

Beyond the Shannon-Wiener Index: Disparities in Lecturers' Conceptual Knowledge of Effective Species Numbers

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Abstract: This study aimed to explore lecturers' knowledge of the Shannon-Wiener index and Effective Species Numbers in the context of biodiversity measurement, examining both factual and conceptual knowledge dimensions. A mixed-methods design with an embedded component was employed. Respondents were selected through purposive sampling, and data were collected using an open-ended questionnaire and a procedural competency test (to reinforce qualitative results). The factual knowledge dimension focused on the relevance of species as a measurement unit, while the conceptual knowledge explored index selection, application, and interpretation of the logarithmic base of the Shannon-Wiener index, and emphasis on Effective Species Numbers. The data analysis was carried out through the stages of qualitative and quantitative data analysis, data integration, and conclusion drawing and verification. The results showed that, regarding factual knowledge, lecturers agreed that species remain the basic unit of biodiversity measurement because they reflect ecosystem conditions and serve as a basis for representing environmental health. In the conceptual dimension, the dominant use of the Shannon-Wiener index, based on the natural logarithm, as a methodological standard was found, driven by pragmatic considerations and its suitability with academic textbooks. Lecturers also pointed out the unitless, scaling, and monotonicity properties of the index, as well as the mathematical implications of choosing a logarithmic base. However, absolute differences in logarithmic bases can make index values incomparable across studies. Despite this understanding, a notable gap emerged regarding Effective Species Numbers. While some respondents acknowledged its importance as an advancement that addresses the limitations of entropy-based measures, others were unfamiliar with the concept. This disparity highlighted the need for curricular enhancement and academic updating. Overall, the study underscored the importance of strengthening mathematical-biological literacy and updating ecological education. Beyond routine calculation of traditional biodiversity indices, learning should encourage deeper conceptual reasoning, ecological interpretation, and awareness of contemporary methodological developments.

Keywords: shannon-wiener index, effective species numbers, factual knowledge, conceptual knowledge.

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■ INTRODUCTION

Biodiversity (biodiversity or biological diversity) is all life on Earth—the extraordinary richness and variety of the living world, from genetic variability within species to the diversity of ecological systems (Miller & Spoolman, 2009; Odenbaugh, 2021). One of the most important aspects of biodiversity is how it is assessed. Scientists use different methods to assess biodiversity. Many ecologists argue that the basic

unit of biodiversity is the species, hence the term species diversity (Krebs, 2009; Hohenegger, 2014; Latimer, 2014; Roswell et al., 2021). Species are considered a deductive tool for understanding ecological systems (ecosystems). However, Reydon (2019) argues that species are not a good unit of biodiversity.

The species diversity index is a quantitative measure (a number) that describes the total proportion of species relative to the total number

of individuals present (Krebs, 2009; Miller & Spoolman, 2009; Latimer, 2014). As a quantitative measure, the species diversity index is useful in monitoring and conserving the biodiversity of a region (Spellerberg, 2008; Morris et al., 2014), especially regions with areas that have many species, such as Indonesia, which is one of the megabiodiversity countries (Indrawan et al., 2007; Von Rintelen et al., 2017). One of the species diversity indices often used is the Shannon diversity index, also known as the Shannon-Wiener index (Magurran, 2004; Mendes et al., 2008; Spellerberg, 2008; Mårtensson, 2016; Strong, 2016).

Strong (2016) noted that many biology publications do not clearly identify the logarithm base used, which can affect the results of the Shannon-Wiener index calculations. One example of a logarithmic base that was not clearly stated was the article by Suwadji and Nugraha (2022), in which the Shannon-Wiener index was expressed in base 10 (the common “log”). Then the statement “ \ln = natural logarithm” appeared after it. Using the logarithmic base as the basis for calculating the Shannon-Wiener index can lead to misconceptions (Barrantes & Sandoval, 2009). Differences in the logarithmic base used in the Shannon-Wiener index complicate interpretation, making it difficult to compare results across studies. This is because the Shannon-Wiener index is very abstract and its practical meaning is difficult to understand (Tuomisto, 2010; Gatti et al., 2020; Roswell et al., 2021). Furthermore, the use of Effective Species Numbers as a basis for comparing species diversity is not widely applied by biologists (Strong, 2016).

For the monitoring and conservation of biodiversity in Indonesia, a megadiverse country, a good understanding of species diversity indices is required, including the Shannon-Wiener index and the Effective Number of Species. This good understanding must be possessed by university

lecturers. Lecturers in the field of Biology (Ecology) or other fields relevant to biodiversity must have a good understanding of the Shannon-Wiener index and the Effective Species Numbers as evidence of mastery of the concepts (material) to be conveyed to students. Although the focus was not on specific statistics or indices, Butler et al. (2014) showed that educators can be an (unintentional) source of misconceptions about basic ecological concepts, which can significantly affect the quality of students’ understanding.

