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Including geoconservation in the management of protected and conserved areas matters for all of nature and people

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ABSTRACT

Geoconservation is an integral part of nature conservation. It protects our diverse and valued geoheritage, contributes to the sustainable management of ecosystems, provides a range of economic, cultural and social benefits, and connects people, landscapes and their cultures. Geoconservation has a vital part to play in managing the natural environment and helping society to address global challenges, such as biodiversity loss, adaptations to climate change and sea-level rise, and sustainable development. The IUCN *Guidelines for Geoconservation in Protected and Conserved Areas*, published in 2020, outline the key principles of geoconservation and demonstrate their application across the full range of IUCN protected area management categories and other conserved areas. Protected and conserved areas, including geoparks, have a vital educational role in promoting better understanding and awareness of geoconservation and the values and benefits of geodiversity and geoheritage for nature and society. Integrating geoconservation into the management of all categories of protected and conserved areas would benefit not only the conservation of geoheritage, but also all of nature and contribute to a sustainable future.

1. Introduction

In discussions about nature conservation and sustainability, biodiversity tends to be the primary focus. Frequently, the non-living components of nature, encapsulated in the term 'geodiversity', are neglected in nature conservation policies, strategies and protected area management. In particular, they have low priority in determining protected and conserved area status, in evaluating natural capital and ecosystem services, and in contributing to sustainable solutions to global issues (Brilha, Gray, Pereira, & Pereira, 2018; Chakraborty & Gray, 2020; Crofts, 2014, 2018; Gray, 2018). This is unfortunate as understanding of the role of abiotic components and their integration into nature conservation and sustainable stewardship are fundamental to these conservation objectives (Knudson, Kay, & Fisher, 2018; Lubchenco, Barner, Cerny-Chipman, & Reimer, 2015; Schrodt, Bailey, Kissling, et al., 2019).

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The aim of this perspective paper is to outline the values of geodiversity and geoheritage, arguing that geoconservation is an essential part of nature conservation across all categories of protected and conserved areas, both in its own right and for its potential contributions to the wider global agenda on nature conservation and sustainability (Gordon, Crofts, Díaz-Martínez, & Woo, 2018). The paper is based on a synopsis of key literature supported by selected examples. It emphasises the importance of education and the role of protected and conserved areas, and particularly geoparks, in raising awareness of the value of geoconservation in the public sphere.

The paper is aimed primarily at managers and staff of protected and conserved areas and their advisors, but also includes geoheritage specialists, and follows the key principles and recommendations set out in the IUCN *Guidelines for Geoconservation in Protected and Conserved Areas* (Crofts, Gordon, Brilha, et al., 2020). As a starting point, the paper outlines the definitions of geodiversity, geoheritage and geoconservation. It then summarises their values and why these are important for people and nature. Finally, it examines the role of education, identifying key messages in raising public awareness of the value of geoconservation and the need for integration of geoconservation into the management of all categories of protected and conserved areas.

2. Geodiversity, geoheritage and geoconservation

Geodiversity has been formally defined as: "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes" (Gray (2013, p. 12). In layman's terms, it is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes that form and alter them (Crofts et al., 2020). Essentially, geodiversity comprises the abiotic, non-living parts of the landscape, and the term has been used since the 1990s as an equivalent to biodiversity (Gray, 2013). Geodiversity occurs at all scales from global to regional and local (Gray, 2013). For example at a global scale, it comprises multi-layered components including major tectonic features (e.g. where continental plates are colliding or separating), geological provinces (e.g. shields, sedimentary/structural basins and large volcanic provinces), major terrain units (e.g. mountains, plateaux and plains), distributions of rock types (e.g. sedimentary, igneous and metamorphic rocks), geomorphological systems (e.g. glaciers, volcanoes, deserts and coasts), hydrological features (e.g. river systems, lakes and estuaries) and major soil groups. At a regional or local scale, geodiversity reflects the rocks, minerals, topography, landforms, soils and geomorphological processes present.

Geoheritage refers more specifically to those features of Earth's geodiversity that are considered to have special geological, geomorphological or pedological value, primarily for scientific and educational reasons (Brilha, 2016, 2018; Reynard, Perret, Bussard, Grangier, & Martin, 2016). Features of geoheritage value principally include:

- rock exposures that are unique or representative of particular geological processes or stages in the evolution of the Earth, either globally or in particular regions;
- unique, classic or representative landforms and soils; and
- outstanding examples of active geological or geomorphological process systems (Crofts et al., 2020).

These features may range in scale from minerals or fossil beds in individual rock outcrops to extensive landscapes comprising assemblages of glacial or volcanic landforms, for example. In the same way that an area may be important for a single plant or animal species in biodiversity conservation, a site or area of geoheritage significance can comprise a single feature of value and does not require the presence of a diversity of features to be of geoheritage value. Geoheritage features may also have intrinsic, cultural, aesthetic, spiritual and ecological values that support or enhance the primary geoscientific value (Crofts et al., 2020; Reynard et al., 2016). For example, a landform such as a rock monolith in a desert can be of intrinsic value simply because it exists; a spectacular cave may contain indigenous rock art, and have wide aesthetic appeal and spiritual connections for local people; and a coastal system may support a mosaic of sand-dune and saltmarsh habitats and species of biodiversity value. Often these values are inter-connected (Fig. 1).

