Nature: Clarifying its definition for strengthened protection and management

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Executive Summary

“Nature” is a widely used but rarely defined term amongst scientists, policy makers, business leaders and the public. It is at the heart of many important international frameworks and conventions that, in turn, shape national policy and regulation towards the natural environment. Not only is nature often freely used interchangeably with the term “biodiversity”, but the abiotic component is also often poorly understood and frequently overlooked.

In a world facing widespread ecosystem degradation, shifting baseline syndrome and unsustainable resource use, overlaid by a changing climate and rising sea levels, stakeholders share a common interest in ensuring that environmental initiatives apply to the whole of nature. The current situation of focusing on the biotic component without consideration of the all-important abiotic features and functions, such as the soil and water and the resulting dynamism and productivity of natural systems, is no longer tenable. The key resources required by biotic system come directly from abiotic features and processes. Pursuit of aligned biotic and abiotic management and protection, informed by systems thinking and wider temporal insights, can promote stronger ecosystems, building a robust and evolving platform on which all facets of nature can fully function and thrive (Brazier et al., 2012; Cienciala, 2024).

As a result, more effective management and protection of the whole of the natural environment will result, alongside a just and sustainable future, in which humans are an integral player. It is therefore proposed that the IUCN definition of nature, as used in the 2024 draft IUCN 20-year Strategic Vision to 2045 (IUCN, 2024), is broadened and strengthened such that nature is defined as *"encompassing both the non-living components (i.e. geodiversity) and the living components (i.e. biodiversity) of the natural world*".

Introduction

Many organizations globally and regionally are mobilized for the stewardship of the natural world. Heightened awareness of shared challenges ranging from climate change, sea-level rise, biodiversity loss, land use change and unsustainable resource use has led to the development of a series of international frameworks and conventions for the protection and restoration of the Earth (United Nations Framework Convention on Climate Change, Convention on Biological Diversity, UN Convention to Combat Desertification, UN Sustainable Development Goals). In turn, these have triggered cascading regional and national policies, regulations and reporting obligations catalysing this stewardship ambition at ever more local levels. Initiatives to optimize financial flows and economic activity contributing to the conservation and restoration of the natural world have been framed under the terms "natural capital" and "ecosystem services".

"Nature" is a central notion in all these accords and instruments. It is, however, rarely defined by scientists, or in the framework of these conversations (Ducarme & Couvet, 2020). In addition, much of the work addressing the natural world is led in English and built on Western scientific principles.

Politicians, business and thought leaders increasingly talk about sustainability and the natural environment. However, it can be observed that their rhetoric switches seamlessly between the use of the terms “nature” and “biodiversity” (European Commission, 2020 and 2022). This follows a precedent set by popular and scientific literature as noted by Gray (2018). A new generalized, but incomplete, notion of nature is now widely accepted and employed. In this, although the biotic element remains anchored in debate with the use of the term biodiversity, nature’s abiotic components are marginalized; in practice their direct connection with the biotic elements goes unrecognised, as does the functional interdependence of bio and geo systems.

It is interesting to consider the sparse definitions of nature used by international bodies. IPBES defines nature as either “*the natural world with an emphasis on its living components*” or “*the natural world, with particular emphasis on biodiversity*” (Nature | IPBES Secretariat, n.d.). In contrast, the IUCN position towards nature has evolved over time. Initially IUCN protected areas were defined only as relating to biological conservation. Since 2008, however, the notion of geoconservation has been incorporated in IUCN World Conservation Congress resolutions in 2008, 2012, 2016 and 2021 (Monge-Ganuzas et al., 2024; Woo et al., 2015). Its inclusion is, however, conditional, as exemplified in the definition of nature presented by the IUCN in its Best Practice Protected Area Guidelines Series No 21: “*…nature always refers to biodiversity, at genetic, species and ecosystem level, and often also refers to geodiversity, landform and broader natural values*” (Dudley, 2008). The 20-year IUCN Strategic Vision submitted for member consultation during 2024 uses a further variation on the definition of nature, such that it encompasses “*both the non-living and the living components (i.e. biodiversity) of the natural world*”. Despite the comparatively inclusive definition of nature, the draft strategy makes no further reference to non-living nature, geodiversity or geoheritage (IUCN, 2024). These documents demonstrate an important but incomplete progress. Interestingly, there is a tacit acceptance of the significance of geodiversity by conservation bodies internationally, including the World Heritage Committee, as has been demonstrated through the recognition of numerous sites solely or substantially for their geological heritage and active geomorphological processes (Figure 1).

