Chapter

Geodiversity as a Tool for the Nature Conservation

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Abstract

Geodiversity and biodiversity are the two fundamental components of Nature that must be analyzed simultaneously for good management of the natural environment. Geodiversity, including geomorphodiversity, has values that make it possible to define the geosystem services on the basis of which it is possible to establish protocols for the sustainable development of the territory analyzed. Both the values of geodiversity and the geosystem services they provide are key elements for the definition of Natural Protected Areas (NPAs). Furthermore, it is also necessary to consider the assessment of the geodiversity and geomorphodiversity of the territory under consideration, so that a zoning can be established in terms of the geodiversity index (geodiversity/geomorphodiversity gradient) that favors the establishment of specific geoconservation protocols according to the value of these indices. In addition, NPAs should be considered as elements belonging to a network in which the different natural systems of the territory in which the network is defined are represented. In the case of geodiversity or geomorphodiversity, the network must be supported by the definition of geological contexts, representative of the major geological units that are observable in the territory.

Keywords: geodiversity, biodiversity, geomorphodiversity, geodiversity assessment, natural protected areas, sustainable development

1. Introduction

Geodiversity is a term first used as analogous to biodiversity, but their development in the scientific and administrative sectors has been very different. A formal definition of biodiversity was presented in Río de Janeiro Earth Summit in 1992 and was quickly incorporated in the national and international guidelines for nature conservation, whereas geodiversity was not formally defined. Although a proposal was made to this respect [1], its international impact was limited. Geodiversity did not acquire an international scientific dimension until the publication of Gray's book in 2004 [2], where the conceptual bases of geodiversity are developed. Later, the concept was analyzed and a preliminary methodology for the assessment of geodiversity [3] was presented, to be applied in the management of Natural Protected Areas (NPAs). The book edited by Reynard et al. in 2009 [4] was another important milestone in the analysis of geological features and their interest on nature conservation. In this book, the concept of geomorphosites is unified, a comprehensive analysis of the state of the art was made, and the foundations are laid for the rigorous analysis of geomorphological features of the territory with goals as diverse as their conservation, simply because they are natural elements with some value, or as a support for biodiversity that may be conditioned by them. Panizza, in 2009 [5], proposed a definition of geomorphodiversity. This author considers that it is the specific assessment of geomorphological features of an area, considering the scale of the studied area. Recently, Worboys et al. [6] edited a comprehensive book about the management of natural protected areas where the geodiversity, geological heritage, and geomorphosites have been considered.

Consolidation of the term geodiversity came in the wake of another key concept, the sustainable development (World Commission of Environment and Development, or Brundtland Commission [7]). Strongly anchored in this concept is the notion of the nature conservation (goal 13: climate action; goal 14: life below water; goal 15: life on land; www.un.org/sustainabledevelopment). Geology and Geomorphology adopted a perspective centered on the relationship between the man and environment, accenting not just the use, but the sustainable use, of natural resources, while avoiding or preventing hazards for the population and minimizing the degradation of nature [3, 5, 8–10]. Thus, Environmental Geology arose to safeguard nature and the conceptual framework embracing geodiversity, and its methodology began to evolve. The need to consider geodiversity when defining or managing NPAs has since gained importance, especially from the International Union for Conservation of Nature (IUCN) Congress of 2008 and 2012, where the 4.040 and 5.048 resolutions respectively highlight that the geodiversity as part of the nature and geoheritage belongs to natural heritage (https://portals.iucn.org/library/node).

Traditionally, in the Anglo-Saxon literature (any of the papers cited so far can be reviewed), Geology and Geomorphology, although Earth Sciences, have been considered independent, which has been transferred to the field of geoconservation, with geodiversity and geological heritage being considered separately from geomorphodiversity and geomorphological heritage. This has led to the distinction between geosites and geomorphosites. Panizza [5] makes a detailed analysis of this problem. Besides, definitions of geodiversity that integrates in its totality all those topics related to the conservation of geomorphological features of the terrain [1–3] have been proposed. The geodiversity has been defined as the number and the variety of structures (sedimentary, tectonic, geomorphological, hydrogeological, and petrological) and geological materials (minerals, rocks, fossils, and soils) that made up the lithosphere in a given region, upon which organic activity is settled, including anthropic activity. This concept was complemented adding to study of the geological elements of a specific zone, there is a need to appraise the relationship existing among them, so that geological processes are seen as a further trait of the geodiversity of the zone under study [3–6].

In this way, geodiversity is perceived as an intrinsic property of a territory that allows one to establish its geological interest [1, 2, 5, 11]. Geodiversity materializes in certain tangible geological elements: outcrops, landforms, their groupings… A detailed analysis of numerous studies on geodiversity valuation [8–10] shows that geomorphodiversity and geomorphosites play an important role in the final value of geodiversity. The geodiversity elements should not merely be studied in independent fashion, but rather in view of their interrelations. The geodiversity of two or more regions can thus be compared by assessment of this property in each one. The fact that geodiversity can be analyzed at very different scales, from global (continents and oceans) to elemental (atoms and ions), is something it shares with biodiversity, which can likewise be studied at macroscales (global ecosystems), the scale of genetic diversity, or the scale of biotechnology and microbiology [11–17].

The goal of this paper is to analyze the role of geodiversity, and the geomorphodiversity as part of it, as components of the natural environment, in delimiting Natural Protected Areas (NPAs) and the development management protocols for these natural areas, always from the standpoint of sustainable development. To achieve this goal, it is necessary to know what values geodiversity has, how it contributes to human well-being from the consideration of the geosystem services, and what relationship it has with biodiversity. An important tool to develop these actions is the assessment of geodiversity/geomorphodiversity of the territory where the NPA is located and enclosed it.

2. Geodiversity values

Geodiversity values reflect the physical basis upon which ecosystems and anthropic activity settle. The geodiversity entails seven values [2, 14]: (a) intrinsic, (b) cultural, (c) esthetic, (d) economic, (e) functional, (f) scientific, and (g) educational.

An intrinsic value is understood as the value given to a geological element by virtue of its existence, and geodiversity is upheld as a nonrenewable resource. Ethical and philosophical dimensions of the relations between society and nature condition belief that things have value because they are useful to man. Certain authors [18] have equated intrinsic and scientific values. However, the two values should be seen as distinct, since intrinsic value is directly and exclusively related to the existence of the geodiversity itself, while scientific value should be associated with certain qualities that at least provide knowledge. Intrinsic value should be understood as a value that is the support on which others can be developed.

Cultural value is attributed by society to some qualities of the abiotic part of the environment owing to its social significance or its role in the community. Variants of cultural value are folkloric value (geomythology), archeological/historical value, spiritual value, and a sense of dependence on "Mother Earth." Closely related with cultural value is the educational value. Knowledge of the composition and origin of an area's geodiversity can be shared with the local population and visitors, promoting social development as well as the communication of geological hypotheses and theories. These ideas were basics by the firstly development of the Granada Geopark (South Spain; **Figure 1A** and **B**). So, the diversity of clays outcropped in this territory and the forestry they conditioned were explained to population of the territory as the source of the ceramics and economic activities as the manufacture of grass tools (www.geoparquedegranada.com). On the other hand, the badlands landscape of this territory is the main goals of the natural tourism of the region (**Figure 1C**). This is because the development of this landscape is the immediate expression of the desertification of the region, which has been commonly associated with an impact of climate change, although it is indeed the result of a change in the base level of a paleo-fluvial system [19].

