

DIVERSITY

Enhancing global nature conservation by integrating geodiversity in policy and practice

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KEYWORDS

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INTRODUCTION

Flora and fauna are commonly in the spotlight in nature conservation. However, geodiversity, the richness of Earth's surface and subsurface features and processes, has gained increasing attention in research (Schrodt et al., 2019) and conservation practice (Brilha, 2022; Crofts et al., 2020). Geodiversity is essential for sustaining biodiversity (Beier et al., 2015; Schrodt et al., 2019) but is not yet in the mainstream of conservation policy and practice (Brilha & Reynard, 2018; Schrodt et al., 2019; Chakraborty & Gray, 2020; Crofts, 2022). We devised a four-step plan toward consistent consideration of geodiversity for the benefit of nature that we call PCII: promotion, collaboration, integration (i.e., policy), and implementation (i.e., practice).

In 2015, there was a *Conservation Biology* Special Section dedicated to geodiversity in biodiversity conservation (Beier et al., 2015). The framework of “conserving nature's stage” (CNS) was introduced: geodiversity forms the stage for actors (organisms) and the more diverse the stage, the more diverse the actors. This is because diverse abiotic conditions create many niches and microhabitats for different species, offering a range of ecosystem functions, even as the wider environment changes (Beier et al., 2015). The range of environmental conditions also creates opportunities for two-way interactions between species and the physical environment (Viles, 2020). Empirical works support the existence of a geodiversity–biodiversity relationship at various spatial scales (Tukiainen et al., 2022).

Geoconservation is advanced at the international level (Brilha, 2022), with geosite assessments readily conducted (Brilha & Reynard, 2018). Leading conservation organizations, including the International Union for Conservation of Nature (IUCN), recognize the role of geodiversity and geoconservation in their own right and for their benefits to biodiversity (Crofts et al., 2020). The explicit mention of geodiversity in the revised IUCN categories of protected areas (Dudley, 2008) is particularly important. The Geoheritage Specialist Group of the World Commission on Protected Areas (WCPA) and IUCN are currently defining the methods, criteria, standards, and governance to be applied as key geoheritage areas, which would complement the key biodiversity areas program (Brilha, 2022). The Global Geoparks Network has grown from 17 European and eight Chinese Geoparks in 2004 to 177 UNESCO Global Geoparks across 46 countries (as of October 2022).

Despite the growing recognition of geodiversity, geoconservation still lags biodiversity conservation (Brilha & Reynard, 2018; Schrodt et al., 2019). Excellent examples of geodiversity recognition exist for some regions (examples in Table 1), but geodiversity is not routinely acknowledged. Yet, its features are susceptible to damage by human activities (Crofts et al., 2020). For instance, deterioration of Natural World Heritage Sites listed under criterion (viii) “geology” has been reported (Osipova et al., 2020). According to the CNS framework, geodiversity may play a vital role in supporting biodiversity in a changing climate. This is because the stage, or physical environment,

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TABLE 1 Examples of nature conservation policies, frameworks, tools, and legislation that acknowledge geodiversity.

Scale or extent	Location	Name	Short description	Objectives	More information (reference or link)
International	Global	United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geoparks Network	The network consists of areas that have sites of international geological significance and are managed with a holistic concept of protection, education, and sustainable development. Geoparks promote the importance of protecting Earth's geodiversity through actively engaging with local communities.	Statutes of the International Geoscience and Geoparks programme state that the aim of the network is to set a "mechanism of international cooperation by which areas of geological heritage of international value, through a bottom-up approach to conserving that heritage, support each other to engage with local communities to promote awareness of that heritage and adopt a sustainable approach to the development of the area."	https://unesdoc.unesco.org/ark:/48223/pf0000234539
International	Global	World Heritage Sites	The list promotes the conservation of natural and cultural sites of outstanding universal value. To be included on the list, sites must meet at least one out of 10 criteria, of which one is geology, or criterion (viii): "to be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features." Criterion (vii) acknowledges sites with high scenic value or exceptional natural beauty.	There are 11 themes introduced for guiding the application of criterion (viii): (1) history of planet earth and the evolution of life; (2) tectonic systems; (3) erosional systems; (4) volcanic systems; (5) river, lake, and delta systems; (6) cave and karst systems; (7) coastal systems; (8) marine systems; (9) glacial and periglacial systems; (10) desert and semi-desert systems; (11) meteorite impacts.	Mc Keever & Narbonne, 2021
National	France	The National Inventory of Natural Heritage	A region-by-region inventory program for the nation's geological heritage, launched in 2007 by the French Ministry of Environment.	The inventory is based on the law enacted in 2002 that grants the formal notion of geological heritage for the first time in France (French Law 2002–276, February 27th, art.411–5): "The inventory of natural heritage is set up for the entire national territory of France. A natural inventory encompasses the inventory of the richness of ecologic, faunistic, floristic, geologic, mineralogical and paleontological richness. It is also defined that the inventory is conducted under the scientific responsibility of the National Museum of Natural History of France."	http://hdl.handle.net/10026.1/4995