Increasingly, awareness is being raised about the importance of transdisciplinary systems thinking, given the varied challenges faced by society today (Steffen et al., 2020). This is an approach that is inherent to the geosciences and is built on the understanding of the Earth and its processes, past, present and future, over human- and deep- timescales. Given that nature fundamentally incorporates biotic and abiotic elements, it is timely to further strengthen its definition such that these two components are systematically present and acknowledged. This will pave the way for a consistent, integrated and holistic position to be established towards the natural world to maximise its protection, conservation and restoration (Gordon et al., 2018; Justice, 2024; Scorpio et al., 2020).

History – How did we get here?

Religious, social and intellectual developments since the Greeks and Romans have incrementally set the scene for the development of western scientific tradition towards nature (Bowler, 1992). Pivotal thinkers emerging since the 18th century, such as Alexander von Humboldt (1769-1859), James Hutton (1726-1797) and Charles Darwin (1809-1892), produced remarkable observations and theories about the natural world spanning geology, biology, astronomy, meteorology, oceanography and more. Important examples include Von Humboldt’s use of detailed empirical evidence to describe the relationship between vegetation and the abiotic environment over large spatial scales and in different ecosystems

(Schrodt, Santos, et al., 2019; von Humboldt & Bonpland, 1807). This early natural science tradition firmly excluded the wider value and perception of nature derived from religious and philosophical traditions. Its proponents viewed the whole Earth as a system with many spheres, interconnections and relationships (Figure 2).

The application of scientific method to gain a deeper, factual understanding of the world led to intense specialisation within the sciences. Despite this trend, certain scientists maintained a whole-picture perspective, as demonstrated for example by the research of V. Vernadsky (1863-1945) into the influence of biological processes on subsurface geochemistry, or importantly the definition of the ecosystem formulated by Tansley, (1935), as a "*whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense*". These cross-disciplinary scientific positions, born through consideration of all aspects of nature, biotic and abiotic, use a systems approach to explore the breadth of relationships and interactions of the natural world.

What is the abiotic component of nature, why is it important?

Abiotic nature can also be referred to as geodiversity, 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). It provides a range of benefits for nature and for people and is considered to have intrinsic, economic, cultural, aesthetic and ecological values (Brilha et al., 2018; Gordon et al., 2018).

For more than fifty years the need to protect and sustainably manage geodiversity has been internationally recognised (Brilha, 2022). However, it is notable that since the establishment of the Convention on Biological Diversity (CBD) at the Rio Earth Summit in 1992 strong international efforts concerning geodiversity and its conservation have been made (Figure 3). Within the IUCN World Commission on Protected Areas, geodiversity has assumed an increasingly important role since it was officially included within the aims of protected areas in 2008. Conservation of geodiversity featured in a series of World Conservation Congress resolutions in 2008, 2012, 2016 and 2021. A dedicated specialist group was established in 2013, with a continuing programme of work (Vogel et al., 2018), including development of the Key Geoheritage Area concept (Woo et al., 2022). Furthermore, practical guidelines have been issued by the IUCN to help protected and conserved area managers understand and implement the conservation of geoheritage - those parts of geodiversity selected for conservation. Indeed, the heritage value of geodiversity can be so significant that sometimes it justifies conservation, even if there is no significant link with biodiversity, i.e. geoconservation.

