Geodiversity and the ecosystem approach

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ABSTRACT

The term "biodiversity" has become well known in recent years, but much less so is the non-living or abiotic diversity of the planet, known since the 1990s as its "geodiversity." In simple terms, geodiversity is the variety of the earth's rocks, minerals, fossils, topography, landforms, physical processes, soils, and hydrological features. Geodiversity is part of the planet's natural capital assets. In turn, natural capital provides goods and services to society identified through the "ecosystem services" approach. This paper gives several examples of how geodiversity brings many benefits to society that deserve to be better known by the public.

GEODIVERSITY

Nature comprises both biotic and abiotic elements. The biotic ones are well known as the earth's flora and fauna and for many decades the term "biodiversity" has been used to describe their variety. "Geodiversity" is a less well-known or -understood concept but, put simply, it is the abiotic equivalent of biodiversity. The term was first coined by Chris Sharples in 1993 and has subsequently come into general use in the geoscience literature. Many definitions of geodiversity have been proposed but Boothroyd and McHenry (2019) found that 88% of these were centered on the one originally proposed by me, which states that geodiversity is

> the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assem-

Landforms with spiritual significance, such as Mount Fuji in Japan, demonstrate cultural aspects of geosystem services. TIANSHU LIU

> blages, structures, systems and contributions to landscapes (Gray 2013: 12).

Many geology and earth science textbooks describe the diversity of these elements, which include around 5,000 minerals, hundreds of named rock types and soils, thousands of fossil species, a huge range of landforms and physical processes, and an infinite variety of topographies and landscapes.

NATURAL CAPITAL AND THE ECOSYSTEM APPROACH

Geodiversity is part of global "natural capital," which, according to the *World Forum on Natural Capital,* comprises "the world's stocks of natural assets which include geology, soil, air, water and all living things." We are used to thinking of "capital" as involving financial assets, but in fact several types of capital have been described, including:

- Financial capital: monetary wealth;
- Produced capital: e.g., roads, buildings, machines;
- Human/Social/Intellectual capital: e.g., health, knowledge, culture, institutions; and
- Natural capital: stock of natural assets.

Natural capital is a way of viewing the world's natural assets as being of value to human society, since traditionally nature has not been valued in this way. The value can be quantified in a methodology known as "natural capital accounting." The values that natural capital bring to society are often now described as "ecosystem services," but first we must discuss ecosystems and the ecosystem approach.

The term "ecosystem" was first coined by A.G. Tansley (1935). His definition was modified in Article 2 of the Convention on Biological Diversity (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.

The use of "non-living environment" in this definition means that an ecosystem includes geodiversity *but only where this involves an interaction with the living environment.* However, as I shall describe below, there are many values of geodiversity that do not involve any interaction with the living environment. The CBD also describes "the ecosystem approach" as

> a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.

So, again, there is a recognition here that this approach involves the interaction of both non-living (land and water) and living natural resources. Given this relationship, it follows that the recently designated United Nations Decade of Ecosystem Restoration (2021–2030) should involve an integrated abiotic/biotic approach. An example of this is river restoration, which recreates natural river form and functioning and also brings ecological benefits. It is also clear that since land restoration helps to achieve all of the UN's Sustainable Development Goals (SDGs), geodiversity needs to be intimately involved in this project too (see Gray and Crofts, this issue).

ECOSYSTEM SERVICES

The increasing human impact on the environment and lack of public understanding of how society benefits from nature led a group of scientists in the US in the 1980s and 1990s to promote an "ecosystem services" approach (Daily 1997). As Joshua Reichert argued,

> we have too lightly valued some of the most basic resources on which we depend, including the air we breathe, the water we drink, and the ability of the earth to support a wide variety of life. The cumulative impact of human activity on the natural systems that produce these resources … and our rather recent understanding of the dramatic scope of that impact make it impossible for us to take them for granted any longer (Myers and Reichert 1997: xviii–xix).

