Preprints.org

Article

Not peer-reviewed version

Conservation Imperatives: Securing the Last Unprotected Terrestrial Sites Harboring Irreplaceable Biodiversity

Eric Dinerstein * , Anup R. Joshi , Nathan R. Hahn , Andy T. L. Lee , Carly Vynne , Karl Burkart , Greg P. Asner , Charlotte Beckham , Gerardo Ceballos , Richard Cuthbert , Rodolfo Dirzo , Oliver Fankem , Sarah Hertel , Binbin V. Li , Haley Mellin , Felix Pharand-Deschênes , David Olson , Bivash Pandav , Carlos Peres , Rudi Putra , Amy Rosenthal , Caspar Verwer , Eric Wikramanayake , Andrew Zolli

Posted Date: 11 March 2024

doi: 10.20944/preprints202309.1827.v2

Keywords: Conservation imperatives; 30 by 30; Protected area targets; Rare species; Land cover fraction mapping; Geospatial analysis; Land costs analysis

Article

Conservation Imperatives: Securing the Last Unprotected Terrestrial Sites Harboring Irreplaceable Biodiversity

Eric Dinerstein [1,*], Anup R. Joshi [2], Nathan R. Hahn [1], Andy T.L. Lee [1], Carly Vynne [1], Karl Burkart [3], Gregory P. Asner [4], Charlotte Beckham [5], Gerardo Ceballos [6], Richard Cuthbert [5], Rodolfo Dirzo [7], Oliver Fankem [8], Sarah Hertel [3], Binbin V. Li [9], Haley Mellin [10], Félix Pharand-Deschênes [11], David Olson [12], Bivash Pandav [13], Carlos A. Peres [14,15], Rudi Putra [16], Amy Rosenthal [17,18], Caspar Verwer [19], Eric Wikramanayake [20] and Andrew Zolli [17]

1 RESOLVE, Washington, DC, United States; nhahn@resolve.ngo; alee@resolve.ngo; cvynne@resolve.ngo
2 University of Minnesota, Minneapolis, MN, United States; joshi002@umn.edu
3 One Earth, Culver City, CA, United States; karl@oneearth.org; sarahmhertel@gmail.com
4 Arizona State University, Tempe, AZ, United States; gregasner@asu.edu
5 World Land Trust, Halesworth, Suffolk, United Kingdom; charlotte.beckham@worldlandtrust.org; richard.cuthbert@worldlandtrust.org
6 National Autonomous University of Mexico (UNAM), México, Mexico; ceballos.gerardo58@gmail.com
7 Stanford University, Palo Alto, CA, United States; rdirzo@stanford.edu
8 Global Conservation, Yaounde, Cameroon; oliverfankem@globalconservation.org
9 Duke Kunshan University, Suzhou, Jiangsu, China; bl113@duke.edu
10 Conserve, Fairfax, CA, United States; haley@conserve.org
11 Globaïa, Wellington, New Zealand; felix@globaia.org
12 Conservation Earth, Sharma, Saudi Arabia; conservationearth@live.com
13 Wildlife Institute of India, Chandrabani, Dehra Dun, India; bivash.pandav@wii.gov.in
14 University of East Anglia, Norwich, United Kingdom; C.Peres@uea.ac.uk
15 Instituto Juruá, Manaus, AM, Brazil
16 Leuser Rhino Foundation, Aceh, Indonesia; rhinoleuser@gmail.com
17 Planet Labs PBC, San Francisco, CA, United States; amy.rosenthal@planet.com; andrew@planet.com
18 Field Museum of Natural History, Chicago, IL, United States
19 International Union for Conservation of Nature (IUCN) - Netherlands, Amsterdam, Netherlands; caspar.verwer@iucn.nl
20 Environmental Foundation, Colombo, Sri Lanka; ericw@efl.lk
* Correspondence: edinerstein@resolve.ngo

Abstract: Ambitious biodiversity goals to protect 30% or more of the Earth's surface by 2030 (30x30) require strategic near-term targets. To define areas that must be protected to prevent the most likely and imminent extinctions, we propose Conservation Imperatives—16,825 unprotected sites harboring rare and threatened species and spanning ~164 Mha of the terrestrial realm. We estimate that protecting the Conservation Imperatives would cost approximately US$169 billion [90% probability: $146 — $228 billion]. Globally, 38% of the 16,825 sites are either adjacent to or within 2.5 km of an existing protected area, potentially reducing land acquisition and management costs. These sites should be prioritized for conservation action over the next five years as part of a broader strategy to expand the global protected area network. The expansion of global protected areas between 2018–2023 incorporated only 7% of sites harboring range-limited and threatened species, highlighting a renewed urgency to conserve these habitats. Permanently protecting only 0.74% of land found in the tropics, where Conservation Imperatives are concentrated, could prevent the majority of predicted near-term extinctions once adequately resourced. We estimate this cost to be US$29 billion to US$46 billion per year over the next five years. Multiple approaches will be required to meet long-term protection goals: providing rights and title to Indigenous Peoples and Local Communities (IPLCs) conserving traditional lands, government designation of new protected areas on federal and state lands, and land purchase or long-term leasing of privately held lands.

Keywords: conservation imperatives; 30x30; protected area targets; rare species; land cover fraction mapping; geospatial analysis; land costs analysis

Introduction

In late December 2022, at the United Nations Convention on Biological Diversity's 15th Conference of Parties (COP15), more than 190 parties adopted the 30×30 target—to protect at least 30% of the world's lands, oceans, and inland waters by 2030 (Convention on Biological Diversity, 2022). Conservation biologists, Indigenous Peoples, science-based NGOs, corporate leaders, and others have endorsed the 30×30 target and also called for protecting half of the terrestrial realm to have the best chance for humanity to reverse biodiversity loss, stabilize Earth's climate, prevent ecosystem collapse, and avoid future pandemics (Locke, 2015; Pimm et al., 2018; Dinerstein et al., 2020; IUCN World Conservation Congress, 2021). Either goal—30% protected or 50% protected—will encourage protection of large areas of land to meet targets, but this strategy can easily result in underrepresentation of biodiversity (Kuempel et al., 2016). Land protection targets must account for the urgency of preventing numerous species extinctions and extirpations of small, rare, and range-restricted populations.

The purpose of this paper is to offer a science-based strategy to secure and protect the remaining homes of rare and endangered species through timely, affordable investments in land acquisition and habitat conservation. To this end, we introduce the term Conservation Imperatives, defined as currently unprotected sites that contain rare, threatened, and narrow-range endemic species. Specifically, our approach is to map unprotected sites harbouring rare species while accounting for converted habitat and estimate costs to put these lands under conservation stewardship. We also seek to determine progress in protection of global sites of rarity from 2018-2023. Finally, we outline new efforts to leverage Conservation Imperatives to finance protection where immediate focus is needed and create anchor points for wider conservation planning under a five-year global strategy.

Advancing Conservation Imperatives is a global prioritization scheme in the sense that preventing extinctions is proposed as an immediate conservation target. We strive for maximum buy-in by all nations, Indigenous groups, and local communities who have jurisdiction over such lands to preserve opportunities for expanding protection to Conservation Imperatives. We intentionally avoid prioritizing among the sites at a global scale. The maps and data we present here should be used as a starting point for subsequent ecoregion-based or regional prioritizations within each realm. A rich literature on systematic conservation planning and reserve design can inform methodologies for evaluating and delineating proposed sites at a regional level (Margules and Pressey, 2000; Bottrill and Pressey, 2012; Watts et al., 2017; Wolff et al., 2023). Local teams of experts in each country can also take advantage of higher-resolution spatial data—for species distributions, population viability of threatened species, representation of rare habitats, land cover, extent of degraded lands, restoration potential, connectivity options, threats from development, extensive records of land purchase or leasing prices, and feasibility of conservation effort—often unavailable in global assessments. These essential planning efforts reinforce local ownership of Conservation Imperatives and will help reduce extinction risk by considering likely future conditions in each region.

Methods

Species rarity layer

We combined six widely used data layers employed in published global biodiversity assessments to identify sites supporting rare, narrow-range endemic, and endangered species (Dinerstein et al., 2020). Using the latest dataset of global protected areas (UNEP-WCMC and IUCN, 2023) as our base map, we sequentially intersected polygons identified as supporting rare and threatened species to avoid double counting of the overlapped areas. These include Alliance for Zero Extinction (AZE) sites, the range-restricted rarity of forest species, the IUCN Red List, Key

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 March 2024 doi:10.20944/preprints202309.1827.v2

Biodiversity Areas (KBAs), a second estimator of range-restricted rarity among vertebrates, and range-restricted vascular plants. For more details on construction of the species rarity layer, see Dinerstein et al. (2020) (SM Table 1). The total extent of these six data layers, minus the area covered by global protected areas, determines the remaining unprotected segment, which defines the extent of Conservation Imperatives (Figure 1). This layer of species rarity was then refined using the fractional land cover analysis described below.

