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Geodiversity and its implications in the conservation of biodiversity: Some case studies in central Mexico

Geodiversidad y sus implicaciones en la conservación de la biodiversidad: algunos estudios de caso en el centro de México

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Abstract
We explore the conceptualization of geodiversity and its implication in the conservation of biodiversity; furthermore, we present the perspective of some Mexican naturalists of the XIX century regarding geodiversity, and case studies from central Mexico that evidence the importance of the fossil record in the conservation of nature. The study is based on the revision of previous interpretations about the concepts and field work in fossiliferous localities of Puebla and Hidalgo. It is shown that fossils are part of geodiversity that testify the evolution of biota in the geological past, playing an important role in the proposal of strategies for biological conservation. Thus, paleobiological conservation integrates paleontological and ecological information used as evidence to understand current environmental modifications and alterations.

Keywords: geodiversity, biodiversity, fossils, paleobiology conservation.

Resumen
Se explora la conceptualización de geodiversidad y su implicación en la conservación biológica; asimismo, se presenta la perspectiva de algunos naturalistas mexicanos del siglo XIX sobre la geodiversidad y estudios de caso del centro de México que evidencian la importancia del registro fósil en la conservación mediante la revisión de interpretaciones previas acerca de los conceptos y trabajo de campo en localidades fosilíferas de Puebla e Hidalgo. Los fósiles forman parte de la geodiversidad, los cuales testifican la evolución de la biota en el pasado y tienen un papel importante en la propuesta de estrategias para la conservación. Así, la paleobiología de la conservación integra información geológica y ecológica utilizada como evidencia para reconocer las modificaciones y alteraciones ambientales actuales.

Palabras clave: geodiversidad, biodiversidad, fósiles, paleobiología de la conservación.

Introduction

The Earth is an open system integrated by abiotic (geosphere, atmosphere, and hydrosphere) and biotic (biosphere) components (Shikazono, 2012), which represent the natural diversity of our planet (Tukiainen, 2019). Hence the terms geodiversity and biodiversity have been proposed to refer to these two elements respectively (Figure 1).

There is a close relationship between geodiversity and biodiversity, considering that the geological evolution of a particular area has produced the range of geomorphological features that make up the landscape, which in turn represents a variety of habitats potentially inhabited by different kinds of organisms (Gray, 2005; Gordon & Barron, 2013); furthermore, components of geodiversity provide resources for species, such as energy, water, nutrients, and space (Parks & Mulligan, 2010).

By the same token, geodiversity affects patterns of biodiversity directly and indirectly. In this regard, conditions of the environment directly affect the physiological limits of individuals, whereas the topography, the habitat arrangement, and the geophysical configuration define (partially) the diversity of niche (Zarnetske *et al*., 2019).

Ecosystem services that benefit humankind are not only defined by the biotic elements of an area, but they are also related and supported by abiotic characters, such as rocks, minerals, soils, and water among others, which correspond to the geodiversity of the area. The interrelationships between biodiversity and geodiversity allow the maintenance of ecosystem services, although it is not always recognized. The benefits to humans produced by geodiversity, independent of the interaction with biotic nature have been referred to as geosystem services or abiotic ecosystem services (Gordon, 2019; Gray, 2012, 2019; Fox *et al*., 2020); nevertheless, these valuable geosystem services are usually excluded in management decisions (Fox *et al*., 2020).

