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Impact of an IUCN national Red List of threatened flora on scientific attention

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ABSTRACT: Red Lists are thought to attract attention to the conservation of threatened species. Determining the impact of these lists on the attention of scientists is a matter of consequence for biodiversity conservation. We evaluated trends in mentions of Brazilian angiosperm plants in the biodiversity conservation literature and tested the effect of the Red List of Brazilian Flora (RLBF) publication on these mentions. We collected mentions in the literature available in Google Scholar from the years 1990–2020, for 2449 Brazilian angiosperm species assessed in different IUCN categories. We used a Bayesian structural time-series method to test the effect of the RLBF publication on the number of mentions for the set of species in the IUCN categories, angiosperm families, and plants of commercial interest. The results showed a gap in mentions for many threatened and Data Deficient species in the scientific literature. We also found that the mentions were biased toward species of commercial interest and were unrelated to their threat status. Publication of the RLBF positively affected the number of mentions for IUCN threat categories and for more than half of the angiosperm families. These results were obtained after a few species of commercial interest were excluded from each treated group. This study suggests that the Red List assessments are essential to determine priorities for resource allocation to scientific activities. However, this effect was not sufficient to reduce the bias in scientific attention. Our findings support the need to stimulate more effective programs to fund research on threatened plant species.

KEY WORDS: Plants · Bibliometric analysis · Data Deficient · Threatened species · Conservation priorities · Extinction risk

1. INTRODUCTION

Research conducted by the scientific community is essential to increase our knowledge of threatened species. The available information on taxonomy, biology, population status, threats, and protection measures undergirds action and management plans, which are needed to change the threat category of conservation targets to the IUCN status of 'Least Concern' (Baillie et al. 2004, Pullin et al. 2004, Sutherland et al. 2004). However, research bias, i.e. the disproportionate investigation of certain species more than others, is a well-known problem in the study of conservation (Clark & May 2002). Several authors have suggested that research efforts may be geographically, taxonomically, and phylogenetically biased (Moustakas & Karakassis 2005, Lawler et al. 2006, Brodie 2009, Zhang et al. 2015, Donaldson et al. 2016), and unrelated to the threat status of the studied species (Murray et al. 2015). In particular, species that are threatened or facing a high probability of extinction may attract proportionately less research effort than non-threatened species, as has been shown for sturgeon and marine mammal species (Jarić & Gessner 2012, Jarić et al. 2015). Conversely, charismatic threatened species in habitats in the developed world and those that have socioeconomic or socio-cultural value dominate the scientific literature (Amori & Gippoliti 2000, Sitas et al. 2009).

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The Red List of Threatened Species (RLTS) assembled by the IUCN is a robust system for compilation, synthesis, and dissemination of species data (https://www.iucnredlist.org/en). In summary, the list includes 9 categories, ranging from 'Not Evaluated' to 'Extinct', with intermediate categories reflecting both the state of knowledge and the level of threat (Baillie et al. 2004). Among the numerous contributions to conservation strategies is the capacity of the RLTS to influence the allocation of resources to species in the most critical categories (Rodrigues et al. 2006), including research efforts aimed at increasing knowledge of the species of concern. Thus, the determination of the impact of RLTS publication on research efforts is a matter of consequence for biodiversity conservation (Betts et al. 2020). Recent studies have tested this possible contribution; for example, the IUCN global Red List assessment was pivotal in attracting research efforts to several groups of animals, although this effect was most pronounced for species classified as Data Deficient (Jarić et al. 2017). Similarly, the creation of the list of the 'World's 25 Most Endangered Primates' increased the research efforts mentioning the listed primates (Acerbi et al. 2020).

Brazil, a globally recognized center of biodiversity, houses approximately 37 000 vascular plant species, of which slightly more than half are considered endemic (Flora do Brasil 2020). This number represents 9–11 % of all known vascular plant species (Nic Lughadha et al. 2016, WCVP 2020). The country is also considered one of the highest priorities for flora conservation (Myers et al. 2000). To illustrate, in 2013 the IUCN Red List authority in Brazil, the National Center for Flora Conservation at the Rio de Janeiro Botanical Garden (CNCFlora-JBRJ), published the Red List of Brazilian Flora (hereafter RLBF). This list included 2097 vascular plant species assessed in the IUCN threat categories Critically Endangered, Endangered, and Vulnerable (Martinelli & Moraes 2013). The total of threatened plants represented an addition of 1641 species to the previous Official List of Endangered Species of the Brazilian Flora, produced in 2008 (MMA 2020). This result positioned Brazil as one of the countries with the highest number of threatened plants (IUCN 2021).

Brazil harbors much of the global biodiversity that is of interest to research groups dedicated to conservation biology; however, few attempts have been made to analyze the global research effort on threatened plants. Among the biodiversity conservation studies assessing the research effort directed toward Brazilian taxa (Frehse et al. 2016, de Barros et al. 2020, Guerra et al. 2020, Teixido et al. 2020), only a few dealt with threatened animals (Gomes 2016, Tourinho et al. 2020), and only exceptionally were threatened plants addressed (Ribeiro et al. 2016). Additionally, the propensity of biodiversity scientists to undertake studies following the publication of a national Red List has not been tested, indeed comprehensive studies to determine this effect are recent and deal only with groups of animals (Jarić et al. 2017, Acerbi et al.2020).

Here we used a bibliometric approach to evaluate trends in mentions of Brazilian angiosperm plants in the biodiversity conservation literature and to test the effect of the RLBF publication on these mentions. Specifically, these investigations were conducted for the sets of species in different IUCN categories (Critically Endangered, Endangered, Vulnerable, Near Threatened, and Data Deficient), species of commercial interest, and angiosperm families.

