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Discussion

# Boundary of ecosystem services: A response to Chen et al. (2023)

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ABSTRACT

Chen et al. (2023) have proposed a scheme to define which services should be included as ecosystem services and which should be excluded so as to avoid “an all-encompassing metaphor that captures any benefit”. We discuss the proposals, drawing attention in particular to definitions of ‘natural capital’ and ‘ecosystems’, the complexities of separating biotic from abiotic flows, and the importance of geodiversity and geosystem services in delivering societal benefits. We conclude that rather than trying to separate out bits of nature in order to draw the boundary of ecosystem services, it is perhaps time to avoid using ‘nature’ and ‘biodiversity’ as synonyms and think instead of a more holistic and integrated approach involving ‘environmental’, ‘natural’ or ‘nature’s services’, in which the role of abiotic nature is fully recognised in both ecosystem services and non-ecosystem domains.

## 1. Introduction

Chen et al. (2023) have discussed the need to distinguish ecosystem services (ESs) from “other ecosystem-related benefits …” in order to “avoid the risk of using ESs as an all-encompassing metaphor that captures any benefit” (p.1). They pursued this task by discussing a number of boundary issues and concluded that ESs should meet five criteria:

(1) Primary contributions of ecosystems;
(2) Flows during a period of time (not stocks);
(3) Renewable on a timeframe relevant to human use;
(4) Affected by biotic parts of ecosystems, but recognising that ESs “include both biotic and some abiotic flows (e.g., water provisioning) but exclude abiotic flows (e.g., wind and solar energy) whose occurrence is unaffected by ecosystem functions, processes, or characteristics” (p.4);
(5) Inclusive of the benefits actually and potentially received.

After outlining some of the context behind the concept of ecosystem services, this response discusses a number of issues related to Chen et al.’s (2023) paper and proposes a holistic approach that more fully recognises and integrates abiotic components.

## 2. Nature, ecosystems and geodiversity

We live on a rocky planet, but unlike other rocky planets in the solar system, the Earth has a living skin populating oceanic and terrestrial environments. Concern about the human impact on the planet’s environments has a long history (see Mooney and Ehrlich, 1997), but key landmarks in efforts to reverse this trend have included, first, the *Rio Earth Summit* and international signing of the *Convention on Biological Diversity* (CBD, 1992) and, second, the publication of Gretchen Daily’s edited book (1997) on *Nature’s services: societal dependence of natural ecosystems.* Subsequent work on ecosystem services (e.g. Costanza et al., 1997, 1998; MEA, 2005; Fisher and Turner, 2008; de Groot et al., 2012;

