

Article

Phytosociological Research and Meaningful Learning: Constructivist Approaches for Teaching Vegetation

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Abstract: Phytosociology reached its peak development during the 20th century, particularly after 1992 with the implementation of the EU Habitats Directive, which incorporated plant associations into habitat classifications. The objective of this study is to assess the diversity of Mediterranean grasslands using the phytosociological methodology, focusing specifically on the PBTs and BsHl associations. Although both types of grasslands are of interest for livestock farming, we emphasize those belonging to *Poetea bulbosae* (PbTs), which are included in the priority habitat 6220 and are of high value for sheep grazing. The results indicate that $V_{ca-Vco} = 0.390$ for PBTs and 0.525 for BsHl, the latter due to the absence of companion species diversity in BsHl. A strong linear correlation was observed for both associations, with $R^2 > 0.8$ for PbTs and $R^2 > 0.9$ for BdHl. Given the importance of grassland diversity research, its teaching should be predominantly practical and conducted outside the classroom. To achieve this, an inquiry-based constructivist methodology is employed, which is particularly suitable for learning the phytosociological method, allowing students to take ownership of their learning process. The aim of this teaching approach is to expose students to field research methodologies, enhancing their scientific training. The results are highly positive, with a 100% success rate in students’ comprehension of the two grassland types after the teaching-learning process.

Keywords: association; grasslands; diversity; learning; holistic; botany; ecology



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1. Introduction

1.1. Phytosociological Background

Various methodologies have been developed to study vegetation and its associations. Humboldt’s physiognomic-ecological perspective, combined with subsequent contributions from other researchers, has significantly influenced the epistemological foundations of modern Vegetation Science and Phytosociology. Since Grisebach introduced the concept of “formation” in 1838, it has primarily been maintained within a physiognomic context. During the 1910 International Botanical Congress in Brussels, plant formation was defined as the “expression of specific living conditions, organized by associations differing in floristic composition but coinciding in seasonal conditions and biological forms”.

Phytosociology, an ecological science derived from Geobotany, focuses on the study of phytocoenoses—plant communities—by examining their floristic composition, environmental relationships, biogeographical distribution, and temporal dynamics. By synthesizing

these data through inductive and statistical methods based on phytosociological inventories, a universal hierarchical typology is established [1]. This typology facilitates the identification of plant associations, which represent the fundamental units of the system. Each association must demonstrate characteristic and differential species that are statistically faithful to specific environments, assuming a stabilized succession within which the association exists. Furthermore, every association is embedded within a hierarchical system encompassing alliance, order, and class [2].

Acquiring this knowledge is essential for developing specialized scientific competencies [3,4].

Throughout the 20th century, European phytosociological knowledge expanded significantly due to intensive research efforts. Phytosociological research has been published in hundreds of articles, as noted by Ivanova [5]. This author highlights 1168 articles based on Braun-Blanquet's methodology, and among the 187 references on vegetation studies, we emphasize the contributions of prestigious researchers such as Biondi, Blasi, Braun-Blanquet, Guinochet, Rivas-Martínez, Mucina, Tüxen, and Van der Maarel, demonstrating the continued relevance of phytosociology today.

Based on floristic composition, distribution, and ecological factors, two major groups of plant communities can be distinguished:

1. Non-endangered habitats: Communities with broad distribution, lacking endemic or rare species, and not under significant threat.
2. Fragile habitats: Communities with limited distribution, endemic species, or unique synecology, which are highly susceptible to degradation or disappearance, necessitating conservation measures.

This phytosociological methodology is applicable to any plant community. In this study, the focus is on grasslands, which are of particular interest for livestock farming and as CO₂ sinks. Grassland research should be recognized and supported globally due to its substantial cultural, educational, and economic value. Understanding grassland ecology, dynamics, and diversity is crucial for sustainable local development and highlights the importance of these ecosystems as valuable societal resources.

As with plant associations, the criteria for diagnosing higher-rank syntaxa—such as alliances, orders, and classes—are based on the principle of fidelity. Consequently, characteristic and differential species can also be identified at these higher taxonomic levels.

The alliance represents the rank immediately superior to the association and encompasses similar plant associations defined by characteristic species of the alliance. These species are typically absent or occur with low abundance in other alliances, reflecting distinct ecological niches. Within an alliance, species may be classified as characteristic, transgressive, differential, or introgressive. Additionally, associations with diverse ecological traits can coexist within the same alliance.

Floristically similar alliances are grouped into orders, which, in turn, are aggregated into vegetation classes. The characteristic species of a class possess broad ecological amplitude, making them less stenotopic than species associated with lower-rank syntaxa.

Sinphytosociology represents an entirely new discipline. Although its conceptual foundations have been recognized since the early 20th century, contemporary phytosociologists have systematically developed the principles of community integration as a defining feature of the landscape. Key contributors to this field include Braun-Blanquet, Tüxen, Bolós, Gèhu, and Rivas-Martínez, who pioneered the philosophical underpinnings of this innovative methodology for landscape analysis [6].

