalizability of findings across diverse contexts and populations, fostering a deeper understanding of the phenomena under study (Hurlbert 1984; Leung 2015). Here, we define generalizability as the ability to extrapolate the results of a study to broader populations than the one studied. This process advances scientific knowledge and promotes transparency and accountability within the research community, as it enables the validation of methods and data, thereby upholding ethical standards. The generalizability and reliability of a study's results are key factors that drive the implication and relevance of these studies.

In this way, we might define genuine replication as the application of the same treatment (i.e., variables that determine the variable response, such as ethnic group, IDH–Human Development Index, temperature, urbanization on knowledge of local people; Figure 1) to multiple and independent sample units, while pseudoreplication occurs when incorrectly assumed independence of a sample unit (Hurlbert, 1984; Lazic, 2016). Sample independence is when the observations or elements in our sample are not dependent on each other, meaning other observations or elements do not influence them. However, the presence of pseudoreplication has been the main obstacle to the quality of ethnobiological studies, and there is often confusion in the definition between genuine replication and pseudoreplication (Giday *et al*. 2003; Asase *et al*. 2005). An example of pseudoreplication in ethnobiological studies is when individual people are used as replicates in a study, comparing the treatment in villages where the sampling or experimental unit is the village. However, the analysis

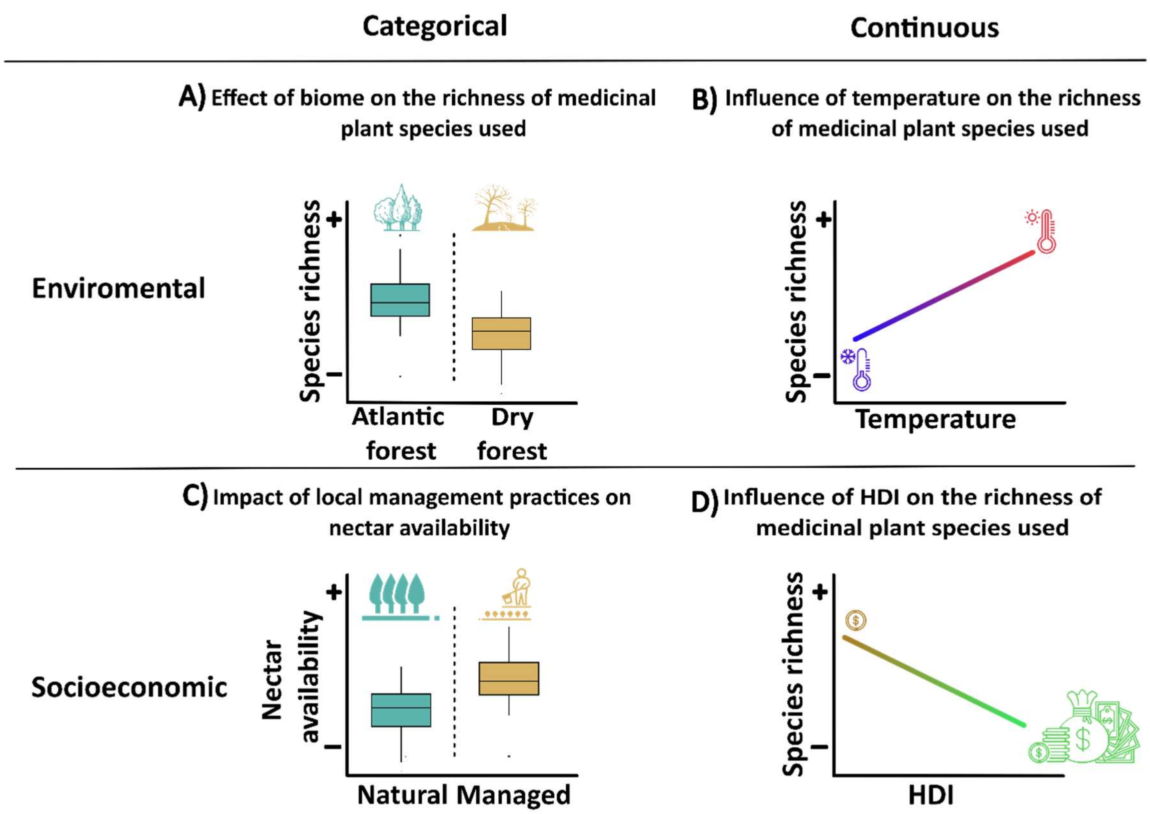


Figure 1. Examples of treatments evaluated on ethnobiology. Ethnobiology studies might evaluate the effect of categorical (A and C) or Continuous treatment (B and D) in the variables of interest, represented on the "Y" axis. The treatments are independent variables, represented on the "X" axis, and could be environmental (A and B) or socioeconomic (C and D). HDI - Human Development Index.

is performed using the individual as the unit of analysis. When using individuals from a community as a sampling unit, results are obtained about the specific community, consequently not allowing generalization to other villages with different socioeconomic and environmental conditions. Therefore, the results cannot be generalized to other villages; they only have implications for the village studied. In this way, the most appropriate way would be to sample people in different villages and analyze the villages with sampling units, allowing greater generalization of the result (Figure 1).