Table 1. Extent of habitat by biogeographic realm after applying fractional land cover to species rarity sites and removing non-habitat area.

Realm	Forested habitat (km^2)	Non-forested habitat (km^2)	Total habitat (km^2)	% habitat reduction*
Afrotropic	65,301	350,050	415,351	32%
Australasia	180,550	37,066	217,616	36%
Indomalayan	150,262	4,662	154,924	56%
Nearctic	17,512	23,501	41,012	49%
Neotropic	174,945	137,045	311,990	54%
Oceania	1,766	241	2,007	84%
Palearctic	73,220	423,791	497,010	49%
Total	**663,556**	**976,355**	**1,639,911**	**46%**

*Approximate reduction of unprotected rare and threatened species areas from 2019 levels, versus total area extent from newly compiled data sets.

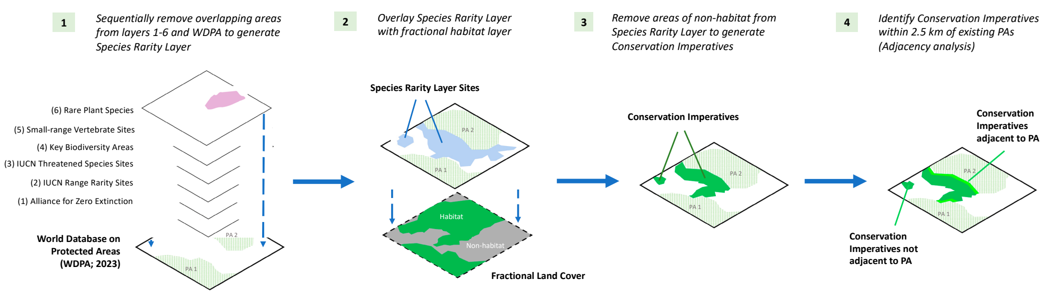

Figure 1. Schematic illustrating the construction of Conservation Imperatives and adjacency analysis. 1) Six layers of rare species data were overlaid together with the World Database on Protected Areas (WDPA; 2023) to remove overlapping areas to generate the Species Rarity Layer; 2) The resulting Species Rarity Layer was overlaid on a fractional land cover map with areas of habitat and non-habitat; 3) areas of non-habitat were removed from theSpecies Rarity Layer to derive Conservation Imperatives; 4) After completion of the previous steps, spatial analysis was performed to identify Conservation Imperatives that are adjacent to an existing reserve (i.e., within 2.5 km).

For freshwater species, which are on average more endangered than terrestrial species, we relied on the same data layers because: 1) the life histories of some of the most endangered vertebrates in the IUCN Red List of Endangered Species (Layer 3, see Figure 1) could be considered freshwater, rather than terrestrial species, or at least freshwater-dependent. These taxa include amphibians and some reptile groups; 2) the IUCN Red List polygons (Layer 3) also contain the spatial distributions of several relatively well-studied freshwater taxa for which range maps exist. These include: freshwater turtles, freshwater fish, freshwater crabs, freshwater molluscs, freshwater crayfishes and shrimps, odonates (dragonflies and damselflies), and some aquatic plants; 3) more than half of all endangered vertebrates in the Alliance for Zero Extinction layer (Layer 1) are amphibians.

 doi:10.20944/preprints202309.1827.v2

Fractional land cover analysis

We introduced a fractional land cover analysis to derive a more accurate estimate of the true Area-of-Habitat (hereafter "AoH") for rare and threatened species because published range data contain varying amounts of agricultural, pastoral, and urban lands. The uneven resolution of the most widely used global biodiversity layers, coupled with rapid land-use change from conversion to agriculture and urbanization, results in many species rarity sites now containing areas of non-habitat. To identify and remove non-habitat, we used Copernicus Global Land Cover Layers CGLS-LC100 Collection 3 at 100 m resolution (Buchhorn et al., 2020) (hereafter "Copernicus data") and Google Earth Engine (Gorelick et al., 2017) to generate a land cover map that includes fractions of all land cover types occurring in a pixel at 100 m resolution.

We used seven classes to create the fractional layer: Forest, Shrub, Grass, Crop, Urban, Bare Ground, and Permanent Water (inland water bodies). We defined Forest using percent tree cover in the Copernicus data that varied by biome, and set cutoff levels based on expert knowledge in each biome and their distinguishing ecological characteristics. Forest is defined as pixels with tree cover fraction > 80% for the Tropical forest biome, > 50% for the Temperate forest biome, and > 30% for the Boreal forest and Mangrove biomes. To differentiate desert habitat from bare ground in the Desert and Xeric shrub biome, desert is defined as > 70% bare soil and bare ground is defined as 50-69% bare soil in this biome. For all other cover types, we did not differentiate percent cover among biomes. Shrub cover is defined as pixels with shrub cover fraction ≥ 30%; Grass as grass cover fraction ≥ 50%; Bare ground as bare cover fraction ≥ 50%; Urban as urban cover fraction ≥ 10%; Permanent Water (inland) as permanent water cover fraction ≥ 30%; and Crop as cropland cover fraction >1% (to avoid any potential cultivated areas).

The species rarity layer and the fractional land cover map were overlaid to calculate the contribution by different cover types to unprotected polygons (Figure 1). To calculate the AoH (Brooks et al., 2019) in species rarity sites, we masked all land in the Crop, Urban, and Bare Ground cover types. We recognize that crops and bare ground can represent suitable habitat for some species that are threatened or have restricted ranges. Evaluating these individual species' requirements is, however, beyond the scope of this global assessment. In instances where the fractional land cover analysis resulted in small isolated fragments of rare species habitat surrounded by developed or cultivated land, fragments smaller than 1 ha were removed, due to high near-term conversion risk. Finally, we overlaid the resulting species rarity layer with the world's 846 terrestrial ecoregion boundaries to be able to categorize Conservation Imperatives by ecoregion (Dinerstein et al., 2017). The result of these sequential overlays allows us to identify Conservation Imperatives (Figure 1).

Adjacency Analysis

To determine the adjacency of Conservation Imperatives to existing reserves mapped in the World Database on Protected Areas (WDPA) layer (Figure 1), we buffered protected areas by 2.5 km and assessed which sites fell within this buffer. For this exercise we assumed that site protection and management could be easier as the expansion of existing protected areas or corridor establishment. We chose 2.5 km as the upper limit based on the minimum corridor width recommended for the largest terrestrial vertebrates (elephants) to move between isolated patches of habitat (Beier, 2019).

Cost assessment

Establishing accurate spatial delineation of Conservation Imperatives sets the stage for estimating the expected costs of protected area designation. Previous assessments of costs for conservation at the global scale have relied on extrapolation of land values based on agricultural and pastoral potential (Naidoo and Iwamura, 2007; Strassburg et al., 2020). Despite recent calls for datasets reflecting the real costs of land for conservation (Coomes et al., 2018; White et al., 2022), comprehensive datasets remain unavailable. Complicating this xestimation is that multiple stewardship mechanisms with different cost implications—such as private land purchase, leasing of community reserves and forests, re-establishing Indigenous land rights, and government re-designations—affect the true total costs to protect sites harbouring rare species. Using actual data on costs to place land under conservation stewardship can provide a clearer approximation of the resources required to secure critical sites for biodiversity (Coomes et al., 2018).

To estimate the cost of securing Conservation Imperatives sites in the tropical belt, we collected empirical data from land protection projects occurring between 2008 and 2022, fit generalized linear regression models, and applied a simulation approach. Our dataset consisted of 1,016 projects compiled from IUCN Netherlands, the Quick Response Fund for Nature, and World Land Trust (Quick Response Fund for Nature, n.d.), supplemented by unpublished data from other NGOs focused on land purchase that met our criteria for inclusion. These organizations regularly fund land acquisition, designation, and protection projects globally, with a higher concentration in the tropics. This portfolio includes a range of projects, including expansion of existing parks and community reserves, establishment of privately protected areas, and creation of community forest reserves. Acquisition costs cover the purchase price and legal and notary fees, which were as much as 10% of the acquisition cost. For leased land projects of varying lengths, we calculated an annual value and then extrapolated the cost per hectare for 10 years, the dataset's median lease length. We adjusted all costs to 2023 dollars to account for inflation. We removed projects with incomplete information on location, purchase cost, purchase size, and lease length. After cleaning the dataset, the remaining locations contained 833 sites distributed across all 6 major realms and 14 biomes (SM Figure 1).

We next fit linear regression models to the empirical cost per hectare of land protection projects. We used a log transformation on cost-per-hectare values to reduce skew and create an approximately normal distribution. We hypothesized that land value could be influenced by biogeographical realm, region, ecoregion, the area of land being secured, type of land acquisition, and country-level economic factors (Tulloch et al., 2021; Dinerstein et al. 2020). We used the following covariates as predictors: realm, size of acquisition, type of acquisition (categorized into purchase or lease), national per capita GDP, and country population size (World Bank, 2022). All continuous covariates were scaled and centered for interpretation. The mean per capita GDP and population were extracted based on the country in which the project occurred between 2010 and 2020. A random effect for data source was added to account for possible variation among the groups that supplied project data. We fit candidate models and used Akaike Information Criterion and conditional R^2 values to select the most informative model for land value (MuMin R Package; Burnham and Anderson, 2004). We tested for correlations among continuous covariates and excluded variables with $R > 0.65$ prior to the analysis (Dormann et al., 2013). We also tested for multiple collinearity using the variance inflation factor (Dormann et al., 2013). Neither test required removal of covariates.