Since its inception, numerous authors have further refined and expanded this methodology [7–11]. The concepts of sigmetum, sinassociation, and vegetation series are intrinsically linked to territorial climate conditions, rendering vegetation series inherently

climatophilous in nature [12,13]. Each vegetation series is characterized by a unique dynamic-catena process [14], with the climax stage representing the territorial climax, determined by the interplay of thermoclines and ombroclimatic conditions. For example, territories may support rainforests when water availability depends on rainfall. Conversely, when water availability is driven by soil conditions, the series is classified as edaphophilous. These are further subdivided into edaphohydrophilous series (e.g., riparian ecosystems) or edaphoxerophilous series (e.g., communities on rocky outcrops) [15].

In this study, we examine the exceptional diversity of grasslands in Mediterranean climates, which constitute a vital resource for humanity. These ecosystems support diverse livestock systems, with specific animal species depending on particular grass types. This interdependence underscores the ecological and economic value of grasslands as a key ecosystem service [16].

Our analysis focuses on the ecology, dynamics, floristic composition, and diversity of various grassland types, situating them within broader grassland classifications. Particular attention is given to their role as EU-designated habitats, including subnitrophilous and nitrophilous grasslands dominated by *Trifolium*, *Medicago*, *Taeniatherum*, *Hordeum*, and *Poa bulbosa* communities. These grasslands are especially significant for sheep farming, contributing substantially to grazing value and sustainable livestock systems [10,17].

Subnitrophilous-nitrophilous grasslands are widespread in dehesas and agricultural landscapes. However, in agricultural settings, these grasslands are often heavily modified due to herbicide application. To address this, several authors advocate for enhanced rural education within agricultural environments, emphasizing the importance of understanding natural resources and adopting a more practical, outdoor-focused approach to education [18–23].

Subnitrophilous grasslands and manure-enriched meadows, where approximately 50% of the botanical families belong to Fabaceae and Poaceae, hold significant grazing value. These grasslands are particularly suited for cattle, deer, and horse grazing due to their structural characteristics and high biomass/biovolume, which align well with the oral systems of these animals. Moreover, they act as effective CO₂ sinks, contributing to climate change mitigation efforts [24].

A noteworthy case involves grassland communities dominated by *Poa bulbosa*, *Trifolium subterraneum*, *Biserrula pelecinus*, and *Astragalus sesameus*, classified under the EU's Habitat 6220. While these species are valuable for grazing, their limited biomass/biovolume makes them primarily suitable for sheep. These grasslands, along with other communities, form the structural foundation of Spanish dehesas and Portuguese montados, classified as Habitat 6310. This habitat, protected under EU regulations, represents a sociocultural and economic system shaped by historical land-use practices [25].

The main objective of this research is to highlight the diversity of Mediterranean grasslands, establish a relationship between the type of grassland and the type of livestock, and propose the phytosociological method for their study.

1.2. Vegetation Education

This study aims to enhance vegetation education through the application of the phytosociological method. Originally developed in Central Europe and now widely applied across European countries, this method plays a pivotal role in diagnosing and assessing habitats. Such knowledge is crucial for environmental managers and educators to foster behaviors that support sustainability and promote environmental education [26–28].

Vegetation studies have reached their greatest advancement in Europe, primarily through the efforts of the Central European school of phytosociology, culminating in initiatives such as the EU's Habitats Directive 92/43 [29]. This highlights the importance of

integrating such knowledge into educational curricula at all levels. García Barros et al., Cañas, and Cañas et al. [3,4,30] have emphasized the role of environmental activities in promoting scientific competencies among students. Similarly, Miño et al. [31] advocate for the inclusion of biological texts in education to enhance the comprehension of ecological principles. They further stress the importance of training future educators in these critical subjects [32,33], particularly in addressing urgent global challenges such as climate change [34–36].

The effectiveness of environmental education is influenced not only by the context in which it is delivered but also by the level of environmental literacy that students attain. As Da Silva et al. [37] argue, understanding habitats requires an interdisciplinary approach.

The development of phytosociology necessitates integrating knowledge from diverse disciplines, including soil science, climatology, physical-chemical factors, floristics, and even artistic elements. This interdisciplinary framework equips students with a comprehensive education, embodying a holistic approach that prepares them for meaningful integration into cultural, educational, and socioeconomic contexts [38].

Holistic education emphasizes empowering students to take ownership of their lives [39,40]. It seeks to achieve the integral formation of individuals across multiple dimensions: biological, ecological, psychological, and sociological. Recent advancements in this paradigm incorporate cognitivism, aligning it with contemporary constructivist principles [41]. This approach promotes the development of students' full potential and supports comprehensive education and human development [42].

Rivas et al. [43] highlight the necessity of educating university students on sustainability, climate change, and ecosystem services through a holistic lens. A significant gap exists in students' understanding of ecosystem services [44], which translates into broader societal challenges, including food insecurity [45]. Everjoy et al. [46] link reduced rainfall in semi-arid regions, as a consequence of climate change, to increased poverty, advocating for educational campaigns to raise awareness among farmers about these impacts [47]. Vilches and Gil-Pérez [48] similarly argue that sustainability education must be a critical objective in addressing the ongoing environmental crisis.

Within this framework, discovery-based inquiry methodologies enable students to tailor their learning experiences, fostering active participation and personal investment in their educational journey [49]. This paradigm not only prepares students to understand complex environmental systems but also equips them to contribute meaningfully to sustainability efforts and societal progress. The aim of this teaching approach is to promote the transmission of the research methodology on vegetation to students, using an essentially practical inquiry methodology. For this purpose, we apply constructivist theory, as the teaching of the phytosociological method is ideal for this teaching model.