In studies of different areas, including ethnobiology, there are three common causes of pseudoreplication (Schank & Koehnle 2009; Davies & Gray 2015; Gaoue *et al.* 2021):

(I) Inappropriate use of individual people as replicates is the most frequent cause of pseudoreplication in ethnobiology research. Studies that compare phenomena at the community, ethnic, or village level tend to inappropriate use of individual subjects as replications. For example, sampling several people from a single village of an ethnic group and discussing the level of ethnicity is a common error because it disregards the socioeconomic and environmental differences within this ethnic group. This practice gives rise to the false determination that the subjects are independent replicates;

(II) Inadequate consideration of spatial autocorrelation- Insufficient attention is often dedicated to spatial autocorrelation in the data. Samples taken close to one another may not be independent, for example, studies that evaluate the distribution of knowledge about fauna and flora in distinct local communities. Thus, it is expected that geographically closer communities will have more remarkable species similarity than distant communities, which, by not taking into account the spatial autocorrelation between these communities, can result in pseudoreplication and lead to an overestimation of the degree of freedom as well as an inflation of the Type I error rate in statistical tests (reject the null hypothesis when it is true - find significance when there is none);

(III) Temporal pseudoreplication- This happens when data are not collected independently between experimental units due to changes in timing, which may lead to pseudoreplication. For example, data on the local knowledge of communities are obtained in a specific year, and after a period (e.g., five years), the same community is resampled. These data may not be temporally independent; if the resampling period is short, there may be an influence from previous knowledge, and even with long periods between samplings, it is impossible to be sure of this independence due to the transmission of knowledge. Furthermore, statistical tools are recommended to reduce this bias (Generalized mixed models with the sample unit like a random effect - see more details Gaoue *et al*. 2021).

Thus, it is important to evaluate each data point's independence thoroughly; consequently, genuine replication in ethnobiological studies might guarantee the validity of statistical analyses and study conclusions. The use of genuine replication in ethnobiological studies has several advantages, including increased statistical power, improved generalizability, and higher reliability of results (Lazic *et al.* 2018). On the other hand, there are also some disadvantages to using genuine replication, such as increased cost, time, and complexity of the studies (Lazic *et al.* 2018). Overall, the advantages of genuine replication in ethnobiological studies outweigh the disadvantages. Thus, it is recommended that future ethnobiology studies add genuine replications and appropriate analyses to mitigate the problems associated with replication.

The Number of Participants Matters, But So Does Who They Are

Sample size sufficiency is a central criterion in any research requiring data collection, widely discussed across various fields (Ramsey & Hewitt 2005; Martínez-Mesa *et al.* 2014; Schooling & Jones 2014; Olsen & Orr 2016; Walters 2021; Silva *et al.* 2022). Among ethnobiologists, there seems to be a belief that the choice of the minimum number of individuals in a study does not need to be supported by any protocol or statistical inference, often due to the logistical challenges of field data collection.

This approach often leads to 'black box' scenarios, where information about the criteria used to determine the study's participants is limited or completely missing. This lack of clarity ultimately compromises the validity and representativeness of the results, opportunities for meta-analyses and generalizable conclusions across study areas. Traditional or Local Ecological Knowledge, being heterogeneous and subject to variations (Berkes *et al*. 2000; Fernández-Llamazares *et al*. 2015; Mata *et al*. 2023; Santos *et al*. 2023), underscores the need for a sample that captures this diversity for a more comprehensive understanding.

The sample size is intrinsically linked to the studied population and available information, such as population size. This information determines whether sampling should be probabilistic or non-probabilistic (Gil 2008; Hibberts *et al*. 2012; Albuquerque *et al*. 2014). In an ideal scenario, probabilistic sampling is (a) random, where every individual has an equal chance of being chosen; (b) numerically representative, with a minimum number of individuals selected based on criteria like confidence level and sampling error; (c) stratified by groups, where the proportion among groups (e.g., men and women; age groups, etc.) is similar in both the sample and the studied population (Gil 2008; Hibberts *et al*. 2012; Albuquerque *et al*. 2014).