To calculate the price to place Conservation Imperatives under conservation stewardship, we used Monte Carlo simulations (Mooney, 1997) to estimate cost per hectare and total land value of all sites under simulated purchase scenarios. Each simulation used the land value model to predict the cost per hectare of each Conservation Imperatives site using random values for acquisition size (assuming multiple smaller purchases would be needed to secure large sites), acquisition type (assuming a mix of purchase and lease), and data source, and determined land value by multiplying the predicted cost per hectare by the known size of the site. We ran 10,000 simulations with random values drawn from distributions parameterized by realm. Total cost estimates were calculated as the mean across all simulations, and we used 90% probability distributions to measure uncertainty. We used this approach to determine the total cost to place all Conservation Imperatives in the tropical belt under conservation stewardship. We then identified the top 10 ecoregions in each realm harbouring the most Conservation Imperatives and assessed the price to conserve those sites by ecoregion. We converted all results to US dollars per square kilometer to keep units comparable to the fractional analysis. Code used for model fitting and simulation can be found in the supplementary materials.

Representation of species rarity among newly created protected areas

To determine if the increases in the global protected area estate over the last five years have effectively addressed rare and endemic species exposed to the greatest risks of extinction, we

 doi:10.20944/preprints202309.1827.v2

intersected the Conservation Imperatives polygons with the most recent map of the WDPA, using protected area categories 1-7 (April 2023) (UNEP-WCMC and IUCN, 2023). We predicted that new reserves created during 2018-2023 would cover > 50% of the Conservation Imperatives.

Results

Fractional land cover analysis

We identified 16,825 sites harbouring rare and threatened species, covering ~164 Mha or 1.22% of the Earth's land surface (Figure 2). This AoH represents a 46% reduction from earlier estimates based on published compilation of identified areas of importance for rare and threatened species (e.g. KBAs, Red List sites; Dinerstein et al., 2020). Most of these reductions occurred in large blocks of unprotected habitat rather than in smaller fragments.

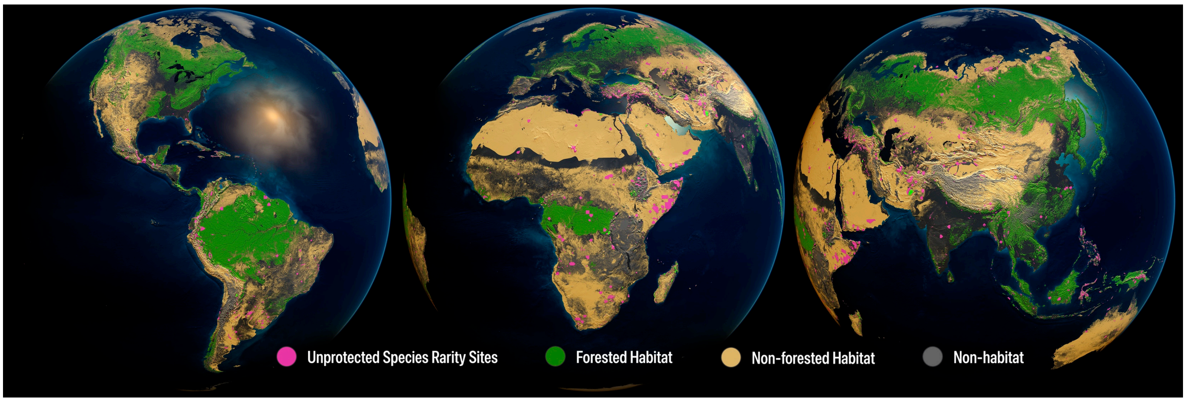

Figure 2. Map of global unprotected species rarity site. Global distribution of the unprotected species rarity sites (magenta area) across predominantly forested habitat (green) and non-forested habitat (yellow), with non-habitat areas (grey) removed from previously designated species rarity sites, covering 1.22%. Non-habitat areas include land classified as urban, agricultural, and degraded.

Reduction in total AoH harbouring unprotected rarity differed by latitude and by biome. In the four major tropical realms, we found a 45% reduction in total land area. In the non-tropical realms, we estimated a 49% reduction in area (Table 1). Within biomes that comprise the tropical realms, tropical and subtropical dry broadleaf forests underwent the largest reduction in target habitat (77%), followed by tropical and subtropical coniferous forests (58%). Tropical and subtropical moist broadleaf forests, which contained the highest concentration (75%) of Conservation Imperatives, had a 49% reduction in area (Figure 3; Table 2).

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 March 2024 doi:10.20944/preprints202309.1827.v2

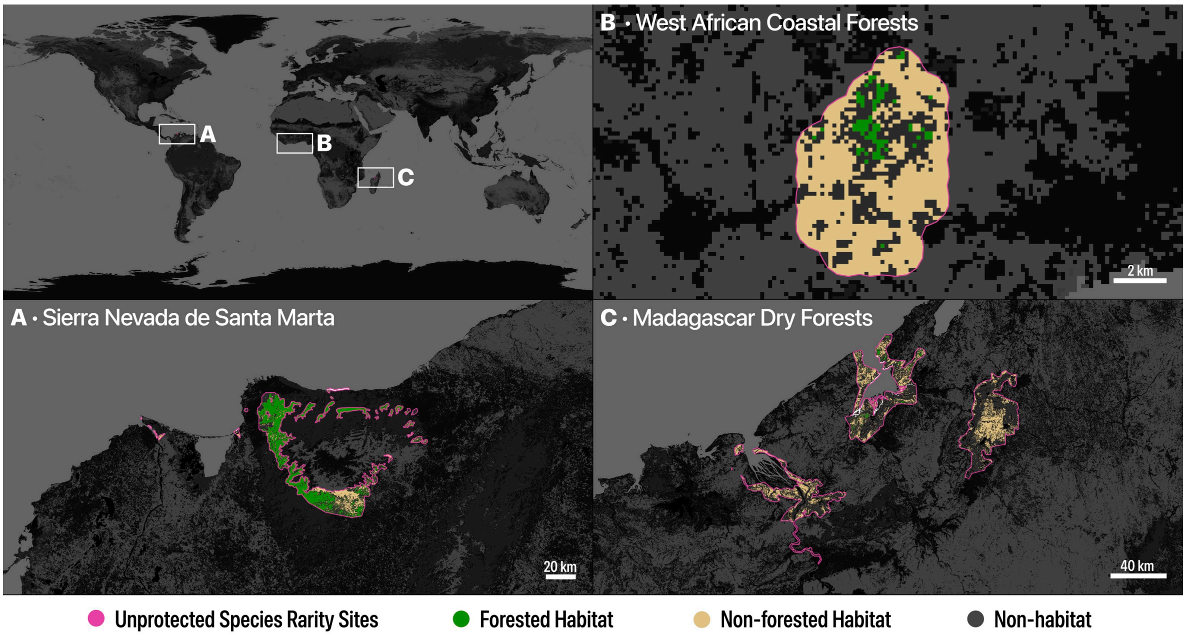

Figure 3. Effect of fractional analysis in identifying and removing non-habitat (Other) areas from species rarity polygons in several regions with high species rarity. Forested and non-forested habitat are retained. (A) Sierra Nevada de Santa Marta, Colombia; (B) West African coastal forests; and (C) Madagascar dry forests.

Table 2. Extent of habitat by biome after applying fractional land cover to species rarity sites and removing non-habitat area.