2. MATERIALS AND METHODS

2.1. Selection of species

The RLBF comprised an assessment of 4582 vascular plants species (Martins et al. 2018). However, we included only angiosperms for our study list. In addition, for each angiosperm species, we excluded those that changed IUCN categories or their taxonomic status, i.e. the merging of several species into a single species ('lumping'), or the division of a species into 2 or more species ('splitting') during the period from 2013 to January 2021. Thus, we ensured that the scientific attention of the species studied was not affected by these types of recategorizations (Jarić et al. 2017, Tessarolo et al. 2017). Ultimately, 2449 angiosperm species were included in the dataset. Of these, 358 angiosperm species were assessed as Critically Endangered (CR), 912 as Endangered (EN), 422 as Vulnerable (VU), 322 as Near Threatened (NT), and 435 as Data Deficient (DD). We built a list with the relevant synonyms of the study species, following the Brazilian Flora 2020 database (Flora do Brasil 2020), as this combination of accepted names and synonyms (Table S1 in the Supplement at www.int-res.com/articles/suppl/n046p175_supp.pdf) can significantly increase the accuracy of the data recovered (Correia et al. 2018).

We also selected Brazilian angiosperm species categorized as Least Concern (LC) as the control group for the analyses, because we considered the baseline trend of frequency of mentions over time (see Section 2.3). For this category, we selected 1276 species that were submitted to the same exclusion criteria as the species in the dataset. These species were evaluated from the IUCN criteria, although they are not mentioned in the RLBF. We used information from the CNCFlora-JBRJ database (CNCFLORA-JBRJ 2020) to compile this list.

We conducted a systematic search for each scientific name in papers (Shanley & Medina 2005, Mendonça 2006, Coradin et al. 2011, 2018, Vieira et al. 2016) and a database (CNCFLORA-JBRJ 2020) that compiled information on species with current or potential economic value, for instance, species used for medicinal, timber or handicraft purposes or those which are edible. As a result, 96% (2353 of the 2449) of the study species were classified as 'unusable' for commercial purposes, and 4% (96 species) as 'usable'. For the control group, 91.7% (1170 of 1276) were classified as 'unusable' and 8.3% (106 species) as 'usable' (Table S2).

2.2. Scientific attention

We chose the Google Scholar database as a bibliometric indicator of the species. This database also includes comprehensive gray literature (e.g. systematic reviews, meta-analyses, or synopses resulting from unpublished dissertations and theses), and this kind of content has provided evidence to inform many conservation decisions (Haddaway & Bayliss 2015, Calver et al. 2017). Furthermore, Google Scholar retrieves a wider range of literature when the content involves endemic species, compared to Scopus and Web of Science (Calver et al. 2017). Last, Brazil has the fifth largest number of university domains indexed in this database (Aguillo 2012), which increases the range of publications in Portuguese and reduces the effect of the massive number of North American, European, and Asian publications found in other databases (Holmgren & Schnitzer 2004, Li et al. 2018).

We conducted a sequence of searches in Google Scholar to quantify scientific attention given to a species. In the search terms, we associated each individual scientific name with the set of terms 'Conservation' AND 'Status' AND 'Threats' AND 'Action'. We used these terms because they are key words in biodiversity conservation literature (Salafsky et al. 2008). In addition, they recorded more data from the scientific literature on conservation of threatened species reported by Google Scholar than other search terms (see our previous controlled experiment in Text S1 for more detail). We also conducted the same searches with the Portuguese language translations of the terms. The searches were also repeated for each synonym. The search results (hereafter, number of mentions) from Google Scholar were used as a measure of scientific attention. The period analyzed was 1990 through 2020, i.e. a total of 31 yr of observations. The search was last updated in March 2021.

2.3. Method for detecting effects

We applied a Bayesian structural time-series (BSTS) model (Brodersen et al. 2015) to test for effects of the RLBF publication on the number of mentions of the listed species in the biodiversity conservation literature. The BSTS model quantifies the impact of an event on a response metric of interest. This method combines concepts from time-series models and synthetic control methods to construct a synthetic counterfactual time series from a donor pool of control cases. In summary, the model requires one or more time series from a set of candidates that are classified by a matching algorithm as similar enough to the treated time series in the pre-treatment period; here, before the RLBF publication. Thus, using BSTS, the relationship between the matched series (hereafter, the control group) and the treated series is modeled on the pre-treatment period and used to predict the post-treatment series of the treated group. This post-treatment prediction is counterfactual to the treated series, under the scenario where no intervention was applied. The difference between the predicted counterfactual time series and the actual data is a measure of the impact of the intervention (Schmitt et al. 2018).

We used the 'Causal Impact' package, version 1.2.4 in R software version 3.6.2 (R Core Team 2019) to calculate the BSTS model. We selected 3 measures provided by the package to estimate the difference between the treated series and the counterfactual series: (1) absolute average effect (i.e. the average yearly difference); (2) absolute cumulative effect (i.e. the average difference of the entire post-intervention period); and (3) relative effect (i.e. the percentage of the difference of the entire post-intervention period). To quantify the error imposed on an effect size, the package provides the confidence interval for each estimation. In general, we consider there to be an effect (increase or decrease) if the confidence interval of the difference between the treated and counterfactual series does not include zero, which means we consider there to be no effect if the confidence interval is centered around zero. Thus, the tests were adjusted to a 99% confidence interval. To test the probability of obtaining any causal effect, the package also provides posterior tail-area probabilities, which can be interpreted as classical p-values, i.e. $p = 0.05$ means a 95% chance of obtaining this effect by chance (see Brodersen et al. 2015 for more detail).

The analysis period of our study was subdivided into pre-intervention (1990 through 2012) and post-intervention (2014 through 2020), considering the year of RLBF publication (2013) as the axis of our causal analysis. We followed the recommendation of a pre-intervention period of approximately 2 or 3 times the length of the post-intervention (Brodersen et al. 2015). The post-intervention interval covers a reasonable time for scientists to respond to the Red List publication (e.g. Jarić et al. 2017).

We used 1276 LC angiosperm species as a control group. This decision was based on 2 fundamental premises of the BSTS model (Brodersen et al. 2015). The first assumption is that the time series values of the control group will not be affected after the intervention. Thus, it is reasonable to assume that the number of mentions in the literature for LC species will be indifferent to the publication of the Red List. Research attention directed at this group is related to other factors, such as their charisma, economic value, suitability for use as model species, and accessibility (Jarić et al. 2019). The second assumption is the existence of a statistical relationship between the treated and the control group during the pre-intervention period.