In probabilistic samples, we can estimate the sample size using formulas $n_0 = \frac{1}{E_0^2}$ and $n = \frac{N.n_0}{N+n0}$, where $\mathbf{n}_0$ represents the initial sample size estimate; $\mathbf{E}_0$ is the tolerable sampling error, commonly used in ethnobiological studies as 0.05, or 5%; **N** is the total population size. These formulas are used in simple random sampling (Barbetta 2012; Albuquerque *et al*. 2014). The following formula is used for stratified sampling: $n = \frac{(Z\alpha/2)^2.p\,.q}{e^2}$, where **n** is the sample size; $\mathbf{Z}_\alpha$ is the critical value corresponding to the desired confidence level; **p** is the population proportion of individuals belonging to a specific category; **q** is the proportion of individuals not belonging to the specific category (1-p); and e is the margin of error (Barbetta 2012; Albuquerque *et al*. 2014). Several software programs, such as G*Power (Faul *et al*. 2007) or R (R Development Core Team 2023), using packages like pwr (Champely *et al*. 2018), can be used to determine sample sizes. Online platforms also allow for sample size calculation – SurveyMonkey (https://www.surveymonkey.com/mp/sample-size-calculator/).

Complex cultural data about the human community such as the number of hunters, midwives, local experts, etc., often makes it difficult to determine an accurate minimum number of participants. Researchers may opt for specific methodologies, like the snowball method (Albuquerque *et al*. 2014), to access these individuals. This approach should be combined with statistical methods, demonstrating the representativeness of the information obtained to the reader. Peroni *et al*. (2014) recommended using species accumulation curves (Colwell & Coddington 1994; Gotelli & Colwell 2001) to indicate the likelihood of new information emerging as more interviews are conducted. This method is often observed in studies involving hunters (Whiting *et al*. 2011; Oliveira *et al*. 2020). Various software like EstimateS (Colwell 2013) or R (R Development Core Team 2023), using packages like vegan (Oksanen *et al*. 2019), can be employed for these analyses.

A probabilistic approach is recommended when feasible, as it provides a more robust statistical basis for generalizations. Furthermore, the inclusion or exclusion criteria for participants play a crucial role in determining the sample size. Transparent disclosure of these criteria enhances the study's replicability and allows for evaluating the consistency of results in different contexts.

Good Theories, Good Methods

Ethnobiology is situated at the confluence of various disciplines, encompassing the complexity of human interactions with the natural environment (Delgado *et al*. 2023). This field of study consistently faces eminent challenges that demand sophisticated theoretical evolution and substantial methodological refinement. This necessity is not merely pragmatic but also epistemological, reflecting the multiplicity and diversity of human-environmental phenomena that Ethnobiology seeks to understand. Added to this are ethical, social, and philosophical challenges of a world in need of transitioning towards environmental, social, and racial justice (Albuquerque *et al*. 2024; Hanazaki 2024) along with a balanced coexistence between humans and the environment.

The relevance of a solid theoretical foundation in Ethnobiology is indisputable, serving as a guiding axis for research, interpretation of human-environmental phenomena, and application in real-world contexts amidst worldwide socio-economic inequalities driving access to natural resources. Robust theories enable the articulation of testable hypotheses and the generation of explanatory models that reflect the intricate relationships between humans and the environment (Gaoue *et al*. 2021). In this context, theory is not static but dynamic and evolutionary, mirroring the continuous interplay between empirical discoveries and conceptual reflections.

Although intrinsically subjective, qualitative research is indispensable for understanding the cultural, social, and symbolic dimensions of human-environmental phenomena of interest to ethnobiologists. Theories in qualitative research play a crucial role as they do in quantitative research, offering deep insights into human perceptions, values, and beliefs, revealing aspects often hidden in strictly quantitative analyses. Unfortunately, there seems to be little advancement in qualitative and quantitative analyses to test robust theories, as if theory and practice could not mutually nourish each other to enhance our understanding of the relationship between humans and nature and how this understanding can help tackle the challenges different peoples face, for example, the social-ecological resilience of people in the face climate and land-use change (see Delgado *et al.,* 2023). Furthermore, to evaluate good theories effectively and to understand how different factors (e.g., socioeconomic, environmental, cultural, etc.) influence the interrelation between humans and nature, we need to adopt good methods with higher reliability.

Beyond these considerations, the incorrect or misguided use of qualitative or quantitative methods also affect the quality of ethnobiological research. In this article, we present some aspects, within the exclusive realm of quantitative research, that can advance the quality of the science we produce. Thus, we explore the integration of quantitative approaches and the hypothetical-deductive method in Ethnobiology, emphasizing challenges like oversimplification and a lack of critical reflection. We examine ecological and cultural diversity indices, sample sufficiency, replication, and the importance of spatial-temporal context in research offering practical suggestions to enhance validity, reliability, and generalizability in Ethnobiological research, aiming to preserve its essence while adapting to scientific evolution.

