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Development of a Graded Biodiversity Assessment (GBA) Index for the Assessment of the Biodiversity of Managed Natural Forests

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Abstract: The purpose of this research is to develop a Graded Biodiversity Assessment (GBA) index to provide an estimation of the biodiversity in managed natural forests. In order to facilitate the present project, parameters are performed, confirmed, and annotated for their use as GBA components, notably the wood stock, age, canopy density, regeneration existence, and aspect of the forest under study. These five parameters are easily retrieved from the standard forest management plans. To assist the application of this forest-specific GBA index, data for each of the five index components is coded in three biodiversity levels as per the original description, with group cut-offs of 0, 0.5, and 1. We compute the Consistency Index to quantify the degree of reliability of our selection of GBA components ξ (Ksi) of the Best-Worst Method (BWM). With the proposed GBA index, foresters canhave a new tool at their disposal, which can be used to drive decision making and determineforest regions with low or high biodiversity value, with five parameters that are common in the standard forest management plans.

Keywords: biodiversity; forest; graded biodiversity assessment

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1. Introduction

One of the greatest and most pressing problems that humanity has today is how to protect and preserve its most valuable living resource, biological variety, in a world where globalization and environmental degradation are on the rise. Humanity's present and future survival depends on maintaining biological variety. It is what binds all living things together into a unified community or ecosystem in which they all play an important part. It is the fabric of existence itself. However, despite its critical nature, we are recklessly depleting these resources at an alarming pace. This loss has a devastating impact on the planet, as its resilience to change weakens with each lost gene, species, and habitat. This adaptability is a matter of life and death for the world's impoverished. It lowers the standard of living for everyone on Earth. The taking of this resource for granted by people, groups, and countries is a key contributor to its depletion. Thousands of years of progress have led to the belief that the Earth's supply of natural resources, including its biological variety, is infinite. Nonetheless, scientific evidence dictates otherwise. The thought that we could be nearing the boundaries of its endurance is beyond the experience and understanding of most of us, despite the fact that there have been rare occasions when communities and even civilizations have neglected this obligation and suffered significantly as a consequence. Humans have overused the biosphere, and one solution is to teach them better habits in the future. A key component of any effective approach for establishing a sustainable future is education that empowers and allows people to explore collaborative strategies to overcome existing damaging tendencies [1].

In [1], they defined biodiversity as “the variety of living organisms that come from any and all sources”. This is in accordance with the Convention on Biological Diversity, which was established in 1992. This includes terrestrial, marine, and other types of aquatic ecosystems, in addition to the ecological complexes that are made up of different types of ecosystems. However, this is not an exclusive list. Genetic diversity, also known as the diversity within a species, biodiversity between species, and ecological diversity are the three levels on which it is often evaluated. These levels are typically taken into consideration simultaneously. Furthermore, the levels of biodiversity hierarchy span from the molecular to the biome. The structure of life may be broken down into various stages, and each one represents a distinct but equally important step in the process. In a nutshell, the term “biodiversity” refers to the myriad of different kinds of life that may be found on Earth.

When discussing ecosystems, the term “biodiversity” is often used to refer to both the number of different plant and animal species that are present as well as the proportion of those species’ total abundance [2]. According to [3], biodiversity is an important factor in maintaining the stability of ecosystems by lowering the likelihood that these systems would become unstable as a result of changes in both their temporal and spatial environments. In addition, biodiversity is vital for the production of a wide range of commodities and services that are essential and of the greatest value to people, their livelihoods, the health of the global community, and well-being in general [4].

When it comes to the protection of the earth’s terrestrial biodiversity, forest ecosystems are among the most vitally important areas to focus on. According to [5], forest ecosystems are the homes to a sizeable proportion of the overall biodiversity found across the globe. Virgin forests, in particular, are recognized as being the most important hotspots for forest biodiversity, given that managed natural forests lack the richness seen in virgin forests [6–8]. This is due to the fact that virgin forests have a diverse range of structural characteristics over a number of different geographical and temporal dimensions. As a consequence of this, the establishment of protected forest areas is considered to be an essential strategy for the preservation of the varied ecological groups that are found around the world [9,10].