No.	Biome Name	Forested habitat (km²)	Non-forested habitat (km²)	Total habitat (km²)	% habitat reduction*
1	Tropical & Subtropical Moist Broadleaf Forests	536,606	55,436	592,043	49%
2	Tropical & Subtropical Dry Broadleaf Forests	7,903	13,248	21,152	77%
3	Tropical & Subtropical Coniferous Forests	13,152	3,073	16,225	58%
4	Temperate Broadleaf & Mixed Forests	28,563	25,156	53,719	68%
5	Temperate Conifer Forests	19,777	8,481	28,257	33%
6	Boreal Forests/Taiga	51,147	35,018	86,165	22%
7	Tropical & Subtropical Grasslands, Savannas & Shrublands	17	370,057	370,075	14%
8	Temperate Grasslands, Savannas & Shrublands	5	82,146	82,151	53%
9	Flooded Grasslands & Savannas	2	8,794	8,796	65%
10	Montane Grasslands & Shrublands	41	32,775	32,816	62%
11	Tundra	1	45,632	45,633	35%
12	Mediterranean Forests, Woodlands & Scrub	5	36,162	36,167	78%
13	Deserts & Xeric Shrublands	7	259,015	259,022	46%
14	Mangroves	6,329	1,361	7,690	44%
	Total	**663,556**	**976,355**	**1,639,911**	**46%**

* Approximate reduction of unprotected rare and threatened species areas from 2019 levels, versus total area extent from newly compiled data sets.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 March 2024 doi:10.20944/preprints202309.1827.v2

Conservation Imperatives

Conservation Imperatives are highly concentrated. We found a distinct skew in the distribution of the 16,825 sites harbouring unprotected rarity across biogeographic realms and biomes (Figure 2; Tables 3 and 4; SM Table 2). The majority of unprotected sites fall within the tropical and subtropical moist forests biome. Within the same biome but sorted by realm, the Neotropics had the most sites (38% of all Conservation Imperatives), followed by the Indomalayan (34%), Australasian (18%), and Afrotropical (9%) realms. Sites were also clustered within realms. The ten ecoregions with the most Conservation Imperatives within the four major tropical realms account for 63.5% of all sites globally (Figure 4; Table 5). The top five countries in the world with the highest number of Conservation Imperatives include the Philippines, Brazil, Indonesia, Madagascar, and Colombia, together accounting for 59% of all sites globally. Over 87% of all Conservation Imperatives occur in just 30 countries (Table 6).

Table 3. Distribution of Conservation Imperatives sites (2023) by realm. The four tropical realms account for 89% of all sites globally.

Biogeographic Realm	Forest (km^2)	Grass (km^2)	Shrub (km^2)	Desert (km^2)	Total (km^2)	Number of Sites	% Total Sites
Afrotropic	65,301	124,904	224,425	722	415,351	1,870	11.1%
Australasia	180,550	30,538	6,210	318	217,616	2,526	15.0%
Indomalayan	150,262	2,681	1,963	18	154,924	4,569	27.2%
Nearctic	17,512	11,355	11,914	233	41,012	184	1.1%
Neotropic	174,945	89,346	47,455	244	311,990	5,972	35.5%
Oceania	1,766	149	92	-	2,007	52	0.3%
Palearctic	73,220	262,573	20,868	140,349	497,010	1,652	9.8%
Total	**663,556**	**521,545**	**312,927**	**141,883**	**1,639,911**	**16,825**	**100%**

Table 4. Distribution of Conservation Imperatives sites (2023) in each biome. The tropical and subtropical moist broadleaf forests biome alone account for three-quarters of all sites globally.

No.	Biome Name	Forest (km^2)	Grass (km^2)	Shrub (km^2)	Desert (km^2)	Total (km^2)	Number of Sites	% Total Sites
1	Tropical & Subtropical Moist Broadleaf Forests	536,606	27,081	28,355	-	592,043	12,580	74.8%
2	Tropical & Subtropical Dry Broadleaf Forests	7,903	5,925	7,323	-	21,152	554	3.3%
3	Tropical & Subtropical Coniferous Forests	13,152	552	2,521	-	16,225	170	1.0%

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 March 2024 doi:10.20944/preprints202309.1827.v2

4	Temperate Broadleaf & Mixed Forests	28,563	24,055	1,101	-	53,719	503	3.0%
5	Temperate Conifer Forests	19,777	7,860	620	-	28,257	125	0.7%
6	Boreal Forests/Taiga	51,147	25,828	9,191	-	86,165	88	0.5%
7	Tropical & Subtropical Grasslands, Savannas & Shrublands	17	165,980	204,077	-	370,075	562	3.3%
8	Temperate Grasslands, Savannas & Shrublands	5	63,503	18,643	-	82,151	439	2.6%
9	Flooded Grasslands & Savannas	2	8,435	358	-	8,796	57	0.3%
10	Montane Grasslands & Shrublands	41	29,993	2,782	-	32,816	428	2.5%
11	Tundra	1	43,136	2,497	-	45,633	37	0.2%
12	Mediterranean Forests, Woodlands & Scrub	5	21,619	14,543	-	36,167	436	2.6%
13	Deserts & Xeric Shrublands	7	96,743	20,389	141,883	259,022	619	3.7%
14	Mangroves	6,329	835	526	-	7,690	227	1.3%
	Total	**663,556**	**521,545**	**312,927**	**141,883**	**1,639,911**	**16,825**	**100%**

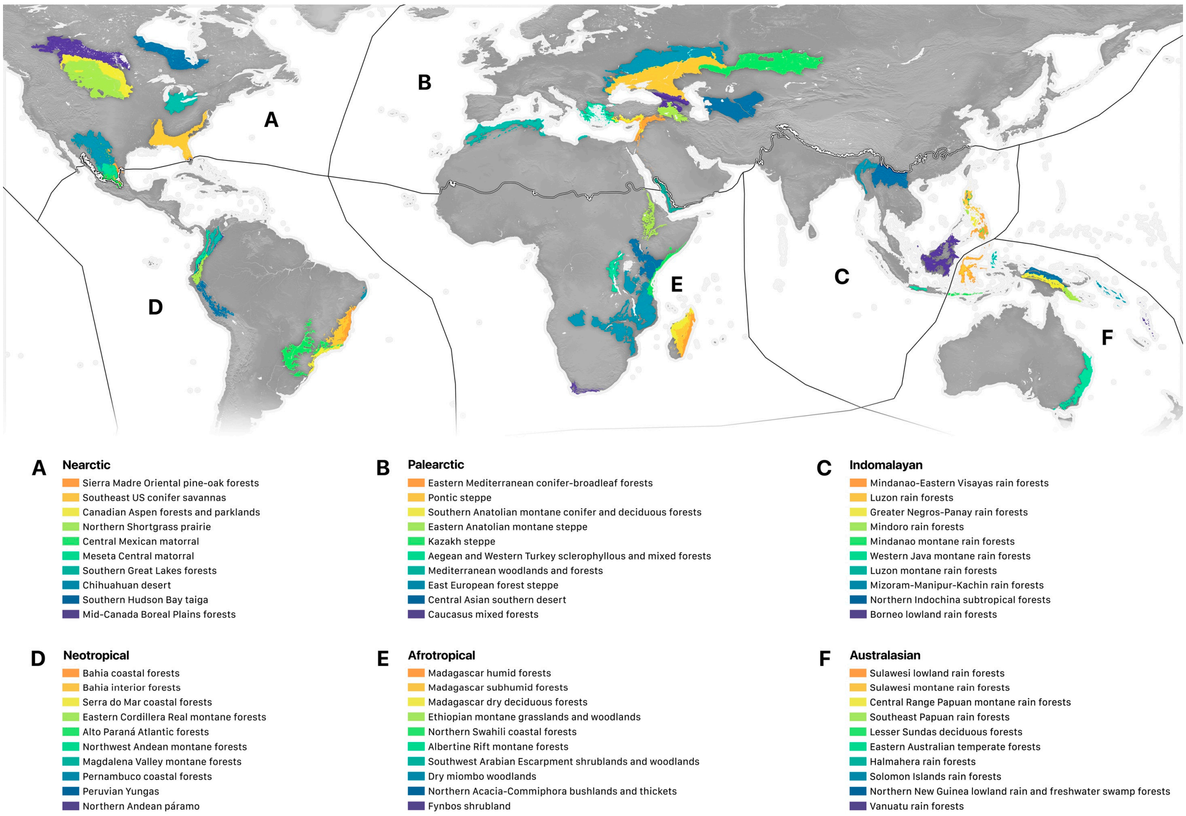

Figure 4. The 10 ecoregions in each realm containing the highest number of Conservation Imperatives.

Table 5. The top 10 ecoregions in each realm with the highest number of Conservation Imperatives sites (2023), and the total remaining natural habitat and estimated cost to place under conservation stewardship. This includes tropical and non-tropical ecoregions.