The esthetic value is closely related to the geomorphodiversity. It evokes a visual or sensual appreciation obtained through incentives from the physical setting. It is related to a contemplation of landscapes (geomorphosites) or the development of recreational activities in the physical environment (i.e., geotourism, **Figure 1C**). The esthetic value often has implications for economic value, given that many geological materials are essential for the socioeconomic development of a region, a country, or a continent, when geodiversity or geomorphodiversity is used from a sustainable standpoint as a touristic or cultural resource. For example, the badlands landscape of the Guadix-Baza basin (Betic Cordillera, South Spain; **Figure 1A**) is the main attractive of

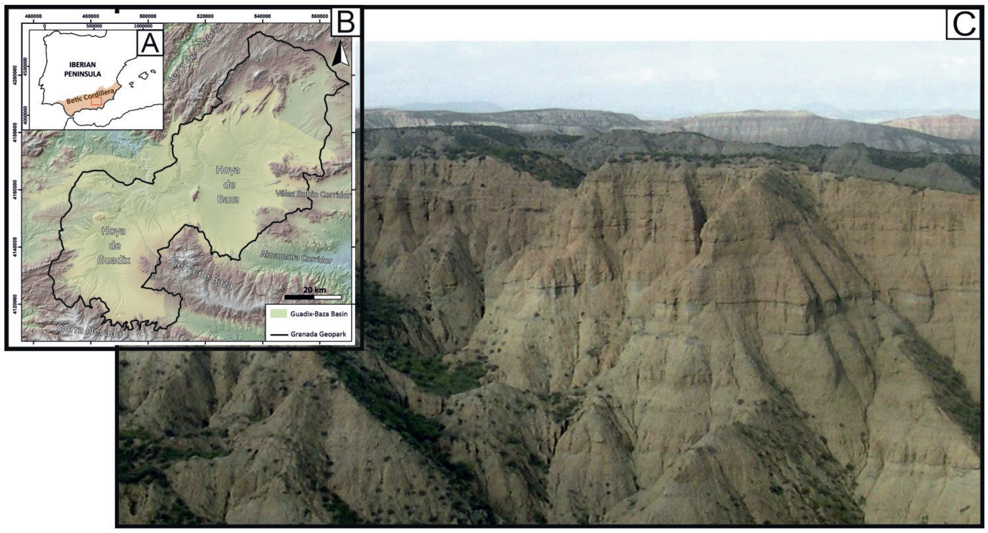

Figure 1.
A: Location of the Granada Geopark in the Iberian Peninsula. B: The Guadix-Baza Basin and the border of the Granada Geopark. C: The badlands landscape of the Granada Geopark is the main attraction to the geotourism, as well as the main regulating factor for the vegetation of the zone. The figures A and B have been made by Dr. Iván Medina.

the nature tourism of the region where the Granada Geopark is delimited (**Figure 1B** and **C**). Other examples where the esthetic value of geomorphodiversity and geomorphosites is highlighted include those related to volcanic areas, karst regions, or areas particularly sensitive to natural hazards [4].

Notwithstanding, the economic value of geodiversity is also linked to the classification of geological materials as resources: fossil fuels, mineral resources, industrial, metallic or precious minerals, or building materials. Related to this topic, in the south of Alicante province (Southeast Spain), the diversity of limestones and dolostones has favored the proliferation of economic activities associated to the ornamental rocks used in the building industry. The economic value of an abiotic environment should also include fossils, soils, and landscapes, as these geological features may lend economic wealth to the place where they are found, either as a means of sustaining agricultural activity or as natural resources to be exploited in the realm of tourism. In this sense, the diversity of ammonoids sites was an important feature considered to define as global geopark the Sierras Subbéticas Natural Park (Betic Cordillera, Córdoba province, South Spain [20]).

Soils, sediments, rocks, landforms, minerals... all play a functional role in the environmental system, which gives them a functional value [2]. Two subdivisions of functional values can be established, depending on whether the elements are perceived as utilitarian values to human society, or as essential substrates to support physical and ecological systems of the Earth. Geodiversity in situ, in its broadest meaning, is useful, regardless of its consideration from an economic standpoint. It is the substrate upon which organic activity settles, providing a means of supporting biodiversity's development.

3. Geodiversity and sustainable development. Geosystem services

Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (https://www.un.org/sustainabledevelopment/development-agenda/; [7]). For sustainable development to be achieved, it is crucial to harmonize three core elements: economic growth, social inclusion, and environmental protection. These elements are interconnected and are basics for the well-being of individuals and societies.

When dealing with environmental protection, both biotic and abiotic resources must be considered, but in different fashion, according to their nature [11, 12, 21, 22]. The definition of ecosystem according to the Convention on Biological Diversity reads a dynamic complex of plants, animals, and microorganisms and their non-living environment, which interact as a functional unit. This definition assumes that the ecosystem includes abiotic elements, the elements of the geodiversity, as well as social elements (**Figure 2**). The World Forum on Natural Capital specifies the world's stocks of natural assets, which include geology, soil, water, and all living things (https://naturalcapitalforum.com/about/), considering geological elements as essential components of the natural environment (Essential Geodiversity Variables, EGV; [10]). The Forum furthermore states that these elements are to be treated differently depending on whether they are renewable or nonrenewable [17]. The latter, which include mineral and energy resources of a geological nature (minerals, industrial rocks, coal, oil, natural gas, etc.) undergo extraction processes that entail environmental impact, particularly visible because it often leads to a deterioration of the wider landscape (biotic and abiotic component), leading to a degradation of the geomorphodiversity [9, 23]. In order to keep this impact minimal, extraction processes that are less and less aggressive with the environment are being designed, and extraction itself is being minimized, with recycling promoted as a sustainability tool [11].

The exploitation of natural resources, integrated into the concept of natural capital, represents benefits for man. These benefits have recently been called ecosystem services [11, 14, 24–26]. However, there are authors [27, 28] who consider that the benefits provided by abiotic elements should not be considered within ecosystem services [11, 29]. This is the reason why some authors have distinguished between ecosystem services, directly linked to biotic natural elements, and geosystem services, provided by abiotic natural elements [14, 17, 29–32].

Geosystem services are directly dependent on the values of geodiversity (intrinsic/scientific, educational, economic, cultural, esthetic, functional). The geosystem services can be defined as the benefits and functions provided to society by the elements that make up geodiversity. Like ecosystem services, geosystems can provide four main types of services [11, 12, 26, 29]: regulating services, supporting services,

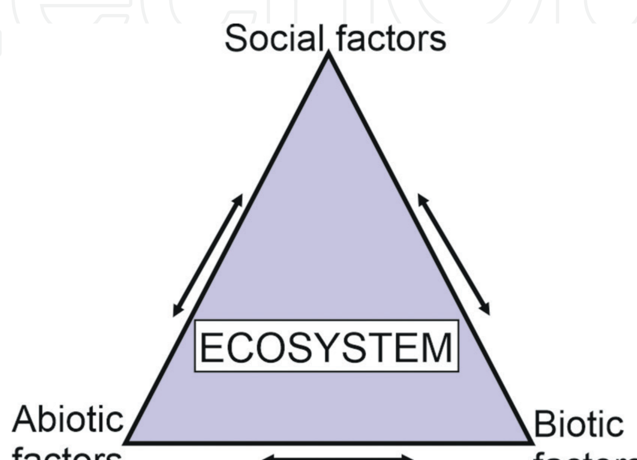

Figure 2.
The three main components of an ecosystem according to the definition of the Convention on Biological Diversity.

provisioning services, and cultural services, which coincide with those proposed by the Millennium Ecosystem Assessment [24]. Besides, Gray [17] has recently proposed a fifth geosystem service, called knowledge, which is related to the fact that Geology provides evidence about the evolution of the planet, both from an inorganic perspective and considering the evolution of life. Regulating services include the natural processes that regulate the environment (oceanic and atmospheric processes, the rock cycle, biogeochemical cycles, flood processes, or the regulation of water quality). These services could be considered at local and regional scales, because should rapport information about the geodiversity of the studied territory and favoring to understand its influence in the human activity.

