International Journal of Geoheritage and Parks 7 (2019) 211–217

Contents lists available at ScienceDirect

International Journal of Geoheritage and Parks

journal homepage: http://www.keaipublishing.com/en/journals/international-journal-of-geoheritage-and-parks/

Linking geoconservation with biodiversity conservation in protected areas

Roger Crofts

IUCN World Commission on Protected Areas, Geoheritage Specialist Group, 6 Eskside West, Musselburgh, Scotland EH21 6HZ, UK

ARTICLE INFO

Article history:
Received 6 October 2019
Received in revised form 3 December 2019
Accepted 15 December 2019
Available online 26 December 2019

Keywords:
Geoconservation;
Biodiversity conservation;
Integrated approaches;
Protected areas;
Conflict resolution

This article explores the interaction between conservation of biodiversity and geodiversity in protected areas. It reflects the guidance booklet being developed by the IUCN World Commission on Protected Areas Geoheritage Specialist Group led by the author. The paper explores the reasons why conservation of biodiversity and geodiversity in protected areas are often considered separately in international systems and processes, in training of staff and in action on the ground. It argues the need for a more integrated and interconnected approach recognising the interdependencies of the two elements and especially the dependency of biological features and processes on geological and geomorphological systems and processes. Examples of integrated approaches and separate approaches are discussed. The framework for resolution of conflict of ecosystem functions is presented. Finally, the practicalities of dealing with the conflicts between the two elements are discussed.

Contents

E-mail address: roger.dodin@btinternet.com (R. Crofts).

https://doi.org/10.1016/j.ijgeop.2019.12.002

1. Introduction

The language of geodiversity is relatively new and therefore definition of terms is appropriate at the outset. **Geodiversity** is: "*the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes) and soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes*" (Gray, 2013, p 12). **Geoconservation** is "*the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values*" (Sharples, 2002, p. 6). **Geo site** is used to refer to any site that has a single or a variety of geological or geomorphological features and processes worthy of protection on account of their scientific value (Brilha, 2018).

The links between biodiversity and geodiversity conservation have become an important topic for debate and most especially for conservation planning and action on the ground. The forthcoming publication of an IUCN World Commission on Protected Areas Best Practice Guideline on Geoconservation in Protected Areas seeks to provide the framework for improved conservation and to identify the linkages between the bio and geo elements of conservation ((Crofts, Gordon, Gray, Tormey, & Worboys, n.d.; Gray, Gordon, & Brown, 2013), in press).

The need for this step change in approach on geoconservation is because geoconservation has played a secondary role to biodiversity conservation in protected areas for many decades (Gordon et al., 2018). It is important to examine the causes of this situation and what action has been taken to rectify the situation. These issues are addressed in the opening section of this paper in order to identify what geoconservation specialists should be doing to improve the position of this important aspect of protected areas development and management.

There is now recognition that there are many interdependencies between the biodiversity conservation and geoconservation. The paper explores these linkages and provides reasons for better connections. There are situations, inevitably, where conflict occurs between biodiversity and geoconservation objectives. The means of resolution are spelled out and some examples given.

2. Geoconservation of second importance?

There are a range of reasons for geoconservation being slow to become a critical component of protected area conservation and management. These have been reviewed by Crofts (2014, 2017). In summary, biodiversity conservation had a sound basis in biological and ecological science (Tansley, 1945), had strong support from the emerging post WW2 conservation movement, backed by the establishment of The International Union for the Conservation of Nature and Natural Resources (now the International Conservation Union: IUCN) (Holdgate, 1999), the multi-party development of conservation strategies which had great international influence in the preparations for and the conclusions of the Rio Earth Summit in 1992 (IUCN et al., 1980, 1991). By contrast, the Earth science community lacked public outreach, was a poor communicator to non-specialists and did not seek to address the broader scale ecosystems approaches being developed by biological scientists. However, the development of ProGEO: the European Association for the Conservation of the Geological Heritage (http://www.progeo.ngo/), the publication of the first international treatise on geodiversity (Gray, 2004), the development of geoconservation systems in many countries in the 1980s onwards (see for example Ellis, 2011) all added impetus to improving the situation.