2.4. Data analysis

First, the BSTS analyses were designed for the number of mentions of species in the different IUCN categories (CR, EN, VU, DD, and NT). For each dataset, we built a time series using an average number of mentions per species for each year from 1990 through 2020. For example, to construct the time series for the CR dataset, we computed the average number of mentions of the 358 species in this category for each year from 1990 through 2020. Second, we also built a time series for 39 angiosperm families in the RLBF (32.5% of the 120 families). The families were selected because they recorded at least 10 species listed as threatened and were therefore considered the most important. Third, new time series were created for the same IUCN categories and angiosperm families, using only the 'unusable' species. This approach avoids a confounding factor caused by the possible bias in mentions toward a few commercial species. For all tests, which totaled 88, we used the average number of mentions of the LC category as the control group.

We used Wilcoxon-Mann-Whitney *U*-tests for pairwise comparisons between the average number of mentions of species in different IUCN categories in the post-intervention period 2014–2020. The tests were also done using the sets of unusable and usable species within each category. Non-parametric tests were used because some variables did not show a normal distribution based on a Shapiro-Wilk test.

3. RESULTS

We recorded 33898 mentions in the biodiversity conservation literature for the species studied from 1990 through 2020. However, 40.4% (684 of 1692) of threatened angiosperm species (CR, EN, and VU) had only 1 or no mention during the entire study period. We found these parameters for 38.8% (125 of 322) of species for NT. This was especially pronounced for DD with 62.7% of species (273 of 435). In contrast, 27.7% (354 of 1276) of the LC species had only 1 or no mentions.

The BSTS indicated no effects on mentions after RLBF publication for IUCN threatened categories (CR, EN, and VU), DD, and NT species during 2014–2020 (Table 1). On the other hand, positive effects were observed in the threatened categories when the few species of commercial interest were excluded from the analysis (unusable datasets, Table 1). For the CR (unusable) species, the mentions showed an increase of 0.407 (99% CI: 0.122, 0.664) compared to their counterfactual series throughout the entire post-intervention period (absolute cumulative effect). This increase was equivalent for EN (unusable) species with 0.400 (99% CI: 0.0542, 0.7) more mentions. The positive impact for the VU (unusable) species was most prominent as the mentions increased by 0.87 (99% CI: 0.527, 1.23); in relative terms, this represents an increase of 57% (99% CI: 35%, 80%). There was no effect on mentions for the DD (unusable) species (0.217; [99% CI: −0.0098, 0.427]). The test for NT (unusable) species was not significant ($p > 0.05$) and is not subject to interpretation.

We reported positive effects for 17 angiosperm families, no effects for 14, and negative effects for 8 (left panel in Fig. 1). The tests using only unusable species indicated positive effects for 20 families,

Table 1. Outcomes of causal impact analysis of the number of mentions in biodiversity conservation literature after publication of the Red List of Brazilian Flora in 2013 for each IUCN Red List category, and their respective 'unusable' (species not used for commercial purposes) species sets. The absolute average effect is the average yearly difference between treated series and counterfactual series (see Section 2.3 for a detailed description of how these series were established). The absolute cumulative effect is the average difference of the entire post-intervention period between the treated and counterfactual series. The relative effect is the percentage of the difference of the entire post-intervention period between the treated and counterfactual series. Values in brackets represent the 99% confidence interval. The p-value represents the tail area probabilities; p = 0.05 means a 95% chance of obtaining this effect by chance. Values in **bold** are considered statistically significant. DD: Data Deficient; CR: Critically Endangered; EN: Endangered; VU: Vulnerable; NT: Near Threatened

Categories	Absolute average effect	Absolute cumulative effect	Relative effect (%)	p
CR	0.072 (−0.028, 0.16)	0.505 (−0.199, 1.12)	16 (−6.3, 36)	**0.020**
CR (unusable)	0.058 (0.017, 0.095)	0.407 (0.122, 0.664)	41 (12, 66)	**0.001**
EN	0.052 (−0.004, 0.11)	0.364 (−0.028, 0.76)	19 (−1.5, 41)	**0.013**
EN (unusable)	0.057 (0.0077, 0.1)	0.400 (0.0542, 0.7)	31 (4.2, 54)	**0.001**
VU	0.15 (−0.062, 0.36)	1.07 (−0.436, 2.54)	14 (−5.8, 34)	**0.040**
VU (unusable)	0.12 (0.075, 0.18)	0.87 (0.527, 1.23)	57 (35, 80)	**0.001**
DD	0.027 (−0.018, 0.062)	0.190 (−0.125, 0.436)	15 (−10, 35)	**0.032**
DD (unusable)	0.031 (−0.0014, 0.061)	0.217 (−0.0098, 0.427)	23 (−1, 46)	**0.008**
NT	0.11 (−0.0056, 0.21)	0.77 (−0.0393, 1.49)	19 (−0.97, 37)	**0.007**
NT (unusable)	0.013 (−0.032, 0.056)	0.093 (−0.239, 0.381)	6.1 (−16, 25)	0.230