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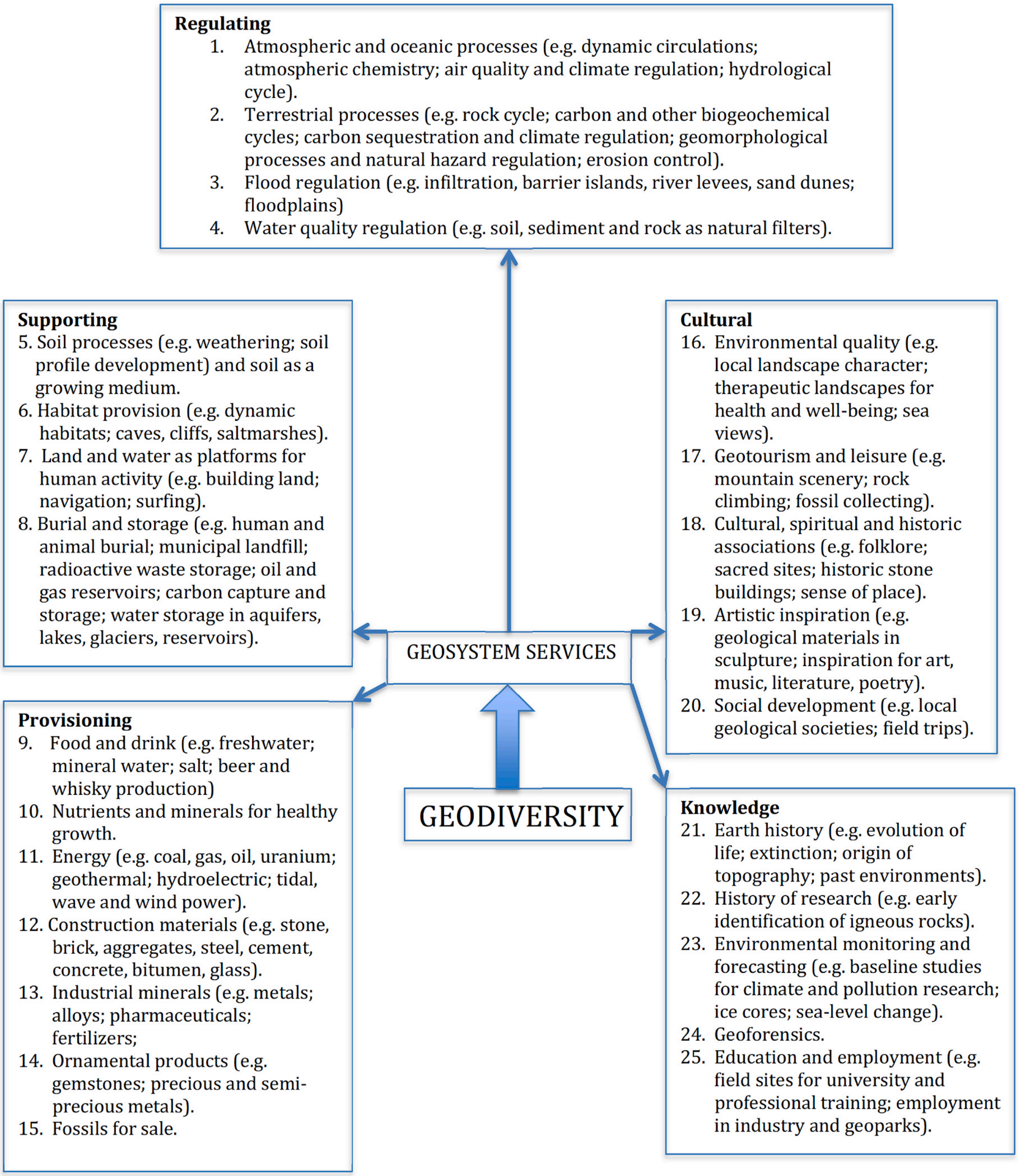


**Fig. 1.** The 25 major geosystem services related to geodiversity (after Gray, 2013).

Hernández-Blanco et al., 2022) has focussed on demonstrating how society is dependent on, but undervalues, the benefits it gains from ecosystems. Whilst sometimes, and perhaps unconsciously (Gray et al., 2013; Gray, 2018; Queiroz and Garcia, 2022), elements of abiotic nature have been included in this research, overall ES literature has tended to focus on biotic flows of benefits (Daily, 1997; UN SEEA-EA, 2021; Chen et al., 2023) to the exclusion of the geosciences (Brilha et al., 2018; Fox et al., 2020; Gray, 2021).

The publicity surrounding the CBD agreement drew the attention of geoscientists to the fact that they also study diverse phenomena (minerals, rocks, fossils, sediments, soils, landforms, abiotic processes, etc.) many of which are non-renewable but can also be threatened by human exploitation, loss or damage and are therefore in need of conservation. And so, in the year after the Rio Earth Summit, the word 'geodiversity' was coined (Wiedenbein, 1993; Sharples, 1993) and research on this topic has since snowballed (see the sequence: Gray, 2004, 2013, 2021). Nature therefore comprises both biotic and abiotic domains (e.g. Australian Heritage Commission, 2002; Scottish Government, 2022) and geoscientists have pointed out that society benefits from goods and services related to, and resulting from, geodiversity. These have been termed as either 'abiotic ecosystem services' (e.g. Urban et al., 2022) or 'geosystem services' (GSs, e.g. van Ree et al., 2017) and Gray (2013) has recognised 25 major services related to geodiversity (Fig. 1).

