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Global status of and prospects for protection of terrestrial geophysical diversity

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Abstract: *Conservation of representative facets of geophysical diversity may help conserve biological diversity as the climate changes. We conducted a global classification of terrestrial geophysical diversity and analyzed how land protection varies across geophysical diversity types. Geophysical diversity was classified in terms of soil type, elevation, and biogeographic realm and then compared to the global distribution of protected areas in 2012. We found that 300 (45%) of 672 broad geophysical diversity types currently meet the Convention on Biological Diversity's Aichi Target 11 of 17% terrestrial areal protection, which suggested that efforts to implement geophysical diversity conservation have a substantive basis on which to build. However, current protected areas were heavily biased toward high elevation and low fertility soils. We assessed 3 scenarios of protected area expansion and found that protection focused on threatened species, if fully implemented, would also protect an additional 29% of geophysical diversity types, ecoregional-focused protection would protect an additional 24%, and a combined scenario would protect an additional 42%. Future efforts need to specifically target low-elevation sites with productive soils for protection and manage for connectivity among geophysical diversity types. These efforts may be hampered by the sheer number of geophysical diversity facets that the world contains, which makes clear target setting and prioritization an important next step.*

Keywords: climate adaptation, conservation planning, geodiversity, soil type, spatial assessment, topography

Condición Mundial y Perspectivas para la Protección de la Diversidad Geofísica Terrestre

Resumen: *La conservación de las facetas representativas de la diversidad geofísica puede ayudar a conservar la diversidad biológica conforme cambia el clima. Llevamos a cabo una clasificación mundial de la diversidad geofísica terrestre y analizamos la variación de la protección del suelo a lo largo de los tipos de diversidad geofísica. La diversidad geofísica se clasificó en términos de tipo de suelo, elevación y reino biogeográfico y después se comparó con la distribución global de las áreas protegidas en 2012. Encontramos que 300 (45%) de los 627 tipos generales de diversidad geofísica actualmente cumplen con el Objetivo Aichi 11 de la Convención sobre la Diversidad Biológica de 17% de protección de área terrestre, lo que sugiere que los esfuerzos por implementar la conservación de la diversidad geofísica tienen una base sustancial sobre la cual fundamentarse. Sin embargo, las áreas protegidas actuales fueron fuertemente parciales hacia los suelos de alta elevación y baja fertilidad. Evaluamos tres escenarios de la expansión de áreas protegidas y encontramos que la protección enfocada en especies amenazadas, si se implementa de lleno, también protegería a un 29% adicional de tipos de diversidad geofísica; la protección enfocada en eco-regiones protegería a un 24% adicional, y un escenario combinado protegería a un 42% adicional. Los esfuerzos futuros necesitan enfocarse específicamente en sitios de poca elevación con suelos productivos para la protección y manejarse para la conectividad entre los tipos de diversidad geofísica. Estos esfuerzos pueden dificultarse simplemente por el número de facetas de diversidad geofísica que existen en el mundo, lo cual hace que el establecimiento claro de objetivos y la priorización sean un siguiente paso importante.*

Palabras Clave: adaptación al cambio climático, evaluación espacial, geodiversidad, planeación de la conservación, tipo de suelo, topografía

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Introduction

The global protected area (PA) network is doing poorly at conserving most elements of biodiversity (Venter et al. 2014), and rapid human-forced climate change will likely exacerbate this problem (Johnston et al. 2013). In 2010, 193 nations responded to drastic shortfalls in PA coverage by setting an ambitious global target of protecting at least 17% of terrestrial areas and inland waters by 2020 (Aichi Target 11, CBD 2011), which could lead to the greatest and potentially the last substantial expansion of the PA estate (Watson et al. 2014). It is clearly vital that this expansion include placing new PAs or enlarging existing ones to increase biodiversity's resilience to current and future climate change (Hannah et al. 2007; Watson et al. 2013).

One promising approach lies in protecting representative facets of geophysical diversity itself, the stage on which biodiversity plays (Hunter et al. 1988; Anderson & Ferree 2010). The hypothesis is that even as the climate changes, geophysical diversity will continue to be important to species and ecosystem processes in the future, even if the species and processes are different than today (Cowling et al. 2003; Beier & Brost 2010).

