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2 Areas of high conservation priority for threatened terrestrial vertebrates are governed by novel ecological conditions

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12 **Abstract:** Over half of the terrestrial biosphere is exposed to highly novel conditions that differ from the historical state,
13 resulting from anthropogenic pressures such as climate change, floristic disruption, and defaunation. Highly novel con-
14 ditions result in unpredictable biodiversity outcomes, impacting the effectiveness of conservation and restoration actions
15 and the ability for threatened species to persist. Here, we quantify the extent to which areas of high conservation priority
16 intersect areas of high ecological novelty, focusing on the distribution of threatened terrestrial vertebrates. We use two
17 proxies for global conservation and restoration priorities, the IUCN Red List and the recent LIFE metric, to identify areas
18 where management actions would have the most effect. We then performed overlay analyses calculating the spatial co-
19 occurrence between these proxies and recent global data on novelty exposure. Species-rich areas of high conservation
20 and restoration value were exposed to highly novel conditions across all regions, but were concentrated in the tropics,
21 with Southeast Asia showing the highest novelty exposure. Birds exhibited the greatest spatial exposure, whereas am-
22 phibians had the highest number of threatened species experiencing highly novel conditions. Climatic novelty emerged
23 as the dominant driver underlying hotspots of threatened species exposed to novelty; however, amphibians were dispro-
24 proportionately exposed to floristic disruption. Finally, we detected strong spatial overlap between areas where conservation
25 and restoration would have the highest impact, concentrated across the tropics. Our results demonstrate that global con-
26 servation and restoration efforts are already governed by novel conditions across most of the biosphere, underscoring the
27 need for adaptive management informed by ecological novelty.

28 **Keywords:** anthropogenic change, climate change, conservation planning, defaunation, ecological novelty, novel eco-
29 systems, threatened terrestrial vertebrates

30 1. Introduction

31 In order to best protect the most vulnerable parts of the biosphere, it is critical to generate an understanding of how
32 threatened species are distributed, what types of processes are threatening them, and how these key threats are distributed
33 across their range (Allan et al. 2019, Nori et al. 2020, Harfoot et al. 2021). A large body of research has therefore focused

on identifying and prioritizing areas for conservation and restoration intervention (Etter et al. 2020), with the goal of identifying new protected area locations, maximizing the protection of different diversity facets, minimizing exposure to threats, and meeting international targets (Etter et al. 2020, Jung et al. 2021).

Current prioritization efforts have used a variety of data sources to define target regions for conservation (Brooks et al. 2006), ranging from studies focused on locating areas with high restoration or conservation potential (Eyres et al. 2025), to identifying restoration priorities located within high-risk ecosystems (Etter et al. 2020), or those that remain wild (Venter et al. 2018). As international targets often include spatial targets, such as the Global Biodiversity Framework target of conserving 30% of global land area, finding methods for scaling up protection have been critical (Robinson et al. 2024). One key resource for area prioritization has been the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (hereafter ‘IUCN Red List’), which provides assessments on the conservation status and distribution of over 100,000 species. In addition to providing spatial information on hotspots of threatened species, the IUCN Red List has been used to provide spatial information on the importance of different threats to species (Harfoot et al. 2021), monitor extinction risk (IPBES 2019, Butchart et al. 2025), and create metrics for understanding restoration impact on potential extinctions (Eyres et al. 2025).

An additional challenge for conservation and restoration policy has been the emergence of novel ecosystems – ecosystems with a set of biotic, abiotic, or social components outside of historical variation (Hobbs et al. 2006, 2013), arising from distributed and often indirect human agency but without ongoing direct management (Hobbs et al. 2014, Morse et al. 2014), and which continue to self-develop novel properties (Kerr et al. 2024): these are non-analogue Anthropocene ecosystems. This ecological novelty, the deviation of novel ecosystem components from a historical baseline (Kerr et al. 2024, Svenning et al. 2024b, Kerr et al. 2026), is already the predominant condition of the biosphere (Kerr et al. 2025) and poses a unique challenge for conservation prioritization: understanding the potential impacts of novelty on an ecosystem is difficult, as individual novel ecosystems may manifest both positive and negative biodiversity outcomes (Evers et al. 2018). Different novelty-generating processes lead to unpredictable diversity dynamics, potentially manifesting as “ecological surprises” (Williams and Jackson 2007). For example, the emergence of novel climate space has a range of potential ecosystem reassembly pathways (Wright et al. 2026), including scenarios with dramatic losses in ecosystem structure and function (Toth et al. 2026), whereas biotic novelty emerging from invasions and naturalisation of species drives shifts in community-level functioning (Garbowski et al. 2024) and stability (Campbell et al. 2022).

Governance and management in novel ecosystems require challenging perceptions of ecosystem states (Montana et al. 2024) and resolving translational mismatches between existing policy and rapidly changing ecological reality (Clement and Standish 2018). Conservation in ecologically novel conditions therefore needs to go beyond current initiatives (Thomas and Gillingham 2015, Duncanson et al. 2023), potentially requiring unorthodox interventions (Svenning et al. 2024b) or novel technological solutions (Volpe et al. 2024). Novel climatic conditions, for example, can be pre-empted by exploring how assemblages may change through the loss of key species (Toth et al. 2026), whereas the historic loss of functional space in the ecosystem can be mitigated through functional and trophic rewilding. With novel ecosystems in modern settings undergoing continuous change that is likely irreversible to past conditions (Perring et al. 2013, Higgs et al. 2014), much of conservation under highly novel conditions will require management of multiple simultaneous processes (Kerr et al. 2026), such as considering climate in rewilding choices (Cromsigt et al. 2018, Kloibhofer et al. 2025).

As a result, understanding where potentially vulnerable ecosystems are exposed to novel conditions is key for guiding and targeting conservation and restoration actions.

Current maps of threats to vulnerable nature do not account for exposure to novel ecological conditions, resulting in priority areas being placed in locations that do not match their historical conditions and potentially widening the disconnect between ongoing ecological research and realistic policy measures. This is especially relevant for wild and semi-wild areas with no direct human management. Recently, large-scale mapping of novel ecological conditions has taken place, with varying goals of mapping exclusively abiotic conditions (Williams et al. 2007, Ordonez et al. 2024), functional diversity of non-native species (Schittko et al. 2020), or a mix of novelty-generating processes (Radeloff et al. 2015, Ordonez et al. 2016, Kerr et al. 2025). Vitrally, key conservation management areas are already experiencing highly novel conditions, with protected areas across biomes exposed to the same level of ecological novelty as areas not currently protected (Kerr et al. 2025). Consequently, current action may not be sufficient for futureproofing and future targets may have to incorporate measures of ecological novelty (Trew et al. 2024).

In this context, we had two main aims: (1) to identify the extent to which areas with high conservation and/or restoration potential are experiencing novel conditions, and (2) to identify the key novelty-generating processes acting on these areas. We focus our analysis on terrestrial vertebrates (mammals, amphibians, reptiles, and birds), identifying hotspots as areas of concern where management decisions require careful consideration. We then combine our estimates with maps of conservation and restoration potential, discussing how potential interventions could be affected by highly novel conditions. By identifying key areas where nature is already vulnerable and likely to transform, we provide a first look at how global conservation initiatives may be affected by novel conditions.

2. Methods

2.1 Global Conservation Priorities

We used two main sources of information as proxies for global conservation priorities. Firstly, we used the spatial distribution of threatened species to generate a measure of where the most vulnerable parts of nature are located. We downloaded data for all species of mammals, amphibians, and reptiles currently assessed by the IUCN Red List (IUCN 2023), in addition to the data on birds from BirdLife International (Birdlife International and Handbook of the Birds of the World 2024). We excluded species which were data deficient (DD), extinct (EX), or extinct in the wild (EW). Following other studies (Huais et al. 2025), we created a binary classification of “threatened” using species who were classified as vulnerable (VU), endangered (EN), and critically endangered (CR). We present analysis in the main text using the binary “threatened” classification and provide supplementary analysis using the individual classifications.

For additional validation and comparison, we used a recent map of 20 hotspots of threatened vertebrates (Huais et al. 2025). These hotspots were calculated using richness and endemism together, prioritizing species that were of high importance, and represent a core fraction (~27%) of traditional hotspot area. Because overlap between the uncovered hotspots and protected areas is low (Huais et al. 2025), our analysis adds context on how rising ecological novelty may matter in high-priority spaces for future protection.

Secondly, we used the LIFE (Land-cover change Impacts on Future Extinctions) metric (Eyres et al. 2025) to estimate the potential impact of restoration and conservation actions. LIFE quantifies the expected change in extinctions caused

107 by either the conversion of natural vegetation to agriculture (normally an increase in the likelihood of extinction) or the
108 restoration of farmland to natural habitat (normally a decrease in the likelihood of extinction). In addition to using the
109 restoration metric as a measure of potential restoration impact, here we interpret the conversion metric as the potential
110 impact of conservation actions: by not converting the land to agriculture, potential extinctions are prevented. Therefore,
111 areas that score highly in either metric are where management actions should occur and may be compromised by highly
112 novel conditions.

113 Finally, to get an understanding of how current protection and conservation measures are distributed, we used the world
114 database of protected areas (UNEP-WCMC and IUCN 2024). Protected areas represent a wide range of potential protec-
115 tion and conservation objectives, and therefore we split the database into four categories: Category I, which combines
116 IUCN category Ia (strict nature reserve) and Ib (wilderness area); Category II (national park); Category III (natural mon-
117 ument or feature); and Category IV (habitat or species management area). For the purposes of our analysis, we excluded
118 any areas with other categorisations, areas not categorised, and marine protected areas.

119 2.2 Novelty Exposure Data

120 To quantify ecological novelty, we used recently published global maps of novel ecological conditions from Kerr *et al.*
121 (2025). Three novel processes were quantified: i) climate novelty (most recent 300-year period where temperature and/or
122 precipitation was outside the modern range), ii) mammal defaunation (relative change in logged species richness and
123 logged maximum body size for mammals since the Pleistocene, when compared to expected present-natural ranges), and
124 iii) floristic disruption (change in native plant communities from land use, combined with the proportion of non-native
125 alien species). We used the novelty scores both as a continuous variable and also a binary delimitation of novel/not novel
126 following the 0.33 cut-off from Kerr *et al.* (2025) – this represents a cell which is, at minimum, maximally novel for one
127 process and most likely highly novel in two of the three processes.

128 Each process represents a different temporal scale and has different impacts on modern ecosystem structure, so we analyse
129 them both separately and as a combined metric of novelty exposure. Specifically, climate novelty measures centennial-
130 to millennial-scale impacts of climate change, mapping areas that have experienced increasing climate shifts and face
131 risks of ecological breakdown (Flores et al. 2024, Brando et al. 2025). Mammal defaunation reflects longer term legacies
132 of past human impacts, highlighting ecosystems which have lost key functions (Svenning et al. 2024a, Czyżewski et al.
133 2026). Floristic disruption drives much more rapid community change, with impacts of both rapid land use change and
134 invasion dynamics on the scale of decades (Gallardo et al. 2024, Roy et al. 2024, Moi et al. 2025). To represent the
135 different temporal scales and impacts of each measure, we use differing cut-offs for a cell being considered novel, rather
136 than universally apply the 0.33 cut-off from above. For climate, we used a cut-off of 0.66, representing a modern climate
137 space that has only been experienced since the start of the Holocene (the average time over which the modern range of
138 temperature and precipitation has been experienced is 7000 years). For defaunation, we used a cut-off of 0.5, representing
139 an average loss of half of the mammalian species pool in both species' richness and body size. For floristic disruption,
140 we used a cut-off of 0.25, representing a community that, on average, has lost 25% of native abundance and is made up
141 of 25% non-native species (or, in extreme cases, has lost 50% of native abundance or is made up of 50% non-native
142 species).

We note that the novelty processes mapped by (Kerr et al. 2025) have conceptual and methodological overlap with the conservation and restoration measures we use in this study. Specifically, mammal defaunation novelty is derived from loss of mammal richness and body size relative to present-natural conditions (Faurby et al. 2018); which then has mammal richness overlaid as a measure of threat. Additionally, floristic disruption uses metrics derived from land-use layers, and the LIFE metric is built from IUCN Red List range data and land-cover maps. Although this means that some of the reported overlap will be structural, our analysis represents an exploration of the key areas in which ecological conditions have shifted from historical norms and therefore areas which are identified will still be of critical conservation importance. Our results, in particular the mammalian distributions, should be interpreted with this overlap in mind, and a deeper exploration of other novelty-generating processes in a particular area would be a critical step before any conservation action begins (Kerr et al. 2026).

2.3 Spatial Mapping and Analysis

Firstly, we calculated and mapped the spatial co-occurrence of high ecological novelty and high local richness of threatened species using the workflow for mapping threats as done by Harfoot et al. (2021). We created three risk maps for each terrestrial vertebrate class by weighing their richness in each cell by the novelty score for each individual novelty-generating process. We converted these into binary maps by retaining only cells in the 90th quantile to map global hotspots of threat, presenting both maps of individual taxonomic groups and a summed layer across taxa to show the relative impact in each cell. We then mapped the relative impact across protected area status and category, counting the frequency of relative impact score across different categories of protection to estimate how much novelty impact was already covered by conservation actions.

Second, we quantified the distribution of novel conditions experienced by each species across its range. For each species, we extracted the novelty exposure for each cell that was more than 50% overlapping with an occupied cell. We then identified species that experienced ecological novelty greater than 0.33 across more than half their range, as well as the mean novelty exposure across their range. We repeated this for each novelty-generating process, using the specific process threshold, to identify the key global and regional processes that impact vulnerable species. For a comparison point, we quantified the same metrics for species which were not categorised as threatened (i.e. has an IUCN Red List category of “least concern” or “near threatened”). We then quantified the novel conditions within each of the 20 hotspots of threatened vertebrate species from (Huais et al. 2025). For each hotspot, we extracted the novelty values for each novelty-generating process in each cell that was more than 50% overlapping with a hotspot polygon.

Third, we repeated the risk map analysis on the LIFE metrics for both conservation and restoration. We used the unmodified LIFE scores for each side and multiplied them by the novelty score for each of the three novelty-generating processes. In the same way as above, we kept the 90th quantile to create our maps; however, because the LIFE metrics, particularly the restoration metrics, are heavily left-skewed, we repeated this analysis in two ways: first by taking the 75th quantile instead of the 90th; second, by first log-transforming the metric before carrying out any calculations.