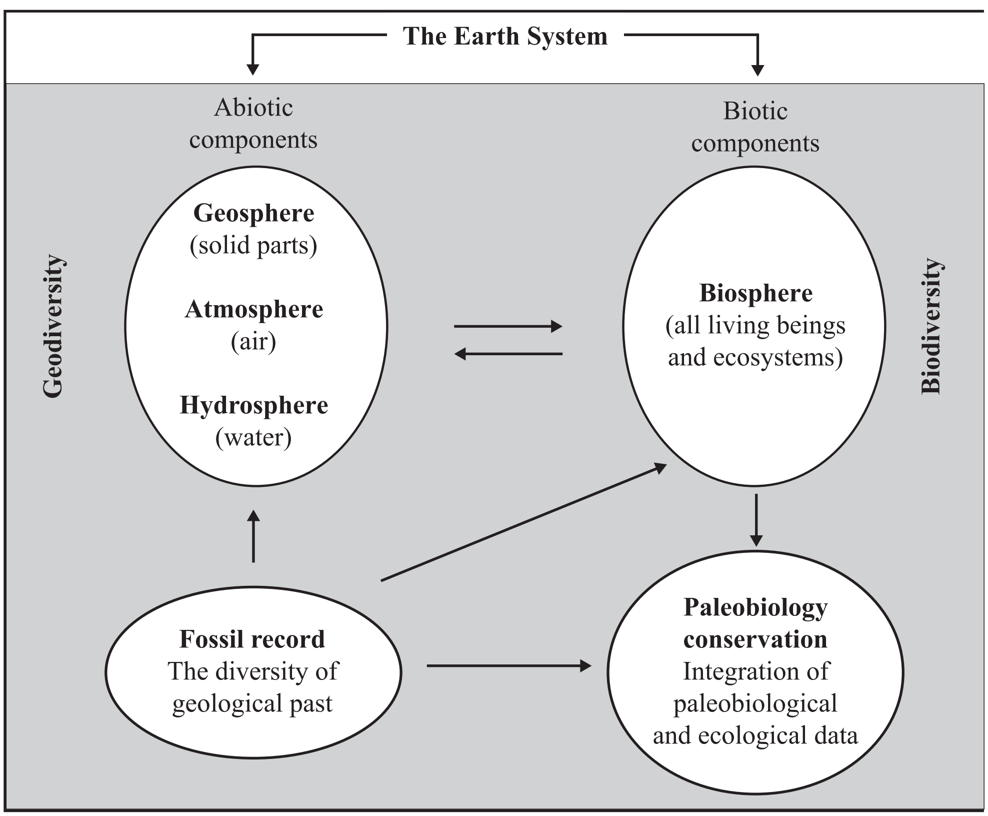

FIGURE 1
The Earth system and interrelationships between the abiotic (geodiversity) and biotic (biodiversity) components, including integration of fossil record and abiotic landscape components in conservation of the biodiversity (Paleobiology conservation). Concept of the figure by the authors and drawing by Elizabeth Ortiz Caballero.

Fossils have been considered as a component of geodiversity (Gray, 2004, 2005, 2011). As it is known, any evidence of an organism (from biomolecules to a single complete individual) or traces produced by biotic activity (tracks, trails, burrows, and coprolites, among others) of a past geological age (minimum age ca. 10 000 years) could represent fossil evidence preserved in sedimentary rocks (Prothero, 2004). Formation of a fossil certainly implies the transition of organic remains from the biosphere into the lithosphere, whose quality of preservation depends on the intervention of the physical-chemical and biological conditions where the process occurred (Martin, 1999). It is observed that fossils in their current form are part of the inorganic substrate, although they were once-living organisms of a particular geochronological interval, evidencing the evolutionary history of life on Earth, i.e., the biodiversity of the geological past. By contrast, biodiversity refers to the extant biota at all levels of organization (from genes to ecosystems), including the ecological, evolutionary, and cultural processes that maintain it, as declared during the Convention of Biological Diversity in 1992.

Conservation of extant biota is one substantial concern for humanity, given the accelerated decline and loss of species and habitats observed in recent decades. Therefore, countries around the world are searching for the best solutions to mitigate these losses. It has been recognized that geodiversity supports biodiversity (Gray, 2004; Zarnetske *et al*., 2018; Boothroyd & McHenry, 2019), although their interactions have not always been analyzed in detail and the importance of each component of geodiversity, such as the fossil record, has neither been evaluated.

As mentioned above, geodiversity provides geosystem services whereas biodiversity provides ecosystem services. Geodiversity has the same fragility as biodiversity because it is impacted by several factors, such as the overexploitation of rocks by quarrying operations, destruction of geosites by urban expansion, interference with the operation of natural processes by engineering of river banks or coastlines, soil erosion derived from unsustainable agricultural practices, and the remodeling of topography among others (Gray, 2008). Hence, it is evident that geodiversity (including fossils), like biodiversity, needs to be preserved (Hjort *et al*., 2015).

The purposes of this study are to present the conceptualization of geodiversity and its effects in the conservation of biodiversity, we also include a historical approach about the perspective of geodiversity of some Mexican naturalists of the XIX century and some case studies of the fossil record from central Mexico to exemplify the importance of paleobiology conservation in the maintenance of nature.

