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Reintroduction biology and the IUCN Red List: The dominance of species of Least Concern in the peer-reviewed literature

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ABSTRACT

Reintroduction biology is a key tool for mitigating the catastrophic reduction in species' ranges, caused by humans over the last 500 years. To assess where reintroduction biology scientific research is targeted, we used text-analysis methods to extract taxonomic and geographic mentions from animal reintroduction-focused articles published between 1990 and 2022 ($n = 2061$). We then related our results to the IUCN's Red List and countries' GDPs. We found most articles were targeted towards species of 'Least Concern', many of which are considered charismatic and/or restore important ecosystem functions. Countries with a higher GDP had a decreased relative proportion of research on imperilled species, with Australia and New Zealand being notable exceptions. The knowledge gained from long-term, well-funded charismatic species (e.g., wolves) has been an important contribution to reintroduction biology, providing vital knowledge that informs reintroductions of other, more threatened, species. In the context of attempting to continue to expand scientific knowledge to an increasing array of threatened species, it is important to acknowledge that some aspects of our knowledge base may be largely derived from a relatively small number of well-studied species. Research focused on reintroductions and restorations of functionally important, but less charismatic, species would be an important contribution to the reintroduction biology knowledge base.

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1. Introduction

In the last 500 years, humans have caused a global wave of biodiversity loss, including extinctions and population declines, akin to those of the previous five mass extinction events (Ceballos et al., 2015; IPBES, 2019). To arrest this loss, scientists have undertaken research to enable the reintroduction of species to areas of their historical range, where they have become locally extinct, and to reinforce the viability of existing threatened species populations (Batson et al., 2015; Taylor et al., 2017). The scientific endeavour of reintroduction biology has been critical in informing the management and improving conservation outcomes in the wider practice of reintroductions. It is important to gain reintroduction knowledge and evidence about species that are most threatened with extinction (Wilson et al., 2016).

The International Union for Conservation of Nature's (IUCN) Red List of Threatened Species is the most comprehensive global data source on the extinction risk of species (IUCN, 2022). It has been crucial in providing information needed by governments, policy-makers, non-governmental organisations, and scientists, to understand the biodiversity crisis and target conservation efforts towards threatened species. The Red List makes for sobering reading; of the more than 134,000 animal, plant and fungus species that have been assessed for the list, 37,000 are threatened with extinction, including over 9500 mammals (26% of all assessed), 15,000 amphibians (41%) and 5000 bird species (13%) (IUCN, 2022).

We reviewed the reintroduction biology scientific literature to assess whether current research efforts are targeted towards threatened species, as assessed by the IUCN. We used modern text-analysis tools to analyse a large global dataset of scientific articles (hereafter 'corpus') on reintroduction biology, spanning from 1990 until 2022, and encompassing 2061 articles (Millard et al., 2020; Evans et al., 2021). We extracted taxonomic and geographic mentions within each article (Millard et al., 2020; Andrew et al., 2021; Evans et al., 2021) and related these to IUCN Red List data on assessed species. We then related these data to the Gross Domestic Product (GDP) of each country, as an index of their capacity to undertake research. Our approach offers a way to analyse a large number of articles whilst also being one of the most objective techniques available – i.e., it lets the data 'do the talking'. To our knowledge, ours is the first study to adopt this approach in reintroduction biology research.

We asked:

1. Which animal taxa are reintroduction biology scientific articles targeted at, and where do they occur?
2. What are the patterns of scientific publication in relation to IUCN threat status?
3. Do countries with higher GDP (as a proxy for capacity to undertake research) target their reintroduction research towards IUCN classified threatened animal species?

2. Methods

2.1. Data preparation

2.1.1. Corpus

On the 16th of June 2022, we searched titles, keywords and abstracts in the Clarivate Analytics Web of Science Core Collection database using a Boolean expression designed to capture a wide range of the published literature on reintroduction biology. We restricted the search to the Web of Science category *biodiversity conservation* and included peer-reviewed articles in English only:

TS = ("reintroduc*" OR "re-introduc*" OR "translocat*" OR "assisted colonisation*" OR "assisted colonization*") AND (WC = ("biodiversity conservation")).

We then screened for missing abstracts and duplicate records leaving 3139 articles.

2.1.2. Taxonomic entity extraction

We used the Global Names Finder v0.17.0 (www.gnrd.globalnames.org) to extract taxonomic mentions in all titles and abstracts in the corpus, including abbreviated records, hybrids, and higher taxa (but not common names). We then used the 'tax_name' function in the 'taxize' package (Chamberlain and Szöcs, 2013) in R version 4.0.2 (R Core Team, 2021), to fetch genera, orders, classes, and kingdoms of all taxonomic mentions, using the National Center for Biotechnology Information database API. We then restricted the articles in our corpus to those that mentioned animals (Metazoa), leaving a final corpus of 2061 articles.

2.1.3. Geographic entity extraction

We used the CLIFF-CLAVIN geoparser to scan all article abstracts and titles for geographic mentions and to then resolve the mentions as the most likely physical coordinates (D'Ignazio et al., 2014; Millard et al., 2020). Mentions were then categorised into 'country' (countries) and 'minor' mentions (specific locations within countries) (Millard et al., 2020). We used a Docker container (Merkel, 2014) to run CLIFF-CLAVIN hosted on the GitHub repository (<https://github.com/havlicek/CLIFF-docker>). We outputted the results to a CSV file and used R for further analysis.