We conducted all analysis in R Version 4.4.1 (R Core Team 2025), leaning heavily on the tidyverse package suite (Wickham et al. 2019). Colour palettes were generated using the scico package (Pedersen and Crameri 2023). Spatial analysis was conducted using the packages terra (Hijmans et al. 2026) and sf (Pebesma 2018).

179 3. Results

180 3.1 Global Hotspots of Novelty Across Threatened Vertebrates

181 Hotspots of the highest threatened species richness and ecological novelty were globally distributed and concentrated in
182 the tropics, with spatial differences in both the hotspot distributions and relevant novelty-generating processes between
183 vertebrate groups (Figure 1). Mammals had a broad spatial range of hotspots exposed to novelty-generating processes,
184 mostly concentrated in the southern hemisphere. Floristic disruption was the main novelty-generating process affecting
185 mammals, being apparent in both the Northern and Southern Hemispheres, while defaunation and the interface between
186 climate and defaunation had a more pronounced impact in the Southern Hemisphere, mainly in the Amazon basin and
187 across Southeast Asia. Amphibians (Figure 1b) had hotspots across a smaller area than other groups, with hotspots mixed
188 among all three processes and concentrated in western Europe, western Central America, and East Asia. Reptiles (Figure
189 1c) experienced high floristic disruption across small patches of South America and Australia and climate disruption in
190 central Africa but had hotspots with all three novelty-generating processes across most of the range. Birds (Figure 1d)
191 had the highest spatial exposure of any group, differing from mammals by large areas of North America and Central Asia
192 exposed to floristic disruption and defaunation and having areas in South America and the Indo-Himalayan region as
193 hotspots of all three processes.

194 When all four maps were overlayed and the number of hotspots was tallied, the region with the highest relative novelty
195 impact was in Southeast Asia (Figure 1f). Areas of high relative novelty impact tended to be outside of protected areas,
196 with under 5% of cells containing at least one hotspot outside of a protected area in IUCN protection categories I, II, III,
197 and IV (Supplementary Table 1). Areas of very high relative novelty impact (10 and 11 hotspots located within a cell)
198 were rare globally, however 22% were located within category II protected areas.

199 3.2 Novelty hotspots differ between threat categories

200 When mapping individual categories of threatened species, the broad spatial distribution of hotspots was similar to the
201 overall pattern (Supplementary Figures 1-3). For species classified as “vulnerable” (Supplementary Figure 1), mammal
202 and reptile distributions were largely similar to the pattern for all threat categories, with mammals having a slightly larger
203 hotspot range in Amazonia and reptiles showing a larger central African hotspot driven almost exclusively by climate
204 novelty. Vulnerable amphibians had hotspots matching their overall pattern, with a reduced hotspot area in South Amer-
205 ica. Vulnerable birds had a much wider range of high novelty hotspots, with a notably larger hotspot of defaunation and
206 floristic disruption novelty across most of North America and for all novelty drivers across parts of central South America.
207 Endangered species (Supplementary Figure 2), in contrast, showed different hotspot distributions to the global pattern,
208 with a much narrower hotspot area in both North and South America. Endangered mammals have exposure that largely
209 mirrors the pattern for mammals across all threat categories, with exposure to floristic disruption across central North
210 America and combinations of climate and defaunation across Southeast Asia, except in Africa, where exposure is reduced
211 in area and driven almost exclusively by climate. Endangered amphibians have a very low hotspot area globally, with the
212 only area of note driven by floristic disruption in eastern Australia, and reptiles are spatially exposed to all processes
213 almost exclusively in the Indo-Himalayan region. For critically endangered species (Supplementary Figure 3) there were
214 no major hotspots for any taxonomic group in mainland North America, with small exposure for mammals, amphibians,

215 and reptiles in South America and the Caribbean. Critically endangered mammals were exposed to climate across most
216 of Central Africa, with exposure to defaunation novelty in Northeastern Africa and floristic disruption in Southern Africa,
217 to climate and defaunation across Southeast Asia, and to floristic disruption in Central Asia. Critically endangered am-
218 phibians had a very small exposure area in Northwestern South America, and reptiles were exposed to all three processes
219 in different combinations almost exclusively across Southeast Asia. Critically endangered birds had the widest exposure
220 of any critically endangered group, with exposure to all three processes across the Indo-Himalayan region and East Africa,
221 with additional exposure to each individual process across the African continent, defaunation novelty across the Indian
222 subcontinent, and climate/defaunation in Southeast Asia.

223 **3.3 Amphibians are disproportionately exposed to novelty**

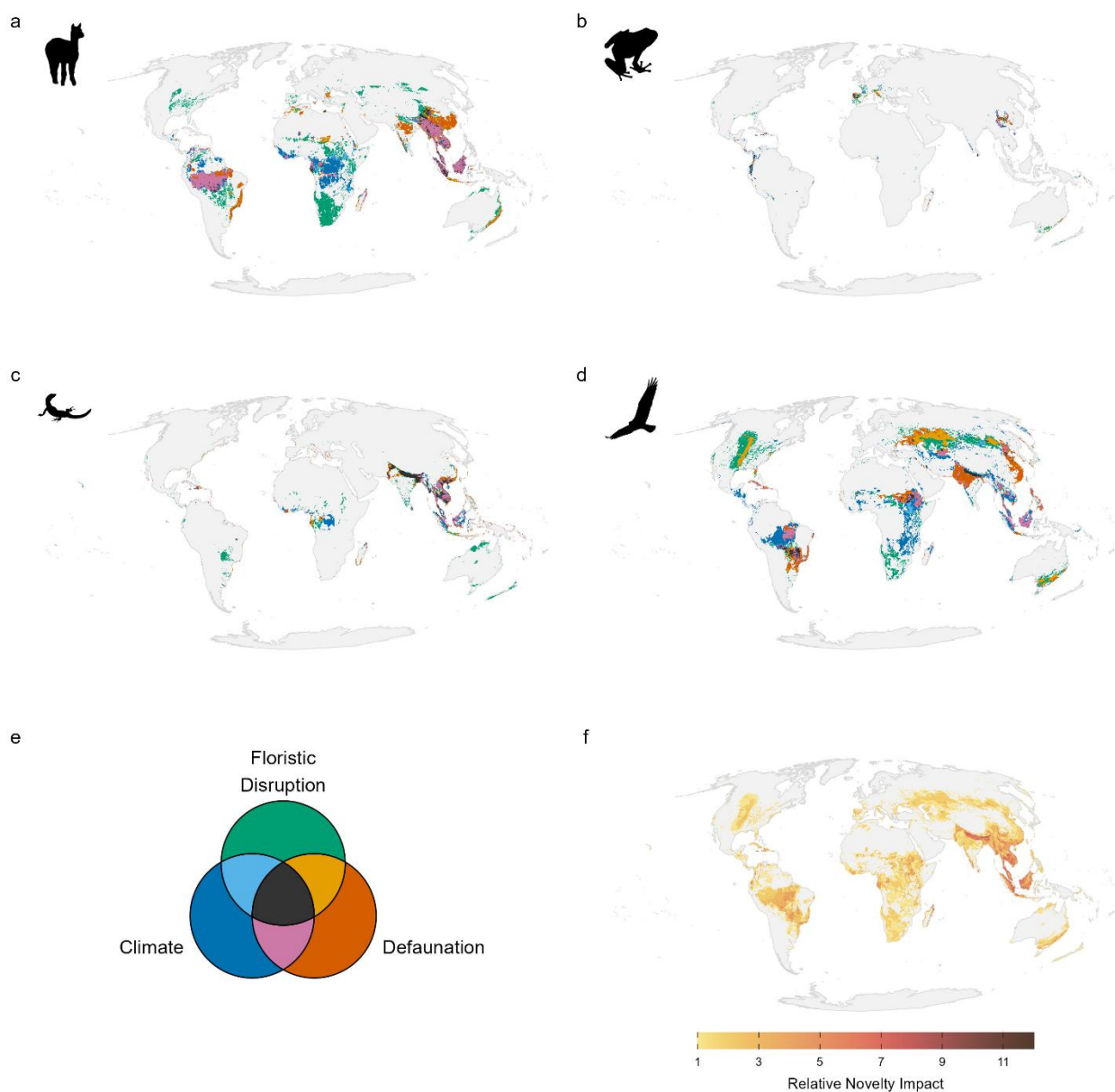
224 Using a novelty cut-off of 0.33 as an indicator of highly novel conditions, exposure across individual species ranges
225 varied by taxonomic category, with threatened amphibians having the highest proportional exposure (Figure 2). A mean
226 novelty of greater than 0.33 across the range of threatened species is experienced by 35% of mammals, 57% of amphibi-
227 ans, 41% of reptiles, and 38% of birds. When split into categories of threat, the percentage of species exposed in each
228 category varied between 30 and 45% for mammals, reptiles, and birds (Figure 2a), however amphibian exposure was
229 between 55% (vulnerable and endangered) and 64% (critically endangered). When novelty exposure is not measured as
230 a binary, the frequency of mean novelty for a species did not vary greatly between taxonomic groups (Figure 2b). For
231 individual novelty-generating processes, exposure to climate novelty (Supplementary Figure 4, calculated using a cut-off
232 of 0.5) was lower for mammals (23-24%), reptiles (24-36%), and birds (21-24%), with exposure for amphibians lower
233 than that for all processes but around double that of other taxonomic groups (45-46% for vulnerable and endangered, 59%
234 for critically endangered). Exposure to defaunation novelty (Supplementary Figure 5, calculated using a cut-off of 0.5)
235 was much lower for all taxonomic groups, varying between 20 and 30% for all groups other than critically endangered
236 birds (16%), with reptiles having the highest percentages of species exposed (24% for vulnerable, 30% for endangered,
237 and 28% for critically endangered). Floristic disruption novelty (Supplementary Figure 6, calculated using a cut-off of
238 0.25) was very low for mammals (4-6%), but high for reptiles (62% for vulnerable, 66% for endangered, 67% for critically
239 endangered) and birds (75% for vulnerable, 70% for endangered, 68% for critically endangered). Amphibians had a very
240 high exposure to floristic disruption, with over 90% of threatened species exposed at 0.25 or above.

241 In comparison, species that were not categorised as threatened (i.e. were categorised as “least concern” or “near threat-
242 ened”) varied in their exposure from threatened species (Supplementary Figure 7). “Near threatened” species generally
243 had a lower exposure, between 32 and 40% experiencing a mean novelty greater than 0.33 across their range. “Least
244 concern” species had a similar exposure to threatened species for mammals (39%), reptiles (47%) and birds (49%), and a
245 lower overall percentage of amphibian species (51%).

246 **3.4 Climatic novelty drives regional hotspot exposure**

247 The novelty exposure of threatened-species hotspots was generally around 0.33, with ten hotspots having a median expo-
248 sure greater than 0.33 (Figure 3), reflecting the global distribution of novelty. Regional hotspot exposure was highest
249 across the Americas and generally lower in the Asia-Pacific, although the hotspots with the highest median exposure were
250 the “Caribbean” and “Western and Southern Australian Forests and Scrubs”. Hotspots had the highest exposure to climate

251 novelty (Supplementary Figure 8), with the highest in the Caribbean Islands and Mesoamerica, and low exposure to
 252 defaunation (Supplementary Figure 9) and floristic disruption (Supplementary Figure 10). When broken into these indi-
 253 vidual processes, the exposure was generally below each respective cut-off (0.5 for climate and defaunation, 0.25 for
 254 floristic disruption).



255
 256 Figure 1: Threatened terrestrial vertebrate groups are globally exposed to different novelty-generating processes across
 257 space. For each terrestrial vertebrate group, the number of threatened species (IUCN category of endangered, vulnerable,
 258 or critically endangered) in each cell is multiplied by the novelty score (0-1) for each of the three novelty-generating
 259 processes (climate, mammal defaunation, floristic disruption). The top 90th quantile for each layer is then overlaid and
 260 plotted for (a) mammals, (b) amphibians, (c) reptiles, and (d) birds. (e) shows the legend for panels a-d, with areas of
 261 overlap showing cells that are scored in the 90th quantile for multiple processes. (f) shows the relative novelty exposure
 262 for each cell, counting the number of times that a cell is present in the 90th quantile of any analysis; for example, a cell

score of 4 would be in the top 90th quantile for four pairs of taxa and processes (the highest possible score would be 12, meaning that a cell would be a hotspot for all four species groups and exposed to high novelty in all three included dimensions). Maps broken down by IUCN threat category are shown in Supplementary Figures 1-3.

