CONSERVATION

Comprehensive conservation assessments reveal high extinction risks across Atlantic Forest trees

Renato A. F. de Lima[1,2]*, Gilles Dauby[3], André L. de Gasper[4], Eduardo P. Fernandez[5], Alexander C. Vibrans[6], Alexandre A. de Oliveira[7], Paulo I. Prado[7], Vinícius C. Souza[2], Marinez F. de Siqueira[5,8], Hans ter Steege[1,9]

Biodiversity is declining globally, yet many biodiversity hotspots still lack comprehensive species conservation assessments. Using multiple International Union for Conservation of Nature (IUCN) Red List criteria to evaluate extinction risks and millions of herbarium and forest inventory records, we present automated conservation assessments for all tree species of the Atlantic Forest biodiversity hotspot, including ~1100 heretofore unassessed species. About 65% of all species and 82% of endemic species are classified as threatened. We rediscovered five species classified as Extinct on the IUCN Red List and identified 13 endemics as possibly extinct. Uncertainties in species information had little influence on the assessments, but using fewer Red List criteria severely underestimated threat levels. We suggest that the conservation status of tropical forests worldwide is worse than previously reported.

Human pressure on nature has increased in recent decades, particularly in the tropics, where most of the planet's biodiversity resides (*1*, *2*). Consequently, we face a global biodiversity crisis (*3*). Reversing this crisis is a pressing challenge and begins by classifying species based on extinction risks, which are used to monitor biodiversity and prioritize conservation actions (*4*, *5*). Also known as red listing, these conservation assessments are a cornerstone of global conservation programs, such as the International Union for Conservation of Nature (IUCN) Red List, which categorizes species extinction risks based on one or multiple criteria, including population size decline (criterion A), geographic range (criterion B), and very small populations (criterion D).

Efforts to include species on the IUCN Red List have grown in recent years, but much remains to be done (*4*–*7*). Even for the well-studied trees of Europe, red listing efforts have been published only recently (*8*). One reason why only a small part of global biodiversity has up-to-date conservation assessments is the difficulty in carrying out these assessments. They require detailed species information and the time, training, and resources to apply the IUCN Red List Categories and Criteria on a species-by-species basis (*9*), all of which are limited, especially in the tropics (*4*, *5*). Therefore, automated assessments are increasingly being proposed as complements or alternatives to manual assessments (*4*, *10*–*13*) to provide fast-track conservation assessments for megadiverse regions (*14*–*16*).

Assessments for tropical biodiversity hotspots, where most threatened species occur (*17*), remain rare. One of these hotspots is the Atlantic Forest in eastern South America, which has more than 15,000 plant species, of which half are endemic (*18*). With 35% of the South American human population living within its borders, about 80% of its original cover has been lost, and deforestation and degradation remain high (*19*, *20*). Species conservation assessments are limited to about 25% of the Atlantic Forest flora and are mostly being conducted using few IUCN Red List criteria (*21*). A comprehensive assessment at the Atlantic Forest scale could provide insights into the conservation status of other tropical biodiversity hotspots, which do not all have the same amount of information available as the Atlantic Forest.

We present the conservation status of the Atlantic Forest tree flora, which represents a third of the entire hotspot's plant diversity and is crucial to providing people with ecosystem services (*5*, *7*, *12*). We automated the conservation assessments for nearly 5000 species using more than 800,000 herbarium records, 1.3 million tree counts from forest inventories, and information on species life histories, commercial uses, and long time-series of habitat loss (fig. S1 and data S1) (*22*). We developed a replicable workflow that strictly adheres to the IUCN Red List Categories and Criteria (*9*) and delivers conservation assessments based on the IUCN criteria A to D (table S1). This workflow also evaluates the sensitivity of the assessments to the number of IUCN criteria applied and uncertainties in species information (tables S2 to S4). Finally, we predicted the conservation status of tropical forests worldwide using the relationship between species threat and habitat loss observed in the Atlantic Forest.

[1]Tropical Botany, Naturalis Biodiversity Center, Darwinweg 2, 2333 CR Leiden, Netherlands. [2]Departamento de Ciências Biológicas, ESALQ, Universidade de São Paulo, Avenida Pádua Dias, 11, 13418-900 Piracicaba, Brazil. [3]Botanique et Modélisation de l'Architecture des Plantes et des Végétations (AMAP), Université de Montpellier, IRD, CNRS, INRAE, CIRAD, Montpellier, France. [4]Departamento de Ciências Naturais, Universidade Regional de Blumenau, Rua Antônio da Veiga, 140, 89030-903 Blumenau, Brazil. [5]Centro Nacional de Conservação da Flora (IUCN SSC Brazil Plant Red List Authority), Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Rua Pacheco Leão, 915, 22460-030 Rio de Janeiro, Brazil. [6]Departamento de Engenharia Florestal, Universidade Regional de Blumenau, Rua São Paulo, 3250, 89030-000 Blumenau, Brazil. [7]Departamento de Ecologia, Instituto de Biociências, Universidade de São Paulo, Rua do Matão, trav. 14, 321, 05508-090 São Paulo, Brazil. [8]Departamento de Biologia, Pontifícia Universidade Católica do Rio de Janeiro, Rua Marquês de São Vicente 225, 22451-900 Rio de Janeiro, Brazil. [9]Quantitative Biodiversity Dynamics, Department of Biology, Utrecht University, 3584 CS Utrecht, Netherlands.
*Corresponding author. Email: raflima@usp.br

Conservation status of the Atlantic Forest tree flora

We classified two-thirds of the 4950 tree species populations that occur in the Atlantic Forest as threatened following the IUCN Red List Categories and Criteria (Fig. 1A). The percentage of threatened species increases to 82% when only endemic species are considered (Fig. 1B), with 2025 endemic Atlantic Forest trees globally threatened with extinction (data S2). The Atlantic Forest's Red List Index (RLI), which measures the overall conservation status for a list of species and ranges from zero (all species are extinct) to one (no threatened species) (*23*), was 0.542 [95% confidence interval (CI): 0.534 to 0.550]. These numbers are worse than the global averages of threatened species (25%) and RLI values (95% CI: 0.55 to 1) reported for other groups of organisms (*2*), indicating that threat levels in highly modified regions, such as the Atlantic Forest, can be much higher than global averages.