The significant interest in abiotic nature is reflected by an increase in published scientific literature, much of which has been achieved amongst a community of geodiversity, geoheritage and geoconservation specialists (Gray, 2023). It must be stressed that biological conservation measures do not inherently protect geodiversity unless changes to the geodiversity have been identified as a key threat to biodiversity. In general, therefore, existing biological conservation approaches cannot be used as a proxy for achieving geoconservation. Natural heritage conservation and management can differ when decisions are made only from a biotic perspective compared to using a combined biotic and abiotic approach (Justice, 2024). It is also recognised that geoheritage management can be important for ensuring functional links within ecosystems (Crofts et al., 2020).

A smaller number of publications have appeared in wider circles, which discuss the importance of applying a holistic view of nature, one that includes geodiversity, to strengthen policy and conservation efforts (Gordon et al., 2018; Hunter Jr et al., 1988; Lawler et al., 2015; Matthews, 2014; Tukiainen & Bailey, 2023). Practical methods and metrics for categorizing and assessing geodiversity to support comprehensive nature management and policy are being developed (Hjort et al., 2024; Schrodt, Bailey, et al., 2019; Schrodt et al., 2024). The establishment of an international definition of nature, one that incorporates both the biotic and abiotic elements, is an important first step in moving towards integrated nature conservation; an approach that can strengthen contributions to the CBD Kunming-Montreal Global Biodiversity Framework including the 30x30 target for 2030, the Agenda 2030 Sustainable Development Goals and the Paris Agreement on climate change.

Biotic – Abiotic Interdependence in Nature

Working from a big-picture, systems perspective, the inherent interdependency of biotic and abiotic nature is well established. This two-way relationship (Lawler et al., 2015; Tukiainen et al., 2023) has been demonstrated to extend back over geological time (Benton, 2009; Hallam, 1974; Salles et al., 2023; Valentine & Moores, 1970) and will continue into the future. A growing number of interdisciplinary research teams are investigating the fundamental relationships between geodiversity and biodiversity.

Geodiversity, for example supports biodiversity in many ways, such as by shaping climate (at all scales), providing landforms, habitats and niches, controlling the hydrology, determining sediment and nutrient fluxes and through extreme disturbances, such as landslides, creating habitat heterogeneity and impacting community dynamics (Antonelli et al., 2018; Kaskela &

Kotilainen, 2017; Opedal et al., 2015). The interdependency can be observed at different scales and timeframes, on land, in wetlands, lakes and rivers but also in the oceans (Harris & Baker, 2020; Salles et al., 2023). Biodiversity is highly controlled by geodiversity notably through energy, water and nutrient availability (Hupp & Osterkamp, 1996; Kozłowska & Rączkowska, 2002). As a consequence, high geodiversity can correlate to high species richness and biological diversity (Hjort et al., 2022; Toivanen et al., 2019), recent work has further linked trait diversity, another biodiversity metric, to geodiversity (Vernham et al., 2023). There are rare exceptions, such as active volcanic areas which have high geodiversity but low biodiversity, or high biodiversity yet low geodiversity such as lowland tropical forests (Gordon et al., 2022). Figure 4 presents examples of geological and geomorphological features that support biodiversity at different scales and environmental settings.

Biotic nature by turn transforms the geosphere. For example, biogeomorphological studies examine ecological and geomorphological interactions to address questions such as the geomorphological signature of life, or indeed how important is biodiversity to landscape evolution and vice versa (Viles, 2020). One significant example is the great oxygenation event ~2.4 billion years ago when O_2 rose to permanent prominence in the atmosphere and surface ocean (Olejarz et al., 2021). Driven by cyanobacterial photosynthesis it completely changed chemical interactions with Earth substrates and transformed weathering, deposition and the availability of elements for biotic nature e.g. the formation of red beds, as well as giving rise to an incredible diversity of minerals in oxidised form (Hazen, 2010). At a different scale, within the modern environment, plants can generate strong soil heterogeneity through their chemical signatures (Waring et al., 2015).

Soil is an excellent example of a natural asset that is both biotic and abiotic. The abiotic geochemical processes that transform the base material of rocks and sediments into soil provide a habitat for the development of microorganisms, such as mycorrhiza, as well as the basis for plant growth (Bockheim, 2014; Darmody et al., 2004; Hulshof & Spasojevic, 2020). Furthermore, soil health in itself is assured not only by soil-living organisms, but also by animals with other behaviours, such as, browsing and grazing (Schmitz et al., 2018).

