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Language-specific hotspots of interest in IUCN Red Listed terrestrial mammals

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ABSTRACT

Biodiversity conservation continues to be a global priority and insights into societal interest and support for targeted species conservation actions are essential for their success. Taking advantage of emerging culturomics methods, here we propose a new methodology for mapping societal interest towards terrestrial mammals by combining the IUCN Red List range maps with indicators of societal interest towards species derived from Wikipedia pageviews data for different languages. We show that societal interest towards terrestrial mammals varies between different language groups and is not necessarily concentrated in areas of high biodiversity. We propose that our mapping method can help to identify hot- and cold-spots of societal interest towards biodiversity for different taxonomic and language groups, and we discuss potential conservation applications of the proposed mapping method.

KEY POLICY HIGHLIGHTS

- A novel methodology is introduced for mapping language-specific hotspots of societal interest in biodiversity.
- Societal interest maps are effective at elucidating distinctions in species richness and social interest hotspots among different language groups.
- Species societal interest maps have the potential to generate new insights in conservation studies, rendering them valuable tools in the decision-making process.

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Culturomics; Wikipedia; species richness; societal interest; mapping methods

1. Introduction

Unsustainable human behaviours continue to threaten natural ecosystems and drive many species toward extinction (IPBES, 2019). Targeted conservation efforts have been successful in maintaining or recovering the populations of several species (Bolam et al., 2021), but many more taxa require conservation action to achieve similar success and avoid extinction. Avoided species extinctions are strongly influenced by bio-cultural processes (Ladle et al., 2023; Ladle & Jepson, 2008), as the success of targeted conservation actions ultimately rests on various ecological and human factors. For example, a robust evidence base is necessary to identify specific conservation needs for each species and select the most effective conservation interventions (Sutherland et al., 2004). It is also important to ensure the availability of sufficient resources, but these are often limited and taxonomically biased (Adamo et al., 2022; Davies et al., 2018; Mammola et al., 2020). Broad societal support for conservation efforts is also essential to ensure the success of any targeted action (Mascia et al., 2003).

Ensuring societal patterns of interest in and awareness of biodiversity and conservation actions is therefore an important component in the development of successful conservation interventions. The importance of biodiversity and its conservation has been widely recognized and encapsulated in international conservation agreements, including in the recent Kunming-Montreal Global Biodiversity Framework (CBD, 2020, 2022). Survey techniques are traditionally used to assess people's awareness of biodiversity and conservation topics, but these methods are usually time-consuming, difficult to implement at large spatial scales and face decreasing response rates, which limits their applicability. One approach that has been proposed as a complementary source of information is to leverage the large amounts of digital data that are increasingly available online (Arts et al., 2015; Di Minin et al., 2015; Ladle et al., 2016). More than half

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of the world's population now has access to the internet (International Communication Union, 2022) and many aspects of people's daily lives, including how they perceive and interact with biodiversity, are now recorded on digital platforms (Correia, Ladle, and Roll, 2021). The development of analytical approaches to explore digital data offers exciting opportunities to generate unique insights about the dynamics of societal interest in and awareness of biodiversity conservation (Correia, Ladle, Jarić, et al., 2021).

Indeed, there is a growing body of research leveraging the use of such approaches to monitor the dynamics of societal interest in biodiversity and conservation topics (Caetano et al., 2023; Cooper et al., 2019; Johnson et al., 2023; Millard et al., 2021). Most of this research has focused on developing indicators of temporal dynamics of biodiversity awareness that can inform international biodiversity conservation policy targets. While the spatial dimension of biodiversity awareness has also been addressed in these studies to some extent, the development of tailored methods and indicators to explore geographical patterns of biodiversity interest and awareness has been comparatively less explored. Digital approaches hold potential to help map cultural dimensions of biodiversity (Ladle et al., 2016) and addressing this gap can help supporting biodiversity conservation decision making (Di Minin et al., 2022). For example, maps of socio-cultural dimensions of biodiversity can be integrated with maps of biodiversity conservation priorities to help identify areas that have species of high conservation priority and also gather societal support for their conservation.

In this paper, we outline a framework to summarize and map societal interest in biodiversity across different cultural contexts. Specifically, we explore the combination of data on online species interest with the IUCN Red List range maps to illustrate interest towards species assemblages found across the world, and compare the use of different methods to summarize online interest towards species on the resulting maps. We also explore hot- and cold-spots of species richness and societal interest between different language groups. We propose that the further development of methods to map societal interest towards species can play an important role in supporting biodiversity conservation planning and decision-making.