It would be useful to mention at this point that a “virgin forest” is one that has grown without interference from people under natural conditions, is original in its structure, and has not been altered in any way. Although most virgin forests are old-growth forests, virgin forests are not restricted to the climax stage [11]. Several organizations have suggested using the term “forest undisturbed by man” as a synonym for “virgin forest,” including the Food and Agriculture Organization of the United Nations (FAO) [12] and the Ministerial Conference on the Protection of Forests in Europe (MCPEE) [13]. However, the concept of undisturbed is less strict than that of virgin forest. A “forest undisturbed by man” is subject to natural forest dynamics, and the region should be vast enough to preserve its natural qualities. Furthermore, there should be no known significant human intervention, or the last human intervention should have occurred long enough ago to allow natural species and processes to reestablish. Regardless, human interference in the past accounts for the distinction between “virgin” and “natural” forests. Since human interference of some sort can always be found in European (including Greek and Mediterranean in general) forests, the term “natural forest” is more appropriate in practice [14].

In a broader sense, we can say that a forest has a high biodiversity when it contains a diverse array of microsites and environments that are able to provide a home for a wide variety of forms of life, including those of amphibians, birds, animals, insects, plants, fungi, and, in general, microorganisms. It is also essential to highlight that higher levels of biodiversity in an ecosystem are often related to the relative health of the ecosystem [1]. This is because higher biodiversity can enhance the resilience of an ecosystem to environmental disturbances, as different species may have different responses to changes in their environment. However, invasive species can disrupt the delicate balance of an ecosystem by outcompeting native species for resources and habitat. They can negatively impact biodiversity by causing declines in native populations and altering the overall structure and function of the ecosystem.

Refs. [15,16] are two of the many studies that focus on the significance of maintaining biodiversity and conducting research on it. It is very important to keep in mind that state-owned, public forest reserves account for the great majority of the forests that are discussed in these studies. However, we should note that the public forests owned by municipalities and regional or national governments are just one part of a larger forest ecosystem. There are also privately owned forests (e.g., church properties) that contribute to the overall biodiversity of a country's forest. Because of this, it is difficult to use this research to estimate the total forest biodiversity in a country.

In other studies, the value of protecting biodiversity was determined by evaluating the annual payments made by various organizations to preserve biodiversity in protected forest regions [17]. These payments were made to ensure that biodiversity would be maintained in the protected forest regions. In this particular scenario, however, the calculations of the value of the biodiversity do not apply to the entirety of the forest. Instead, they are confined to the portions of the forest that have been set aside as protected areas.

This study's objective is to develop a Graded Biodiversity Assessment (GBA) index, which will provide an estimation of the level of biodiversity that can be found in managed natural forested areas—stands. At this point, it is important to note that we are concerned with species diversity within ecosystems, as defined by more traditional ecology, rather than genetic diversity or diversity in all biology. The GBA index will be computed using parameters that can be easily retrieved from standard forest management plans. In addition, the suggested GBA undergoes a reliability analysis throughthe computation of a Consistency Index.

When it comes to calculating biodiversity, each researcher uses a surrogate that serves the purpose of their research. A biodiversity surrogate is defined as an attribute of an ecosystem that is used as a proxy for another aspect of biodiversity of interest [18]. Until today, no documented method exists for the numerical computation of biodiversity using a combination of biodiversity surrogates, neither in Greece nor Europe. The originality of the present approach lies in this very aspect, namely the absence of any other biodiversity index that combines many biodiversity surrogates. This approach offers a unique opportunity to comprehensively assess biodiversity in Greece and Europe by utilizing multiple biodiversity surrogates. By combining various attributes of an ecosystem, this method provides a more holistic understanding of biodiversity patterns and dynamics. Furthermore, the absence of existing numerical computation methods highlights the need for innovative approaches in biodiversity assessment and conservation efforts.

Development of the GBA

Conceptualization is based on the work of [19], where a Graded Prognostic Assessment (GPA) index is calculated for the management of sarcoma patients with brain metastases. In oncology, GPA indices are developed, analyzing survival data at different levels as per the original description, with group cut-offs, with the first GPA group (score 0–some number) having the worst prognosis and the last GPA group (score some number–max) having the better prognosis.

In the work of [19], from the time of brain metastases diagnosis through the date of death or last followup, the overall survival rate was assessed. Four levels of the GPA index were examined, with group cutoffs of 0–1, 1.5–2.5, 3, and 3.5–4. Histology, performance status, and number of central nervous system metastases, were used as input data for the calculation of the GPA index.

This ranking served as inspiration for us as we established our own index for analyzing forest biodiversity. In our work we analyzed biodiversity data atthree levels as per the original description, with group cut-offs, with the first Gradient Biodiversity Assessment (GBA) group (score 0–1.5) having low biodiversity, the second GBA group (score 1.5–3) having moderate biodiversity, and the last GBA group (score 3–5) having high biodiversity. Wood stock, age structure, canopy density, regeneration existence, and aspect were used as input data for the calculation of our GBA index.