Geoconservation is primarily the process of conserving geoheritage, including its management, protection and promotion through interpretation and education, usually in protected or conserved areas. It includes the recognition of formal or informal geosites that have a single or a variety of geological or geomorphological features and processes worthy of protection on account of their scientific value (Brilha, 2016, 2018). Some authorities prefer to restrict geoconservation to the protection and management of geoheritage; others accept a broader interpretation that may include conservation of geodiversity or the application of geoconservation principles where there is demonstrated value (e.g. to support biodiversity conservation or ensure the functioning of healthy ecosystems and the services they provide). There is no justification for the conservation of all geodiversity everywhere regardless of its value. Not only would such an approach undermine the status of the areas of highest value, but would also devalue the whole concept of geoheritage conservation, and practically it would not be possible to find the resources to secure effective management (Brilha, 2018; Crofts et al., 2020).

Many countries now have national and regional geosite inventories based on systematic site assessments (e.g. Brilha, 2018; Garcia, Brilha, de Lima, et al., 2018). However, progress in the international recognition of geodiversity, geoheritage and geoconservation has been slow in comparison with biodiversity (Crofts, 2014). There are no international conventions or systematic site designations for geoheritage, although there have been several other steps (Larwood, Badman, & McKeever, 2013). The UNESCO World Heritage List has made a significant contribution for a number of decades. Geoheritage is recognised in World Heritage natural site listing under criteria (vii) and (viii), and quite correctly, sites must be of 'outstanding universal value'.

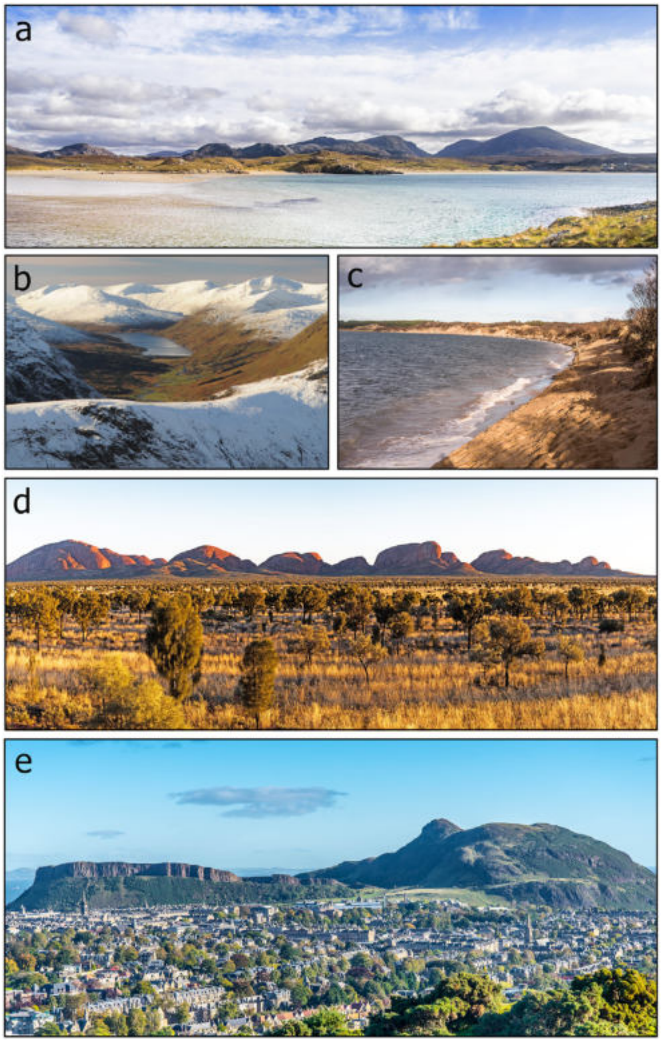

Fig. 1. Examples of the values and benefits of geodiversity and geoheritage. **a.** The islands of the Outer Hebrides, Scotland, comprise some of the oldest rocks in Europe, Archaean gneisses dating from ~3000 Ma. These rocks were heavily scoured by glaciers during the Pleistocene. They form a landscape mosaic of low, rocky hills and hollows, bordered by dynamic coastal systems, including tidal sandflats and sand dunes. This geodiversity supports a corresponding range of habitats, from acid peatlands and species-poor wet heath to calcareous coastal grassland and intertidal marine habitats. **b.** Glacially deepened valleys in the Highlands of Scotland provide locations for reservoirs for public water supply and hydro-electric power generation, but associated dams interrupt natural river flow regimes. **c.** Beaches, sand dunes and saltmarshes act as natural buffers and help to mitigate coastal erosion where there is space inland to allow natural coastal realignment. **d.** The inselberg massif of Kata Tjuṯa forms part of the Uluṟu-Kata Tjuṯa National Park, Australia, a World Heritage site listed for natural and cultural reasons. The site is important for geoheritage, cultural heritage, wildlife habitats, recreation and geotourism. **e.** Geoheritage is a feature of many urban environments. The remnants of Carboniferous volcanoes provide a dramatic backdrop to the city of Edinburgh, Scotland, while many of the buildings of the Old Town, a cultural World Heritage Site, are built of local Carboniferous sandstones. (Photos © John Gordon).