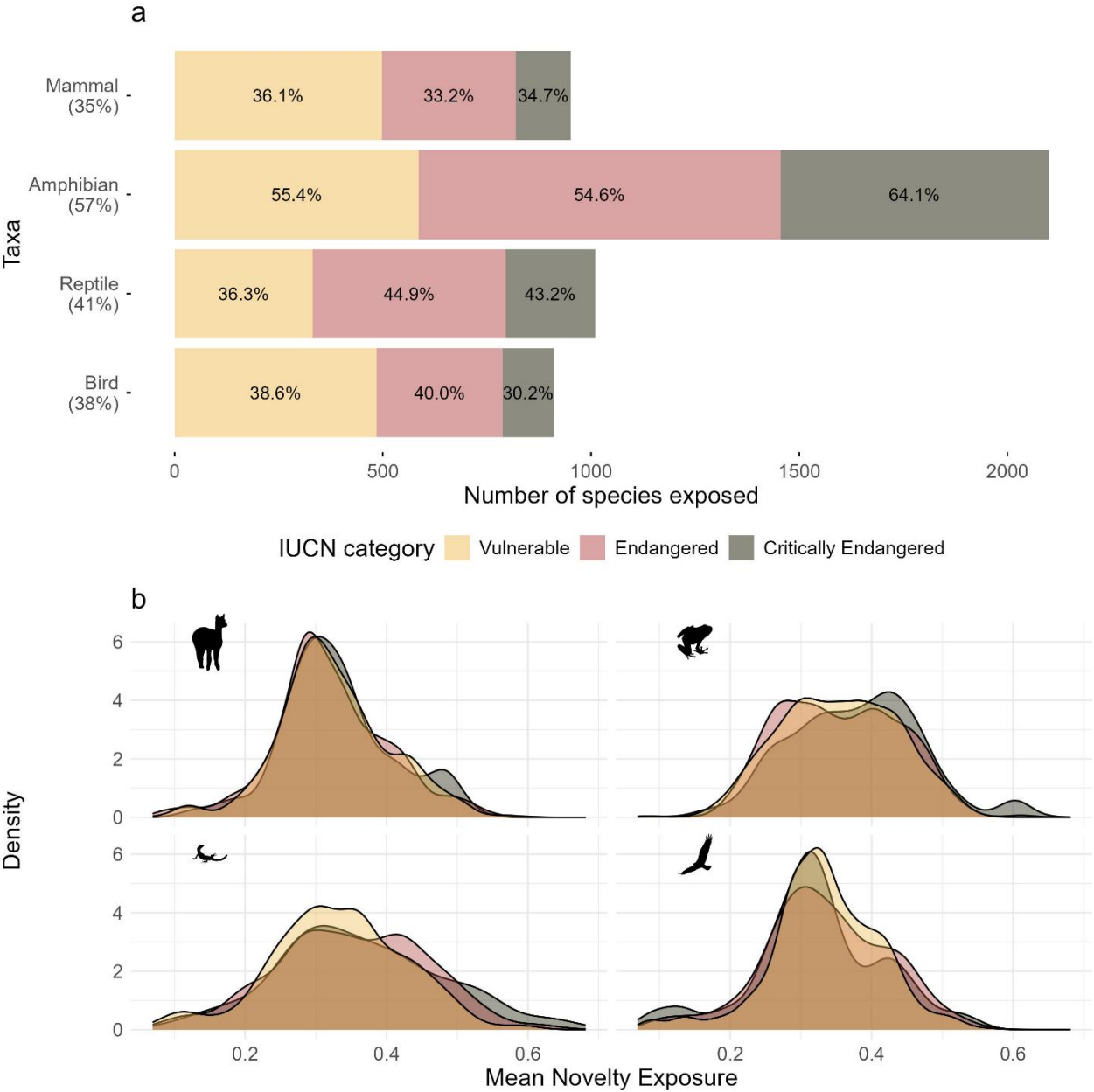


Figure 2: Threatened terrestrial vertebrates are exposed to highly novel conditions across their range. (a) The number of species exposed to highly novel conditions (a novelty score of greater than 0.33 across more than half their range) is plotted for threatened species, within IUCN categories of endangered (EN), vulnerable (VU), or critically endangered (CR) of mammals, amphibians, reptiles, and birds. The plot is stacked and split by threat category, with the text inside the bar sections showing the percentage of species within that taxon and category that are exposed. Percentages displayed in the y-axis labels show the percentage of all species in that taxonomic group that are exposed. Across all taxonomic groups, roughly one third of threatened species are living in highly novel conditions. Amphibians have the highest overall exposure, with over half of threatened amphibian species across categories exposed for over half their range and almost

276 two-thirds of critically endangered amphibians living in highly novel conditions. In (b) the mean novelty exposure across
277 each species' range is plotted, again split by taxa and plotted with categories overlapped. Although there are only very
278 small differences between categories and taxa, most species are exposed to a high mean novelty across their range.

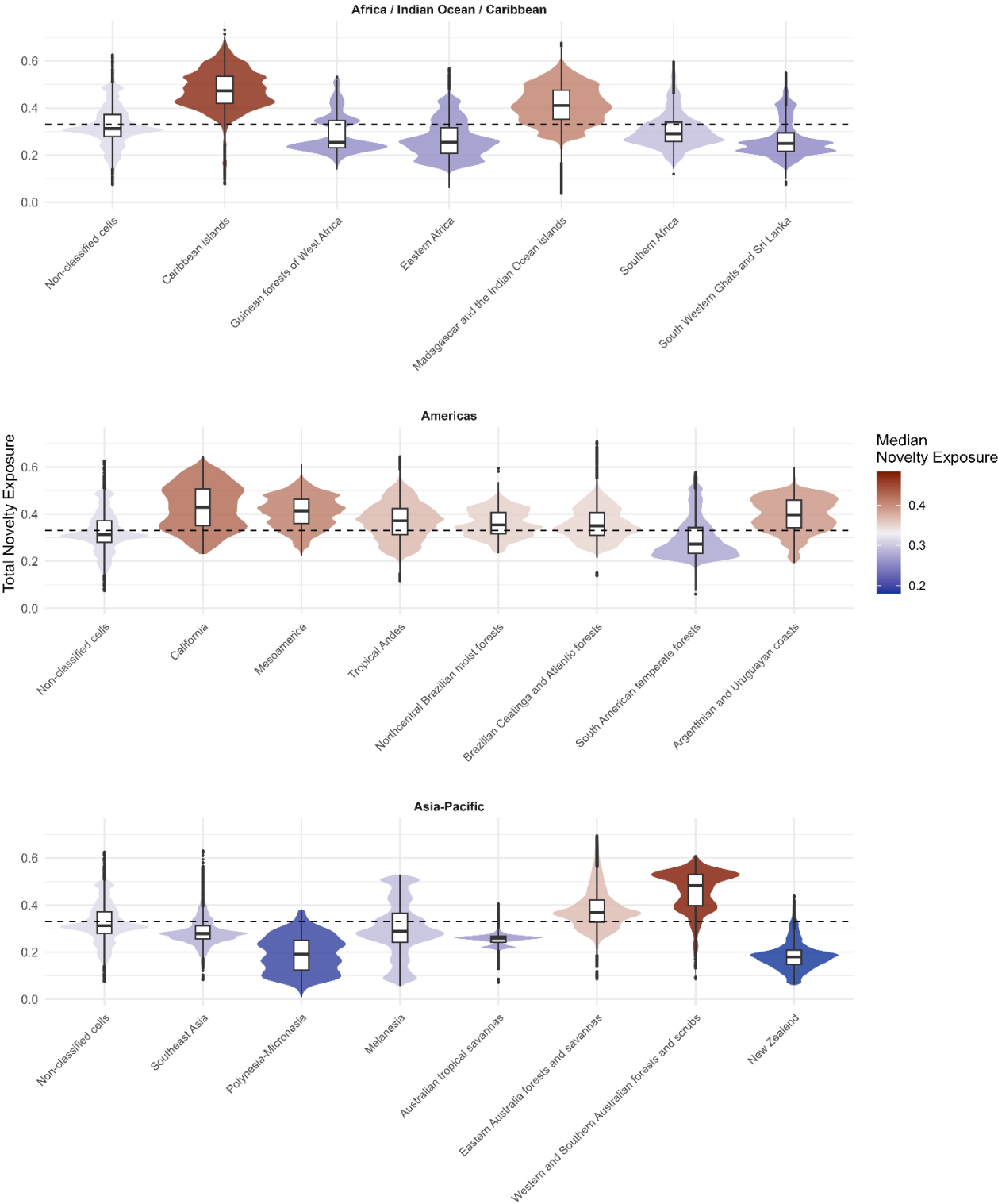
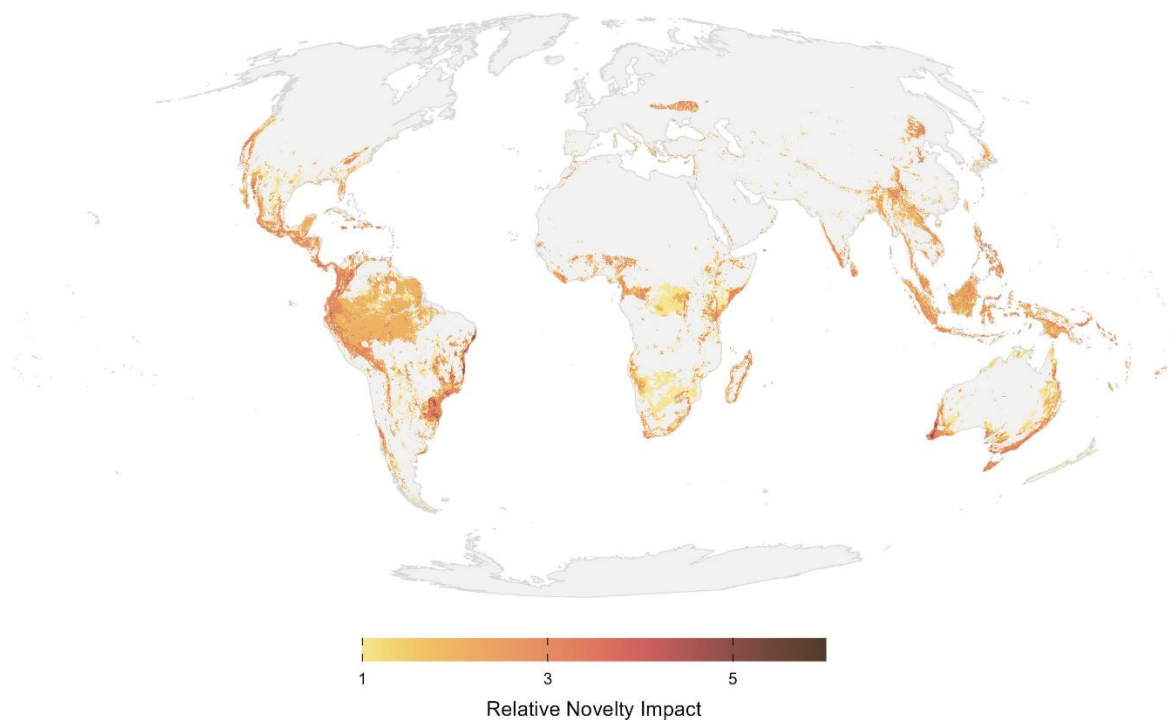


Figure 3: The total exposure of novelty-generating processes varies between hotspots of threatened vertebrates, with hotspots in the Americas generally located in highly novel areas. Within each hotspot, identified using an existing map of threatened vertebrate species hotspots (Huais et al. 2025), we extracted values for each novelty-generating process. Colour scaling of the violin plots is related to the median novelty exposure across the hotspot, with darker red colours representing hotspots that are higher than 0.33 (the cut-off for high novelty used here, marked by the horizontal dashed line) and darker blue colours representing those with much lower novelty than 0.33. The midpoint of the colour scale (light grey) is set to 0.33. The overlaid boxplot shows the median novelty value as a horizontal line. Hotspots are sorted into panels based on broad arbitrary geographical areas for presentation reasons: (a) the Americas, (b) Southeast Asia and Australasia, and (c) the Caribbean and Africa. The novelty-generating processes for areas outside hotspots are shown on the far left of each panel (“Non-classified cells”). Individual novelty generating processes are shown in Supplementary Figures 8-10.

3.5 Global Conservation Priorities

Hotspots of high ecological novelty and the LIFE metric, representing the either restoration or conservation actions having the highest impact, were concentrated across the tropics, coastal Australia, Madagascar, southern North America, and Eurasia (Figure 4). When broken into individual maps of conservation and restoration potential, the pattern can largely be explained by widespread overlap between conservation potential, denoted as areas where there is the greatest increase in extinctions if the remaining natural land were converted to agriculture, and ecological novelty (Supplementary Figure 11a). Specifically, there is exposure to high climatic novelty in Central Africa, floristic disruption across Southern Africa, coastal Australia, and parts of central North and South America, and a combination of climate novelty and defaunation across central Amazonia and Southeast Asia. Hotspots of conservation potential and all three processes were concentrated along the western coastline of South America and, additionally, throughout Southeast Asia. In contrast, very few areas with high restoration potential, denoted as areas where there is the greatest reduction in extinctions if the agricultural land was converted to natural habitat, were simultaneously marked as novelty hotspots (Supplementary Figure 11b). Hotspots for restoration potential were exposed to all three novelty-generating processes and were located on the eastern coastline of South America, Central Africa, coastal southern Australia, East Asia, and East Europe.

When the threshold for a hotspot was lowered to the 75th percentile, the area covered by each novelty-generating process increased (Supplementary Figure 12). Most areas exposed to one or two novelty-generating processes are also exposed to all three, covering most of Southern and Eastern Africa, South and Central America, coastal North America, and Southeast Asia. Floristic Disruption hotspots are now also present in central Australia, and climate hotspots now cover a wider area on the African continent. The area of restoration potential has slightly increased, in the same regions as in the higher cut-off, with additional areas in Madagascar and southern North America also exposed to all three processes. At a cut-off of the 50th percentile (Supplementary Figure 13) most of the terrestrial surface was marked as a hotspot of conservation potential and all three novelty-generating processes, with only areas in the northmost part of the Northern hemisphere not marked as having high potential. The area of restoration potential also expanded, with areas exposed to all three processes broadly across South and Central America, Central and Northern Africa, Madagascar, Southeastern Australia and Southeast Asia.



316

317 Figure 4: The global overlap between high ecological novelty and areas of high conservation priority and high restoration
 318 priority. Here, conservation and restoration priority are defined using the LIFE index (Eyres et al. 2025), which measures
 319 the expected change in extinctions based on converting all natural land into agriculture (and therefore the potential impact
 320 of conservation, see Methods) or by restoring all agricultural land into natural habitat (and therefore the potential impact
 321 of restoration). The LIFE index in each cell is multiplied by the novelty score (0-1) for each of three novelty-generating
 322 processes (climate, mammal defaunation, floristic disruption), with the top 90th quantile for each layer overlayed and
 323 plotted. The map shows the relative novelty impact for each cell, counting the number of times that a cell is present in the
 324 90th quantile of any analysis, for example a cell score of 4 would be in the top 90th quantile for four pairs of LIFE index
 325 and process. Individual overlap maps for conservation and restoration potential are shown as Supplementary Figure 11.
 326 Maps of global overlap using quantile cut-offs of 75 and 50 for the LIFE layers are shown in Supplementary Figures 12
 327 and 13.

328 4. Discussion

329 Ecological novelty is widespread across the areas where conservation and restoration efforts are concentrated. Because
 330 novel conditions weaken the predictive value of historical baselines, this exposure matters not only as an additional threat,
 331 but also as a source of deep uncertainty about how interventions will perform.

332 Threatened species are exposed to high ecological novelty

333 Our results show that multiple facets of conservation are already experiencing high levels of ecological novelty – includ-
 334 ing the exposure of threatened vertebrates. Exposure varied spatially for the various novelty-generating processes: floristic
 335 disruption was a prominent factor in both the Northern and Southern Hemispheres, across vertebrate groups but most

336 prominently for mammals and birds. Notably, as both groups are strongly dependent on certain vegetation states – both
337 structurally and trophically – the higher prevalence of floristic disruption may create additional vulnerability by affecting
338 vegetation structure and composition in their core habitats (Osborne et al. 2018, Matuoka et al. 2020). Climate novelty
339 was most prominent in regions projected to experience the largest climatic anomalies (Ordóñez et al. 2024). The combi-
340 nation of all novelty-generating factors was prominent for all vertebrate groups, especially reptiles and birds, in Southeast
341 Asia, including the Himalayan mountain range. Mountainous areas are highly biodiverse with high densities of narrow-
342 ranged (and thus endemic) species (Rahbek et al. 2019). This make such areas particularly vulnerable to ecological nov-
343 elty, as novel climate envelopes supporting threatened species endemic to mountainous regions are unlikely to arise within
344 their range, making them susceptible to novel conditions in which they might not persist.