Many emblematic endemic trees of the Atlantic Forest were classified as threatened in this work. The iconic *Paubrasilia echinata* (brazilwood), the tree that gave its name to Brazil, was listed as Critically Endangered (CR) owing to an estimated 84% drop in its population size over the past three generations. The once common *Araucaria angustifolia* (Paraná pine), *Euterpe edulis* (palm heart), and *Ilex paraguariensis* (yerba mate) also experienced declines in their wild populations of at least 50% and are thus classified as Endangered (EN). Endemic timber species, such as *Cariniana legalis*, *Dalbergia nigra*, *Melanoxylon brauna*, *Myrocarpus frondosus*, *Ocotea odorifera*, *Ocotea porosa*, *Parapiptadenia rigida*, and *Paratecoma peroba*, also experienced declines ranging from 53 to 89% and are thus classified as EN or CR.

Most species (75%) were classified as threatened under IUCN criterion A, which evaluates population decline in the past three generations. The high deforestation of the Atlantic Forest led to 57% of endemic tree species having estimated population declines above the IUCN threshold of 30% (*9*). By contrast, only 7% of the endemics showed declines below 30%. Another important IUCN criterion to detect threat in the Atlantic Forest was B2 (28% of the cases), which is related to small areas of occupancy (AOO). AOO was below the threshold of 2000 km^2 for most species (median of 208 km^2), but more than two-thirds of these species occurred in more than 10 locations or were not severely fragmented (figs. S2 and

S3) and hence did not meet the conditions necessary to be classified as threatened under criterion B (*9*). Only 5% of all species were classified as threatened under the IUCN criteria C and/or D (small and declining populations or very small populations; fig. S4), with most species (94%) exceeding the critical size of 10,000 mature individuals.

Comparison with previous IUCN assessments

We found previous assessments for 59 and 49% of the Atlantic Forest tree flora at global (*24*) and national levels (*21*), respectively. We thus present the first assessments for 1120 species, 456 of which are Atlantic Forest endemics. We rediscovered five species previously classified as Extinct (EX) on the IUCN Red List: *Campomanesia lundiana*, *Chrysophyllum januariense*, *Myrcia neocambessedeana*, *Pouteria stenophylla*, and *Pradosia glaziovii*. These species were classified as EX because they were known only from their type specimens at the time of the previous assessments (1998). We found taxonomically and geographically validated herbarium records for 2008 or later for all five species. Only *C. lundiana* had no recent taxonomically vetted record, suggesting that it could indeed be assessed as EX or that its taxonomic delimitation remains uncertain. All five species remained classified as threatened in this work but under different categories, which emphasizes the importance of new information to keep the IUCN Red List up to date (*25*–*27*) and how approaches like the one we used can facilitate a higher frequency of reassessments (*13*).

Overall, our reassessments rarely resulted in up-listing species by more than two threat categories (4%) or down-listing species previously assessed as threatened (also 4%), mainly when comparisons considered assessments using only criterion B (table S5). This confirms that automated assessments can provide accurate pictures of species conservation statuses for tropical regions (*14*, *15*). About 3% of the species moved from the Least Concern (LC) or Near Threatened (NT) IUCN Red List categories to CR. These species were previously classified as LC owing to their large extent of occurrence (EOO) (>20,000 km^2), but we estimated population reductions greater than 80%, which is the IUCN threshold to classify species as CR. Another 3% that were previously classified as threatened were assessed in this work as LC or NT. For these species, we found no indications of population declines ≥30%, severe fragmentation, or occurrence in fewer than 10 locations (figs. S2 and S3), which are the necessary conditions to detect threat under the IUCN criterion A or B (*9*).

The RLI value for the endemic Atlantic Forest tree flora deteriorated from 0.74 (95% CI: 0.73 to 0.76) in the assessments that are available on the IUCN Red List to 0.50 (95% CI: 0.49 to 0.51) in our reassessments (Fig. 2). Only 18% of the species previously assessed as LC remained so in our reassessments (Fig. 2). This deterioration may be due to differences in the amount of information available, the number of IUCN criteria used, or a genuine decline in the species' conservation statuses (*28*). To separate these causes, we compared changes for 1170 endemic species that we reassessed using only IUCN criterion B. About 31% of these species had changes in their assessments, resulting in a significantly better RLI value (95% CI: 0.82 to 0.85) than the previous one (95% CI: 0.74 to 0.78). This unexpected finding is likely due to the inclusion of new occurrences, which tends to classify species under lower levels of threat (*29*). Thus, the observed RLI deterioration is more related to the inclusion of more IUCN criteria in our reassessments than to a genuine decline in the Atlantic Forest conservation status (see next section).