Fox et al. (2020, p.151) argued that "supporting services supplied by geodiversity underpin almost all ES …" They gave the examples of the flow of rivers dispersing the seeds of hydrochorous plants, and soils providing key minerals, nutrients and water required to sustain living things. They showed that geodiversity is fundamental for ES delivery

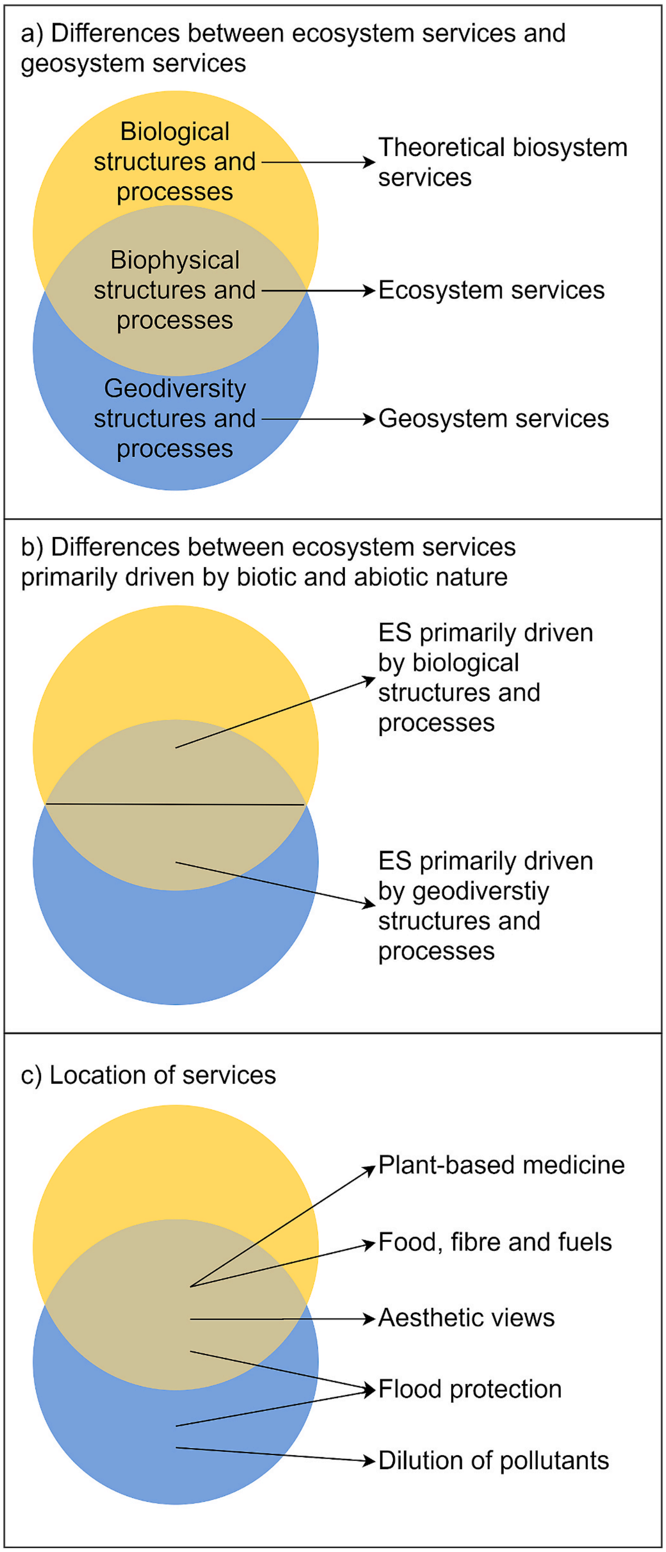


**Fig. 2.** The Geo-Eco Services Framework (after Fox et al., 2020).

and maintenance. In particular, they presented the Geo-Eco Services Framework (Fig. 2) and stated that "though standalone biotic services could exist, we would argue that there is no real-world system in which geodiversity does not in some way directly or indirectly impact on biotic services" (p.154). Importantly, they conclude that the omission of geodiversity and geosystem services from most ES literature and frameworks "impedes efforts to halt and reverse declines in ES" (p.157).