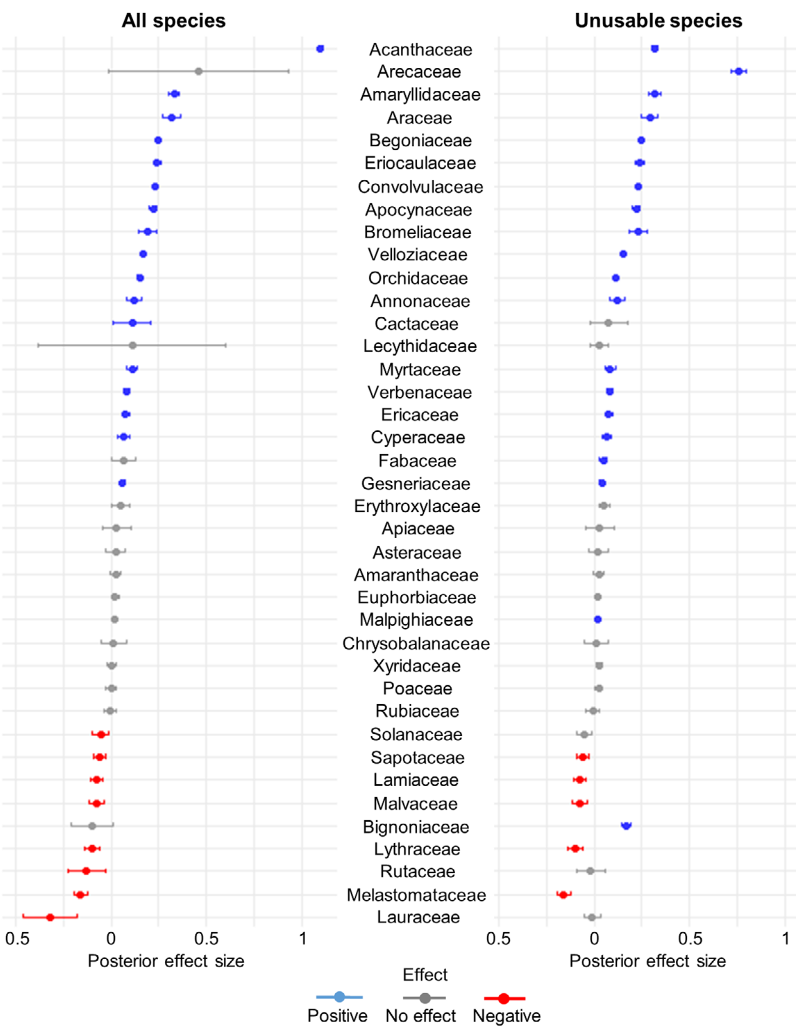

Fig. 1. Effect sizes and 99% confidence intervals of causal impact analysis for 39 angiosperm families in relation to mentions of their species in the biodiversity conservation literature, after publication of the Red List of Brazilian Flora in 2013. The figure shows the outcome of the average absolute effect (i.e. is the average yearly difference between treated and counterfactual series; see Section 2.3 for a detailed description). Significantly positive (negative) effect sizes are in blue (red); gray indicates no effect where the 99% confidence interval is centered around zero. The left panel (all species) shows the outcomes for the overall set of species within each family; the right panel indicates the outcomes for only the set of unusable species (i.e. those of no commercial value)

while no effects were detected for 14 and negative effects for 5 families (right panel in Fig. 1). Table S4 summarizes the BSTS results.

The number of mentions per year for the LC, NT, VU, and DD species had peaks of average mentions concentrated in 2017, with 1.3, 1, 1.4, and 0.3 mentions per species, respectively (Fig. 2). EN species also had their second-highest mentions (0.4) in 2017. CR and EN species had peak mentions in 2014, immediately after the publication of the RLBF (0.4 and 0.5, respectively), although this number of

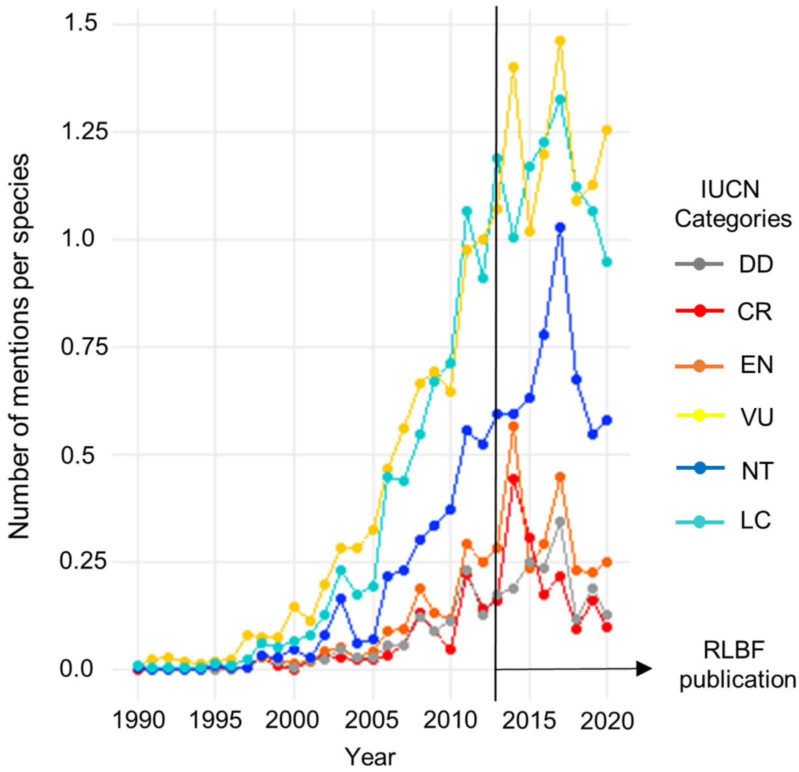

Fig. 2. Trends of mean mentions in the biodiversity conservation literature per species of angiosperm (1990–2020) within each IUCN Red List category. DD: Data Deficient; CR: Critically Endangered; EN: Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concern. Vertical black line indicates the publication of the Red List of Brazilian Flora (RLBF) in 2013

mentions was not sustained in the following years. The VU group also experienced this rapid growth in 2014, with 1.4 mentions per species, although in the following year (2015) it decreased. Also starting in 2014, DD species showed an increase in mentions, which was sustained until 2018. Conversely, LC and NT species had no increase in mentions in 2014.

The mean ± SD number of mentions per species between 2014 and 2020 was 4.86 ± 19.65. Average mentions for species in less-threatened categories (4.58 ± 16.30 for NT and 7.78 ± 21.73 for LC) and VU (7.97 ± 22.86) were higher than for species belonging to DD (1.43 ± 5.02) and to the most threatened categories (1.48 ± 2.37 for CR and 2.24 ± 6.38 for EN; Fig. 3). Table S5 summarizes the statistical tests for both categories.