Mooney and Ehrlich (1997) reviewed the early history of the ecosystem services approach from George Perkins Marsh and Aldo Leopold to the first tentative use of the functioning of ecosystems in terms of "services" in the 1970s. But the biggest step forward was the publication of Gretchen Daily's 1997 book *Nature's Services*. Despite this title, and the use of "environmental services" by others, unfortunately the term "ecosystem services" has come to dominate usage. This is unfortunate for two reasons. First, it was an original purpose of Daily's book to make the public more aware of the extent to which they benefit from nature, but "ecosystem services" is not the

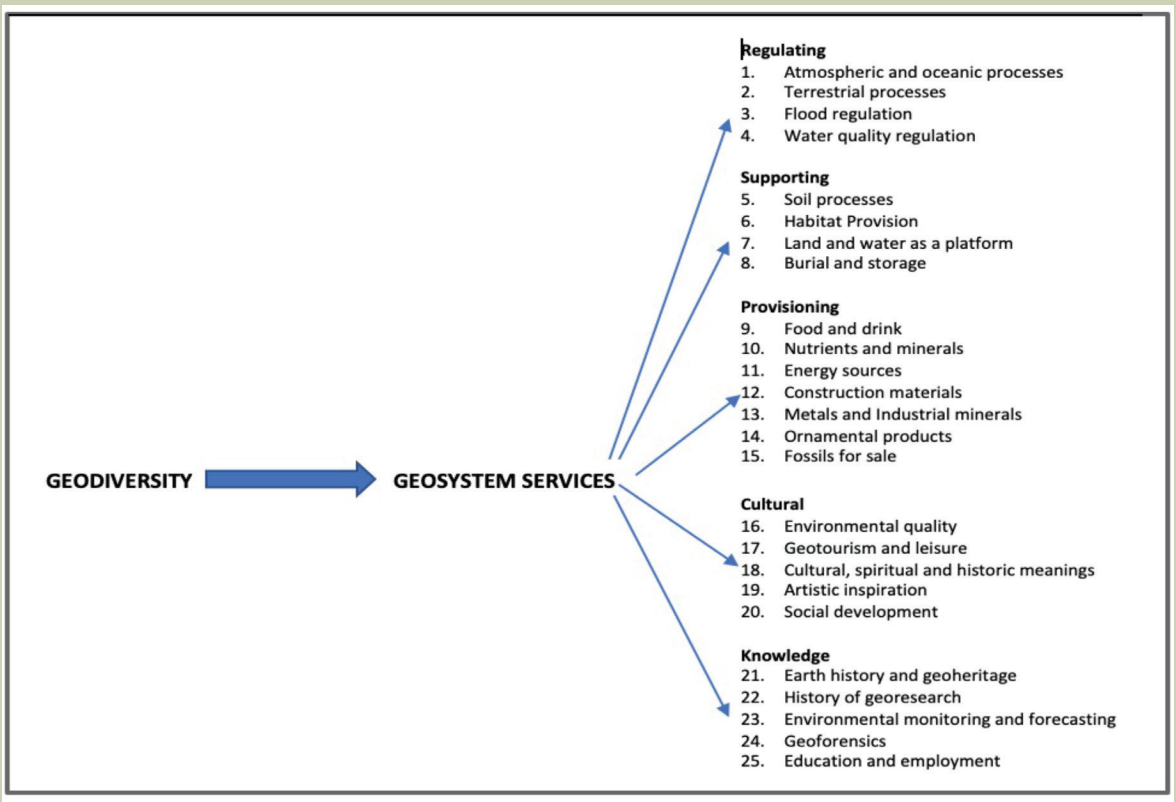
easiest term for the public to understand. Second, to the extent the term is understood by the public, that understanding is dominated by biological services to the almost total exclusion of abiotic nature. So, the problem is that the term "ecosystem services" often gives a limited view of the value of the whole of nature. This can be said to be detrimental to a full recognition of the value of nature to society. Nevertheless, the fact is that the term "ecosystem services" is now firmly established in the literature and in practice. For this reason, some authors have preferred the term "geosystem services" to apply to services provided by geodiversity. Others have used the rather contradictory term "abiotic ecosystem services" or simply "abiotic services."