Ecological Indices: Use Only as Prescribed

In Ecology, several diversity indexes (e.g., Shannon, Simpson, Jaccard, and Morisita) have been used to summarize complex and multidimensional information about ecosystems, however aggregating so much information into a single index has proven problematic in several ways (Magurran 1988; Barrantes & Sandoval 2009). For example, the Shannon index summarizes the communities' characteristics, like species richness, abundance, and evenness, on a single value that becomes more difficult to understand if changes in the value of the index represent variation in which of these characteristics. However, diversity indexes have been commonly used in other areas, such as ethnobiology used mainly to understand the pattern of natural resources used by humans (Begossi 1996; Peroni *et al*. 2014). Consequently, ethnobiology has faced some of the same methodological challenges as ecology. The most common problems with using indexes are that they are often not comparable, do not represent reality well, and poorly summarize complex data from the study system.

For instance, when examining a medicinal plant system within a community following a disturbance, relying solely on diversity indices may not yield a comprehensive understanding of the changes that have taken place. Simply observing a shift in the Shannon index from 2.5 to 2 does not provide sufficient insight into the nature of these changes, particularly when compared to assessments of species richness and abundance. A decrease of 0.5 in the Shannon index does not accurately reflect a 20% loss in species compared to the pre-disturbance period. It fails to capture the proportional loss or gain of species, abundance, and evenness, which are crucial for understanding the dynamics of the system. This is because a decrease of 0.5 does not represent the loss of 20% of species in relation to the pre-disturbance period, that is, the decrease is not proportional. As a result, several ethnobiology studies tend to present the index values with reasonable interpretations due to the limited information provided by the indices, like a single number (Green & Chapman 2011; Daly *et al.* 2018). In this way, the use of single variables (*i.e.*, species richness, abundance, and identity of species) often provides better information about the studied system than the index values.

Quantitative ethnobiological studies often incorporate diversity ecological indexes, like the Shannon and Simpson index which has been indiscriminately and mistakenly used in prior research. Ethnobiology studies need to make clear the limitations of a given method employed and the context in which they are used. The inappropriate use of indices can result in shallow and non-generalizable interpretations when presenting only the value of the index (Barrantes & Sandoval 2009; Green & Chapman 2011). For example, it is likely incorrect to say that the Shannon index is high when a value is close to 4 because values for this index tend to vary from 0 to infinity (Segnon & Achigan-Dako 2014). Thus, four is relatively low when compared to higher values like 10, 20, and 50. This shows that a study area has a specific Shannon index value that is context dependent, or comparing between study areas does not always mean that these results are generalizable to other sites or biological/ human communities.

Another example is the interpretation of the dissimilarity indices, which may be shallow and limited in their predictions. Studies using these indices present the results of whether the communities are not similar, but detecting and affirming these differences with the indices alone is impossible. For example, when evaluating the community of plants used in two local communities, it might be observed dissimilarity Bray-Curtis index next to 1, representing that both communities used are distinct, but is not possible to detect if this difference is due to changes in species richness - number of species - or identity of used plants. Consequently, studies commonly present the index values and state that the index is limited (Toledo *et al*. 2007). Therefore, the question arises: why continue using these indices?

Therefore, understanding the limitations of the indices and seeking alternatives are essential for the appropriate use of the indices and for advancing the understanding of the complexity of ecosystems. The main challenge in ecology and ethnobiology tends to follow the same path: finding alternative paths to indexes that allow us to summarize the complexity of ecosystems without losing explanatory power. Recent studies that evaluate the efficiency of the diversity index in Ecology have shown that these indexes are insensitive to species differences and abundance (Izsák & Papp 2000; Ricotta & Avena 2003; Lamb *et al*. 2009). Moreover, the diversity indexes do not provide good information about environmental changes, like climate and land-use changes (Thiebaut *et al*. 2002; Lamb *et al*. 2009). The following are the principal objections to the diversity indices used in ecological and ethnobiological research (Barrantes & Sandoval 2009):

(I) Failure to recognize intraspecific differences within populations, such as age classes or sexes, results in loss of information. For example, in ethnobiological research, these differences might influence knowledge strategies, social hierarchies, foraging behaviors, and responses to the environment;

(II) most indexes are highly sensitive to sample size because they depend on the number of observed species. This sensitivity is due to nearly all diversity indices incorporating the number of species (S) as a fundamental component in their calculations, making them particularly sensitive to changes in sample size that are correlated with the number of species;

(II) the indexes ignored the heterogeneous sampling units. Thus, the lack of care can lead to using variables with different sampling units, for example, using species abundance and vegetation cover simultaneously and as if they were the same unit of measurement. The indices did not detect these differences;

(IV) It allows only limited insights into communities and evolutionary patterns. The use of indexes is only to describe, and it is not comparable because assigning a probability value to an index is impossible.