The influence of the number of IUCN criteria on species assessments

Around 69% of the plants on the IUCN Red List are assessed using only criterion B (species geographic range) (*24*) owing to limited data on population size and trends for most organisms (*6*, *28*, *29*). To evaluate the impact of using multiple IUCN criteria on conservation assessments, we compared the results for a subset of 2698 species that were assessed in this work using four IUCN criteria (A, B, C, and D; table S1). We found that assessments

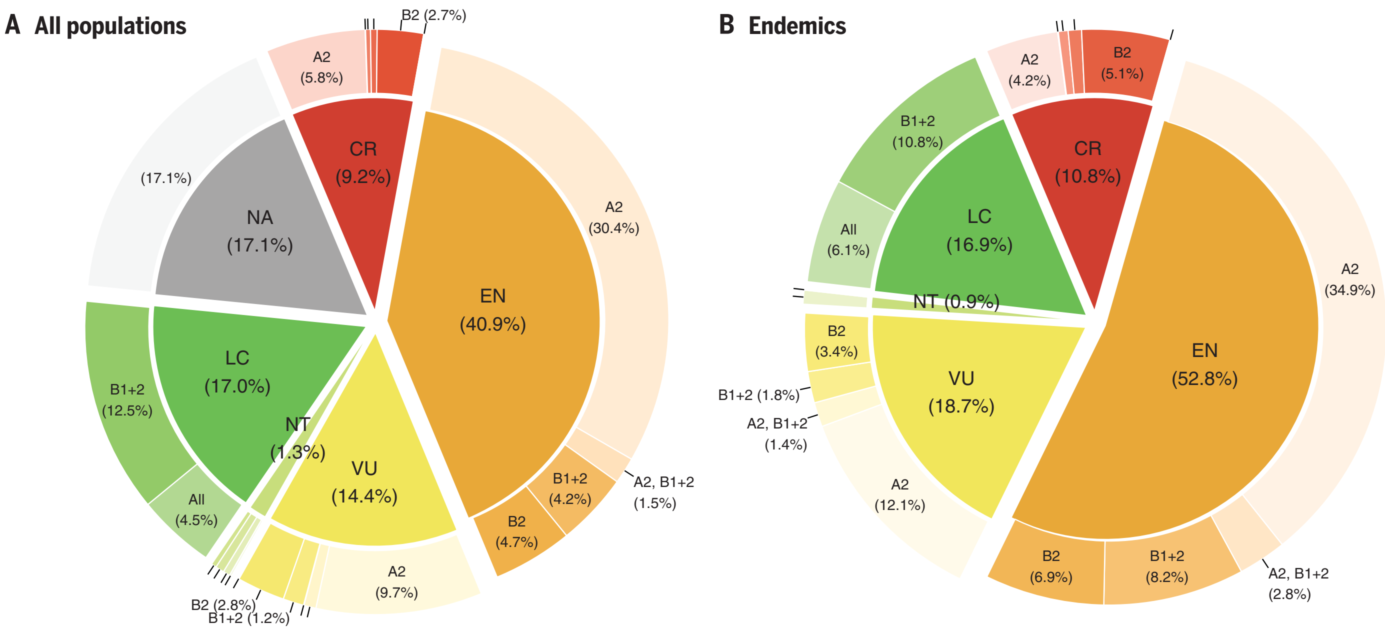

Fig. 1. The proportion of populations classified under each threat category and the corresponding IUCN criteria assigned to the categories. (**A** and **B**) Results are presented for the populations of (A) all tree species occurring in the Atlantic Forest (*n* = 4953) and (B) only endemic species (*n* = 2464). The proportion of populations classified under each threat category and the corresponding IUCN criteria (indicated by letters) are shown in the central pie chart and external donut chart, respectively. Populations classified as NA mainly correspond to the Not Applicable category of IUCN regional assessments, including vagrant species. For clarity, panels do not include the Data Deficient category (too few species). Here, we define "population" as a group of individuals of the same species that inhabit the same geographical area (the Atlantic Forest, in our case). CR, Critically Endangered (red); EN, Endangered (orange); LC, Least Concern (dark green); NA, Not Applicable (gray); NT, Near Threatened (green); VU, Vulnerable (yellow).