1. Conceptualizing geodiversity

The term geodiversity was first used in some works about the significance of landforms and geological sites and its conservation from areas of Tasmania, Australia in the mid-1990s (Sharples, 1993; Dixon, 1995; Kiernan, 1996). There are several definitions of geodiversity, some authors used it to refer to geological diversity whereas others to geographical diversity, and in other instances, it has been related to geological and geomorphological features that comprise the abiotic environment (Carcavilla *et al*., 2008) (Table 1). It is notable the definition of the International Association of Geomorphologists (2003), which indicates that geodiversity includes the geological and geomorphological environments considered as the basis for the biological diversity on Earth. According to Gray (2004: 8), "geodiversity is the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes), and soil features. It includes their assemblages, relationships, properties, interpretations, and systems". The enormous geodiversity on Earth results from different factors, such as plate tectonics, climatic differentiation through space and time, and evolution creating the diversity of the fossil record (Gray, 2008).

It is known that geodiversity provides the abiotic basis for the development of life on Earth (Royal Scottish Geographical Society *et al*., 2010). Particularly, the fossil record evidences the changes [increasing (speciation) or diminishing (extinction)] of biodiversity through geological time (Kozlowski, 2004), representing one of the components of geodiversity that testifies the evolutionary history of the biota.

Conceptualizing geodiversity as the underpinning foundation for living organisms has important implications, for example, *a*) the need for inclusion of geodiversity in the global conservation agenda, such as the United Nations

Agenda for Sustainable Development, *b*) the design and valuing of geodiversity within the criteria to establish and manage natural protected areas (Tukiainen *et al*. 2017), and *c*) the valuation of natural heritage (ProGeo, 2017). These implications gain even more relevance when considering the European Association for the Conservation of the Geological Heritage, which assures that geodiversity, together with biodiversity, give society important ecosystem services. Geoconservation arises then as a response to safeguard geodiversity, which has its foundation from the geological sciences (ProGeo, 2017).

TABLE 1
Components of geodiversity based on several definitions*

Author/year	Nieto (2001)	Gray (2004)	Kozlowski (2004)	ProGEO (2017)
Geodiversity components	Constituents: Minerals, rocks, fossils, soils Sediments Tectonics	Geological features: Rocks, minerals, fossils Soils Geomorphological features: Landforms, geomorphological processes	Atmosphere Lithosphere Morphosphere Pedosphere Hydrosphere Biosphere	Minerals, rocks, fossils, landforms, landscapes, soils Geological processes Geomorphological processes

*Note: Geodiversity can be characterized by three fundamental elements: *a*) terrestrial constituents, *b*) terrestrial processes, and *c*) landforms[1] (Guerrero-Arenas & Bravo-Cuevas, 2011).

2. An integral view of the fossil record

The fossil record is a book in which the history of life is written, although this "document" does not have all the pages because the conditions necessary to preserve organic remains are particular. In this regard, hard parts of organisms are fossilized more frequently and some sedimentary environments are suitable for fossilization. Fossil remains are prone to weathering, erosion, and metamorphism and are eventually expose on the Earth's surface to be discovered. Finally, they are collected and studied by paleontologists (Mayer, 2014). Even with these limitations, the study of life from the past has provided information on the evolution of organisms (morphological, ecological, and biogeographical among others) and biotic changes on the planet throughout the Earth History, which in turn are related to the different environments that have existed over time.

Until the mid-XX century,, the study of fossils was considered a kind of scientific curiosity since the approach was related only to the description and reconstruction of the organism under study. However, since the emergence of paleobiology (Sepkoski, 2009), the fossil record has gained importance in understanding biodiversity and conservation, as many of the inferences obtained from fossils and the rocks where they are found can be extrapolated to current environmental conditions and possible changes that will occur in the future.

In this way, the analysis of fossil record has allowed to answer questions such as: When and how did terrestrial tetrapods emerge? What environmental conditions prevailed for plants to invade land? Which factors were involved in the mass extinction of the late Paleozoic? The answers that have been generated resulted in the interaction between paleontology, biology, and geology, because the study of fossil remains would not be enough to explain such complex queries that allow the history of Earth to be assembled more accurately.

Hence, the conservation of sites with fossil remains is important because they represent pieces of the history of life on Earth. Some sites, due to the conditions that prevailed during the time of their formation, store exceptionally well-preserved fossils that can be used to fine-tune some geological history chapters. These fossil quarries are called Lagerstätten because they carry highly prized specimens to understand the evolution of ecosystems (Nudds & Selden, 2008).