2. Materials and methods

Our proposed method for mapping societal interest towards biodiversity involves the combination of species distribution data with metrics of societal interest towards species (Figure 1). Given there are various potential sources of data that can be used to characterize species distributions and societal interest towards

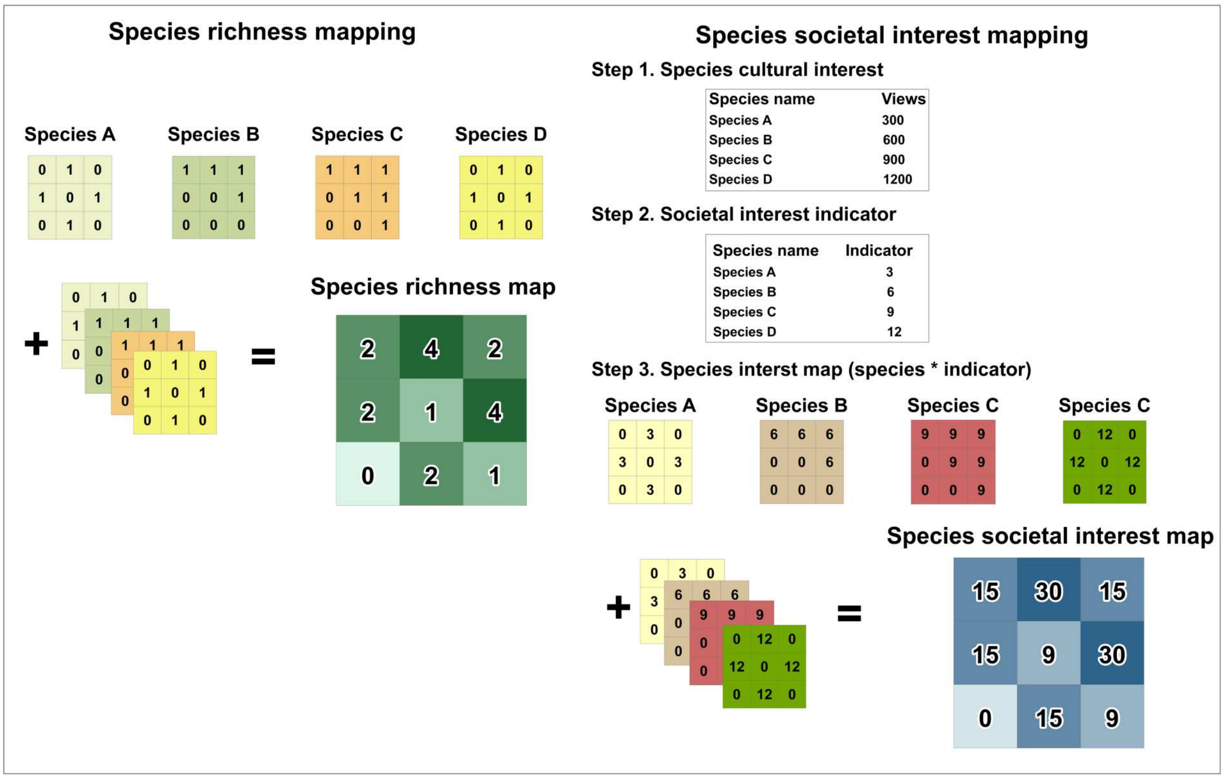

Figure 1. Flowchart of analytical operations for conventional species richness mapping that uses species range data for the IUCN Red Listed terrestrial mammals (https://www.iucnredlist.org/resources/spatial-data-download); and for species interest societal mapping with the species range data and Wikipedia pageviews data. Species richness maps and societal interest maps were calculated in R software with *terra* and *raster* packages.

species, a more detailed description of the data sources and analytical steps used in this work are provided below.

2.1. Wikipedia data

Our measure of societal interest is based on the number of Wikipedia pageviews to each species' page in different languages. Wikipedia is among the most visited websites on the internet (https://www.similarweb.com/top-websites/, accessed on 11 September 2023) and because many species are represented in various language editions of this digital encyclopaedia, it is often consulted by wildlife enthusiasts, researchers and other interested groups from across the world. Wikipedia pageviews reflects a form of voluntary information-seeking behaviour from online content (Correia, Ladle, Jarić, et al., 2021) and is therefore likely to be associated with broad patterns of societal interest towards biodiversity.

We collected Wikipedia monthly pageview data recorded during the period between January 1, 2016 and December 31, 2022 (7 years) for each combination of mammal species and language edition represented on this online platform. Based on data from the IUCN Red List of Threatened Species 2022-2 version (IUCN, 2022), we queried the Wikipedia query service to identify all the species with a Wikidata entry that contained the IUCN Red List ID property (P627). We complemented this search with an additional query for any species with a Wikidata entry that referred to the scientific name of a species contained in the IUCN Red List. We merged the results from the two queries and removed any duplicated entries, resulting in a total of 147 532 species entries. We filtered the resulting species list to include only mammal species for which we had information on distributions ranges (see below). We then identified all the Wikipedia language editions where each mammal species was represented and collected pageview data for each species and language edition using the Wikimedia pageviews API (see https://wikimedia.org/api/rest_v1/). Pageview data collection considered all access modes but was restricted to user pageviews only, thus excluding pageviews originating from automated sources.

We used the Wikipedia pageview data obtained to compute several metrics of societal interest for each species, including total pageviews, mean monthly pageviews, median monthly pageviews, mean of log-transformed monthly pageviews, median of log-transformed monthly pageviews, and percentile of all species pageviews. These metrics were calculated as a means to explore and compare how different metrics used to aggregate online interest reflected on the output maps of societal interest in species.