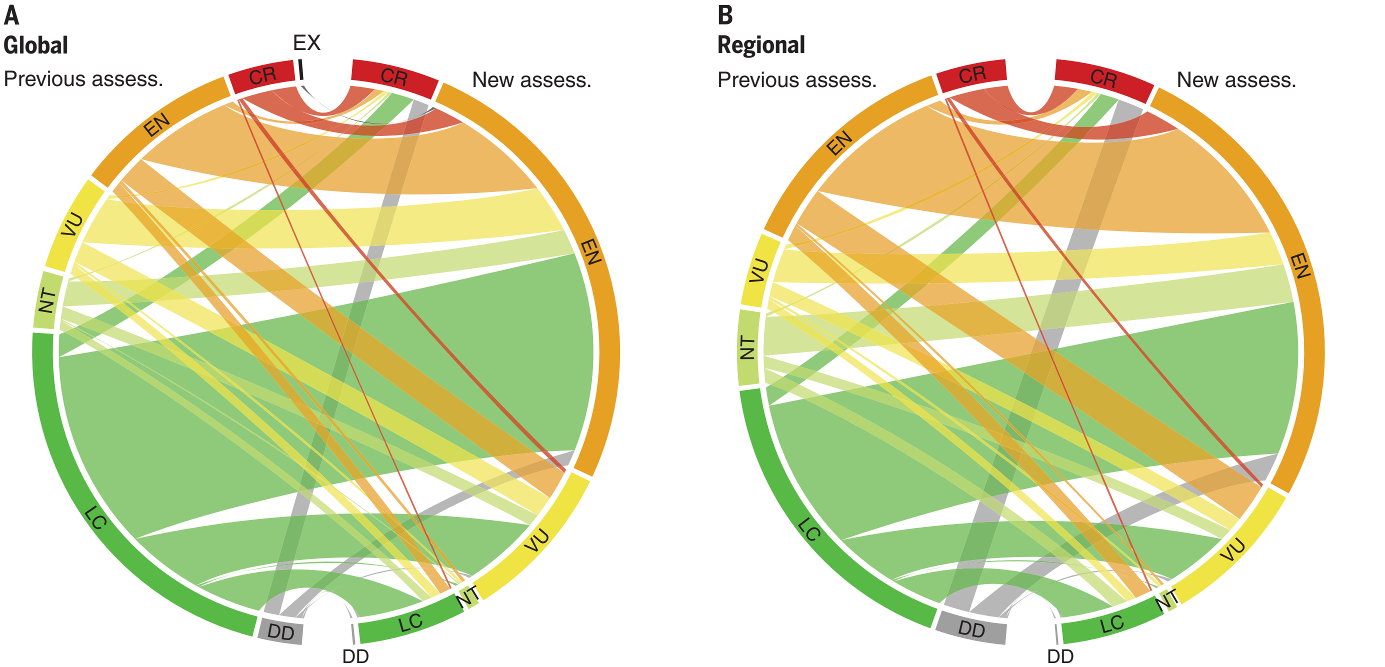

Fig. 2. A comparison between previous conservation assessments and the new ones presented in this work. (**A** and **B**) A comparison between previous assessments (left arcs) and the assessments in this work (right arcs) is presented at (A) global and (B) regional levels. The widths of the linking lines correspond to the proportion of species shared between categories of threat of the two assessments. Previous conservation assessments were obtained at the global level from version 2022-2 of the IUCN Red List (www.iucnredlist.org) and from the national red lists from Argentina, Brazil, and Paraguay. The color legend is the same as in Fig. 1. DD, Data Deficient (gray); EX, Extinct (black).

Table 1. A comparison of the assessments based on individual and multiple IUCN criteria for the populations of all species and only endemic species. A comparison was conducted for a subset of Atlantic Forest populations that had enough information available to assess criteria A, B, C, and D. For the RLI, values in brackets represent the 95% CI around mean estimates obtained from 50,000 bootstraps; different superscript lowercase letters indicate differences of RLI means among categories based on the 50,000 bootstraps that were run for the same set of populations. We define "population" as a group of individuals of the same species that inhabit the same geographical area (the Atlantic Forest, in our case).

Criteria	Populations of all species (n = 2698)		Only endemic species (n = 1586)	
	Threatened (%)	RLI	Threatened (%)	RLI
A	91.4	0.471 (0.464–0.479)[a]	90.3	0.498 (0.488–0.507)[a]
B	10.7	0.951 (0.945–0.956)[b]	16.5	0.924 (0.915–0.932)[b]
C	2.5	0.993 (0.991–0.995)[c]	3.2	0.992 (0.990–0.995)[c]
D	2.3	0.994 (0.993–0.996)[c]	3.2	0.993 (0.991–0.995)[c]
A, B, C, and D	91.7	0.470 (0.463–0.478)[a]	90.6	0.489 (0.479–0.499)[a]

would be substantially different if only criterion B, C, or D was used (Table 1), with six times fewer species found to be threatened if we had used only criterion B. This discrepancy is likely due to the fact that criterion B does not consider population declines within species ranges. Common endemic species with large ranges (>300,000 km^2) and population sizes (>2,000,000 mature individuals), such as *Metrodorea nigra* or *Picramnia ramiflora*, had estimated population declines greater than 90%. Therefore, assessments that use only criterion B can severely underestimate the conservation status of regional biotas, especially in highly modified regions such as the Atlantic Forest and other biodiversity hotspots.

Uncertainty in species information and identifications

Much of the species' information that is needed to apply IUCN criteria A, C, and D is missing for tropical regions. Therefore, we had to make generalizations of species' generation lengths (GLs) and proportions of mature individuals in the population (p) (tables S2 and S3), based on a combination of species' growth forms (e.g., large trees) and ecological groups (e.g., pioneers; data S3). To assess the sensitivity of our assessments to these generalizations, we compared them with assessments that were generated using varying values of GL and p. We found that only the use of GLs smaller than 25 years could considerably change the overall proportion of threatened species (fig. S5). This occurred because, for most species, the peak of Atlantic Forest loss (1950–1980) is more recent than the three GLs defined by the IUCN to evaluate population size decline. So, 57 and 92% of species threatened under criterion A would have remained so if we had considered only one or two GLs, respectively. We also found that using smaller values of p changed few assessments under criteria C and D (figs. S6 and S7) because populations mostly remained well above the IUCN critical population size of 10,000. Our group-specific approach is biologically meaningful because it is based on species life histories and evidence from long-term monitoring of tropical trees (*22*).