In our attempt to assess the validity of the biodiversity criteria we have chosen, we applied the Best-Worst method (BWM) described in [20,21]. To choose the optimal alternative(s) in a multi-criteria decision-making situation, several options are assessed against a number of criteria. According to BWM, the decision-maker starts by identifying the best (e.g., most desirable, most important) and worst (e.g., least desirable, least important) criteria. Then, pairwise comparisons are made between the best and worst of these two criteria and the other criteria. Next, a maximin problem (i.e., a problem created to maximize the minimum objective for all potentials) is created and solved to discover how much each criterion is worth. The same method is used to determine the weights of the alternatives in relation to various criteria. The weights from several sets of criteria and alternatives are combined to create final scores for the alternatives, from which the best option is chosen. For the BWM, a Consistency Index Ksi (Greek ξ) is suggested to evaluate the validity of the comparisons and, thus, the validity of our selected parameters for assessing biodiversity. The Consistency Index Ksi algorithm consists of five steps:

1. Definition of criteria $(c_1, c_2, \ldots, c_n)$ —in our case, there are five biodiversity criteria.
2. Definition of the "best" and the "worst" criteria.
3. Definition of the relations of the "best" criterion over the other criteria (one for the relation of the "best" criterion to itself, up to nine for the relation of the least related criterion to the "best" criterion).
4. Definition of the relations of the "worst" criterion over the other criteria (one for the relation of the "worst" criterion to itself, up to nine for the relation of the least related criterion to the "worst" criterion).
5. Search for the optimal solution, i.e., the optimal weights of the criteria matrix that minimizes the maximum gaps between obtained weighs and the opinion of the decision-maker.

The BWM has been previously used in environmental parameter assessments for:

(a) Choosing the best location for a solar photovoltaic power plant, based on GIS data. The developed model ensured that the optimal location is chosen by taking into account a variety of factors in three areas, namely climatic, location, and orography [22].
(b) Weighting and comparing economic, environmental, social, and technical factors to rank the electricity generation options in Turkey. The findings showed that hydro is the best alternative for generating power, with onshore wind, solar photovoltaics, geothermal, natural gas, and coal ranking second and third [23].
(c) Assessing the environmental effects of construction projects, by determining the most beneficial implementation modes of activities with the least possible cost, duration, and environmental effects. The effects of projects on the environment were identified in three different environments—the biological, physicochemical, and socioeconomic—and their positive and negative effects were weighted with the BWM approach [24].
(d) Assessing the appropriateness of agricultural land. Texture, electrical conductivity, drainage, pH, depth, cation exchange capacity, content of organic matter, soil fertility index (nitrogen, phosphorus, potassium and zinc content), and calcium carbonate % were the nine land parameters that were analyzed. The outcomes demonstrated that the data produced using the BWM were reliable and consistent [25].
(e) Choosing the best sites for rainwater-harvesting agriculture in arid and semiarid regions, using GIS data and rainfall patterns [26].
(f) Evaluating the Grey mangrove reforestation process reported for the first time in the Persian Gulf. The findings demonstrated that the growth of Grey mangroves in the chosen sites was unaffected by reforestation in the greatest latitude of natural forests in the Persian Gulf. The ecosystems of the tidal area were also improved by expanding the Grey mangrove forests in the Persian Gulf, which enhanced fishing opportunities and the economic standing of the nearby populations. This is also the first account of a straightforward technique for teaching the phases of Grey mangrove replanting [27].

2. Materials and Methods

As previously stated, each researcher employs a surrogate that suits the goal of their study when estimating biodiversity. Indeed, there is a broad variety of biodiversity components such as hunting, herbicide, fungicide, and pesticide amounts that are not included in Forest Service management plans (at least components that are not included in management plans in Greece). In addition, several variables are not represented uniformly. Therefore, we chose not to include them in the suggested GBA index. Slope, for example, is critical for biodiversity, but we decided not to include it in our index since it does not appear uniformly in management plans (at least in Greece). It may be expressed as a percentage, in degrees, or words (e.g., small, moderate, or strong slope). Considering the above limitations, we selected five biodiversity surrogates in this study to create a Graded Biodiversity Assessment (GBA) index that can estimate biodiversity in managed natural forests and can be readily obtained from any standard management plan. By incorporating these surrogates into the GBA index, forest managers can obtain a comprehensive assessment of biodiversity that goes beyond what is typically included in standard management plans. Since biodiversity cannot be a binary variable ("yes" or "no" biodiversity, "true" or "false"), we decided to scale our GBA index into the minimum number of three levels, i.e., little or no, moderate, and high biodiversity. The values 0 (indicating little or no biodiversity), 0.5 (indicating moderate biodiversity), and 1 (maximum biodiversity) were chosen as the group cut-offs for the GBA index.