345 Across our analyses, amphibians were the group with the lowest spatial extent of novelty exposure hotspots (Figure 1)
346 but the highest levels of novelty across individual species ranges (Figure 3, Supplementary Figures 4-6) – particularly to
347 floristic disruption, with over 90% of threatened amphibians exposed to high levels of non-native plant species and/or
348 reduced native intactness. Mammals and birds, by contrast, had the largest spatial extent of hotspots (Figure 1, Supple-
349 mentary Figures 1-3), but lower exposure at the species level (Figure 2, Supplementary Figures 4-6). For example, mam-
350 mals had large hotspots of floristic disruption across large areas of North America but low exposure at the species-level,
351 with under 10% of threatened species exposed to high floristic disruption across their range.

352 Our maps show similarities to published maps of threats to terrestrial vertebrates (Harfoot et al. 2021), highlighting that
353 the main regions exposed to anthropogenic threats such as logging, pollution and expansion of agriculture overlap with
354 conditions that will shift ecosystems into new states. Unlike the threat measures included in these other analyses, which
355 have directly antagonistic effects on the species that live with them, the novelty-generating processes we measure here
356 do not represent a direct positive or negative impact on an individual species. The exposure of an area to highly novel
357 conditions cannot be directly interpreted as a risk to the species living there. Instead, the individual novelty results should
358 be interpreted with the future in mind – how does each novelty-generating process lead to changes in the ecosystem, and
359 how could this impact the vulnerable parts of that system? For each novelty-generating process this answer will be dif-
360 ferent, both for the direct impact of the novelty and, just as importantly, the timescale on which it acts. For example, areas
361 with vulnerable species exposed to floristic disruption may need restoration interventions much sooner than those exposed
362 to climatic novelty, as this process happens at much faster rates. By the same token, the actual ecological effects of novel
363 conditions as defined here remain poorly understood and are changing at speed, and should therefore be a key research
364 priority

365 **Conservation areas are widely exposed to novel conditions**

366 In our analyses, we identified broad areas of the biosphere which are both highly novel and have high conservation
367 potential (Figure 4a). The majority of areas identified were exposed to a combination of climate and defaunation, partic-
368 ularly across South America and Southeast Asia, which had areas additionally exposed to floristic disruption - suggesting
369 potentially high environmental mismatches for threatened species in these regions. The broad overlap between areas of
370 high conservation value and areas exposed to highly novel conditions can generally be interpreted on a conservation-
371 prioritization spectrum, representing both risk and opportunity. Areas with coexisting high conservation value and high
372 novelty exposure remain a priority for conservation as they retain high ecological value, but their high ecological novelty

373 means conservation outcomes may be particularly unpredictable over time, making them a priority for adaptive conser-
374 vation management and close monitoring.

375 In contrast, we found relatively few areas that were highly novel and had high restoration potential (Figure 4b). This
376 limited spatial overlap between may indicate that the areas of greatest restoration impact currently lie in comparatively
377 less novel regions. This should be treated cautiously, given the strong skew in the LIFE restoration layer (see Methods),
378 and it would be unsafe to assume ecological stationarity in a rapidly changing biosphere. This highlights one of the biggest
379 ongoing challenges persisting in restoration ecology; predicting the outcome of larger restoration activities emerging
380 across multiple scales, as opposed to singular interventions, for which impacts can more easily be assessed (Bullock et
381 al. 2022, Volpe et al. 2024). Adaptive management approaches are commonly implemented on a site-scale (Gann et al.
382 2026), but the level of upscaling currently needed to comply with global restoration and conservation pledges, such as
383 the Kunming-Montreal Global Biodiversity Framework (CBD 2022) and the Bonn Challenge (IUCN 2020) calls for
384 biome-scale and trans-boundary interventions (Mason et al. 2020).

385 **What do conservation and restoration look like in a novel biosphere?**

386 Anthropogenic activities have already radically altered the terrestrial biosphere, transforming more than half of all land
387 surfaces into areas of high ecological novelty (Kerr et al. 2025). The global expansion of novel ecosystems will likely
388 continue under all projected possible scenarios of climate change, population growth, and land-use intensification (Or-
389 donez et al. 2024). Global upscaling of conservation and restoration considering the intercept between threatened species
390 distributions and novelty generating processes is therefore of utmost significance.

391 Conservation and restoration both currently stand at a challenging crossroad, having to tackle the increasing emergence
392 of novel ecosystems while also considering interventions that may result in states, organisms and processes without his-
393 torical precedent (Volpe et al. 2024). According to our results, a large proportion of areas with high conservation priority
394 are currently exposed to a novelty index of 0.33 or above, agreeing with the results of Kerr et al. (2025) who found that
395 an extensive number of currently protected areas and key biodiversity areas are exposed to ecological novelty. This im-
396 plies that threatened vertebrate species may face synergistic threats or open uncertainties: on top of direct threats such as
397 habitat loss, overexploitation, and conflicts with human land use, their remaining ranges are situated in regions where
398 ecological conditions are shifting into unprecedented states that have mixed outcomes for biodiversity and ecosystem
399 function (Doley and Audet 2013, Collier 2015, Evers et al. 2018). This calls for improved conservation frameworks that
400 account for emergent ecological novelty. Our results can aid in conservation prioritization by expanding traditional frame-
401 works focusing on species richness and endemism, to spatial targeting of threatened species vulnerability, thus highlight-
402 ing emerging hotspots of extinction, loss of function, or community restructuring. Areas containing vulnerable species
403 that are exposed to high ecological novelty should gain high-risk priority status, because novel ecological conditions can
404 undermine the environmental relationships on which these species depend, reducing the likelihood of persistence without
405 intervention.

406 Our results show that, across taxonomic groups, a third of all threatened terrestrial vertebrate species face highly novel
407 conditions. Between 30-64% of all vertebrate species in the Red List-category “critically endangered” are exposed to high

novelty scores. Taken together, these results point beyond habitat degradation towards systemic disruption of the conditions defining species' realised niches. In other words, many critically endangered vertebrate species will experience shifts in their realized niche, and, without aid, go extinct (Scheele et al. 2017). Most vertebrate species are dependent on appropriate dispersal corridors, directly for migration and access to resources (Gilbert-Norton et al. 2010) and indirectly for maintaining genetic diversity (Amos et al. 2012). With projected climate change, dispersal corridors are predicted to become narrower or disappear entirely (Zhu et al. 2022), meaning that threatened vertebrates might become “trapped” in highly novel conditions with limited dispersal activity. In such cases, species conservation will require active interventions, such as assisted migration (Hällfors et al. 2017). This is particularly the case for isolated species in areas experiencing habitat loss, and consequently low connectivity, such as reptiles and amphibians (Tan et al. 2023); the two groups of vertebrates with the highest exposure to novelty according to our results. In the context of adaptive management, many species of vertebrates are predicted to experience polewards distributional shifts (Virkkala and Lehtikoinen 2014, Sinervo et al. 2024), meaning that new suitable areas for conservation may thus consequently emerge in areas currently unsuitable.

Restoration and conservation activities traditionally rely on composition-based definitions of ecosystem integrity that assume stable reference states and focus on native species (Gann et al. 2026). This is also the case for the LIFE-metric, which assumes that heavily modified agricultural lands can be restored to a historical baseline of naturalness. Our results, revealing high novelty exposures of a large majority of currently threatened vertebrate species-ranges, suggest that frameworks solely using historical baselines as a reference for restoration goals may fail entirely, as these ignore novel conditions and resulting future ecosystem functionality and resilience. These findings support recently proposed shifts in restoration and conservation toward frameworks that focus on maintaining functional integrity and evolutionary heritage continuity (Svenning 2026). This includes functional restoration, such as trophic rewilding and utilising non-native species (Trepel et al. 2026, Figueroa et al. 2026), functional revegetation, using plant species more viable under emerging climatic and biotic regimes (McCallum et al. 2018, Ahmad et al. 2026), and restoration of ecological networks (Moracho et al. 2025), with the common goal to incorporate novel ecological conditions in future conservation and restoration targeting.

The three novelty-generating processes differ fundamentally in how tractable they are to management, and this maps directly onto the intervention that fits each. Climate novelty is effectively irreversible on management timescales — the response is accommodation: assisted movement, connectivity, and identifying which configurations can persist rather than which can be restored (Toth et al. 2026, Wright et al. 2026). Floristic disruption is fast-acting and partly reversible, which makes it the process demanding near-term intervention where it overlaps with threatened species (Kerr et al. 2025). Defaunation novelty is the one axis that is directly and deliberately reversible, through trophic rewilding and reintroduction, and restoring large-herbivore and carnivore function may additionally buffer the other two by increasing heterogeneity and constraining plant invasion (Atkinson et al. 2024, Svenning et al. 2024c).

Although decision-making surrounding future conservation and restoration can be supported by knowledge on current threatened species assemblages, there are large uncertainties which cannot easily be accounted for. Future conservation prioritization depends largely on global governance, including sustainable energy and agriculture transitions (Wyborn et al. 2016). Furthermore, the rising ecological novelty of the biosphere may shift the suitability of current protected habitats

444 into suitable land-use areas, which from a socioeconomic perspective must be considered (Ordonez et al. 2024). Concur-
445 rently, new opportunities will open for conservation of threatened species with rising global ecological novelty, exposing
446 areas that may previously have been unfit for conservation (Trew et al. 2024). This calls for adaptive management in both
447 conservation and restoration, where not only current baselines are considered in decision-making (Svenning 2026). Future
448 conservation design should redirect focus to incorporate climate gradients and refugia (Balantic et al. 2021, Morelli et al.
449 2026), connectivity to support transboundary planning (Mason et al. 2020), and generally be more dynamic rather than
450 geographically fixed (Pressey et al. 2007). Future research on this topic should focus on outlining where novelty is likely
451 to arise under different climate change scenarios, the ecological consequences of rising novelty and what ecosystem
452 configurations can persist under future climates while retaining compositional and functional diversity.

453 **Author Contributions**

454 MRK, AMB, AO, FR, and J-CS conceptualized the study. MRK and AMB designed the analyses with input from AO
455 and J-CS. MRK carried out analysis and created the figures with input from all authors. MRK and AMB wrote the first
456 draft. All authors contributed to the final manuscript.

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465 **Conflict of Interest Statement**

466 The authors declare no conflicts of interest.

467 **Data Availability Statement**

468 The layers for ecological novelty are freely available from zenodo.org/records/14677612 (Kerr 2025). LIFE scores are
469 available from zenodo.org/records/14188450 (Eyres et al. 2025). Ranges for Red List species can be downloaded from
470 the IUCN (<https://www.iucnredlist.org/>) for mammals, amphibians and reptiles, and requested from BirdLife ([https://da-
471 tazine.birdlife.org/](https://datazone.birdlife.org/)) for birds. The hotspots for threatened terrestrial vertebrates were downloaded from
472 <https://doi.org/10.5061/dryad.m905qfv8g> (Huais et al. 2025). The world database of protected areas was downloaded
473 from <https://www.protectedplanet.net/> (UNEP-WCMC and IUCN 2024).

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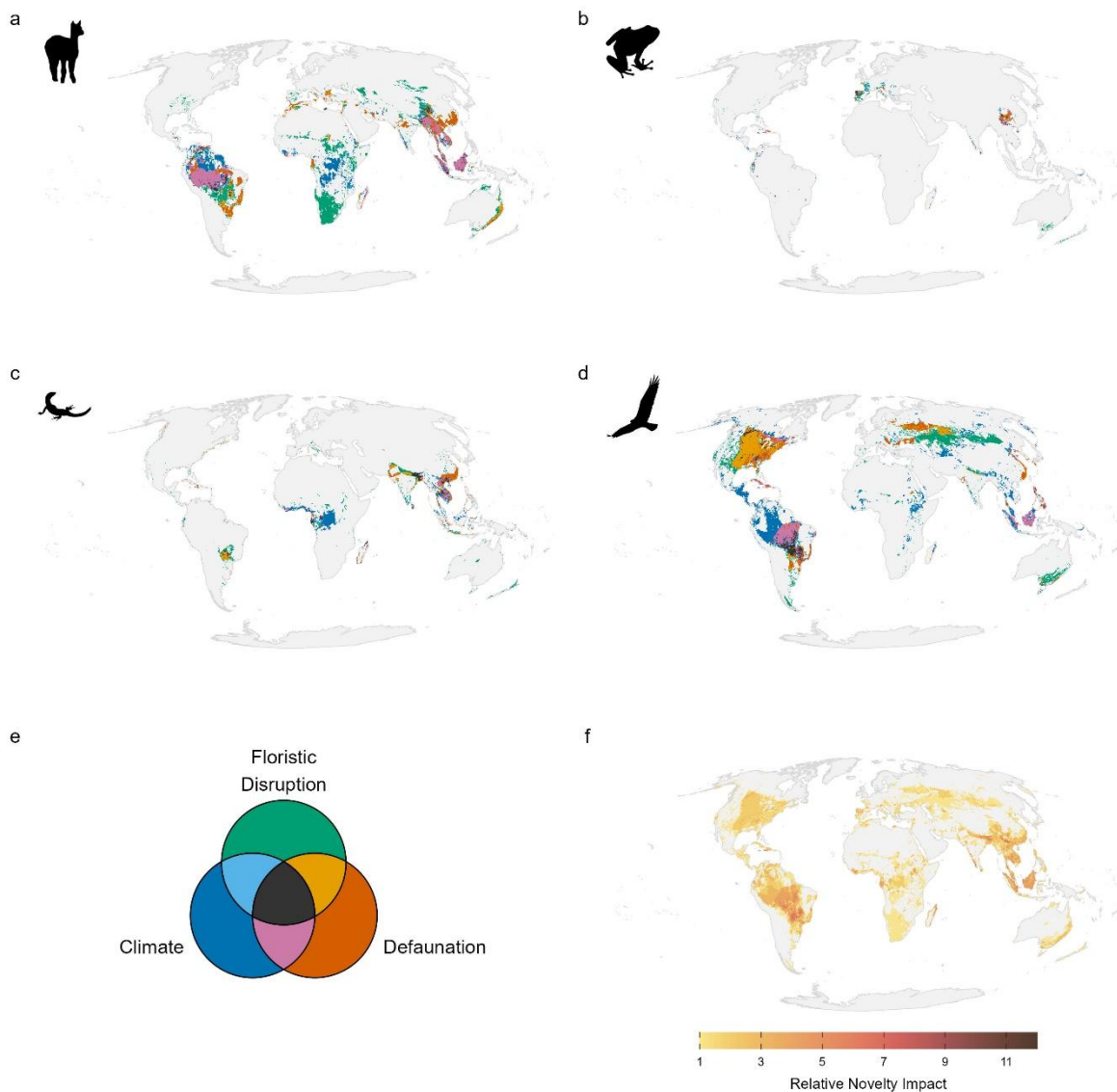
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724	<u>Supplementary Material for “Areas of high conservation priority for threatened terrestrial vertebrates are governed by</u>
725	<u>novel ecological conditions”</u>
726	Contents:
727	Table S1 – Percentage of protected cell area exposed to different relative novelty levels
728	Figure S1 – Maps of overlapping hotspots of ecological novelty and richness for terrestrial vertebrates categorised as
729	“vulnerable” in the IUCN Red List
730	Figure S2 – Maps of overlapping hotspots of ecological novelty and richness for terrestrial vertebrates categorised as
731	“endangered” in the IUCN Red List
732	Figure S3 – Maps of overlapping hotspots of ecological novelty and richness for terrestrial vertebrates categorised as
733	“critically endangered” in the IUCN Red List
734	Figure S4 – Exposure to climate novelty of threatened terrestrial vertebrates across their range
735	Figure S5 – Exposure to defaunation novelty of threatened terrestrial vertebrates across their range
736	Figure S6 – Exposure to floristic disruption novelty of threatened terrestrial vertebrates across their range
737	Figure S7 – Exposure to novelty of terrestrial vertebrates not categorised as threatened across their range
738	Figure S8 – Distribution of climate novelty within hotspots of threatened vertebrates
739	Figure S9 – Distribution of defaunation novelty within hotspots of threatened vertebrates
740	Figure S10 – Distribution of floristic disruption novelty within hotspots of threatened vertebrates
741	Figure S11 – Global overlap between LIFE index and ecological novelty, using a cut-off at the 90 th quantile
742	Figure S12 – Global overlap between LIFE index and ecological novelty, using a cut-off at the 75 th quantile
743	Figure S13 – Global overlap between LIFE index and ecological novelty, using a cut-off at the 50 th quantile
744	Figure Caption References
745	