Supporting services are those processes that serve as a foundation for natural environments, including soil processes, habitat dynamics, land and water as supports for human activity, or the service provided by rocks and sediments for burial and storage. In design and management of the NPAs, the supporting services related to the geodiversity of the territory can firstly understand as the substratum on the living activities is developed. Related to the human activities, the kinds of soils are determinant of the farming activities developed, for example. This is in line with the fact that the consideration of EGVs, especially geomorhodiversity and land uses, entails important heterogeneities in the development of supporting services [9, 10].

Provisioning services are available when natural materials are used by society (water for human consumption, minerals as a source of nutrients or energy (coal, oil, natural gas, tides, winds); ornamental and industrial rocks, fossils, nature conservation, the design of an NPA network …). In the context of the NPA, the provisioning services can be considered according to the use of some rocks in the traditional building activities of the area considered or other local infrastructures.

Finally, cultural services are derived from non-tangible elements of nature that provide spiritual benefits to man (environmental quality, design of natural protected areas, geotourism and leisure, or artistic inspiration, for example). The design of geoturism ways has their support in the cultural services of the geodiversity [8, 9, 33].

Despite this differentiation between ecosystem and geosystem services, several authors [10, 22, 31, 32] propose that both should be considered from a holistic point of view, since both provide well-being to man. However, geosystem services are largely based on the use of nonrenewable natural elements. Their degradation is normally irreversible and cannot be regenerated on the human timescale. However, the analysis of a region's geodiversity and its integration with biodiversity contributes to a higher valuation of geosystem services, especially in natural protected areas, as it provides a better understanding of the natural processes, facilitating the achievement of sustainable development of the NPA under consideration.

4. Relationship between geodiversity and biodiversity

The holistic conservation of nature is an important issue. The coining of terms such as "biophysical management" or "geoecological management" [14, 26] attests to this importance. As used in the definition of IUCN-protected areas, the term "natural" refers to both biodiversity and geodiversity. Following some authors [34, 35], there is a predominance of issues related to biodiversity compared with those of geodiversity, which this organization does not expressly contemplate until its 2008 Congress in Barcelona [21, 22]. Resolution 4040 was approved, urging to design, organize, and oversee activities related with geodiversity and the geological heritage.

To approach the problem of integrated management of the conservation of nature with due precision, the interrelations existing between biodiversity and geodiversity highlighted by several authors [17, 22, 36–38]. They stated that there could be no biodiversity without geodiversity. According to this idea, definitions of geodiversity considered the shared origins, and an interdependency between the two was established. Analysis of these interrelations must consider three levels, global, regional, and local [14, 35].

At the global scale, recognizing the interdependence of biological and geological systems leads inevitably to the hypothesis of Gaia, formulated by Lovelock [39, 40]. He claimed that an interaction among the organic and inorganic components of the Earth existed. The organic elements, along with the air, the oceans, and the terrestrial surface, made up a complex system that may be considered as a cybernetic organism, able to self-adjust through feedback in order to maintain an optimal physical and chemical environment for life on the planet. This integration of biological and geological systems found substantial support with the development of Earth System Science [41–43], investigating the relationships among lithosphere, biosphere, atmosphere, and hydrosphere, in a temporal framework matched to the geological timescale.

Geodiversity, then, incorporates many environmental processes and patterns that manage the biodiversity. They include climate, topography, geology, and hydrology, which altogether provide sources of energy, water, space, and nutrients. In turn, the biological dynamic takes part in processes such as the acceleration or delay of erosion, the stability of hillslopes, fluvial dynamic, and surface water and underwater flow. Knowledge of the action rates of external geological processes, which shape the relief, allows us to know the potential stability of the habitats and the species found in them. A change in these rates would lead to changes in the development of soils, hydrogeological and hydrological conditions, and in short, imbalances in ecosystems [14–16].

At the regional scale, conservation of biodiversity can be best understood through the conservation of geodiversity. It has been postulated that geological factors exert a primary influence on biodiversity patterns [44]. Factors such as the number of rock types, latitude, or the elevation and quantity of carbonate rocks can be used to predict the diversity of species with a high degree of certainty (correlation coefficient $R^2 = 0.94$, according to this research, [44]). These authors conclude that biodiversity is best protected when the geological settings are protected. At this scale, analysis of the relationships between biodiversity and geodiversity cannot overlook three main ideas [3]. The first one is that the spatial-temporal scales of geological and biological processes are different. The second is that the biological processes are interrelated and evolve simultaneously, as do geological processes, but with different rhythms and different timescales. Finally, the third idea is that geological features are related by chronostratigraphic parameters that account for events of short duration as well as events lasting millions of years.

At the local scale, one important step to achieve an integration of biodiversity and geodiversity is to establish relationships among the specific elements to one and other. Three forms of such relations can be distinguished [3]: (a) relations of exclusivity, (b) relations of dependence, and (c) no relation. Relations of exclusivity occur when certain living beings develop in areas with specific geological characteristics. Dependence would prevail when organisms need some (even just one) particular geological feature to develop. For example, vultures need great vertical cliffs to nest, although it does not matter if they are limestone, granite, or conglomerate cliffs. Finally, there is no relation when the living beings of a zone and its geological features have no apparent relationship. In fact, the relationships a and b above as biodiversity-geodiversity interactions should be referred to as dependency relationships between biodiversity and gemorphodiversity, given that organisms can condition their life activity to the development of different landforms that may favor them [22, 44–46].

From the perspective of management and conservation of biodiversity and geodiversity, there is a clear relationship, because both depend on administrative services in charge of the environment. Effective management and conservation of biodiversity call for managing the preservation of the heterogeneity of soils and sediments that ensure its preservation. The degradation of biodiversity in flood plains, for instance, reflects that the methods used to manage the river or changes in land use in the geomorphological fluvial system have led to a separation of the fluvial dynamics and the riverside areas, with the subsequent reduction of natural vegetation diversity [45, 47].

The conservation of nature in areas of high biodiversity should be undertaken from both bioconservation and geoconservation perspectives [2, 14, 35–37]. To this goal, geodiversity and geomorphodiversity must be integrated in the planning of Natural Protected Areas, bearing in mind that they are parts of the ecosystems and that the Earth System approach should entail an integration of biotic and abiotic factors in plans for management and conservation [8–10, 37].

5. Assessment of geodiversity/geomorphodiversity and natural protected areas

The assessment of geodiversity is a subject that has been approached from different perspectives, qualitative or quantitative [11]. The qualitative methods consist of a description of the elements of geodiversity in one area and an explanation of its values based on expert knowledge of the zone. The second group, quantitative methods, attempts to express the spatial variability of the geological elements from an analysis of the diversity, frequency, and distribution of these elements in the studied area (**Table 1**; [3, 46, 48–52]).

Some authors support the assessment on numerical determination of the variety of geosites [53]. It is assumed that a large database of geosites within a given territory means high geodiversity. Other authors look at the geological and geomorphological properties (number of physical elements, roughness coefficient, and surface of the geological/geomorphological unit) of units in a region to define a geodiversity index per geomorphological unit [46, 54]. Other numerical assessments are founded in the use of morphometric, morphoclimatic, and geological classifications to calculate geodiversity indices on the Iberian Peninsula [49]. The use of parameters such as the variety, frequency, and distribution of geological features in a territory has also been proposed as a way of assessing the geodiversity of the territory under study [3].