Planning where to protect different types of geophysical diversity requires mapping them. Geophysical diversity has been mapped at regional scales by characterizing the abiotic condition (e.g., geological substrate, soil type, and topography) through the use of overlay methods (e.g., Pressey et al. 2000) or clustering algorithms (e.g., Brost & Beier 2012). Here we present the first (to our knowledge) framework for defining terrestrial geophysical diversity at the global scale. Although regional studies have been able to use higher resolution descriptions of abiotic condition (e.g., slope, aspect, and ruggedness, Anderson et al. 2015 [this issue]), these variables cannot be meaningfully resolved using global data sets with cell resolutions measured in minutes of latitude and longitude. Similarly, global maps of geomorphological features like drumlins, deltaic fans, and moraines do not exist. Our map is based solely on geodiversity elements like landform and lithology and thus differs from ecological land unit maps (e.g., Sayre et al. 2014) that additionally reflect climate and land cover.

We defined and mapped global terrestrial geodiversity at approximately 3.4 km resolution using 3 well-mapped variables: soil type, elevation, and biogeographic realm. Soils reflect the surface aspect of geophysical diversity that species directly experience and are developed through long-term interactions between topography, vegetation, lithology, and historical climatic regimes (Jenny 1941; Singer & Munns 2005). Land surface elevation affects the amount of incident solar radiation and drives temperature gradients through adiabiatic cooling. Biogeographic realm is a surrogate for latitude and the distribution of continental landmasses as reflected by important biogeographic boundaries like Wallace's Line and the Central American isthmus. These 3 factors generate a set of relatively uniform geophysical diversity types (GDTs), which are further composed of separate geophysical diversity facets (GDFs). We analyzed the extent to which these GDTs and GDFs are currently protected. We also assessed how well recent species-based and ecoregion-based global prioritizations capture GDTs to inform development of a global, climate-adapted, geophysical diversity-based conservation strategy in light of the CBD Aichi Target 11.

Methods

Mapping Global Geophysical Diversity

We overlaid data in a geographic information system (GIS) on the distribution of 7 biogeographic realms (Olson et al. 2001) elevation, and soil types to generate GDTs. Elevation data were obtained from the Shuttle Radar Topography Mission (NGIA & NASA 2009), which provides height above the mean sea level at 0.0083 degree resolution on a geographic coordinate system. We reclassified elevations into 11 elevation zones at 500 m increments (e.g., 0–499 m) up to 4999 m, lumping elevations 5000–8204 m into a 12th zone. Although some regional maps set elevation bands to match patterns of vegetation (Anderson et al. 2015), no single set of elevation bands is appropriate for the entire globe.

Soil typology was based on the taxonomy developed by the U.S. Department of Agriculture (Soil Survey Staff 1999). We used soil orders (mollisols, alfisols, histosols, etc.) that represent variation in long-term patterns of weathering, parent material, dominant vegetation, accumulated organic material, and climatic condition. These are analogous to classes in animal taxonomy (e.g., birds and mammals) and represent distinctive and significant variation in soil types (Singer & Munns 2005). The U.S. Natural Resource Conservation Service (2005) describes the spatial location and extent of 12 soil orders and 4 types of other substrates (Table 1 & Supporting Information) on grid cells of 2-min resolution. We did not explicitly include a lithology map because parent material (i.e., geological substrate) is an input to the soil classification.

All the data were re-projected to the planar Goode homolosine map projection (GHSP) on the WGS84 datum with land-oriented interruptions as defined by ESRI (2008) and resampled with the nearest neighbor method, appropriate for categorical data, to a grid cell size of 3454 m (the average global resolution of the soil data). We included only terrestrial cells that had values from all 3 data sets.

Table 1. Descriptions of 4 substrate types and 12 soil of the world (Soil Survey Staff 1999; U.S. Natural Resources Conservation Service 2005) and representative examples of protected areas that cover them in part.