Regarding commercial interest, average mentions for usable species were significantly higher than for unusable species for each category ($p < 0.01$, Wilcoxon-Mann-Whitney *U*-test; Fig. 4) except CR (7.00 ± 10.14 mentions for usable and 1.35 ± 1.72 mentions for unusable species; $p > 0.05$). Especially pronounced were the differences between these groups in the VU category (usable 79.57 ± 98.78 and unusable 2.40 ± 3.73; $p < 0.01$), the NT category (usable 51.5 ± 49.57 and unusable 1.80 ± 2.32; $p < 0.01$), and the LC category (usable 39.53 ± 56.59 and unusable 4.86 ± 11.30; $p < 0.01$).

4. DISCUSSION

This is the first study to evaluate the impact of a national Red List on scientific attention for the listed species reported in the biodiversity conservation literature. We found that the publication of the RLBF had a clear, significant effect on the allocation of scientific attention to species in the most concerning IUCN categories and for most angiosperm families, when the few species of commercial interest were excluded from the analysis. Species of commercial interest may have already had a high number of mentions in the pre-intervention period, which perhaps made any further increase in mentions unlikely. In any case, the development and implemen-

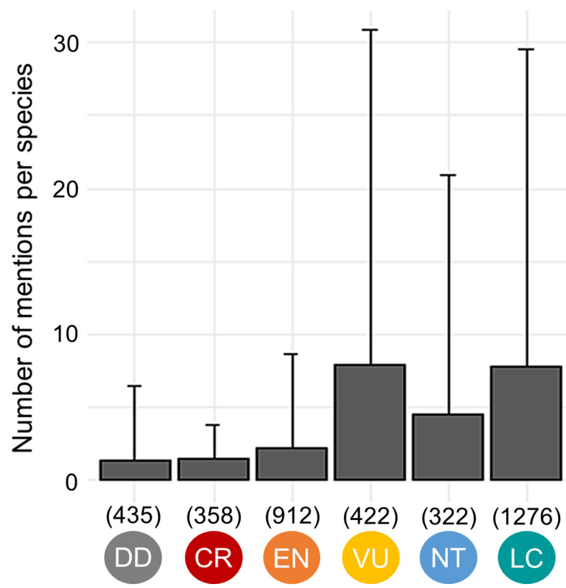

Fig. 3. Mean number of mentions in the biodiversity conservation literature per species of angiosperm (2014–2020) within each IUCN Red List category (defined as in Fig. 2). Error bars represent standard deviations; number of species per category is shown in parentheses

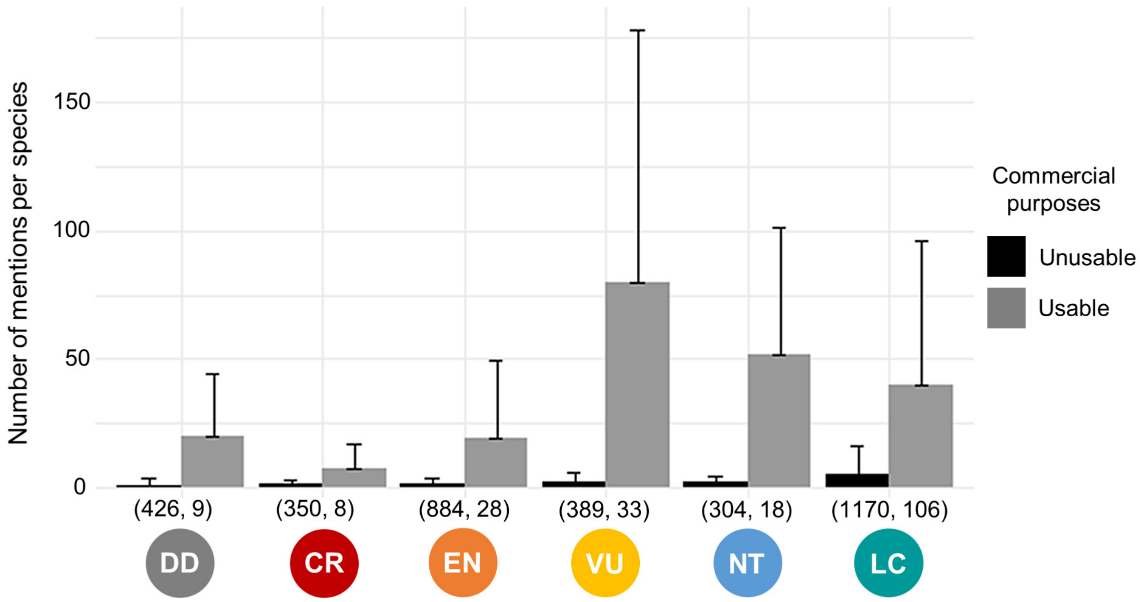

Fig. 4. Mean number of mentions in the biodiversity conservation literature per species of angiosperm (2014–2020) in relation to their commercial purposes (where 'unusable' refers to species of no commercial value), within each IUCN Red List category (defined as in Fig. 2). Error bars represent standard deviations; number of species per category is shown in parentheses

tation of the national IUCN Red List seems to have had the expected effect for threatened plant groups. Although the RLBF did not have the expected impact on the DD species (Jarić et al. 2017), the positive effect detected here is in line with a similar pattern found for threatened animals (Acerbi et al. 2020). This means that the Red List assessments and the inclusion of threatened species in official national lists is likely an important component in catalyzing actions by the scientific community toward threatened species (Rodrigues et al. 2006). This is good news regarding the globally high investments in Red List assessments of species.