ID	Ecoregion Name	Total Habitat Area (km²)	Number of Sites	% of Sites in Realm	Estimated Cost (Million USD) Mean	Lower 90% CI	Upper 90% CI
Afrotropic							
17	Madagascar humid forests	4,295	614	32%	$337	$190	$539
18	Madagascar subhumid forests	3,836	250	13%	$302	$164	$477
32	Madagascar dry deciduous forests	3,025	59	3%	$241	$120	$398
79	Ethiopian montane grasslands and woodlands	725	49	3%	$56	$24	$103
25	Northern Swahili coastal forests	16,190	48	3%	$1,201	$447	$2,259
1	Albertine Rift montane forests	5,200	43	2%	$352	$111	$713
108	Southwest Arabian Escarpment shrublands and woodlands	2,407	38	2%	$272	$133	$462
42	Dry miombo woodlands	376	35	2%	$26	$10	$50
51	Northern Acacia-Commiphora bushlands and thickets	10,976	32	2%	$710	$179	$1,545
89	Fynbos shrubland	2,049	29	2%	$221	$64	$472
	Total Cost of Top 10 Ecoregions				$3,717		
Australasia							

156	Sulawesi lowland rain forests	25,417	1,090	45%	$197	$136	$276
157	Sulawesi montane rain forests	36,785	421	18%	$270	$152	$428
139	Central Range Papuan montane rain forests	39,150	379	16%	$231	$83	$441
153	Southeast Papuan rain forests	15,727	46	2%	$98	$37	$184
163	Lesser Sundas deciduous forests	1,916	41	2%	$15	$9	$22
168	Eastern Australian temperate forests	2,192	39	2%	$31	$19	$45
140	Halmahera rain forests	3,147	32	1%	$24	$16	$35
152	Solomon Islands rain forests	10,456	25	1%	$69	$46	$97
148	Northern New Guinea lowland rain and freshwater swamp forests	6,101	22	1%	$39	$18	$69
159	Vanuatu rain forests	992	18	1%	$7	$5	$10
	Total Cost of Top 10 Ecoregions				$980		
Indomalayan							
247	Mindanao-Eastern Visayas rain forests	22,648	1,561	36%	$14,948	$9,354	$22,070
241	Luzon rain forests	15,139	1,123	26%	$9,912	$6,336	$14,223
231	Greater Negros-Panay rain forests	1,813	190	4%	$1,184	$672	$1,819
248	Mindoro rain forests	1,663	178	4%	$971	$501	$1,664
246	Mindanao montane rain forests	7,517	139	3%	$4,880	$2,411	$8,015
288	Western Java montane rain forests	709	100	2%	$467	$239	$765
240	Luzon montane rain forests	2,644	57	1%	$1,732	$752	$2,975
249	Mizoram-Manipur-Kachin rain forests	5,395	52	1%	$3,037	$1,796	$4,651
256	Northern Indochina subtropical forests	3,171	44	1%	$2,097	$1,174	$3,205
219	Borneo lowland rain forests	13,993	43	1%	$8,399	$2,961	$16,403
	Total Cost of Top 10 Ecoregions				$47,628		
Nearctic							
327	Sierra Madre Oriental pine-oak forests	1,828	16	9%	$76	$47	$112
399	Southeast US conifer savannas	1,149	15	8%	$66	$35	$107
386	Canadian Aspen forests and parklands	121	9	5%	$7	$4	$12
396	Northern Shortgrass prairie	672	9	5%	$40	$21	$64
427	Central Mexican matorral	603	8	4%	$21	$7	$41
432	Meseta Central matorral	819	8	4%	$31	$15	$55
342	Southern Great Lakes forests	222	7	4%	$11	$4	$22
428	Chihuahuan desert	3,490	7	4%	$131	$55	$241
382	Southern Hudson Bay taiga	1,782	6	3%	$99	$42	$177
376	Mid-Canada Boreal Plains forests	561	5	3%	$30	$12	$55

		Total Cost of Top 10 Ecoregions			$513		
Neotropical							
442	Bahia coastal forests	3,563	1,635	27%	$410	$307	$543
443	Bahia interior forests	1,161	579	10%	$138	$107	$174
500	Serra do Mar coastal forests	3,134	434	7%	$372	$277	$481
460	Eastern Cordillera Real montane forests	18,176	279	5%	$1,796	$1,201	$2,541
439	Alto Paraná Atlantic forests	2,177	192	3%	$241	$162	$338
486	Northwest Andean montane forests	18,454	192	3%	$1,888	$1,169	$2,775
477	Magdalena Valley montane forests	9,685	156	3%	$927	$516	$1,511
491	Pernambuco coastal forests	160	150	2%	$19	$13	$26
493	Peruvian Yungas	11,658	142	2%	$1,191	$852	$1,600
593	Northern Andean páramo	892	121	2%	$92	$66	$125
		Total Cost of Top 10 Ecoregions			$7,075		
Palearctic							
791	Eastern Mediterranean conifer-broadleaf forests	6,900	114	7%	$1,092	$634	$1,681
735	Pontic steppe	9,506	101	6%	$1,675	$1,017	$2,497
804	Southern Anatolian montane conifer and deciduous forests	12,680	70	4%	$2,255	$1,241	$3,512
727	Eastern Anatolian montane steppe	9,761	57	3%	$1,501	$757	$2,492
732	Kazakh steppe	9,220	53	3%	$1,504	$845	$2,375
785	Aegean and Western Turkey sclerophyllous and mixed forests	1,577	43	2%	$270	$143	$437
798	Mediterranean woodlands and forests	2,221	40	2%	$295	$137	$511
661	East European forest steppe	2,191	39	2%	$382	$210	$608
819	Central Asian southern desert	3,436	37	2%	$486	$269	$780
650	Caucasus mixed forests	5,851	36	2%	$901	$488	$1,431
		Total Cost of Top 10 Ecoregions			$10,361		

Table 6. Top 30 countries with the highest number of Conservatives Imperative sites, their percentage total, median area of sites (km²), and the number and percentage of sites within the country that are adjacent to existing protected areas (i.e., within 2.5 km of boundary).

Country	Number of Conservation Imperative sites	% of Total sites	Median area of sites (km²)	Total area of sites (km²)	Number of sites adjacent to existing protected area (within 2.5 km of boundary)	% of sites adjacent to existing protected area in country
Philippines	3,355	19.5%	0.46	53,816	833	25%
Brazil	3,342	19.4%	0.31	35,632	781	23%
Indonesia	1,893	11.0%	0.50	116,773	387	20%

Madagascar	968	5.6%	0.37	14,585	183	19%
Colombia	761	4.4%	0.93	39,827	423	56%
Ecuador	653	3.8%	0.38	35,026	157	24%
Papua New Guinea	527	3.1%	0.36	81,800	26	5%
India	437	2.5%	5.23	20,861	65	15%
Peru	342	2.0%	13.42	43,590	101	30%
Turkey	304	1.8%	28.53	50,166	2	1%
Russia	291	1.7%	54.48	138,436	89	31%
China	276	1.6%	22.68	41,276	47	17%
Mexico	230	1.3%	17.22	33,441	63	27%
Argentina	187	1.1%	40.87	61,285	38	20%
Australia	137	0.8%	2.31	35,705	54	39%
United Republic of Tanzania	127	0.7%	0.24	1,041	52	41%
South Africa	116	0.7%	9.74	40,648	52	45%
Myanmar	114	0.7%	16.78	22,883	16	14%
Ethiopia	109	0.6%	0.86	40,513	6	6%
Kazakhstan	104	0.6%	85.39	58,230	19	18%
United States of America	102	0.6%	17.78	10,636	51	50%
Venezuela	93	0.5%	1.77	2,793	50	54%
Kenya	92	0.5%	0.69	16,297	22	24%
Vietnam	85	0.5%	5.47	3,274	42	49%
Bolivia	81	0.5%	16.31	8,612	27	33%
Yemen	78	0.5%	27.00	6,111	1	1%
Malaysia	76	0.4%	7.88	9,141	25	33%
Democratic Republic of the Congo	73	0.4%	13.46	49,350	23	32%
Syria	70	0.4%	5.16	2,360	1	1%
Chile	66	0.4%	3.49	2,652	22	33%
Total of Top 30 Countries	**15,089**	**87.6%**		**1,076,759**	**3,658**	**24%**

Representation of species rarity among newly created protected areas

We predicted that >50% of new protected areas designated between 2018 and 2023 would overlap with unprotected species rarity sites. We estimated that 1.2 million km^2 was added to the global protected area estate over this five-year time period (UNEP-WCMC and IUCN, 2023). Of that, the largest extent was located in two ecoregions (#473 Japura-Solimões-Negro Moist Forests and #831 North Arabian Desert, totalling 192,000 km^2), but based on our analysis these additions had very little overlap with areas harbouring rare and threatened species. In fact, over this same time period only 109,779 km^2, or less than 7% of identified Conservation Imperatives have been added to the World

Database on Protected Areas (Figure 5), leaving the vast majority of these sites at risk of conversion and degradation. Expressed slightly differently, had the 1.2 million km² set aside during 2018-2023 included only Conservation Imperatives, 73% of these sites globally would now be under protection.