The assessment of geodiversity based in the variety, frequency, and distribution of geological features considers that the geodiversity is a continuous property of the territory, defining the geodiversity gradient as a measure of the continuous variation of the geodiversity index [3]. Related to the geodiversity gradient, the concept of geodiversity hot-spot has been redefined as geographic areas that harbor very high levels of geodiversity being threatened by human activities [55]. In addition, closely related to the geodiversity hot-spot concept, the antagonistic term geodiversity cold-spot is proposed. Between both areas that have been classified as such, a gradual and continuous change in geodiversity index values could be detected. As geodiversity hot-spots

Method	Parameters/Index			Comments
Serrano and Ruiz-Flaño [46]	Geodiversity index (Gd)	$Gd = Eg\frac{R}{\ln S}$	R: roughness coefficient of the geomorphological unit Eg: number of abiotic elements S: Surface of the geomorphic unit	They use the geomorphological units as reference to attribute the geodiversity values because these units include structure, lithology, soils, climates or vegetation.
Carcavilla et al. [3]	Intrinsic geodiversity (Gi)	$Gi = \frac{C}{S}$	C: geodiversity kinds. S: Surface of the studied area.	The geodiversity is a territory feature. This can change into them as progressive manner. To valuing this, it must be designed isoline maps; each of isolines will link points with the same numerical value of intrinsic geodiversity.
	Kind frequency (Fc)	$Fc=\frac{r_c}{S}$	r_c enclosure number of a geodiversity kind. S: Surface of the studied area.	
	Fragmentation degree (Gf)	$Gf = \frac{r}{S}$	r: number of enclosures in a territory. S: Surface of the studied area.	
Pereira et al. [48]	The geodiversity index is the sum of partial indices of some geological features of the studied area. They are calculated from the corresponding maps with a grid of regular size and superimposed in a GIS.	Geological index: it results from the consideration of geological units (lithologies) that they are present in each square of the grid.		The geodiversity index for each square grid is the sum of partial indices. From this value, that is considered in the center of each square, it does an interpolation between the closest centers to the goal to draw isolines that link points with the same geodiversity index value.
		Geomorphological index: it is the sum of two sub-index, the topography and the hydrography features. The first one gives the main geomorphology features of the studied area. The second one is calculated from the influence of the hydrographic features in the geomorphology.		
		Paleontological index: number of fossiliferous formations that outcropped in each one of the squares of the grid.		
		Pedological index: soils count that outcrop in the pedological maps of the studied area. It is considered the number of soils nature in each square of the grid.		
		Mineral index: into this index, could be included several kinds of minerals (extractable or not), oil, coal, gas, radioactive minerals, minerals water, springs.		

Table 1.
Synthesis of the main methods for assessing geodiversity.

are particularly threatened areas, it is also possible to calculate a threat index, which, together with the geodiversity index, leads to the definition of the sensitivity index and the sensitivity map, which represents areas in urgent need of geoconservation measures [55]. These hot-spots tend to be surrounded by zones where the application of geoconservation measures is not a great concern (cold-spots).

In consonance with the notion of geodiversity gradient, several authors [48] develop a methodology to calculate the index of geodiversity of a territory from the design of a geographic information system (GIS) made up of different layers. This method has been improved by several groups of researchers [50, 51, 56–58], who have added several parameters to characterize the geodiversity of a territory, compiling geological and geomorphological data on the studied area (**Table 1** and **Figure 3**). The geodiversity index shall be the result of the sum of several partial indices (**Figure 3**): (a) lithological index, (b) geomorphological index, (c) paleontological index, (d) pedological index, (e) mineral occurrence index, (f) water resources index, and (g) geosites index. The indices "a" to "e" were proposed by Pereira et al. [48]. Araujo and Pereira [58] added the water resources index and Fernández et al. [51] included the geosites index. An important topic of this methodology is that different maps of partial indices of geodiversity are obtained, including the geomorphological index, which allows us to know the geomorphodiversity of the territory analyzed.

However, the methodology developed by these authors leads to the design of maps of partial geodiversity indices associated with a space determined by a grid of a specific size (**Figure 3**). Certain partial indices, such as the lithological, geomorphological or pedological indices, as well as the geodiversity index, should not be considered as indices of discrete geological properties of the territory, but as the previous step to define maps of continuous properties, so that between indices of adjacent grids it is possible to establish gradients, such as the geodiversity gradient map designed by some authors [48, 51, 52, 58]. According to this idea, from the geomorphological index map (**Figure 4A**), it is possible to obtain a geomorphodiversity gradient map (**Figure 4B**) by applying Kriging techniques between adjacent grid squares in the defined grid. The geomorphodiversity gradient map allows us to know the variability

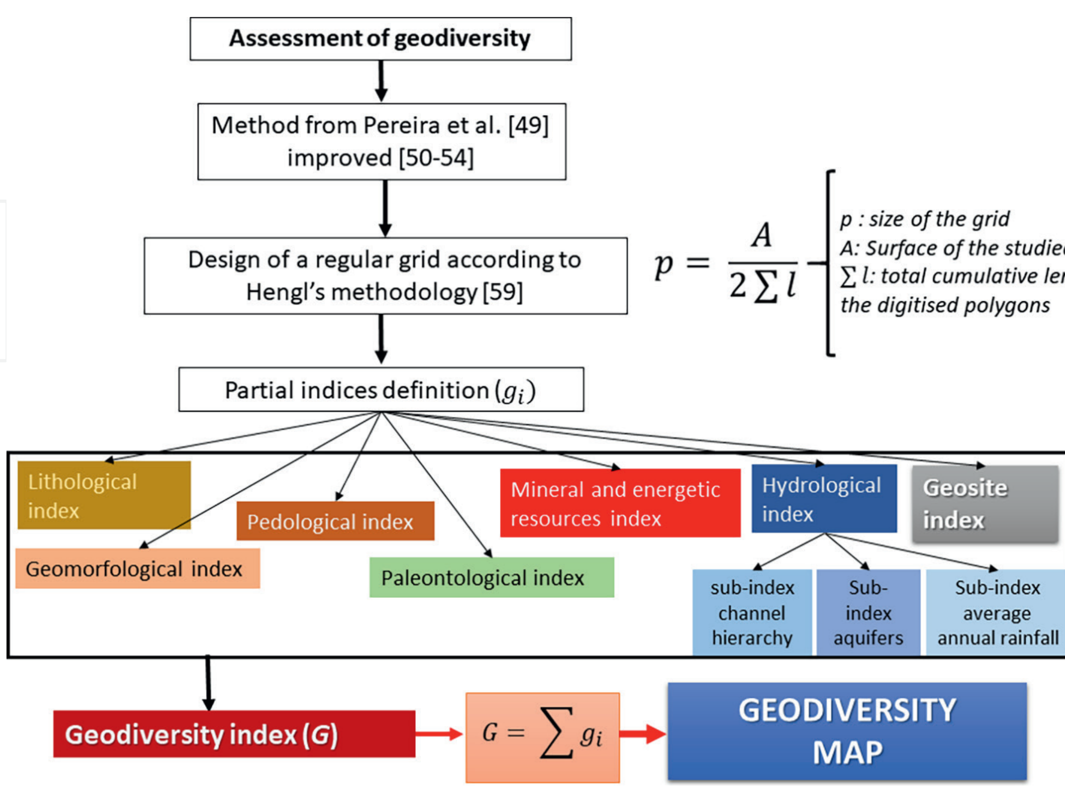

Figure 3.
Flow chart summarizing the geodiversity assessment procedure (see the text) [48, 50, 51, 56–59].