Surprisingly, the Red List publication seemed to have an impact on the scientific community already in the year after the publication of the RLBF, as mentions of species in the threat categories showed a clear increase in 2014 but those of LC species did not. However, this scientific attention was not sustained the following year. A similar rapid positive response pattern was observed in media penetration in searches for the term 'Red List' following the IUCN World Conservation Congress (Betts et al. 2020), and for threatened primate species after the publication of the 'World's 25 Most Endangered Primates' list (Acerbi et al. 2020). In view of the short period of just 1 yr, the published responses of scientists may have been limited to the inclusion of a plant name in a species list. Some examples are mentions in local floristic inventories (Kortz et al. 2014), or in non-peer-reviewed documents such as an *ex situ* survey of threatened flora in botanical gardens (Costa 2014), action plans aimed at priority areas that harbor the listed species (Loyola et al. 2014), or aspects of environmental legislation (Coelho et al. 2014). It was not possible to determine the exact content of the papers from the year 2014 that mention the species. This gap inherent to the bibliometric approach is a recognized limitation for conservation biology studies (Proulx et al. 2014) and indicates the need for further research.

We found a strong bias arising from socio-economic preferences for certain plants. The absolute number of mentions of usable species was up to 33 times higher than for species of no commercial interest in some threat categories. At the same time, several threatened and DD species with no commercial interest remain understudied. Indeed, the socio-economic factors associated with species may be consistent drivers of scientific attention, while also helping to perpetuate research biases (Jarić et al. 2019). This asymmetry imposes challenges to infer general principles and to put in place effective strategies for biodiversity conservation (Troudet et al. 2017). For example, it is difficult to develop action plans that incorporate interactions between ecological, evolutionary, and environmental processes for species that are poorly known (Sitas et al. 2009). For this reason, it is urgent to allocate a similar or greater effort (Trimble & Aarde 2010) that is focused on nationally or regionally endemic threatened plants compared to wild plants that contribute to human livelihoods. Although our analysis of scientific activity after the publication of the RLBF suggests that some researchers have transferred their scientific interest to these historically neglected species, this transfer is still insufficient.

Remarkably, research output is disproportionately directed toward less threatened species. The only exception is the Vulnerable category, which may be due to the large number of species of commercial interest in this group. This scientific attention unrelated to threat status is not unique to Brazil (Brito 2008, Brito & Oprea 2009, Jarić et al. 2015, Roberts et al. 2016) or to plants (Jarić & Gessner 2012, Gessner et al. 2013). Several factors other than threat status can increase scientific attention towards a particular taxonomic group. Those factors most closely related to plants are abundance, range size, range proximity to or overlap with research facilities, and habitat accessibility (Jarić et al. 2019). That is, the prevalence of rarity and endemism of the threatened and DD species (Kunin & Gaston 1997, Pimm et al. 2014) may create additional difficulties for scientific research. First, the locations of rare plants may be very remote and difficult to reach, affecting the likelihood of locating populations in the wild (Royle & Nichols 2003, Gu & Swihart 2004, Chen et al. 2009); this difficulty is aggravated when dealing with life forms that are less conspicuous or have short life cycles (Kéry & Gregg 2003, Moore et al. 2011). This set of constraints may pose greater challenges in tropical environments (Banks-Leite et al. 2014), which are typically highly biodiverse (Wright 2002). Second, these difficulties also require more practical training of researchers in plant identification (Ahrends et al. 2011). Finally, research groups may require more time and consequently more financial resources and effort. As a result, these problems may lead specialists to select species that are more abundant, widely distributed, and close to research facilities (Moerman & Estabrook 2006).

The degree of scientific attention is not only a matter of the choice of specific scientific questions. Scientists' activities are strongly affected by the possibility of obtaining research funding to support particular lines of research, especially in competitive funding environments (Himanen et al. 2009). In addition to the scarce funding for species conservation programs in developing countries (Lawler et al. 2006, Waldron et al. 2013), the degree of investment in conservation-oriented research is often controlled by the preferences and interests of sectors of society outside the academic world (Wilson et al. 2007). In particular, government funding allocated to species research programs is directed primarily toward vertebrates; similarly, NGOs usually prioritize species with high public appeal (i.e. charismatic species or species with economic value) to concentrate their conservation efforts (Martín-López et al. 2009). As funding follows these societal preferences, scientific attention would follow that preference as well (Jarić et al. 2019). To our knowledge, no studies have examined the influence of sociological factors on project funding for the conservation of Brazilian threatened species. However, the patterns found in our study, such as the strong bias toward commercial species and the lack of relationship to the threat status, suggest that these factors possibly influence how research goals have been set and funded.

Although we recognize that our study was not exhaustive, the database that we constructed is the most comprehensive assessment of scientific attention to threatened plants in the field of biodiversity conservation to date. This allowed us to show that biases and the lack of scientific attention affect research on plants even after an IUCN listing. On the other hand, the development and implementation of the IUCN Red List has again proved to foster positive results for conservation efforts. Surprisingly, its impact on scientific attention can occur within a short period and benefit historically neglected species. However, its impact has proven to be insufficient to reduce biases in research on threatened plants. Our findings indicate the need to design studies that incorporate the information available in national Red Lists and to devote attention to gaps in knowledge of threatened flora. To accomplish this, there is a need for better integration among stakeholders in the biodiversity conservation arena with the goals of the Global Strategy for Plant Conservation and the Aichi Biodiversity Targets regarding scientific knowledge of threatened species.