A significant role has been played through IUCN in enhancing the status of geoconservation by its geoconservation members. Ultimately, IUCN recognised the importance of geoconservation alongside biological conservation in a number of Resolutions at its General Assemblies (IUCN, 2008, 2012, 2016). These Resolutions represent a benchmark in recognising the integrative role and relevance of geoheritage and geodiversity which must be considered in the assessment and management of natural areas. More specifically, in a review of the IUCN Guidelines for Protected Areas Management published in 2008, a new definition was approved that took specific account of geoconservation with the clear statement that all protected areas should aim where appropriate to '*conserve significant landscape features, geomorphology and geology*' (Dudley, 2008). In addition, in 2013 the IUCN World Commission on Protected Areas approved the establishment of a Geoheritage Specialist Group to develop a programme of work (https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/geoheritage). IUCN also has a specific responsibility for the Outstanding Universal Value evaluation of UNESCO's World Heritage nominations regarding Criteria vii) and viii), both related to geoheritage.

The final step in this journey was on 17 November 2015, when the 195 Member States of UNESCO ratified the creation of the UNESCO Global Geoparks network. The objective is to express international recognition of the importance of managing outstanding geological sites in a sustainable development context. UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development.

3. Why is geoconservation important?

Geodiversity supports a diversity of habitats across a wide range of temporal and spatial scales. At a global scale, for example, centres of vascular plant diversity coincide with mountain areas in the humid tropics and subtropics with high geodiversity. At regional and local scales, geodiversity supports habitat heterogeneity arising from the characteristics of the physical substrate, soil properties and stability, geomorphological processes and landforms, topographic effects on microclimate, water availability and disturbance regimes arising from continual and episodic processes. Consequently, habitat diversity and species richness are generally greater in areas of high abiotic heterogeneity. In many environments, from mountains to coasts, the complex and dynamic patterns of micro- and meso-scale topography, soils and geomorphological processes provide mosaics of habitats, corridors and topographical variations for high species richness.

Geodiversity has an important **ecological value in supporting biodiversity and ecosystem functioning** and is therefore a key element in protected areas as an integral part of nature and natural heritage. By definition, geodiversity is a vital component of ecosystems in which biotic and abiotic components form an interacting ecosystem (Gray et al., 2013). The linkages and interdependencies between abiotic and biotic nature are clear across a wide range of scales from global to local. The substrate of rocks and soils provides the rooting zone and much of the nutrient supply for plant growth and survival. The specific characteristics of the substrate and soil, such as acidity/alkalinity, moisture retention capacity, chemical composition, determine its capacity to host plants and animals. In some cases, the chemical composition of the rocks will determine particular plant types which are so unusual that they justify protection.

Equally important are the dynamic processes (e.g. soil formation, cycling of water and chemicals, stream flows, erosion and sedimentation) that provide nutrients and maintain habitat condition and ecosystem health. In many environments the complex and dynamic patterns of micro- and meso-scale topography, soils and geomorphological processes provide mosaics of habitats, corridors and topographical variations for high species richness.

This biotic-abiotic relationship is an essential component in the concept of ecosystems. The recently coined term ‘conserving nature's stage’ is based on flora and fauna being the actors with geodiversity as the stage on which they thrive. In this approach, the conservation of biodiversity is seen as best achieved by conserving the stage, particularly in times of climate change when having a range of habitats for plants and animals to relocate to may be crucial to their survival (see Anderson & Ferree, 2010). In their paper, Anderson and colleagues conclude that “Our results suggest that protecting geophysical settings will conserve the stage for current and future biodiversity and may be a robust alternative to species-level predictions”. Most habitats and species therefore depend on the abiotic ‘stage’.