2.1.4. IUCN Red List data

To match species mentions to species on the Red List we first needed to match those mentions to the accepted IUCN Red List species binomial name. We necessarily excluded taxonomic mentions that did not include the full species name. We determined the synonyms for each of the binomial species' name mentions using the synonyms() function in the 'taxize' package (Chamberlain and Szöcs, 2013), the 'rl_synonyms()' function in the 'rredlist' package (Chamberlain, 2020), and the species matching dataset provided in Upham et al.

(2019). We then used the 'rl_sp()' function in the 'rredlist' package to download the most up to date IUCN Red List species list with species' current Red List category. We then matched the species mentions to the Red List categories. For those species that did not appear in the Red List, we categorised them as "Not Assessed". For those species that appeared multiple times in the Red List with differing categories, we used the 'rlhistory()' function in the 'rredlist' package to assign their most up-to-date Red List categories. To determine the number of listed species in total for each Red List category in each country (independent of mentions in the corpus), we used the 'rl_sp_country()' function in the 'rredlist' package.

2.1.5. Gross domestic product data

We used the "WDI" package (Arel-Bundock, 2021) in R (R Core Team, 2021) to extract Gross Domestic Product (GDP) data

Fig. 1. The eight most mentioned species in the corpus and their Red List category. "EN" = Endangered, "VU" = Vulnerable and "LC" = Least Concern. Images were obtained from Wikicommons (https://commons.wikimedia.org/) or Pixabay (https://pixabay.com/) and are classified as being in the public domain.

(indicator = 'NY.GDP.MKTP.CD') from the World Bank's API (The World Bank, 2021). As a simple index of the capacity of a country to undertake research, we calculated the mean GDP from 1990 until 2021 for every country globally.

2.2. Analysis

For both taxonomic and geographic mentions, we treated mentions as 'unique' at the article level. For example, a unique taxon

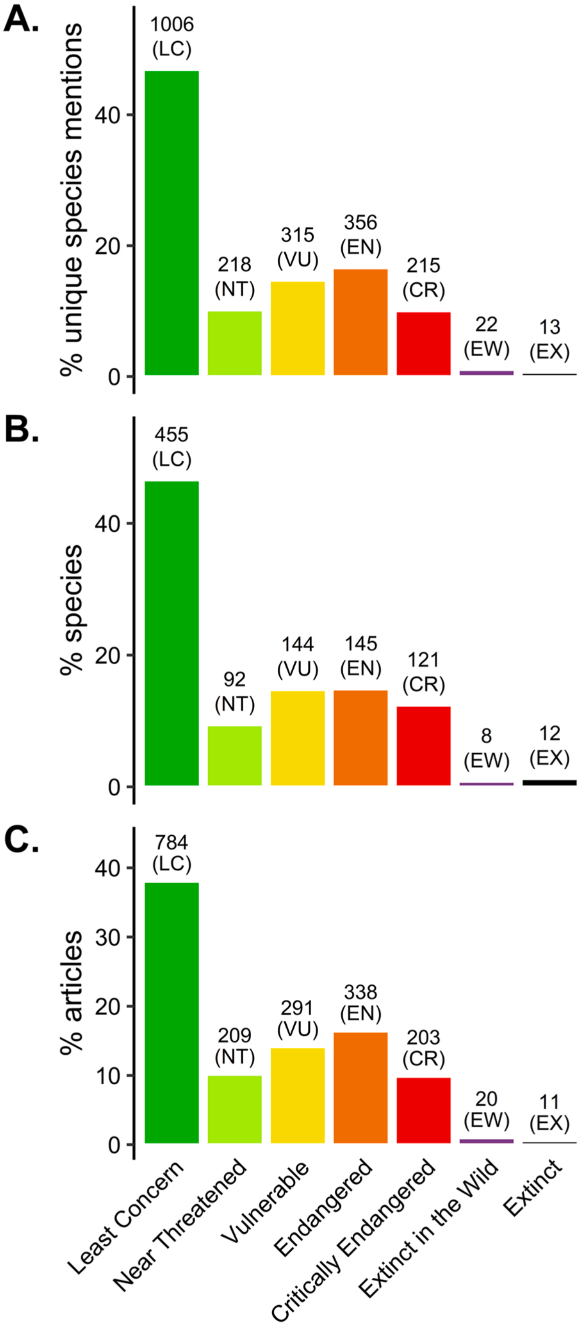

Fig. 2. **A.** Unique species mentions percentages (y-axis) and counts (number above bar) (2145 in total, not including five classified as Data Deficient and 445 not assessed for the Red List) in each of the Red List categories in the corpus. **B.** Unique species percentages (y-axis) and counts (number above bar) (977 in total, not including five classified as Data Deficient and 316 not assessed for the Red List) in each category mentioned across the whole corpus. **C.** The percentage and number (above bar) (1856 in total, not including five classified as Data Deficient and 379 not assessed for the Red List) of articles that contain mentions of species in each Red List category. Colours are the same as IUCN Red List colours.

mention can be the same taxon in multiple articles or can be multiple taxa mentioned within the same article, but it cannot be the same taxon mentioned multiple times within the same article. Similarly, a unique geographic mention can be the same location across multiple articles or can be multiple locations within the same article.