The profound links between biotic and abiotic nature are the basis for integrated conservation approaches, such as the Conserving Nature's Stage or "CNS" concept (Beier et al., 2015; Gordon et al., 2022). CNS is a metaphor for the interlinked, interdependent relationship between geodiversity as the stage, scenery and props upon which biodiversity as the many actors, perform. The play is only a success because the stage and the actors are an ensemble, as is the case for geodiversity and biodiversity in nature. These interdependencies are central to the CNS concept which is advocated as the basis for a coarse-filter approach for conserving biodiversity (Beier et al., 2015; Miller et al., 2024), but which by extension offers a holistic approach for conservation of geodiversity and biodiversity recognising the connections across a range of scales from global to local (Bailey et al., 2017; Tukiainen et al., 2017; Zarnetske et al., 2019). While species and communities may change, conserving geodiversity and making space for natural processes that enhance landscape heterogeneity enhances opportunities for biodiversity to adapt or relocate under both current and future climates (see below). However, it is essential to underline that Nature's stage in CNS is far from static; geodiversity gives rise to incredible variations in physical environments and fluxes over space and time, responding to geomorphological processes and disturbance regimes of different magnitudes and frequencies which contribute to landscape heterogeneity and ecosystem functioning (Brazier et al., 2012; Cienciala, 2024).

Since the emergence of the concept of CNS, the large body of research work has not only established the wealth of connections between biotic and abiotic nature, but also the potential of the CNS approach for enhanced nature conservation (Miller et al., 2024).

The argument for applying an integrated approach to nature is further confirmed through the impact of initiatives such as UNESCO Global Geoparks (UGGps), established by UNESCO and the Global Geoparks Network in 2015. This young UNESCO designation applies to regions whose sites and landscapes of international geological significance are the motor for natural, cultural and intangible heritage conservation, education and sustainable development (UNESCO Global Geoparks | UNESCO, n.d.). Although not systematically considered to be protected areas, UNESCO Global Geoparks integrate geodiversity throughout their workstreams and are regions where holistic nature conservation and management approaches are successfully applied (Justice, 2024). Other traditional protected area approaches, such as mixed World Heritage listings under criterion (viii) with criterion (ix) and/or criterion (x), also underscore the value of taking an integrated view of nature.

Although the importance of geodiversity in nature is well documented in scientific literature and emerging examples demonstrate the scope for this approach, its systematic introduction into nature policy and conservation methods is still to be achieved (Matthews, 2014; Tukiainen & Bailey, 2023).

Attitudes towards nature have however evolved, leading for example to the development approach known as Nature-based Solutions (NbS). This integrates people and nature and is defined by the IUCN as "*actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing* *human well-being and biodiversity benefits*" (Cohen-Shacham et al., 2016). Working with an ecosystem approach and drawing on Earth's natural processes, projects designed using an NbS are lauded for their successes in reducing costs, providing longer-term solutions than traditional engineering whilst also delivering biodiversity gains. Although full consultation around a scheme may determine its on-balance benefits, the role of geodiversity in these large-scale infrastructure developments appears little considered in site assessments, particularly in downstream aspects e.g. sand, silt and gravel sourcing (Staudt et al., 2021). Labelled "mega-nourishment" projects, coastal protection is achieved by extracting millions of cubic metres of non-renewable material from the seabed, or on land, that has permanent impacts on source site integrity and dynamics (Herman et al., 2021). These examples further underscore that a holistic approach towards nature is crucial.