Consequently, geoconservation is crucial for sustaining living species and habitats, both to maintain the abiotic setting or ‘stage’ and the natural processes (e.g. floods, erosion and deposition) necessary for habitat diversity and ecological functions. This is particularly relevant for protected area design and management in the context of climate change since geodiversity can convey a degree of resilience and enable the survival of species through the availability of suitable environmental mosaics, corridors and elevational ranges that provide a range of macro- and micro-refugia. Where species and communities are likely to change, robust protected area networks that are founded on the conservation of geodiverse, heterogeneous landscapes should help to optimise the resilience and adaptive capacity of biodiversity and key ecosystem processes under both current and future climates (Anderson et al., 2015; Anderson, Clark, & Sheldon, 2014; Comer et al., 2015). This active approach to conservation includes maintaining the dynamics of natural processes, both to assist landscape heterogeneity and ecosystem evolution. Hence, delivering long-term biodiversity targets where natural communities are likely to change may be enhanced by protecting geodiversity and making space for natural processes that enhance landscape heterogeneity.

How the abiotic components of ecosystems respond to climate change, and how these changes are managed, will also have fundamental impacts on biodiversity as well as geodiversity. For example, such changes may include increased rates, occurrence, intensity and seasonality of flooding, droughts, slope failure, erosion, sediment supply and transfer, channel mobility and coastal change. They may result in changes in the spatial distributions of landforms (e.g. saltmarshes and sand dune systems as coastlines migrate landwards and patterns of erosion and deposition alter). Such geomorphological changes are likely to be non-linear and changes in one part of a system will have impacts elsewhere. In some cases, increased rates of geomorphological change may be too fast for some habitats and species to adapt or there may be less recovery time between extreme events (e.g. wash-out of fish spawning areas). For example, coastal retreat inland, reduced width of the coastal area and steepening of the coastal profile will reduce habitat availability. In addition, management responses to flooding and sea-level rise (e.g. more coast protection) may have significant knock-on effects (e.g. reduced sediment supply to maintain beaches and dunes). Consequently, management interventions and adaptive management of ecosystems will require the application of geoscience knowledge and geoconservation principles.

Conservation of geosites and geodiversity is also important in preserving vital temporal records of recent environmental change and historical range of variability. Analysis of changes in fossils, pollen and fungal spores, for example, and changes in factors that affect biodiversity (e.g. climate change, volcanism, erosion and sedimentation) in protected areas can provide increased understanding of the dynamics of biodiversity. While the past is unlikely to provide exact analogues for restoration ecology, palaeoenvironmental records nevertheless have an important part to play in supporting conservation biology through enabling understanding of ecological and evolutionary processes, ecosystem dynamics and past ranges of natural variability. In addition, the long-term perspectives provided by palaeoenvironmental records should improve awareness of trends in ecosystem services and potential future trajectories and help to validate conservation management decisions and prioritise limited resources for management intervention.

4. Framework of ecosystem functions

Geodiversity is a critical component of ecosystems, and specifically provides many **environmental goods and ecosystem services**, which are the direct and indirect benefits that humans receive from the natural environment and properly functioning ecosystems. Gray (2013, 2018a, 2018b) has described in detail the basic framework.

This provision means that working with nature, rather than against it, and seeking to maintain the natural systems and processes is a fundamental role of protected area management. It also means that all elements of ecosystems must be seen as a whole, rather than, for example, considering only biodiversity or only geodiversity. In other words, we should think of *nature's services*. There is no doubt about the integrated approach to ecosystems as defined in Article 2 of the Convention on Biological Diversity:

"'***Ecosystem***' means a *dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*."

5. Examples of interaction and interdependence

There are many examples from around the world to illustrate the interaction and interdependency between the bio and geo components of nature. Six different interdependencies are described highlighting the conservation management issue.

5.1. Specialist plants

Specialist plants have developed genetically that are tolerant of the chemical composition of the substrate. A good example is the plants developed on the serpentine rocks (termed ophiolites derived from the ocean mantle). These can be seen at the Keen of Hamar National Nature Reserve, Unst, Shetland, UK, (https://www.nature.scot/keen-hamar-nature-reserve-miniature-mosaic). The specialist plants include northern rock cress *Arabis petraea*, Norwegian sandwort *Arenaria norvegica* and – rarest of all – Edmondston's chickweed or Shetland mouse-ear *Cerastium nigrescens*, which is only found on the serpentine debris at Keen of Hamar. The conservation management issues are to ensure that the substrate of serpentine rock debris is not disturbed, and the plants are not removed by collectors.

