nature climate change

ARTICLES
https://doi.org/10.1038/s41558-019-0500-2

Amazonian tree species threatened by deforestation and climate change

Vitor H. F. Gomes[1,2]*, Ima C. G. Vieira[1,2], Rafael P. Salomão[3] and Hans ter Steege[3,4,5]

Deforestation is currently the major threat to Amazonian tree species but climate change may surpass it in just a few decades. Here, we show that climate and deforestation combined could cause a decline of up to 58% in Amazon tree species richness, whilst deforestation alone may cause 19–36% and climate change 31–37% by 2050. Quantification is achieved by overlaying species distribution models for current and future climate change scenarios with historical and projected deforestation. Species may lose an average of 65% of their original environmentally suitable area, and a total of 53% may be threatened according to IUCN Red List criteria; however, Amazonian protected area networks reduce these impacts. The worst-case combined scenario—assuming no substantial climate or deforestation policy progress—suggests that by 2050 the Amazonian lowland rainforest may be cut into two blocks: one continuous block with 53% of the original area and another severely fragmented block. This outlook urges rapid progress to zero deforestation, which would help to mitigate climate change and foster biodiversity conservation.

The Amazonian lowland rainforest is the single largest rainforest block on Earth. At ~5.7 million km^2 it currently holds close to 13% of all trees (diameter at breast height, dbh > 10 cm) of the world and 49% of those in tropical moist forests[1]. Amazonia is arguably the richest rainforest but the actual tree species richness is still under debate, ranging from ~7,000 (ref. [2]) to 16,000 (ref. [3]) species. Amazonian diversity is not immune to deforestation and human-driven climate change, and their impacts are usually estimated separately because of the differences in time scales and patterns of biodiversity loss[4]. A realistic scenario that will guide public policies, however, should take both processes into account.

The future of Amazonia facing global change has been debated[5]. Amazonia had lost ~11% of its area by 2013[6]. This is enough to qualify 27% of all Amazonian tree species as being globally threatened by IUCN categories at present. Projections show that deforestation may increase Amazonian forest loss to 21–40% by 2050 and the number of threatened species to 40–64%[7]. Although habitat loss caused by deforestation is currently a major source of threat to Amazonian tree species diversity[8], evidence suggests that human-induced climate change may surpass the impact of deforestation in a few decades[9]. Amazonian forest may have already crossed a climate resiliency threshold due to climate change[10]. The median spatial distance between current climate of sites within the Amazonian rainforest and their closest future climate analogues may increase by more than 300 km in 2050 based only on annual temperature and up to 475 km when including annual precipitation, thereby increasing species vulnerability, particularly when considering that deforestation creates migration barriers for slowly migrating species[11]. However, as environmental tolerance is a driver of the geographic distribution of species, species must either tolerate new climates or track optimal environmental conditions[12]. Driven by climate change during the late Holocene, Amazonian tree communities expanded their distribution south beyond the forest boundaries but reached no further than 100 km over a three millennia process[13]. As future climate change is predicted to occur in a shorter time period than during the late Holocene, most tree species are probably unable to track future climate, facing extinction in areas where climatic conditions are no longer suitable[14].

Here, we quantify the combined impacts of deforestation and climate change of 10,071 Amazonian tree species. We model the original environmental suitability for species, which we call estimated area of occupancy (AOO), based on a species distribution model (SDM) but constrained by the known extent of occurrence (EOO)[15] (Supplementary Fig. 1). We then quantify losses produced by historical deforestation, two deforestation scenarios for 2050, two climate change scenarios for 2050 and their interactions. We also ask to what extent the Amazonian protected area (PA) network may prevent habitat loss and the decline in species richness. Finally, we assess the species' threat status for each of the scenarios, based on the criteria of the IUCN Red List of Threatened Species.