Alternatively, to remedy some of these challenges, adopting multivariate analysis and model-based approaches can allow a greater understanding of the drivers of human-environmental interactions in a given study system more adequately. For example, understanding the effect of environmental change on the use of medicinal plants by local people can be assessed more adequately by using explicit variables, like plant species richness and abundance, rather than diversity indexes of used plants (Barrantes & Sandoval, 2009). Explicit variables allow a mechanistic and clear comprehension of communities' responses to environmental changes. Furthermore, we recommended that future studies in ethnobiology continue to consider the methodological advances in ecology and ethnobiology while adopting new model-based approaches, and the use of explicit variables (e.g., the use of piecewise and hierarchical models allowing multiple dependent and independent variables simultaneously - see more details Gaoue *et al*. 2021).

In summary, we recommend employing multivariate analysis and model-based approaches instead of relying solely on diversity indices for a more comprehensive understanding of the drivers of human-environmental interactions. Clearly report the specific variables used in your studies, such as species richness and abundance, to provide a more detailed and accurate representation of the study system. Additionally, acknowledge and discuss the limitations of the indices used and the specific contexts in which they are applicable to avoid misinterpretation and overgeneralization.

Ethnobiological Indices Do Not Necessarily Make Your Work More Attractive or Robust

The use of cultural importance indices to quantify the level of importance of a given plant species to a particular cultural group has become widespread, often with aims to understand better medicinal plant use and selection, species use, economic, and ethnotaxonomic values, and aid in defining conservation priorities (Turner 1988; Stoffle *et al*. 1990; Phillips & Gentry 1993a; Bennett & Prance 2000; Pieroni 2001; Garibaldi & Turner 2004; Reyes-García *et al*. 2006; Silva *et al*. 2006; Hoffman & Gallaher, 2007; Tardío & Pardo-De-Santayana 2008; Thomas *et al*. 2009; Franco *et al*. 2014; Tudela-Talavera *et al*. 2015; Mateo-Martín *et al*. 2023). While studies seeking to quantify the cultural importance of plant taxa often aim to do so by defining a particular set of unique variables that comprise a given index proposed to provide a replicable and objective measure of species cultural values, significant limitations to these approaches hinder the ability of these indices to provide a generalizable methodology that can be confidently applied to ensure appropriate and adequate estimates of cultural importance over time, various study systems and geographic ranges. First, there lacks a clear, concise, and operational definition of species' cultural importance in ethnobiology beyond the general statement, "the importance of the role that a plant species plays in a given culture." This brings into question, "What specific roles does a species have to fulfill within a given society to be culturally important, and to what extent?"

In a foundational study, Turner (1988) asked fundamental questions on how species cultural importance could be documented and compared in a meaningful, systematic, and quantifiable way while building on the work of her mentors (Berlin *et al*. 1973; Hunn 1982) and highlighting the complexities of such an undertaking. However, only some ethnobiological studies have continued to pose these essential questions on what specific factors or criteria adequately define species' cultural importance while systematically testing predictions to reach a consensus among researchers and a generalizable conclusion. Instead, numerous studies arbitrarily propose a given quantitative index assuming it estimates specy's cultural importance with little to no theoretical support for the choice or inclusion of specific variables and discussion on why they are adequate to provide a rigorous, generalizable, and unbiased estimate. Second, most studies aiming to quantify cultural importance define variables of a given index primarily from the researcher's perspective and need to incorporate adequate metrics of cultural importance defined from the participant's emic perspective. It has been suggested that adequate evaluations of cultural importance should be done by Indigenous peoples and local communities themselves (Turner 1988). As such, there are inherent biases driven by the researcher's values included in estimates of species' cultural importance from the etic perspective regardless of whether a variable for participant consensus is included as a metric (see Silva *et al*. 2006) along with variables defined, ranked, or estimated from the researchers themselves (Tardío & Pardo-De-Santayana 2008; Thomas *et al*. 2009). This topic has been discussed in the literature (Coe & Gaoue 2020) and warrants further research and honest discussions to determine if the quantification of species' cultural importance can be adequately estimated from the emic or etic perspectives. Third, there has been a noticeable trend for ethnobiologists to propose a novel index based on either current study objectives or aims to improve upon existing indices that have been criticized for limitations (e.g., for lacking a given variable or for incorporating researcher subjectivity) (Stoffle *et al*. 1990; Pieroni 2001; Reyes-García *et al*. 2006; Tardío & Pardo-De-Santayana 2008; *Franco* et al. 2014; Tudela-Talavera *et al*. 2015).