Geothermal pools and plants are an excellent example of the dependency of biodiversity on geodiversity. Thermophiles are plants that have evolved to adapt to extreme conditions of temperature and chemical composition. They are generically termed extremophiles. Examples occur at the Giant Prismatic Spring in Yellowstone National Park, USA, and in the Waimangu volcanic valley, Rotorua, New Zealand. At the latter site, the geothermal area has been in existence for only 5000 years and the most recent eruption ceased in 1886. The conservation management issue at these sites is to ensure that the fragile plants are not damaged by visitors and that visitors are kept away from the very hazardous geothermal areas.

5.2. Niches for animals

Caves have long been known as environments for specialist animals because of the lack of light, specific humidity conditions and limited air flow. For example, the Jenolan Karst Conservation Reserve (JKCR), on the eastern flank of Australia's Great Dividing Range is significant geologically and biologically providing critical habitat for rare, endangered and relict species (Musser, n.d., in press). The caves specifically provide essential habitat for vertebrate species such as bats, owls and rock-wallabies. Cave-dwelling invertebrates are of special conservation value and include troglobitic and stygobitic faunas completely dependent on the cave environment and adapted to the current conditions within the caves. Changes to the light through artificial lighting, too many visitors changing the ambient temperature and humidity all have deleterious effects on unique or endemic troglobitic/stygobitic faunas. Conservation management is focussed on addressing these specific issues.

An interesting example is recently reported research in the Egyptian Western Desert White Desert National Park. The sooty falcon *Falco concolor* has a clear distribution pattern, density and breeding success in solution cavities formed within tower karsts, rather than the other karst landforms present in the area (Salama, Aref, Saleh, Thabet, & Gebrel, 2019, in press). The conservation management issue is to ensure that the tower karst is fully protected against attempts to disturb the falcons in any way.

More simply, the niches in rocks and on rock faces can provide the roosting place for birds, such as the night heron *Nyctanassa violacea* on San Cristóbal, in the Galapagos National Park, Ecuador, and the nesting sites of the Golden eagle *Aquila chrysaetos* in many protected areas of the Scottish Highlands (see Watson, 2010).

5.3. Emerging or refashioned land providing new habitats

Land emerging from the sea as sea level falls relative to the land provides new habitats for plants. There are places around the Gulf of Bothnia between Sweden and Finland where the land is still rising after the release of load of the ice cap. The rate is the greatest of anywhere in the world. On the Kvarken archipelago, on the Finnish side, new habitats are being continually created for colonisation by pioneer vegetation. The management of the site for protecting biodiversity is therefore continually evolving to take account of the new land emerging from the sea and the resultant different substrates and water regimes (https://whc.unesco.org/en/list/898).

Land at the outlet of glaciers and ice caps is continually changing due to the deposition of new materials from advances of the ice front or from floods of sediment charged meltwater. This often provides new habitats for plants to colonise and a plant succession to establish. A good example is on the Skeiðarásandur on the southern side of the Vatnajökull ice cap on the south east coast of Iceland. A major flood in 1996, resulting from a volcanic eruption under part of the ice cap, caused large scale erosion of the sandur plain and the removal of soil and vegetation, as well as the deposition of mineral debris from the glacier. Since then with no human interference or herbivore grazing pressure, birch trees and ground flora have colonised the site. The conservation issue is therefore 'to let nature take its course', i.e. to allow the land to flood and then naturally be recolonised by restricting vehicular access and ensuring that the reconstructed roads do not intrude unduly on the natural dynamics of the area.

5.4. Rock strata significant for tracing biological evolution

Evolutionary insights from palaeontological research on rocks have been a major area of interaction between geodiversity and biodiversity. Two examples, both from Canada, illustrate the importance of this connection.