Other aspects of the history of Earth, such as the geographic distribution of species, can be visualized through fossils, as it is described in the following example with Mexican fossils. In the late 1990s, in a small town called Ventoquipa in the southeastern region of the state of Hidalgo, central Mexico, the skeleton remains of an individual of *Mammut americanum* and some isolated vertebrae of *Bison* sp. were collected. The presence of bison remains in the area is indicative of a Rancholabrean NALMA (North America Land Mammal Age) (Bell *et al*., 2004). The American mastodon *Mammut americanum* was one of the most abundant and widespread proboscideans of North America during the Pleistocene, which has been reported from Alaska to northern and central Mexico. The record from Hidalgo represents the southernmost occurrence of an American mastodon within the subcontinent, providing evidence that this proboscidean reached areas of southern temperate North America where savanna-like habitats were common (Bravo-Cuevas *et al*., 2015, 2017).

As it is observed, the fossil record contains information that leads to a better understanding of the history of life on the planet, and in the same manner, the conservation of fossil sites is necessary. The conservation of geodiversity is of paramount importance because it testifies the biotic and abiotic changes that have occurred on the planet in the geological past. This information represents the basis to understand the actual environmental perturbations (natural and/or anthropic) and could be used in the development of strategies for conservation of the extant biota.

3. A historical approach of the Mexican geodiversity

As it was previously stated, until the middle of the XX century, the study of fossils was considered a scientific curiosity that involved only describing and reconstructing the organisms under study. However, this was due to the scope of the discipline. In the XIX century, natural history was a single science that took in geology, paleontology, mineralogy, botany, and zoology, so some naturalists carried out studies that integrated multiple environmental aspects. These studies can be considered background to geodiversity as a basis for biodiversity.

In one of these studies, Mariano Bárcena (1875) investigated the Mesozoic rocks of the Mineral del Doctor System in the state of Queretaro and the Santa María de Los Alamos System in the state of Hidalgo. He divided his work into four parts. In the first part he made a study of the rocks, in the second he described the fossils he found (various species of the genera *Hippurites*, *Nerinea*, *Ammonites*, and *Scaphites*), in the third he dealt with stratigraphy and orography, and in the fourth, he set out his general observations and his conclusions. A very interesting aspect of his study is that he compared the two systems, not only in terms of the aspects treated in the first three parts of his work (rocks, fossils, stratigraphy, and orography) but also the vegetation growing on them. He found that in Mineral del Doctor, cactuses grew at low elevations where the soils were calcareous, while cypresses, oaks, and firs grew in clayey deposits at elevations above one thousand meters above sea level. In Santa María de Los Alamos sweetgum forest was abundant.

In another article, Bárcena (1876) described a new species of crustacean, which he named *Spheroma burkartii*. He also remarked on some of the geological features of the Ameca Valley, Jalisco, where the crustacean was found. He noted the changes that the region had undergone through different geological periods: in the early Cenozoic period there were seas where spheromas lived, such as the species he had studied; later on, in the Pleistocene, elephants and mastodons lived near the lakes that occupied a great part of the valley. In his own present time, Bárcena added, there was fauna typical of our warm climates, such as jaguars, pumas, ocelots, lynxes, coyotes, Mexican wolves, deer, rodents, armadillos, and peccaries.

Another naturalist, Manuel María Villada, made several visits to different volcanic areas of Michoacán to study their geology and botany. He explored the San Andres, Las Humaredas, and Los Azufres Mountains, among others, and described the fumaroles that "act as safety valves to attenuate the terrible manifestations of the inner forces of the Earth" (Villada, 1890: 419). One of his interests was to find out how the sulphurous waters that flow out of the ground impact the vegetation. He observed that the trees near the Azufres lagoon were withered and destroyed. He made lists of the species of plants he found in the different sites he visited. The only observation he made about fossil evidence was that the volcanic and sedimentary formations along the road, of Cenozoic origin, are related to those of the Mesozoic because of the remains of *Ammonites* found in them.

Villada visited the Tolantongo caves in the state of Hidalgo during the first decade of the XX century (Villada, 1910), where lead mines had been exploited in El Cardonal. He stopped at this site to learn more about the extraction process and inspected some samples. In the area, he described the rock unit Los Libros that was at a ravine with pines and junipers and whose named derived from a series of limestone layers arranged in prismatic columns that look like the backs of giant books. He continued his journey to the Rancho La Mesa and the Hacienda Santa Rosa La Florida, observing waterfall and native vegetation such as anacahuite (*Cordia alba*) and angular fruit milkvine (*Gonolobus virescens*). As he crossed a plateau that led him back to El Cardonal, he described arid vegetation and pointed out that the rocks in the region were of marine origin, considering the presence of fossil fragments belonging to rudists, extinct marine heterodont bivalves, which were scattered on the terraces of some of the mines. He explained the presence of these marine fossils based on The History of the Earth by Launay, which proposes that orographic movements caused the emergence of mountain ranges, such as the Alps in Europe and the Andes in America, where ancient seas were located. In this regard, Villada mentions that "Thus we see in the region under consideration, folded and dislocated layers containing marine fossils, raised to hundreds of meters high" (Villada, 1910: 43).