(Continues)

TABLE 1 (Continued)

Scale or extent	Location	Name	Short description	Objectives	More information (reference or link)
National	Norway	EcoSyst framework	EcoSyst demonstrates how to account for all of nature as part of a systematic framework, defining principles for measuring natural variation at different ecodiversity levels, considering variables that can account for variation, hierarchies, and guidelines for mapping. Nature in Norway is the implementation of EcoSyst for Norway, with examples provided.	EcoSyst aims to provide a systematic approach to ecological diversity, explicitly accounting for biotic and abiotic nature, in the same way as we have a taxonomy for species. It aims to be globally applicable, having been demonstrated for Norway.	Halvorsen et al., 2020
National	Scotland (UK)	Scotland's Geodiversity Charter 2018–2023	The charter presents a national vision of how Scotland can better appreciate and integrate geodiversity into various aspects of conservation, policy, and society.	Scotland's Geodiversity Charter has 96 signatories who all work toward "promotion and management of Scotland's geodiversity and better integration of geodiversity into policy and guidance, consistent with the economic, social, cultural and environmental needs of Scotland."	https://scotlandsgiodiversitycharter.org/
National	Spain	Spanish Law 42/2007 on Natural Heritage and Biodiversity (Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad)	This law, adopted in December 2013, establishes the basic legal regime for the conservation, sustainable use, improvement and restoration of natural heritage (including geodiversity and geosites), and biodiversity. The conservation of geological heritage is one of the foundations of the law. Spanish national inventory of sites of geological interest is processed in the context of the law.	As Carcavilla et al. (2009) have summarized, there are three main geodiversity-related aspects in the law: (1) specific reference to geology, the geological heritage, geoparks, and geodiversity; (2) boost for inventories and measures for the conservation of the geological heritage and geodiversity; (3) enhancement of protection mechanisms.	https://www.boe.es/buscar/act.php?id=BOE-A-2007-21490 . See also the summary about geoconservation in Spain: Carcavilla et al. 2009
National	USA	National Parks Service Geodiversity Atlas	The atlas provides a repository for geodiversity information across the portfolio of national parks, explicitly identifying features and processes across geology, soil, hydrology, and geomorphology. It also provides "Field Notes" to assist visitors, educators, and students.	The atlas actively recognizes and promotes geodiversity by allowing people to easily engage with geodiversity across the country. Information from the atlas is used to support the management of geodiversity and biodiversity.	https://www.nps.gov/articles/geodiversity-atlas-map.htm
Subnational	Andalusia (Spain)	Andalusian Geodiversity Strategy (Estrategia Andaluza de Gestión integrada de la Geodiversidad)	A strategy that establishes mechanisms for the conservation, promotion, and sustainable use of geological heritage in Andalusia area. Includes an Andalusian Geosites Inventory conducted in 2011.	The objectives of the strategy are to: (1) define institutional policy and model for integrated geodiversity management; (2) guarantee geodiversity in Andalusia; (3) promote geotourism in Andalusia; (4) strengthen education and training for conservation and geotourism; (5) promote participation in international programs; (6) assess and monitor of the action plan.	https://www.juntadeandalucia.es/medioambiente/portal/landing-page-planificacion/-/asset_publisher/Jw7AHInevbs0/content/estrategia-andaluza-de-gestion-integrada-de-la-geodiversidad-2/20151

(Continues)

TABLE 1 (Continued)