This is not sufficiently clearly defined and is necessarily restrictive. Work is therefore underway, led by IUCN, to provide improved definition of the criteria. Also, despite expert reviews (e.g. Dingwall, Weighell, & Badman, 2005; Goudie & Seely, 2011), the site coverage of the range of geological and geomorphological features is not comprehensive or systematic. Recent reviews have underlined this lack of adequate coverage for volcanic features (Casadevall, Tormey, & Roberts, 2019) and granite landscapes (Migoń, 2018, 2021). One of the reasons is that the international expert community has not been perhaps sufficiently influential with host governments in persuading them to develop the detailed cases for submission to the World Heritage Committee, and another is that the latter may see greater value in the recognition of cultural heritage sites, which substantially outnumber the natural sites. The approval of the Global Geoparks Programme by UNESCO in 2015 has resulted in it playing an increasingly important role in geoconservation nationally and globally. However, UNESCO Global Geoparks serve a broader purpose, including to develop sustainable tourism based on geoheritage, and are primarily community driven (UNESCO, 2016).

Over the last decade, progress in recognising geoconservation has been made within IUCN. This follows acknowledgement, both in the revised definition of a protected area and in the *Guidelines for Applying Protected Area Management Categories*, that nature "often *also* refers to geodiversity, landform and broader natural values" and that "all protected areas should also aim where appropriate to conserve significant landscape features, geomorphology and geology" (Dudley, 2008, pp. 9 and 12). Several IUCN Resolutions now address geoconservation issues. Resolutions WCC-2008-Res-040 (https://portals.iucn.org/library/node/44190) and WCC-2012-Res-048 (https://portals.iucn.org/library/node/44015) recognise that geodiversity is an integral part of natural diversity, that geoheritage is an integral part of natural heritage, that geodiversity is "an important natural factor underpinning biological, cultural and landscape diversity" and that "it possesses cultural, aesthetic, landscape, economic and intrinsic values that must be preserved and transmitted to future generations." Resolution WCC-2020-Res-074 (https://portals.iucn.org/library/node/49213) is significant in gaining members' agreement to mainstreaming geoconservation within the IUCN national and regional programmes and the work of the secretariat. It also supports the development of preparatory work for a future IUCN initiative on Key Geoheritage Areas, complementary to the Key Biodiversity Areas Programme, provision of information and interpretation to increase visitor awareness and geoheritage assessments, the integration of nature conservation principles and methods into the management of protected areas to ensure the effective protection of this component of natural heritage and the implementation of effective geoconservation measures through national legislation. More specifically, Resolutions WCC-2016-Res-083 (https://portals.iucn.org/library/node/46500) and WCC-2020-Res-088 (https://portals.iucn.org/library/node/49227) address movable geoheritage and enhanced protection and conservation of mining environments for their natural heritage values, respectively.

Two key messages emerge from these developments. First, there is a need for an agreed, systematic, international framework of assessment for key geoheritage sites or areas within which geoheritage features of global conservation significance are identified, and can be protected and managed effectively. This is recognised in IUCN Resolution WCC-2020-Res-074 and outlined by Woo, Ju, and Brilha (2018). To date, this has been lacking despite a number of attempts (Díaz-Martínez, Brilha, Brocx, et al., 2016). This needs to be a joint initiative including the Geoheritage Specialist Group of the IUCN World Commission on Protected Areas (WCPA) and the International Union of Geological Sciences International Commission on Geoheritage.

Second, there is a need for a more integrated approach to nature conservation at all scales, so that geoconservation is included comprehensively. This means not only conservation of geoheritage in dedicated geosites, but also embedding geoconservation principles and methods into the management of other protected areas to ensure the effective protection of geoheritage and valued aspects of geodiversity. This is discussed in more detail in the next section.

Features of geoheritage interest may occur within other conserved areas, including community conservation areas and private conservation areas. Consequently, measures for privately protected areas and other effective area-based conservation measures (OECMs), now recognised to have a role in biodiversity conservation (IUCN-WCPA Task Force on OECMs, 2019; Mitchell, Stolton, Bezaury-Creel, et al., 2018), should also apply to geoconservation. Hence as advocated in IUCN Resolution WCC-2020-Res-074 and by others (Brilha et al., 2018; Crofts et al., 2020; Gordon, 2019; Gordon et al., 2018), geoconservation principles and methods should be integrated into the management of all protected and conserved areas, including not only terrestrial areas, but also those in the marine environment where there are geoheritage features and important functional connections between geodiversity and biodiversity (e.g. Coratza, Vandelli, Fiorentini, Paliaga, & Faccini, 2019; Gordon, Brooks, Chaniotis, et al., 2016; Kaskela, Rousi, Ronkainen, et al., 2017). Such integrated approaches should also help to enhance conservation of biodiversity (Crofts, 2019; Gordon, 2019). The IUCN Resolutions provide a springboard. The challenge now for the geoconservation community is to work with IUCN member organisations and Commission members to ensure that geodiversity and geoheritage are incorporated across the range of IUCN's work, including in its quinquennial programmes, globally and regionally, and in its policies and strategies.