Substrate or soil order	Description	Representative protected area
Shifting sand	moving sands with little or no soil development	Central Kalahari Game Reserve, Botswana; Munga-Thirri National Park, Australia
Rock	undecomposed surface rocks with little or no soil development	Aconcagua Provincial Park, Argentina; Badakhshan National Park, Tajikistan; Yosemite National Park, U.S.A.
Ice	surface ice fields with little or no soil development	Northeast Greenland National Park, Denmark; Russian Arctic National Park, Russia; Sagarmatha National Park, Nepal
Undefined	unknown	Bakhtegan National Park, Iran; Pampa del Tamarugal National Reserve, Chile
Gelisols	form in very cold climates with permafrost within 2 m of the soil surface; typically support tundra type vegetation	Jungfrau-Aletsch-Bietschhorn UNESCO World Heritage Site, Switzerland; Northeast Greenland National Park, Denmark; Wapusk National Park, Canada
Histosols	organic soils formed either in cool climates or very wet areas or a combination of both; often associated with bogs or swamps even after the land has been drained	Ben Nevis and Glen Coe National Scenic Area, UK; Berbak National Park, Indonesia; Everglades National Park, U.S.A.
Spodosols	typical of both coniferous and deciduous forests in cooler climates and some heathlands; typically have a rich organic layer over a highly leached sand or mineral layers	Algonquin Provincial Park, Canada; Parc Naturel Régional des Landes de Gascogne, France; Putoransky State Nature Reserve, Russia
Andisols	dominated by minerals derived from volcanic ash; typically weakly weathered with a high content of volcanic glass	Nahuel Huapi National Park, Argentina; Volcans National Park, Rwanda
Oxisols	highly weathered soils of the tropics; similar to ultisols but more weathered such that nutrient content and carbon content is low; some oxisols have been previously classified as laterite soils	Parc National de la Salonga, Democratic Republic of Congo; Vale do Javari Indigenous Area, Brazil
Vertisols	contain a high proportion of expanding lattice clays so tend to swell when wet and shrink up drying	Attwater Prairie Chicken National Wildlife Refuge, U.S.A.; Oberpfälzer Wald Naturpark, Germany
Aridosols	develop in very dry conditions; surface patterns may show the effects of extreme wetting and drying events but with little evidence of moisture penetration to the subsoil	Death Valley National Park, U.S.A.; Dundas Nature Reserve, Australia; Parque Nacional Natural Macuira, Colombia
Ultisols	most weathered of the temperate zone soils; characterized by a thin or absent surface horizon with a thick, strongly expressed B horizon; deep and can be productive if well-managed; often red or orange in color	Capitol Reef National Park, U.S.A.; Ruaha National Park, Tanzania; Zona de Amortiguamiento (Bosawas) Biosphere Reserve, Nicaragua
Mollisols	deep, dark, nutrient rich layer at the surface; typically form under temperate grassland vegetation as the result of the long-term addition of organic materials derived from plant roots; make productive cropland	Dongying-Huang He Sanjiaozhou Nature Reserve, China; Hawkeye State Wildlife Management Area, U.S.A.; Sjeverni Velebit National Park, Croatia
Alfisols	intermediate in maturity between mollisols or spodosols and ultisols; often found in co-ocurrence with mollisols; more weathered than mollisols and generally have less weatherable material remaining	Kaimur Wildlife Sanctuary, India; Parc Naturel Régional Périgord Limousin, France; Waterloo State Recreation Area, Michigan, U.S.A.
Inceptisols	earliest indications of horizon development; small amounts of organic matter darken the topmost horizon; weathering minimal; high amounts of weatherable minerals remain in profile	Dasos Pafou Special Protection Area, Cyprus; Luengué Hunting Reserve, Angola; Serengeti National Park, Tanzania
Entisols	very young soils formed from freshly deposited or heavily reworked material like flood deposits or sand dunes	Naybandan Wildlife Refuge, Iran; Sian Ka'an UNESCO-MAB Biosphere Reserve, Mexico; Yellowstone National Park, U.S.A.

We combined the 3 raster data sets by assigning numeric codes to each realm, elevation zone, and soil order type. We used magnitude to differentiate the input data (i.e., soil codes were multiplied by 10,000, elevation codes by 100, and realm by 1) and added the codes to create a unique code for each GDT (e.g., code 10201 represents 0–499 m, Australasian shifting sands). To examine the size of individual facets, we converted rasters to polygons, creating regions of contiguous cells of the same GDT, which were labeled and analyzed as geophysical diversity facets (GDFs).