The common definition of an 'ecosystem' stems from the work of Tansley (1935) and was adopted by the CBD (1992) which defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (our emphasis). So ecosystems include biotic and abiotic nature, but many GSs also exist with no interaction with biotic nature, e.g. flood protection by barrier islands, renewable energy sources such as hydroelectric, tidal and geothermal power, and geotourism. The many roles of these GSs are increasingly being recognised in ES research. For example, the CICES iteration of ESs (V5.1; Haines-Young and Potschin, 2018) includes an "abiotic extension".

## 3. Critique of Chen et al. (2023)

Chen et al.'s world is very different to that described above in that it is dominated by either "ecosystem services" or "other ecosystem-related benefits". In places, they appear to regard all of abiotic nature as included in these two domains. For example, non-renewable flows including the extraction of fossil fuels and many geological minerals are described as part of "other ecosystem-related benefits" (p.2). But, elsewhere, they accept that non-biotic geosystem services (GSs) exist and are "derived from geological processes and characteristics" (p.4).

Chen et al. define natural capital as "the stock of ecosystems that yield flows of benefits" (p.3), but without referencing this definition. This represents a very limited view of natural capital. Although the geosciences have been excluded from most ES work, they are included in accepted definitions of natural capital (Gray, 2018). For example, the most common definition is that of the World Forum on Natural Capital (2013) which defined it as "the world's stock of natural resources which includes geology, soils, air, water and all living organisms". This has been updated by the Natural Capital Coalition (2016) which defines natural capital as "the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people". In other words, natural capital includes all natural assets, both abiotic and biotic. So, Chen et al.'s statement (p.1) that "there is a growing recognition that all human wellbeing is fundamentally derived from ecosystems" is an extremely biocentric view of the world in that it largely ignores the contribution that geodiversity and GSs make to human well-being as described above and explained in full by Gray (2013).

It is true that Chen et al. recognize that some abiotic flows are included in ESs, but they argue (p.4) that water storage and provisioning can be regarded as an ES as this refers to "the storage and supply of potable water regulated (e.g. being intercepted and purified) by functioning ecosystems". However, this ignores the fact that much storage of water takes place in rock aquifers and much purification of water is achieved as it moves downwards through sediments and rocks towards a water table, i.e. by abiotic adhesion and filtration processes, and dilution by groundwater.

Chen et al. provide a contradictory stance on how the absence of components of nature in ES understanding can lead to its degradation and loss. For example, they claim (p.4) that "the benefits from biotic parts of ecosystems to human wellbeing is often ignored and undervalued, which results in ecosystem degradation and biodiversity loss", yet when discussing geodiversity they state that "recognition does not necessarily require considering all abiotic benefits as ESs" (p.4). So, they acknowledge that excluding biodiversity elements from ESs can contribute to biodiversity loss yet overlook how this exact same scenario could lead to geodiversity degradation and loss.

Chen et al. also state (p.3), in the context of renewable benefits, that ESs are intended to meet a number of objectives. The first two of these are to:

1. "Raise awareness of nature's contributions to socio-economic development";

2. “Highlight the interdependence between humans and the rest of nature”.

Since nature includes both the biotic and abiotic worlds, these two statements could be seen as arguments that they believe that ESs include all of abiotic nature.

The third objective of ESs is listed as:

3. “Promote biodiversity conservation”.

In this context, it should be noted that much research in nature conservation is recognising that one way of conserving biodiversity is to conserve geodiversity, the physical habitats, niches and lithologies that species can migrate to, particularly at times of climate or environmental change. Known as the *Conserving Nature's Stage* approach, it uses the metaphor of biodiversity actors on a geodiverse stage. Although not necessarily applying in all areas and at all scales, the approach was originally described by Hunter et al. (1988), advanced by Anderson and Feree (2010) and Beier and Brost (2010), consolidated in a special issue of the journal *Conservation Biology* (29, no.3, June 2015; see Beier et al., 2015; Hjort et al., 2015) and now being researched by biodiversity conservationists working in cross-disciplinary teams that include geoscientists (e.g. Alahuhta et al., 2018; Tukiainen et al., 2019; Zarnetske et al., 2019; Falco et al., 2021; Hjort et al., 2022; see also Gordon et al., 2022).