While innovation has been an integral force at the forefront of methodological advancements developed from and built upon the entire body of ethnobiological research, it is important for researchers to clearly understand and consider the assumptions of a given index concerning appropriate methods employed for study questions being addressed or hypotheses being tested (Hoffman & Gallaher 2007). In a thorough examination of 12 indices used to predict species' cultural importance and identify cultural keystone species, Coe and Gaoue (2020) found that most indices were correlated, meaning that most importance indices contain similar variables suggesting that the species' cultural values aim to quantify were repetitive and most often not unique. Given that these indices were also shown to perform poorly in predicting species cultural values (Coe & Gaoue 2020) within the cultural keystone species framework (Garibaldi & Turner 2004), it is important to consider their appropriate use to avoid unreliable and ungeneralizable data interpretation (Medeiros *et al*. 2011).

As the emphasis on quantification and hypothesis testing in ethnobiology continues, it is important to ask if ethnobiologists need an index to quantify species' cultural importance. As noted in the seminal paper by Turner (1988), who provided the first quantifiable index to estimate species' cultural importance, and asked a knowledgeable elder participant directly, "Which plants are important?" she replied, "I would pick them all – they are all important."

In summary, we recommend establishing clear and operational definitions for cultural importance and the specific roles that species fulfill within a society. It is important to ensure that cultural importance indices include metrics defined from the participants' perspectives to reduce researcher bias (see Sousa *et al*. 2024). Additionally, critically evaluate the need for new indices and their theoretical support to ensure they provide meaningful and generalizable estimates.

Where Are We? When Are We?

Most ethnobiological studies are conducted at local scales, aiming to address issues related to the knowledge or use of natural resources. However, these studies often neglect spatial and temporal information, resulting in biases that impede the findings' understanding, replication, and generalization.

Spatial biases are linked to the absence of specific spatial information about the study location. Often, studies provide generic descriptions of the locality, such as "The study was conducted in São Desidério, Bahia, Brazil" with minor variations including the name of the community "The study was conducted in the Licuri community, in the municipality [...]" or the central coordinate of the municipality "The study [...], 12° 21' 8''S, 44° 59' 3''W." The issue with this information is that it does not precisely provide the exact location of the community; this is the specific geographical position. In this example, the community could be located anywhere within the ~15,200 km² of the locality.

The sociocultural, environmental, and political context in which the investigated communities are embedded plays an equally crucial role in constructing a comprehensive spatial overview for the reader. For example, in the context of ethnobotanical research aimed at understanding the use of medicinal species, the presence of information such as the availability of modern health services (Saynes-Vásquez *et al*. 2016; Weckmüller *et al*. 2019), the dynamics of different land use patterns (Kunwar *et al*. 2015; Arjona-García *et al*. 2021), and cultural context (Kidane *et al*. 2014) are elements that often explain the dynamics of medicinal plant knowledge. Without this information, the reader might accept the presented results without fully understanding the scenario in which the community is embedded.

Among the spatial biases discussed, we can classify the community's location as essential in all studies. Other information is relevant in specific contexts and should be adjusted according to the objectives of each research, emphasizing the socio-environmental, cultural, and political contexts in which Indigenous Peoples and Local Communities are situated, as these elements can influence the interpretation of results.

Temporal biases, in turn, are linked to the lack of temporal information during the study. The presence of information indicating the period in which the data were collected, such as "Data was collected between April/2023 and July/2023" becomes crucial. This precision becomes even more critical when considering the dynamic nature of traditional or local ecological knowledge over time. For example, Sousa *et al*. (2022) observed significant changes in the most popular plants in a rural community in Northeast Brazil over two years.

Furthermore, studies with clear spatial and temporal information provide a broader range of data, enabling greater robustness and eligibility in systematic reviews and meta-analyses. For example, Santoro *et al*. (2017) tested whether the pharmacopoeias of African populations - broad spatial scales - incorporated more medicinal species as the incidence of malaria increased, which was not corroborated. However, due to the use of temporal data - articles with different publication years - it was possible to understand that the stability of pharmacopoeias may be related to public interventions aimed at controlling malaria, where pharmacopoeias do not need to increase the number of species. In this sense, when conducting ethnobiological studies, it is essential to provide clear spatial and temporal information to ensure a more complete and contextualized understanding of the studied communities that seek to understand the relationship between human beings and biodiversity. By addressing these aspects, researchers can build a more solid scientific foundation, promoting significant advances in understanding and addressing ethnobiological issues.