Conceptual knowledge is the foundation or core component of conceptual mastery (Anderson & Krathwohl, 2001). Conceptual knowledge serves as the glue that connects isolated facts into a unified understanding (Faulconer & Gruss, 2018). Lecturers’ conceptual knowledge is crucial in learning, particularly the Shannon-Wiener index, as it shapes how students interpret concepts, formulas, mathematical logic, and the ecological interpretation of the index. In learning the Shannon-Wiener index, lecturers play a crucial role in bridging mathematical logic and ecological phenomena (Roswell et al., 2021). Integrating mathematical logic and ecological interpretation requires a deep understanding of the mathematical framework to avoid interpretation bias (Jost, 2006; Chao et al., 2020). When lecturers effectively transmit conceptual knowledge, students will interpret the Shannon-Wiener index not merely as a calculation task but as an analytical tool for understanding species abundance distributions and ecosystem complexity.

Furthermore, the integration of technology into ecology learning often acts as a double-edged sword. The widespread use of statistical software can simplify calculations, but if not balanced by strong conceptual knowledge, it will lead only to a black-box approach (a procedural tutorial approach). Lecturers tend to provide technical, step-by-step instructions that ignore the conceptual essence (Acevedo, 2020).

Barraquand et al. (2014) emphasized that many young ecologists (including students) can use statistical tools and models but lack a deep understanding of the underlying mathematical and statistical concepts. This condition reflects the dominance of procedural knowledge without conceptual knowledge. Students may be able to operate the software but fail to understand why a particular logarithmic base is used or the implications of changes in index values for ecosystem stability.

This phenomenon emphasizes that lecturers' mathematical literacy must extend beyond operational aspects to pedagogical-translative ones. When lecturers are unable to separate the technical constraints of computation (procedural tutorials) from mathematical logic, students tend to experience cognitive overload. This condition triggers persistent math anxiety (Shoemaker et al., 2021). As a result, students turn to rote learning rather than in-depth understanding, which, in turn, hinders the future integration of quantitative principles into ecological science. The mathematical literacy gap among lecturers has implications for the reproduction of conceptual misunderstandings from lecturers to students (Moreno-García et al., 2017).

Learning that emphasizes conceptual knowledge (rather than just procedural knowledge) has been shown to improve learning outcomes significantly (Edulsa, 2022; Hussein & Csíkó, 2023). Lecturers who have in-depth conceptual knowledge have been proven to be able to make significant contributions to students' conceptual progress (Kleickmann et al., 2014). Given the importance of conceptual knowledge as a strong predictor of learning outcomes, this study explores how this knowledge manifests among lecturers, specifically in the context of the Shannon-Wiener index and Effective Species Numbers.

Given the background of the problem described, this study aims to explore lecturers' knowledge of the Shannon-Wiener index and Effective Species Numbers. This exploration of lecturers' knowledge is based on the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) cognitive level, specifically the dimensions of factual and conceptual knowledge. Thus, the questions for this study to answer the aims are: 1) How is the lecturers' factual knowledge reflected in the relevance of species as a unit of biodiversity measurement? Moreover, 2) How do lecturers organize conceptual knowledge related to the use and meaning of the logarithmic base of the Shannon-Wiener index and the Effective Species Numbers in biodiversity interpretation?

■ **METHOD**

Participants

The study was conducted using a mixed-methods design, with respondents being lecturers who teach Ecology courses or courses relevant to biodiversity at state and private universities. Respondents were selected using purposive sampling technique with the following criteria: 1) lecturers who teach ecology courses or courses relevant to biodiversity, 2) active lecturers at state or private universities (based on Ministry of Higher Education's Database), 3) having experience teaching or using the Shannon-Wiener index and/or Effective Species Numbers in learning, research, or other academic activities, and 4) willing to participate in filling out the research instrument. The number of respondents was guided by the principle of data saturation; recruitment was stopped when the existing data were sufficient to yield meaningful answers in the context of the research (Rahimi & Khatooni, 2024). The demographic categories of the study respondents are shown in Table 1.

Table 1. Demographics of research respondents

Category	Subcategory	Percentage (%)
Institutional Status	State Universities	77.42
	Private Universities	22.58
Education Level	Master's Degree (S2)	61.3
	Doctoral Degree (S3)	38.7
Area of Expertise	Ecology & Conservation (Plant/Animal/Environmental)	67.74
	Biology Education	22.58
	General Biology & Ethnobotany	9.68
Teaching Experience	< 10 Years	48.39
	10–20 Years	41.93
	> 20 Years	9.68
Regional Distribution	Sumatra	41.94
	Java	25.81
	Sulawesi	16.13
	Nusa Tenggara Islands	9.68
	Papua	6.45

Research Design and Procedures

The mixed design in this study was an embedded design, in which qualitative data were dominant and quantitative data were supporting (Creswell, 2014). This study used a mixed-methods design to explore lecturers' factual and conceptual knowledge of the use of the Shannon–Wiener index and the Effective Species Numbers, based on the knowledge dimensions in the Revised Bloom's Taxonomy. Meanwhile, a quantitative design that described the respondents' procedural abilities (work steps) reinforced the results obtained from the qualitative design. The mixed-methods procedure was carried out in the following stages: preparation, data collection, and data verification.

Research Preparation. The initial phase of research preparation focused on developing and validating the data collection instrument (questionnaire) and the procedural competency test (work steps). The first step was to develop the questionnaire and procedural competency test questions based on the established research indicators. Once the questionnaire and procedural competency test draft were finalized, the

instrument underwent expert judgment (validation) to assess the suitability of the material/substance, construction, and language, ensuring that the questions were unambiguous and truly appropriate for addressing the research aim and questions.