2. Materials and Methods

2.1. Analysis of the Phytosociological Research Method

The phytosociological methodology was employed to study vegetation associations, with a particular focus on the alpha and beta diversity of the *Trifolio subterranei*–*Periballion* communities (*Poo bulbosae*–*Trifolietum subterranei*, PbTs) and *Hordeion leporini* communities (*Bromo scoparii*–*Hordeetum leporini*, BsHl) [50–53], as well as their conservation status. The Shannon diversity index was applied to evaluate the diversity of characteristic species (Ca), companion species (Co), and scenarios where the association comprised only two characteristic species (Ca2). Indices calculated include Shannon_Ca, Shannon_Co, Shannon_Ca2, and Shannon_Ca-Co (the difference between characteristic and companion diversity). This last index provides insights into the dynamics and conservation status of the associations.

Given the ecological significance of these vegetation associations under the EU Habitats Directive 92/43, the dynamics of the associations were further analyzed through comparative assessments of the abundance and frequency of characteristic and companion species.

The phytosociological method involves two key phases:

1. Analytical Phase: This phase requires the meticulous selection of sampling plots to ensure homogeneity and representativeness.
2. Synthetic Phase: Data collected in the analytical phase are integrated to develop a comprehensive understanding of the plant community.

Sampling involves the delineation of homogeneous plots where the total coverage of the phytocoenosis is recorded. Coverage, expressed as a percentage, represents the proportion of soil covered by vegetation. Plot sizes vary according to the type of phytocoenosis and biome:

- Forests: Mediterranean zones require plot sizes of 300–500 m², while tropical and subtropical zones necessitate larger areas of approximately 1000–2000 m².
- Shrublands: Plot sizes range from 50–200 m².
- Grasslands: Optimal plot sizes are between 0.5–2 m².

The minimum area method is recommended to maximize floristic diversity within the smallest possible surface. For example, in a plot measuring 100 m², if 45 m² are covered by vegetation, the coverage degree is 45% [7,54,55].

2.2. Teaching the Phytosociological Method to Students

The teaching of these techniques is designed for university students, particularly those in Botany and Geobotany courses, as well as for future educators and environmental managers working within the framework of the EU Habitats Directive.

To evaluate the effectiveness of this educational intervention, a 17-question survey was administered to students of Botany (131 students) and Geobotany (12 students) before and after the instructional process. The survey included questions designed to assess the students' understanding of:

- The concept of vegetation associations.
- Methods for calculating diversity indices.
- The ecological and conservation implications of phytosociological studies.
- Practical applications of the EU Habitats Directive.

This approach not only facilitates the development of technical and analytical skills but also emphasizes the integration of ecological theory with practical conservation strategies. Questions posed to students before and after the teaching process included the following:

1. To what extent do you believe there is a relationship between diversity and conservation?
2. Do you think it is important to understand an ecosystem's diversity to assess its conservation status?
3. Do you consider that, in a plant community, a higher number of species indicates better conservation?
4. Do you know how to calculate the minimum area?
5. Do you know how to perform a phytosociological inventory?
6. Do you know how to calculate Alpha, Beta, and Gamma diversity?
7. What sciences are involved in the concept of biodiversity?
8. Define the concept of biodiversity.
9. Do you know the differences between characteristic and companion species?
10. Do you know what sustainable development means?
11. Define sustainable development.

12. The set of terrestrial ecosystems that, by sharing similar climatic conditions, host the same types of living beings is called?
13. What is the action plan to conserve biodiversity?
14. What is biodiversity?
15. How is biodiversity measured?
16. What are endemic species?
17. What is a biodiversity hotspot?

This study results from the application of field-based methodologies to university students, assessing their knowledge through the aforementioned questions. The focus is on fostering a deeper understanding of vegetation and stimulating observational skills by guiding students on how to conduct systematic observations and interpret their findings effectively.

Student motivation is heavily influenced by the instructor's ability to navigate natural settings, interpret ecological observations, and accurately convey the complexities of natural ecosystems. Observations must faithfully represent the ecological reality, ensuring that students grasp the key principles underlying biodiversity and conservation.

Practical, outdoor education has been widely advocated by various authors [21,56] for its ability to enhance hands-on learning and critical thinking. Fieldwork group sizes should not exceed 20 students to minimize distractions and maximize individual engagement with the proposed activities. Following field observations, group discussions are conducted to collectively interpret findings, fostering a collaborative learning environment.

As part of the learning process, students are tasked with creating diagrams or illustrations of the ecosystems where the studied vegetation associations occur. This exercise reinforces their ability to synthesize observations into visual representations, a critical skill in ecological studies.

The teaching methodology prioritizes student-centered learning, with the instructor serving as a motivator and guide. For students entering the program with limited foundational knowledge, often influenced by educational and social disparities, specific didactic strategies are employed. These include:

- Formulating new hypotheses.
- Conducting additional observations.
- Interpreting observed phenomena through "feedback" and "feedforward" mechanisms.

This approach aims to address knowledge gaps and preempt errors in reasoning, promoting a deeper understanding of ecological principles. Moreover, it underscores the importance of providing a robust foundational scientific education that extends beyond traditional classroom settings [57,58].