There are several ways in which ecosystem services are classified. The Millennium Ecosystem Assessment (MEA 2005) uses four types of service—regulating, supporting, provisioning and cultural. In the MEA, provisioning services are listed as:

- Food (plants, animals);
- Fiber (wood, wool, cotton, etc.);
- Fuel (wood, etc.);
- Genetic resources;
- Biochemical & pharmaceuticals;
- Ornamental resources (shells, flowers); and
- Freshwater.

Apart from freshwater, all these are biological services. There is no mention of, for example, mineral fuels, construction materials, industrial minerals, or gemstones. This simply reinforces the point that the ecosystem services approach, as currently practiced, is biologically based and does not do justice to the services provided by geodiversity. Because of these deficiencies, I have used the MEA classification as a basis for showing the goods and services related to geodiversity, but have introduced a fifth category of "knowledge services," which would be part of "cultural services" in the MEA classification. This is because of the importance of geodiversity in providing evidence for the history of planet Earth and the evolution of life. Figure 1 lists 25 major geosystem services identified as being of significant benefit to society, and all result from the fact that the earth is a geodiverse system. Full details and descriptions are

Figure 1. The 25 major geosystem services demonstrating how the earth's geodiversity benefits society (from Chakraborty and Gray 2020).



given in Gray (2013), but a few examples are outlined below. Habitat provision (number 6 in Figure 1; hereafter, numbers in parentheses refer to this figure) is excluded from these descriptions as this is a subject covered by Gordon et al. (2022) later in this issue.