2.2. Species range data

Species range maps for terrestrial mammals were collected from the IUCN Red List (2022-2 version) web site's Spatial Data Download page (IUCN, 2022). All available range maps for mammal species were transformed into raster format, with pixel values assigned as binary indicators of presence or absence (1/0) based upon the certainty of species presence within each range map. Following Montesino Pouzols et al., 2014 and Veach et al., 2017, areas marked as 'extant' or 'probably extant' were categorized as probable presences (1), whereas range polygons assigned to the categories 'possibly extant,' 'possibly extinct,' 'extinct,' or 'presence uncertain' were treated as absences (0). The final dataset consisted of 5623 terrestrial mammal species rasterized range maps, representing all species of terrestrial maps included in the IUCN Red List v2022-2, and over 85% of all known extant mammal species (Burgin et al., 2018). We originally rasterized range maps at a pixel size of 0.00833×0.00833 degrees (approx. 0.85×0.85 km at the Equator) but aggregated all species range raster layers at 0.05×0.05 degrees (approx. 5.5×5.5 km at the Equator) resolution to avoid computational constraints in subsequent analyses. All data were masked with a continental land mask, and the Antarctic region was also excluded. We then combined the species range maps with Wikipedia pageviews data for the mammal species. Here, we considered only languages with at least 1000 species represented as (i) Wikipedia pageviews may not accurately reflect societal interest in mammals for languages with less species represented, and (ii) preliminary analyses suggested that results for languages with less species represented on Wikipedia were essentially similar to those of the presence (or absence) of species. Ten languages met the criteria (Table 1), and for these languages we used the *app* function from the *terra* R software package to calculate summary rasters for each language based on the species richness represented on Wikipedia and the different coefficients derived from the Wikipedia data outlined above.

Table 1. IUCN Red Listed Threatened mammal species range data for 10 languages included in this study. The languages include were selected because more than 1000 terrestrial mammal species were represented in the respective Wikipedia language edition.

Language	Code	Terrestrial mammals (*n*)
Egyptian Arabic (arz)	(Q29919)	3115
German (de)	(Q188)	3133
English (en)	(Q1860)	5170
Spanish (es)	(Q1321)	4172
French (fr)	(Q150)	2515
Italian (it)	(Q652)	3431
Portuguese (pt)	(Q5146)	3151
Russian (ru)	(Q7737)	1803
Swedish (sv)	(Q9027)	4759
Chinese (zh)	(Q7850)	1257

2.3. Data analysis and mapping

We first investigated the relationship between species richness and species societal interest raster maps in the various languages by calculating Pearson's Correlation Coefficient *(r)* using the *layerStats* function in the R *raster* package. To compare the different mapping methods across languages, we calculated the mean correlation coefficient between each map pair across the ten languages and used this metric to assess the similarity between maps produced with different metrics of societal interest (Figure 2).

We then aimed to explore spatial patterns of societal interest in more detail for selected languages. For this analysis, we chose the raster calculated using the mean of log-transformed monthly pageviews. This metric was selected because it represents an intermediate picture between maps of species richness and total species, and it thus represents a balanced representation of both metrics that seems to represent well societal interest of different species assemblages (see results and discussion). We calculated species interest maps for the ten represented Wikipedia languages. We also aimed to outline how these maps can be used to identify clusters of language-specific interest in biodiversity, which can for example be used to compare areas of high and low species interest between languages. For this analysis, we selected two sample languages for which over half of the mammal species were represented: English (language code Q1860; 5170 species represented) and Italian (language code Q652; 3431 species represented). Raster maps of log mean monthly pageviews were converted to the 0–1 range and we utilized map algebra to compute differences between the maps for both languages. We also assessed the patterns of spatial autocorrelation in interest as an indicator of spatially clustered societal interest towards specific species assemblages. We did this by using global Moran's *I* (Moran, 1950) for the full data set, as well as individually for English and Italian (Table 2). Global Moran's *I* computes the degree of spatial autocorrelation throughout the entire study area. Moran's *I* values