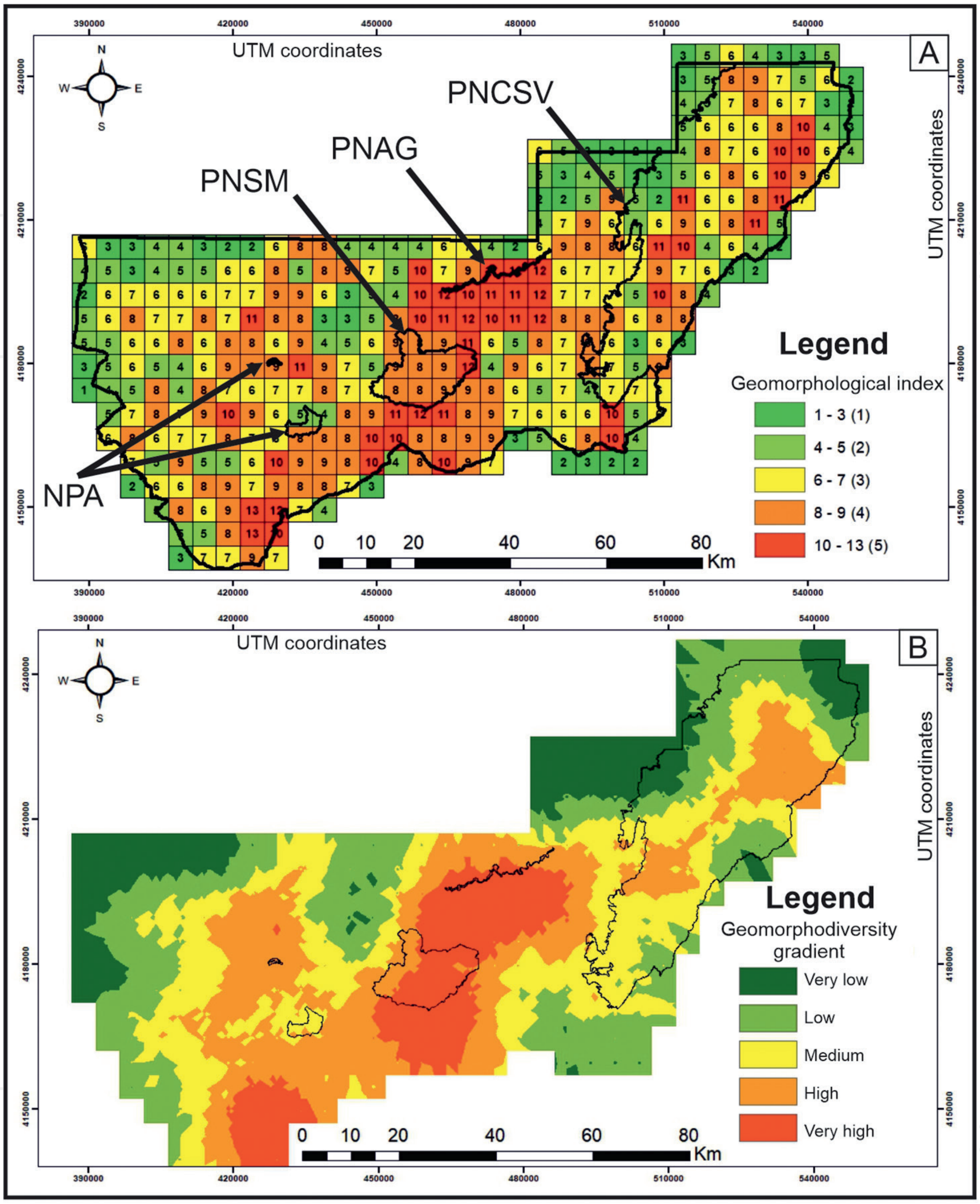

Figure 4.
A: Geomorphological index map of the south and east of the Jaén province determined from the methodology described by Fernandez et al. [51]. The grid has 5×5 km (25 km²). B: Geomorphodiversity gradient map developed to applying kriging on the geomorphological index map. In both maps, PNCSV: boundaries of the Natural Park of Sierra de Cazorla, Segura y Las Villas; PNAG: Alto Guadalquivir Natural Place; PNSM: Natural Park of Sierra Mágina; NPA: other natural protected areas. Both maps are part of an in-progress research project.

of the geomorphological qualities of the territory analyzed, considering that it is a continuous property.

Methods categorized as quantitative are based on a conception of geodiversity index as a measure of the intensity of a certain geological feature or a set of geological elements that characterize the natural setting [60]. This definition of geodiversity indices is useful for reduce the amount of territorial data to be studied, while enhancing the comparability of data belonging to the different areas investigated. On the other hand, the consideration of the lithological, geomorphological, pedological, and water resources indices involves the introduction of the essential variables of geodiversity (EGV, [22]), which have been used, together with other geoenvironmental maps for the assessment of geodiversity and to establish an adequate use of the territory, so that maps on the effects of anthropic activity on the natural heritage are also included in this assessment [10].

Whatever the method applied, the point of departure should be consideration of geodiversity as a key element behind ecosystem dynamics (understood from an integral standpoint, **Figure 2**) for the management of a territory and the use of land and for the development of anthropic activities in a sustainable way. The basic system of representation for an assessment of geodiversity or geomorphodiversity should be the map [60]. This kind of presentation is in line with the conception of both as continuous properties of the territory, in which discrete elements can be delimited and valued independently, but as part of a continuum. A common misconception associated with considering discrete elements of geodiversity (geosites/geomorphosites) as parameters for valuing geodiversity/geomorphodiversity, which is a continuous property, has led to confusion between geodiversity and geological heritage [48].

6. Geodiversity/geomorphodiversity and natural protected areas (NPA)

Several authors argue that to ensure effective management of Natural Protected Areas (NPAs), it is essential to consider the values and the relevance of their geodiversity and the geological heritage as elements of nature [8, 14, 17, 38, 61–63]. This basic notion must materialize and be developed by means of international norms and national laws [64, 65]. Furthermore, it is necessary to establish close links between the inhabitants around the NPA, the geological and biological features of the NPA, and the manager of NPA so that the values of nature, as geodiversity as biodiversity, and the geo- and eco-system services they provide, are clearly inserted in the popular traditions. In UNESCO's definition of Geopark, this is expressed as a basic condition [13, 16, 66].

In the international context, recognition of the importance of geodiversity in general and geomorphodiversity in particular, as well as the geological heritage in a broad sense, calls for their consideration as basic elements of nature, according to the International Union for Conservation of Nature, IUCN [62]. In successive congress, the IUCN has incorporated resolutions about the interest of geoconservation and the need to manage it, within plans for the development of NPAs (Resolution 4040, IUCN 2008; Resolution 5048, IUCN 2012; Resolution 6083, IUCN 2016). It is moreover essential that the principles of geoconservation (**Table 2**) be implemented in the daily practice of NPA management [67, 68].