As for the query "why 5 variables and not more or less?", we provide the following justification:

Exploratory Factor Analysis (EFA) is a statistical technique used to reduce data to a smaller set of summary variables, thereby identifying the structure of the relationship between variables and factors. In EFA, each variable (manifest variable) loads on one or more factors (latent variables) [28]. So, by definition, at least two manifest variables are required per factor (because at least two variables are required to reduce their number), whereas [29] recommended at least three manifest variables per factor.

In general, a model with more manifest variables for each factor tends to have better reliability, validity, generalizability, and more robust tests of competing models than one with just two or three manifest variables. However, "the more, the better" may not be true when there is a possibility of suboptimal solutions ("bloated" variables), which refers to an abundance of similar variables leading to redundancy and lack of unique information [28].

In the present work, having biodiversity as factors and trying to develop an index measuring biodiversity, composed by a number of manifest variables (surrogates, components, criteria), we decided that five is an appropriate number, because it safely covers the minimum requirements and will not lead to suboptimizations. By selecting five biodiversity components, we can capture a diverse range of biodiversity, ensuring a comprehensive assessment. This approach allows us to avoid oversimplification while still maintaining practicality and feasibility in our index development process.

Next, in order to get an idea of how reliable our selection of GBA components was, we calculated the Consistency Index ξ(Ksi) of the Best-Worst Method BWM, with Microsoft Excel Solver add-in program. This allowed us to assess the degree to which our selection was appropriate [20,21]. In order to implement the BWM and determine the value of the Consistency Index Ksi, we must first select the best (the most important) and the worst (the least important) criteria for biodiversity estimation. Next, we must weigh the importance of the best criterion over the other four, and the importance of the worst criterion over the other four, on a scale that ranges from 1 (the best or worst criterion is very closely related to one of the remaining four) to 9 (the best or worst criterion is very loosely related to one of the remaining four). The better things are, the closer the Ksi is to zero (our choice and weight of criteria are more reliable).

According to [30–32], biotic and abiotic variables have a significant impact on the biodiversity seen in forest ecosystems. Light, temperature, and the availability of water are all factors of climate and microclimate that have a role in determining the presence of flora and fauna species as well as their distribution over several scales [10,30,31,33]. On the other hand, organic matter and structures are essential components of the habitats of many different organisms, affecting the sources of food and the cover of nesting sites [10,30,31,34]. In this work, we suggest five factors in order to create a GBA index. These parameters are the wood stock, age, canopy density, existence of regeneration, and aspect of the forested area—stand that is being studied. We will support our choice of these particular parameters as follows:

The stand's structure affects the climate inside the stand and the properties of the biomass produced by dead and living plants and trees [10,30,31,34–36]. Stand structure analysis is employed in the study of stand tree species ecology [36] and the planning of stand, i.e., forest conservation measures [37], while stand structure diversity, such as tree diameter diversity, is studied and analyzed using biodiversity indexes [38]. Except for this aspect, all other criteria employed in the formulation of the GBA index are related to stand structure.

The total quantity of wood stock, the first criterion for measuring biodiversity, is highly correlated with the impact of trees on the climatic variables (light, temperature, etc.) within a stand and with the amount of biomass from both dead and alive trees and plants [30,31,34]. In addition, wood stock is related to the presence of large trees, which play an important role in the biodiversity of a stand [10]. This is the rationale behind choosing wood stock as the top criterion for assessing biodiversity. Note that we only recommend using the wood stock biodiversity surrogate for the GBA index of managed natural forests, not cultivated plantations, which, depending on how intensively they are cultivated, can be very different from managed natural forests. For the Greek forests, we decided that wood stock thresholds of <100, [100, 250] and >250 m^3/ha are suitable for assigning biodiversity to low or no, moderate, and high, respectively.