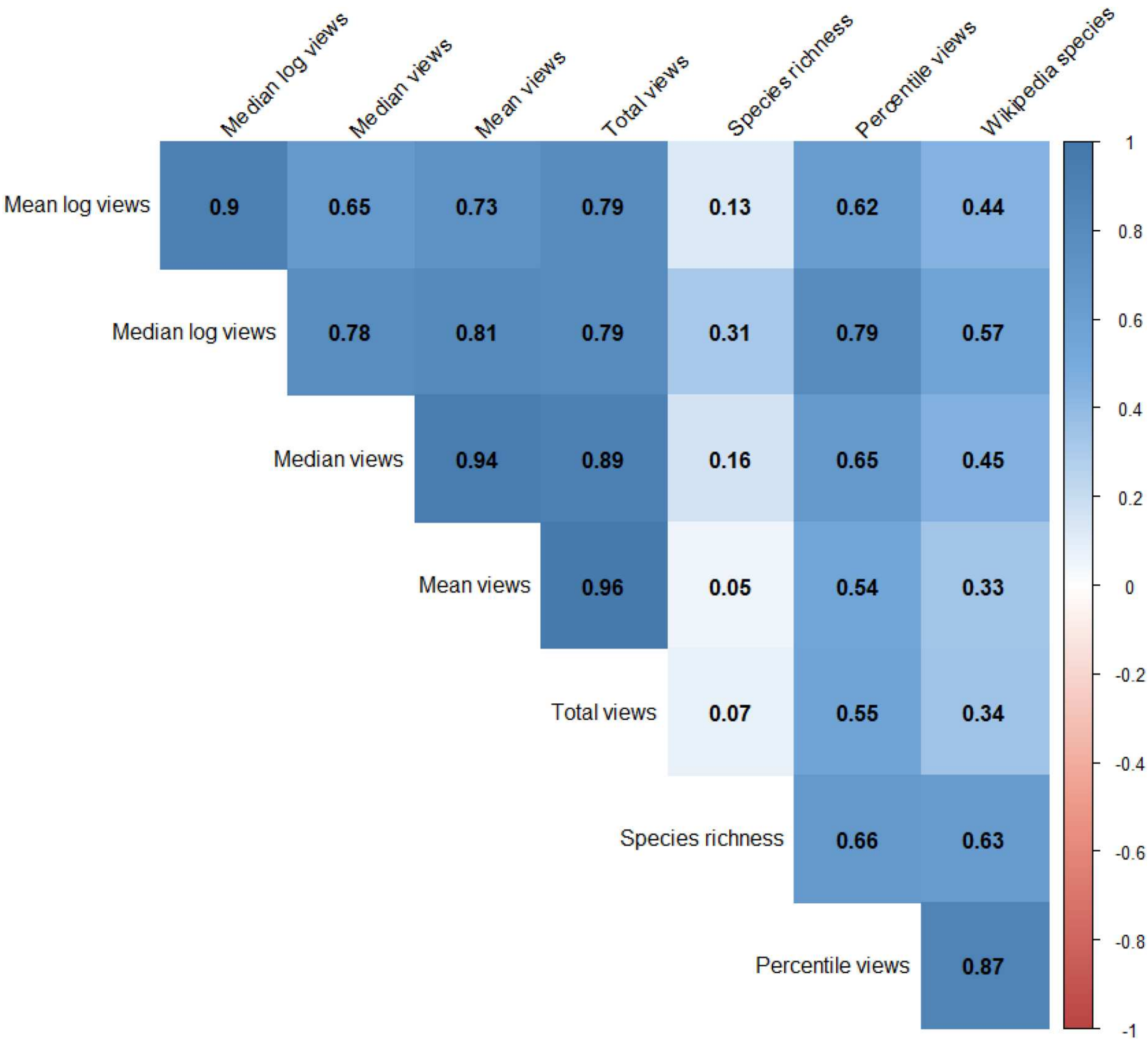

Figure 2. Correlation matrix representing the similarity between species richness and societal interest maps calculated using different metrics of societal interest in species. Map similarity was calculated using Pearson's *r* correlation coefficient.

Table 2. Global Moran's *I* values with z-values and pseudo *p*-values of the English and Italian language group Red Listed Terrestrial mammals Species richness and societal interest maps.

Mammals data set	Moran's *I* value	Z-score	Pseudo *p*-value
Species richness – full data set	0.9846	697.35	0.001
Species richness – English language	0.9848	695.47	0.001
Species richness – Italian language	0.9843	697.01	0.001
Species societal interest – English language	0.9848	671.17	0.001
Species societal interest – Italian language	0.9841	671.70	0.001

vary from −1 to +1, with a positive Moran's I value showing clustering of similar values, a negative Moran's I value indicating clustering of different values, and a value of 0 indicating random distribution. Local Indicators of Spatial Association (LISA) (Anselin, 1995) was used to detect statistically significant local spatial clusters with high values high-high (H-H) or low values low-low (L-L), as well as non-significant values (Figure 5). Global Moran's I and LISA statistics were calculated in GeoDa version 1.18.0 (Anselin et al., 2006). A Monte Carlo simulation of 999 random iterations was used to estimate the pseudo p-value and z-score of the global Moran's I for each summary raster.

3. Results

Our proposed method provides novel opportunities for exploring patterns of societal interest in biodiversity. We adopted several different methods for summarizing societal interest in species, and a comparison of the maps generated by the different methods suggests some similarities between them, but also suggests differences when compared to maps representing species richness (Figure 2). The similarities observed between the different ways to map societal interest are somewhat expected, and mainly driven by the way that different methods weight societal interest data when producing the maps. Maps using raw pageview data, compiled either as a sum or measure of central tendency, also tend to be more similar to each other than to those compiled using log-transformed pageviews or percentile data. This is because transforming the raw data ends up reducing the weight given to more popular species in the mapping process. The different approaches – using raw or transformed data – may be therefore suitable for different applications. Raw societal interest data may be preferable when the aim is to identify areas where remarkably popular species are found for a given language-group. Using the log-transformed data provides a more balanced representation between species richness maps and those identifying the presence of highly popular species, and may thus be most suitable when the aim is to characterize the relative popularity of species assemblages across regions.