At this point, it is wise to take a closer look at current Spanish laws of nature conservation. In agreement with article 17 of the Law of Natural Heritage and Biodiversity (Law 42/2007, December, 13, BOE number 299, December, 14, 2007), the goals of Natural Resources Planning (in Spanish, PORN) include the identification and georeference of significant spaces and elements of the natural heritage of a territory. Geodiversity hot-spots [55, 69] are areas on the Earth's surface having a high geodiversity index, but also a high sensitivity index, where geodiversity provides support to biodiversity. In order to conserve geodiversity, it is moreover necessary to consider areas with a low index of geodiversity with the presence of geosites and/or geomorphosites with some heritage value. In both situations, a correct assessment of

1	The values of geodiversity and geological heritage must be recognized
2	Effective geoconservation requires a systematic approximation of all aspects of geosite identification and its management
3	Natural systems management must be a work developed in the nature
4	Natural systems and processes must be managed in a comprehensive way
5	It must be recognized that natural changes are inevitable
6	The effects of global climate change must be considered and acted upon
7	The sensitivity of natural systems must be recognized and managed in accordance with the limits of their ability to change
8	Management of the conservation of active systems must be based on knowledge of abiotic processes
9	Sensitive geosites should manage the number of visitors and promote the education and interpretation of the natural heritage as a whole
10	The interaction and interdependence of geodiversity and biodiversity must be considered in the management of the integral conservation of nature

Table 2.
The ten key points of geoconservation [67].

geodiversity is necessary. Any one of the methods mentioned in the **Table 1** may be used, though the most objective methodology is that of Pereira et al. [48] (**Figure 3** and **Table 1**), improved by subsequent authors. Thus, Araujo and Pereira [58] developed a geodiversity map of the Brazilian state of Ceará with two hot spots, one in the northwest part of the state, and another in the south, where the Global Geopark of Araripe is located. For this same territory, Bétard and Peulvast [55] show a map of the sensitivity index in which the hot-spots—also defined considering biodiversity—do not exactly coincide with those of the previous authors [58]. Nonetheless, the Araripe Geopark hot-spot is nearly coincident in the two research studies.

Mapping helps to zone and regulate land uses that would be formulated in the PORN of the NPA, and in its Plan of Use and Management (PRUG in Spanish). These documents, besides identifying the geological values, should register the risk of degradation of the NPA. In addition, they should check the state of conservation of the geodiversity, so that more adequate management and zoning can be proposed. By distinguishing areas of different geodiversity index values and geosystem services, those with a greater value come to occupy the central zone of the NPA (core zone), surrounded by zones of lesser geodiversity index values, denoted as buffer zones. The maps in **Figure 4** show the boundaries of several NPAs, including the Cazorla, Segura y Las Villas Natural Park (PNCSV), the Alto Guadalquivir Natural Place (PNAG), and the Sierra Mágina Natural Park (PNSM). In these maps it can be seen that the areas covered by these NPAs contain in their central part areas of high geomorphodiversity (PNCSV) or very high geomorphodiversity (PNSM, PNAG), which would be considered as core zones of each of these natural areas. The map of geodiversity gradients can then be confronted with biodiversity maps, affording greater precision and resolution when the limits, zoning, and uses of a territory or NPA are established [51]. Such core zones may contain geosites, to be favored by means of the protection protocols defined for the zone. If a geosite/geomorphosite is located in areas with a low geodiversity index but within a NPA, then the PORN and PRUG could set forth specific actions for the geoconservation of these geosites in view of their nonrenewable nature and according to the key principles shown in **Table 2**.

A common practice for the administrations in charge of NPAs is grouping them in networks of protected natural areas that have common objectives for conservation and management. The network could be defined as a set of natural systems most representative of the territory to which they belong or a synthesis of the best natural heritage. This concept has been developed by the administration in charge of management of the natural environment in Spain. The law governing the National Park Network (Law 5/2007, April 4, of the National Parks Network, BOE n° 81, April 4, 2007) covers the outstanding natural heritage of Spain, whether of a biological or a strictly geological character. The geological ones are defined in frameworks within the Global Geosites Project [70].

The concept of network is advantageous for the management of NPAs as they can ensure an adequate framework for the conservation of natural systems, help the integration of sustainable development models in the area of socioeconomic influence of NPAs, and contribute to raising awareness of the importance of nature conservation in society. The analysis of geodiversity and geomorphodiversity is highly useful in achieving these goals. The continuum of geodiversity or geomorphodiversity allows us to understand the distribution of biodiversity in the NPA in terms of the relationships that can be established between both [67]. On the other hand, the recognition of geodiversity/geomorphodiversity gradients provides information on the natural processes occurring in the territory of the NPA. If areas of high sensitivity are detected (geodiversity hot-spot), specific conservation measures will have to be established for them.

Where anomalies in natural geological processes are detected, specific monitoring measures should be put in place to reveal what is causing the disturbance. Specific conservation protocols will then be established. These situations are particularly easy to observe when analyzing geomorphodiversity [67], as changes in geomorphodiversity often lead to negative impacts on ecosystems and thus changes in biodiversity. It should be considered that the degradation of geomorphodiversity can lead to the development of new geomorphosites associated with new topographic, climatic, hydrological, and pedological conditions, which translate into new environmental conditions that favor the proliferation of biodiversity.

7. Conclusions

Geodiversity, understood in a broad sense, also considering geomorphodiversity, is an element of Nature that is closely related to the biotic components of ecosystems, so that no management of the natural environment can be conceived without considering the interrelations between biodiversity and geodiversity. To this goal, it must be borne in mind that the values of geodiversity (intrinsic, cultural, esthetic, economic, functional, scientific, and educational) provide criteria that support the characterization of the territory. They also help to define the geosystem services that geodiversity entails, so that, from the interaction between geosystem and ecosystem services, it is possible to analyze and design activities that enhance the socioeconomic development of the territory within a framework of sustainability. In order to make a good definition of the NPA, it is also necessary to have an assessment of geodiversity and geomorphodiversity, which provides information on the distribution of the abiotic environment that is considered in the delimitation and definition of the NPA. From this assessment, geodiversity and geomorphodiversity gradient maps are obtained that show geodiversity hot-spot and geodiversity cold-spot, areas of higher geodiversity, with special sensitivity, and areas of lower geodiversity and, therefore, with less restrictive geoconservation needs, respectively. This variability in geodiversity and, in particular, on geomorphodiversity is usually associated with biodiversity, so that areas with high geodiversity or geomorphodiversity are associated with higher biodiversity. Between geodiversity hot-spots and geodiversity cold-spots, there is a gradual transition, which materializes the continuous value of the geodiversity and geomorphodiversity of any territory, which can be an indicator of progressive biodiversity variability.

Of particular interest is the consideration of NPA networks, systems that consider that NPAs are not isolated territorial units, but are closely interrelated on the basis of their natural values (bio- and geo-diversity). The NPAs integrated in the network must be representative of the natural systems of the territory in which the network is defined. From a geodiversity perspective, the network must be based on the consideration of geological contexts (frameworks) that are representative of the main geological units observable in the territory (region, country, ...) in which the network is defined. This variability in geodiversity associated with the differences between geological units (frameworks) leads to biological diversity and the need to establish specific conservation measures (geological and biological), which must be included in the management plans of the NPAs.

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Conflict of interest

The author declares no conflict of interest.