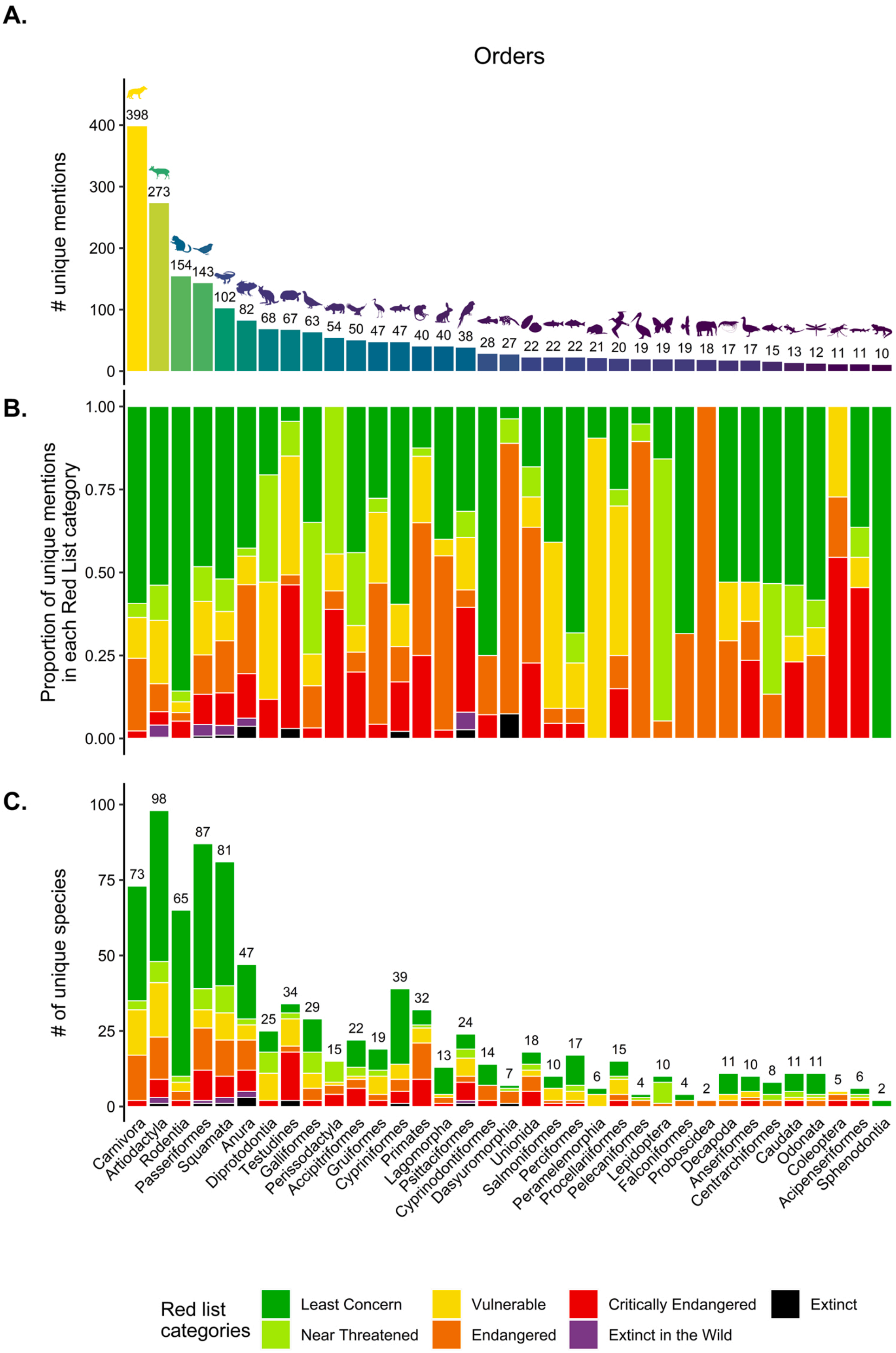

Fig. 3. **A.** Unique taxonomic mentions of orders with ten or more mentions (excluding species not assessed or classified as Data Deficient in the Red List. **B.** the distribution of these mentions according to Red List category. **C.** The number of species mentioned in each order. Silhouettes were sourced from phylopic.org or created by author ME. Colour of bars and silhouettes in A. are scaled with the number of unique mentions. Colours in B. and C. are the same as IUCN Red List colours.

To test where countries with more economic capacity are currently targeting research, we fitted linear models with the log-transformed count of unique species mentions categorized as threatened (Vulnerable [VU], Endangered [EN], Critically Endangered [CR], Extinct in the Wild [EW]) in each country as our response variable. We used the mean GDP (US$) and count of non-threatened species (Least Concern [LC], Near Threatened [NT]) in each country as linear and interactive predictor variables. To test whether countries with more capacity are targeting research to where it is needed the most, we fitted a second model with the same response variable and the mean GDP and the total number of Red List threatened species (including those not mentioned in the corpus) in each country as linear and interactive predictor variables. In both models we rescaled the predictor variables to have a mean of zero and standard deviation of one to enable direct comparisons of their effects. We used the 'performance' (Lüdecke et al., 2021) package in R to check for variable inflation, heteroscedasticity, and normality of the residuals. Other software not mentioned previously used for analyses and plotting include the 'countrycode' (Arel-Bundock et al., 2018), 'ggflags' (Auguie, 2021), 'ggimage' (Yu, 2020), 'ggplot2' (Wickham, 2016), 'maps' (Becker et al., 2018), 'MuMIn' (Barton, 2014), 'revtools' (Westgate, 2019a, 2019b), and 'viridis' (Garnier et al., 2018) R packages.

3. Results

Our text analysis revealed 2595 unique full animal species name mentions (i.e., species counted once per article), encompassing 1298 animal species across 791 genera and 115 orders. Of these species, 977 were categorised in the Red List. Unique species mentions were heavily biased towards the 'Least Concern' Red List categories (Figs. 1–3, Table 1). The most mentioned species were *Canis lupus* (LC), *Cervus elaphus* (LC), *Lycaon pictus* (EN), and *Oryctolagus cuniculus* (EN) (Fig. 1, Table 1). Carnivora, Artiodactyla, Rodentia and Squamata were the four most mentioned orders (Fig. 3).