On the other hand, the differences observed between maps representing mammal species richness and those depicting language-specific interest in mammal species highlight that species-rich areas are not always those that concentrate most interest. Importantly, these differences are to some extent independent of the metric used. Most mammal species occur in the Amazon region of South America, sub-Saharan Africa and Southeast Asia, which are well known for its biodiversity importance. Yet, for many languages, areas concentrating high levels of interest do not overlap, or overlap only partly, with these species-rich areas. Using Italian, as an example (Figure 3), we can see that the areas gathering most societal interest are concentrated in Europe, where most Italian speakers are concentrated, for most of the methods tested. Similar results can be observed for the remaining languages explored here (see Supplementary Material 2). These results suggest that our proposed method is effective in capturing language-specific dynamics of species interest, although results can vary slightly depending on the method used to capture and summarize societal interest as discussed above.

One potential application of our method is to facilitate a comparison between the areas with species assemblages that gather most interest for different language contexts. Visual inspection of the societal interest maps calculated using log-transformed data, and rescaled to a 0–1 scale for comparability, suggest there are indeed clear-identifiable spatial differences where popular groups of mammal species can be found for each language group (Figure 4). The observed differences were confirmed by calculating the correlation between the maps obtained for the different languages (Supplementary Material Figure S1); the correlation coefficient ranged between 0.96 (For Italian and German languages) and −0.1 (for Portuguese and German languages). As outlined earlier, the maps suggest societal interest tends to be concentrated where most speakers of a given language are concentrated. For languages such as German, French, Italian and Swedish, interest is therefore focused on mammal species found in central and southern Europe. Similarly, interest is concentrated in South America for both Portuguese and Spanish languages, across the palearctic region for Russian, or in east and Southeast Asia for Chinese. The hotspots of interest for English language overlap more with species richness hotspots, likely owing to the fact that English is commonly spoken as a first or second language across most of the globe. The main exception seems to be sub-Saharan Africa; species in the region gather relatively high levels of interest even in languages that are not as commonly spoken locally, such as Chinese, Italian, Russian or Swedish. This may be due to the