This methodology aligns with emerging trends in constructivist education, which emphasize active learning and the construction of knowledge. By integrating observational activities with group discussions and personalized feedback, students are equipped to critically engage with the complexities of biodiversity and sustainability. This holistic approach fosters not only academic competence but also the development of transferable skills essential for addressing real-world environmental challenges.

Practical sessions must be planned with the same meticulous care as theoretical classes, ensuring that students have opportunities to observe, analyze, and experiment independently. These sessions often represent students' first direct engagement with real-world laboratory and fieldwork, experiences that frequently ignite an interest in scientific research.

As highlighted previously, the ideal structure involves small groups of 15–20 students, with practical sessions running parallel to theoretical instruction. This approach fosters a close professor-student relationship, emphasizing critical observation and discussion. By applying theoretical principles to practical contexts, whether in the field or the laboratory,

students develop a more profound understanding of scientific concepts and sharpen their reasoning abilities. This dynamic reinforces the retention and application of knowledge while also improving the quality and depth of information through hands-on activities. Practical sessions thus serve as a vital component of scientific education, allowing students to experience firsthand the phenomena under study and acquire essential skills for their academic and professional development [18].

To ensure the effectiveness of practical sessions, students must understand the objectives and theoretical foundations of each activity beforehand. The instructor begins by delivering a brief introductory presentation that fosters dialogue and contextualizes the session's goals. Students then undertake independent and responsible work, conducting observations and recording their findings in practice notebooks under the instructor's supervision.

Fieldwork and laboratory activities proceed according to a carefully designed protocol that balances structure with opportunities for student exploration. Sessions conclude with a group discussion to critically analyze results, reinforcing the connection between observation, data interpretation, and broader scientific principles. This structured yet flexible methodology helps students internalize key concepts while encouraging active participation and critical thinking.

By integrating theoretical instruction with practical experiences, this pedagogical approach not only enhances learning outcomes but also cultivates students' confidence and competence in scientific inquiry.

3. Results

3.1. Phytosociological Analysis

The application of the phytosociological method allows for the diagnosis of a specific plant community, a process carried out through syntaxonomy. Adhering to the international standards established in the Phytosociological Nomenclature Code [1] is essential, as it provides a hierarchical system of syntaxonomic ranks. The association functions as the foundational unit of this system.

Syntaxonomy should be understood as the systematics of plant communities, involving a hierarchical classification system that is recognized for a given phytocoenosis. The core unit of syntaxonomy is the plant association. Within this classification, various syntaxonomic units of vegetation are defined based on the presence or absence of specific botanical species. These units include subassociation, association, alliance, order, and class.

The association, as the fundamental unit of phytosociology, is analogous to the species in taxonomic classification. It represents the primary building block of phytosociology, derived from vegetation inventories conducted under ecologically homogeneous conditions. Associations must exhibit a distinct and original floristic composition that is statistically faithful to their biogeographical distribution and habitat. Subassociations and variants are subordinate to the association.

A specific phytocoenosis can be classified as an association only if it contains a minimum number of characteristic and companion species. The characteristic species, along with those consistently present, form the core framework of the community. The greater the proportion of constant species relative to the total species composition, the more homogeneous the association becomes. A higher proportion of characteristic species indicates a more clearly defined association, both from a floristic and ecological standpoint.

An association may become fragmented due to factors such as limited space, unfavorable habitat, human or animal interventions, or other disturbances. A characteristic species is one that consistently appears in a community, distinguishing it from others from a floristic, ecological, and chorological perspective. To define an association, a plant must have a minimum distribution range. If the plant's range is excessively large, it may belong

to a higher-ranking syntaxon. Conversely, if its range is smaller than the required threshold for the association, the plant may be classified within a subassociation.

Thus, within any phytocoenosis, taxa may be characteristic of subassociations, associations, alliances, orders, and classes. This classification is closely tied to a plant's ecological specialization: the more specialized a plant is, the smaller its distribution range, which typically correlates with lower-ranking syntaxa. In contrast, less specialized plants have broader distribution ranges and may characterize higher-ranking syntaxa [2,55].

Furthermore, there are species that do not define the community but are referred to as companion species. These species, typically from neighboring associations, may overlap or intrude into the studied association due to their relatively low ecological specialization. These plants are considered introgressive. Similarly, species from the studied association may encroach upon neighboring communities, making them transgressive species.

Differential species are those that exist within a specific community (or association) and contribute to its differentiation from other communities. If subsequent studies reveal species that differ from the original diagnostic description, these species are labeled as differential species (Figure 1).

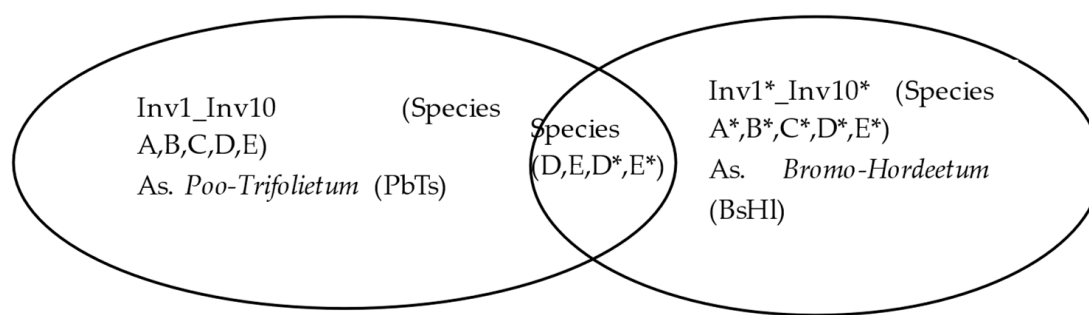


Figure 1. Differential and common species between the *Poa bulbosae*–*Trifolietum subterranei* and *Bromus scoparii*–*Hordeetum leporini* associations. * Differential species.