We revealed 6843 unique geographic mentions, condensing down to 2325 unique country mentions across 160 countries. Of those articles with species that were in the Red List, the US had the most unique country-species mentions by far (630), followed by Australia (170), New Zealand (103), Canada (96), UK (96), South Africa (75), and Spain (61) (Fig. 4). Around two thirds of these mentions in the US (61%) and Canada (68%) and about three quarters in the UK (78%) were species of 'Least Concern' (Fig. 4). Comparatively fewer mentions in Australia (34%) and New Zealand (44%) were species of 'Least Concern' (Fig. 4). In general, countries in Europe over-represented species of 'Least Concern'; most notably, Germany, Georgia, Ireland, and Slovenia (Fig. 4). Countries in Africa and Asia had either a very high or low proportion of unique mentions of species in the threatened Red List categories, but rarely an average number (Fig. 4 & 5).

Overall, more threatened species were researched in countries with higher GDPs, and there was a significant positive relationship

Table 1
The top 32 species according to unique species mentions in the corpus and their Red List Categorisations.

Species name	Common name	Number of mentions	Red List category
Canis lupus	Grey wolf	47	Least Concern
Cervus elaphus	Red deer	27	Least Concern
Lycaon pictus	African wild dog	24	Endangered
Oryctolagus cuniculus	Rabbit	20	Endangered
Vulpes vulpes	Red fox	19	Least Concern
Castor fiber	Eurasian beaver	18	Least Concern
Lynx lynx	Eurasian lynx	18	Least Concern
Mustela nigripes	Black-footed ferret	18	Endangered
Lontra canadensis	Northern American river otter	17	Least Concern
Notiomystis cincta	Stitchbird	17	Vulnerable
Ursus arctos	Brown bear	17	Least Concern
Ovis canadensis	Bighorn sheep	16	Least Concern
Diceros bicornis	Black rhinoceros	15	Critically Endangered
Ursus americanus	American black bear	15	Least Concern
Odocoileus virginianus	White-tailed deer	14	Least Concern
Oryx leucoryx	Arabian oryx	14	Vulnerable
Grus americana	Whooping crane	13	Endangered
Loxodonta africana	African savanna elephant	12	Endangered
Lynx pardinus	Spanish lynx	12	Endangered
Nipponia nippon	Crested ibis	12	Endangered
Bettongia lesueur	Boodie	11	Near Threatened
Bison bison	American bison	11	Near Threatened
Canis lupus baileyi	Mexican grey wolf	11	Least Concern
Cynomys ludovicianus	Black-tailed prairie dog	11	Least Concern
Gopherus agassizii	Agassiz's desert tortoise	11	Critically Endangered
Acinonyx jubatus	Cheetah	10	Vulnerable
Bison bonasus	European bison	10	Near Threatened
Falco peregrinus	Peregrine falcon	10	Least Concern
Lutra lutra	Eurasian otter	10	Near Threatened
Panthera leo	Lion	10	Vulnerable
Petroica longipes	North Island robin	10	Least Concern
Vulpes velox	Swift fox	10	Least Concern