Climate Change Resilience

Modification of the natural environment in response to modern climate change is already being observed (IPCC, 2021). From a biotic perspective, community composition and species range are impacted, as too are ecosystems. Concerning the abiotic element, climate change is altering sedimentary and geomorphic processes although widespread measurement of the effects remains challenging, it is already well documented in the cryosphere (East et al., 2022; IPCC, 2019). Given that a healthy and diverse geosphere can foster a healthy and diverse biosphere, and vice versa, application of an integrated understanding of nature for conservation and management should result in the highest possible natural diversity and thus greatest resilience to change (Anderson et al., 2014, 2023; Dudley, 2008; Knudson et al., 2018; Theobald et al., 2015). The IUCN best practice guidelines "Applying Protected Area Management Categories, N° 21" includes information on planning for climate change. In this context, advice is given to protected area managers to connect protected areas though corridors and networks in order to facilitate the movement of species. Frequently these corridors are abiotic components of nature such as topographic relief, structural and lithological features, or geomorphological systems and hydrological systems. The guidelines further call to use a greater biogeographical range when establishing a protected area, where biogeography is inherently linking the biotic and abiotic. Hence using a holistic notion of nature to inform management decisions can systematically increase climate resilience (Sanderson et al., 2015). This is essentially founded on a CNS approach in which the physical template (geodiversity) forms the foundations of most habitats in terrestrial and marine environments (Beier et al., 2015). As species and community compositions shift in response to climate change, conserving areas of high geodiversity and specific niches (e.g. hot springs and limestone pavements), and maintaining the geomorphological processes that enhance landscape heterogeneity, will help to sustain robust protected area networks. These should provide suitable environmental mosaics and corridors to assist the adaptive capacity and hence resilience of biodiversity in the face of climate change (Anderson et al., 2014, 2023; Gross et al., 2017; Theobald et al., 2015). Such an approach involves planning for change and a shift from short-term preservation to protecting areas with a high probability of harbouring high biodiversity in the future and can help inform the design and management of protected area networks under changing climate, including identification of gaps or biases and localities for new protected areas as species ranges change (Miller et al., 2024; Zhu et al., 2021).

A region with high geodiversity provides a mosaic of niches and habitats, that can be further multiplied by seasonal fluctuations or extreme events within the same location (Parks & Mulligan, 2010). Areas of high abiotic diversity can therefore contribute to the resilience and adaptation of biodiversity to climate change by providing environmental connections or climate refugia (Hjort et al., 2015). Likewise, faced with extreme winds, changing precipitation patterns or floods, the resilience of the geosphere can be strengthened by biological diversity, for example through the resistance to coastal erosion provided by mangroves (Menéndez et al., 2020). Furthermore, integrated conservation can ensure that organic soils, peat and coastal and marine ecosystems and sedimentary systems continue to play an important role in climate regulation through their role in carbon sequestration and storage (Atwood et al., 2020; Beaulne et al., 2021; Beaumont et al., 2014; Smeaton et al., 2021).

Cultural and Spiritual Values of Nature

The separation of people and nature observed in Western civilisation has generally not occurred in other world cultures. However, Western traditions have influenced international management practices, and the institutional need to reconcile cultural and natural conservation is recognised (Verschuuren et al., 2021). It may be argued that the ambition to develop stronger links between culture and nature can be accelerated by using a fully comprehensive definition of nature, that embraces the importance of non-living diversity (Ducarme & Couvet, 2020). This in turn is coherent with reasoning that led to the evolution of the 1997 IUCN protected area definition into the current formulation, that incorporates geodiversity, as approved in 2008. Not only does the IUCN explicitly represent nature as a whole, as evidenced by the title of the organisation, but this change also recognised the fundamental contribution brought by the views and practices of many Indigenous Peoples towards the natural world, that fall outside the bounds of traditional conservation ecology. For example, many natural features such as rock outcrops and caves have sacred values and cultural meanings (Crofts et al., 2020; Kiernan, 2015), while many also have been sources of inspiration for art, literature and poetry and provided the foundation for landscape character and people's sense of place (Gordon, 2018; Reynard & Giusti, 2018).