One specific way of ensuring incorporation of geoheritage in nature conservation is by using the full range IUCN protected area management categories (Dudley, 2008). Sites or areas of geoheritage significance may exist within any of the six IUCN protected area management categories, either as primary interests in their own right or as components within a wider assemblage of natural features. Although Category III, 'Natural monument or feature', is likely to be the principal category for geoheritage conservation, all 6 categories of protected area may be appropriate to deliver geoconservation according to the circumstances; Crofts et al. (2020) provide examples of geoheritage interests for each category. On the other hand, some protected areas designated primarily for biodiversity or other non-geoconservation reasons may include geoheritage features or processes of value in their own right, or that exist as part of a wider assemblage of natural features in which they play a critical supporting or functional role (e.g. in terms of providing a platform or essential physical processes to maintain priority habitats or species).

The Ngorongoro Conservation Area in northern Tanzania is an example. Bounded in the east by the Western Escarpment of the Gregory Rift system, the landform suite contains several shield volcanoes and volcanic craters, including the spectacular Ngorongoro Crater, the world's largest caldera, and Olduvai Gorge. The area, which forms part of the Ngorongoro Lengai UNESCO Global Geopark, is globally significant for species and ecosystem protection primarily for the large number and variety of animals within the Serengeti ecosystem. Migratory wildebeest, zebras, gazelles and elands are present in significant numbers in the rainy season, attracted by the feeding provided by the abundant grasslands growing on mineral-rich soils derived from volcanic ash. These animals are preyed on by lions, cheetahs and leopards, and the remains picked over by scavengers – hyenas, jackal, black kites and vultures. In addition, the area also has a stable black rhino population. To the north, the soda-rich waters of Lake Natron Ramsar site support a spectacular lesser flamingo population about 2.5 million strong. The water is intensely alkaline, pH 10.5, and derives from weathering of the trachyte, sodium-rich lavas. The flamingos breed on the islands in the lake and wash in its waters around the shore. To complete the picture, the Olduvai Gorge is a globally significant site recording the evolution of hominoids.

3. Wider values of geodiversity and geoscientific knowledge

While geoheritage features and processes, and individual sites (geosites), must primarily have special geological, geomorphological or pedological value, geodiversity has a wider range of values in terms of contributing to natural capital and delivering a range of services and benefits for nature and society (Fig. 1). Many of these services overlap with the supporting, provisioning, regulating and cultural categories of ecosystem services set out in the Millennium Ecosystem Assessment (2005). Others may be more exclusively categorised as 'geosystem services' (e.g. provision of minerals) (Gray, 2011, 2019; Van Ree & van Beukering, 2016). These services are now well documented in qualitative terms (Chakraborty & Gray, 2020; Gordon & Barron, 2013; Gray, 2012, 2018, 2019; Gray & Gordon, 2020; Gray, Gordon, & Brown, 2013), including in regional and thematic reviews covering, for example, mountains (Gordon, 2018a), coasts (Garcia, 2019) and urban areas (Reverte, Garcia, Brilha, & Pellejero, 2020), and specific categories of service such as cultural services (Gordon, 2018b; Kubaliková, 2020). Hence only a summary is included below.

Supporting services include the platform that geodiversity provides for biodiversity in both terrestrial and marine environments (Fig. 1a). The links between abiotic factors and biodiversity are well-known, apply to both common and rare biota (e.g. Crofts, 2019; Hjort, Gordon, Gray, & Hunter, 2015) and are embodied in the concept of 'nature's stage' (Beier, Hunter, & Anderson, 2015). Metaphorically, the physical environment is a 'stage' that supports biodiversity. Geodiversity factors are important drivers of biodiversity, for example in mountain (Antonelli, Kissling, Flantua, et al., 2018; Hu, Wang, Sun, et al., 2020) and freshwater (Toivanen, Hjort, Heino, et al., 2019) environments where geology, soils, landforms and geomorphological processes interact with climate to produce environmental mosaics that support a diversity of habitats and species. Species may change, but conserving areas of high geodiversity (Gray, 2008) and specific niches (e.g. hot springs and limestone pavements), and maintaining the natural processes that enhance landscape heterogeneity more generally, can help to sustain robust protected area networks. In turn, these will provide suitable environmental mosaics and corridors to assist the adaptive capacity and hence resilience of biodiversity in the face of climate change (Anderson, Clark, & Sheldon, 2014); for example, the diversity of hydrological and geomorphological process zones in river systems drives habitat complexity at a basin scale (Thorp, Flotemersch, Delong, et al., 2010). The concept also applies to conservation planning for endangered species, where conservation of the abiotic habitat is central to recovery plans that envision recovery of the endangered species or migration to more suitable adjacent habitat as the climate changes. 'Conserving nature's stage' can therefore support biodiversity conservation and delivery of targets where there are strong abiotic drivers of species distributions (Lawler, Ackerly, Albano, et al., 2015).

Provisioning services include both renewable and non-renewable resources essential for human existence and economic development (Brilha et al., 2018; Gray, 2019). Soils support agricultural production, and rocks provide minerals and building materials. Fossil fuels have underpinned economic development since the Industrial Revolution, while new renewable energy and low-carbon technologies depend heavily on critical minerals (Smelror, 2020). Paradoxically, these latter technologies are significantly more mineral intensive than the former, and the clean energy transition will place a high demand on particular non-renewable mineral resources, particularly graphite, lithium, cobalt and rare earth elements. For example, it is estimated that over 3 billion tons of minerals and metals will be required to deliver the scale of wind, solar and geothermal energy and its storage to achieve a 2 °C limit to global warming (World Bank Group, 2020). Geodiversity also provides many other resources, including fresh water and the locations for reservoirs for public water supply and hydro-electric power (Fig. 1b), and is an influencing factor in the location of onshore and offshore wind farms.