The Burgess Shales, in the Yoho National Park in British Columbia, Canada, preserve life forms from the so-called 'Cambrian Explosion'. Detailed palaeontological research has identified many life forms and ecosystem associations previously unknown (see Coppold & Powell, 2006). The geoconservation objective, as stated by Parks Canada, is to "protect the Burgess Shales and its fossils for the understanding, appreciation and enjoyment of present and future generations". Clear interpretation is provided in and outside the visitor centre to allow visitors to gain a greater understanding of the global importance of these deposits. The conservation management issue is to strictly regulate access to the shale beds and collection of fossils, to coordinate research and to ensure dissemination of research results to the public.

Joggins Cliffs, Nova Scotia, Canada is important as the first site where fossil reptiles were discovered anywhere and for the evolution of amphibians, often embedded in fossilised tree stumps of the Carboniferous period (Ferguson, 1988). The site has been researched from the mid-19th century by such experts as Sir Charles Lyell who stated following visit in 1842 "I went to see a forest of fossil coal-trees – the most wonderful phenomenon perhaps I have seen". Conservation management focusses especially on visitor education through a well laid out visitor centre and guided walks along the beach. Fossil collecting is not allowed from the cliff strata or intertidal strata, but is allowed from the beach where many fossils occur due to erosion from the cliffs by wave action and the consequences of the very high tidal range in the Bay of Fundy.

5.5. Ecosystems dependent on water and nutrients

Conservation of wetland systems has often focussed on biodiversity, but ignoring the diversity of natural processes. However, the hydrological system, water supply sources and the mineral and other nutrients are equally important considerations if protection of the whole ecosystem of a wetland is to be ensured.

In the Shaumari Reserve Jordan, east of Amman there is a long standing project to reintroduce and achieve a biologically viable population of the Arabian Oryx. However, the project is dependent on a supply of fresh water. This has proved a major problem because the underground aquifer has been used for many years as a source of water for the city of Amman. No solution has been found due to the scarcity of water supply. This demonstrates that the whole ecosystem needs to be understood and the necessary conservation management measures put in place to ensure effective species conservation.

A major area of temperature climate blanket bog occurs in the north of the Scottish mainland, called The Flow Country (Lindsay et al., 1988). Its conservation has been very controversial due to traditional grazing practices and more especially because of plantation forestry using non-native species (Stroud, Reed, Pienkowski, & Lindsay, 1988). The effect of deep ploughing to drain the land and provide mounds for tree planting on this sensitive hydromorphological system was substantial and resulted in the loss of natural vegetation communities and the failure of many of the planted trees to grow. The conservation action was supported by the scientific understanding of the whole ecosystem, including the hydrological processes on which the vegetation complexes depended for their ecological health. Protection measures were begun by the government direction to halt formally the tree planting, providing government and independent financial resources to remove trees and re-establish the hydrological regime. In addition, transfer of land ownership was achieved where possible to organisations with environmental objectives. And, significantly, the area is protected for its biodiversity interest and the underlying geodiversity processes using national and European level statutory protected area mechanisms.

5.6. Vegetation growth getting in the way of geoheritage features and forms

There are many examples where two conservation objectives can come into conflict within a protected area. An obvious one is where from an ecological restoration standpoint, it is beneficial to allow vegetation to grow, but from a geoconservation standpoint this growth can obscure important geoheritage features and forms.

For example, a significant issue for the conservation management of tors, which occur in areas below the treeline as is commonly the case in Central Europe, is the growth of bushes and trees which obscures these landforms. The problem is particularly acute for low tors, a few metres high, which can be overgrown even by scrub. The experience from countries such as Austria, Czech Republic, Germany, Hungary and Poland, where tors are mostly within the limits of forest growth, shows various approaches to the issue and various policies of stakeholders (Migoń, n.d. in press; Migoń, Różycka, & Michniewicz, 2018). Removal of trees and shrubs and reinstatement of herbivore grazing have been used successfully as conservation management measures.