Bárcena and Villada were professors of geology and paleontology at the National Museum, the first research center in post-independent Mexico. They were not the only naturalists who carried out this type of work but they are mentioned here as an example of how the discipline of natural history allowed for a more holistic view of science before it was divided into many specialized disciplines. Although this division was necessary if natural phenomena were to be studied in more depth.

4. Fossils in the conservation of biodiversity

The fundamental tasks of biological conservation include the assessment of the human activities impact on biodiversity and the proposal of strategies to minimize the impairing of the biodiversity. Several methods have been developed to obtain information concerning the "health status" of the biosphere (Gerber, 2010). In this regard, the strategies are primarily based on the current status of the ecosystems, the anthropic impact, and global warming (Rudd, 2011).

The success of biological conservation, developed by more than one hundred countries around the world, added to the Convention on Biological Diversity (1992) that is based on instruments and national action plans proposed by many entities at different levels that focus in the conservation and sustainable use of biodiversity, as well as to equally distribute the benefits that it provides to human societies. According to Crofts (2014), the Earth Science community should develop similar statements and protocols for conserving geodiversity; nevertheless, in many instances this not occurs. It is noted that geodiversity could be used as a strategy for the conservation of biodiversity, considering that areas where geodiversity is high are (potentially) able to support high biodiversity, because organisms depend on the abiotic "stage" on which they exist (Tukiainen, 2019).

The formalization of biological conservation occurred over half a century ago and it is considered as a holistic discipline supported by other sciences, such as genetics, ecology, biogeography, and evolutionary biology, among others. At the beginning of this century, the significance of the fossil record in the better understanding of the processes that regulate and maintain an ecosystem has become evident, resulting in the paleobiology conservation (Louys, 2012; Dietl & Flessa, 2017). Hence, the fossil record represents evidence that can be used to recognize the natural variation of an ecosystem ("noise") or detect changes related to an ecological disturbance ("signal") (Hadly & Barnosky, 2009, 2017). Hence, it could be used in the proposal of strategies for the optimal management of current ecosystems (Conservation Paleobiology Workshop, 2012).

Conservation paleobiology is a new discipline that has been developed during the last two decades (Tyler & Schneider, 2018). Its scope consists of the integration of paleontological and ecological data in order to conserve the current biodiversity and ecosystem services, as well as to have a better understanding of long-term ecological processes (Dietl & Flessa, 2011; Dietl *et al*., 2015; Tyler & Schneider, 2018; Schrodt *et al*., 2019). Conservation paleobiology has been generally applied in ecological phenomena whose time interval includes the Quaternary

(2.58–0.0 Ma) and has been informally named as the Anthropocene, although the entire biodiversity of the geological past is potentially considered (Dietl & Flessa, 2011, 2017; Tyler & Schneider, 2018). Two approaches in conservation paleobiology have been proposed, using the beginning of the Pleistocene epoch as an arbitrary temporal line, referred as to "near-time" (pre- 2 Ma) and "deep-time" (post- 2 Ma) studies (Dietl & Flessa, 2009, 2011).

Conservation of biodiversity and environmental services require an imbricated relationship between paleontological and ecological data. Many efforts have been accomplished to evaluate and to preserve biodiversity through the establishment of global conservation strategies, laws, and budgets among others, but the importance of geodiversity has been commonly underestimated.

Biodiversity provides genetic resources, fibers, aesthetic value, and other components of provision, support, regulation, and cultural services. Geodiversity provides the substrate and landform mosaics for habitat development, spiritual benefits (e. g. caves are important elements of many cultures), and information regarding long-term processes such as evolution (Hjort *et al*., 2015).