In discussing whether ESs can include abiotic flows of benefits, Chen et al. argue that “While abiotic components of ecosystems, such as sand dunes and rocks, may potentially provide a habitat service (which is an ES), it is important to recognize that a habitat service inherently involves biotic inputs … In other words, abiotic components alone cannot constitute a habitat without the presence of biotic components” (p.4). While this is certainly true, it misses the point that the abiotic world comprises a wide diversity of physical habitats with which biotic nature is inherently connected. Recent research examples include the importance and need for conservation of rock cliff niches for nesting seabirds in Brittany, France (Eveillard-Buchoux et al., 2019), the role of caves and crevices for mammals and bats (Rivero-Castro et al., 2023; Hughes et al., 2023) and the development of biological rock crusts on the Xitle lava flow around Mexico City (Téllez et al., 2023).

A further important example concerns the role of geological minerals in affecting healthy growth of living things. Chen et al. state (p.4) that “while ecological processes and the production of ESs (e.g. nutrient cycling) may consume minerals (e.g. iron and potassium) in soil, we do not consider provisioning of geological minerals (e.g. natural diamond, gold, copper) as an ES …“. In fact, the search for diamonds and gold have influenced human history and settlement as part of important economic cycles in the past (e.g. the Gold Rush in USA and the search for Eldorado in South America). Furthermore, like iron and potassium, copper is an essential nutrient and, therefore, vital to the health of humans, animals and plants. In humans, this includes making energy, connective tissue and blood vessels, maintaining normal growth of the foetus during pregnancy, healthy brain functioning and repair of wounds and injuries. Copper also helps maintain the nervous and immune systems and activates genes. Both copper deficiency and copper toxicity can occur. (e.g. Robbins and Harthill, 2003; Urio-Adams and Keen, 2005; Araya et al., 2007; Copper Alliance, 2023). Over 90% of the Earth's crust is composed of silicate minerals including feldspars, micas, amphiboles, pyroxenes and clay minerals. These very common minerals are the main ones that often contain elements that are essential for plant, animal and human health (e.g. calcium, phosphorus, potassium, sodium, magnesium, iron, zinc, iodine, sulfur, cobalt, copper, manganese, selenium). These elements are transferred into soils during the physical, chemical and biological weathering of rocks and sediments, are absorbed by plants and then animals by ecological processes and thereafter become human foodstuffs. Therefore, there is a definite link between geological minerals/rocks and the healthy growth of all living things. It follows that most of the soils, sediments and rocks forming the surface of the Earth and the foundation of all life must, by Chen et al.'s reasoning, be ESs.


**Fig. 3.** The Swindale Beck, Cumbria England, before and after river restoration (after BBC).

## 4. Discussion and conclusions

From the above discussion, it should be clear that the abiotic and biotic components of nature are inherently and intricately interconnected. It seems almost inconsequential that, because there is a desire not to have an “all-encompassing term that captures everything related to human wellbeing” (p.2), we should instead spend time deciding which bits of nature to include and which to exclude, when it is actually nature as a whole that is in crisis and natural capital that is being lost. Yet decisions are being made to select parts of both the biotic and abiotic sections of nature, draw a boundary around them, and then label them as ‘ecosystem services’. The following are some reasons for thinking a different approach might be appropriate and more successful in preventing environmental degradation.

1. One of the original justifications for developing ESs was that the values of natural assets are often under-appreciated and under-assessed and therefore there is a need to try to demonstrate the full and real value of nature to decisions-makers, politicians and society at large. But if we exclude large sections of nature, we simply undervalue nature as a whole, to the detriment of a comprehensive view of its importance to society. Kofi Annan, former UN Secretary General and instigator of the Millennium Ecosystem Assessment (MEA, 2005) introduced its publication as follows: “Only by understanding the environment and how it works, can we make the necessary decisions to protect it. Only by valuing all (our emphasis) our precious natural and human resources can we hope to build a sustainable future”. It is our view that “understanding the environment and how it works” requires a comprehensive and integrated approach to environmental research and management involving both abiotic and biotic systems and processes.
2. Continuing the theme of the United Nations and sustainability, it is now clear that, despite an absence of geoscientists from the development of the UN's Sustainable Development Goals (SDGs), the geosciences have a clear role to play in working towards their eventual achievement (Gill and Smith, 2021; Gray and Crofts, 2022).
3. In terms of the important issue of climate change, much carbon storage takes place in mixed abiotic/biotic environments including estuarine sediments, saltmarshes, Holocene peat deposits and many soils. These need to be conserved *in situ* or restored in order to retain or improve their carbon storage capacity.