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References

[1] Nieto LM. Geodiversidad: Propuesta de una definición integradora. Boletín Geológico y Minero. 2001;**112**:3-12

[2] Gray M. Geodiversity: Valuing and Conserving Abiotic Nature. Chichester: Wiley; 2004. p. 434

[3] Carcavilla L, López-Martínez J, Durán JJ. Patrimonio geológico y geodiversidad: Investigación, conservación, gestión y relación con los espacios naturales protegidos. Madrid: IGME; 2007. p. 360

[4] Reynard E, Coratza P, Regolini-Bissing G. Scientific research on geomorphosites over the last eight years: Improvements and aims of the book. In: Reynard E, Coratza P, Regolini-Bissig G, editors. Geomorphosites. München: Verlag Dr Friedrich Pfeil; 2009. pp. 5-8

[5] Panizza M. The Geomorphodiversity of the Dolomites (Italy): A key of Geoheritage Assessment. Geoheritage. 2009;**1**:33-42. DOI: 10.1007/s12371-009-0003-z

[6] Worboys GL, Lockwood M, Kothari A, Feary S, Pulsford I, editors. Gobernanza y gestion de áreas protegidas. Canberra: ANU Press; 2019. p. 1013. DOI: 10.22459/GGAP.2019

[7] Brundtland Commission. Our Common Future [Internet]. 1987. Available from: http://www.un-documents.net. [Accessed: 2022-February]

[8] PelliteroR,González-AmuchasteguiMJ, Ruiz-Flaño P, Serrano E. Geodiversity and geomorphosite assessment applied to a natural protected area: The Ebro and Rudron Gorges Natural Park (Spain). Geoheritage. 2011;**3**:163-174. DOI: 10.1007/s12371-010-0022-9

[9] Cameron E. Outside geomorphosites. Geoheritage. 2022;**14**:13. DOI: 10.1007/s12371-022-00652-5

[10] Pereira-Balaguer L, Motta-Garcia da G M, Leite-Ribeiro de L MA. Combined assessment of geodiversity as a tool to territorial management: Application to Southeastern Coast of State of São Paulo, Brazil. Geoheritage. 2022;14:60. DOI: 10.1007/s12371-022-00696-7

[11] Brilha J, Gray M, Pereira DI, Pereira P. Geodiversity: An integrative review as a contribution to the sustainable management of the whole of nature. Environmental Science and Policy. 2018;**86**:19-28. DOI: 10.1016/j.envsci.2018.05.001

[12] Alahuhta J, Ala-Hulkko T, Tukiainen H, Purola L, Akujärvi A, Lampinen R, et al. The role of geodiversity in providing ecosystem services at broad scales. Ecological Indicators. 2018;**91**:47-56. DOI: 10.1016/j.ecolind.2018.03.068

[13] Gordon JU, Bailey JJ, Larwood JG. Conserving nature's stage provides a foundation for safeguarding both geodiversity and biodiversity in protected and conserved areas. Parks Stewardship Forum. 2022;**38**(1):46-55. DOI: 10.5070/P538156118

[14] Gray M. Geodiversity: Valuing and conserving abiotic nature. 2nd ed. Chichester: Wiley-Blackwell; 2013. p. 512

[15] Gray M. Geodiversity: The backbone of geoheritage and geoconservation. In: Reynard E, Brilha J, editors. Geoheritage. Assessment, Protection and Management. Amsterdam: Elsevier; 2018. pp. 13-25. DOI: 10.1016/B978-0-12-809531-7.00001-0

[16] Gray M. Geodiversity, geoheritage and geoconservation for society. International Journal of Geoheritage and Parks. 2019;7:226-236. DOI: 10.1016/j.ijgeop.2019.11.001

[17] Gray M. Geodiversity: A significant, multi-faceted and evolving, geoscientific paradigm rather than a redundant term. Proceedings of the Geologists' Association. 2021;**132**:605-619. DOI: 10.1016/j.pgeoIa.2021.09.001

[18] Brilha J. Inventory and quantitative assessment of geosites and geodiversity sites: A review. Geoheritage. 2016;**8**:119-134. DOI: 10.1007/s12371-014-0139-3

[19] Calvache ML, Viseras C. Long-term control mechanisms of stream-piracy processes in southeast Spain. Earth Surface Processes and Landforms. 1997;**22**:93-105. DOI: 10.1002/(SICI)109-9837

[20] Carruana-Herrera D, Martínez-Murillo JF. Valoración de la geodiversidad del Parque Natural y Geoparque de las Sierras Subbéticas (Córdoba, sur de España). Cuaternario y Geomorfología. 2020;**34**(1-2):5. DOI: 10.17735/cyg.v34i1-2.75529

[21] Gill JC. Geology and the sustainable development goals. Episodes. 2017;**40**(1):70-76. DOI: 10.18814/epiiugs/2017/v40i1/017010

[22] Schrodt F, Bailey JJ, Kissling WD, Rijsdijk KF, Seijmonsbergen AC, van Ree D, et al. To advance sustainable stewardship, we must document not only biodiversity but geodiversity. Proceedings of the National Academy of Sciences. 2019;**116**(33):16155-16158. DOI: 10.1073/pnas.1911799116

[23] Prikryl R. Geomorphosites and quarries. In: Reynard E, Coratza P, Regolini-Bissig G, editors. Geomorphosites. München: Verlag Dr Friedrich Pfeil; 2009. pp. 225-233

[24] Millenium Ecosystem Assessment. Ecosystems and Human well-being: A framework for assessment [Internet]. 2005. Available from: https://wedocs.unep.org/20.500.11822/8768. [Accessed: 2022-June-2]

[25] Gray M. Other nature: Geodiversity and geosystem services. Environmental Conservation. 2011;**38**:271-274. DOI: 10.1017/S0376892911000117

[26] Gray M, Gordon JE, Brown EJ. Geodiversity and the ecosystem approach: The contribution of geoscience in delivering integrated environmental management. Proceedings of the Geologists' Association. 2013;**124**:659-673. DOI: 10.1016/j.pgeola.2013.01.003

[27] Diaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, et al. The IPBES conceptual framework – Connecting nature and people. Current Opinion in Environmental Sustainability. 2015;**14**:1-16

[28] Haines-Young R, Potschin M. Common International Classification of Ecosystem Services (CIDES) V5.1: Guidance on the Application of the Revised Structure [Internet]. 2018. Available from: http://www.cices.eu. [Accessed: 2020-February-15]

[29] Van Ree CCDF, Beukering PJH. Geosystem services: A concept in support of sustainable development of the subsurface. Ecosystem Services. 2016;**20**:30-36. DOI: 10.1016/j.ecoser.2016.06.004

[30] Gordon JE, Barron HF. Scotland's geodiversity: Development of the basis for a National framework. Scottish Natural Heritage Commissioned Report. 2011. p. 417

[31] Gordon JF, Barron HF. Valuing geodiversity and geoconservation: Developing in more strategic ecosystem approach. Scottish Geographical Journal. 2012;**128**:278-297. DOI: 10.1080/14702541.2012.725861

[32] Gordon JE, Barron HF, Hanson JD, Thomas MF. Engaging with geodiversity – Why it matters. Proceedings of the Geologists' Association. 2012;**123**:1-6. DOI: 10.1016/j.pgeola.2011.08.002

[33] Panizza M, Piacente S. Cultural geomorphology and geodiversity. In: Reynard E, Coratza P, Regolini-Bissig G, editors. Geomorphosites. München: Verlag Dr Friedrich Pfeil; 2009. pp. 35-48

[34] Dingwall PR. Legislation and international agreements: The integration of the geological heritage in nature conservation policies. In: Barettino D, Wimbledon WAP, Gallego E, editors. Geological Heritage: Its Conservation and Management. Madrid: ITGE; 2000. pp. 15-28

[35] Matthews TJ. Integrating geoconservation and biodiversity conservation: Theoretical foundations and conservation recommendations in a European Context. Geoheritage. 2014;**6**:57-70. DOI: 10.1007/s12371-013-0092-6

[36] Pemberton M. Conserving geodiversity, the importance of valuing our geological heritage. National Conference, Geological Society of Australia Inc [Internet]. 2001. Available from: https://dpipwe.tas.gov.au/Documents/geocon_abstract.pdf. [Accessed: 2019-December-14]