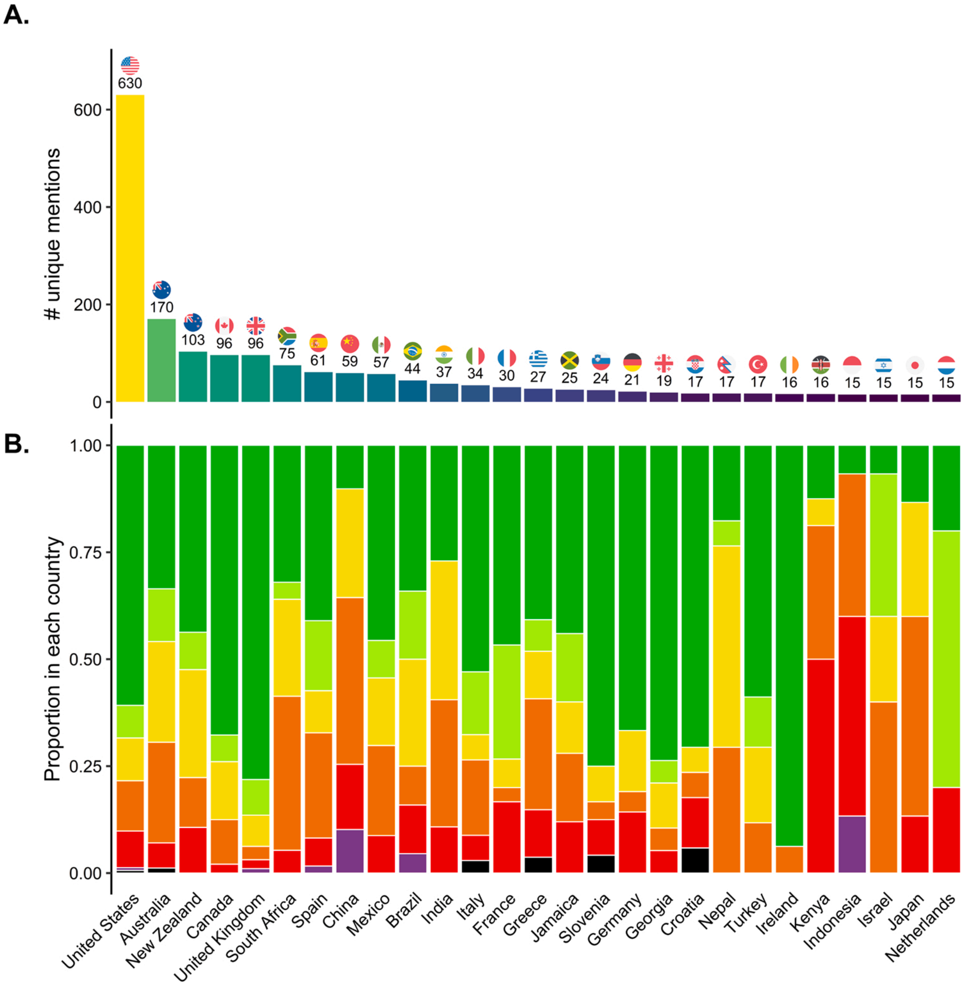

Fig. 4. **A.** Unique species-country mentions and **B.** the proportion of unique species mentions in each category in each country for countries with 15 or more mentions (excluding species mentions not in the Red List or classified as Data Deficient). Colour of bars in A. are scaled with the number of unique mentions. Colours in B. are the same as IUCN Red List colours. Circular flags are plotted using the 'ggflags' package (Auguie, 2021) in R (R Core Team, 2021) and are taken from EmojiOne (CC-BY-4.0 licence, Brad Erickson).

between the number of species studied in the threatened categories and the number of species studied in the non-threatened categories (Table 2). As GDP increased, however, this positive relationship reduced, indicating that higher GDP countries research a lower proportion of threatened species than those with low GDP. Countries with more species listed in the threatened categories had more articles researching those species (Table 3). As GDP increased, this relationship was reduced.

4. Discussion

Our results show that, although many reintroduction biology scientific articles are targeted towards threatened species, there is a large proportion of work focused on species in the 'Least Concern' IUCN Red List category. This proportion increases in wealthier countries, such as the US, UK, and countries in Europe. Further, there is a clear bias towards so called 'charismatic species' such as wolves, big cats, bears, and antelopes (Albert et al., 2018). A large proportion of the world's biodiversity exists in the developing world (Myers et al., 2000), yet it seems that non-threatened species in developed countries have been given priority. On first reading, these patterns might be of concern – they suggest that most knowledge in reintroduction biology is gained from species that are not threatened. It might seem antithetical to the needs of conservation – i.e., that research should be directed towards those species in most need of conservation. There are, however, several subtleties and complexities to this pattern, which warrant discussion as well as a full consideration of the limitations of our study.

Firstly, we should be clear that the intention of our study is not an exploration of all reintroductions globally, and not every article in the corpus is necessarily a reintroduction project per se. Rather, our study is an interrogation of the body of peer-reviewed and widely available scientific work that is focused on the evidence base to improve global reintroduction practices. In this way, reintroduction biology *science* should be considered as separate to reintroduction *practice* (i.e., actual projects on the ground). It is