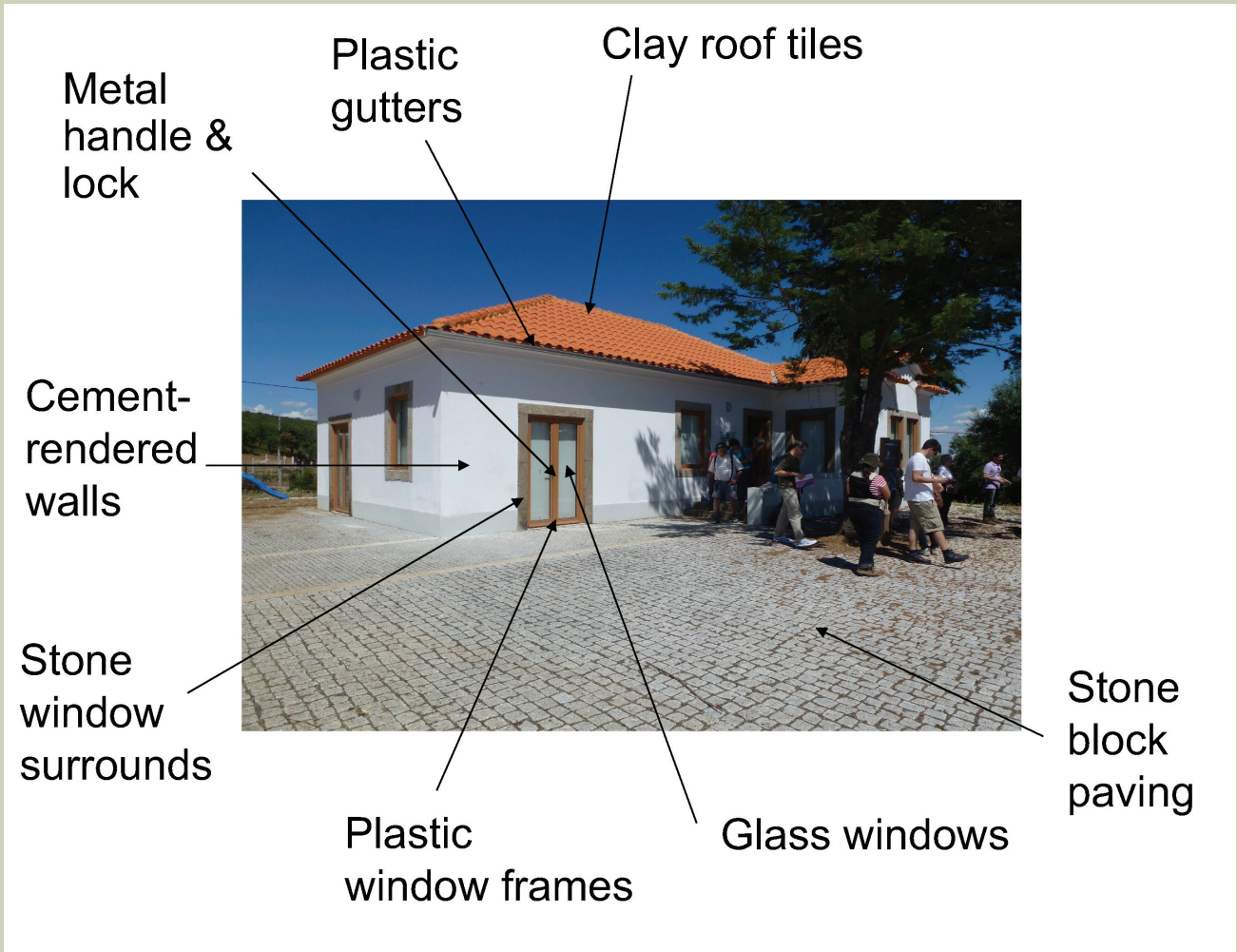
GEOSYSTEM SERVICES: CASE STUDIES

It is a truism to say that if a resource has not grown, it must have been excavated from the earth's crust. Although some wood and other organic materials may be involved, the construction of our towns and cities is dominated by materials extracted from the earth's surface or sub-surface. These building materials (12) were once dominated by stone, but today are more likely to involve other materials. For example,

- Bricks derived from firing brick clays with other additives;
- Concrete, a mixture of cement (derived from limestone and clay or ash) and gravel aggregate;
- Steel, a mixture of iron with added carbon, plus other additives such as chromium for stainless steel;
- Glass, manufactured from a particularly pure form of sand;
- Plaster, mainly composed of gypsum plus additives; and
- Asphalt, also known as bitumen, combined with aggregate and most commonly used in road surfacing.

Figure 2 shows a small geological museum in Portugal annotated to show the diversity of geomaterials used in its construction. Using this type of approach can help the public to understand how much their lives rely on the earth's geodiversity.

Figure 2. A small geology museum in Portugal demonstrating the variety of geomaterials used in its construction.



Also, in this connection, within the industrial minerals category (13), the modern smartphone contains over 80% of the non-radioactive elements in the periodic table (Rohrig 2015), all of which are extracted from the earth's crust and some of which are rather rare. And all of these elements play a different role in the functioning of the smartphone. For example, indium tin oxide allows the screen to function as a touch screen; a variety of rare earth elements, including lanthanum, terbium, and dysprosium, are used in small quantities to produce screen colors; and copper, gold, and silver are used in the microelectrical components. Thus, smartphones would not exist without the planet's geodiversity.

Environmental quality (16) brings both physical health and mental well-being benefits. In fact, the World Health Organization has recently promoted the benefits of being out in nature. For example, increased contact with nature has been associated with lowering cortisol, blood pressure, and the risk of developing type 2 diabetes. Nature provides opportunities for stress reduction, physical exercise, and a physically active lifestyle; for restoration and relaxation; and for socializing with friends and family. Access to nature increases life satisfaction and happiness ratings (WHO 2021). Although these benefits frequently only mention "green spaces" or "biodiversity," the natural health benefits often come from access to diverse physical landscapes or the physical exercise involved in hiking, hill walking, or rock climbing.

Tourism is driven by the diversity of places around the world and the desire of people to visit different locations and have experiences different from those in their home environment. Similarly, geotourism (17) is based on the fact that we live on a highly geodiverse planet that creates opportunities for people to see different landscapes or take part in particular sightseeing or active geoactivities. Many of the most visited tourism sites in the world are based on physical landscapes. For example, Gray (2021) attempted to identify the world's top ten geotourism destinations. Top of this list was the Iguaçu Falls, an extensive and diverse waterfall complex on the Argentina/Brazil border (Figure 3).

In second place was the Grand Canyon, one of the world's most visited tourism locations. If the

Figure 3. Part of the Iguaçu Falls, a protected area on the Brazil/Argentine border.