Characterization of Areal Protection for Geophysical Diversity

Terrestrial PA boundaries were obtained from the World Database on PAs (IUCN and UNEP 2012). Following Venter et al. (2014), we included only PAs with national designations. In the database, PAs are represented either as polygons or by point locations with an associated area. For PAs represented only by points, we created a circular buffer of the given area centered on the location. Buffered PA points and polygons were merged into a single layer to remove overlaps. After re-projecting to the GHSP, we tabulated areas of intersection with the GDTs. We conducted GIS work with ArcGIS 10.1 and plotted graphs in R (R Core Team 2014).

Assessment of Future Possible Protection Scenarios

Using the data available in Venter at al. (2014), we assessed how 3 future scenarios for expansion of PAs would increase the levels of coverage afforded to GDTs: adequate capture of all globally threatened bird and amphibian targets (hereafter species scenario); capture of 17% of all terrestrial ecoregions (hereafter ecoregion scenario); and a combined prioritization that achieved both species and ecoregion targets (hereafter combined scenario). New PAs identified in each of the 3 scenarios were re-projected to the GHSP and overlaid on the GDTs to assess additional coverage afforded by the PA expansion scenario.

Results

We mapped 672 global geophysical diversity types (GDTs) ranging in total area from 12 km^2 to 5.4 million km^2 (Supporting Information). Some combinations of soil order, elevation, and biogeographic realm produced a GDT with a non-zero area (Fig. 1). Of the biogeographic realms, the Palearctic had the most (138 GDTs), while Oceania had the least (29 GDTs.) The GDTs generally declined in area as elevation increased, although not in all cases (e.g., particularly gelisols, rock, and ice types).

The single most extensive single GDT in the world was the low elevation (0–499 m) Palearctic Inceptisols, which covered approximately 4% of the land's surface (outside Antarctica) and was associated with the extensive boreal forest ecosystems of northern Eurasia. Most GDTs were much smaller in extent: 29% were <1000 km^2 in area, 50% were <10,000 km^2, 79% were <100,000 km^2; and 95% were <1 million km^2. The next 3 most extensive types were the 0–499 m Palearctic entisols (4.9 million km^2), distributed mainly in the Sahara Desert and the Rub' al Khali (Empty Quarter) of the Arabian Peninsula; the 0–499 m Neotropic oxisols (4.7 million km^2) of the Amazon Basin and other tropical forests of South America; and the 0–499 m Palearctic gelisols (3.6 million km^2) of the northern Siberian plain.

We mapped 418,511 global geophysical diversity facets (GDFs), which are areas of contiguous cells that are homogenous with respect to biogeographic realm, elevation zone, and soil type. The GDTs varied in the number of GDFs they contained. Each of 39 types had only 1 facet globally, while conversely the 500–999 m Palearctic inceptisol GDT had 13,862 facets (Supporting Information). Within GDTs, the average size of facets varied from 12 km^2 for 50 of the types to 30,665 km^2 for the 0–499 m Indo-Malay shifting sands, which had only 1 very large tract: the Thar Desert of India and Pakistan. About 66% of GDTs had average facet sizes of <100 km^2; 93% had average facet sizes of <1000 km^2; and all but 1 had average facet sizes of <10,000 km^2.

Only 68 (10.1%) of 672 GDTs have no PA coverage, and 300 (44.6%) of GDTs met the 17% CBD Aichi Target 11 (Table 2). Forty-five types were >90% protected, each of which had small extent (average of 285 km^2). Protection was skewed toward higher elevations and less productive soil types (particularly ice and gelisols). Topographically rugged areas, which are often well protected, were also richer in GDTs of smaller extents, which may help explain why so many of montane types already met the 17% goal. The least protected soil types globally were mollisols (3.4%), undefined soil types (5.4%; mainly in south-central Asia and South America), and vertisols (6.5%). Mollisols, in particular, are noted for their agricultural productivity (Singer & Munns 2005); they were currently best protected in Australasia (12.3%) and least protected in Oceania (1.3%). Interestingly, all GDTs below 3000 m had yet to meet Aichi Target 11; all above already surpassed it (Table 2).