The Quantity of Ingredients is as Important as the Ingredients Themselves

Researchers frequently overlook important information like the mean or median value of their samples, the spread of the data (standard deviation), and whether any unusual data points – outliers – were excluded (Zuur *et al.* 2010; Gerstner *et al.* 2017). Highlighting the means or medians of samples can provide insights into the central tendency of the dataset. At the same time, the standard deviation shows how spread out the data points are from the average. For example, after interviewing individuals from a community, we calculated that, on average, each person used seven medicinal plants. While researchers often stop after pointing out the mean of a sample in the results section, they can offer more pertinent details. For instance, the average number of cited species was 7, with a standard deviation of ±3.5 ranging from 3 to 15 species. This gives a general idea of the data obtained and gives readers a clearer idea of the sample discussed. Neglecting to report such details hampers the study's reproducibility and impedes transparency in understanding the primary results.

Another common but lesser problem facing data transparency is the need for more information about outliers, whether the author removed them from the samples or kept them (Zuur *et al.* 2010). An outlier is a data point representing an observation that differs significantly from other observations. It can happen for many reasons, such as measurement errors or conditions that differ from norm (Kelley & Preacher 2012). Sometimes, an outlier can be a genuine great variation in the studied phenomenon. For instance, encountering an elderly individual who is a specialist or generally well-versed in medicinal herbs during interviews could introduce outliers compared to the sampled population. These outliers can skew averages and affect statistical evaluations, particularly those relying on mean-based analyses like linear models. Genuine outliers are often kept in the sample; however, genuine outliers are often difficult to tell apart from measurement errors. Whether it be the decision of the ethnobiologist, it is a transparent and reproducible practice to inform why the decision better fits the research goals. Therefore, providing clarity on handling outliers ensures the integrity and accuracy of the research findings.

Similarly, when testing a hypothesis, it is common for researchers to prioritize p-value reports over the effect sizes in analysis and hypothesis testing (Popovic *et al.*, 2024). P-values indicate the probability of observing the data or more extreme ones, assuming the null hypothesis is true (Kelley & Preacher 2012; Gerstner *et al*. 2017). A small p-value, typically less than 0.05, suggests that the observed data is unlikely to have occurred by chance alone (under the null hypothesis), providing strong evidence supporting the alternative hypothesis and representing the phenomenon being tested. The effect sizes, in turn, represent the magnitude of the relationship between dependent variables (those that are measured, such as knowledge of medicinal species) and independent variables (those that are used to explain the knowledge, such as age or gender) (Kelley & Preacher 2012; Rosenberg *et al*. 2013). In systematic reviews and meta-analyses, effect sizes are standardized for comparison across different studies, even when study designs differ (Rosenberg *et al*. 2013; O'Dea *et al*. 2021). Interpreting p-values and effect sizes helps the researcher validate the studied phenomenon and its magnitude.

Moreover, these values provide insight into the strength of a particular phenomenon, including coefficients in a linear model, differences between means (common in ethnobiology studies), correlation coefficients, and more (Kelley & Preacher 2012; O'Dea *et al*. 2021). For example, two distinct studies investigate whether there are differences in the knowledge of medicinal species among populations living in urban and rural contexts. In both studies, the authors were limited to reporting the following statement: - "Our study demonstrated that, compared to urban populations, rural populations know more medicinal species ($p<0.05$)". However, upon observing the effect, we noticed that, on average, one population knew 5.5 more plants than the other, whereas in the other study, the average difference was only 1.5 plants. This information facilitates the reader's interpretation of the study's main message and the search for explanations for such discrepancies.

Additionally, consider a linear regression example: when testing a hypothesis on whether the diversity of medicinal plants responds to an environmental gradient (e.g., urbanization, altitude, proximity to main roads) and obtaining a p-value of 0.04 and an effect size of 0.19 (in this case, represented by a linear coefficient β) strongly suggests that the environmental gradient correlates with the response variable – in this case, the diversity of species declared by individuals. In linear regression, the linear coefficient is the value that multiplies the predictor variable (consider $Y= \beta x+a$, the linear coefficient would be β) and gives an idea of the magnitude of how much independent variables (x) affect the dependent variables (Y). In our example, this can be interpreted as every one-unit change in the predictor variable (urbanization, altitude, proximity to main roads) corresponds to a 0.19 change in the number of species. Therefore, solely reporting p-values may be insufficient for fully interpreting results (Popovic *et al*. 2024) and should be accompanied by effect sizes that are crucial for theoretical understanding and conveying the magnitude of a statistically significant phenomenon.