Considering the two neighboring associations, *Poa bulbosae*–*Trifolietum subterranei* (PbTs) and *Bromus scoparii*–*Hordeetum leporini* (BsHl), their characteristic species differ due to the distinct ecological niches they occupy. However, common species (D, E, D*, E*) appear in both associations, as they are capable of thriving under a broader range of ecological conditions.

For PbTs, the characteristic species are *Poa bulbosa* and *Trifolium subterraneum*, while for BsHl, they are *Bromus scoparius* and *Hordeum leporinum*. The transition zone between these two associations is referred to as an ecotone, which contains species from both associations. In this context, the BsHl introgressive generalist species (*Coleostephus myconis*, *Sherardia arvensis*, *Leontodon taraxacoides*, *Ornithopus compressus*, *Plantago lagopus*, *Echium plantagineum*, *Medicago arabica*, *Medicago polymorpha*) appear within the PbTs association.

The ecotone is an intermediate zone where gradual changes in ecological factors occur, promoting an increase in plant diversity, as species from both associations coexist. In this intermediate zone, plants exhibiting both ecological and chorological (spatial) characteristics, as well as dynamic features, are considered differential species. These species are particularly useful for diagnosing subassociations (Figure 2).

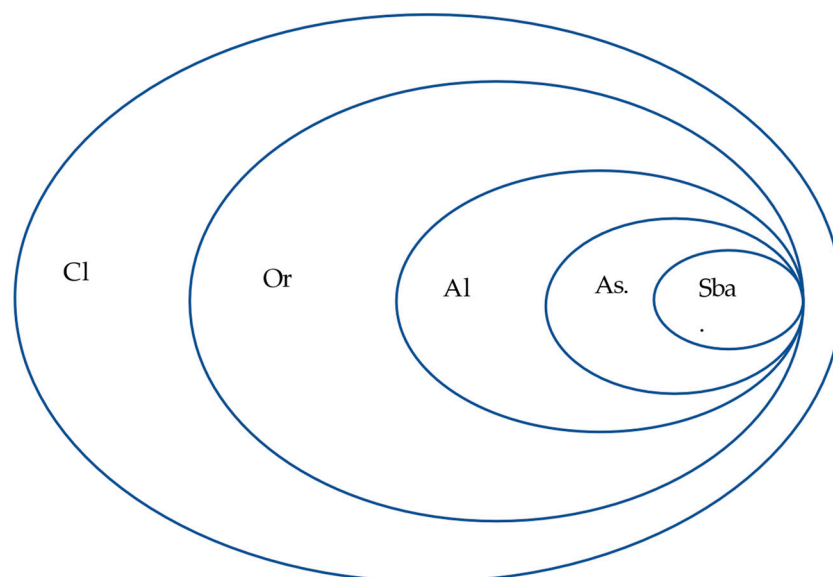


Figure 2. Hierarchical arrangement of syntaxonomic ranks: Cl = Class, Or = Order, Al = Alliance, As = Association, Sba = Subassociation.

3.2. Diversity Measures

The diversity study of *Poa bulbosae–Trifolietum subterranei* reveals the highest diversity values in inventory 3, with a Shannon_T of 2.671, which represents the total diversity of the association. However, when analyzing diversity based on the number of characteristic and companion species, changes are observed in inventories 3, 4, and 8 (Table 1). A notable case arises when the association is considered solely based on the two guiding species. In these instances, Shannon_Ca2 exceeds Shannon_Ca in all cases.

Table 1. Diversity indices for *Poo bulbosae–Trifolietum subterranei*. Shannon_T = Total diversity. Shannon_Ca = Diversity of characteristic species. Shannon_Ca2 = Diversity of the directive characteristic species of the association. Shannon_Co = Diversity of companion species. Shannon_Ca-Shannon_Co (Shannon_Ca-Co) = Difference between the diversity values of characteristic species and companion species.

	Inv1	Inv2	Inv3	Inv4	Inv5	Inv6	Inv7	Inv8	Inv9	Inv10
Shannon_T	2.131	2.339	2.671	1.972	2.603	2.005	1.762	1.908	1.765	1.749
Shannon_Ca	1.566	1.756	1.911	1.011	2.051	1.518	1.082	1.082	1.089	1.099
Shannon_Ca2	1.696	1.895	2.258	1.834	2.059	1.542	1.587	1.754	1.579	1.564
Shannon_Co	1.369	1.594	2.059	1.609	1.772	1.082	1.061	1.332	1.055	1.079
Shannon_Ca-Co	0.197	0.162	−0.148	−0.598	0.279	0.436	0.021	−0.25	0.034	0.02

For the *Bromus scoparii–Hordeetum leporini* grassland, the highest Shannon_T value is observed in inventory 2, where Shannon_Ca2 is less than Shannon_Ca. In this case, inventories Inv3–Inv9 show a Shannon_Co of 0 (Table 2).