The second criterion, tree age structure, which affects biodiversity in a stand [10], is likewise associated with the variability of stand structure [32,34,39]. Tree age structure refers to the distribution of trees across different age classes within a stand. This variability in age classes can have a significant impact on the overall biodiversity of the stand. Different age classes provide different habitats and resources for various species, contributing to a more diverse ecosystem. Additionally, tree age structure can also influence the successional dynamics and resilience of the stand, as younger trees may replace older ones over time, ensuring a continuous cycle of growth and regeneration [10,30–35,39]. We chose to treat the age structure component as a binary variable and give the biodiversity scores 0 (little or no biodiversity) and 1 (high biodiversity) to the characterizations "even-aged" and "uneven-aged" since these terms do not require specific age ranges and can be retrieved from any forest management plan.

Canopy density is the third criterion that is utilized for the assessment of biodiversity. This is due to the fact that it is connected to the impact that trees have on the climatic conditions of a stand. In addition, canopy density has been shown to be a predictor of site productivity in a stand [38], and as a result, it has the potential to have an effect on the biodiversity of forests [30,31,34]. Canopy density is the ratio of the total areas of canopy projections (if we put one projection next to another) to the area that these trees occupy [39]. There is a range of possible values for canopy density, from 0 to over 1. As the crowns of the trees grow more entangled with one another, the canopy density increases. Canopy density differs from ground cover, which may have values as high as 1. Canopy density boundaries are specified in Table 1, making reference to the management plans' stated values. There are two different canopy densities stated in the stand description sheets. Any observer can recognize the difference between three distinct stands: one with both canopy density values less than one, another with one value less than one and the other larger than one, and a third with both values greater than one. In consideration of the specific entries in the management plans, we chose to give the biodiversity score of 0 (little or no biodiversity) to areas with both canopy density values <1, 0.5 (moderate biodiversity) to areas with one canopy density value <1 and the other >1, and 1 (high biodiversity) to areas with both canopy density values >1.

Table 1. Biodiversity criteria and their graded biodiversity degree.

Biodiversity Criterion	Biodiversity Degree per Criterion			Forest Biodiversity (Sum of the 5 Criteria)
	0 (little or no biodiversity)	0.5 (moderate biodiversity)	1 (maximum biodiversity)	<1.5 Low biodiversity [1.5, 3] Moderate biodiversity >3 High biodiversity
Wood stock m^3/ha	<100	[100, 250]	>250	
Age structure	Even-aged	-	Uneven-aged	
Canopy density	<1 for both bounds	<1 for the lower bound, >1 for the upper bound	>1 for both bounds	
Regeneration existence	Little or no regeneration	Moderate regeneration	Maximum regeneration	
Aspect	1	2	>2	

Species diversity unquestionably contributes to biodiversity. However, we chose to leave this biodiversity surrogate out of the proposed criteria for calculating a GBA index for the reasons stated below:

- Tree age structure and canopy density cover a certain amount of the biodiversity caused by species mixing. We expect a mixed forest to have an uneven age structure, and, as the crowns of trees get increasingly entangled, we expect increased canopy density. When mixed stands are evenly aged, it means that they were established at the same time following a disturbance. In these stands, in many cases, several species with varied growth rates produce layered canopies, with the fastest-growing, intolerant species as dominants, trees with more intermediate tolerance as codominants, and more shade-tolerant species in the midstory. Therefore, even if we are discussing evenly aged stands that were produced after a disturbance, the canopy density criterion still partly covers the assessment of their biodiversity [40]. The presence of layered canopies in these stands indicates a diverse range of species and their ability to adapt to different light conditions. This suggests that evenly aged stands following a disturbance can still support a high level of biodiversity, as the various species occupy different niches within the canopy structure.
- The recommended biodiversity criteria may be collected with little effort from Greece's typical forest management plans. In these management plans, if the standsare not pure, the proportion of cover per species is not specified. Additionally, the minimal proportion of each species' cover required to qualify a forest as mixed is often not indicated. Therefore, we believe that a biodiversity index for Greece should not contain the "species mix" component. However, we underline that forest managers in other countries should modify the biodiversity assessment criteria not only according to their varied forest types but also according to the standard content of their management plans. If the species mix percentage is included in a country's management plans, it should be considered whether this parameter should be included in the computation of the biodiversity index. This consideration is important because the inclusion of the species mix component in the biodiversity index should align with the specific goals and objectives of each country's forest management plans. Therefore, a thorough evaluation of the relevance and significance of the species mix percentage is necessary before incorporating it into the computation of the biodiversity index.