Similarly, graphs depicting various approaches, such as barplots, boxplots, and scatter plots, often need more detail, mirroring sample deficiencies (Gerstner *et al*. 2017). For instance, barplots and boxplots are frequently presented without indicating means or medians, maximum and minimum values, and even without explicitly specifying the measures depicted on the axes (e.g., the number of species, biomass (g), temperature (ºC), etc.; see Table 1) and their respective units. Moreover, whether the unit of measure has undergone any transformation, such as log transformations, remains unclear. This presents a significant challenge as it not only diminishes the reproducibility of the study but also impedes the comprehension of the results, making it difficult to grasp the main ideas of the study (Gerstner *et al*. 2017).

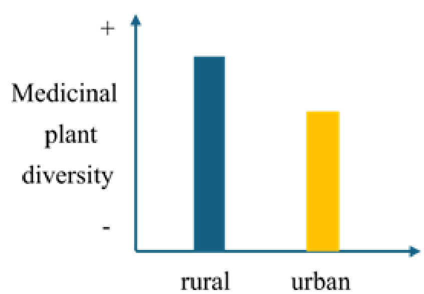
Furthermore, improving reporting mean or median values, addressing outliers, and providing standard deviation and effect sizes are important for replicability and help validate the research conducted by ethnobiologists. However, considering the limited word count and space typically available in research articles, it is advisable to include these details in supplementary materials and make the article's metadata available for readers and potential researchers conducting reviews. Thus, adopting these practices enhances the probability of the research being included in a systematic review or meta-analysis, thereby increasing its impact (Gerstner *et al*. 2017; Popovic *et al*. 2024). Consequently, even a small additional effort in handling challenging data can yield significant rewards.

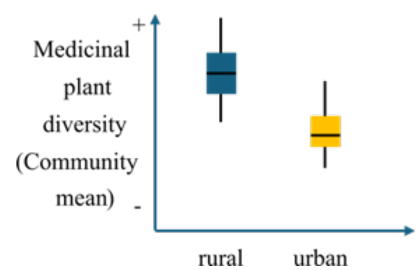
Future Directions

As we look ahead in Ethnobiology, several key directions emerge for future research. Firstly, developing integrated methodologies that seamlessly blend quantitative tools with the rich, qualitative roots of Ethnobiology is paramount. This approach would maintain the depth of traditional knowledge and enhance it with the precision of quantitative analysis.

Table 1. A Synthesis of Principal Thematic Problems and Solutions in Data Reporting and Analysis

Thematic	Common Problems	How to Solve Them
Mean or median, standard deviation, and maximum and minimum values	Lack of details in reporting sample characteristics	Provide sample characteristics, including key statistics and range.
	"[..] the average number of medicinal plant species known in the community is seven species."	"[...] the number of known medicinal species ranges from 3 to 15 (7 mean ± 3.5 SD species)."
Effect sizes	Prioritization of p-value reporting over effect sizes	Emphasize the importance of reporting effect sizes alongside p-values for a comprehensive understanding of relationships between variables.
	"[...] urbanized and rural communities differed significantly (P<0.05)."	"[...] Rural areas had an average of 3.2 more species than urban areas (P=0.032), indicating a significant difference between the two."
Graphical communication	Lack of detail and clarity in graph representation	Enhance graph clarity by including essential details like standard deviation and axis labels complete with units (e.g., °C, mm, etc.), ensuring transparency in data representation. The legends should encompass adequate information to ensure the comprehension of the graph independently from associated textual explanations.





Secondly, critically evaluating the tools and indices currently in use is essential. This involves thoughtful examination of ecological and ethnobiological indices and exploring alternatives that can adequately estimate the intricacies of ecosystems and cultural importance without oversimplification.

Thirdly, the issue of sample representation and replication in studies needs to be addressed with greater rigor. Establishing robust sampling strategies that accurately reflect the diversity within communities and ensuring replication will enhance the reliability and applicability of research findings.

Moreover, greater attention should be given to ethnobiological studies' spatial-temporal context. Detailed reporting of geographical and temporal data is crucial for a comprehensive understanding of ecological knowledge and practices' dynamic nature.

Additionally, enhancing data transparency and reporting standards is vital for the field's progress. This includes providing detailed information on sample characteristics, the handling of outliers, and effect sizes, which would improve the reproducibility and validity of research findings.

Lastly, embracing new technologies and analytical tools to understand and visualize complex ethnobiological data will be a step forward in this evolving field. By addressing these future directions, Ethnobiology can continue to grow as a discipline that respects its qualitative heritage and thrives on methodological innovation and scientific rigor.

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Authors' Contribution

Ulysses Albuquerque: Conceptualization; All authors: Writing Original draft, Writing- Reviewing and Editing,

Conflicts of Interest

The authors have no conflicts of interest to declare.

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