Only records with species identifications that were vetted by taxonomists should be included in conservation assessments (*25*). In our dataset, only 38% of the records were taxonomically vetted, which would lead to fewer records available per species and thus less-reliable assessments (*10*, *30*). Therefore, we implemented an approach

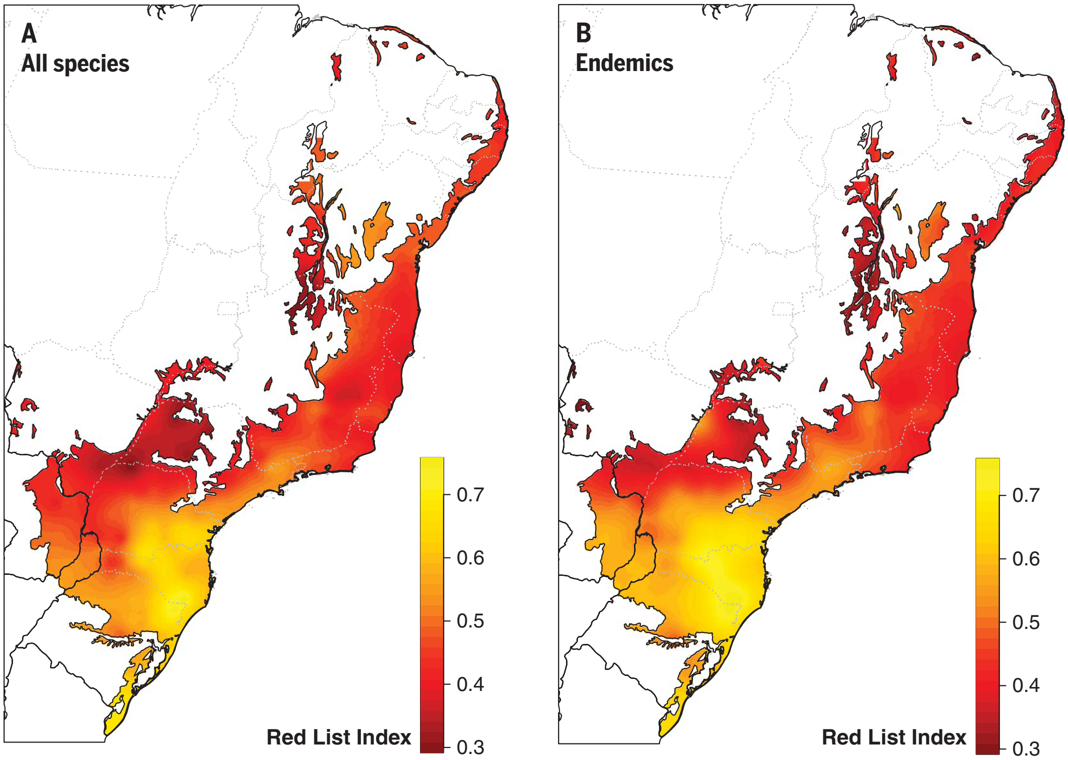

Fig. 3. The spatial distribution of tree species threat in the Atlantic Forest biodiversity hotspot. (**A** and **B**) Maps present the spatial interpolation of the RLI across the Atlantic Forest biodiversity hotspot, considering the populations of (A) all tree species and (B) only endemic species. The RLI interpolation was obtained based on the list of species recorded (and their threat categories) across the cells of a grid covering the entire region. The RLI ranges from zero (all species are classified as extinct) to one (all species are not threatened). The color scale ranges from lower, or worse, RLI values (dark red) to higher, or better, values (yellow).

to add records while losing as little taxonomic confidence as possible (fig. S8 and table S4). We compared this approach to assessments using only taxonomically vetted records (fig. S8A) and found that our approach resulted in fewer threatened species (17%) than the latter approach (27%). Consequently, the RLI was significantly higher here (0.906; 95% CI: 0.900 to 0.912) than when using only taxonomically vetted records (0.843; 95% CI: 0.841 to 0.855). Differences between approaches were larger for assessments that used less than 60% of taxonomically vetted records (fig. S8B). These differences emerge from the different number of records available: Assessments that use more records often yield higher EOO and AOO estimates (*30*, *31*). Alternatively, adding misidentified records outside species' natural ranges overestimates their EOO and AOO (*25*). Together, these explanations suggest that we likely underestimated the threat status of species that have fewer taxonomically vetted records.

Threatened species in time and space

Of the 815,000 valid herbarium records, the first dates from the 17th century, but 79% were made after the 1980s. We found no valid records over the past 50 years for 41 endemic species. Thirteen species are only known from their type specimen (fig. S9), which is one of the criteria for tagging threatened species as possibly extinct (*9*). These are priority species for new studies (data S2) to assess whether they have limited sampling and/or taxonomic treatment or are probably extinct in nature (*9*).

The spatial distribution of threatened species in the Atlantic Forest was similar when considering all species or only endemic ones. We found that the western, central, and northern regions had the worst RLI values (Fig. 3) and the highest proportions of threatened species (figs. S10 to S13). Previous studies have shown that the western and northern regions have fewer species and endemism than the central region (*18*, *32*), but they all share the highest fragmentation levels of the Atlantic Forest (*19*), except for the Misiones region in Argentina. In addition, we found that the Serra do Mar and *Araucaria* regions, which are home to the largest Atlantic Forest remnants and systems of strictly protected areas (*19*, *20*), had smaller proportions of threatened species. This highlights that threatened species are concentrated where habitat loss and fragmentation are greater. Therefore, in situ conservation actions in the Atlantic Forest (e.g., reverting forest degradation, fostering landscape restoration, and the creation and strengthening of protected areas) should target not only areas with high species richness and endemism (*18*, *33*) but also highly modified areas where threatened species are less likely to sustain their populations owing to low habitat quantity, quality, and connectivity (*34*, *35*).