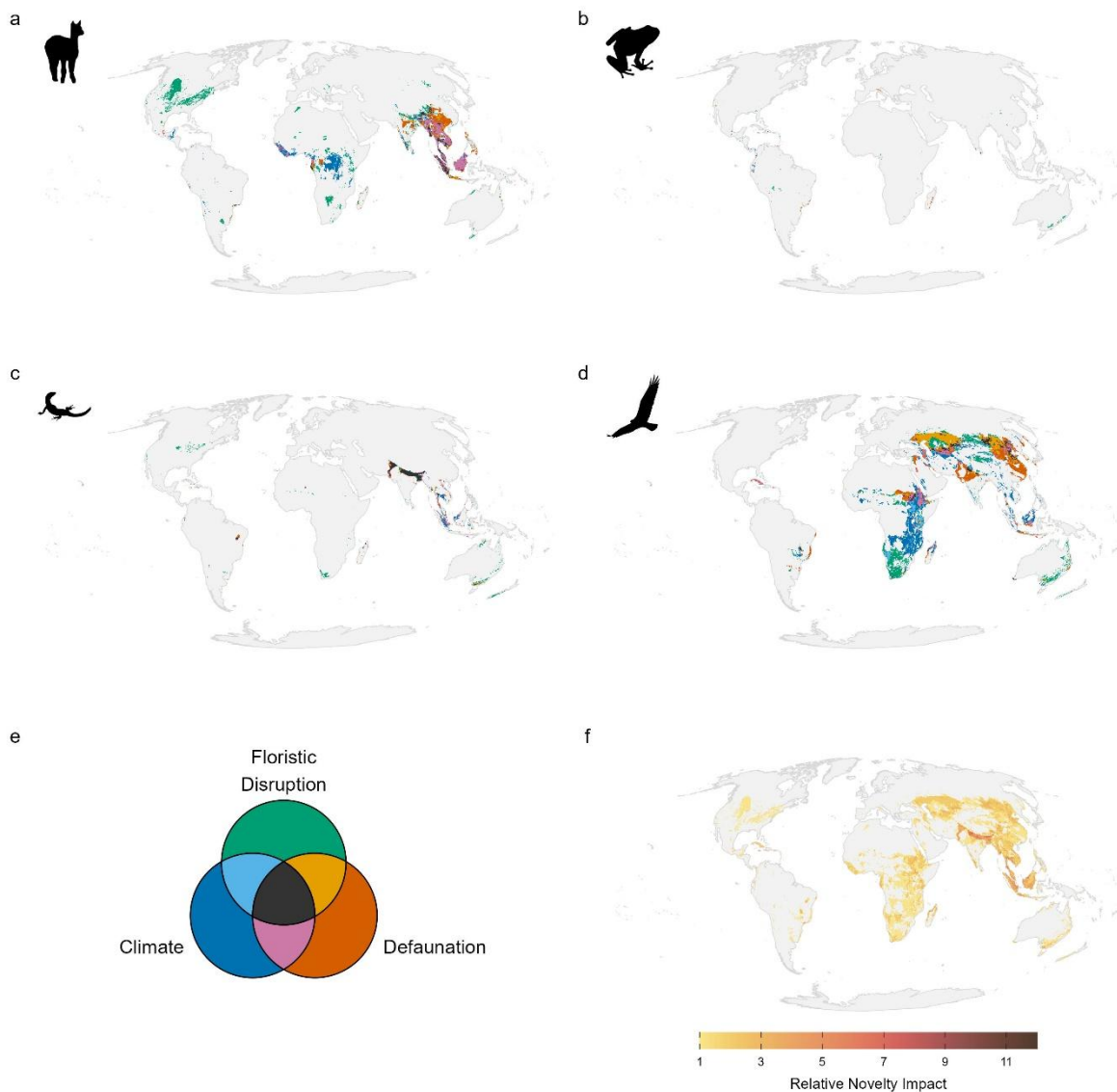
Supplementary Table 1: The percentage of the biosphere impacted by high ecological novelty that is covered by protected areas. The total area of relative novelty impact, defined by the number of hotspots of threatened vertebrate richness weighted by ecological novelty in a cell (see Figure 1 and main text), is shown as “Total Area” and expressed as the area in 100km². The percentage of the total impacted area covered by protected areas is then shown for IUCN protected area categories I through IV. The protected area network covers very little of the impacted area, with under 5% coverage for most individual categories and under 10% coverage if categories are combined.

Relative Novelty Impact	Total Area (100 km ²)	IUCN Protection Category (% coverage)				
		Ia & Ib	II	III	IV	Total Coverage
1	212023	0.95	3.30	0.74	2.23	7.22
2	142255	1.04	3.58	0.44	2.35	7.41
3	50941	1.10	5.31	0.18	1.46	8.05
4	29195	1.91	5.67	0.11	1.52	9.21
5	13235	1.37	4.81	0.11	2.20	8.49
6	9375	1.30	4.26	0.06	2.30	7.92
7	4313	1.39	2.00	0.02	0.94	4.35
8	2008	1.53	3.61	0.09	0.86	6.09
9	548	0.23	2.20	0	1.97	4.40
10	18	0	22.48	0	0	22.48
11	3	0	22.22	0	0	22.22
12	<1	0	0	0	0	0



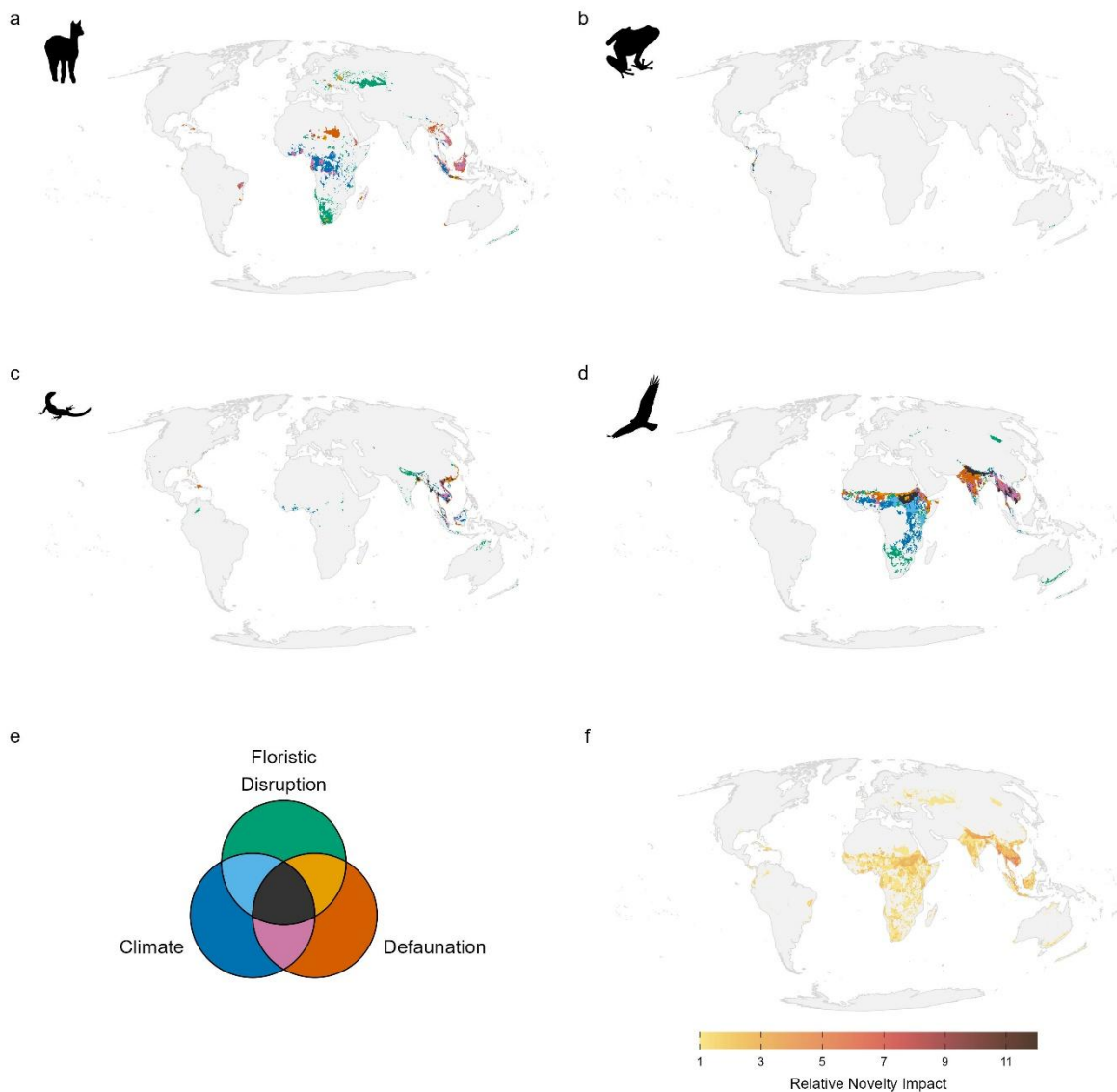
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754 Supplementary Figure 1: Vulnerable terrestrial vertebrate groups are globally exposed to different novelty-generating
 755 processes across space. For each terrestrial vertebrate group, the number of species categorised as “vulnerable” in each
 756 cell is multiplied by the novelty score (0-1) for each of three novelty-generating processes (climate, mammal defaunation,
 757 floristic disruption). The top 90th quantile for each layer is then overlaid and plotted for (a) mammals, (b) amphibians,
 758 (c) reptiles, and (d) birds. (e) shows the legend for panels a-d, with areas of overlap showing cells that are scored in the
 759 90th quantile for multiple processes. (f) shows the relative novelty impact for each cell, counting the number of times that
 760 a cell is present in the 90th quantile of any analysis, for example a cell score of 4 would be in the top 90th quantile for four
 761 pairs of taxa and process.



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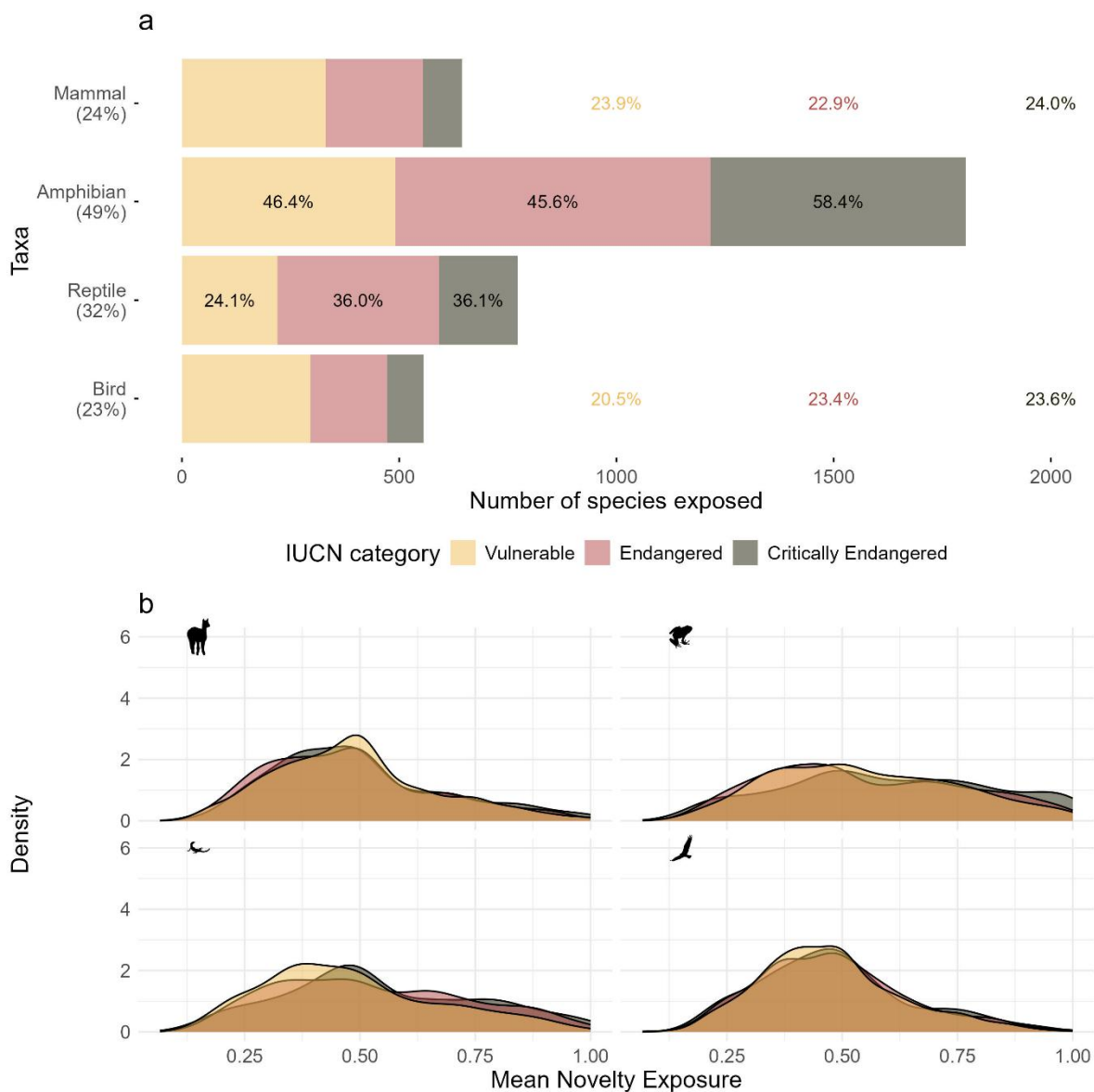
763 Supplementary Figure 2: Endangered terrestrial vertebrate groups are globally exposed to different novelty-generating
 764 processes across space. For each terrestrial vertebrate group, the number of species categorised as “endangered” in each
 765 cell is multiplied by the novelty score (0-1) for each of three novelty-generating processes (climate, mammal defaunation,
 766 floristic disruption). The top 90th quantile for each layer is then overlaid and plotted for (a) mammals, (b) amphibians,
 767 (c) reptiles, and (d) birds. (e) shows the legend for panels a-d, with areas of overlap showing cells that are scored in the
 768 90th quantile for multiple processes. (f) shows the relative novelty impact for each cell, counting the number of times that
 769 a cell is present in the 90th quantile of any analysis, for example a cell score of 4 would be in the top 90th quantile for four
 770 pairs of taxa and process.