Reflected by economic, social, religious and philosophical approaches, the complex, intertwined integrity of nature remains intact in the majority of worldviews; a holistic relationship that is echoed by the majority of world languages. Around the Earth, the intrinsic value of nature and its profound spiritual and cultural significance is firmly built on both abiotic and biotic elements. Interestingly, the IUCN protected area category III for "natural monuments" includes not infrequently both geographical or geological features (e.g., rock outcrops) and sacred natural sites. Further examples are provided in the table below demonstrating imbricated heritage recognition:

	Heritage		
Site	Geological	Biological	Cultural and Spiritual
Kilimanjaro National Park, Tanzania *World Heritage, Natural Site.*	Diverse abiotic heritage. Largest freestanding mountain in the world, a stratovolcano, last active in the Pleistocene. Ice-core records of climate change.	Large scale ecological processes with characteristic ecosystems including rare and endemic species.	The traditional Chagga religion posits that the sacred spirit Ruwa, is embodied by the mountain and the sun, and pervades all aspects of the world including plants and animals (Clack, 2011).
Uluru-Kata Tjuta National Park, Australia *World Heritage, Cultural, Traditional, Aesthetic, Geological Site.*	The sandstone monolith of Uluṟu and the conglomerate domes of Kata Tjuṯa, rise abruptly above the surrounding sandplains and woodland. The inselbergs are outstanding examples of tectonic, geochemical and geomorphic processes and reflect the age, and relatively stable nature, of the Australian continent. Uluru and Kata Tjuta are surrounded by red sand dunes, sand plains and alluvium deposits.	The main species found in Uluru and Kata Tjuta are Puli-ili (native fig), Arnguli (plum bush) and Mintjingka (native fuchsia). These can be found in common habitats within the reserve, such as Puti (woodlands) and Karu (creek beds and gullies). Vulnerable or rare flora and fauna include *Cymbopogon dependens* (native lemongrass), *Delam pax* (legless lizard) and *Egernia kintorei* (Great Desert skink).	This iconic sacred site is an integral part of local Anangu cultural and spiritual traditions, creation stories and customary law (Tjukurpa). The Tjukurpa is an outstanding example of traditional law and spirituality and reflects the relationships between people, plants, animals and the physical features of the land.
Majella National Park, Italy *UNESCO Global Geopark.*	Mountains constituted by an imbricate fan of thrust sheets transported towards the Adriatic between about 5.5 Ma and the early Pleistocene (1.8 Ma). Made up of the Mesozoic-Tertiary platform-and-basin-derived carbonate sequences capped by siliciclastic flysch deposits, sedimentary structures and fossil content attest a long period of sedimentation in warm, shallow, marine environments, as in the present-day Bahamas and Persian Gulf.	An important biodiversity refuge with over 78% of the species of mammals (except Cetaceans) living in Abruzzi, and over 45% of the Italian species. With more than 2000 floristic species, the Park hosts 65 % flora of Abruzzo region, 37 % of Italy and 22 % of the European species (Majella National Park 2011). Vegetation in Majella is divided into several distinct forest types. Each forest type has characteristic tree species composition.	A sacred mountain since time immemorial, the area is characterised by a layered cultural and spiritual heritage shaped by human-environment interaction. Spiritual significance is attributed to the entire Majella Massif as well as to smaller features, especially grottos. Many caves were used already in pre-Christian times as dwellings, burials, worship sites, and shelters for mobile pastoralism (transhumance). After Christianization, they have been revered as hermitages and sites of divine apparitions.

Recognition of the importance of Indigenous people's knowledge of, cohabitation with, and contribution to nature has been acknowledged and for example is actively being used to shape responses to biodiversity loss and climate change (Pontifical Academy of Sciences and the Pontifical Academy of Social Sciences, 2024). Equally, approaches to the conservation of abiotic sites can be diversified and strengthened by including Indigenous communities in protected area management, as demonstrated in the recent inscription of Anticosti Island, Quebec, Canada on the World Heritage list (UNESCO World Heritage Centre, n.d.). Examples provided by Verschuuren et al. (2021) and Brierley et al. (2023) illustrate how cultural and spiritual approaches to both biotic and abiotic nature by Indigenous peoples contribute through adapted governance structures to stronger natural heritage management.

Of fundamental importance, however, are the benefits that an integrated approach to nature can bring to the world's population, contributing to a just future for humanity, notably for those most in need. Robust environmental protection of the environment and effective climate change resilience developed on an integrated biotic-abiotic approach to nature can increase the impact of responses under the United Nations' 17 Sustainable Development Goals which seek to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity (Gill & Smith, 2021; United Nations, n.d.).