Data Collection. After the questionnaire and the procedural competency test underwent expert validation, the next stage was data collection, which involved distributing them to target respondents via email and the biology lecturer's WhatsApp group. This distribution began with an introduction of the researcher and the study's aim, as well as a request for permission and instructions for completion to ensure respondents understood. To increase the response rate and maintain data quality, follow-up was conducted with non-respondents via reminder emails and resends via the biology lecturer's WhatsApp group. A total of 10.7% of the data was collected from the questionnaires distributed over eight months.

Data Verification. After all the data had been collected (through questionnaire and procedural competency test), the next stage was data

verification through a focus group discussion (FGD). This FGD presented lecturers who directly apply and understand the research context, as well as mathematics lecturers specializing in logarithms who are competent in the mathematical principles underlying the index calculation. The main purpose of the FGD was to verify the interpretation of the data obtained and to ensure methodological accountability, particularly regarding the use of the Shannon-Wiener index. Thus, this FGD was the final step in data verification, ensuring that all data had been reviewed from a strong theoretical and mathematical perspective.

Instruments

The instrument used in this study was an open-ended questionnaire (a qualitative instrument) designed to explore lecturers' factual and conceptual knowledge dimensions through the cognitive process dimension at the analyzing level (C4) according to the Revised Bloom's Taxonomy. In the factual knowledge dimension, the questionnaire questions focused on the relevance of species as the unit of biodiversity measurement. Meanwhile, in the conceptual knowledge dimension, the questionnaire guided respondents to confirm the species diversity index used, focus on the Shannon-Wiener index, select and interpret its logarithmic base, and emphasize Effective Species Numbers.

Another instrument used in the study, as a quantitative instrument, was a procedural competency test (work steps) with the following indicators: use of logarithmic base, interpretation of Shannon-Wiener index value, calculation of the conversion of Shannon-Wiener index value to Effective Species Numbers, and comparison of the linearity of Effective Species Numbers. Data from this quantitative instrument reinforced the results obtained from the qualitative instrument. Validation of these instruments (questionnaire and procedural competency test) involved three

validators with knowledge of biodiversity and expertise in research instrument assessment. There were no notes from the validators to revise, and these instruments were ready to be used directly for study.

Data Analysis

Data analysis in this study was conducted in four stages: qualitative data analysis, quantitative data analysis, data integration, and drawing conclusions and verification. The qualitative data analysis steps consisted of: 1) organizing the data, collecting all questionnaire responses and transcribing them into analytical format to ensure consistency and readability, 2) reading and memoing, involved thoroughly reading the data to gain an initial understanding of emerging patterns/concepts, accompanied by recording reflective memos as a basis for categorization, and 3) describing, classifying, and interpreting (coding & theming), involved identifying meaningful parts (creating codes) from respondents' answers, then grouping the codes into themes/categories that represented the answers to the research questions.

The quantitative data analysis stage involved examining the procedural competency test, with results expressed as percentages to complement the qualitative data. In the data integration stage, the analysis was carried out by entering quantitative data into a qualitative framework that described the relationships between themes and the main themes, resulting in a concept diagram (concept map). The final stage, drawing conclusions and verification, namely presenting the results of the integration analysis in tabular form to ensure that the main themes generated were consistent with the theoretical framework and the FGD verification results.

■ RESULT AND DISCUSSION

This section presents the results and discussion, focusing on lecturers' knowledge of

the Shannon-Wiener index and Effective Species Numbers across two dimensions: factual and conceptual. The results are formulated to answer two research questions, namely how the lecturers' factual knowledge is reflected through their competency to focus on the relevance of species as a unit of biodiversity measurement, and how the lecturers organize conceptual knowledge related to the use and meaning of the logarithmic base of the Shannon-Wiener index and the Effective Species Numbers in the interpretation of biodiversity.

Based on qualitative data analysis from open-ended questionnaire, respondents' answers to two research questions based on factual and conceptual knowledge indicators gave rise to 7 themes, namely 1) taxonomic validity, 2) varied study objects, 3) Shannon-Wiener index dominance, 4) Shannon-Wiener index preference, 5) natural logarithm (ln) preference, 6) understanding of scale and proportion, and 7) emphasis on Effective Species Numbers. Themes 1 and 2 emerged from the indicator of species' relevance as a unit of measurement for factual knowledge. Themes 3 to 7 are themes for conceptual knowledge. Theme 3 is based on the indicator confirming the diversity index used. Theme 4 is based on the indicator of the use of the Shannon-Wiener index. Themes 5 and 6 are based on the choice and meaning (interpretation) of the logarithmic base. Theme 7 emphasizes the Effective Species Numbers. The exposition of each theme is as follows.

Theme 1: Taxonomic Validity

Taxonomic validity ensures that units counted in the field correspond to biological reality. Without clear species boundaries, biodiversity data loses its meaning. Respondents' answers to Theme 1 revealed two subthemes: absolute relevance and ease of classification.

Absolute Relevance. Species are highly relevant because they serve as universal standards

in scientific communication. In measurements, identification to the species level is crucial because each species has a unique ecological role (niche). Ignoring small differences between species can lead to fatal errors in population estimates and environmental carrying capacity.