When future PA expansion scenarios based on either species-based targets, ecoregion-based targets, or a combination of both were considered, the number of GDTs meeting 17% coverage targets increased (Table 3). The species-based prioritization would protect another 197 GDTs at the 17% level, whereas the ecoregional scenario would add 158 GDTs. The combined scenario would add 279 GDTs at the 17% level, leaving only 18 GDTs insufficiently protected, but this scenario almost doubled the global PA estate (Table 3). The species-focused prioritization appeared to perform better than the ecoregional one because of the interaction of cost (based on the value of agricultural land) and how area goals were set (see Venter et al. 2014). Species prioritization favored selection of places where range-limited species predominated (e.g., on islands), whereas large ecoregions provided more flexibility to lower costs by avoiding productive and therefore, expensive, soil types, allowing fewer GDTs to be covered. This result is important because many nations are currently using ecoregional coverage targets as a way to plan future expansion of their PA estate (Watson et al. 2014).

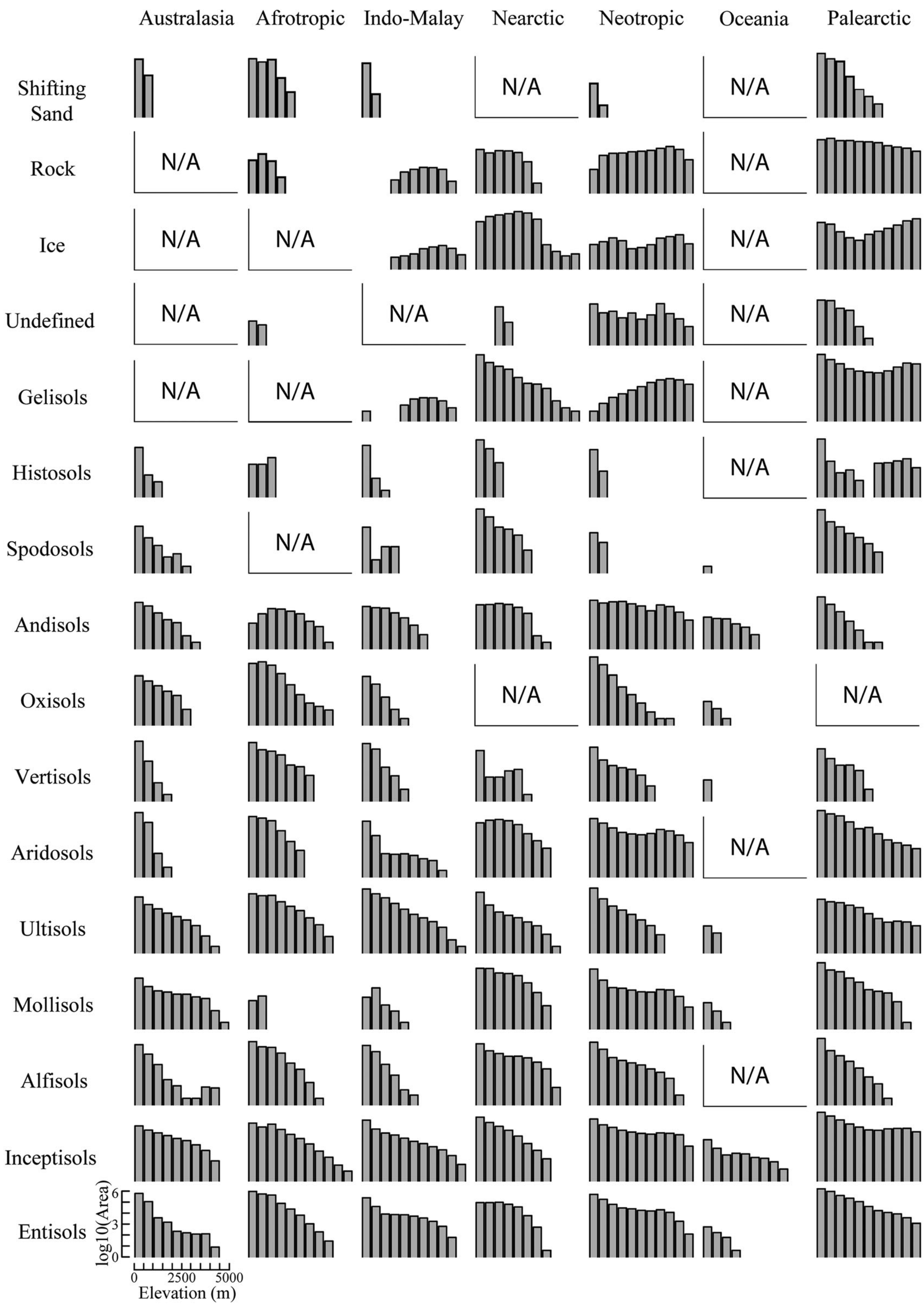

Figure 1. Differences in area (square kilometers on a log10 scale) of geophysical diversity types for combinations of soil type, biogeographic realm, and elevation. Each panel represents a combination of soil type (y-axis) and biogeographic realm (x-axis); units of measure are shown on the lowest left panel. Panels with N/A indicate combinations of soil type and biogeogeographic realm that do not exist; lack of elevation bars indicates combinations of soil type, biogeographic realm, and elevation that do not exist.