The Great Debate – the Value of Nature

Outside the natural sciences and conservation arena, governments and the private sector, for example, have started to work with nature, adopting the concepts of natural capital (Helm, 2015) and ecosystem services (Costanza et al., 1997; Ehrlich & Mooney, 1983) to quantify nature and its services for humanity. Ascribing an economic value to nature has improved its visibility and integration by varied parties such as the European Commission, the World Bank, non-governmental organisations and increasingly corporates (European Commission, n.d.;

World Bank, n.d.). This in turn has led to nature being introduced into non-financial sustainable reporting initiatives worldwide, for example by the International Accounting Standards Board, the European Financial Reporting Advisory Group or the US Securities and Exchange Commission. This development has focused the attention of the financial and business sector on nature, but one that is built around interpretations of its direct or indirect economic value (United Nations Environment Programme, 2023). Using AI to process big data, sophisticated commercial assessments are being made of direct and indirect stakeholder interaction with the natural world. These valuations are inherently sensitive to the assumptions used to represent nature, which underscores the importance that all parties—government, conservationists, and business— work with a common definition of nature. This is crucial given that private sector decisions can provoke significant capital flows with direct impacts, positive and negative, on the natural world.

Within academic circles it is considered that natural capital generally includes abiotic nature (Gray, 2018) and in contrast, the notion of ecosystem services is developed principally around biotic nature (Brilha et al., 2018). However, in practice in the public and private sector both approaches generally emphasise the biotic element of nature (Capitals Coalition, n.d.; S&P Global, 2024), to the exclusion of the abiotic.

Use of non-renewable resources

Non-renewable abiotic resources are used abundantly to fuel economic growth; for example the current drive toward a sustainable, low-carbon future relies heavily on the use of rare earth elements.In 2022 the United Nations Environment Programme reported that 50 billion tons of sand and gravel are mined or extracted each year (UNEP, 2022), which exceed rates of natural replenishment (Hackney et al., 2021; Peduzzi, 2014). International resolutions have been established to address this consumption and its ecosystem impacts, (IUCN, 2020; United

Nations Environment Assembly, 2022). However, intense use of non-renewable resources continues (Chase-Lubitz, 2024).

Another component of geodiversity, groundwater, is managed to support human activity. Generalised, persistent subsidence due to anthropogenic action, notably extraction, is well documented (Karegar et al., 2016) with studies identifying impacts on biodiversity, economy, and society (Keith et al., 2020; United Nations Environment Assembly, 2022). Similarly, degradation of biotic communities, such as grassland ecosystems, can influence the recharge rates of groundwater. The incursion of saline waters, loss of aquifer storage capacity, habitat loss, rising sea level as well as exposure to extreme weather events can have far reaching and persistent consequences on ecosystems and biodiversity. Earth system assessments do not incorporate this type of driver (Ohenhen et al., 2023). An integrated definition of nature would support a more comprehensive approach to investigate and understand the natural world and wise use of non-renewable resources.

Conclusions

Advances are being made in the conservation and management of biodiversity and ecosystems, as well as in environmental education outside technical and academic realms. This is demonstrated by the general progress made towards the Global Biodiversity Framework and the 2030 30x30 goal (Gurney et al., 2023). However, an integrated definition of nature, where both geodiversity and biodiversity are systematically included, would strengthen the whole-ecosystem approach to conservation, to improve not only conservation outcomes, but also wider positive environmental and societal outcomes on land and in the oceans.

In anticipation of future climatic and other anthropogenic stresses, a stronger functionally integrated Earth system can offer greater opportunity for all of nature to persist. It is essential that our reference for the environment is updated and that all stakeholders define nature such that it *"refers to biodiversity at genetic, species and ecosystem level, to all the dynamic processes and features of geodiversity, and to all their interactions";* and in shortened form building on the definition used in the 2024 draft IUCN 20-year Strategic Vision to 2045, that nature is defined as *"encompassing both the non-living components (i.e. geodiversity) and the living components (i.e. biodiversity) of the natural world*".