Regulating services include the role of natural systems in mediating biogeochemical cycles essential for maintaining healthy ecosystems and life on Earth. In helping to mitigate natural hazards, geomorphological features such as beaches and saltmarshes act as natural forms of coastal defence, providing that sediment supply to them is maintained, for example through managed realignment or beach replenishment (Fig. 1c). Maintaining or re-instating the connections between rivers and their floodplains encourages healthy wetlands and mitigates flooding downstream. Working with natural processes and allowing space for them to operate therefore helps to deliver multiple benefits for biodiversity, flood management and erosion mitigation through natural means of coast and flood protection. This is now termed 'Nature-based Solutions' (see: https://www.iucn.org/theme/nature-based-solutions/about and https://www.iucn.org/resources/issues-briefs/ensuring-effective-nature-based-solutions).

Cultural services are many and varied. Geological features and landforms are fundamental to perceptions of scenic quality and natural beauty and as sources of inspiration, spirituality, and human health and wellbeing (Fig. 1d). In Western cultures, the characteristics of the physical landscape and its natural features, as interpreted through literature, poetry and art, underpinned the aesthetics of the sublime and Romantic-era tourism in the 18th and 19th centuries and provide strong visitor appeal today (Gordon, 2018b; Hose, 2016). In Eastern cultures, the close connections between people and nature have been celebrated in art, poetry, literature and mythology for over two millennia (Chen, Lu, & Ng, 2015) and are reflected today, for example, in many geoparks in China (Fig. 2). The cultural value of geoheritage is also demonstrated through the links of rocks, landforms and use of building stones with architecture and the built environment, historical and literary associations, archaeology, mining heritage, land use and mythology (Fig. 1e) (Gordon, 2018b; Reynard & Giusti, 2018).

An additional category is knowledge services (Gray, 2013). For example, geoscience understanding and geological knowledge are fundamental to environmental management, natural hazard assessment and urban planning (Culshaw & Price, 2011; Gill, Taylor, Duncan, et al., 2021; Gray et al., 2013; Smelror, 2020), while information from ice cores, palaeoenvironmental records and landforms enables a better understanding of past climate change, ecological processes and landscape dynamics (e.g. Fordham, Jackson, Brown, et al., 2020; Harrison, Mighall, Stainforth, et al., 2019; Lear, Anand, Blenkinsop, et al., 2021). This knowledge has been described as "humankind's insurance policy for the future" (de Mulder, Derbyshire, & Nield, 2008).

Fig. 2. a. Huangshan UNESCO Global Geopark, Anhui Province, China, is also a natural and cultural UNESCO World Heritage Site and a UNESCO Biosphere Reserve. It is one of the most popular scenic areas in China, exceptional for its granite peaks and spectacular rock formations, and widely celebrated in art and literature and for its spiritual connections, rich flora and important habitats. Rock pillars, formed by weathering and erosion exploiting near-vertical jointing in the granite, are imaginatively interpreted as 'Eighteen arhats worshipping the South Sea'. **b.** Sanqingshan UNESCO Global Geopark and natural World Heritage site, Jiangxi Province, China, is noted for its granite pillars and peaks, forested slopes and aesthetic and atmospheric qualities that attract high visitor numbers. It supports a rich biodiversity and contains notable Taoist associations and cultural relics. Visitor access is facilitated by extensive 'skywalk' routeways with interpretation of distinctive rock features. Both geoparks are supported by geological museums which recognise the links between geoheritage, biodiversity and cultural heritage. (Photos © John Gordon).

Many of these wider values map directly across to the UN Sustainable Development Goals (SDGs). Geoscience has a role in delivering all 17 of the SDG targets (Gill, 2017). For example, soil conservation is central to sustainable development and food security (SDG2); natural features provide spaces for recreation opportunities to support healthy lives (SDG3); groundwater resources deliver clean water (SDG6); geotourism supports sustainable economic growth (SDG8); and conserving nature's stage contributes to conservation and wise use of oceans (SDG14) and terrestrial ecosystems (SDG15), and hence to the delivery of the Convention on Biological Diversity's Aichi Targets 11, 14 and 15. Geoparks can be potential role models for delivering the SDGs and in particular sustainable benefits for local communities (Catana & Brilha, 2020; Henriques & Brilha, 2017; UNESCO, 2017). Geoscience knowledge is also fundamental to the Sendai Framework for Disaster Risk Reduction in terms of understanding risk from natural hazards and informing resilience, recovery, rehabilitation and reconstruction (Gill et al., 2021). Similarly, many of these ecosystem values are embedded in China's strategy for Ecological Conservation Redlines (Gao, Wang, Zou, et al., 2020).