771

772 Supplementary Figure 3: Critically endangered terrestrial vertebrate groups are globally exposed to different novelty-
 773 generating processes across space. For each terrestrial vertebrate group, the number of species categorised as “critically
 774 endangered” in each cell is multiplied by the novelty score (0-1) for each of three novelty-generating processes (climate,
 775 mammal defaunation, floristic disruption). The top 90th quantile for each layer is then overlaid and plotted for (a) mam-
 776 mals, (b) amphibians, (c) reptiles, and (d) birds. (e) shows the legend for panels a-d, with areas of overlap showing cells
 777 that are scored in the 90th quantile for multiple processes. (f) shows the relative novelty impact for each cell, counting the
 778 number of times that a cell is present in the 90th quantile of any analysis, for example a cell score of 4 would be in the top
 779 90th quantile for four pairs of taxa and process.

780



781

782 Supplementary Figure 4: Threatened terrestrial vertebrates are exposed to high climate novelty across their range. (a) The

783 number of species exposed to high climate novelty (a novelty score of greater than 0.5 for climate novelty) is plotted for

784 threatened species (IUCN category of endangered, vulnerable, or critically endangered) of mammals, amphibians, reptiles

785 and birds. The plot is stacked and split by threat category, with the text inside the bar sections showing the percentage of

786 species within that taxa and category that are exposed. Percentage values for mammals and birds are shown outside of

787 the bars for visibility, with the ordering unchanged and text coloured to match the categories. Amphibians have the highest

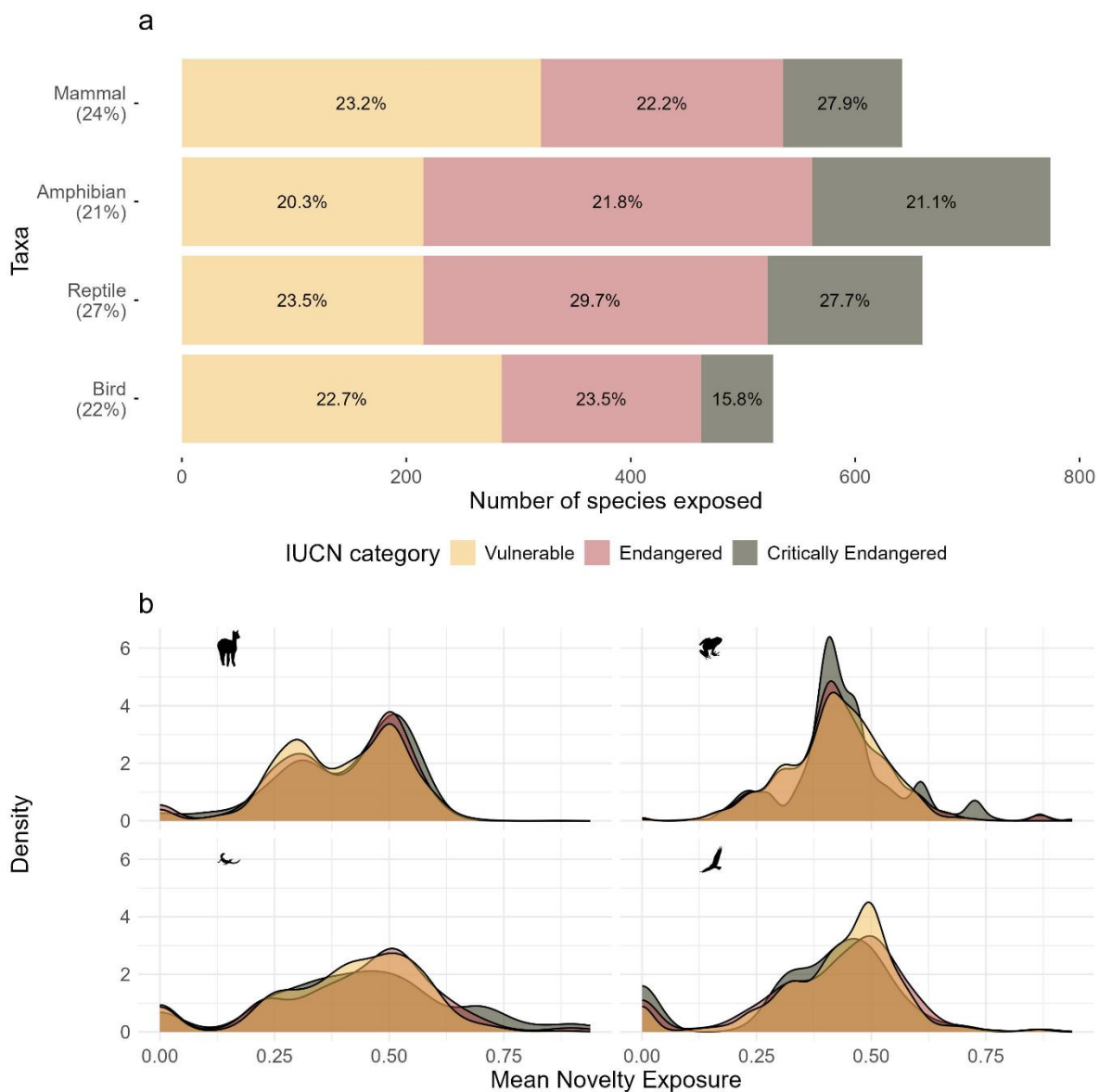
788 overall exposure, with around half of threatened amphibian species across categories exposed for over half their range,

789 with the highest exposure experienced by critically endangered species. In (b) the mean novelty exposure across each

790 species' range is plotted, again split by taxa and plotted with categories overlapped. Although there are only very small

791 differences between categories and taxa, most species are exposed to a high mean novelty across their range.

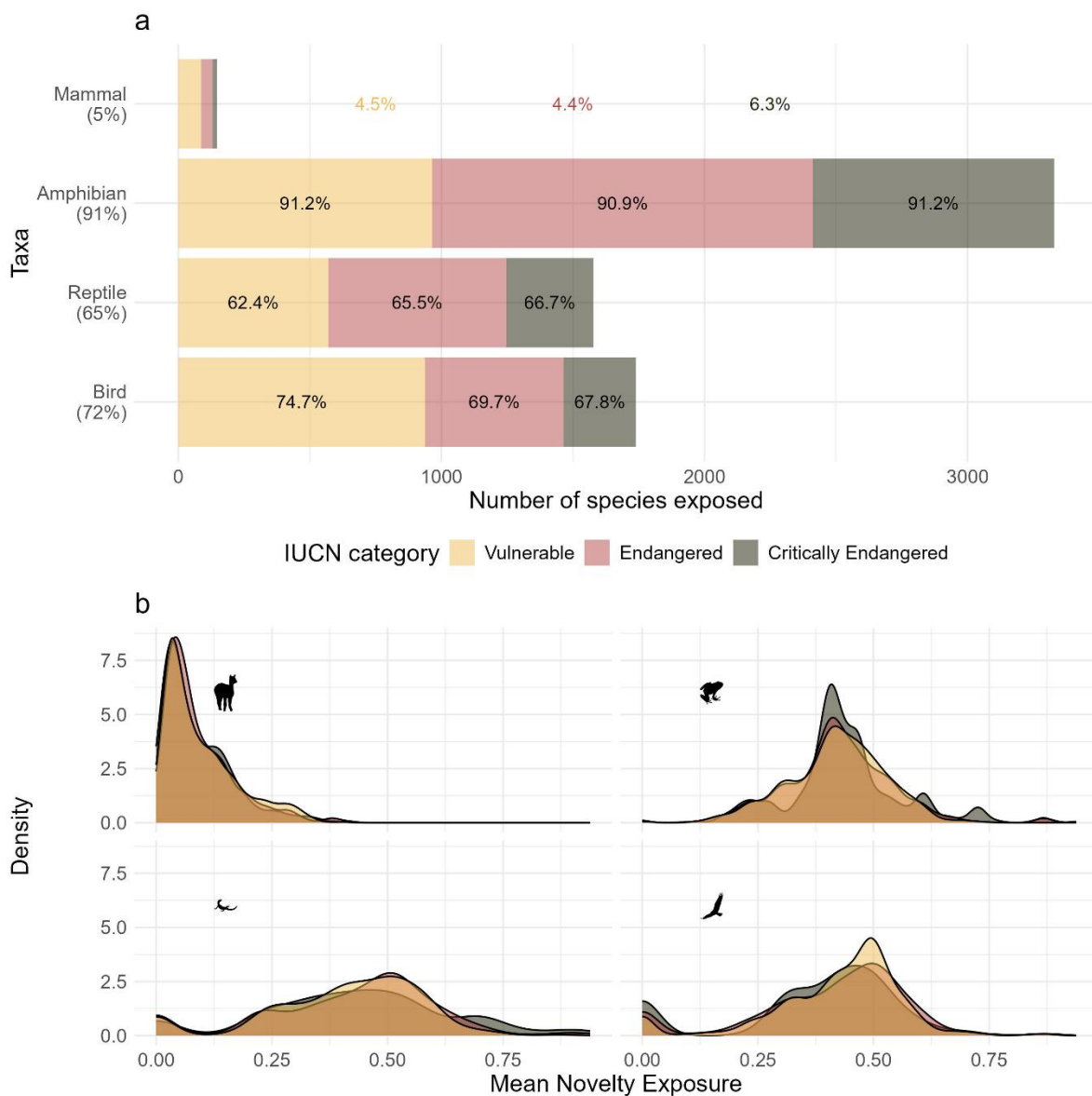
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794 Supplementary Figure 5: Threatened terrestrial vertebrates are exposed at low levels to high defauna novelty across
 795 their range. (a) The number of species exposed to high defauna novelty (a novelty score of greater than 0.5 for de-
 796 fauna novelty) is plotted for threatened species (IUCN category of endangered, vulnerable, or critically endangered)
 797 of mammals, amphibians, reptiles and birds. The plot is stacked and split by threat category, with the text inside the bar
 798 sections showing the percentage of species within that taxa and category that are exposed. In (b) the mean novelty expo-
 799 sure across each species' range is plotted, again split by taxa and plotted with categories overlapped. Although there are
 800 only very small differences between categories and taxa, most species are exposed to a high mean novelty across their
 801 range – a mean novelty across the range of greater than 0.5 is experienced by 24% of mammals, 22% of amphibians, 28%
 802 of reptiles, and 25% of birds.