6. Practicalities: dealing with conflicts

Interactions between geodiversity and biodiversity conservation can be both positive and negative. The topic is addressed by Crofts and Gordon (2015). The negative elements need to be recognised and solutions found by protected area managers. The essence of the resolution should be recognition of the interconnections between the biotic and abiotic features and the processes that brought them into existence and those processes which maintain them. Taking a one-dimensional approach, favouring either geoheritage or biodiversity conservation, is most unlikely to result in a resolution benefiting conservation as a whole. The following issues will need to be addressed. What is the basis of the conflict between the biotic and abiotic interests in and around the protected area? Is the conflict capable of resolution without undermining both interests or is it more fundamental? If the latter, is one of the interests more important in the long term to national and international nature conservation than the other and needs to be safeguarded and the other sacrificed?

There will also be a series of practical issues to be addressed. Is vegetation growth damaging or obscuring the geodiversity interest and would its removal or restraint damage the biodiversity interest? Alternatively, should the geodiversity interest be taken off-site or allowed to be obscured provided that it can be periodically re-exposed for re-examination in the light of new knowledge? Are current Earth processes, for example, glacier melt or river erosion, which are important for maintaining the geodiversity interest, having a damaging effect on the biodiversity interest, on human uses such as tourism and recreation, or on perceptions of infrastructure investments or risk? If so, can manipulation of the processes to have minimal effect on their natural pattern be undertaken to achieve biodiversity conservation benefits?

Sometimes, it will not be possible to achieve a solution at the protected area level, and the wider context of the habitat, ecosystem or biome will need to be considered in determining the relative merits of conserving one element in one place and the other in another place within the biogeographical unit. In the case of mobile or transient features, management has important roles both within the protected areas boundary and in the context of wider protected area networks. Large scale landscape issues are likely to be trans-boundary in relation to individual management areas, illustrating the need to assess relative contributions and for collaboration between protected area managers. For dynamic natural features, such as coastal dunes and lagoons, a holistic view of protected areas management is essential to address incremental environmental changes, for example sea level rise effects under climate change. Adaptation strategies that integrate across networks will be important to accommodate such changes. Associated with this, protection mechanisms that address connectivity and underlying processes are likely to be important at the scale of both the network and within individual areas. Implications include the importance of evaluating the dynamic properties of a particular site or feature in relation to management objectives and timelines. These aspects may affect the design and effectiveness of the available protection methods. Aside from challenges and decisions for conserving extant examples, interesting aspects include the potential to accommodate the continued development of dynamic land and seascapes within protected areas. For some features and their associated ecosystems this is likely to be a necessary component of adaptation.

Finally, it is important to discourage attempts to maximise habitat/species diversity by landscape modifications that result in the creation of incongruous landforms/landscapes (e.g. through raising the land surface by infill in areas of flat topography or creation of ponds with shapes that are atypical of local natural features). This requires attention to the physical state of environment and degree of acceptable modification, and also to the continued operation of important physical processes.

7. Conclusion

There is increasing recognition in conservation thinking and practical management about the interaction and interdependencies between biological conservation and geoheritage conservation in protected. Despite a slow start, the Earth science and management community has made rapid strides to ensure that these interactions are recognised, communication improved and action in practice evolved. The publication of the IUCN WCPA Best Practice Guideline on Geoconservation in Protected Areas is aimed at maintaining this momentum.

This [paper argues that there are a number of ways to enhance this interaction in a positive manner. First, Earth scientists should understand why geodiversity conservation has lagged well behind biodiversity conservation and use the IUCN General Assembly Resolutions to promote this aspect of nature conservation. Second, Earth scientists should refrain from using obscure terminology and communicate in language colleagues in other conservation disciplines can readily understand. Third, and most significant, clear articulation of the linkages between geodiversity conservation and biodiversity conservation should be made at all times in both theoretical treatments and in practical management. This should be based on the ecosystems functions and services approach which demonstrates clear linkages between biotic and abiotic nature. The 'conserving nature's stage' concept is a very useful articulation of these linkages. Fourth, and building on the third point, is that a greater understanding of the importance of natural geological and geomorphological processes to maintain biodiversity would ensure that the dynamic element of habitats and ecosystems is not ignored to the detriment of improved conservation of nature and natural processes. This dynamism is particularly relevant in addressing the impacts of climate change and unpredictable weather patterns on nature conservation. Fifth, there will be occasions when there is conflict between conservation of geodiversity and biodiversity. A set of questions is listed in the paper which, when addressed, should help to determine what the key issues are and what measures are necessary to avoid or at least lessen the conflict.