Recognition of the range of intrinsic, scientific, cultural and ecological values of geoheritage and geodiversity aligns with the wider nature conservation agenda and the management of natural systems for the benefit of people and nature. This includes dealing with biodiversity loss, climate change adaptation, sustaining natural capital and ecosystem services, marine conservation, soil conservation and connecting people, place and nature (Gordon et al., 2018). This accords with the IUCN vision for the role of protected areas, as set out at the World Parks Congress in Sydney in 2014 and the World Conservation Congress in Hawai'i in 2016, which focuses on: i) valuing and conserving nature; ii) natural solutions to global problems; and iii) reconnecting people with nature (MacKinnon & Londoño, 2016). In this wider framework, there are long-term benefits of more integrated nature conservation planning and protected and conserved area management that combine conservation of both geoheritage and the effective application of the wider values and principles of geoconservation in the management of natural systems. Moreover, a sustainable society is fundamentally predicated on understanding the values of geodiversity and the sustainable management of geo-resources (Brilha et al., 2018; Chakraborty & Gray, 2020; Zoback, 2001). This is reflected in a growing number of publications linking geology, geoconservation, society and sustainable development in their titles (e.g. Gill, 2017; Gray, 2019; Prosser, Bridgland, Brown, & Larwood, 2011; Prosser, Brown, Larwood, & Bridgland, 2013; Stephens, 2020; Stewart & Gill, 2017). Hence, as noted by Brilha (2018), geology and geodiversity are seen to have much wider value than the narrow and commonly perceived economic gain from exploitable mineral resources. If people understand these wider values and benefits of geodiversity and have a deeper connection with geoheritage, they are more likely to view them as assets and help to manage them sustainably.

4. Protected and conserved areas: Enhancing education and awareness about geodiversity, geoheritage and the need for geoconservation

Protected and conserved areas have a vital part to play in enhancing education and awareness about geodiversity and geoheritage and in doing so to promote geoconservation. Geoheritage experienced in protected and conserved areas can serve as a gateway to developing a broader conservation ethic by first capturing the interest and understanding of visitors through creative storytelling. These visitors, particularly young visitors, may then move on to gain a deeper understanding and appreciation of the values of geodiversity and geoheritage through educational programs, in school, college or university, online, or through place-based learning in protected and conserved areas (Semken, Ward, Moosavi, & Chinn, 2017). Ultimately these inspiring and educational experiences should lead to a deeply felt conservation ethic and a willingness to engage in geoconservation activities, or contribute to broader conservation efforts.

However, the values of geodiversity and geoheritage are still poorly recognised at strategic, policy and citizen levels, and also within the wider nature conservation community (Crofts, 2014). Consequently, geoconservation is not well integrated into protected area interpretation and education programmes and in the wider nature conservation and sustainable development agendas in spite of its relevance. There are several reasons for this. First, biodiversity is more advanced as a conservation discipline, with a strong biological and ecological science underpinning. Second, there is the small size and political voice of the geoconservation community and limited involvement from the geoscience academic community in developing the theoretical basis and communicating its applications as part of integrated approaches to conservation issues. Third, although the links between geodiversity and biodiversity may be acknowledged in passing by the biodiversity community, the implications have not been sufficiently explicit or widely understood in terms of what this means for conservation management, at both strategic and practical levels, and in helping to deliver nature conservation targets. Fourth, most people are unfamiliar with geology and its concepts (Stewart & Gill, 2017), and all too often the language used by specialists is too technical and jargon-riddled and therefore has not been easily understood by others involved in conservation or by the general public (Crofts, 2014). Fifth, geology has been regarded traditionally as an exploitative profession, with geologists trained for employment in mineral extractive industries and receiving little training in geoconservation, contrasting with a greater conservation focus in the biological sciences (Pemberton, 2001).

A challenge for geoscience is to raise wider awareness of the values and relevance of geodiversity and geoheritage and the many benefits they provide for nature and people, including the merit of more integrated nature conservation planning and management linking geodiversity and biodiversity. The challenge is both in developing compelling information content, and in delivering that content effectively for different audiences (e.g. through interpretive programmes, education, or public outreach and geoconservation planning) in ways that raise questions as well as entertain (Ham, 2013).

With respect to content, there are several key messages. First, geoheritage is important in its own right and merits conservation as a record of Earth's history. Second, geodiversity forms an integral part of natural diversity and the foundation upon which plants, animals and humans live and interact. Third, understanding geodiversity is fundamental to the ecosystem approach and development of a more sustainable future. This requires better integration of geodiversity, biodiversity and landscape management and conservation. Opportunities to achieve this may arise in response to calls to strengthen and diversify area-based conservation for biodiversity (Maxwell, Cazalis, Dudley, et al., 2020), through incorporating geodiversity and recognising the role of 'conserving nature's stage' to maintain and enhance the resilience and adaptive capacity of the biosphere. Fourth, geodiversity knowledge is vital to help society adapt to climate change and sea-level rise; in particular, awareness and understanding of natural processes and hazards and working with natural processes are fundamental to living with change and managing adaptations. Fifth, geodiversity provides economic and social benefits, including public health and wellbeing through opportunities for outdoor recreation and being in the natural world. Sixth, through their links to cultural heritage, geodiversity and geoheritage help connect people, landscapes and their cultures. Delivering these messages of the real tangible and intangible benefits for nature and society requires engaging with audiences outside the geoscience and geoconservation community in order that the concepts and values of geodiversity and geoheritage become more familiar and validated (Boothroyd & McHenry, 2019). None of these messages will be received by the target audiences unless there is clear communication and a recognition that it is essential to understand the positions and perspectives of the target audiences and to make the communication meaningful to those audiences.