**Table 1**
The four phases of modern nature conservation framing in the developed world (after Mace, 2014) and a possible fifth.

| Rough timeline | Framing of conservation | Summary description |
|---|---|---|
| 1950s &1960s | 'Nature for itself' | Wilderness and natural habitats generally without people |
| 1970s & 80s | 'Nature despite people' | Threats to species and habitats from humans |
| 1990s & 2000s | 'Nature for people' | Sustainable benefits for people from ecosystem services |
| 2010s | 'Nature and people' | Two-way, dynamic relationship between people and nature |
| 2020s? | 'Holistic nature and people | Dynamic relationship between people and a holistic nature |

4. Very importantly, both the physical links that exist between geodiversity and biodiversity through habitat provision, and the chemical links essential for healthy plant, animal and human growth by nutrient cycling from rocks and sediments into soils demonstrate the fundamental basis of ecosystems as defined by Tansley (1935) and the CBD.
5. Following on from the previous item, in terms of nature conservation, the *Conserving Nature's Stage* approach offers a potentially pragmatic, broad-scale approach to conserve species by conserving the diversity of physical habitats, niches and lithologies into which they can migrate as climate and environments change.
6. Attempts at rewilding or nature recovery can also benefit from an integrated approach. A case in point is where river restoration by re-meandering straightened reaches, slows down stream velocity allowing in-channel gravels to accumulate in which fish can once again spawn. An example is the Swindale Beck in Cumbria, England shown in Fig. 3 as before and after restoration.
7. Chen et al. argue that only renewables should be included as ESs, but it can be argued that it is the non-renewables that should have priority for conservation and sustainable use for the simple reason that many abiotic resources are finite, and will eventually become exhausted and not available to future generations, thus infringing the principle of inter-generational equity. At least one company understands that both biodiversity and geodiversity are crucial for the planet's health (Tanskanen, 2022).

In conclusion, we believe that we have demonstrated that Chen et al.'s approach fails to capture the intricacies, dynamism and interconnectedness of nature and that drawing the boundary of ESs is more complex and difficult than they propose. Mace (2014) reviewed the modern development of nature conservation and identified four phases in the developed world (Table 1). All four phases use 'nature' as a synonym for the biosphere. Perhaps the 2020s are the time for a fifth phase to come into effect where 'nature' and 'biodiversity' are not used as synonyms and where the term 'environmental', 'natural' or 'nature's services' (the title of Daily's (1997) seminal work) are introduced as a holistic and integrated approach to the benefits society gains from all of nature. This would be particularly appropriate given the ways in which abiotic nature has progressed in recent years, for example through the publication of IUCN's guidelines on geoconservation in protected and conserved areas (Crofts et al., 2020), UNESCO's designation of 6 October as International Geodiversity Day (Zwolinski et al., 2023), recognition of the potential role of the geosciences in achieving the UN's Sustainable Development Goals (Gill and Smith, 2021), and the success of UNESCO's Global Geoparks Network (Brilha, 2018). Arguably, this approach would be a more effective, modern, conservation philosophy, particularly if it recognised the intrinsically interconnected value of the whole of nature in the face of accelerating human impacts and climate change.

## Statement of authors' contributions

MG drafted the paper with assistance from NF and JEG. The other authors provided many valuable insights and edits during the several revisions of the paper. All authors reviewed and approved the final version of the manuscript for submission.

## Declaration of competing interest

None of the authors has any known competing financial or personal interests influencing the ideas reported in this paper.

## Data availability

All data is referred to in the article

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