We found that most threatened endemic trees (82%) had at least one confirmed occurrence inside strictly protected areas. However, 75% of them had less than a quarter of their records and one-tenth of their EOO inside protected areas (fig. S14). Species classified as CR had fewer occurrences in protected areas than those in other threat categories, which is partially explained by the smaller proportion of protected areas within their EOO (fig. S14). Also, the terrestrial area of habitat (AOH) that remained in 2018 was significantly lower for species classified as CR (median of 19%) than for those in other threat categories (fig. S15). These results indicate that many threatened Atlantic Forest tree species occur mostly in unprotected areas and have limited habitat left. A comprehensive study on the type, design, and extent of conservation actions that are able to increase habitat availability, quality, and protection of threatened Atlantic Forest trees is needed. Maps of regions with higher concentrations of threatened species (figs. S11 and S13), especially CR endemics (fig. S16), are crucial for prioritizing those conservation actions.

Implications for tree species conservation

The conservation status of the Atlantic Forest tree flora is alarming but probably worse in reality. Our assessments focused more on the decline of habitat quantity (i.e., deforestation) rather than quality (i.e., forest fragmentation and degradation). Estimated population declines would have been greater if only the intact Atlantic Forest was considered (3.5 to 7% instead of the 12 to 28% of all forest cover) (*19*, *36*). Additionally, we used conservative values of GL, *p*, and exploitation levels for valuable species and incorporated as much data as possible for the assessments of species with fewer occurrences. These choices likely

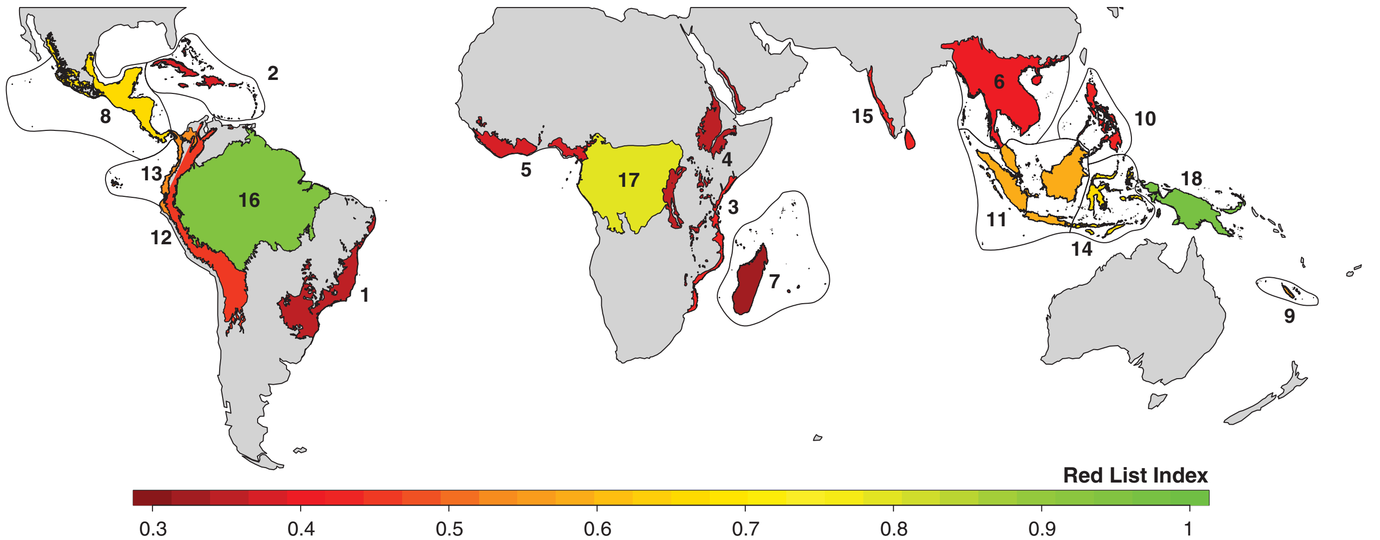

Fig. 4. Predicted RLI values for the 18 main tropical forest areas of the world. Predictions are based on the relationship between population size reductions and habitat loss, which could be obtained for all forests from forest cover maps and reports of their number of endemic species. Thus, these predictions are based solely on the population size reductions (i.e., IUCN criterion A2) of endemic species. The RLI ranges from zero (all species are classified as extinct) to one (no species are classified as threatened). The color scale ranges from lower, or worse, RLI values (dark red) to higher, or better, values (green). See supplementary materials and tables S6 and S7 for details and the full tropical forest names that correspond to the numbers in the map.

led to more conservative estimates of species threat (i.e., smaller species ranges, population sizes, and/or declines), particularly for late-successional species (*37*). This is less the case for early-successional species, whose population declines due to habitat loss are often mitigated by changes in habitat quality (e.g., increase of forest edges). These changes were accounted for in our assessments (*22*), but there are still uncertainties related to their population declines. Furthermore, most Atlantic Forest loss occurred in the past 50 to 70 years, which, for many tree species, falls within two to three GLs into the past. So, despite the smaller Atlantic Forest deforestation today, the effects of past habitat loss, fragmentation, and selective logging on these long-lived species may not have had enough time to fully express themselves (*38*), which suggests an extinction debt yet to be paid in the coming decades (*39*, *40*).