Figure 4. Part of the Grand Canyon's attractiveness is its internal stratigraphic and topographic geodiversity.

canyon had been eroded into a single rock type it would still be an impressive feature, but a major attraction of the site is its internal stratigraphic and morphological diversity. The horizontal strata are of varying resistances resulting in a stepped vertical profile, while there is also an attractive, longitudinal, morphological diversity (Figure 4).

Cultural, spiritual, and historical meanings (18) include

- Folklore stories concerning the origin of particular landforms;
- The use of stone in cultural monuments, as in the Egyptian pyramids, the Taj Mahal in India, or Great Wall of China; and
- Landforms with spiritual significance, such as Uluru in Australia or Mount Fuji in Japan.

The history of the earth since its origin 4,600,000,000 years ago is one of huge complexity and has only been deciphered through meticulous work by thousands of geologists over the last few centuries. It has been reconstructed by analysis and interpretation of evidence displayed in rock and sediment outcrops and boreholes in all countries of the world. And it is research that continues, with several new fossil species being discovered every year. In fact, the fossil record has demonstrated the evolution of life on Earth from the simplest unicellular organisms to the earliest evidence of humans. It follows from this that it is important to do all we can to conserve the

Figure 5. An important global stratigraphic site marking the Cambrian/Ordovician boundary, Gros Morne National Park, Newfoundland, Canada.

most important parts of this planetary history and geoheritage (21) so that it is available to all future scientists and students for further research and study.

Geoconservation is therefore an important activity, and one method of achieving it is to legally designate sites or areas containing important geoscience features. An example of a protected geosite is shown in Figure 5 (previous page). But geoconservation ought to go beyond this into taking a responsible approach to the wider landscape and to conserving the natural resources of the planet as described in the above examples.

CONCLUSIONS

As well as millions of different species, our planet has a huge and magnificent geodiversity that is part of the planet's natural capital. This geodiversity has been brilliantly exploited by human societies over recent millennia from the Bronze Age and Iron Age through to our modern Silicon Age and Oil Age. Today, our modern society would not exist without the benefits of living on a geodiverse planet. However, it is regrettable that most members of our modern society are hardly aware of this fact, and it remains a major challenge for the geosciences to explain this to the public. This article has been a modest attempt to demonstrate how this might be achieved.

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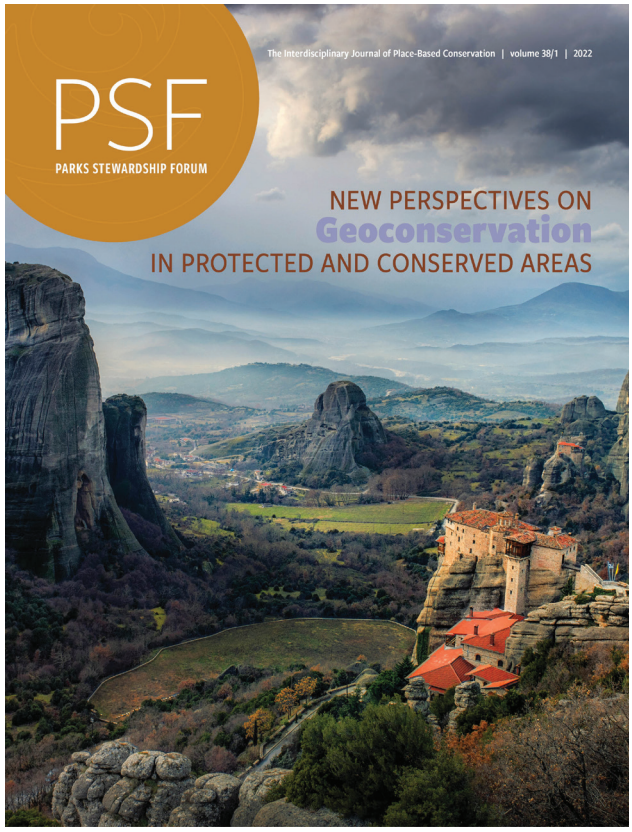

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