The presence of regeneration is the fourth criterion, which is a component of stand structure and is associated with the availability of food resources for a variety of animal and plant species [30,34,41]. This process plays a crucial role in maintaining biodiversity and ecosystem stability. It ensures the continuous replenishment of plant populations and provides habitat and sustenance for numerous animal species, contributing to the overall functioning of the ecosystem. We chose to treat the regeneration component as a 3-level categorical variable and give the biodiversity scores 0 (little or no biodiversity), 0.5 (moderate biodiversity), and 1 (high biodiversity) to the characterizations "little or no regeneration", "moderate regeneration", and "high regeneration" since these terms do not require specific regeneration density ranges and can be retrieved from any forest management plan.

The fifth and last biodiversity component to be considered is exposure, which has the most impact on the climate conditions of a region [30,31,42]. Due to its effect on the local climatic conditions, we decided that it was the most erratic criterion to use when estimating biodiversity. This "exposure" (i.e., aspect) refers to the number of distinct directions it faces (north, south, east, and west). In the event that the aspect is a composite, such as the north-east, we register it with the initial composite (in the previous example, it is registered as north). This criterion allows us to understand how different areas of the forest receive sunlight. By considering the aspect of a forest, we can better assess the diversity of species that can thrive in different microclimates within the region. For the Greek forests, we decided that one aspect, two aspects, and more than two aspects are suitable for assigning biodiversity to low or no, moderate, and high, respectively.

Canopy density was determined to be the criterion that came the closest to matching the wood stock that was selected as the best criterion, followed by the occurrence of regeneration. On the other hand, the age structure is farther off from the criteria that were previously discussed. A stand may have evenly aged, young trees, thus showing low wood stock, or it can have evenly aged treesandshow a high wood stock, if it is elderly. The aspect was assessed to be the most remote to wood stock criterion, since it may impact plant communities indirectly, i.e., via the effect of climatic circumstances [30,31].

Regarding the factor that was ranked as the worst criterion for the assessment of biodiversity, regeneration is the criterion that comes the closest to it without being quite as near. Climate circumstances, such as freezing temperatures and drought, make the process of tree regeneration more precarious [39]. It was believed that the other criteria were loosely related to aspect, with wood stock being the one that was the least related.

The quantification of the effect on biodiversity of the criteria that are most strongly related to the structure of the forest (wood stock and canopy density) was carried outwith the logic that "the more the forest increases (either in terms of increased wood stock or increased canopy density), the more positive the effect on biodiversity is". As surrogates for biodiversity, many types of forests and attributes of forests may be employed [10]. In terms of age structure, the stand structure of unevenly aged stands is more complex and diverse than that of evenly aged stands, and this is related to a high species diversity [10,32,39]. The idea behind the presence of the criterion of regeneration is that the more regeneration there is, the greater the biodiversity will be, because there will be more food for the various species. Lastly, in the case of the aspect, the more aspects that are present in a stand, the more different the abiotic conditions are, and as a result, the greater the biodiversity is.

Summarizing the five criteria for assessing biodiversity and the relationships of the best and the worst with the rest, we end up with two tables, i.e., Table 2 for the "best to others" and Table 3 for the "others to worst" relationships.

Table 2. Assessment of the "best to others" biodiversity criterion.

Best to Others	Total Amount of Wood Stock m^3/ha	Age Structure	Canopy Density	Regeneration Existence	Aspect
Wood stock m^3/ha	1	5	3	4	8

Table 3. Assessment of the "others to worst" biodiversity criterion.

Others to Worst	Aspect
Aspect	1
Wood stock m^3/ha	8
Age structure	7
Canopy density	6
Regeneration existence	4

Based on the above weighing of the five biodiversity criteria, the Ksi Consistency Index is equal to 0.15, meaning that our combinations are reliable in assessing biodiversity. At this point, we underline that the total biodiversity index is calculated by adding the biodiversity values for each of the five criteria, each of which has a minimum and maximum value (0 and 1, respectively). The "best" and "worst" criteria, as well as how the rest are linked to these two (hence the weighting), are only used to calculate the Ksi Consistency Index. They only show how well these five criteria fit together, not how important they are when calculating biodiversity. The Ksi Consistency Index helps assess the overall coherence and consistency of the five criteria in measuring biodiversity. However, it does not determine the relative importance of each criterion in calculating biodiversity, as that is solely based on their individual biodiversity values.