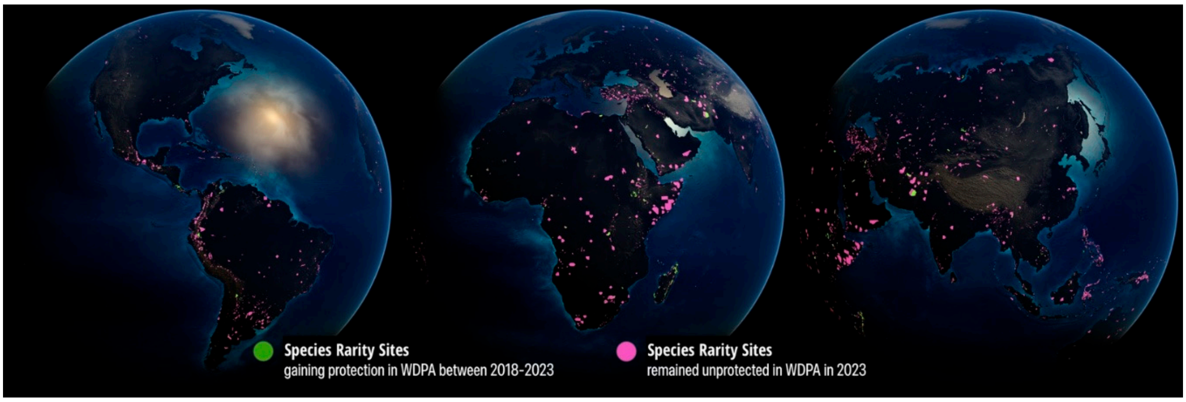

Figure 5. Expansion of protection in species rarity sites under World Database on Protected Areas (WDPA) between 2018 and 2023, after overlaying the fractional land cover. Green polygons show unprotected species rarity sites that have gained protection between 2018 and 2023, representing only 7% of the global increase in protection coverage. Magenta polygons represent sites that remain unprotected in 2023.

Cost Analysis

The model of land acquisition costs per hectare that included realm, purchase type, purchase size, per capita GDP, and population size performed best and had an R^2 of 0.76 (SM Table 4). Among the variables we tested, acquisition size (-0.67, 95% CI [-0.71, -0.64]; larger acquisitions had lower per-ha costs), acquisition type (0.97, 95% CI [0.66, 1.28]; purchases were more expensive than leases), and realm were the most useful predictors, and explained much of the model variation on their own. We also found that higher per capita GDP (0.18, 95% CI [0.07, 0.28]) and human population density (0.03, 95% CI [0.02, 0.08]) increased land prices (SM Table 4).

In Monte Carlo simulations of the land cost for Conservation Imperatives, we found that total cost of the Conservation Imperatives in the tropics is US$169 billion, with a 90% probability between US$146 and $228 billion (SM Figure 2). Much of this uncertainty appeared to come from variations in the size and type (purchases and leases) of land acquisitions. Land acquisition was least expensive in Australasia and most expensive in Indomalaya, but somewhat similar in the other realms (Table 7, SM Figure 2b). The Afrotropical, Indomalayan, and Neotropical realms showed the largest variation in predicted total cost, which appeared to arise from larger cost differences between lease arrangements and purchases and the number of sites that were either leased or purchased in each simulation (SM Figure 2). Land costs for the top 10 ecoregions—ranked by number of species rarity sites—from each of the four major tropical realms would be US$59.4 billion (90% probability of US$29–$108 billion), safeguarding 63% of all sites (Figure 4; Table 5). To cover Conservation Imperatives at all latitudes, the total cost increases to US$263 billion (90% probability of US$204–339 billion).

Table 7. Predicted cost per km² and total purchase cost for securing Conservation Imperatives (2023) within tropical latitudes by realm. All costs are in 2023 $US dollars. The mean total cost and 90% probability intervals are reported in billions of dollars.

Realm	Mean cost/km² (USD)	Mean acquisition size (km²)	Mean total cost (Billions USD)	90% probability (Billions USD)
Afrotropic	$32,548	21,811	$38.53	$24.39–59.70
Australasia	$5,800	131,750	$1.59	$1.19–2.11

 doi:10.20944/preprints202309.1827.v2

Indomalayan	$361,840	1,840	$90.39	$72.36–112.49
Nearctic	$29,545	14,911	$0.14	$0.08–0.22
Neotropic	$75,010	11,025	$28.39	$23.84–34.02
Palearctic	$61,082	7,441	$9.50	$3.58–19.70

Adjacency analysis

Adjacency analysis of Conservation Imperatives sites to existing protected areas revealed that 38% (SD = 36.01) of the 16,825 sites either bordered or were within 2.5 km of a nearby existing protected area (Table 6). The five countries with the most Conservation Imperatives had at least 20% located next to existing protected areas (SM Figure 3). Colombia ranked highest among the top 30 countries with 56% of all Conservation Imperatives bordering protected areas.

Discussion

Key Findings

Five key insights emerging from this study elevate the need to prioritize the conservation of rare and threatened species and their habitats as an urgent near-term target within a larger global biodiversity strategy: 1) Conservation Imperatives identified in this study represent a mere 1.2% of the Earth's terrestrial surface (0.74% in the tropical belt); 2) Conservation Imperatives were underrepresented in the creation of new protected areas during the last five years, indicating that a focus on species rarity is necessary; 3) had new protected areas created during 2018-2023 been more strategically located to cover polygons identified as Conservation Imperatives, 73% of them could have been protected; 4) the bulk of the world's rare and endangered species could be represented in protected areas for approximately $25 billion/year for five years, and for only $5 billion/year for five years in the Neotropics, where ecoregions contain the largest number of Conservation Imperatives; and 5) the proximity of 38% of the 16,825 Conservation Imperatives to existing protected areas could greatly reduce barriers to protection and the costs of subsequent management of these areas while enhancing connectivity and augmenting climate adaptation strategies.

Preventing Extinction is an Unfulfilled Conservation Mandate

These insights raise a strategic question: Why have sites harbouring rarity and impending global extinction been overlooked? Numerous studies have shown that the goals of stabilizing Earth's climate and reversing biodiversity loss are interdependent (Arneth et al., 2020; Dinerstein et al., 2020; Shin et al., 2022). Efforts and investments to address the climate crisis have overshadowed the attention governments and intergovernmental processes have paid to the biodiversity crisis. The recent Biodiversity COP held in Montreal, Canada in December 2022 (Convention on Biological Diversity, 2022) was an important milestone, helping spur more urgent and ambitious efforts to protect biodiversity. The COP also linked nature conservation with climate interventions that maintain the Earth's forest cover and carbon sinks, sometimes referred to as nature-based climate solutions (IUCN, 2020). Major investments to prevent forest conversion in carbon-rich regions, such as the Amazon Basin, the Congo Basin, and boreal regions are essential and must be afforded a high priority as some of the last remaining wilderness areas. However, a focus on unprotected rare species areas is needed as the world sets about to expand the protected area network from 17% today to 30% or more by 2030.

Our results corroborate observations that conservation efforts are failing to target regions rich in rare species (Maxwell et al., 2020). Only 7% of the 1.2 million km^2 added to the global protected area estate over the past five years covered unprotected species rarity sites. These included protected areas that had been established prior, but only recently been recorded in WDPA—so the actual expansion of protection during this period could be even smaller. Several analyses point to a pattern where the addition of new protected areas to the global coverage is largely attributable to areas

 doi:10.20944/preprints202309.1827.v2

characterized by low agricultural productivity (Venter et al., 2018), and have had limited success at protecting threatened species (Pimm et al., 2014). Clearly, the combined efforts of international and local conservation NGOs, foundations, and government agencies to increase protected area coverage to avoid extinctions and extirpations of species needs greater support. This analysis shows that this will not happen *de facto* even with 30x30 goals, given the limited progress over the past five years.

Of most concern is that only 2.4% of newly created protected areas added to the WDPA were in the tropical and subtropical moist forest biome containing by far the highest numbers of Conservation Imperatives. In contrast, 69% of protection occurred in the temperate broadleaf and mixed forests biome, 14% in Boreal forest/taiga, and 6% in temperate conifer forests – none of which contain high numbers of Conservation Imperatives. As a result, targeted effort is now required to secure the remaining fraction of rare unprotected species sites, before more land conversion occurs, and without leaving to chance the selection of new protected areas. Our results yield a surprisingly low number of Conservation Imperatives in the five ecoregion complexes that make up the endemism-rich Mediterranean scrub biome. This finding may be because this biome is one of the most heavily converted among the 14 terrestrial biomes and much of what remains is either protected or so degraded that the fractional land cover analysis inadvertently removed areas that are still viable.

Preventing Extinction is Affordable and Doable

Using the Conservation Imperatives identified in this analysis, a starting strategy that targets the 10 ecoregions within each of the four tropical realms containing the highest number of sites could put 63% of all identified sites under conservation stewardship and represent 12 different biomes. With the geographic concentration of Conservation Imperatives sites, this approach will retain representation across distinct biomes and realms (Margules and Pressey, 2000; Pressey et al., 2007). The land value for those sites is estimated at US$59 billion (90% probability of US$29–$108 billion). Focusing more narrowly on the 10 Neotropical ecoregions containing the largest number of Conservation Imperatives would represent 23% of all identified sites, involving a land acquisition cost of US$1.4 billion/year for five years in this realm. Several studies have suggested that up to US$224 billion per year for 10 years would be needed to protect nature globally (Waldron et al., 2020). The Conservation Imperatives could help focus these investments in the next five years to protect sites where irreplaceable biodiversity is concentrated while allowing individual nation states to formulate longer-term strategies to address less threatened taxa, habitats, and ecological processes.