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LITERATURE CITED

Acerbi A, Kerhoas D, Webber AD, McCabe G, Mittermeier RA, Schwitzer C (2020) The impact of the 'World's 25 Most Endangered Primates' list on scientific publications and media. J Nat Conserv 54:125794

Aguillo IF (2012) Is Google Scholar useful for bibliometrics? A webometric analysis. Scientometrics 91:343–351

Ahrends A, Rahbek C, Bulling MT, Burgess ND and others (2011) Conservation and the botanist effect. Biol Conserv 144:131–140

Amori G, Gippoliti S (2000) What do mammalogists want to save? Ten years of mammalian conservation biology. Biodivers Conserv 9:785–793

Baillie J, Hilton-Taylor C, Stuart SN (2004) IUCN Red List of Threatened Species. A global species assessment. International Union for Conservation of Nature, Gland. https://www.iucnredlist.org/resources/baillie2004 (accessed July 2019)

Banks-Leite C, Pardini R, Boscolo D, Cassano CR, Püttker T, Barros CS, Barlow J (2014) Assessing the utility of statistical adjustments for imperfect detection in tropical conservation science. J Appl Ecol 51:849–859

Betts J, Young RP, Hilton-Taylor C, Hoffmann M, Rodríguez JP, Stuart SN, Milner-Gulland EJ (2020) A framework for evaluating the impact of the IUCN Red List of threatened species. Conserv Biol 34:632–643

Brito D (2008) Amphibian conservation: Are we on the right track? Biol Conserv 141:2912–2917

Brito D, Oprea M (2009) Mismatch of research effort and threat in avian conservation biology. Trop Conserv Sci 2: 353–362

Brodersen KH, Gallusser F, Koehler J, Remy N, Scott SL (2015) Inferring causal impact using Bayesian structural time-series models. Ann Appl Stat 9:247–274

Brodie JF (2009) Is research effort allocated efficiently for conservation? Felidae as a global case study. Biodivers Conserv 18:2927–2939

Calver MC, Goldman B, Hutchings PA, Kingsford RT (2017) Why discrepancies in searching the conservation biology literature matter. Biol Conserv 213:19–26

Chen G, Kéry M, Zhang J, Ma K (2009) Factors affecting detection probability in plant distribution studies. J Ecol 97:1383–1389

Clark JA, May RM (2002) Taxonomic bias in conservation research. Science 297:191–192

CNCFLORA-JBRJ (2020) Red List of Brazilian Flora. http://cncflora.jbrj.gov.br/portal/pt-br/listavermelha (accessed 7 August 2020)

Coelho GF, Sousa RFB, Correia AF, Cordeiro J, Caramelo EB, Malavasi UC (2014) Aspectos da legislação ambiental para a revegetação de matas ciliares no estado do paraná. Acta Iguazu 2:22–34

Coradin L, Siminski A, Reis A (2011) Espécies nativas da flora brasileira de valor econômico atual ou potencial: plantas para o futuro: Região Sul. Ministério do Meio Ambiente, Brasília/DF

Coradin L, Camillo J, Pareyn F (2018) Espécies nativas da flora brasileira de valor econômico atual ou potencial: plantas para o futuro: Região Nordeste. Ministério do Meio Ambiente, Brasília/DF

Correia RA, Jarić I, Jepson P, Malhado ACM, Alves JA, Ladle RJ (2018) Nomenclature instability in species culturomic assessments: why synonyms matter. Ecol Indic 90:74–78

Costa MLMN (2014) Conservação de espécies ameaçadas de extinção nos jardins botânicos brasileiros. PhD dissertation, Escola Nacional de Botânica Tropical – Jardim Botânico do Rio de Janeiro

de Barros G de, da Silva Brito MT, Peluso LM, de Faria É, Izzo TJ, Teixido AL (2020) Biased research generates large gaps on invertebrate biota knowledge in Brazilian freshwater ecosystems. Perspect Ecol Conserv 18: 190–196

Donaldson MR, Burnett NJ, Braun DC, Suski CD, Hinch SG, Cooke SJ, Kerr JT (2016) Taxonomic bias and international biodiversity conservation research. Facets 1:105–113

Flora do Brasil 2020 (2020) List of species of the Brazilian flora. http://floradobrasil.jbrj.gov.br/ (accessed 20 Mar 2021)

Frehse F de A, Braga RR, Nocera GA, Vitule JRS (2016) Non-native species and invasion biology in a megadiverse country: scientometric analysis and ecological interactions in Brazil. Biol Invasions 18:3713–3725

Gessner J, Jarić I, Rochard E, Pourkazemi M (2013) As we see it: Sturgeon and paddlefish research focuses on low risk species and largely disregards endangered species. Endang Species Res 22:95–97

Gomes MA (2016) Lista vermelha de espécies ameaçadas: efeitos sobre a produção científica e percepção de estudantes sobre a mastofauna ameaçada do Cerrado. MSc dissertation, Universidade Estadual de Goiás, Anápolis

Gu W, Swihart RK (2004) Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biol Conserv 116:195–203

Guerra A, Reis LK, Borges FLG, Ojeda PTA and others (2020) Ecological restoration in Brazilian biomes: identifying advances and gaps. For Ecol Manag 458:117802

Haddaway NR, Bayliss HR (2015) Shades of grey: two forms of grey literature important for reviews in conservation. Biol Conserv 191:827–829

Himanen L, Auranen O, Puuska HM, Nieminen M (2009) Influence of research funding and science policy on university research performance: a comparison of five countries. Sci Public Policy 36:419–430

Holmgren M, Schnitzer SA (2004) Science on the rise in developing countries. PLOS Biol 2:e1

IUCN (2021) The IUCN Red List of Threatened Species. https://www.iucnredlist.org/search (accessed 20 March 2021)

Jarić I, Gessner J (2012) Analysis of publications on sturgeon research between 1996 and 2010. Scientometrics 90: 715–735

Jarić I, Knežević-Jarić J, Gessner J (2015) Global effort allocation in marine mammal research indicates geographical, taxonomic and extinction risk-related biases. Mammal Rev 45:54–62

Jarić I, Roberts DL, Gessner J, Solow AR, Courchamp F (2017) Science responses to IUCN Red Listing. PeerJ 5: e4025

Jarić I, Correia RA, Roberts DL, Gessner J, Meinard Y, Courchamp F (2019) On the overlap between scientific and societal taxonomic attentions — insights for conservation. Sci Total Environ 648:772–778

Kéry M, Gregg KB (2003) Effects of life-state on detectability in a demographic study of the terrestrial orchid *Cleistes bifaria*. J Ecol 91:265–273

Kortz AR, Coelho S, Castello ACD, Leite EC, Corrêa LS, Koch I (2014) Wood vegetation in Atlantic rain forest remnants in Sorocaba (São Paulo, Brazil). Check List 10: 344–354