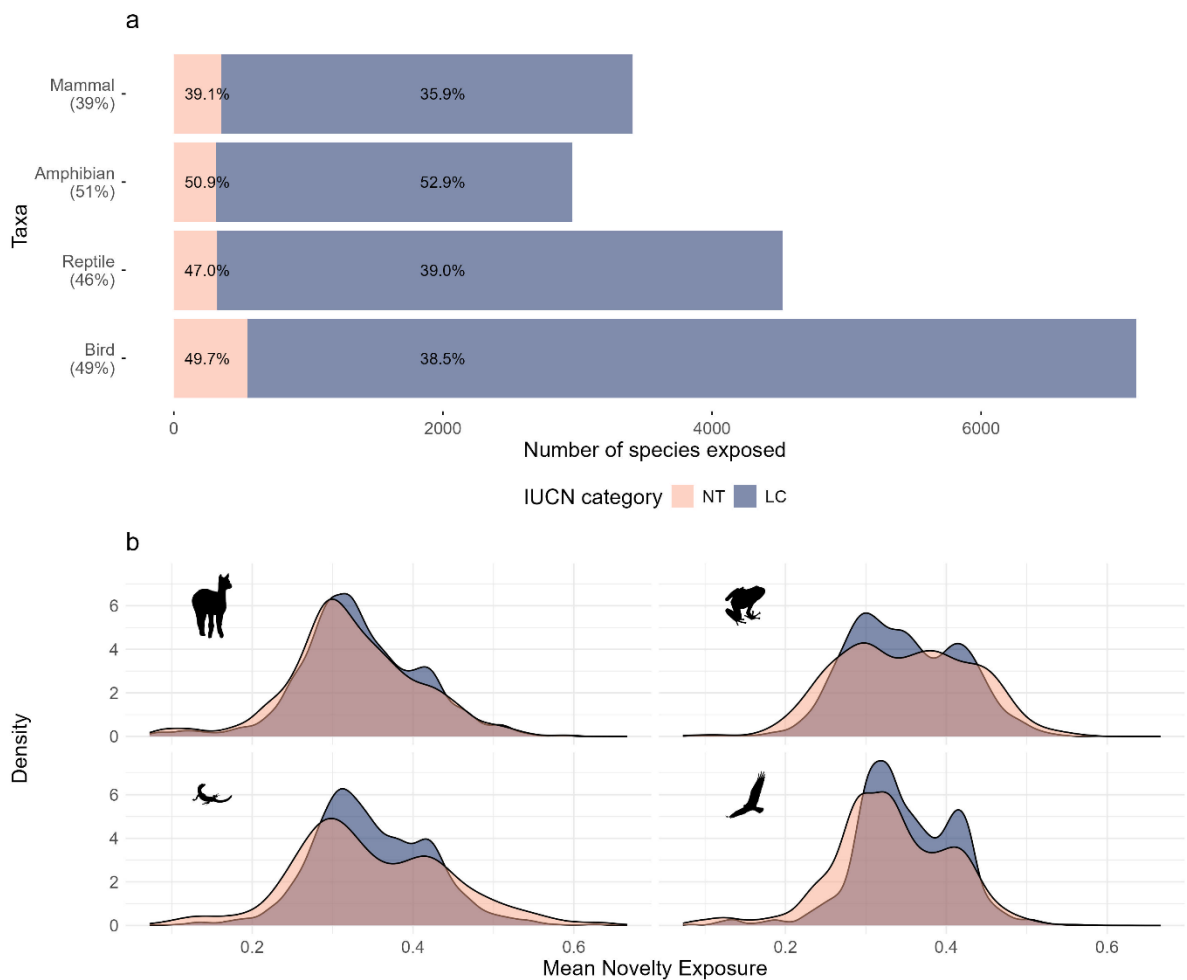
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805 Supplementary Figure 6: Threatened terrestrial vertebrates are exposed to high floristic disruption novelty across their
 806 range. (a) The number of species exposed to high floristic disruption (a novelty score of greater than 0.25 for floristic
 807 disruption) is plotted for threatened species (IUCN category of endangered, vulnerable, or critically endangered) of mam-
 808 mals, amphibians, reptiles and birds. The plot is stacked and split by threat category, with the text inside the bar sections
 809 showing the percentage of species within that taxa and category that are exposed. Percentage values for mammals are
 810 shown outside of the bars for visibility, with the ordering unchanged and text coloured to match the categories. Amphib-
 811 ians have the highest overall exposure, with over 90% of threatened amphibian species across categories exposed for over
 812 half their range. In (b) the mean novelty exposure across each species' range is plotted, again split by taxa and plotted
 813 with categories overlapped. Although there are only very small differences between categories and taxa, most species are
 814 exposed to a high mean novelty across their range – a mean novelty across the range of greater than 0.25 is experienced
 815 by 5% of mammals, 91% of amphibians, 67% of reptiles, and 77% of birds.

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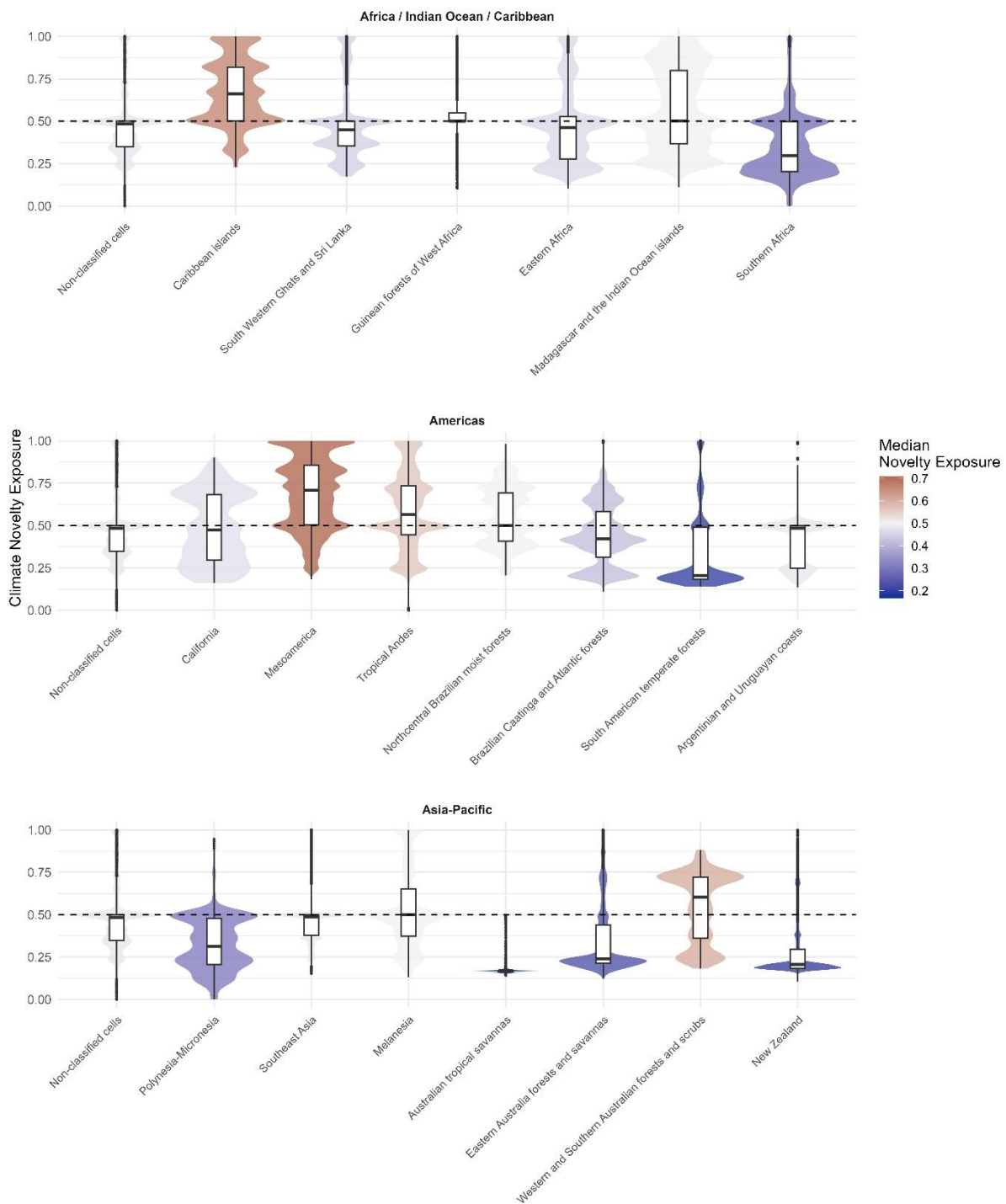


818

819 Supplementary Figure 7: Unthreatened terrestrial vertebrates are exposed to highly novel conditions across their range.
820 (a) The number of species exposed to highly novel conditions (a novelty score of greater than 0.33 across more than half
821 their range) is plotted for species not classified as threatened, within IUCN categories of least concern (LC) or near
822 threatened (NT) of mammals, amphibians, reptiles, and birds. The plot is stacked and split by threat category, with the
823 text inside the bar sections showing the percentage of species within that taxon and category that are exposed. Percentages
824 displayed in the y-axis labels show the percentage of all species in that taxonomic group that are exposed. Across all
825 taxonomic groups, roughly one third of threatened species are living in highly novel conditions. Amphibians have the
826 highest overall exposure, with over half of threatened amphibian species across categories exposed for over half their
827 range and almost two-thirds of critically endangered amphibians living in highly novel conditions. In (b) the mean novelty
828 exposure across each species' range is plotted, again split by taxa and plotted with categories overlapped.

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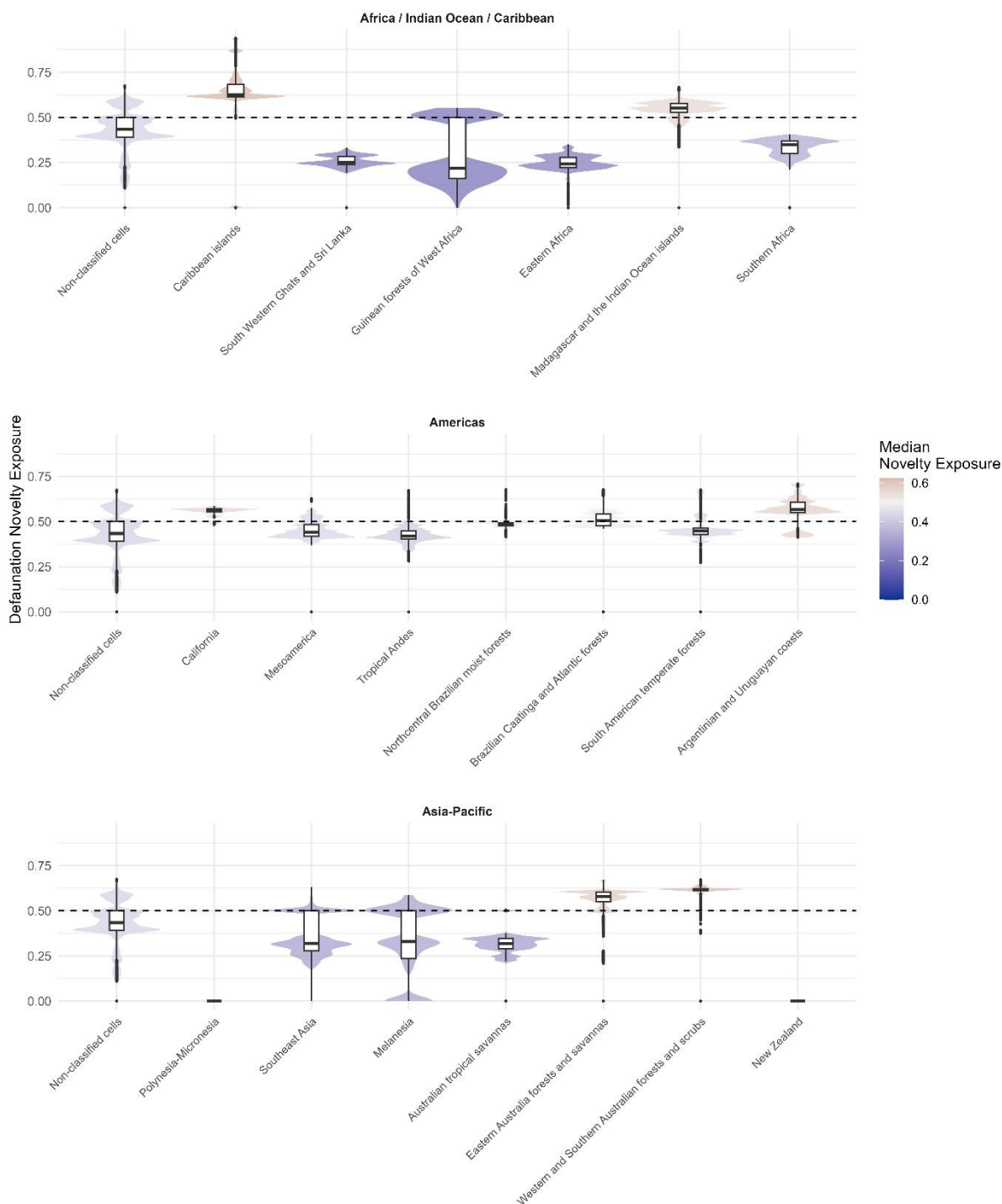


831

832 Supplementary Figure 8: The total exposure of climate novelty varies between hotspots of threatened vertebrates. Within
 833 each hotspot, which were identified using an existing map of threatened vertebrate species hotspots (Huais et al. 2025),
 834 the values for climate novelty were extracted. Colour scaling of the violin plots is related to the median novelty exposure
 835 across the hotspot, with darker red colours representing hotspots that are higher than 0.5 (the cut-off for high novelty used
 836 here, marked by the horizontal dashed line) and darker blue colours representing those with much lower novelty than 0.5.
 837 The midpoint of the colour scale (light grey) is set to 0.5. The overlaid boxplot shows the median novelty value as a
 838 horizontal line. Hotspots are sorted into panels based on broad arbitrary geographical area for presentation reasons: (a)

839 the Americas, (b) Southeast Asia and Australasia and (c) the Caribbean and Africa. The novelty-generating processes for
840 areas outside hotspots are shown on the far left of each panel (“Non-classified cells”).

841

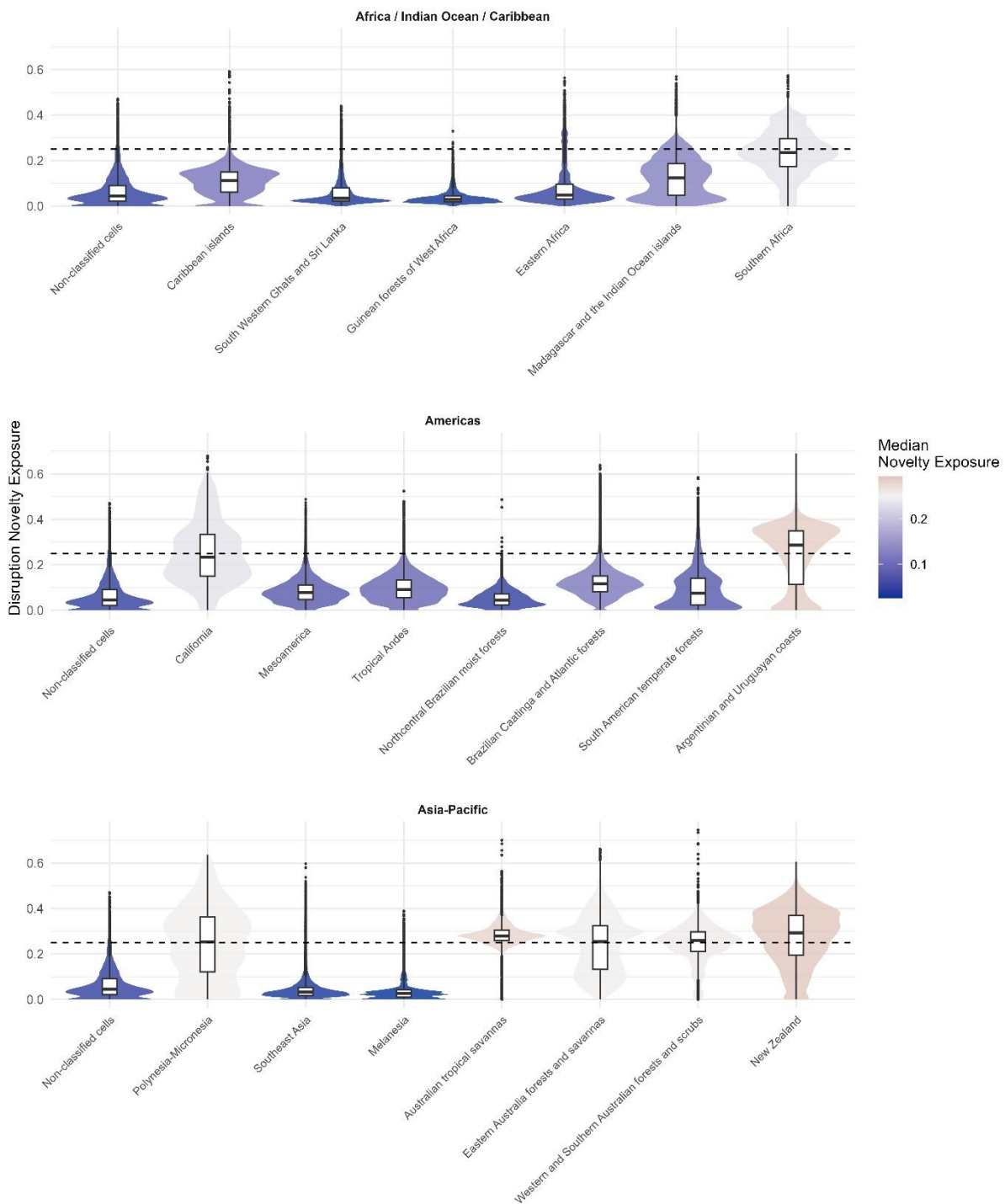


842

843 Supplementary Figure 9: The total exposure of defaunation novelty varies between hotspots of threatened vertebrates.
 844 Within each hotspot, which were identified using an existing map of threatened vertebrate species hotspots (Huais et al.
 845 2025), the values for defaunation novelty were extracted. Colour scaling of the violin plots is related to the median novelty
 846 exposure across the hotspot, with darker red colours representing hotspots that are higher than 0.5 (the cut-off for high
 847 novelty used here, marked by the horizontal dashed line) and darker blue colours representing those with much lower
 848 novelty than 0.5. The midpoint of the colour scale (light grey) is set to 0.5. The overlaid boxplot shows the median novelty
 849 value as a horizontal line. Hotspots are sorted into panels based on broad arbitrary geographical area for presentation