Factors Affecting Cost of Conservation Imperatives

While land purchase or leasing values provide a starting point for costs, a diversity of approaches will be needed to secure protection of Conservation Imperatives. Whereas traditional land trust models focus on purchase of land for private management, options such as community reserves, government re-designations, private sector commitments, and other effective area-based conservation measures (OECMs) may be more effective, less costly, and more sustainable. Where national governments incorporate creation of new protected areas into their sovereign biodiversity strategies as a unique contribution, the global cost of initial protection of Conservation Imperatives will drop dramatically.

Conservation Imperatives that are adjacent to or within 2.5 km of an existing reserve could be much cheaper to manage than isolated Conservation Imperatives. This would especially be true where entities or agencies responsible for protecting nearby reserves could extend management protocols to the adjacent Conservation Imperatives. Alternatively, where these adjacent lands constitute buffer areas or corridors, they could be managed as community reserves. Promoting this landscape approach to reserve management will help ensure these protected areas remain home to the rare and endangered species they protect, even in a rapidly changing world.

As the best conservation strategy will depend on site conditions and land tenure, much of the work to secure Conservation Imperatives will depend on close collaboration with local groups, communities, and governments. For example, 17% of Conservation Imperatives are located within current and historical Indigenous lands (Dinerstein et al., 2020). Indigenous Peoples and local communities (IPLCs) have been among the most effective stewards of biodiversity, and recognition of land rights can play an outsized role in protecting people and biodiversity (Ban et al., 2018; Dinerstein et al., 2020; Dawson et al., 2021; Duarte et al., 2023). Resource management by local communities can further secure the protection of millions of hectares of critical habitat within sustainable-use forest reserves, such as Amazonian floodplains (Campos-Silva and Peres, 2016), with the added bonus of raising thousands of local households above the poverty line (Campos-Silva et al., 2021). Where this strategy is appropriate, funding through conservation payments could provide a viable means to pay for site protection and restoration (Börner et al., 2010; Zander and Garnett, 2011).

Finer Scale Assessment of Conservation Imperatives

Conservation Imperatives can serve as a starting point to guide biodiversity protection commitments from the public and private sector. Efforts are now underway to finance Conservation Imperatives in five of the top 10 countries (Table 6) for sites deemed appropriate for land purchase through private philanthropy. By the end of 2024, similar initiatives could be underway in all of the top 30 countries. Many companies are now developing strategies to become "nature positive" by avoiding impacts on biodiversity-sensitive sites and increasing financial commitments to nature and biodiversity. Conservation Imperatives should be considered in such plans, and can guide the direction of globally flexible resources towards the highest priorities. These discrete sites are measurable and relatively straightforward to monitor, and thus could appeal to companies concerned about clearly defined nature-positive outcomes. Of course, in all cases, the local context must be assessed to ensure that conservation actions will be sustainable and support local and Indigenous communities where applicable.

Conservation Imperatives can also act as "anchor points" or connectivity nodes in comprehensive conservation planning efforts. Multicriteria analysis and decision-making platforms can utilize Conservation Imperatives to optimize broader strategies for designing compact and connected protected area networks at the national, ecoregional, or subnational levels (Zhang et al., 2021). Systematic conservation planning can also prove valuable, although these assessments must take into account natural, financial, social, human, and institutional factors that are best assessed and finer scales (Bottrill and Pressey, 2012). Existing planning tools such as Marxan (Watts et al., 2017) and new tools allowing dynamic conservation planning from automated satellite-based habitat monitoring (Shirk et al., 2023) could underpin these regional assessments.

One of the most critical aspects of these fine-scale assessments is to determine the viability of sites. A number of Conservation Imperatives that are not adjacent to existing protected areas are small fragments. The long-term viability of these sites and the endangered populations they contain must be subjected to feasibility analyses, such as those conducted recently for a subset of mammal species (Wolff et al., 2023). These in-depth analyses can also better assess the dynamic nature of threats, model the effects of climate change, and incorporate other features.

Efforts to reach the 30×30 goal will incur long-term costs for protection and restoration. As assessments of Conservation Imperatives move to the country, ecoregional, or landscape scales, the work of local teams of scientists and planners to identify critical areas for restoration and tap into these resources could help safeguard many threatened Conservation Imperatives. Such funding is typically earmarked for restoring lands by allowing for natural regeneration or targeted re-planting (preferably with native species) and not applicable to land purchase. However, time frames for restoration of degraded habitats can be on the order of 5-20 years or more. A central point of our paper is that the Conservation Imperatives require protection within the next five years. This urgency is underlined by two levels of extinction crisis of documented by conservation biologists: the accelerated rates of species extinction compared to historical background rate (Pimm et al., 2014; Ceballos et al., 2015); and the extinction of small populations (Ceballos et al., 2017). So these conservation targets—safeguarding the last populations of rare and endangered species, and protection and restoration of habitats—are on different timelines.

Gaps in our Approach

The largest gap in our approach occurs where adding new parcels alone will not achieve the desired outcome of avoiding extinctions. The best examples of this problem are where exotic invasive species introduced into tropical archipelagos, and where poaching of endangered species, particularly keystone species, remains unchecked. In the first instance, simply setting aside land will not guarantee a future for island endemics that have evolved in the absence of exotic invasive herbivores, omnivores and carnivores, invasive plants, or new diseases. Even those archipelagos that contain formally protected areas are subjected to these threats. Here, targeted eradication and control campaigns are the primary approaches to prevent extinctions, and funding is desperately needed to conserve the large number of tropical flora and fauna on remote islands facing these threats. In the second instance, excessive hunting and poaching of large mammal species could remove critical species whose presence or abundance are essential to maintain critical ecological function. New technologies are emerging to assist those charged with protecting endangered populations and should be part of this global funding effort to avoid extinctions (Dertien et al., 2023).

Conclusion

Conservation Imperatives can contribute to a science-based priority-setting strategy for expanding the global protected area network to at least 30% by 2030, in line with ambitious targets set forth in the Kunming-Montreal Global Biodiversity Framework. Area-based conservation targets have moved to the forefront of conservation, and we welcome this approach. Embedded in the area-based approach, however, should be the commitment to protecting irreplaceable sites harbouring rare and endangered biodiversity as we strive towards 30×30. Conservation Imperatives occupy only a small portion of the emerging global conservation portfolio but offer high-quality opportunities to protect the diversity of life on Earth.

Acknowledgments: This paper is dedicated to a visionary in biodiversity conservation, Dr. Thomas Lovejoy, friend of wild nature, colleague, mentor, and inspiration to us all. We would like to thank R. Naidoo, S. Butchart, and S. Pimm, for helpful comments on the manuscript. We thank N. D. Burgess and A. Arnell at UNEP-WCMC for providing support and verification of the use of the World Database on Protected Area data in the analysis and for valuable editorial comments. The findings and perspectives in this paper do not necessarily reflect the position of Planet Labs PBC. A pre-print version of this manuscript is submitted to Preprints.org and is available online at https://www.preprints.org/manuscript/202309.1827/v1 (Dinerstein et al., 2023).

References

Armsworth, P. R. (2014). Inclusion of costs in conservation planning depends on limited datasets and hopeful assumptions. *Ann. N. Y. Acad. Sci.* 1322, 61–76.

Armsworth, P. R., Cantú-Salazar, L., Parnell, M., Davies, Z. G., and Stoneman, R. (2011). Management costs for small protected areas and economies of scale in habitat conservation. *Biol. Conserv.* 144, 423–429.

Arneth, A., Shin, Y.-J., Leadley, P., Rondinini, C., Bukvareva, E., Kolb, M., et al. (2020). Post-2020 biodiversity targets need to embrace climate change. *Proc. Natl. Acad. Sci.* 117, 30882–30891.

Ban, N. C., Frid, A., Reid, M., Edgar, B., Shaw, D., and Siwallace, P. (2018). Incorporate Indigenous perspectives for impactful research and effective management. *Nat. Ecol. Evol.* 2, 1680–1683.

Beier, P. (2019). A rule of thumb for widths of conservation corridors. *Conserv. Biol.* 33, 976–978.

Birdlife International (2018). Digital boundaries of Key Biodiversity Areas from the World Database of Key Biodiversity Areas.

Börner, J., Wunder, S., Wertz-Kanounnikoff, S., Tito, M. R., Pereira, L., and Nascimento, N. (2010). Direct conservation payments in the Brazilian Amazon: Scope and equity implications. *Ecol. Econ.* 69, 1272–1282.

Bottrill, M. C., and Pressey, R. L. (2012). The effectiveness and evaluation of conservation planning. *Conserv. Lett.* 5, 407–420.

Brooks, T. M., Pimm, S. L., Akçakaya, H. R., Buchanan, G. M., Butchart, S. H. M., Foden, W., et al. (2019). Measuring terrestrial area of habitat (AOH) and its utility for the IUCN Red List. *Trends Ecol. Evol.* 34, 977–986.

Buchhorn, M., Smets, B., Bertels, L., De Roo, B., Lesiv, M., Tsendbazar, N.-E., et al. (2020). Copernicus global land service: Land cover 100m: collection 3: epoch 2019: Globe. *Version V3. 0.1*.