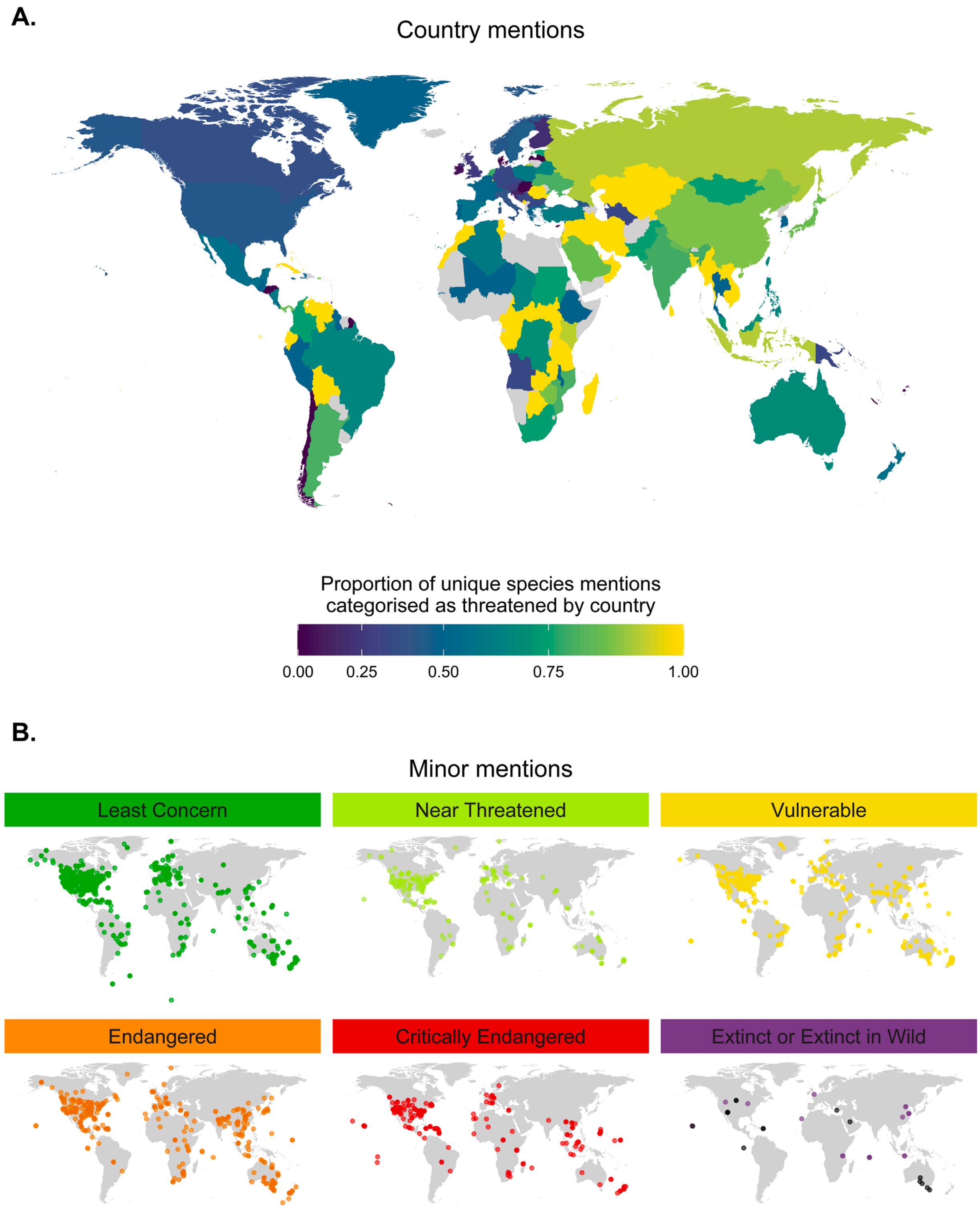

Fig. 5. A. Global map, excluding Antarctica, of the proportion of unique species country mentions that is threatened compared to non-threatened. Grey polygons represent countries with no country mentions. **B.** Unique minor mentions in the same articles as species categorised in the Red List Category. Colours in B. are the same as the IUCN Red List colours.

Table 2
The effects of threatened species mentions against GDP, the number of non-threatened species and their interaction. Threatened species include those listed as 'Vulnerable', 'Endangered', 'Critically Endangered', or 'Extinct in the Wild' in the IUCN Red List. The predictor variable (threatened species mentions) was log-transformed to satisfy the assumption of normality in the model residuals. The predictor variables were scaled (mean = 0, SD = 1) to allow direct comparisons of their effects. ***= Very strong evidence (Muff et al., 2021).

Predictor	Estimate	Standard Error	P value	$F_{(3, 142)}$	R^2
Intercept	1.627	0.064	< 0.001 ***	42.383	0.472
GDP	0.512	0.120	< 0.001 ***		
Non-threatened mentions	1.434	0.205	< 0.001 ***		
GDP:non-threatened mentions	-0.154	0.021	< 0.001 ***		

Table 3
The effects of threatened species mentions against GDP, the number of listed threatened species in the country and their interaction. Threatened species include those listed as 'Vulnerable', 'Endangered', 'Critically Endangered', or 'Extinct in the Wild' in the IUCN Red List. The predictor variable (threatened species mentions) was log-transformed to satisfy the assumption of normality in the model residuals. The predictor variables were scaled (mean = 0, SD = 1) to allow direct comparisons of their effects. *= Moderate evidence, ***= Very strong evidence (Muff et al., 2021).

Predictor	Estimate	Standard Error	P value	$F_{(3, 142)}$	R^2
Intercept	1.536	0.069	< 0.001***	28.777	0.378
GDP	0.694	0.155	< 0.001***		
Threatened in country	0.316	0.070	< 0.001***		
GDP:threatened in country	-0.119	0.057	0.039*		

important to ask, therefore, whether a bias towards charismatic and 'Least Concern' species in reintroduction biology science should be of any concern. What follows is discussion of 1) the reasons why there may be a bias towards Least Concern species in the reintroduction scientific literature, and 2) whether this bias should be of any concern to the broader goal of species conservation.

4.1. Bias

4.1.1. Taxonomic bias

The corpus was dominated by vertebrates, many of which are considered charismatic (Albert et al., 2018). Further, many of these charismatic species are classified as of 'Least Concern' in the Red List (Table 1). For example, the first and second most mentioned species were *Canis lupus* 'LC' and *Cervus elaphus* 'LC', both of which are classified as Least Concern (Table 1). There is recognition in the wider conservation literature, that through concentrating on charismatic and easily-studied species, conservation suffers from taxonomic bias, a prioritisation towards a select group of species (Bonnet et al., 2002; Ducarme et al., 2013). It appears that this may also be the case for the reintroduction biology scientific literature.

4.1.2. Geographic bias

Our analysis revealed that most research is undertaken in countries with high GDP. This bias is expected. The bulk of academic institutions that produce scientific output are based in countries with high GDP (Amano et al., 2016). It follows, therefore, that much research is likely dedicated to well-studied species in countries where these institutions are based (dos Santos et al., 2020). This trend towards familiarity might reflect the ways in which researchers overcome many of the challenges of conducting science. The pressure to publish within short time frames, especially for early-career researchers (Hughes et al., 2017), likely leads to an outputs-orientated approach, rather than an outcomes approach, whereby research is focused on the number of articles rather than conservation effectiveness (Parsons and Cigliano, 2020). Further, the costs, logistical challenges, and sometimes dangers, of conducting research on threatened species in other countries, makes this kind of research, in light of the 'publish or perish' academic culture, far less attractive than research on local, more easily studied, species.

4.1.3. Global status hides local reasons for reintroductions

The choice to reintroduce a species is not necessarily driven by their global threatened status. The IUCN Red List is necessarily conducted at a global level, leading to a simplification of any given species' regional status. Reintroductions may target locally threatened or extinct species which are still common elsewhere and, therefore, of 'Least Concern' on the Red List. The red kite (*Milvus milvus,* 'LC'), for example, was once common across England, Scotland, and Wales, but became a victim of persecution and the harmful effects of agricultural insecticides leading to near extirpation throughout the UK by the 1930s (Molenaar et al., 2017). From 1989, individuals of this species, which was still common in Europe, were translocated from Sweden, Spain, and Germany to various regions in the UK. Now its population is increasing across much of the UK with an estimated population of over 3000 pairs (Molenaar et al., 2017; IUCN, 2022). This highlights the weaknesses of global-level metrics and maps which tend to overlook the local- and regional-level conservation status of species (Wyborn and Evans, 2021). Indeed, Wyborn and Evans (2021) argue that conservation should be conducted as a bottom-up endeavour because at the regional and local levels, research can be tailored for its specific context.