The status of the Atlantic Forest tree flora has direct implications for the Global Tree Assessment initiative (*5*, *7*) and the IUCN post-2020 global biodiversity framework. We provide all the IUCN-required information to ease the incorporation of our assessments into their Red List (data S4), seeking to bridge the gap between research and its integration into conservation practice (*13*). We also highlight habitat loss as the main threat to tropical tree diversity, which raises the question about its impact on other tropical forests (*14*, *16*, *17*, *41*–*43*). Thus, based on the present forest cover of 18 main tropical forests and the relationship between species threat and Atlantic Forest loss (fig. S17) (*22*), we roughly estimate that 20,504 to 24,910 tropical tree species are likely threatened because of habitat loss alone (Fig. 4 and tables S6 and S7). This represents 35 to 43% of tree species worldwide (*7*, *14*) and confirms that tropical forests shelter most of the globally threatened species (*17*). Despite its assumptions and limits, this prediction includes only tree species that are endemic to these 18 tropical forests (*22*). Therefore, it is higher than the present estimate of 30% of threatened tree species (*7*) and closer to the 43% that is estimated using artificial intelligence (*12*). If we account for temperate species and tropical species that are shared among tropical forests or woodlands (i.e., nonendemics), threats of habitat loss to global tree diversity will be even greater than previously recognized, making trees one of the most threatened groups of organisms on the planet (*2*). Considering the ecological and sociocultural importance of tree species (*5*, *7*) and the continued pressure on tropical forests (*1*–*3*), fighting tropical deforestation and effectively implementing both in situ and ex situ conservation must be prioritized if we are to prevent the extinction of thousands of tree species in the next decades.

REFERENCES AND NOTES

1. S. L. Lewis, D. P. Edwards, D. Galbraith, *Science* **349**, 827–832 (2015).
2. S. Díaz *et al.*, *Science* **366**, eaax3100 (2019).
3. G. Ceballos *et al.*, *Sci. Adv.* **1**, e1400253 (2015).
4. S. P. Bachman *et al.*, *Biol. Conserv.* **234**, 45–55 (2019).
5. A. Newton *et al.*, *Oryx* **49**, 410–415 (2015).
6. N. A. Brummitt *et al.*, *PLOS ONE* **10**, e0135152 (2015).
7. Botanic Gardens Conservation Initiative (BGCI), "State of the world's trees" (BGCI, 2021).
8. M. Rivers *et al.*, "European Red List of Trees" (International Union for Conservation of Nature, 2019).
9. IUCN Standards and Petitions Committee, "Guidelines for using the IUCN Red List Categories and Criteria, Version 14" (IUCN, 2019).
10. E. Nic Lughadha *et al.*, *Philos. Trans. R. Soc. London Ser. B* **374**, 20170402 (2018).
11. S. E. Darrah, L. M. Bland, S. P. Bachman, C. P. Clubbe, A. Trias-Blasi, *Divers. Distrib.* **23**, 435–447 (2017).
12. S. V. Silva, T. Andermann, A. Zizka, G. Kozlowski, D. Silvestro, *Front. Plant Sci.* **13**, 839792 (2022).
13. V. Cazalis *et al.*, *Trends Ecol. Evol.* **37**, 359–370 (2022).
14. H. Ter Steege *et al.*, *Sci. Adv.* **1**, e1500936 (2015).
15. T. Stévart *et al.*, *Sci. Adv.* **5**, eaax9444 (2019).
16. V. H. F. Gomes, I. C. G. Vieira, R. P. Salomão, H. ter Steege, *Nat. Clim. Chang.* **9**, 547–553 (2019).
17. T. M. Brooks *et al.*, *Conserv. Biol.* **16**, 909–923 (2002).
18. R. A. F. de Lima, V. C. Souza, M. F. de Siqueira, H. ter Steege, *Biol. Conserv.* **252**, 108825 (2020).
19. M. R. Rosa *et al.*, *Sci. Adv.* **7**, eabc4547 (2021).
20. R. A. F. de Lima *et al.*, *Nat. Commun.* **11**, 6347 (2020).
21. E. Martins, R. Loyola, G. Martinelli, *Ann. Mo. Bot. Gard.* **102**, 347–356 (2017).
22. Materials and methods are available as supplementary materials.
23. S. H. M. Butchart *et al.*, *PLOS ONE* **2**, e140 (2007).
24. IUCN, The IUCN Red List of Threatened Species, Version 2022-2 (2023); https://www.iucnredlist.org [accessed 26 January 2023].
25. E. M. Nic Lughadha *et al.*, *Conserv. Biol.* **33**, 511–522 (2019).
26. A. Newton, S. Oldfield, *Endanger. Species Res.* **6**, 137–147 (2008).
27. A. M. Humphreys, R. Govaerts, S. Z. Ficinski, E. Nic Lughadha, M. S. Vorontsova, *Nat. Ecol. Evol.* **3**, 1043–1047 (2019).
28. L. Santini *et al.*, *Conserv. Biol.* **33**, 1084–1093 (2019).
29. Ł. Tracewski *et al.*, *Conserv. Biol.* **30**, 1070–1079 (2016).
30. M. C. Rivers *et al.*, *Biol. Conserv.* **144**, 2541–2547 (2011).
31. S. Bachman, B. E. Walker, S. Barrios, A. Copeland, J. Moat, *Biodivers. Data J.* **8**, e47018 (2020).
32. V. P. Zwiener, R. A. F. de Lima, A. Sánchez-Tapia, D. S. B. Rocha, M. C. M. Marques, *The Atlantic Forest*, M. C. M. Marques, C. E. V. Grelle, Eds. (Springer, 2021), pp. 115–131.
33. A. Bonn, A. S. L. Rodrigues, K. J. Gaston, *Ecol. Lett.* **5**, 733–741 (2002).
34. K. V. Root, *Ecol. Appl.* **8**, 854–865 (1998).
35. J. A. Hodgson, A. Moilanen, B. A. Wintle, C. D. Thomas, *J. Appl. Ecol.* **48**, 148–152 (2011).
36. S. Sloan, C. N. Jenkins, L. N. Joppa, D. L. A. Gaveau, W. F. Laurance, *Biol. Conserv.* **177**, 12–24 (2014).
37. D. J. Bender, T. A. Contreras, L. Fahrig, *Ecology* **79**, 517–533 (1998).
38. M. B. Lauterjung *et al.*, *For. Ecol. Manage.* **435**, 144–150 (2019).
39. M. Vellend *et al.*, *Ecology* **87**, 542–548 (2006).
40. Q. Cronk, *Science* **353**, 446–447 (2016).
41. N. S. Sodhi *et al.*, *Biodivers. Conserv.* **19**, 317–328 (2010).
42. E. W. Seabloom, A. P. Dobson, D. M. Stoms, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 11229–11234 (2002).