Table 2. Percentage of the area of each geophysical diversity type protected in 2012 (IUCN & UNEP 2012).[a]

Aspect of geophysical diversity	Soil order or substrate type																
	Shifting sands	Rock	Ice	Undefined	Gelisols	histosols	spodosols	andisols	oxisols	vertisols	aridosols	ultisols	mollisols	alfisols	inceptisols	entisols	Totals
Elevation bands (m)																	
0 - 499	11.0	3.5	40.6[b]	5.7	15.3	8.1	7.1	10.2	30.9[b]	5.7	7.1	14.9	2.5	7.4	11.8	9.6	11.3
500 - 999	15.7	8.9	40.7[b]	5.7	15.7	3.2	11.7	17.3[b]	13.6	9.2	9.6	15.6	3.8	10.5	11.4	11.6	11.8
1000–1499	13.5	12.6	35.4[b]	3.1	19.1[b]	14.9	26.5[b]	21.2[b]	15.9	15.9	10.5	21.5[b]	4.6	10.6	16.4	13.7	14.5
1500–1999	9.9	11.4	42.1[b]	23.5[b]	20.6[b]	<0.1	21.1[b]	21.3[b]	10.1	8.6	7.0	11.5	5.2	9.9	15.7	9.0	13.0
2000–2499	<0.1	12.1	39.4[b]	8.3	19.3[b]	<0.1	24.7[b]	21.8[b]	34.3[b]	7.4	6.5	16.1	7.3	11.2	16.3	7.2	16.5
2500–2999	<0.1	6.6	44.0[b]	1.7	21.5[b]	NA	32.4[b]	25.4[b]	65.0[b]	2.0	5.8	28.7[b]	11.5	16.1	16.8	8.3	21.0[b]
3000–3499	<0.1	6.4	53.8[b]	<0.1	22.7[b]	54.0[b]	85.0[b]	36.5[b]	76.7[b]	6.6	15.4	37.0[b]	21.3[b]	30.1[b]	20.3[b]	9.9	22.0[b]
3500–3999	NA	7.2	17.3[b]	0.7	22.4[b]	46.8[b]	NA	8.1	92.9[b]	NA	19.2[b]	42.1[b]	11.8	39.6[b]	23.3[b]	10.6	17.9[b]
4000–4499	NA	11.9	26.2[b]	8.1	42.6[b]	83.2[b]	NA	12.6	100.0[b]	NA	23.0[b]	29.4[b]	5.4	25.6[b]	21.8[b]	10.7	26.9[b]
4500–4999	NA	14.9	42.1[b]	3.3	58.5[b]	23.5[b]	NA	24.5[b]	NA	NA	19.4[b]	14.7	11.1	100.0[b]	19.1[b]	14.5	43.0[b]
>5000	NA	21.1[b]	44.4[b]	8.3	51.9[b]	11.9	NA	50.9[b]	NA	NA	17.9[b]	9.0	40.0[b]	NA	16.4	30.9[b]	44.6[b]
Realm																	
Afrotropic	15.4	<0.1	NA	<0.1	NA	14.0	NA	20.0[b]	11.6	11.9	12.6	18.6[b]	4.8	14.2	18.4[b]	12.9	13.9
Australasia	25.8[b]	NA	NA	NA	NA	23.2[b]	39.0[b]	16.1	16.5	3.6	7.7	16.0	12.5	7.2	16.6	12.7	11.4
Indo-Malay	21.1[b]	8.1	46.6[b]	NA	50.0[b]	9.9	16.6	23.9[b]	10.0	3.2	8.1	12.2	4.5	5.4	5.4	8.2	9.1
Nearctic	NA	26.7[b]	41.4[b]	0.5	19.2[b]	6.7	7.9	26.4[b]	NA	1.1	8.8	3.8	3.3	5.1	17.7[b]	11.5	13.8
Neotropic	69.3[b]	9.8	35.2[b]	3.5	17.5[b]	23.1[b]	0.2	15.5	33.7[b]	8.6	8.0	24.2[b]	5.0	9.5	23.7[b]	11.5	20.9[b]
Oceania	NA	NA	NA	NA	NA	NA	<0.1	12.7	<0.1	<0.1	NA	<0.1	1.3	NA	7.2	4.1	7.5
Palearctic	7.1	8.1	39.6[b]	7.2	21.2[b]	5.7	7.6	6.6	NA	5.4	7.1	7.9	2.8	5.2	9.3	8.6	9.5
Totals	12.3	9.3	41.0[b]	5.4	20.4[b]	8.5	8.2	16.3	24.5[b]	6.5	8.3	15.7	3.4	8.3	13.1	10.6	12.9