The framework about environmental services recognizes that many processes occurred in the interphase between the biotic and abiotic components of the Earth. The maintenance of environmental services and conservation of nature requires the incorporation of biodiversity and geodiversity criteria with a multiscale approach, including landscape, regional, and small geosites. Given the relationship between biodiversity and geodiversity is that biota has adapted to particular geosites, including caves, cliffs, and metalliferous soils, among others (Hjort *et al*., 2015). Additionally, there is evidence that suggests that species richness is related to several geodiversity variables (Kärnä *et al*., 2019). Therefore, a higher geodiversity would promote higher biodiversity, considering time enough to allow adaptation and speciation.

5. Significance of Mexican geodiversity: Some case studies from central Mexico

As previously stated, geodiversity carries many supporting services for biodiversity, such as the substrate and landform mosaics for the habitat development, the soil formation, the biogeochemical and water cycling, and the geomorphological processes for habitat maintenance. It also contains information about past biodiversity (fossils, pollen, fungal spores) and about changing factors that affect biodiversity (e. g., climate change, volcanism, erosion, and sedimentation) (Hjort *et al*., 2015).

Geosites are important to biodiversity because they support rare or unique biota adapted to distinctive environmental conditions or create microenvironments that improve species richness, including caves, cliffs, limestone, tufa, travertine, waterfalls, river bars, frost sites, dunes, and temporary pools (Hjort *et al*., 2015). Geosites are susceptible to pressures from human activity; the urbanization, commercial, industrial and infrastructure developments, mineral extraction, land use changes, coastal defenses, river engineering, and loss of moveable geoheritage like fossils and minerals, could produce this vulnerability (Gordon, 2019).

There are many examples of this vulnerability and new studies and methods to manage geoconservation and biological conservation have emerged recently (Gordon & Barron, 2013; Gordon, 2019; Tukiainen *et al*., 2017; Brilha, 2018; Brilha *et al*., 2018; Toivanen *et al*., 2019, Kärnä *et al*., 2019; Fox *et al*., 2020). These studies have been developed mainly in Europe but in the Americas they are scarce.

The International Union for Conservation of Nature (IUCN) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO by its acronym in Spanish) have proposed some geological sites as protected areas, such is the case of the Yellowstone National Park, which has suffered damage over the years by visitors who have removed almost complete fossil tree trunks from the area (Gray, 2008). In this regard, Mexico is not an exception, as it is evidenced in the following cases.

The locality San Juan Raya in the state of Puebla of Aptian age is an example of a loss of geodiversity by human activities. More than twenty years ago the site was completely covered by marine fossils of bivalves, gastropods, corals, annelids (serpulids), echinoids, and ammonoids, recovered from different lithofacies of shale and siltstone, and fine-grained sandstone (Serrano-Brañas & Centeno-García, 2014), which support an enormous biodiversity of xerophilous scrub plants and animals (Figure 2A-2B, Figure 3A). It should be noted that for many years, residents and visitors, have reduced considerably the volume of fossils, because of traded. Fortunately, inhabitants of the municipality and authorities understood the importance of this patrimony and built a local museum where fossil specimens are preserved and exhibited for visitors. They also develop activities of geotourism that help them to their economy; furthermore, the zone has been included in the Biosphere Reserve Tehuacán-Cuicatlán, which was recognized by the UNESCO (2018) as a World Heritage Site.

Over the Mexican territory, several examples show geodiversity as an important component of the landscape that supports biodiversity. In the state of Hidalgo, it is possible to identify a part of the geological evolution of the Mexican territory. Particularly, areas in the Sierra Madre Oriental and the Trans-Mexican Volcanic Belt physiographic provinces become of interest in terms of their geodiversity. The landscape of the northeastern portion of the state of Hidalgo in the Sierra Madre Oriental physiographic province is characterized by mountains, canyons, plateaus, and rivers, where Proterozoic and Paleozoic rocks outcrop, in some areas in Molango (Suter *et al*., 1997; Ortega-Gutiérrez *et al*., 1997), as well as in Calnali and Tianguistengo (Buitrón *et al*., 1987, 2017). Fossil remains referable to crinoids, fusulinids, and brachiopods have been recovered from these rocks, which represent the substrate of pine and oak forests inhabited by an important diversity of fauna. Likewise, rocks belonging to the Huayacocotla Formation from the Lower Jurassic are exposed in this region, containing ammonoids, bivalves, and crinoids (Esquivel-Macías *et al*., 2017).