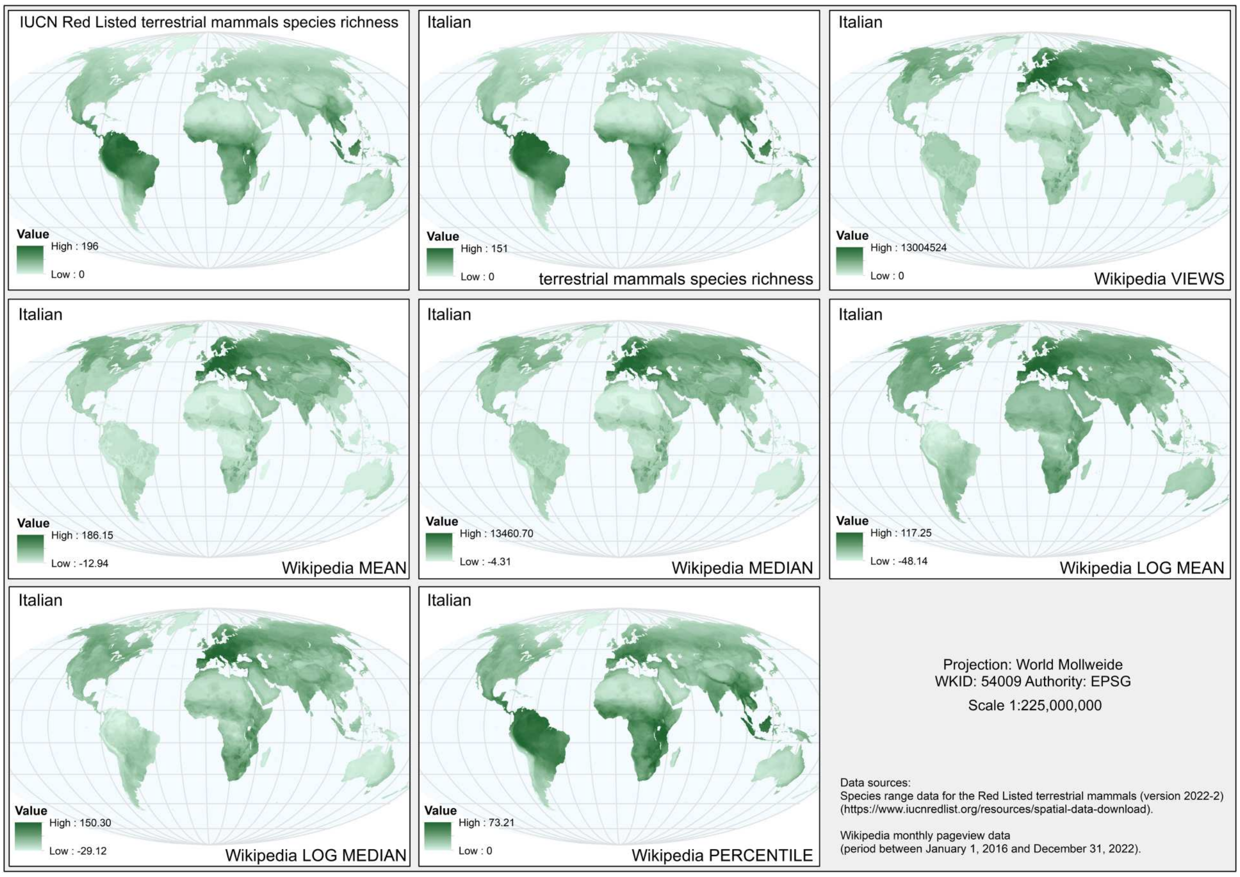

Figure 3. A map showing IUCN Red Listed terrestrial mammal species richness and accompanying maps for societal interest in mammals within the Italian language, based on several Wikipedia metrics: total pageviews, average and median monthly pageviews, log-transformed monthly pageview averages, log-transformed medians, and overall pageview percentiles.

fact that sub-Saharan Africa is the only region in the globe that retains some of its historical megafauna (Galetti et al., 2018), and many of these species are considered broadly appealing and thus tend to generate high levels of public interest. More broadly, each language shows particular areas with high and low interest that seem to be language-specific.

In this context, a more detailed analysis of the spatial patterns associated with species that gather high societal interest can provide further insights on species interest for different language groups. Using English and Italian languages as an example, our analysis revealed that spatial autocorrelation was strongly positive in the output maps produced for both languages (Table 2), indicating high clustering in maps of both mammal species richness and societal interest data. The analysis of species richness clusters using LISA shows that high-high (H-H) species clusters were generally found in the tropics, whereas low-low (L-L) clusters were mostly found in high-latitudes and arid regions in northern Africa, central Asia, Australia, and southern South America (Figure 5). In contrast, high-high (H-H) clusters of species interest for both languages can be found in Europe, sections of Sub-Saharan Africa, and North America. We also identified areas of contrasting interest between English and Italian languages, namely in the Amazonian region, Southeast Asia, Central America, for which higher interest was observed in the English language, and some sections of Siberia, for which interest was higher in the Italian language. These regions are clearly represented in the normalized difference raster map between English and Italian social Interest data. The Amazonian region, North and Central America, Southeast Asia, and sub-Saharan Africa had the greatest societal interest variations between English and Italian language maps. More broadly, when taken together as outlined in the main map associated with this work (Supplementary material 1), the different steps of our analytical workflow provide new approaches and perspectives to explore and study how societal interest for biodiversity varies across space, within and between languages.

4. Discussion and conclusions

The maps here presented show intriguing patterns and clearly demonstrate socio-cultural differences in the interest generated by species assemblages distributed across the world. We propose that such information can be used to further explore and validate the spatial links between societal interest and biodiversity