Kunin WE, Gaston KJ (1997) The biology of rarity: causes and consequences of rare–common differences. Springer, Berlin

Lawler JJ, Aukema JE, Grant JB, Halpern BS and others (2006) Conservation science: a 20-year report card. Front Ecol Environ 4:473–480

Li K, Rollins J, Yan E (2018) Web of Science use in published research and review papers 1997–2017: a selective, dynamic, cross-domain, content-based analysis. Scientometrics 115:1–20

Loyola R, Machado N, Vila Nova D, Martins E, Martinelli G (2014) Áreas prioritárias para conservação e uso sustentável da flora Brasileira ameaçada de extinção. Jardim Botânico do Rio de Janeiro, Rio de Janeiro

Martín-López B, Montes C, Ramírez L, Benayas J (2009) What drives policy decision-making related to species conservation? Biol Conserv 142:1370–1380

Martinelli G, Moraes MA (2013) Livro Vermelho da Flora do Brasil. Andrea Jakobsson Estúdio, Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Rio de Janeiro

Martins E, Martinelli G, Loyola R (2018) Brazilian efforts towards achieving a comprehensive extinction risk assessment for its known flora. Rodriguésia 69:1529–1537

Mendonça M (2006) Lista da flora de importância econômica atual ou potencial da região sudeste. Fundação Biodiversitas, Belo Horizonte

MMA (Ministério do Meio Ambiente) (2020) Lista oficial traz 472 espécies da flora brasileira ameaçadas de extinção. https://www.gov.br/mma/pt-br/noticias/lista-oficial-traz-472-especies-da-flora-brasileira-ameacadas-de-extincao (accessed 4 March 2020)

Moerman DE, Estabrook GF (2006) The botanist effect: counties with maximal species richness tend to be home to universities and botanists. J Biogeogr 33:1969–1974

Moore JL, Hauser CE, Bear JL, Williams NSG, McCarthy MA (2011) Estimating detection–effort curves for plants using search experiments. Ecol Appl 21:601–607

Moustakas A, Karakassis I (2005) How diverse is aquatic biodiversity research? Aquat Ecol 39:367–375

Murray HJ, Green EJ, Williams DR, Burfield IJ, Brooke M de L (2015) Is research effort associated with the conservation status of European bird species? Endang Species Res 27:193–206

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858

Nic Lughadha E, Govaerts R, Belyaeva I, Black N and others (2016) Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates. Phytotaxa 272(1):82–88

Pimm SL, Jenkins CN, Abell R, Brooks TM and others (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science 344:1246752

Proulx R, Massicotte P, Pépino M (2014) Googling trends in conservation biology. Conserv Biol 28:44–51

Pullin AS, Knight TM, Stone DA, Charman K (2004) Do conservation managers use scientific evidence to support their decision-making? Biol Conserv 119:245–252

R Core Team (2019) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Ribeiro GVT, Teixido AL, Barbosa NPU, Silveira FAO (2016) Assessing bias and knowledge gaps on seed ecology research: implications for conservation agenda and policy. Ecol Appl 26:2033–2043

Roberts BEI, Harris WE, Hilton GM, Marsden SJ (2016) Taxonomic and geographic bias in conservation biology research: a systematic review of wildfowl demography studies. PLOS ONE 11:e0153908

Rodrigues ASL, Pilgrim JD, Lamoreux JF, Hoffmann M, Brooks TM (2006) The value of the IUCN Red List for conservation. Trends Ecol Evol 21:71–76

Royle JA, Nichols JD (2003) Estimating abundance from repeated presence–absence data or point counts. Ecology 84:777–790

Salafsky N, Salzer D, Stattersfield AJ, Hilton-Taylor C and others (2008) A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv Biol 22:897–911

Schmitt E, Tull C, Atwater P (2018) Extending Bayesian structural time-series estimates of causal impact to many-household conservation initiatives. Ann Appl Stat 12:2517–2539

Shanley P, Medina G (2005) Frutíferas e plantas úteis na vida Amazônica. CIFOR, Belém

Sitas N, Baillie JEM, Isaac NJB (2009) What are we saving? Developing a standardized approach for conservation action. Anim Conserv 12:231–237

Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends Ecol Evol 19:305–308

Teixido AL, Gonçalves SRA, Fernández-Arellano GJ, Dáttilo W and others (2020) Major biases and knowledge gaps on fragmentation research in Brazil: implications for conservation. Biol Conserv 251:108749

Tessarolo G, Ladle R, Rangel T, Hortal J (2017) Temporal degradation of data limits biodiversity research. Ecol Evol 7:6863–6870

Tourinho MP, Costa APT, Martins KP, Bandeira MGS, Barbosa FG (2020) Scientific knowledge on threatened species of the Brazilian Red List: freshwater fish as a case study. Environ Biol Fishes 103:719–731

Trimble MJ, Aarde RJV (2010) Species inequality in scientific study. Conserv Biol 24:886–890

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Sci Rep 7:9132

Vieira R, Camillo J, Coradin L (2016) Espécies nativas da flora brasileira de valor econômico atual ou potencial: plantas para o futuro: Região Centro-Oeste. Ministério do Meio Ambiente, Brasília, DF

Waldron A, Mooers AO, Miller DC, Nibbelink N and others (2013) Targeting global conservation funding to limit immediate biodiversity declines. Proc Natl Acad Sci USA 110:12144–12148

WCVP (2020) World checklist of vascular plants, version 2.0. Facilitated by the Royal Botanic Gardens, Kew. http://wcvp.science.kew.org/ (accessed 1 September 2020)

Wilson JR, Procheş Ş, Braschler B, Dixon ES, Richardson DM (2007) The (bio)diversity of science reflects the interests of society. Front Ecol Environ 5:409–414

Wright JS (2002) Plant diversity in tropical forests: a review of mechanisms of species coexistence. Oecologia 130: 1–14

Zhang H, Hu Y, Zhang Y, Li W (2015) Evidence of the Matthew effect in scientific research on mammals in the Chinese First-class National Protected Animals list. Biodivers Conserv 24:2883–2886

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