Scale or extent	Location	Name	Short description	Objectives	More information (reference or link)
Subnational	Tasmania (Australia)	Natural Heritage Strategy for Tasmania (2013–2030)	A strategy that guides conservation and management of Tasmania's natural heritage. It provides directions for nature conservation programs managed by the Department of Primary Industries, Parks, Water and Environment. The strategy is based on a landscape approach that accounts for biodiversity and geodiversity (so, natural heritage) in both terrestrial and aquatic environments.	There are four goals in the strategy: (1) Tasmania's biodiversity and geodiversity values are identified, understood, and conserved; (2) all stakeholders and the community have the opportunity to support and protect natural heritage; (3) Tasmanians experience social, economic, and environmental benefits from sound landscape-scale conservation and management; (4) the Natural Heritage Strategy is implemented in a coordinated, efficient, and effective way that achieves measurable results, and improves through experience. A Tasmanian Geoconservation Database is used as a planning tool in land management and in assessing development proposals, and it can be accessed from https://nre.tas.gov.au/conservation/geoconservation/tasmanian-geoconservation-database	https://nre.tas.gov.au/conservation/natural-heritage-strategy-(2013-2030) See also the summary about geoconservation in Australia: Cresswell, 2019
Local	Grand Canyon National Park (GPNP), Arizona (USA)	Grand Canyon National Park: Geologic Resources Inventory Report	The GCNP is a keystone protected area in the U.S. National Park System, a World Heritage Site, and one of the seven natural wonders of the world. It is especially known for its geologic landscapes and resources, which are extensively discussed in the inventory report.	The report provides geological map data and pertinent geologic information to support resource management and science-informed decision-making and it is conducted for the natural resource parks through the U.S. National Park system. The purpose of the GCNP is to preserve and protect Grand Canyon's unique geologic, paleontologic, and other natural and cultural features, as well as to provide the public opportunity to experience Grand Canyon's outstanding natural and cultural features and to protect and interpret Grand Canyon's extraordinary scientific and natural values.	Graham, 2020
Local	Northumberland National Park, England (UK)	Northumberland National Park: Geodiversity Audit and Action Plan	The plan addresses the varied facets of geodiversity in the national park and adjoining area. It provides practical suggestions (e.g., objectives and related actions, the list of geodiversity sites) for the increased protection of and enhancement of geodiversity and encourages the involvement of local community. It is made to complement the policies for the protection of wildlife, cultural, and historical issues.	Altogether, there are 11 objectives and 49 related actions that the plan sets out. An example of an objective and related action: Objective 5. Geodiversity of active quarries. Action 6.1 Encourage Quarry Operators to prepare quarry-specific Geodiversity Action Plans Action 6.2 Seek opportunities to report, record, conserve, and enhance geodiversity in active quarries	https://nora.nerc.ac.uk/id/eprint/7493/1/CR07037N.pdf

may have greater resilience to climatic changes compared with biological communities (Beier et al., 2015; Comer et al. 2015).

Thus, it is important to ask how geodiversity can be better recognized and how geodiversity conservation can be better integrated as an important component and target of nature conservation policies and practice. From our perspective, the major challenge is to raise awareness of the significant role of geodiversity and have this formalized in conservation planning, which will then inform practical conservation efforts. The successful policy requires societal and political will and evidence and knowledge of the practical steps and tools. Therefore, to tackle this challenge, we suggest four important steps: promotion, collaboration, integration, and implementation (PCII).

Promotion of the importance of geodiversity for nature conservation at different scales (step 1)

The first step is to justify and share information about the importance of geodiversity in itself and for living nature by asking and answering the question, across audiences: why should geodiversity, in the current nature conservation context, be recognized? In promoting geodiversity, it is useful to highlight its role in ecosystem service provision (Chakraborty & Gray, 2020) and its contribution to United Nations Sustainable Development Goals, such as clean water and sanitation and life on land, for example, by introducing the CNS strategy (Gray & Crofts, 2022). Events like the World Biodiversity Forum and International Geodiversity Day (6 October) present prime opportunities for promotion.

Collaboration between relevant stakeholders in policy, wildlife conservation, protected area management, geoconservation, and local communities (step 2)

The second step is to increase communication and collaboration among stakeholders in biodiversity conservation and geoconservation, such as between local communities and policymakers or among researchers from different disciplines, such as geology, geography, and ecology. Efforts could focus on the topics highlighted in the *Conservation Biology* CNS Special Section (Beier et al., 2015), such as testing the effectiveness of CNS (especially at fine spatial scales), exploring the vulnerability of various geodiversity features to climate change, and scrutinizing how geodiversity conservation can best support ecological and evolutionary processes. Steps toward aligning different stakeholders are being made in science (e.g., Anderson et al., 2015; Schrodt et al., 2019; Gordon et al., 2022) and in practice (such as work done by different international organizations, e.g., International Union of Geological Sciences, ProGEO, IUCN, and UNESCO), but there is space and need for more. In addition to collaboration among different organizations and stakeholders, it is important to advocate discussion within major nature

conservation organizations. For instance, there could be a joint task force among the IUCN WCPA and the IUCN Commission on Environmental, Economic and Social Policy to investigate stakeholder involvement, or with WCPA and IUCN Species Survival Commission to determine practical possibilities of the conservation of geodiversity contributing to the conservation of at-risk species.