4.2. Should we be concerned about the bias?

4.2.1. Ecological function

The large, charismatic vertebrates that dominate the corpus tend to have disproportionate effects on ecosystems when compared to smaller species as top-order predators (e.g., Grey Wolf, *Canis lupus* (LC)) and ecosystem engineers (e.g. Eurasian beaver, *Castor fiber* (LC)) (Sergio et al., 2008; Ducarme et al., 2013; Albert et al., 2018). Indeed, reintroductions may be undertaken to restore ecological function by using keystone or ecosystem engineer species to elicit cascading effects that benefit other species or help restore ecosystems (Byers et al., 2006; Zamboni et al., 2017; Palmer et al., 2020; Ross et al., 2020). Consequently, these types of reintroductions, often referred to as 'trophic rewilding' (Bakker and Svenning, 2018), can benefit threatened species and communities regardless of whether the reintroduced species is itself threatened (e.g., wolves at Yellowstone, described above, Laundré et al., 2001, Ripple and Beschta, 2012). Reintroductions of apex predators are now advocated to mitigate the impacts of mesopredators on vulnerable prey populations (Elmhagen et al., 2010) and herbivores on vulnerable ecosystems (Ripple and Beschta, 2012). Likewise, non-predator ecosystem engineers can benefit other species and ecosystems, regardless of their threatened status. For example, the Eurasian beaver (*Castor fiber*, 'LC') is an ecosystem engineer whose reintroduction was beneficial for threatened riparian ecosystems with flow-on effects to other species (Law et al., 2017). It might be appropriate, therefore, for the IUCN Red List to provide categories or ratings for each species based on their importance to the function of the ecosystems in which they inhabit.

It should be noted, however, that there were very few mentions of other functionally important groups. For example, there were very few reintroductions of insect species in the corpus, despite them being the most diverse and abundant eukaryotic group that are fundamental to the majority of ecological processes that humans depend on (Scudder, 2017). Insects are, however, difficult to study because they are small, cryptic and knowledge about them is poor compared to larger, more charismatic species (Ford et al., 2017). Reintroduction biology research, therefore, might contribute more broadly to biodiversity conservation if there was more work focussed on insects and other less charismatic species.

4.2.2. An opportunity to gain knowledge without risking threatened species

Using 'Least Concern' species for reintroduction biology research provides the chance to gain valuable discoveries and knowledge without exposing threatened species to unnecessary risk. Reintroduction research needs to pose the least risks to the threatened species of concern whilst simultaneously gaining the most scientific evidence to maximise ultimate chances of success, i.e., the approach must be parsimonious (Wilson et al., 2020; Evans et al., 2022). A key predictor of success in reintroduction programs is the number of individuals released (Morris et al., 2021), but by definition a rare species on the IUCN Red List has few individuals available for reintroduction projects. Some might argue that experimental reintroductions and trials that involve controls and treatments impose undesirable risks to threatened species (Evans et al., 2022). Further, the most scientifically robust projects (i.e., those with many individual animals) would likely not be approved by relevant regulatory authorities for this reason (assuming enough individuals could actually be sourced – which is rarely the case). This sets up a 'Catch-22' situation for rarer species, i.e., fewer individuals mean fewer founders for reintroduction, which would be riskier and less likely to be attempted or approved by regulators. A consequence is that uncertainty and lack of knowledge about how to achieve reintroduction success continues without preliminary small cohort experiments and trials being conducted. This might lead to a species never being restored, or a "full" reintroduction with large numbers of founders of a threatened species ultimately proceeding without the scientific knowledge to mitigate risk thus risking ultimate failure. Such an approach risks missing learning opportunities and using far more individuals than would have been used in a series of small cohort experiments and trials. In some cases, however, it is possible that lessons learned from reintroductions of one species can be applied to another species (e.g., swamp buffalo (*Bubalus arnee*) and greater one-horned rhinocerous (*Rhinoceros unicornis*), Jhala et al., 2021). Clearly, therefore, using 'Least Concern' species for reintroduction biology research is much less risky and offers the chance to gain valuable discoveries and knowledge on techniques that can be transposed to threatened taxa. It is not clear, however, whether this work lowers the risk when findings are applied to more threatened species – where species-specific knowledge may be essential to achieve reintroduction success.

4.2.3. Providing opportunities that increase orientation towards conservation

Cases like the red kite are very important for conservation from a sociological perspective. Reintroductions can play a role in raising awareness for the plight of biodiversity on the planet. If a community can witness the successful establishment of a regionally extinct species, then this creates awareness that humans can mitigate or even recover biodiversity loss, which, in turn, might influence more people to act. This well-established principle is the basis for community-based conservation programs, which aim to promote local community participation in the management of natural resources (Mehta and Heinen, 2001; Baruch-Mordo et al., 2009; Störmer et al., 2019; Carpenter, 2022; Szydlowski, 2022). Ultimately, increased awareness, which includes increased positive attitudes towards threatened species, should theoretically lead to improved conservation outcomes.

Successful reintroductions, regardless of the global threatened status can also mitigate a 'shifting baseline syndrome' (Manning et al., 2006; Soga and Gaston, 2018), where people's expectations for their environment are established during childhood and can degrade over multiple generations where environmental conditions are worsening (Miller, 2005). By providing *opportunities* for people to experience a more intact assemblage of biodiversity, reintroducing species might improve the *orientations* of people to preserve all types of biodiversity (Soga and Gaston, 2016). In this way, charismatic species, such as the red kite and the wolf, can be of particular benefit to conservation more broadly by encouraging people to act (Ducarme et al., 2013; Albert et al., 2018).