Ease of Classification. In the field, species identification generally relies on visible morphological characters (such as body shape, size, color, leaf/flower structure, and behavioral patterns). These characters can be quickly recognized through experience, simple identification keys, or field guides, allowing for real-time grouping of specimens.

Theme 2: Varied Study Objects

Using species as the basic unit enables the broad application of the Shannon-Wiener index. Although data collection methods differ, the units calculated remain species richness and relative abundance. It shows that species are a universal "currency" in ecology, enabling comparisons across kingdoms. The species used by respondents in their research can be grouped into two subthemes: flora (from phytoplankton to forestry plants) and fauna (zooplankton, benthos, coral reefs, and bats/mammals).

Theme 3: Shannon-Wiener Index Dominance

The Shannon-Wiener index has dominated the global literature due to its ability to balance species richness and evenness (Krebs, 2009). The Shannon-Wiener index has become a standard in biodiversity research due to its non-parametric nature, meaning it does not assume a specific distribution within a population. The Shannon-Wiener index's dominance in research is well-founded; it is a reliable tool for testing. However, data confirmation will be much stronger when supported by other indicators, such as the Importance Value Index (IVI), for analyzing the internal dynamics of a study object. Therefore,

the subthemes that emerged from Theme 3 are the standard (Shannon-Wiener index) and the combination (Shannon-Wiener index + IVI).

Theme 4: Shannon-Wiener Index Preference

In scientific literature, the choice of measurement tools is often influenced by academic tradition. Researchers tend to use the Shannon-Wiener index because most previous research databases employ it. Furthermore, the habit of using the Shannon-Wiener index is based on its competency to capture aspects of evenness. Researchers feel safer using this index because it gives rare species greater weight. Thus, the habit of using the Shannon-Wiener index becomes a subtheme for Theme 4.

Theme 5: Natural Logarithm (ln) Preference

In ecological calculations, numbers are not simply calculations, but representations of biological structures. One technical but crucial debate concerns the choice of logarithmic base (Jost, 2006; Tuomisto, 2010; Chao et al., 2020). While, in theory, the Shannon-Wiener index can use either \log_2 (bits) or \log_{10} (decibels), the natural logarithm (ln, base e) has become the de facto standard worldwide. Theme 5 gave rise to two subthemes: consensus on the use of ln (base e) and convenience & habit.

Consensus on the Use of ln (Base e). Global scientific consensus has established ln as the standard base for the Shannon-Wiener index formula. This consensus is based on the work of pioneers such as Shannon (1948) and Margalef (1958), who observed that natural population growth often follows an exponential pattern, making the natural logarithm the most suitable mathematical “match” for biological phenomena. In base e, diversity values are expressed in nat units.

Convenience and Habit. Beyond theoretical reasons, there are practical factors that reinforce the preference for ln, the default function in almost

all statistical software. Using other bases would require additional conversion steps, which could introduce calculation errors.

Theme 6: Understanding of Scale and Proportion

Behind the numbers provided by the Shannon-Wiener index lies a deep understanding of scale and proportion. This understanding is crucial so that researchers do not get caught up in the mere number of species but also consider how the distribution of individuals among those species is proportioned. Theme 6 **brought out** two subthemes based on respondents' answers: unitless and evenness indicator.

Unitless. One of the unique characteristics of the Shannon-Wiener index is its unitless nature, meaning it lacks physical units (such as meters or grams) and serves as an abstract measure of information (Daly et al., 2018). Although expressed in nat units (when using ln), in practice, the number functions as a relative index score (Morrison & Rosenberg, 2023). This provides researchers with the flexibility to view community proportions without being burdened by differences in the physical size of the organisms being studied.

Evenness Indicator. The logarithm in the Shannon-Wiener formula measures the proportion of abundance (π). This makes this index a highly sensitive indicator of evenness. The use of logarithms ensures that the addition of new species contributes differently to the index value depending on their relative abundance.

Theme 7: Emphasis on Effective Species Numbers

Although the Shannon-Wiener index is widely used, the values it yields are often abstract and difficult to visualize in real ecological contexts (Tuomisto, 2010; Gatti et al., 2020; Roswell et al., 2021). To address this, the concept of Effective Species Numbers, often referred to as

true diversity, emerged. However, the transition to this concept created a gap in understanding among researchers. Consequently, respondents' answers emerged with two subthemes: understanding the Effective Species Numbers and not understanding (a new/unheard-of concept).

Understanding the Effective Species Numbers. Researchers who understand the Effective Species Numbers realize that the Shannon-Wiener index value needs to be converted back to understandable units, namely the "number of species," calculated by exponentiating the Shannon-Wiener index value (H_2). If a location has $H_2 = 2.3$, then the Effective Species Numbers is $e^{2.3H} \times 10$, meaning the diversity of the location is equivalent to a community with 10 species with a perfectly even number of individuals.

Not Understanding (New Concept/Never Heard of). There is a group of researchers who are unfamiliar with the Effective Species Numbers because this concept is considered more modern in the ecological literature (it began to gain widespread popularity after Jost's work in 2006). Researchers in this group tend to report only raw index numbers, without explaining the quantitative significance of the changes. They may see a small increase in the Shannon-Wiener index (H_2) from 2.0 to 2.3, even though the effective diversity has increased significantly.

Of the seven themes, four subthemes emerged for factual knowledge and nine subthemes for conceptual knowledge. The percentage occurrence of each subtheme, based on the total number of respondents, is shown in Figure 1.