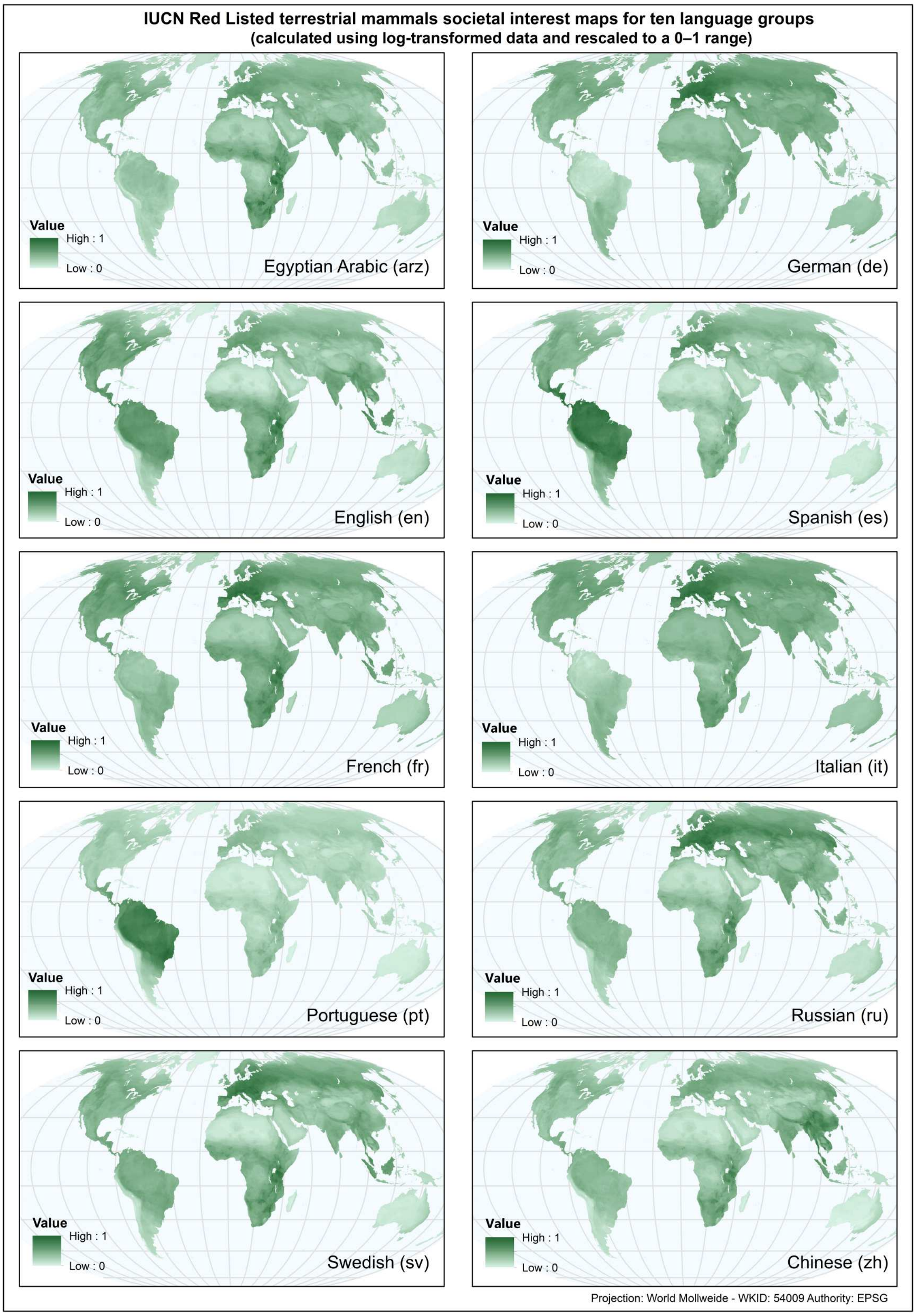

Figure 4. Societal interest maps for IUCN Red Listed terrestrial mammal species, calculated for ten language groups using log-transformed data, standardized on a 0–1 scale. These maps reveal spatial interest patterns, with areas of high and low interest clearly identified across language groups.

conservation, and to support the consideration and inclusion of socio-cultural dynamics in quantitative spatial analyses aiming to inform conservation planning and decision-making (Di Minin et al., 2022). For instance, interest in biodiversity is often linked to human value (Ladle et al., 2019), and such mapping exercises can unlock new instruments to communicate and manage the contributions provided by nature to human societies. Taking an ecosystem services perspective, this could be approached by mapping the cultural ecosystem services flow from areas where biodiversity generates societal interest towards areas