4.2.4. Appropriateness of reintroduction

Much of the developed world has a long history of biodiversity loss due to overexploitation, habitat loss, and urbanisation from historic development, particularly during the industrial revolution. Parts of the developing world, however, still retain remnant habitats and species (Myers et al., 2000). The most appropriate conservation actions in some regions, therefore, might be to sustain existing species' habitats, abundance, and resilience, avoiding the need for reintroductions in the first instance. Focussing efforts on in-situ conservation and habitat protection might achieve greater conservation outcomes in some situations. However, the value of reintroduction in the right circumstances has been shown globally, so when it is the appropriate tool, it should be supported, and publication of resulting science facilitated.

Reintroductions can be challenging, and expensive, and technical expertise is required to develop a founder population, understand the target species' breeding requirements and population dynamics, and establish monitoring regimes. Further, reintroduction projects need to ensure that the threats that may have led to the initial decline or local extinction of a species are reduced before any translocations occur (IUCN/SSC, 2013). In particular, poaching makes reintroduction attempts difficult (Byers et al., 2006; Jhala et al., 2021), a common problem in the developing world (Le Roex and Ferreira, 2020). Greater support for reintroduction science from high GDP countries for developing countries could help increase the amount of reintroduction science that is published and would provide an increase in valuable case studies.

Other threats also need to be grasped before reintroductions take place. For example, despite a concerted 30-year reintroduction effort to conserve the golden lion tamarin (*Leontopithecus rosalia*, 'EN') in Brazil, fragmentation of its habitat through the expansion of public infrastructure remains a substantial threat (Lucas et al., 2019). Threats like these have likely led to a recent increase in risk-aversion in reintroductions (Morris et al., 2021).

4.3. Limitations to our study

Our approach is a large-scale and empirically based overview of the reintroduction biology scientific literature enabled by the application of text analysis tools. We acknowledge that we have not delved into the finer patterns we found, rather, we present a global overview that is exceedingly difficult to achieve using conventional manual review techniques.

We also acknowledge that there is a large amount of grey literature on reintroductions, in the form of 'file-draw' and 'practitioner-generated' research, that we did not include (Haddaway and Bayliss, 2015), such as the IUCN's Global conservation translocation perspectives (Soorae, 2021). Additionally, there is a considerable proportion of research that is not in the global academic *lingua franca* (Amano et al., 2021). The potential impacts of biases driven by language are recognised in the literature (Christie et al., 2021a), and access to non-English research has increased (e.g., TRANSLATE - https://translatesciences.com/). There is also a significant delay in progressing conservation research through the peer-review process to publication, with a mean publication delay of over three years in conservation science (Christie et al., 2021b), meaning there is likely a large backlog of unpublished data at any one time. Yet, peer-review is the standard in science. An article that has been through peer review has been stress-tested for integrity, quality, scientific robustness, and accuracy, and as a result is afforded weight as a valuable addition to knowledge that is broadly available to the scientific community (i.e., accessible in the reintroduction biology scientific corpus). Thus peer-review work has an important role in managing risk when reintroducing threatened species. Grey literature can provide highly valuable insights (especially in the absence of any other information); however, it has often not been through the rigours of scientific peer review (or it is often hard to verify when it has) and access to a global audience can be limited. Consequently, the weighting given to grey literature as conservation evidence versus peer-reviewed literature should be considered.

It is important to recognise that a mention of a species within an article does not necessarily correspond to the species of conservation concern. For example, reintroduction research is often focussed on species that cause a threat to the reintroduced species, such as the red fox and feral cat in Australia.

4.4. Conclusions

Our data show a clear pattern, as has previously been recognised in conservation science (Wilson et al., 2016), that reintroduction biology research seems targeted to species of 'Least Concern', especially in the developed world. Indeed, other studies have revealed that biodiversity conservation is hindered by a severe lack of context-specific evidence (Christie et al., 2020, 2021a, 2021b). The knowledge gained from long-term, well-funded charismatic species (e.g., Grey wolves. *Canis lupus* LC) has been an important contribution to reintroduction biology. However, in the context of attempting to continue to expand scientific knowledge to an increasing array of threatened species, it is important to acknowledge that some aspects of our knowledge base may be largely derived from a relatively small number of well-studied species. Reintroductions and restorations of functionally important, but less charismatic species would be an important contribution to both biodiversity conservation and the reintroduction biology knowledge base. The emergence of 'trophic rewilding' (Bakker and Svenning, 2018) might suggest that there will be effort directed towards reintroductions of ecosystem engineers and keystone species. Reintroduction biologists, therefore, will need to invest in knowledge about threatened species that are impacted (positively or negatively) by the reintroduction of such species. Greater support and collaboration of conservation scientists based in high GDP countries for colleagues working in countries with less resources could help in addressing the imbalances we have found in the reintroduction biology literature. The unavoidable need for parsimony in reintroductions impacts progress towards successfully reintroducing threatened species. The challenge of needing scientific evidence on rare and threatened species could be overcome by using innovation (Black, 2021), iteration (e.g., Wilson et al., 2020), and long-term thinking. That is, biologists might need to achieve reintroductions in small, incremental steps where risk is managed adaptively as knowledge is accumulated.

Declaration of Competing Interest

The authors declare no competing interests.

Data availability

Data will be made available on request.

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Open research statement

Data used in this study were accessed from the public domain. However, datasets used for plotting and analyses are available at figshare.com (https://doi.org/10.6084/m9.figshare.20359395.v1).

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