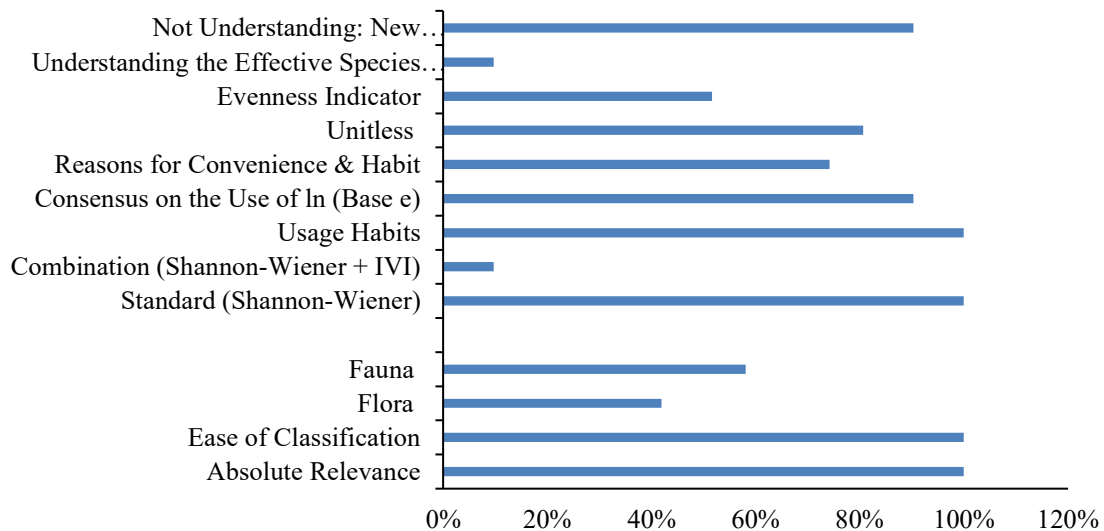


Figure 1. Percentage of occurrence of each subtheme based on the total number of respondents. (Note: Absolute relevance, ease of classification, flora, and fauna are subthemes for factual knowledge. Standard (Shannon-Wiener index), combination (Shannon-Wiener index + IVI), habitual use of Shannon-Wiener index, consensus on use of ln (base e), reasons for convenience & habitual use, unitless, evenness indicator, understanding the Effective Species Numbers, and not understanding (new/unheard concept) are subthemes for conceptual knowledge)

Furthermore, the results of the quantitative analysis of the procedural competency test, which reinforce the seven themes identified in the qualitative data, are displayed in Table 2. The results of the procedural competency test conducted among respondents revealed a

contrasting pattern of mastery between the operational technical aspects and the advanced interpretive aspects.

Table 2 shows that the majority of respondents (90.3%) have strong procedural skills using the natural logarithm (ln). This is in

Table 2. The results of the respondents' procedural competency test

No.	Procedural Competency Indicator	Percentage of Respondents' Answers
1	Using the natural logarithm (ln) (base e)	90.3%
2	Interpreting the Shannon-Wiener index as a measure of community stability	80.6%
3	Calculating the conversion of the Shannon-Wiener index to Effective Species Numbers	12.9%
4	Comparison of the linearity of Effective Species Numbers	12.9%

line with the lecturer consensus data stating that the use of base e has become the standard due to its ease of calculation. However, there were significant findings regarding respondents' competence in interpreting the calculation results. Although 80.6% of respondents understood that the Shannon-Wiener index reflects community stability, their ability to translate the data into a more readily applicable form of understanding remained very limited. This is clearly evident in the low percentage of respondents (12.9%) who answered the procedure for converting Shannon-Wiener index values to Effective Species Numbers.

Theoretically, failure to convert to Effective Species Numbers leads to poor analytical accuracy across communities. Test results indicate that most respondents struggled to compare two research sites linearly, focusing solely on small differences in Shannon-Wiener index values, without realizing that ecologically, these differences can represent up to a twofold difference in species richness. This finding confirms that current field biodiversity calculation procedures often focus on abstract index numbers.

Based on the dominant pattern and variation of respondents' answers in Figure 1 and respondents' procedural competency in Table 2, it is clear that species are understood as relevant units across contexts, reflecting universal taxonomic validity, as well as a strong reliance

on methodological conventions such as the standard Shannon–Wiener index and the use of a specific logarithmic base. However, the emergence of pragmatic reasons (habit, convenience, unitless) alongside a low level of understanding of Effective Species Numbers indicates limited mathematical-biological literacy in linking the index's meaning to ecological interpretation. Overall, this pattern indicates a disparity in understanding advanced concepts: methods are well established, but deeper conceptual meanings are not yet evenly distributed. Thus, universal taxonomic validity, methodological conventions, mathematical-biological literacy, and disparity in understanding advanced concepts (Effective Species Numbers) are four main interrelated themes, illustrated in Figure 2.