[37] Peña L, Monge-Ganuzas M, Onaindia M, Fernández de Manuel B, Mendia M. A holistic approach including biological and geological criteria for integrative management in protected areas. Environmental Management. 2017;**59**:325-337. DOI: 10.1007/s00267-016-0781-4

[38] Crofts R, Tormey D, Gordon JE. Introducing new guidelines on geoheritage conservation in protected and conserved areas. Geoheritage. 2021;**13**:33. DOI: 10.1007/s1237-021-00552-0

[39] Gaia LJ. Una nueva visión de la vida sobre la Tierra. Barcelona: Orbis; 1979. p. 126

[40] Lovelock J. The ages of Gaia. 2nd ed. Oxford: Oxford University Press; 1995. p. 255

[41] Lohmann G, Grosfeld K, Wolf-Gladrow D, Unnitham V, Notholt J, Wegner A. Earth System Science: Bridging the Gaps Between Disciplines. Berlín: Springer Briefs in Earth Sciences; 2013. p. 134. DOI: 10.1007/978-3-642-32235-8

[42] Kump LR, Kasting JF, Crane RG. The Earth System. 3rd ed. Harlow: Pearson; 2014. p. 432

[43] Stanley SM. Earth System History. 4th ed. New York: Freeman and Company; 2015. p. 624

[44] Anderson MG, Ferree CE. Conserving the stage: Climate change and the geophysical underpinnings of species diversity. PLoS One. 2010;**5**:e11554. DOI: 10.1371/journal.pone.0011554

[45] Richards K, Brasington J, Hughes F. Geomorphic dynamics of floodplains: Ecological implications and a potential modelling strategy. Freshwater Biology. 2002;**47**:559-579. DOI: doi.org/10.1046/j.1365-2427.2002.00920.x

[46] Serrano E, Ruiz-Flaño P. Geodiversidad: Concepto, evaluación y

aplicación territorial. El caso de Tiermes Caracena (Soria). Boletín de la AGE. 2007;**45**:79-98

[47] Lane SN, Tayefi V, Reid SC, Yu D, Hardy RJ. Interactions between sediment delivery channel change, climate change and flood risk in a temperate upland environment. Earth Surface Process Landforms. 2007;**32**:429-446. DOI: 10.1002/esp.1404

[48] Pereira DI, Pereira P, Brilha J, Santos L. Geodiversity assessment of Paraná State (Brazil): An innovative approach. Environmental Management. 2013;**52**:541-552. DOI: 10.1007/s00267-013-0100-2

[49] Benito-Calvo A, Pérez-González A, Magri O, Meza P. Assessing regional geodiversity: The Iberian Península. Earth Surface Processes and Landforms. 2009;**34**:1433-1445. DOI: 10.1002/esp.1840

[50] Forte JP, Brilha J, Pereira DI, Nolasco M. Kernel density applied to the quatitative assessment of geodiversity. Geoheritage. 2018;**10**:205-2017. DOI: 10.1007/s12371-018-0282-3

[51] Fernández A, Fernández T, Pereira DI, Nieto LM. Assessment of geodiversity in the Southern part of the Central Iberian Zone (Jaén Province): Usefulness for delimiting and managing Natural Protected Areas. Geoheritage. 2020;**12**:20. DOI: 10.1007/s12371-020-00447-6

[52] Nobre da Silva ML, Leite do Nascimento MA, Mansur KL. Quantitative assessments of geodiversity in the area of the Seridó Geopark Project, Norteast Brazil: Grid and Centroid analysis. Geoheritage. 2019;**11**:1177-1186. DOI: 10.1007/s12371-019-00368-z

[53] Ruban DA. Quantification of geodiversity and its loss. Proceedings of the Geologists' Association. 2010;**121**:326-333. DOI: 10.1016/j.pgeola.2010.07.002

[54] Hjort J, Luoto M. Geodiversity of high-latitude landscape in northern Finland. Geomorphology. 2010;**115**:109-116. DOI: 10.1016/j.geomorph.2009.09.039

[55] Bétard F, Peulvast JP. Geodiversity Hotspots: Concept, method and cartographic application for geoconservation purposes at a regional scale. Environmental Management. 2019;**63**:822-834. DOI: 10.1007/s00267-019-01168-5

[56] Silva JP, Rodrigues C, Pereira DI. Mapping and analysis of geodiversity indices in the Xingu River Basin, Amazonia Brazil. Geoheritage. 2015;**7**:337-350. DOI: 10.1007/s12371-014-0134-8

[57] Silva JP, Pereira DI, Aguiar AM, Rodrigues C. Geodiversity assessment of the Xingu drainage basin. Maps. 2013;**9**:1-9. DOI: 10.1080/17445647.2013.775085

[58] Araujo AM, Pereira DI. A new methodological contribution for the geodiversity assessment: Applicability to Ceará State (Brazil). Geoheritage. 2018;**10**:591-605. DOI: 10.1007/S12371-017-0250-3

[59] Hengl T. Finding the right pixel size. Computer & Geosciences. 2006;**32**(9):1283-1298. DOI: 10.1016/j.cageo.2005.11.008

[60] Zwoliński Z, Najwer A, Giardino M. Methods for assessing geodiversity. In: Reynard E, Brilha J, editors. Geoheritage. Assessment, Protection and Management. Amsterdam: Elsevier; 2018. pp. 27-51. DOI: 10.1016/B978-0-12-809531-7.00002-2

[61] Henriques MH, Pena Do Reis R, Brilha J, Mota T. Geoconservation as an emerging geoscience. Geoheritage. 2011;**3**:117-128. DOI: 10.1007/s12371-011-0039-8

[62] Gordon JE, Crofts R, Díaz-Martínez E, Woo KS. Enhancing the role of geoconservation in protected area management and nature conservation. Geoheritage. 2018a;**10**:191-203. DOI: 10.1007/s12371-017-0240-5

[63] Gordon JE, Crofts R, Díaz-Martínez E. Geoheritage conservation and environmental policies: Retrospect and prospect. In: Reynard E, Brilha J, editors. Geoheritage. Assessment, Protection and Management. Amsterdam: Elsevier; 2018b. pp. 213-229. DOI: 10.1016/B978-0-12-809531-7.00012-5

[64] Nieto LM, Pérez-Lorente F, Guillén-Mondéjar F, Díaz-Martínez E. Estado actual de la legislación para la Geoconservación en España. Trabajos de Geología. 2006;**26**:187-201

[65] Carcavilla L, Durán JJ, García-Cortés A, López-Martínez J. Geological heritage and geoconservation in Spain: Past, present, and future. Geoheritage. 2009;**1**:75-91

[66] Brilha J. Geoheritage and geoparks. In: Reynard E, Brilha J, editors. Geoheritage. Assessment, Protection and Management. Amsterdam: Elsevier; 2018. pp. 323-335. DOI: 10.1016/B978-0-12-809531-7.00018-6

[67] Gordon JE. Geoconservation principles and protected area management. International Journal of Geoheritage and Parks. 2019;**7**:199-210. DOI: 10.1016/j.ijgeop.2019.12.005

[68] Woo KS, Worboys G. Geological monitoring in protected areas. International Journal of Geoheritage and Parks. 2019;**7**:218-225. DOI: 10.1016/j.ijgeop.2019.12.004

[69] Gray M. Geodiversity: Developing the paradigm. Proceedings of the Geologists' Association. 2008;**119**:287-298. DOI: 10.1016/S0016-7878(08)80307-0

[70] García-Cortés A, Rábano I, Locutura J, Bellido F, Fernández-Gianotti J, Martín-Serrano A, et al. First Spanish contribution to the Geosites Proyect: List of the geological frameworks established by consensus. Episodes. 2001;**24**(2):79-92