Six different settings are used to describe examples from around the world of interactions and some of the practical issues to achieve improved conservation.

The major change in understanding of the interactions between geodiversity and biodiversity conservation will come when all the specialists can communicate effectively with each other, identify common goals, and consider how to achieve them through collective action. Ultimately, beneficial change will be reflected by a shared and common interest in nature conservation, rather than focussing on its component parts of biodiversity or geodiversity conservation.

Acknowledgements

This article is part of the work in progress on the preparation of the IUCN WCPA Best Practice Guideline on Geoconservation in Protected Areas. I am grateful for the contributions of many colleagues, and in particular to John Gordon and Murray Gray. I thank

Anne Musser and Piotr Migoń for allowing me to quote from their contributions. Thanks for funding from the Cultural Heritage Administration, Government of Korea.

References

Anderson, M. G., Clark, M., & Sheldon, A. O. (2014). Estimating climate resilience for conservation across geophysical settings. *Conservation Biology*, *28*, 959–970.

Anderson, M. G., Comer, P. J., Beier, P., Lawler, J. J., Schloss, C. A., Buttrick, S., ... Faith, D. P. (2015). Case studies of conservation plans that incorporate geodiversity. *Conservation Biology*, *29*, 680–691.

Anderson, M. G., & Ferree, C. E. (2010). Conserving the stage: Climate change and the geophysical underpinnings of species diversity. *PLoS One*, *5*, e11554. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0011554.

Brilha, J. (2018). Geoheritage: Inventories and evaluation. In E. Reynard, & J. Brilha (Eds.), *Geoheritage. Assessment, protection, and management* (pp. 69–85). Amsterdam: Elsevier.

Comer, P. J., Pressey, R. L., Hunter, M. L., Schloss, C. A., Buttrick, S. C., Heller, N. E., ... Shaffer, M. L. (2015). Incorporating geodiversity into conservation decisions. *Conservation Biology*, *29*, 692–701.

Coppold, M., & Powell, W. (2006). *A geoscience guide to the Burgess Shale*. Filed, British Columbia, Canada: Burgess Shale Geoscience Foundation.

Crofts, R. (2014). Promoting geodiversity: Learning lessons from biodiversity. *Proceedings of the Geologists Association*, *125*, 263–266.

Crofts, R. (2017). Putting geoheritage conservation on all agendas. *Geoheritage*, *10*(2), 231–238.

Crofts, R., & Gordon, J. E. (2015). Geoconservation in protected areas. In G. L. Worboys, M. Lockwood, A. Kothari, S. Feary, & I. Pulsford (Eds.), *Protected area governance and management* (pp. 531–568). Canberra, Australia: Australian National University Press. http://press-files.anu.edu.au/downloads/press/p312491/pdf/CHAPTER18.pdf.

Crofts, R., Gordon, J.E., Gray, M., Tormey, D., and Worboys, G. (in press). Best Practice Guideline on Geoconservation in Protected Areas. IUCN, Gland, Switzerland.

Dudley, N. (Ed.). (2008). *Guidelines for applying protected area management categories*. Gland, Switzerland: IUCN (x + 86pp) https://portals.iucn.org/library/sites/library/files/documents/PAG-021.pdf.

Ellis, N. (2011). The geological conservation review (GCR) in Great Britain: Rationale and methods. *Proceedings of the Geologists' Association*, *122*, 353–362.

Ferguson, L. (1988). *The fossil cliffs of Joggins*. Halifax, Nova Scotia: Nova Scotia Museum.

Gordon, J. E., Crofts, R., & Diaz-Martinez, E. (2018). Geoheritage conservation and environmental policies: Retrospect and prospect. (2018) In E. Reynard, & J. Brilha (Eds.), *Geoheritage: assessment, protection and management* (pp. 213–235). Amsterdam, Netherlands: Elsevier.

