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M., Lawler, Joshua J., Monge-Ganuzas, Manu, Royse, Katherine
R., Stewart, Iain, Record, Sydne, Turner, Woody, Zarnetske,
Phoebe L. and Field, Richard (2019) Opinion: To advance
sustainable stewardship, we must document not only biodiversity
but geodiversity. Proceedings of the National Academy of Sciences
(PNAS, USA), 116 (33). pp. 16155-16158.

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To advance sustainable stewardship, we must document not only biodiversity but geodiversity

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Rapid environmental change is driving the need for complex and comprehensive scientific information that supports policies aimed at managing natural resources through international treaties, platforms, and networks. One successful approach for delivering such information has been the development of essential variables for climate (1), oceans (2), biodiversity (3), and sustainable development goals (4) (ECVs, EOVs, EBVs, and ESDGVs, respectively). These efforts have improved consensus on terminology and identified essential sets of measurements for characterizing and monitoring changes on our planet. In doing so, they have advanced science and informed policy. As an important but largely unanticipated consequence, conceptualizing these variables has also given rise to discussions regarding data discovery, data access, and governance of research infrastructures. Such discussions are vital to ensure effective storage, distribution, and use of data among management agencies, researchers, and policymakers (5, 6).

Although the current essential variables frameworks account for the biosphere, atmosphere, and some aspects of the hydrosphere (1–4), they largely overlook geodiversity—the variety of abiotic features



Mining is one example of the human impact on geodiversity. Active mines cause a decrease in local biodiversity, but in some cases they can provide an important habitat for specialized and rare species after the mine has been abandoned. Image credit: Shutterstock/1968.

and processes of the land surface and subsurface (7). Analogous to biodiversity, geodiversity is important for the maintenance of ecosystem functioning and services (8), and areas high in geodiversity have been

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The authors declare no conflict of interest.

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Any opinions, findings, conclusions, or recommendations expressed in this work are those of the authors and have not been endorsed by the National Academy of Sciences.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1911799116/-/DCSupplemental.

Meanwhile, extraction and storage of vast quantities of soil and rock that are byproducts from mining metals, as well as associated land requirements, are currently not part of integrated broad-scale management frameworks (16).

Essential Variables

In presenting the EGV concept, we aim to 1) complement and augment existing essential variables (ECVs, EOVs, EBVs, and ESDGVs) (Fig. 1), 2) improve global coordination of monitoring strategies, and 3) advance communication between policymakers and geoscientists. To achieve these goals, we propose a framework for policymakers and researchers to guide future definitions of relevant measurements that capture the key elements of geodiversity. We define EGVs as abiotic state and process variables related to geology, geomorphology, soils, and hydrology 1) relevant to natural resource management and human well-being, conservation, or ecology; 2) complementary to (and not duplicating) the other suites of essential variables; and 3) feasible and cost effective to measure (Fig. 1). In Table S2, we propose a candidate set of variables.

Some aspects of EGVs are already used by international conservation organizations; these provide a solid basis for further integrating EGVs into global treaties and international conventions. For example, the International Union for Conservation of Nature (IUCN) refers to the relevance of geodiversity for the conservation of natural resources within three resolutions titled “Conservation of Geodiversity and Geological Heritage,” “Valuing and Conserving Geoheritage Within the IUCN Programme,” and “Conservation of Moveable Geological Heritage.” Furthermore, the United Nations Educational, Scientific and Cultural Organization recognizes the outstanding universal value of geodiversity elements with their inclusion in both the World Heritage List (in May 2019, 95 properties in 53 countries worldwide) and in the Global Geoparks Network (140 Geoparks in 40 countries, as of May 2019). Many protected areas have the preservation of geodiversity and geoheritage as a goal of their management planning, including the Spanish network of Biosphere Reserves, Australia’s New South Wales National Parks, and the US National Park Service. Meanwhile, the Food and Agriculture Organization coordinates a Global Soil Partnership that seeks to monitor the state of global soils and improve the governance and effectiveness of soil information.

Data and information products to measure changes in EGVs at management-relevant timescales are increasingly available and sometimes linked to global observatories, such as the Global Earth Observation System of Systems, with its Societal Benefit Areas (SBAs). However, these mainly cover natural hazards such as floods, earthquakes, and landslides (e.g., SBA disaster resilience). Where dangers are more diffuse or related to natural resource use, EGVs are not yet available (e.g., relating to global sand extraction and domestication of soil resources).

Making EGVs Work

Overall, despite the clear global importance of geodiversity, very limited international efforts have been devoted to developing measures that support decision making for supranational and global policy targets and SDGs [although there have been efforts to do so in the past (17)]. Geodiversity is highly relevant, for example, to the IUCN World Parks Congress, the World Conservation Congress, the Convention on Biological Diversity’s Aichi targets, SDGs, and the Sendai Framework for Disaster Risk Reduction (Table S2). In Table S1, we specifically link EGVs to the 17 SDGs and four Sendai Framework priorities.

We advocate a holistic approach that recognizes and tracks the integrity of the abiotic and biotic components of geosystems and ecosystems as the most effective means to address global environmental challenges. Following the examples of the ECV, EOV,

Attaining a sustainable circular economy and safeguarding our natural resources, while also accounting for population growth, further urbanization, and improved well-being, will require international consideration of material flows and their impacts across terrestrial and aquatic systems globally.

and EBV communities, we recommend collaborative development of comprehensive and interoperable databases of geodiversity globally, following common protocols, a standardized terminology (e.g., controlled vocabularies), and a consistent metadata reporting. We further recommend forming an expert panel, for example within the Group on Earth Observation framework, to further develop the conceptual framework of EGVs. Finally, we encourage better communication with policymakers about the importance of considering EGVs in international conventions and policy documents. This could be enhanced by applying a “geosystem services” concept, which would complement the successful ecosystem services concept whose use within a policy and international treaties context was advanced by the Millennium Ecosystem Assessment (11). Better communication would also be enhanced by applying the recently published International Panel on Climate Change communication recommendations.

We now have the technical capacity and experience from other scientific communities to describe abiotic characteristics of Earth’s surface and subsurface and to develop holistic and parsimonious measures of geosystem and ecosystem structure, function, and risks. Attaining a sustainable circular economy and safeguarding our natural resources, while also accounting for population growth, further urbanization, and improved well-being, will require international consideration of material flows and their impacts across terrestrial and aquatic systems globally. This will entrench a more holistic approach to nature, improving our efforts to designate protected areas and enhance the management of

natural resources. Doing so is essential for safeguarding biodiversity, geodiversity, ecosystem, and geosystem services in a rapidly changing world and for integrating and balancing the economic, social, and environmental dimensions of sustainable development.

Acknowledgments

F.S. acknowledges support by the University of Nottingham Anne McLaren fellowship; J.H. received funding from the Academy of Finland project 315519; W.D.K. acknowledges support from the University of Amsterdam Faculty Research Cluster “Global Ecology.”

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