The analysis of the difference between the mean values of characteristic and companion species, denoted as Vca-Vco, yields a value of 0.390 for the *Poa bulbosae–Trifolietum subterranei* grassland and 0.525 for the *Bromus scoparii–Hordeetum leporini* grassland.

The linear regression analysis for *Poa bulbosae–Trifolietum subterranei* (Figure 3) reveals a strong relationship, with an R² value greater than 0.8. For the *Bromus scoparii–Hordeetum leporini* grasslands, the R² value is even higher at greater than 0.9 in the Sh_T-Sh_Ca case. However, for the Sh_T-Sh_Co case, the R² value is low (Figure 4, due to the absence of companion especie in inventories Inv3–Inv9).

Table 2. Diversity index for *Bromo scoparii–Hordeetum leporini*. Shannon_T = Total diversity. Shannon_Ca = Diversity of characteristic species. Shannon_Ca2 = Diversity of the directive characteristic species of the association. Shannon_Co = Diversity of companion species. Shannon_Ca-Shannon_Co (Shannon_Ca-Co) = Difference between the diversity values of characteristic species and companion species.

	Inv1	Inv2	Inv3	Inv4	Inv5	Inv6	Inv7	Inv8	Inv9	Inv10
Shannon_T	2.566	2.674	2.463	2.216	2.321	2.288	2.305	2.085	1.818	2.624
Shannon_Ca	2.408	2.463	2.38	2.117	2.223	2.192	2.213	1.967	1.662	2.39
Shannon_Ca2	1.305	1.461	0.9596	0.5297	0.9949	0.9923	0.984	0.9596	0.5297	1.481
Shannon_Co	0.673	1.04	0	0	0	0	0	0	0	1.079
Shannon_Ca-Co	1.735	1.423	2.38	2.117	2.223	2.192	2.213	1.967	1.662	1.311

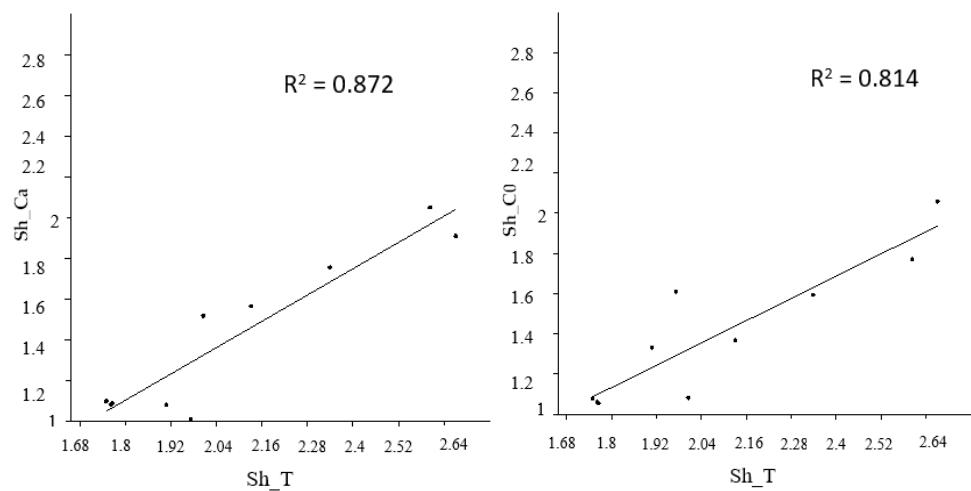


Figure 3. Linear regression analysis between Shannon values of total species with characteristic and companion species (*Poo bulbosae–Trifolietum subterranei*).

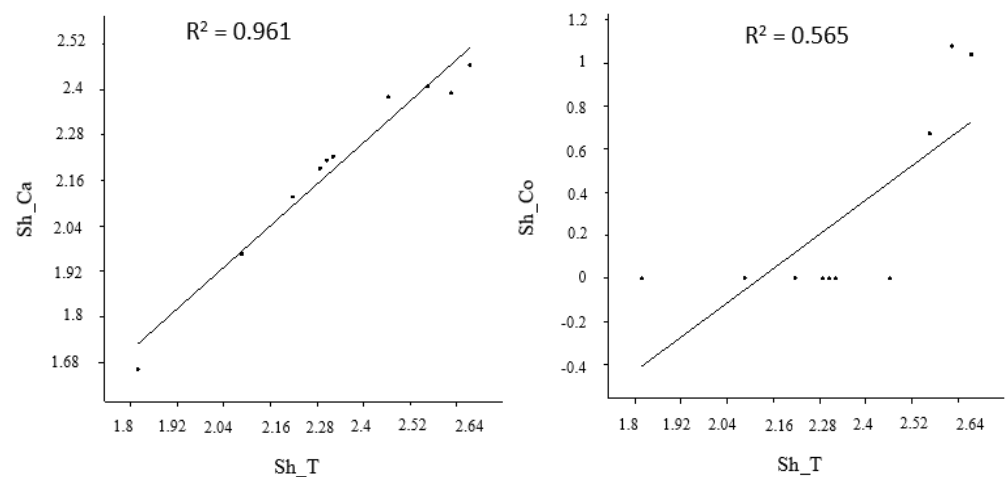


Figure 4. Linear regression analysis between Shannon values of total species with characteristic and companion species (*Bromo scoparii–Hordeetum leporini*). Sh_T = Total species diversity. Sh_Ca = Diversity of characteristic species. Sh_Co = Companion species diversity.