Burnham, K. P., and Anderson, D. R. (2004). Multimodel inference: understanding AIC and BIC in model selection. *Sociol. Methods Res.* 33, 261–304.

Campos-Silva, J. V., and Peres, C. A. (2016). Community-based management induces rapid recovery of a high-value tropical freshwater fishery. *Sci. Rep.* 6, 34745.

Campos-Silva, J. V, Peres, C. A., Hawes, J. E., Haugaasen, T., Freitas, C. T., Ladle, R. J., et al. (2021). Sustainable-use protected areas catalyze enhanced livelihoods in rural Amazonia. *Proc. Natl. Acad. Sci.* 118, e2105480118.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., and Palmer, T. M. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Sci. Adv.* 1, e1400253.

Ceballos, G., Ehrlich, P. R., and Dirzo, R. (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proc. Natl. Acad. Sci.* 114, E6089–E6096.

Convention on Biological Diversity (2022). COP15: Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement. *Off. CBD Press Release*. Available at: https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022.

Coomes, O. T., MacDonald, G. K., and de Waroux, Y. le P. (2018). Geospatial land price data: A public good for global change science and policy. *Bioscience* 68, 481–484.

da Silva, J. M. C., Barbosa, L. C. F., Topf, J., Vieira, I. C. G., and Scarano, F. R. (2022). Minimum costs to conserve 80% of the Brazilian Amazon. *Perspect. Ecol. Conserv.* 20, 216–222.

Dawson, N. M., Coolsaet, B., Sterling, E. J., Loveridge, R., Gross-Camp, N. D., Wongbusarakum, S., et al. (2021). The role of Indigenous peoples and local communities in effective and equitable conservation.

Dertien, J. S., Negi, H., Dinerstein, E., Krishnamurthy, R., Negi, H. S., Gopal, R., et al. (2023). Mitigating human–wildlife conflict and monitoring endangered tigers using a real-time camera-based alert system. *Bioscience* 73, 748–757.

Dinerstein, E., Joshi, A. R., Hahn, N. R., Lee, A. T. L., Vynne, C., Burkart, K., et al. (2023). Conservation Imperatives: Securing the Last Unprotected Terrestrial Sites Harboring Irreplaceable Biodiversity. *Preprints*. doi: 10.20944/preprints202309.1827.v1.

Dinerstein, E., Joshi, A. R., Vynne, C., Lee, A. T. L., Pharand-Deschênes, F., França, M., et al. (2020). A "Global Safety Net" to reverse biodiversity loss and stabilize Earth's climate. *Sci. Adv.* 6, eabb2824.

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., et al. (2017). An ecoregion-based approach to protecting half the terrestrial realm. *Bioscience* 67, 534–545.

Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., et al. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography (Cop.).* 36, 27–46.

Duarte, D. P., Peres, C. A., Perdomo, E. F. C., Guizar-Coutiño, A., and Nelson, B. W. (2023). Reducing natural vegetation loss in Amazonia critically depends on the formal recognition of indigenous lands. *Biol. Conserv.* 279, 109936.

Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D., and Ramankutty, N. (2010). Anthropogenic transformation of the biomes, 1700 to 2000. *Glob. Ecol. Biogeogr.* 19, 589–606.

Enquist, B. J., Feng, X., Boyle, B., Maitner, B., Newman, E. A., Jørgensen, P. M., et al. (2019). The commonness of rarity: Global and future distribution of rarity across land plants. *Sci. Adv.* 5, eaaz0414.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., and Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* 202, 18–27.

Green, J. M. H., Burgess, N. D., Green, R. E., Madoffe, S. S., Munishi, P. K. T., Nashanda, E., et al. (2012). Estimating management costs of protected areas: a novel approach from the Eastern Arc Mountains, Tanzania. *Biol. Conserv.* 150, 5–14.

Hansen, M. C., Potapov, P. V, Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science (80-.).* 342, 850–853.

Hill, S. L. L., Arnell, A., Maney, C., Butchart, S. H. M., Hilton-Taylor, C., Ciciarelli, C., et al. (2019). Measuring forest biodiversity status and changes globally. *Front. For. Glob. Chang.* 2, 70.

Iacona, G. D., Sutherland, W. J., Mappin, B., Adams, V. M., Armsworth, P. R., Coleshaw, T., et al. (2018). Standardized reporting of the costs of management interventions for biodiversity conservation. *Conserv. Biol.* 32, 979–988.

IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. Gland, Switzerland.

IUCN World Conservation Congress (2021). 101 - Setting area-based conservation targets based on evidence of what nature and people need to thrive. in (Marseille). Available at: https://www.iucncongress2020.org/motion/101.

Kuempel, C. D., Chauvenet, A. L. M., and Possingham, H. P. (2016). Equitable representation of ecoregions is slowly improving despite strategic planning shortfalls. *Conserv. Lett.* 9, 422–428.

Locke, H. (2015). Nature needs (at least) half: a necessary new agenda for protected areas. *Prot. wild Park. wilderness, Found. Conserv.*, 3–15.

Margules, C. R., and Pressey, R. L. (2000). Systematic conservation planning. *Nature* 405, 243–253.
Mooney, C. Z. (1997). *Monte carlo simulation*. Sage.
Naidoo, R., and Iwamura, T. (2007). Global-scale mapping of economic benefits from agricultural lands: Implications for conservation priorities. *Biol. Conserv.* 140, 40–49.
Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., et al. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science (80-.).* 344, 1246752.
Pimm, S. L., Jenkins, C. N., and Li, B. V (2018). How to protect half of Earth to ensure it protects sufficient biodiversity. *Sci. Adv.* 4, eaat2616.
Pressey, R. L., Cabeza, M., Watts, M. E., Cowling, R. M., and Wilson, K. A. (2007). Conservation planning in a changing world. *Trends Ecol. Evol.* 22, 583–592.
Quick Response Fund for Nature (n.d.). Available at: www.quickrespondfund.org.
Shin, Y., Midgley, G. F., Archer, E. R. M., Arneth, A., Barnes, D. K. A., Chan, L., et al. (2022). Actions to halt biodiversity loss generally benefit the climate. *Glob. Chang. Biol.* 28, 2846–2874.
Shirk, A. J., Jones, G. M., Yang, Z., Davis, R. J., Ganey, J. L., Gutiérrez, R. J., et al. (2023). Automated habitat monitoring systems linked to adaptive management: a new paradigm for species conservation in an era of rapid environmental change. *Landsc. Ecol.* 38, 7–22.
Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., et al. (2020). Global priority areas for ecosystem restoration. *Nature* 586, 724–729.
Tsendbazar, N.-E., Tarko, A. J., Li, L., Herold, M., Lesiv, M., Fritz, S., et al. (2020). Copernicus global land service: Land cover 100m: Version 3 globe 2015-2019: Validation report.
Tulloch, V. J. D., Atkinson, S., Possingham, H. P., Peterson, N., Linke, S., Allan, J. R., et al. (2021). Minimizing cross-realm threats from land-use change: a national-scale conservation framework connecting land, freshwater and marine systems. *Biol. Conserv.* 254, 108954.
UNEP-WCMC and IUCN (2018). Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM). Available at: www.protectedplanet.net.
UNEP-WCMC and IUCN (2023). Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM). Available at: www.protectedplanet.net [Accessed April 6, 2023].
Venter, O., Magrach, A., Outram, N., Klein, C. J., Possingham, H. P., Di Marco, M., et al. (2018). Bias in protected-area location and its effects on long-term aspirations of biodiversity conventions. *Conserv. Biol.* 32, 127–134.
Waldron, A., Adams, V., Allan, J., Arnell, A., Asner, G., Atkinson, S., et al. (2020). Protecting 30% of the planet for nature: costs, benefits and economic implications.
Watts, M. E., Stewart, R. R., Martin, T. G., Klein, C. J., Carwardine, J., and Possingham, H. P. (2017). Systematic conservation planning with Marxan. *Learn. Landsc. Ecol. A Pract. Guid. to Concepts Tech.*, 211–227.
White, T. B., Petrovan, S. O., Christie, A. P., Martin, P. A., and Sutherland, W. J. (2022). What is the price of conservation? A review of the status quo and recommendations for improving cost reporting. *Bioscience* 72, 461–471.
Wolff, N. H., Visconti, P., Kujala, H., Santini, L., Hilbers, J. P., Possingham, H. P., et al. (2023). Prioritizing global land protection for population persistence can double the efficiency of habitat protection for reducing mammal extinction risk. *One Earth* 6, 1564–1575.
World Bank (2022). World Databank. World Development Indicators.
Zander, K. K., and Garnett, S. T. (2011). The economic value of environmental services on indigenous-held lands in Australia. *PLoS One* 6, e23154.
Zhang, R., Lu, Y., Adams, K., Sefair, J. A., Mellin, H., Acevedo, M. A., et al. (2021). A visual analytics framework for conservation planning optimization. *Environ. Model. Softw.* 145, 105178.