43. M. Barstow, T. Jimbo, K. Davies, . *Plants People Planet* **5**, 508–519 (2023).
44. D. A. L. Canhos *et al*., *Biota Neotrop.* **22**, e20221394 (2022).
45. L. A. E. da Silva *et al*., *Rodriguésia* **68**, 391–410 (2017).
46. GBIF.org, GBIF Occurrence Download (2019); https://doi.org/10.15468/dl.mzmat2.
47. R. A. F. de Lima *et al*., *Biodivers. Conserv.* **24**, 2135–2148 (2015).
48. R. A. F. de Lima, G. Dauby, Scripts, functions and data to reproduce the results of "Comprehensive conservation assessments reveal high extinction risks across Atlantic Forest trees," Version 0.0.1, Zenodo (2023); https://doi.org/10.5281/zenodo.8253431.
49. ESA, "Land Cover CCI Product User Guide Version 2" (2017); http://maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf.
50. M. Hoffman, K. Koenig, G. Bunting, J. Costanza, K. J. Williams, Biodiversity Hotspots, Version 2016.1, Zenodo (2016); https://doi.org/10.5281/zenodo.3261807.
51. E. Dinerstein *et al*., *Bioscience* **67**, 534–545 (2017).
52. UNEP-WCMC, IUCN, Protected planet: The World Database on Protected Areas (WDPA) (2020); www.protectedplanet.net.

ACKNOWLEDGMENTS

We thank H. R. Akçakaya and CNCFlora staff (P. da Rosa, G. Martinelli, E. Martins, R. Loyola, P. H. A. de Melo, and T. L. B. da Cunha) for advice on the IUCN Red List Categories and Criteria. Special thanks go to M. Rivers and E. Beech [Botanic Gardens Conservation International (BGCI)] for reviewing the methods used to generate the conservation assessments. We acknowledge J. S. Wright and H. Muller-Landau (Smithsonian Tropical Research Institute) for their input on the estimation of age of first reproduction and C. Canteiro (Global Center for Species Survival, Indianapolis Zoo) for the clarifications of the GL used in previous IUCN Red List assessments. We also thank M. Barstow and E. Beech (BGCI) for providing their list of commercial timber species. **Funding:** This research was funded by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement no. 795114 (R.A.F.d.L. and H.t.S.). Forest inventory data was funded by grants 2013/08722-5 [São Paulo Research Foundation (FAPESP)], 312075/2013-8 [Brazilian National Council for Scientific and Technological Development (CNPq)], and 2017TR1922 [Santa Catarina Research Foundation (FAPESC)] to R.A.F.d.L., P.I.P., A.C.V., and A.L.d.G. A.L.d.G., A.C.V., M.F.d.S., and P.I.P. were supported by CNPq grants 311303/2020-0, 305199/2022-6, 310206/2019-7, and 313055/2020-3, respectively. **Author contributions:** Conceptualization: R.A.F.d.L., H.t.S.; Data curation: R.A.F.d.L., A.L.d.G., A.C.V., V.C.S.; Formal analysis: R.A.F.d.L., G.D.; Funding acquisition: R.A.F.d.L., A.L.d.G., A.C.V., P.I.P., H.t.S.; Methodology: R.A.F.d.L., G.D., E.P.F., M.F.d.S., A.L.d.G., H.t.S.; Software: R.A.F.d.L., G.D.; Visualization: R.A.F.d.L.; Writing – original draft: R.A.F.d.L.; Writing – review and editing: G.D., A.L.d.G., E.P.F., A.C.V., A.A.d.O., P.I.P., V.C.S., M.F.d.S., H.t.S. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** Herbarium occurrence data were compiled from *species*Link, Jabot, and GBIF (*44*–*46*). The forest inventory and species trait data were extracted from the Neotropical Tree Communities database (version 4.1; http://labtrop.ib.usp.br/doku.php?id = projetos:treeco:start) (*20*, *47*) and are available to researchers by request from the database managers. The full sources of the publicly available herbarium, inventory, and species trait data used in this study are provided as supplementary materials (data S1). All scripts, functions, and data that support the findings of this study are openly available at https://github.com/LimaRAF/THREAT and deposited at Zenodo (*48*). The maps used to assess habitat cover change, assess species occurrences in protected areas, and delimit the main tropical forests are available online (*49*–*52*). A summary of species information, population metrics, and conservation assessment results are provided as supplementary materials (data S2). Reference values of population parameters from the literature and an exploration of parameters used for the group-specific generalizations performed in this study are also provided as supplementary materials (data S3). All files necessary to enter the assessments in the IUCN Species Information Service (SIS) system (SIS Connect) are provided as supplementary materials (data S4). Data S1 to S4 are also deposited at Zenodo (*48*).

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.abq5099
Materials and Methods
Figs. S1 to S17
Tables S1 to S7
References (*53*–*163*)
Data S1 to S4

Submitted 12 April 2022; resubmitted 6 May 2023
Accepted 5 December 2023
10.1126/science.abq5099