Universal Taxonomic Validity: This theme emerged from the consistency of respondents' answers on the dimension of factual knowledge regarding the object of study. The analysis showed that, amid the development of genetic technology, the species-based approach remains the most relevant and fundamental unit of measurement. Respondents from various study backgrounds (general biology, forestry, herpetofauna, and mammals) agreed that species are the main “currency” in ecology. This finding confirms that mastery of classical taxonomy remains a crucial factual competency. The variety of respondents' study objects shows that, although the objects

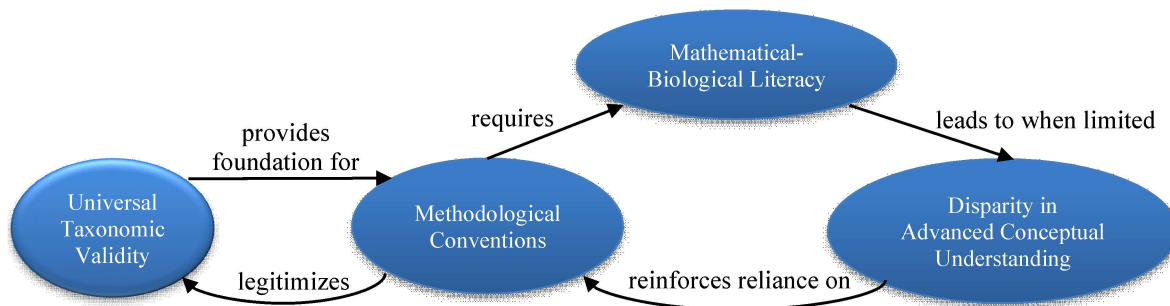


Figure 2. The interrelationship of four main themes: universal taxonomic validity, methodological conventions, mathematical-biological literacy, and disparity in understanding advanced concepts (Effective Species Numbers)

differ, their taxonomic framework is uniform. Respondents view species not merely as labels, but as valid operational units for measuring biodiversity, including ecosystem health. However, Reydon (2019) suggested adopting a broader, pragmatic approach that considers diversity at genetic and ecosystem levels rather than focusing solely on species counts.

Methodological Conventions, in the conceptual dimension related to the use of measurement tools, showed a pattern of “hegemony” or dominance of the Shannon-Wiener index based on the natural logarithm (\ln). Almost all respondents confirmed that they used this index as the standard for their research. The reasons behind this choice tended to be pragmatic and textbook-oriented. The use of the natural logarithmic (\ln) base was chosen because of its ease of teaching and its suitability with the general literature used by students. This dominance indicates a standardization of methods among researchers. However, this consistency can also be interpreted as a form of methodological convenience, in which researchers tend to use established methods rather than explore alternative indices, unless combined with the Importance Value Index (IVI) or other diversity measurement indices.

Mathematical-Biological Literacy, respondents understood that the choice of logarithmic base (whether base 2, 10, or e) for

the Shannon-Wiener index was simply a matter of scaling and did not change the essence of the observed biological phenomena, and that the index was unitless. Respondents’ competency to articulate the concepts of unitlessness and scaling was based on their understanding that the index represents proportions. This understanding was technically correct due to the monotonicity property the rank order of diversity across locations remains unchanged.

Disparity in Understanding Advanced Concept (Effective Species Numbers): A significant divergence occurred when respondents were asked about the concept of Effective Species Numbers. The data divided respondents into two groups: the Awareness Group and the Knowledge Gap Group. The Awareness Group understood that entropy indices (such as the Shannon-Wiener index) are difficult to interpret directly and require conversion to Effective Species Numbers to assess “true diversity” by accounting for dominance. In the Knowledge Gap Group, some respondents acknowledged that this concept was new to them, suggesting that Effective Species Numbers (or Hill Numbers) have not been fully integrated into their curriculum or routine research practices. This gap indicates a transition point in respondents’ development of ecological science. While the concept of Effective Species Numbers has become a global standard in the last decade (popularized by Jost (2006)),

some local researchers are still fixated on the value of the Shannon-Wiener index. These findings suggest the need for educational interventions or training to update researchers' understanding from simply calculating the Shannon-Wiener index (entropy index) to understanding the "linear biological meaning" through Effective Species Numbers.

The four main themes not only describe respondents' tendencies in understanding but also

relate them to theoretical foundations, clarifying the quality and depth of the demonstrated knowledge. Respondents' understanding tendencies across these four themes were verified through a focus group discussion (FGD) to ensure the data were viewed from robust theoretical and mathematical perspectives (Table 3).

Factual knowledge is the foundation for conceptual knowledge. Factual knowledge (facts, terminology, basic elements) must first be

Table 3. Verification of lecturers' understanding based on four main themes

Lecturers' Knowledge in Using Shannon-Wiener Index and Effective Species Numbers	
Main Theme	Verification through FGD
Factual Knowledge	
Universal Taxonomic Validity	Consistent with respondents' answers, species remain relevant as a basis for measuring biodiversity because the population condition of certain species reflects the overall condition of the ecosystem, including the presence of bioindicator or keystone species.
Conceptual Knowledge	
Methodological Conventions	In line with the respondents' answers, the use of the Shannon-Wiener index based on natural logarithms is the most frequently used because it is pragmatic and textbook-oriented. However, it needs to be combined with the Importance Value Index (INP) or other diversity measurement indices.
Mathematical-Biological Literacy	The respondents' understanding is technically correct due to the monotonicity property. However, mathematically and comparatively, the choice of logarithmic base significantly changes the absolute value and units of the Shannon-Wiener index. Without standardizing the logarithmic base, research results are incomparable.
Disparity in Understanding Advanced Concept (Effective Species Numbers)	There is still limited research in Indonesia that uses Effective Species Numbers to assess biodiversity. Effective Species Numbers are interpreted as Hill Numbers.

understood before it can be categorized, connected, or integrated into larger concepts. Conceptual knowledge then uses these facts to understand the relationships between concepts, theories, and classifications. Based on the results of verification through FGD (Table 3), factual knowledge in the form of universal taxonomic validation (species as a unit of measurement for biodiversity) forms the basis of the respondents' (lecturers) conceptual knowledge, which includes

methodological conventions, mathematical-biological literacy, and disparity in the concept of Effective Species Numbers.