The National Institute for Federalism and Municipal Development (INAFED by its acronym in Spanish) has considered the Mezquital Valley as a geocultural region of the state of Hidalgo. This region includes 28 municipalities in the Sierra Madre Oriental and the Trans-Mexican Volcanic Belt physiographic provinces (INEGI, 1992). Mesozoic and Cenozoic rocks resulted from the Laramide Orogeny and erosional processes are observed in this region. The topography is heterogeneous, including basins, rivers, springs, plateaus, and mountains, which in most of its extension is covered by xerophilous scrub typical of dry weather and alkaline soils (e. g., cactus, biznaga, nopal, and maguey), although conifer forests are also present (Figure 2C-2D). Marine Cretaceous calcareous rocks of the Albian-Cenomanian referable to El Doctor Formation and those of the Trancas Formation of Late Jurassic and Turonian are exposed in the Mezquital Valley (Segerstron, 1956), which also support xerophilous scrub. These rock units are exploited for building and construction in some quarries of the Ixmiquilpan, Zimapán, and Nicolás Flores municipalities. A great part of the quarrying is artisanal, although in the National Park Los Mármoles, the largest natural protected area in Hidalgo, the exploitation is intensive.

The National Park Los Mármoles is situated in the Sierra Gorda physiographic province of Hidalgo and the Valles - San Luis Potosí carbonate platform geological province, separated from the El Doctor platform by the Zimapán shelf basin (Suter *et al*., 1997). The calcareous rocks of the Valles-San Luis Potosí Platform are the precursors of the marble originated by hydrothermal metamorphism during the Eocene-Oligocene. The topography of the park includes regions at elevations of 2,820 masl like the Cangandó Mountain and the San Vicente Canyon with a depth of 600 m. The flora consists of juniper, oak-pine forest, ferns, lycopodia, scrubs, and grasses to a lesser extent (Ramírez-Cruz *et al*. 2009), some of these vegetation types use calcareous rocks that bear fossil remains as a substrate (Figure 3B).

The geological richness in the park is enormous, consisting of limestone, shale, slate, marble, and minerals such as silver, lead, zinc, and copper, which are exploited in sites such as Zimapán, Pacula, Nicolás Flores, and Jacala (SGM, 2011). It is noted that the exploitation of calcareous rocks and minerals is continuous, deteriorating the ecosystem at different levels and promoting the loss of biodiversity. In this regard, the exploitation of limestone and marble are mainly handmade and empirical, whereas mining companies exploit minerals. The lack of experience in limestone and marble quarries exploitation, construction of roads to communicate mines, mine waste disposal (e.g., sediments and arsenic), expansion of the urban stain, deforestation, soil erosion, among others, have modified considerably the landscape.

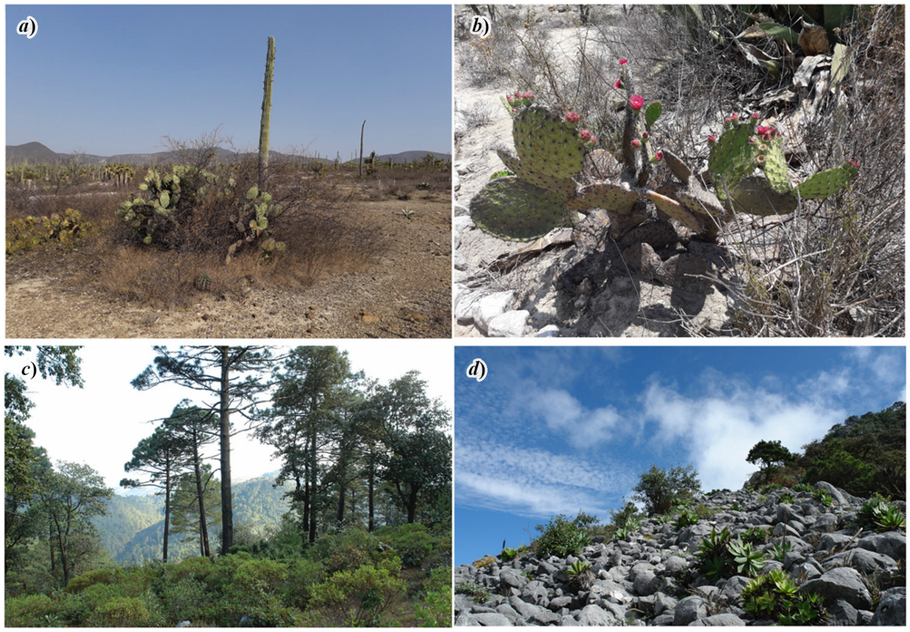

FIGURE 2

Note: A. Typical xerophilous scrub plants of San Juan Raya, Puebla state, showing the columnar cactus *Neobuxbaumia tetetzo* growing on the fossiliferous substrate; B. Flourishing *Opuntia* sp. from San Juan Raya; C. *Pinus* sp. forest of Puerto de Piedra, Los Mármoles National Park, state of Hidalgo; D. *Agave celsii* Hook growing in the calcareous rocks of Cerro Cangandho, Los Mármoles National Park, state of Hidalgo. Figure by Victor Manuel Bravo-Cuevas and Katia A. González-Rodríguez.