3.3. Learning Outcomes

The assessment of students’ knowledge regarding vegetation, prior to engaging in theoretical and practical instruction, revealed significant deficiencies across both the Botany and Geobotany groups. Among the Botany students, there were no affirmative responses to questions 4, 5, and 6, while only minimal positive responses were recorded for questions

13 and 14. In contrast, Geobotany students provided affirmative answers to all questions; however, their responses to questions 4 and 5 were limited, and no responses were recorded for questions 6 and 13 (Table 3 and Figure 5).

Table 3. Responses obtained from students before and after learning. I-Gb % = Percentage of Geobotany students’ responses before learning. I-Bg % = Percentage of Botany students’ responses before learning. F-Gb % = Percentage of Geobotany students’ responses after learning. F-Bg % = Percentage of Botany students’ responses after learning.

	I-Gb %	I-Bg %	F-Gb %	F-Bg %
1. Very high	100	100	100	100
2. Very important	100	100	100	100
3. No	58	48	100	100
4. Yes	25	0	100	76
5. Yes	8	0	100	76
6. Yes	0	0	100	38
7. Correct	100	99	100	100
8. Correct defined	92	66	100	98
9. Yes	83	25	100	100
10. yes	100	100	100	100
11. Correct defined	100	93	100	100
12. Correct	100	55	100	100
13. Correct	0	1	67	60
14. Correct	100	72	100	100
15. Correct	100	2	100	100
16. Correct	100	97	100	100
17. Correct	100	67	100	100

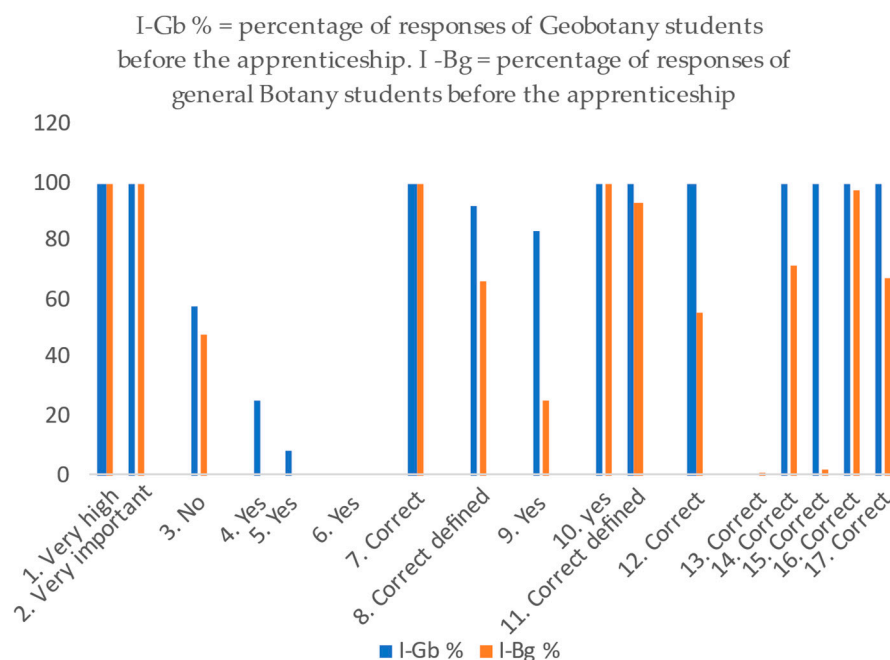


Figure 5. Graphical representation of students’ responses to the 17 questions posed before instruction.

After the instruction focused on two specific vegetation associations, used as prototypes for learning the phytosociological method, 100% of the Geobotany students demonstrated proficiency in the methodology, except for question 13, where the knowledge level reached only 75%.

For the Botany students, 13 questions were answered correctly, while the remaining four (questions 4, 5, 6, and 13) showed response percentages ranging from 40% to 80% (Figure 6).

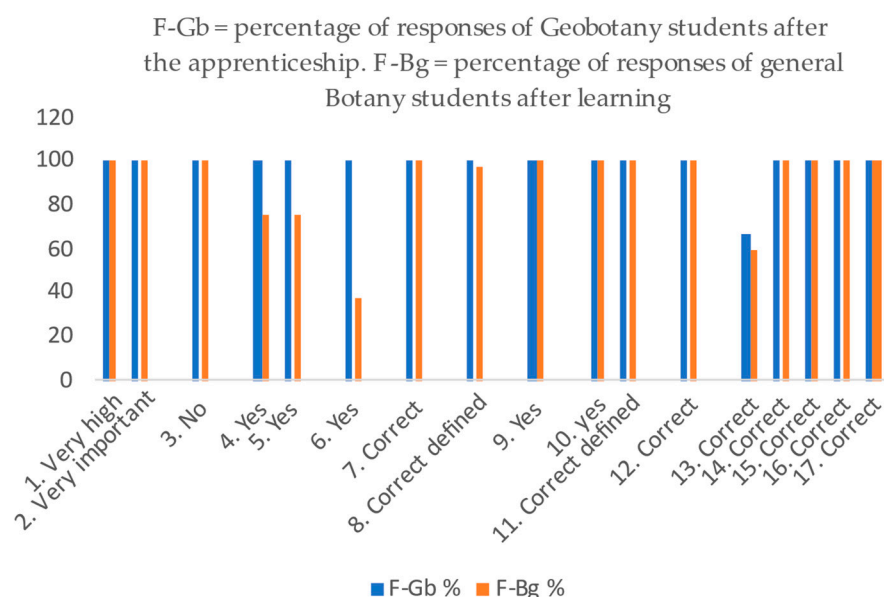


Figure 6. Graphical representation of students' responses to the 17 questions posed after instruction.