Factual Knowledge: The Relevance of Species as a Unit of Measurement

The FGD results confirmed that species remain the fundamental unit of biodiversity measurement. This aligns with the global ecological consensus that species diversity is the

fundamental currency of conservation biology. The use of certain species as proxies for ecosystem condition, as mentioned in the FGD results, is supported by the concepts of bioindicators and keystone species. According to Magurran (2004), diversity measurement is not simply about counting entities, but also about understanding their biological roles. Indicator species provide a quick indication of environmental health, validating why the species-based approach to taxonomy is still maintained by lecturers amidst the emergence of phylogenetic or functional approaches.

Conceptual Knowledge: Pragmatism in Methodological Conventions

Regarding the use of the Shannon-Wiener Index, the findings indicate a pragmatic, textbook-oriented tendency to use the natural logarithm (\ln) base. This is understandable because most ecological software and standard textbooks in Indonesia use the natural logarithmic (e) base. However, the FGD validation highlighted the importance of combining the Shannon-Wiener Index with the Importance Value Index (IVI). This is supported by Spellerberg & Fedor (2003), who stated that a single index cannot capture the complexity of biological communities. The Shannon-Wiener index is more sensitive to rare species, while the IVI provides an overview of dominance and density. Therefore, the multi-index approach suggested by respondents is an appropriate methodological step to avoid interpretation bias.

Conceptual Knowledge: Mathematical-Biological Literacy (Implication of Logarithmic Bases)

A crucial point in Table 2 concerns mathematical literacy regarding the base of logarithms. Respondents are technically correct that monotonicity is maintained meaning, the ranking order of diversity between sites will

remain unchanged whether using base 2, 10, or e (natural). However, in absolute terms, the difference in base changes the units of the index (entropy units):

- a. The natural logarithm (\ln) produces units of nats.
- b. The base 2 logarithm (\log_2) produces units of bits.
- c. The base 10 logarithm (\log_{10}) produces units of decits.

Without standardization, Shannon-Wiener index (H_2) values become incomparable across studies. Jost (2006) strongly criticized this practice, stating that many ecological researchers treat entropy values as if they were values of diversity itself, even though the mathematical units are different. These findings underscore the need to strengthen mathematical literacy among lecturers to prevent them from becoming trapped in routine calculations without understanding their mathematical implications. This can lead to systemic misconceptions about the meaning of H_2 and the concept of diversity itself something Strong (2016) and several modern ecologists have warned about.

Conceptual Knowledge: Disparity in Understanding Advanced Concept (Effective Species Numbers)

The most significant finding is the minimal use of Effective Species Numbers or Hill's Numbers in Indonesia. In fact, in modern ecological literature, the use of the Shannon-Wiener index as a measure of diversity is considered biased due to its non-linear nature. According to Hill (1973) and re-popularized by Jost (2006), Effective Species Numbers converts an abstract entropy value into the number of equivalent species in a hypothetical community. The fact that respondents rarely use this concept indicates a gap between the development of global theoretical ecology and teaching or

research practices at the local level. Adopting the Effective Species Numbers is crucial because it fulfills the doubling property (if a community is doubled, diversity values should double), which the Shannon-Wiener index does not.

The following is evidence supporting the assertion that most ecology software and standard textbooks in Indonesia use the natural logarithm (ln) or the base-e logarithm.

Evidence from Standard Software

The most authoritative ecological data analysis software, frequently referenced internationally and by researchers in Indonesia, tends to use the natural basis (e) as the default setting. One example of such software is the vegan (vegetation analysis) package in the R statistical programming language. Technically, the “diversity()” function in R has a default setting of “base=exp(1),” which means it uses the natural logarithm (ln) unless the user changes it. Another example is Microsoft Excel. Many students and lecturers in Indonesia perform manual calculations using Excel. Formulas taught in practical modules generally use the “=LN()” function, not “=LOG10()” or “=LOG(..., 2).”

Evidence from Indonesian Textbooks

In Indonesia, references on ecology teaching are dominated by a few key books, all of which define the Shannon-Wiener formula using ln. Citations from these books are frequently found in Chapter 3 (Research Methods) of undergraduate biology/forestry student theses in Indonesia.

Eugene P. Odum’s *Dasar-dasar Ekologi* (translated by Tjahjono Samingan) is the primary reference in almost all universities in Indonesia. In this book, although Odum discusses information theory, the practical formula that students often cite is to use ln or convert to it to obtain a consistent value with reference table.

The book *Metode Ekologi untuk Penyelidikan Ladang dan Laboratorium*

(translated by P. Michael, UI-Press) consistently uses ln as the formula.