3. Results

The preceding information may be put to use by looking at an example with dummy values for the biodiversity components of the GBA index, regarding a hypothetical forest covered region that will be assessed for its biodiversity (Table 4). These dummy data are neutral information that contain no actual data, but are used to test the GBA index, in which real input data will be inserted in future applications. The dummy data in our example were selected with such values to avoid depicting unrealistic environments. In Table 4, for each biodiversity criterion, their (dummy) values, as well as their biodiversity degree, according to Table 1, are given. There are eight fictitious forest areas, each with its own area in ha, that are combined to form a larger forest area. The last row of the table gives the total GBA value for each area, together with its corresponding biodiversity classification (low, moderate, or high). The hypothetical map of the larger forest region, shown in Figure 1, is formed of the aforementioned eight distinct areas. The extent of the different shades of grey in Figure 1 corresponds to the extent of each area (ha), as listed in Table 4.

Table 4. Hypothetical example for biodiversity assessment usingthe proposed GBA index.

	Area 1 (Stand of 18 ha)	Area 2 (Stand of 35 ha)	Area 3 (Stand of 15 ha)	Area 4 (Stand of 34 ha)	Area 5 (Stand of 45 ha)	Area 6 (Stand of 29 ha)	Area 7 (Stand of 23 ha)	Area 8 (Stand of 17 ha)
Total amount of wood stock m^3/ha	90	180	50	270	150	120	150	140
Biodiversity degree	0	0.5	0	1	0.5	0.5	0.5	0.5
Age structure	Unevenly aged	Evenly aged	Evenly aged	Evenly aged	Unevenly aged	Evenly aged	Unevenly aged	Evenly aged
Biodiversity degree	1	0	0	0	1	0	1	0
Canopy density	0.4–0.9	0.8–1.1	0.4–0.5	1.1–1.1	0.8–1.1	0.6–1.1	0.8–1.1	1.1–1.3
Biodiversity degree	0	0.5	0	1	0.5	0.5	0.5	1
Regeneration existence	Moderate	Little	Little	No	Maximum	No	Moderate	No

Table 4. *Cont.*

	Area 1 (Stand of 18 ha)	Area 2 (Stand of 35 ha)	Area 3 (Stand of 15 ha)	Area 4 (Stand of 34 ha)	Area 5 (Stand of 45 ha)	Area 6 (Stand of 29 ha)	Area 7 (Stand of 23 ha)	Area 8 (Stand of 17 ha)
Biodiversity degree	0.5	0	0	0	1	0	0.5	0
Aspect	North, East	North	South	North, East, South	North, East, South	East	North, East	South
Biodiversity degree	0.5	0	0	1	1	0	0.5	0
GBA	2	1	0	3	4	1	3	1.5
	Moderate	Low	Low	Moderate	High	Low	Moderate	Moderate

The pseudo-map resulting from Table 4 is given below.