Source: Photographs C and D are courtesy of Dr. Arturo Sánchez González.

FIGURE 3

Fossils preserved in Cretaceous rocks that provide a substrate to some extant vegetation types in central Mexico. Figure by Victor Manuel Bravo-Cuevas

Note: A. Specimens of gastropods and bivalves from San Juan Raya, state of Puebla; B. Remains of rudists (indicated by arrows) preserved in rocks that outcrop in Los Mármoles National Park, state of Hidalgo.

Conclusions

a) The fossil record is a component of geodiversity and biodiversity, representing an intercepting element between both that testifies the biological diversity of the geological past. As it is observed, fossils in their current form are part of the inorganic substrate and not the biotic substrate, although they were once living organisms that inhabited the Earth in the remote past.

b) Conservation of nature needs and integral scope that considers geodiversity and biodiversity as components that evidence changes of the abiotic and biotic conditions that occurred throughout the history of Earth. In this regard, paleobiological conservation has tried to integrate paleontological and ecological data to provide information that would lead to suitable preservation of current biodiversity and ecosystem services, using the fossil record as an indicator.

c) Fossils have an important value in the conservation of biodiversity because they provide information on the dynamics of ecosystems through time, representing historical evidence of their modifications and potential ecological consequences. Hence, they should be included in global strategies to conserve nature and safeguard the biodiversity and geoheritage of a given region. This necessity is exemplified by the indiscriminate exploitation of calcareous and metamorphic rocks in the National Park Los Mármoles, promoting a loss of geodiversity that sustains an important and diverse extant biota that inhabit areas of central Mexico.

Prospective analysis

Nowadays, there is a concern of the scientific community and governmental instances to have information about the "health status" of the Earth. Particularly, the impact of human activities in the environment has conducted to propose strategies that minimize its accelerated degradation. Geodiversity evidences the abiotic and biotic processes that have regulated and maintained ecosystems through time. In this regard, paleobiology conservation and geoconservation are new integrative perspectives that could be useful in the development of alternatives to conserve the biodiversity. As it is shows in the present report, some areas of central Mexico and potentially many others across the country need to be studied and evaluated under these scopes. This situation leads to pose the following actions: *a*) paleobiology conservation and geoconservation must be explained at the different educational stages and be included in subjects such as biology, geology, ecology, paleontology, and conservation; *b*) the training of human resources with knowledge and abilities in the development of studies that integrate geoconservation and conservation should be promoted in undergraduate and graduate programs related to environmental sciences; *c*) geodiversity needs to be incorporated into Mexican legislation.

Moreover, to involve communities in the conservation of geodiversity and geoheritage, the establishment of geoparks has become a potential alternative. Geoparks are sites that include geodiversity, biodiversity, and cultural heritage; they have been created in many nations around the world, to involucrate communities with the territory and the environment, promoting geotourism, educational programs, and natural and cultural heritage. Mexico has already two geoparks recognized by the UNESCO. The geopark Mixteca Alta, with 37 geosites immersed in nine municipalities of Oaxaca, and the geopark Comarca Minera in Hidalgo that includes nine municipalities with 37 potential sites for geotourism. A third site, pending to be recognized by UNESCO is the Tlalpujahua-El Oro Mine District belonging to the states of Michoacán and Estado de México. Besides, some other Mexican geosites are candidates to receive this recognition.

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Nota

[1] *a*) Terrestrial constituents comprise the materials of the Earth's crust, including minerals, rocks, soils, and fossils; among these, only fossils represent evidence of organic origin. *b*) Terrestrial processes include the endogenous (plate tectonics, volcanism, and seismicity) and exogenous (weathering, erosion, and climate) manifestations related to Earth dynamics, which in turn configure the geomorphology. In this regard, alterations related to anthropic activities are also included. *c*) Landforms represent geomorphology as a tool to explain the heterogeneity of terrestrial surface, related to crust dynamics and its material composition (including fossils), and supported by information derived from climatological, hydrological, pedological, paleontological, and sedimentological evidence.