Evidence for Pragmatism: The Criteria of “Value 1 to 3”

The strongest evidence of the textbook-oriented nature is the use of uniform diversity index assessment criteria throughout Indonesia without questioning the basis of the logarithm. Nearly all theses and research reports in Indonesia use the following benchmarks to interpret Shannon-Wiener index (H_2) values:

- a. $H_2 < 1$: Low Diversity
- b. $1 < H_2 < 3$: Moderate Diversity
- c. $H_2 > 3$: High Diversity

This range of values is only valid when using the natural logarithm (ln). If researchers use the base-2 logarithm (log₂), the maximum value for a community with just 10 species is 3.32 bits, and for 100 species it is 6.64 bits. If the criteria “1–3” above were forced into a base 2 calculation, nearly all ecosystems would be assessed as having “High Diversity,” which is clearly a misinterpretation. The consistent use of criteria “1–3” proves that, consciously or not, academics in Indonesia have locked themselves into using the natural basis (e) for practicality (pragmatism) to comply with the standard criteria in textbooks.

This study implies the need to strengthen academic capacity and update the ecology curriculum so that it focuses not only on traditional entropy index calculations but also integrates biological interpretations through Effective Species Numbers to minimize bias and improve the accuracy of biodiversity understanding. Furthermore, these results can encourage greater mathematical literacy in science education, particularly in understanding the consequences of using different logarithmic bases, thereby enabling more valid comparisons of research results. The following are specific, practical recommendations that can be implemented immediately to strengthen

academic capacity, update the ecology curriculum, and improve mathematical literacy in science education (ecology education).

Training/Workshop Model: Ecological Data Transformation (From Abstract Index to True Diversity)

A visualization workshop, which trains lecturers using case simulations to calculate the same data using three different bases (\ln , \log_{10} , and \log_2), then demonstrates that even though the H_2 values differ, the results are identical after being converted to Effective Species Numbers using the appropriate exponent formula. The workshop also trains lecturers to create comparison graphs between research locations using Effective Species Numbers, enabling them to visually see that a small difference in the H_2 index (e.g., from 1.5 to 2.2) actually represents a drastic linear increase in diversity.

Narrative interpretation module, which provides practice in constructing narratives for research reports that are more intuitive for policymakers, for example: “This forest has a richness equivalent to 20 effective species” rather than simply “The H_2 value is 2.9.”

Integration into the Curriculum (Ecology Course and Relevant Courses)

Update on the vegetation analysis practicum module by adding a mandatory column to the results table: “Effective Species Numbers” column in the index calculation chapter. Students are required to complete the final step: converting the Shannon-Wiener index to Effective Species Numbers, depending on the logarithmic base used.

Comparative case studies, by assigning students to compare two communities with nearly identical H_2 values (e.g., 1.8 and 2.1). Students are asked to explain, based on Effective Species Numbers, why the second location has a much higher level of diversity. This aims to practice the previously lost linear logic.

Alignment of exam questions by including a higher-order thinking skills (HOTS) question that asks: “If an area undergoes restoration and the H_2 value increases from 1.0 to 2.0, how many times will the number of effective species be restored?” (Answer: $e^2/e^1 H^*$ 2.7 times).

CONCLUSION

The results of the study indicate that lecturers’ knowledge regarding the use of the Shannon-Wiener index and Effective Species Numbers is reflected in two dimensions of knowledge: factual and conceptual. In the factual dimension, lecturers emphasized that species remain the basic and most relevant unit in measuring biodiversity, regardless of the variety of study objects. In the conceptual dimension, the dominant use of the Shannon-Wiener index, based on the natural logarithm (\ln), is a methodological standard that is both pragmatic and textbook-oriented. However, there is a knowledge gap regarding the advanced concept of Effective Species Numbers, with many respondents unfamiliar with it, indicating a disconnect between the development of modern global ecology and local research practices. This finding is important because it illustrates the quality of lecturers’ mathematical-biological literacy and the need to update the concept of diversity in ecological education.

Based on the finding regarding the disparity in knowledge, the strategic steps are needed to align lecturers’ understanding with modern ecological standards through the following practical recommendations: 1) training/workshop (transformation of ecological data from abstract indices to true diversity) through: a) visualization workshop to train lecturers with case simulations in calculating the same data with three different bases and train lecturers to create comparison graphs between research locations using Effective Species Numbers values that visually show that small differences in the H_2 index actually represent a drastic linear increase in diversity, and

b) narrative interpretation module as exercise in composing narratives of research reports that are more intuitive for policy makers, and 2) integration into the curriculum (ecology course and relevant courses) through: a) updating the vegetation analysis practicum module by adding an Effective Species Numbers column in the results table in the index calculation chapter, b) training students' linearity logic by comparing two communities that have almost similar H2 values but it turns out that the two communities have very different levels of diversity based on the concept of Effective Species Numbers, and c) aligning exam question by including higher-order thinking skills (HOTS) type questions in the form of interpretation of H' values that aligned with Effective Species Numbers.

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■ DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the writing of this manuscript, the authors employed ChatGPT and Google Gemini to code respondents' answers and visualize relationships among the main themes. The authors also employed Google Translate and Grammarly to improve the quality of English writing. The authors have reviewed and edited the content

generated by these tools and assume full responsibility for the content of the published article.

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