With respect to content delivery, presenting informative interpretation through panels and leaflets in protected and conserved areas may be adequate to meet the basic expectations of many visitors. However, Earth's geological history is engaging, and when told in a compelling narrative that places the visitor within the ancient scene, can lead to a sense of time travel. Park rangers and interpretative staff therefore have a vital role in creating more meaningful and memorable visitor experiences (Stern & Powell, 2013; Stern, Powell, McLean, et al., 2013). They are typically trained in conservation biology and so require additional training and tools to be effective storytellers of Earth's history as recorded in its rocks. These areas may also provide opportunities, particularly in terms of engaging younger visitors, as well as older ones, both through on-site and wider outreach initiatives that follow best practice principles that identify the growing number of visualization tools available to support interpretation and education, as well as innovative and traditional platforms for knowledge flow (Crofts et al., 2020; Gordon, 2018b; Tormey, 2019). Different approaches, both on-site and virtually, that offer new opportunities to experience and enjoy the landscape in diverse and memorable ways can help people not only to rediscover a sense of wonder about the stories in the rocks and the landscape but also to reveal the wider values of geoheritage and geodiversity as part of everyday life. Making connections with the cultural landscape, exploring links with people's cultural roots and sense of place and enhancing the deep connections between people and the natural world can help to foster a holistic appreciation of nature, recognising that geoheritage and geodiversity are also part of the cultural and spiritual value people attach to 'nature' (Brown & Verschuuren, 2018; Verschuuren, Mallarach, Bernbaum, et al., 2021). These connections help to place the physical or virtual visitor within the scene formed by the geoheritage interests, and thereby to experience them in a direct way that fosters deeper understanding.

As argued by Bernbaum (2017), in order to gain both public and community support, "protected areas need to ground their programs of interpretation, management, and conservation in not only solid scientific research and practice, but also deeply held spiritual, cultural, and aesthetic values and ideas that will engage and inspire people to care for nature over the long term and, when necessary, make sacrifices to protect the environment" (p. 168). Such engagement applies not only to visitors, but should include local communities and provide opportunities to tell and preserve their local stories and enhance their sense of place. From a geoethical perspective, this may require balancing economic imperatives for geotourism development against primary requirements for geoconservation. In practice, this means making a balanced assessment of the risks of physical and aesthetic deterioration from recreational impacts, overuse and commodification, while at the same time respecting the value systems of local communities (Antić, Peppoloni, & Di Capua, 2020; Gordon, 2018b; Poiraud & Dandurand, 2017; Stoffelen, 2020). These issues require engaging in dialogue and working with local stakeholders (Stewart & Lewis, 2017), and can in themselves form part of educational activities, involving local communities, visitors, schools and colleges. Moreover, the deployment of local guides can greatly enhance the process of communication and public engagement, as well as add value to people's experiences.

Several examples serve to make the point. First, the US National Park Service developed the Junior Ranger program, an activity-based experience conducted in almost all USA national parks. Interested participants complete a series of activities guided by a workbook during a park visit. The activities appeal to the senses, place the young visitor in the scene and pose thought-provoking questions. Once complete, the results are reviewed by a park ranger, and if successful, participants receive an official Junior Ranger patch and Junior Ranger certificate. They also take the Junior Ranger Oath, which includes the motto 'Explore, Learn, and Protect!' Junior Rangers frequently continue their interest in conservation and learning well after the visit (NPS, 2021).

Second, the National Conservation Foundation (NCF)-Envirothon is an independent, classroom- and place-based environmental and natural resources educational program for high school students (grades 9–12 or ages 14–19) (Fig. 3). It culminates in the annual NCF-Envirothon Competition in which winning teams from participating high schools in the United States, Canada and now China compete for recognition and scholarships by demonstrating their knowledge of environmental science and natural resource management. The program has a strong outdoor component and is sponsored by the USDA Natural Resources Conservation Service, the US Forest Service and others. Much of the field education and field competitions are held in areas protected for their geoheritage and biodiversity values, and this use of geoheritage as a gateway to the broader educational goals is central to the program (Tormey et al., submitted). Students work in teams in the field to answer questions related to soil and land use, forestry, aquatic ecology, wildlife and current environmental issues. Additionally, because the ability to communicate clearly and effectively is a crucial skill when addressing environmental issues, they are challenged to prepare and give an oral presentation on a scenario featuring the current environmental theme (e.g. groundwater, watersheds, biodiversity, renewable energy, invasive species, climate change, or other topic). Working collaboratively as a team, students learn through project-based learning, and the focus on field applications in areas of geoheritage significance incorporates place-based learning (NCF-Envirothon, 2019). The mission of the program is to develop knowledgeable, skilled and dedicated adults who have an understanding of natural resources and are willing and prepared to work towards achieving and maintaining a balance between the quality of life and the environment, accomplished by developing in young people an understanding of the principles and practices of natural resource management and ecology and through practice in dealing with complex resource management decisions (NCF-Envirothon, 2019).

Third, further development of China's national park system under China's pilot national park initiative could potentially provide opportunities to develop many of these aspects. China has stated the goal for a complete national park system by 2030 (Peng, 2018; Tang, 2020). This program has the potential to instil national pride in the geodiversity and biodiversity of the country and areas of outstanding geoheritage values (Fig. 4). The first park of the system is in Qinghai province, a region in western China close to Tibet, and is named the Sanjiangyuan National Nature Reserve. The region is home to native and endangered species like the snow leopard and Chinese mountain cat and encompasses the headwaters of three of Asia's great waterways, namely the Yangtze, Yellow and Lancang/Mekong rivers. Concurrent with the development of the park has been the development of a range of interpretive materials including for the outstanding geoheritage of the area (Wei, 2019). This example from China demonstrates the conscious use of designation of protected areas of high geoheritage value to support meaningful interpretive programs, place-based education and the development of a conservation ethic in society.