850 reasons: (a) the Americas, (b) Southeast Asia and Australasia and (c) the Caribbean and Africa. The novelty-generating
851 processes for areas outside hotspots are shown on the far left of each panel (“Non-classified cells”).

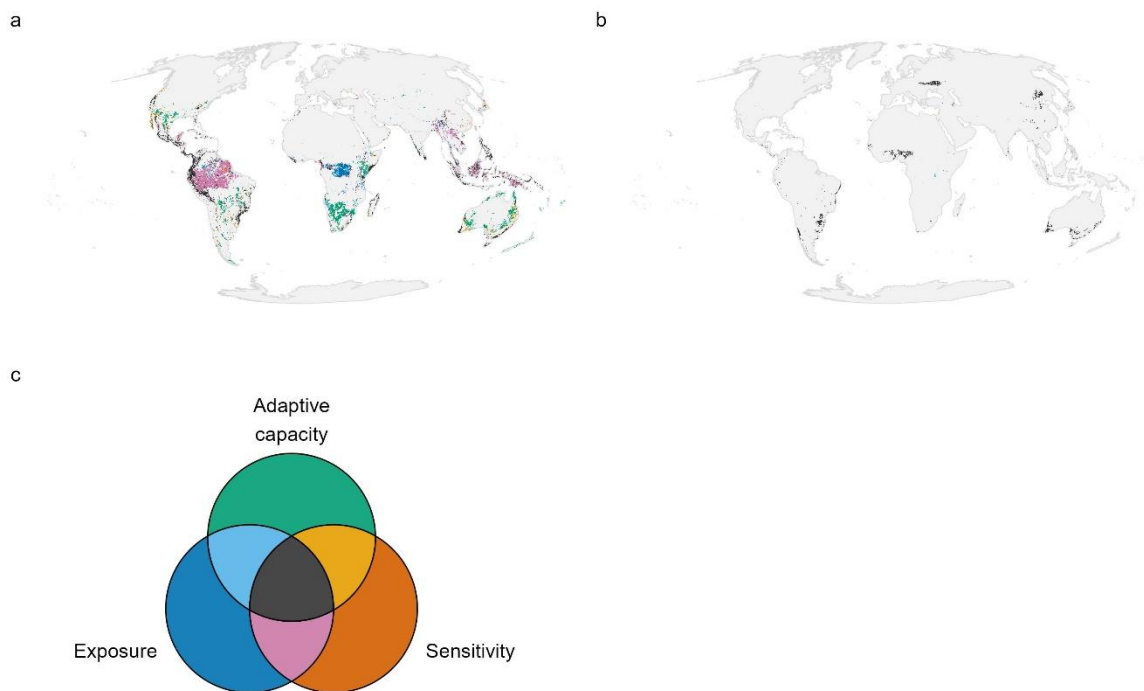
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854 Supplementary Figure 10: The total exposure of floristic disruption varies between hotspots of threatened vertebrates.
 855 Within each hotspot, which were identified using an existing map of threatened vertebrate species hotspots (Huais et al.
 856 2025), the values for floristic disruption were extracted. Colour scaling of the violin plots is related to the median novelty
 857 exposure across the hotspot, with darker red colours representing hotspots that are higher than 0.25 (the cut-off for high
 858 novelty used here, marked by the horizontal dashed line) and darker blue colours representing those with much lower
 859 novelty than 0.25. The midpoint of the colour scale (light grey) is set to 0.25. The overlaid boxplot shows the median

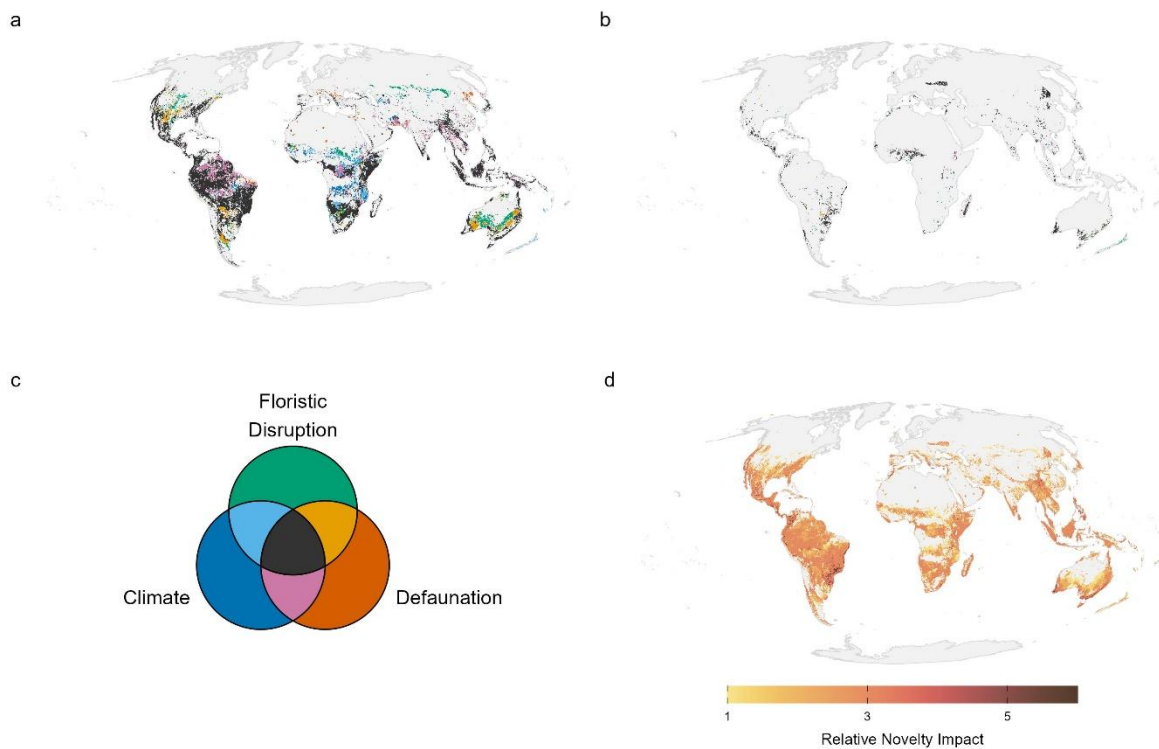
860 novelty value as a horizontal line. Hotspots are sorted into panels based on broad arbitrary geographical area for presen-
861 tation reasons: (a) the Americas, (b) Southeast Asia and Australasia and (c) the Caribbean and Africa. The novelty-gen-
862 erating processes for areas outside hotspots are shown on the far left of each panel (“Non-classified cells”).
863



864

865 Supplementary Figure 11: The global overlap between high ecological novelty and areas of (a) high conservation priority
 866 and (b) high restoration priority. Here, conservation and restoration priority are defined using the LIFE index (Eyres et
 867 al. 2025), which measures the expected change in extinctions based on converting all natural land into agriculture (and
 868 therefore the potential impact of conservation, see Methods) or by restoring all agricultural land into natural habitat (and
 869 therefore the potential impact of restoration). The LIFE index in each cell is multiplied by the novelty score (0-1) for each
 870 of three novelty-generating processes (climate, mammal defaunation, floristic dis-ruption), with the top 90th quantile for
 871 each layer overlayed and plotted. (c) shows the legend for panels (a) and (b), with areas of overlap showing cells that are
 872 scored in the 90th quantile for multiple processes. The relative novelty impact for each cell, counting the number of times
 873 that a cell is present in the 90th quantile of any analysis, is shown as Figure 4 in the main text. Maps of global overlap
 874 using quantile cut-offs of 75 and 50 for the LIFE layers are shown in Supplementary Figures 12 and 13.

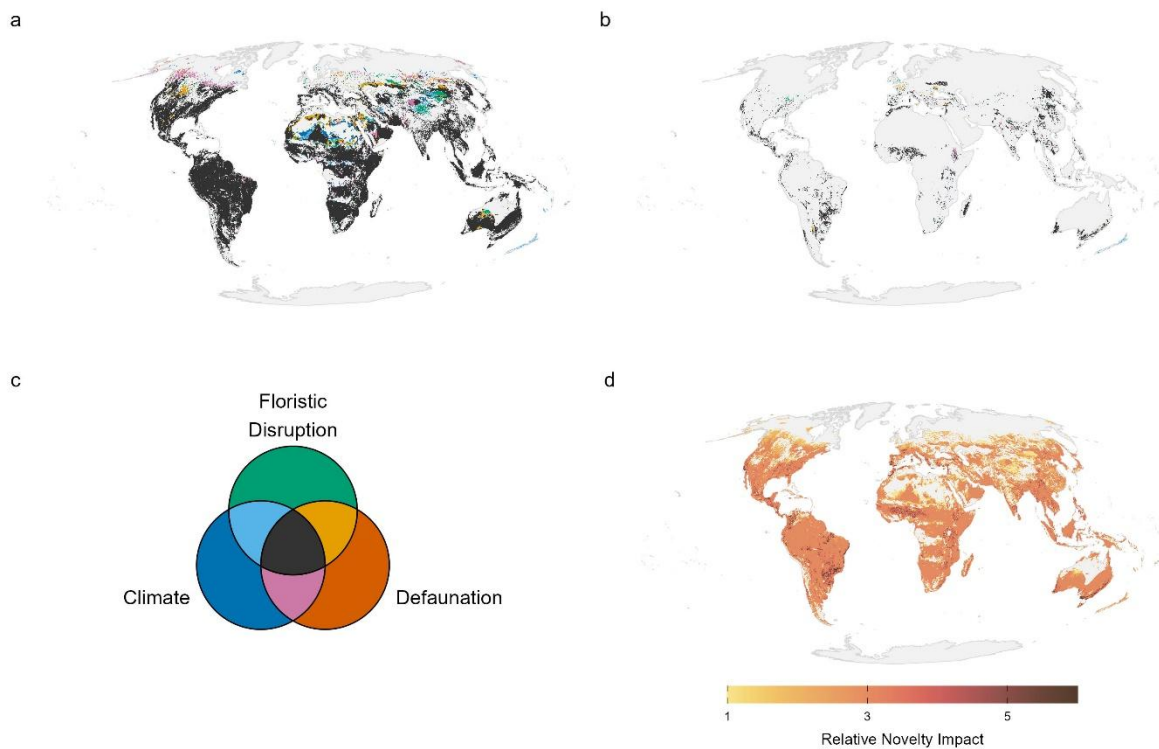
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876

877 Supplementary Figure 12: The global overlap between high ecological novelty and areas of (a) high conservation priority
 878 and (b) high restoration priority, using a hotspot cut-off of the 75th quantile. Here, conservation and restoration priority
 879 are defined using the LIFE index (Eyres et al. 2025), which measures the expected change in extinctions based on con-
 880 verting all natural land into agriculture (and therefore the potential impact of conservation, see Methods) or by restoring
 881 all agricultural land into natural habitat (and therefore the potential impact of restoration). The LIFE in each cell is mul-
 882 tiplied by the novelty score (0-1) for each of three novelty-generating processes (climate, mammal defaunation, floristic
 883 disruption), with the top 75th quantile for each layer overlayed and plotted. (c) shows the legend for panels (a) and (b),
 884 with areas of overlap showing cells that are scored in the 75th quantile for multiple processes. (d) shows the relative
 885 novelty impact for each cell, counting the number of times that a cell is present in the 75th quantile of any analysis, for
 886 example a cell score of 4 would be in the top 75th quantile for four pairs of LIFE index and process.

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888

889 Supplementary Figure 13: The global overlap between high ecological novelty and areas of (a) high conservation priority
 890 and (b) high restoration priority, using a hotspot cut-off of the 50th quantile. Here, conservation and restoration priority
 891 are defined using the LIFE index (Eyres et al. 2025), which measures the expected change in extinctions based on con-
 892 verting all natural land into agriculture (and therefore the potential impact of conservation, see Methods) or by restoring
 893 all agricultural land into natural habitat (and therefore the potential impact of restoration). The LIFE in each cell is mul-
 894 tiplied by the novelty score (0-1) for each of three novelty-generating processes (climate, mammal defaunation, floristic
 895 disruption), with the top 50th quantile for each layer overlayed and plotted. (c) shows the legend for panels (a) and (b),
 896 with areas of overlap showing cells that are scored in the 50th quantile for multiple processes. (d) shows the relative
 897 novelty impact for each cell, counting the number of times that a cell is present in the 50th quantile of any analysis, for
 898 example a cell score of 4 would be in the top 50th quantile for four pairs of LIFE index and process.

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