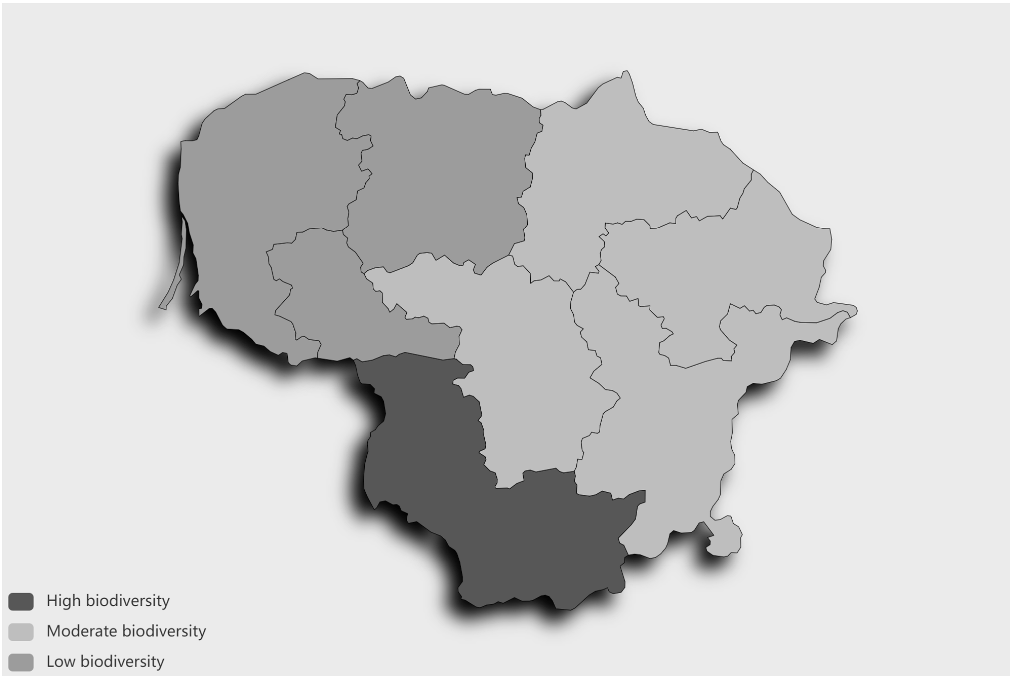

Figure 1. Hypothetical thematic map for biodiversity assessment via the proposed GBA index.

4. Discussion

The ever-increasing number of scientific studies and projects that are now being produced is proof of the relevance of the contribution that forests offer to society in terms of the biodiversity they maintain and the ecological services they provide. In other words, this is evidence of the significant role that forests play in society. Studies have demonstrated that biodiversity is not just a reaction to changes in the environment. Instead, it is also a predictor of many activities and services offered by ecosystems that are crucial to the well-being of people [43]. According to [44], there are a considerable number of reference frameworks relating to its preservation that have relevance in the forestry sector and concern the robust development of sustainable forest management. In this regard, there are a substantial number of reference frameworks connected to its preservation.

Estimates of biodiversity can be beneficial to the management of managed natural forests and stands, as well as the selection of appropriate activities to reverse the negative effects caused by human management techniques or to apply important treatments for the establishment of conditions associated with high biodiversity. This can include both the selection of suitable activities to reverse the negative effects caused by human management techniques and the application of important treatments [10].

In addition, determining the level of biodiversity in managed or unmanaged natural forests may help with the selection of potential locations for protected areas of varying sizes and, more generally speaking, with the planning of protected areas on a wide range of spatial scales [10].

In the present work, an example was provided, with theoretical values for the biodiversity components we propose to use in the computation of the GBA index, and its accompanying biodiversity map, in order to illustrate the implementationof the proposed index. The area to which these values apply is fictitious, yet realistic. Since these values are part of every forest management plan in Greece, we can certainly use the values for any managed natural forest as input. In fact, we could create a map showing the country's whole forest ecosystem biodiversity. However, we cannot verify the integrity of the proposed GBA index by comparing it to the value of another index that already exists for biodiversity. No documented method exists for the numerical computation of biodiversity using a combination of biodiversity criteria, neither in Greece nor Europe. The originality of the present approach lies in this very aspect, namely the absence of any other biodiversity index that combines many biodiversity criteria. This unique approach of the proposed GBA index opens up new possibilities for assessing and monitoring biodiversity in a more comprehensive and holistic manner. By incorporating multiple criteria, the GBA index can provide a more accurate representation of the overall diversity of an ecosystem, allowing for better-informed conservation efforts and policy decisions. Additionally, the absence of existing biodiversity indices that combine various criteria highlights the need for further research and development in this field to enhance our understanding of ecosystem dynamics and promote effective conservation strategies.

It is important to emphasize that these five criteria, as well as the relationships that we defined between them in the BMW approach, are recommended for forests in Greece or forests with biological characteristics that are comparable to those of Greek forests. The whole Mediterranean forests ecoregion may fall within the purview of this recommendation. Also, this recommendation demonstrates an understanding of the distinctions between the forest ecosystems of the Mediterranean and other regions throughout the world; evidently, there can be no single GBA index that covers all ecosystems, from the Mediterranean to the taiga. The five components of biodiversity we are considering here, as one walks up and down slopes, vary greatly between the Mediterranean and other regions of the globe. Also, even if degraded to a great extent, the GBA of complex, highly diverse forests may still be higher than those of natural forests with less diversity, and there are obvious limitations to making broad-scale comparisons.

It is evident that forest managers should alter the biodiversity assessment criteria and/or the balancing between them suitably according to the various forest types and/or management plans that include variable standard content. In this context, forest managers, whose types of forests and management goals might differ, are encouraged to adjust biodiversity assessment criteria and/or establish a more suitable balance between them, depending on the circumstances. This flexibility in adjusting biodiversity assessment criteria and balancing them according to forest types and management plans allows for a more accurate and effective evaluation of biodiversity conservation efforts. By considering the specific characteristics and objectives of each forest, forest managers can ensure that their strategies align with the unique needs of the ecosystem, ultimately promoting sustainable management practices.

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