[a] *An NA indicates the combination of soil type and elevation or soil type and biogeographic realm does not exist.*
[b] *Exceeds Aichi target of 17%.*

Table 3. Benefits of 3 future protection scenarios (based on Venter et al. [2014]) for terrestrial geophysical diversity type (GDT) coverage.

Protection scenario	Size of protected area (PA) estate as a percentage of global terrestrial area	Number of GDTs meeting or exceeding 17% target (%)	Number of GDTs not meeting 17% target (%)	Number of GDTs with no representation in global PA estate (%)
Current (circa 2012)	12.9	300 (44.6)	372 (55.4)	68 (10.1)
Species[a]	18.1	497 (74.0)	175 (26.0)	23 (3.4)
Ecoregion[b]	21.1	458 (68.2)	214 (31.8)	44 (6.5)
Combined[c]	23.1	579 (86.2)	93 (13.8)	18 (2.7)

[a]*Expansion of protected areas (PAs) that meets representation targets for threatened terrestrial birds, mammals, and amphibians.*
[b]*Expansion of PAs meets or exceeds 17% of all terrestrial ecosystems.*
[c]*Expansion of PAs meets both species and ecoregion targets.*

Discussion

Advancing a geophysical diversity conservation strategy requires an operational definition of geophysical diversity on the global scale and the assessment of current conservation efforts for areas of different geophysical diversity types. We highlighted some practical problems that future geophysical diversity conservation planners should consider. One problem was the sheer number of GDTs (672) at the global scale. Although increasing the number of variables and the number of classes per variable would better describe global geophysical diversity, this would lead to thousands of GDTs. A large number of types can be difficult to interpret or explain to stakeholders and implementers (Beier & Brost 2010). Planning for conservation of geophysical diversity at regional extents (as is typically the case [Anderson et al. 2015]) naturally focuses on locally relevant geophysical characteristics and a manageable number of types. Limiting the extent, however, creates potential boundary issues and does not address the fact that climate change is a global, not a regional, conservation problem.

The current geography of protection presented here provides a useful starting point for conservation of terrestrial geophysical diversity. Relatively few (~ 10%) geophysical diversity types existed without at least some modicum of protection, and 300 types (44%) were already protected at the Aichi Target 11 level of 17%. Like other studies (e.g., Joppa & Pfaff 2009), we found a bias toward protecting soil types and elevation zones that were less productive or less suitable for human habitation. It seems unlikely that these general findings would be affected by a different choice of soil classification or a different set of intervals dividing elevation.

We also showed that if global PA prioritizations based on meeting species and ecoregion targets were enacted, geophysical diversity would be more protected, but not entirely protected (Table 3). These results will have ramifications for how nations address CBD Aichi Target 11 in the future because species and ecoregional coverage targets could be met without conserving all of geophysical diversity. Our results indicate that conservation planners should look for opportunities to prioritize low elevation areas and productive soil types like mollisols, vertisols, and alfisols, which may mean turning more attention to cities, suburbs, and agricultural areas, where most of these soil types are found. As competition for this type of land is often fierce, systematic planning approaches that address opportunity, efficiency, and complementarity will be necessary to ensure conservation gains can be achieved (Carwardine et al. 2008).

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Supporting Information

A color figure showing the global distribution of terrestrial GDTs and their constituent elements (e.g., soil orders, elevation zones, and biogeographic regions) (Appendix S1) and a complete list of GDTs with summary statistics on area and number and area of facets (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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