Gray, M. (2013). *Geodiversity: Valuing and conserving abiotic nature* (2nd. ed.). Chichester, UK: Wiley Blackwell.

Gray, M. (2004). *Geodiversity* (1st ed.). Chichester, UK: Wiley Blackwell.

Gray, M. (2018a). Geodiversity: The backbone of geoheritage and geoconservation. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: assessment, protection, and management* (pp. 13–25). Amsterdam: Elsevier.

Gray, M. (2018b). The confused position of the geosciences within the "natural capital" and "ecosystem services" approaches. *Ecosystem Services*, *34*, 106–112.

Gray, M., Gordon, J. E., & Brown, E. G. (2013). Geodiversity and the ecosystem approach: the contribution of geoscience in delivering integrated environmental management. *Proceedings of the Geologists' Association*, *124*, 659–673.

Holdgate, M. (1999). *The Green Web: a union for world conservation*. London: IUCN/Earthscan.

IUCN (2008). *Resolutions and recommendations adopted at the 4th IUCN World Conservation Congress. Resolution 4.040: Conservation of geodiversity and geological heritage*. Gland, Switzerland: IUCN. https://portals.iucn.org/library/node/44190.

IUCN (2012). *Resolutions and recommendations, World Conservation Congress, Jeju, Republic of Korea, 6–15 September 2012, WCC-2012-Res-048 valuing and conserving geoheritage within the IUCN Programme 2013–2016*. Gland, Switzerland: IUCN Available at: https://portals.iucn.org/library/node/44015.

IUCN (2016). Resolution 6.083 Conservation of moveable geological heritage adopted at the IUCN World Conservation Congress, Hawaii. https://portals.iucn.org/library/node/46500.

IUCN-UNEP-WWF (1980). *World Conservation Strategy: living resources conservation for sustainable development*. Gland, Switzerland: IUCN, UNEP, WWF.

IUCN-UNEP-WWF (1991). *Caring for the Earth: a strategy for sustainable living*. Gland, Switzerland: IUCN, UNEP, WWF.

Lindsay, R., Charman, D. J., Everingham, F., O'Reilly, R. M., Palmer, M. A., Rowell, T. A., & Stroud, D. A. (1988). *The Flow Country: The peatlands of Caithness and Sutherland*. Peterborough, England: Nature Conservancy Council.

Migoń, P. (in press). Tors and vegetation – a key challenge. In Crofts, R. et al. (in press). Best Practice Guideline on Geoconservation in Protected Areas. IUCN, Gland, Switzerland.

Migoń, P., Różycka, M., & Michniewicz, A. (2018). Conservation and geotourism perspectives at granite geoheritage sites of Lower Austria. *Geoheritage*, *10*, 11–21.

Musser, A. (in press). Jenolan Karst Conservation Reserve, New South Wales, Australia. In Crofts, R. et al. (in press). Best Practice Guideline on Geoconservation in Protected Areas. IUCN, Gland, Switzerland.

Salama, A., Aref, M., Saleh, M., Thabet, W., & Gebrel, M. (2019). *Geodiversity of Karst landforms with high priority conservation areas for sooty falcon Falco concolor in the White Desert National Park, Western Desert, Egypt*. (in press).

Sharples, C. (2002). *Concepts and principles of geoconservation*. Hobart: Tasmanian Parks & Wildlife Service. www.dpiw.tas.gov.au/inter.nsf/Attachments/SJON-57W3YM/$FILE/geoconservation.pdf.

Stroud, D. A., Reed, T. M., Pienkowski, M. W., & Lindsay, R. A. (1988). Birds, bogs and forestry: The peatlands of Caithness and Sutherland. *Nature Conservancy Council*. England: Peterborough.

Tansley, A. G. (1945). *Our heritage of wild nature*. Cambridge, UK: Cambridge University Press.

Watson, J. (2010). *The Golden Eagle*. London: Poyser.