Fourth, as well as delivering geoconservation and promoting sustainable economic and social development linked to geotourism and wise use of geoheritage resources, UNESCO Global Geoparks have a requirement to "develop and operate educational activities for all ages to spread awareness of our geological heritage and its links to other aspects of our natural, cultural and intangible heritages" (UNESCO, 2016, p. 9). This is partly delivered through educational activities for schools and others and partly through geotourism activities. Most geoparks have their own schools' educational programmes and publications and they provide

Fig. 3. Logo of the National Conservation Foundation (NCF)-Envirothon programme, which involves an annual competition on an environmental theme for high schools. Field education in areas protected for their geoheritage introduces students to a range of environmental issues including geoconservation. (Photo © the National Conservation Foundation).

Fig. 4. Noticeboard at Huanjiang Karst, part of the South China Karst World Heritage Site, Guangxi Province. The message encourages local people and visitors to take pride in protecting the karst landscape and the pristine, subtropical, mixed-forest ecosystem with its numerous endemic plant and animal species. (Photo © Murray Gray).

valuable educational resources for fieldwork and learning about geology through a wide range of activities (e.g. Henriques, Tomaz, & Sá, 2012; Han, Wu, Tian, & Li, 2018; Silva & Sá, 2018; Fernández Álvarez, 2020; Catana & Brilha, 2020; Gomes, Castro, Ferenandes, & Loureiro, 2020). Geoparks are particularly well-suited to developing experiential, enquiry-led and place-based learning approaches in geoscience and personally meaningful appreciation of geoheritage through links to cultural heritage and landscape aesthetics (Gordon, 2018b).The educational role of geoparks also includes raising awareness of the wider values of geodiversity and geoheritage, including the interdependencies of geodiversity, geoheritage, biodiversity and cultural heritage and the links to sustainability, and hence the need for geoconservation not only within the geoparks but more widely. In this regard, geotourism also has an important educational component (Newsome & Dowling, 2018; Ólafsdóttir & Tverijonaite, 2018).

Formal education in schools and universities clearly also has a critical role to provide better understanding of how the Earth works, the connections between geodiversity, biodiversity and people, and the ways in which geodiversity and geoconservation deliver multiple benefits and services and support sustainable development. This requires an interdisciplinary approach linking natural and human systems – geodiversity, biodiversity, cultural heritage and socio-economics (Knudson et al., 2018). It also requires the integration of geoconservation and sustainability into geoscience education, training and continued professional development (Geology for Global Development, 2020; Gosselin, Burian, Lutz, & Maxson, 2016; Stewart & Gill, 2017). In turn, this should ultimately help to improve the recognition and demonstrate the relevance of geoconservation at public, policy and decision-making levels.

5. Conclusions

Geoconservation is primarily concerned with protecting the 'memory of the Earth', but has an equally important and wider value in helping to sustain nature and people. Geoconservation should be an essential consideration for nature conservation at all scales from global to local. It should be integrated across the full range IUCN protected area management categories and other conserved areas to ensure the effective protection of geoheritage and valued aspects of geodiversity where these provide vital ecosystem functions or services. Such integration should also help to enhance the conservation of biodiversity and promote environmentally sustainable stewardship of all of nature. To make progress at a strategic level, geoconservation bodies and experts should engage actively with IUCN and the WCPA Geoheritage Specialist Group to support the implementation of Resolutions on geoheritage and protected areas and the integration of geoconservation across the range of IUCN's work globally. They should also engage more effectively in the development of national and regional policies and strategies for nature conservation to ensure that the values of geodiversity and geoheritage are fully incorporated. At a practical level, managers and staff of all protected and conserved areas should consult and adopt the IUCN *Guidelines for Geoconservation in Protected and Conserved Areas* (Crofts et al., 2020) and consider how their areas can be managed to achieve conservation of both biodiversity and geoheritage, and also recognising the functional links between geodiversity, habitats and species.

Protected and conserved areas, including geoparks, also have a key educational and demonstration role in promoting better understanding and awareness of geoheritage and the values and benefits of geoconservation for nature and society, recognising that the application of geoscience knowledge is fundamental to managing the natural environment and helping society to address global challenges in a sustainable way. Nevertheless, although such understanding and awareness should arguably be a key part of science literacy at all levels, the challenge still remains to communicate beyond the geoscience and geoconservation communities and to encourage greater public participation in geoconservation. The promotion of these values and the benefits of geodiversity and geoheritage more widely in protected and conserved areas and through geopark activities are part of the solution when combined with other educational and public engagement initiatives. This requires the adoption of best-practice approaches and methods in interpretation, education and public outreach, making connections with people, their cultural landscapes and sense of place while conveying a sense of wonder about the geological stories in a scientifically correct way but fostering a more holistic appreciation of nature, people and landscape through place-based aesthetic and emotional experiences. It also requires developing geoconservation interpretation and education programs, educating conservation biologists and other biodiversity specialists in geoconservation, and bringing geoconservation into university training.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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