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Figure 1: Examples of protected areas recognised wholly or substantially for their geodiversity. (a) Siccar Point Site of Special Scientific Interest, UK. The site vividly demonstrates a 55-million-year discontinuity in the geological record between two different sets of rocks and was discovered by geologist James Hutton in 1788; it supports Hutton's theory of deep time and Earth's long and dynamic geological history © J. Gordon. (b) The Swiss Tectonic Area Sardona, Switzerland, is inscribed on the World Heritage list under criterion viii. A key site for geological research, it has significantly contributed to understanding the dynamics of plate tectonics and the formation of the Alps © G. Regolini. (c) Los Glaciares National Park, Argentina, where the largest ice cap outside of Antarctica and Greenland, approximately 2,600 km^2, is associated with a diverse range of geomorphological processes, glacial features and subject to a changing climate. Image shows Laguna Torre © J. Gordon.

Figure 2: Physical Description of the Andes and Neighbouring Regions by A. von Humboldt, (1807). This figure shows how von Humboldt's meticulous observations and illustrations laid the groundwork for understanding the geography, geology, and natural history of the region. Courtesy of Peter H. Raven Library/Missouri Botanical Garden (CC BY-NC-SA 4.0).

Figure 3: The timeline of major international initiatives related to geoconservation and geoheritage. From Brilha, 2022, (CC BY-NC 4.0).

Figure 4: Examples of geological and geomorphological features that support biodiversity at different scales and in different environmental settings. **a.** Joints and fissures in limestone pavement in Ingleborough National Nature Reserve, northern England, provide habitat for vascular plants, bryophytes, lichens and insects. **b.** The landscape of Qeqertarsuaq (Disko Island), West Greenland, is dominated by Palaeocene basalt mountains, plateaux and steep glacial valleys with moraines, glacial outwash and talus slopes, which support herb, shrub, heath, fellfield and snowpatch vegetation on soils underlain by permafrost and subject to solifluction and frost disturbance. **c**. The huge range in altitude and geology supports a variety

of ecosystems in the Grand Canyon, USA, including riverine at the lowest elevations, through to boreal and pine forests at the higher elevations, as well as juniper woodland and deserts. **d**. Table Mountain National Park forms part of the internationally important Cape Floristic Region. Geology, topography and climate have played an important role in the evolution and distribution of the fynbos vegetation mainly developed on nutrient-poor, acidic soils derived from the sandstone rocks that form the core of the park. **e**. Getbol, Korean Tidal Flats World Heritage Site represents an outstanding example of island-type tidal flats on the SW coast of Korea, where a combination of geological, oceanographic and climatic conditions have enabled the development of diverse coastal sedimentary systems that support high levels of biodiversity, including numerous endemic species of flora and fauna, and provide critical habitats for many migratory bird species. **f.** The Rwenzori Mountains National Park and World Heritage Site are of outstanding importance for the altitudinal zonation of vegetation. They comprise a block of Precambrian metamorphosed crystalline rocks uplifted above the surrounding plains during the formation of the Western (Albertine) Rift Valley in the Late Pliocene. High precipitation, cloud cover and humidity, in conjunction with the mainly acidic soils and altitudinal range of topography, support the richest montane flora in Africa, including giant heathers, groundsels and lobelias. **g.** The granite inselberg of Mount Chudalup, in D'Entrecasteaux National Park, Western Australia, rises above a low-relief coastal plain covered in blown sand, sedge and heathlands. Karri and marri woodland on loamy soils formed from weathered granite around the base of the inselberg is succeeded by peppermints, grass trees, snottygobbles, banksias and sheoaks on sandier soils on the lower slopes and by numerous species of mosses, lichens and liverworts on the upper slopes. **h.** The geodiverse volcanic landscape of the Fjallabak Nature Reserve, southern Iceland, includes the partly moss covered Laugahraun lava field and provides specialised habitats for thermophilic bacteria and archaea associated with geothermal activity**.** From Gordon et al., 2022. Images a, d, e, f, g, © John Gordon; b, c, h © Joseph Bailey (CC BY-SA 4.0).