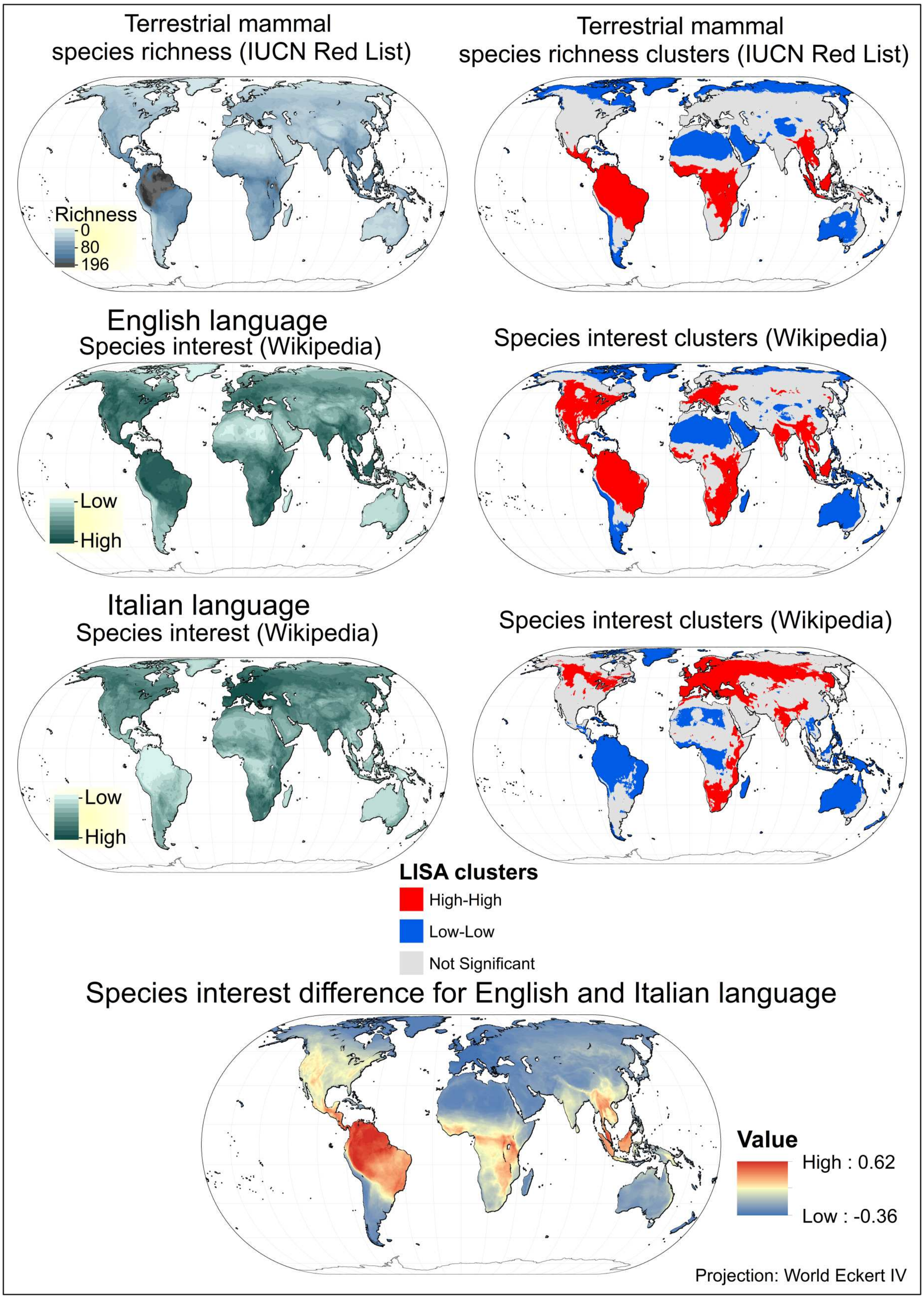

Figure 5. A map illustrating the IUCN Red Listed mammal species richness and societal interest for species in both English and Italian languages. Local indicators of spatial autocorrelation (LISA) are applied to the data of IUCN Red Listed mammal species richness and species societal interest. The cluster types distinguish statistically significant clusters of high values (H–H), statistically significant clusters of low values (L–L), and non-significant values. The bottom map delineates areas of species interest difference between English and Italian languages.

where this interest emerges from (Koellner et al., 2019). Such information can be used to foster synergies between ecosystem services and biodiversity conservation (Cimon-Morin et al., 2013). These approaches can also help to identify potential risk to nature due to lack of support for conservation and prioritize areas for campaigns aimed at rallying conservation support (Guedes-Santos et al., 2021). Other potential uses include identifying suitable areas for eco-tourism beyond those where charismatic species can be found (Hausmann et al., 2017a; Hausmann et al., 2017b), or identifying potentially effective flagships among specific language-groups and societies to maximize the effectiveness of conservation actions (Jepson & Barua, 2015).

While the mapping approaches proposed here hold potential to contribute meaningfully to inform conservation action, they are also affected by important limitations that need to be carefully considered in any potential application. Access to the internet and digital applications suffers from relevant socio-cultural and geographical biases, which reflect on how and by whom the data is generated and can be accessed (Correia, Ladle, Jarić, et al., 2021; Jarić et al., 2020). Furthermore, it is important to remain critical about what is being mapped (Malavasi, 2020). Digital metrics serve as a good proxy for broad societal interest, but they do not directly reveal the drivers (e.g. curiosity, desire, persecution) and valence (i.e. positive or negative) of that interest. Acknowledging these limitations and developing methods to address them will be essential to realize the full potential of these approaches. Yet, despite these limitations, there are also strong indicators that online interest contains information that is relevant for conservation. Species that are popular online are usually those that people feel attached to, either because they are familiar with them due to frequent encounters in the wild (Correia et al., 2016; Mittermeier et al., 2021), or because they possess characteristics that ascribe them strong cultural value despite few encounters in nature (Schuetz & Johnston, 2019), and thus for which conservation efforts are more likely to find broader societal support. More importantly, there is also some evidence that online interest in species is associated with important dimensions of conservation, namely funding allocation (Davies et al., 2018; Mammola et al., 2020). These results support the idea that online data provides relevant information that can be used to inform biodiversity conservation efforts, but further assessing the extent to which online preferences reflect societal preferences and support for conservation will be essential to ensure such contributions are meaningful and effective.

In summary, we propose that the methods presented here provide new ways to explore and visualize societal interest in biodiversity across different cultural contexts, and that the further development of these approaches can provide relevant information to advance biodiversity conservation and sustainability efforts. Possibilities to further develop and explore the approach presented here include testing new methods to summarize societal interest for mapping purposes, and comparing the relative contribution of widespread and narrow-range species in the output maps (similarly to what has been done for species richness maps; e.g. see White et al., 2023). Developing societal interest maps for other biological groups would also open the door for expanding the potential conservation applications of the proposed approach.

Software

The monthly pageview data from Wikipedia underwent processing using R software (version 4.2.2). Spatial data for IUCN Red Listed species range maps were edited and transformed in ArcGIS 10.8, employing a custom polygon-to-raster Python script. Database management tasks were executed in MS Access software. Computational and statistical analyses were conducted using R software (version 4.2.2) with the *terra* and *raster* packages, as well as in GeoDa (version 1.18.0). The final cartographic design was created using ArcGIS 10.8 for map layout, with additional editing in GIMP (version 2.10.38) and PDF-XChange Editor (version 10.4.2) for the development of the Main map.

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Data availability statement

Red Listed species range data for terrestrial mammals are available from the IUCN Red List Spatial Data Download page. Wikipedia pageview data are openly available for download through the Wikimedia API.

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