Integration of geodiversity into global and national policy frameworks (step 3)

For the integration of geodiversity into policy frameworks and systematic conservation planning, long-established (e.g., IUCN protected area categories) and newer area-based conservation approaches should be utilized (e.g., other effective area-based conservation measures [OECMs]). For instance, geodiversity considerations could be incorporated into ecological gap analysis, which is used to identify biodiversity that is not sufficiently conserved in existing protected areas or through other effective and long-term conservation measures (Dudley, 2008). Across scales and locations, national policy should more explicitly require the consideration of geodiversity as an integral part of nature conservation and monitoring (Gordon et al., 2022). For example, in Scotland, the Geodiversity Charter places expectations on local authorities, while in Tasmania, geodiversity has an equal part with biodiversity in the Natural Heritage Strategy (more examples in Table 1).

In geoconservation, the inventory of geosites has been essential when integrating geoheritage into the management of protected areas (Mucivuna et al., 2022) across a range of methods and places (Brilha & Reynard, 2018). Ongoing work by the IUCN and its Geoheritage Specialist Group on defining the characteristics of key geoheritage areas offers possibilities for the mobilization of local administrations and communities for enhanced geoconservation with a unified geosite evaluation framework (Brilha, 2022).

Some designated sites will be for geoconservation (e.g., a geosite or geopark). The level of legal protection for these sites is highly variable between countries, but many that offer some sort of long-term protection for geodiversity will also have biodiversity benefits because pressures from humans will be limited. In such cases, sites may be considered OECMs (i.e., biodiversity is not the focus, but is a beneficiary). Although a relatively new concept in area-based conservation, OECMs could offer a consistent mechanism for integrating geodiversity into a national policy based on existing IUCN guidance (IUCN-WCPA Task Force on OECMs, 2019).

Implementation of geodiversity-biodiversity management in practice (step 4)

The fourth step is the integration of geodiversity into conservation management, which can be done by utilizing existing best practice in geoconservation (e.g., Crofts et al. [2020] give an

overview of geoheritage management in protected areas) and biodiversity conservation (e.g., Open Standards for the Practice of Conservation and the Conservation Measures Partnership frameworks). The implementation would benefit from a clear, practical framework for classifying and mapping geodiversity features, assessing trends in their condition, and monitoring their conservation based on robust metrics.

Gordon et al. (2022; see their Figure 2) demonstrate the application of geodiversity to biodiversity conservation for protected area managers; their approach could easily be applied outside protected areas (e.g., for OECMs). Integrating geodiversity requires collecting data on a site's geology, geomorphology, soil, topography, and hydrology, the landscape, and paleoenvironmental records, as applicable. Geodiversity must then be assessed regarding the ecological relevance and connectivity between features; these features define the site's conservation objectives. Finally, geoconservation measures must be implemented to protect and manage features of conservation significance, which will require monitoring and consideration in the wider geographic context (e.g., connectivity) with future environmental change in mind.

Effectiveness should then be assessed based on guidance developed by the IUCN WCPA (Hockings et al., 2006). Effective conservation requires understanding the local social, cultural, and environmental context (e.g., links between geodiversity and biodiversity); setting objectives and planning how to achieve them; obtaining adequate resources; establishing a management process; monitoring; delivering objectives; and assessing outcomes. Ultimately, existing management effectiveness systems will need to be modified to explicitly account for geodiversity and its role in maintaining biodiversity to better reflect their close connection. This could mean, for example, monitoring a hydrological feature (e.g., a freshwater spring) or geomorphological process (e.g., slope stability) toward measuring the effectiveness of practical efforts to reduce pressures on these features and, ultimately, the species that benefit from them.

SUMMARY

Integrating geodiversity into mainstream nature conservation planning and management is essential for the sake of biodiversity, which could be better protected by recognizing geodiversity, and for the intrinsic value of geodiversity itself. We need a holistic approach to nature to safeguard both biodiversity and geodiversity. Our PCII steps offer a pathway toward consistent consideration of geodiversity in nature conservation.

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