4. Discussion

4.1. Diversity Analysis

Regarding the study of diversity [52], we analyzed the Shannon index for both characteristic and companion species. The relationship between the abundance of characteristic and companion species showed negative values in inventories 3, 4, and 8 for the *Poa bulbosae*–*Trifolietum subterranei* (PbTs) association. However, linear regression analysis revealed consistently high R^2 values greater than 0.8, demonstrating the influence of companion species on the total species count. These inventories are undergoing transformation into neighboring communities of *Bromo scoparii*–*Hordeetum leporini* (BsHl) due to the introgression of plants from that association [17], likely a consequence of poorly managed grazing. As a result, these pastures, classified under habitat type 6220, are now considered endangered [29,53].

Positive values observed in the *Bromo scoparii*–*Hordeetum leporini* (BsHl) association are further supported by linear regression analysis, which shows an $R^2 > 0.9$ for Shannon diversity between total species (Sh_T) and characteristic species (Sh_Ca). However, for Shannon diversity between total species (Sh_T) and companion species (Sh_Co), the R^2 value is lower ($R^2 = 0.565$, Figure 6). This is attributed to the low number of companion species, with Sh_Co values in inventories Inv3–Inv8 being equal to 0.

4.2. Analysis of the Teaching-Learning Process

The results from the pre-teaching assessment show significant deficiencies in the Botany group, with somewhat lesser shortcomings in the Geobotany group. This is understandable, as these students come from secondary education (Bachillerato) backgrounds, where exposure to botanical or geobotanical content is limited or nonexistent.

The Botany students' responses to questions related to diversity, phytosociology, and ecosystems were predominantly negative or absent. In contrast, the Geobotany students demonstrated a greater number of correct responses, as they had prior exposure to Botany

content through earlier courses. However, they still showed gaps in their understanding, particularly with questions 3, 4, 5, and 6.

By diagnosing the students' knowledge levels, we were able to address deficiencies in their understanding of Botany and Geobotany through inquiry-based methodologies, all while being guided and supervised by the instructor. The students studied two grassland communities from phytosociological, ecological, and floristic perspectives.

We applied a blended learning approach (Flipped Classroom), project-based learning (PBL), STEN, STEAM, and collaborative learning [21,56–59]. The results indicate a 100% success rate in most questions, except for questions 4, 5, 6, and 13, where the success rate ranged from 40% to 80%. Therefore, practical, out-of-class teaching methods proved to be highly effective. Students demonstrated improved observation and interpretation skills regarding plant associations, grasped the concept of ecological niches, and learned to distinguish between characteristic and companion species [2].

Based on these results, the instructor applies the “feedforward” method to address potential errors in the applied methodology or to confirm the findings [59]. In this case, the results are validated, as the BsHl association shows a very low total count of companion species, suggesting a healthy conservation status, as previously demonstrated by Cano-Ortiz et al. [53].

These findings underscore the importance of new educational spaces where students acquire knowledge that they can later share with society [60,61]. Through these practical studies of plant associations, their diversity, conservation status, and integration into specific ecosystems, students engage in an integrated learning process that connects the fields of science, technology, engineering, art, and mathematics (STEAM) (Figure 7).



Figure 7. Image of a holm oak dehesa (*Pyro rotundifoliae*–*Quercetum rotundifoliae* habitat 6310) where the BsHl grasslands and the PbTs grasslands of habitat 6220 are developed.

5. Conclusions

5.1. Conclusion on the Research

The study of the two Mediterranean grassland associations reveals the differences in floristic diversity between the two grassland types. It highlights the total species diversity compared to the diversity of characteristic species within the association and the companion species. Of particular significance is the relationship between characteristic species and companion species. Specifically, the greater the diversity of characteristic species, the lower the number of companion species, which suggests greater stability within the association. These findings are relevant to livestock farming, as the *Poo bulbosae*–*Trifolietum subterranei* (PbTs) pastures are particularly important in dehesas and Iberian montados for sheep farming, while the *Bromo scoparii*–*Hordeetum leporini* nitrophilous pastures support cattle and horses.

5.2. Conclusion on the Teaching and Learning Process

The teaching model based on constructivist theory has proven to be highly effective, as it equips students with the skills and motivation necessary to manage and educate about economically and socially important grasslands. Through this model, students gain an understanding of the hierarchical system of syntaxonomic units. The combination of field inventories and subsequent laboratory analysis enables students to develop a comprehensive understanding of the floristic diversity of the association and its conservation status.

The multidisciplinary, integrated learning approach has created an educational environment where students take ownership of their learning. Starting from a baseline of limited knowledge, significant progress has been made in students' understanding of both Botany and Geobotany. In conclusion, it can be stated that the learning process has successfully enhanced students' grasp of geobotanical concepts. Students are now able to differentiate between specific grassland associations and understand their floristic diversity.

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