Original AOO

Our analysis was conducted for 6,394 Amazonian tree species (62% of the 10,071 species) with available records, after we removed inconsistencies from the collection data. Furthermore, species with available records below the minimum (<6), an environmental suitability model not significantly different from a bias corrected null model, and no estimated AOO within Amazonia were removed (Supplementary Table 1). A total of 406 species with restricted EOO (325) and AOO (81) were qualified as threatened according to the IUCN B1 and D2 criteria (Table 1; Supplementary Table 1). Further analyses were conducted for 4,935 species (49%, Supplementary Table 2), as in the example of *Eschweilera coriacea* (DC) SA Mori, one of the most common tree species of Amazonia[3] (Fig. 1). The mean original species richness was 1,458 (by 0.1° cells), with a median of 1,394 (Fig. 2a; Table 1; Supplementary Table 3). Species richness was highest in north-western Amazonia (3,784 total species, 1,896 average by 0.1° cells), the Guiana Shield (3,865 total, 1,406 average) and central Amazonia (3,840 total, 1,813 average) (Supplementary Tables 3 and 4).

[1]Programa de Pós-Graduação em Ciência Ambientais, Universidade Federal do Pará, Belém, Brazil. [2]Coordenação de Botânica, Museu Paraense Emílio Goeldi, Belém, Brazil. [3]Universidade Federal Rural da Amazônia, Belém, Brazil. [4]Naturalis Biodiversity Center, Leiden, the Netherlands. [5]Systems Ecology, Free University, Amsterdam, the Netherlands. *e-mail: vitorhfreitas@gmail.com

Table 1 | Results for all scenarios showing estimation of losses of AOO, mean species richness and total number of threatened species[a]

Scenarios	Average loss of AOO (%)	Mean species richness	No. of species listed in IUCN A2/A4 criteria	No. of species listed in IUCN B1/D2 criteria	Total no. of threatened species	% of threatened species	Mean species richness within PAs	Mean species richness outside PAs
Original	0.0	1,458	0	406	406	4.0	1,544	1,353
Original and 2013	7.3	1,353	406		807	8.0	1,535	1,113
Original and IGS	18.7	1,183	1,802		2,099	20.8	1,417	898
Original and BAU	33.2	929	3,512		3,704	36.8	1,158	650
RCP 2.6	46.5	1,013	4,320		4,434	44.0	1,082	929
RCP 8.5	53.4	919	4,588		4,689	46.6	980	844
RCP 2.6 and IGS	52.7	834	4,782		4,872	48.4	995	639
RCP 2.6 and BAU	60.3	672	4,871		4,957	49.2	831	478
RCP 8.5 and IGS	58.8	757	4,854		4,940	49.1	901	583
RCP 8.5 and BAU	65.4	612	4,908		4,993	49.6	756	438

[a]The total number of threatened species are non-overlapping (species listed for B1 and D2 criteria are not included when they are also listed for A2 and A4).

Impacts of historical and projected forest loss

The historical forest loss of ~11% (Supplementary Fig. 2a) impacted mainly species in southern and eastern Amazonia (Supplementary Tables 3 and 4). The forest loss by 2013 was responsible for a mean decline of 7% in the estimated AOO of Amazonian tree species (median = 3%) (Supplementary Table 2). A total of 423 (4.2%) species lost a sufficiently large proportion of their original AOO to be qualified as threatened according to IUCN A2 criterion (Supplementary Table 2). Including the 406 species already listed in the IUCN B1 and D2 criteria, a total of 807 (8%) can be considered threatened by 2013 (Table 1). Only 133 (1.3%) species showed no losses of their original AOO. Most of them were predicted to occur on the Guiana Shield (58%) or in north-western Amazonia (25%) and only 3% of these species were predicted in eastern and southern Amazonia (Supplementary Tables 2 and 4). The correlation between the estimated loss of AOO by deforestation with population loss, as estimated by ter Steege et al.[7], throughout Amazonia was significant but moderate for historical deforestation by 2013 ($\rho = 0.48$) (Supplementary Fig. 3a; Supplementary Table 5). The loss of AOO inside the PAs was 0.9% by 2013; the loss outside was 23% (Supplementary Figs. 4a and 5a). The PAs covered 54.8% of the remaining forest and mean species richness (by 0.1° grid cells) by 2013 was 1,535 inside and 1,133 outside the PAs (Table 1; Supplementary Tables 6 and 7).

The projected deforestation for 2050 (with forest loss of 21% in improved governance deforestation scenario (IGS) and 40% in business-as-usual scenario (BAU)) is expected to produce an average loss of AOO of 19% for IGS and 33% for BAU (Fig. 2b,c; Supplementary Fig. 2b,c; Supplementary Table 2). Mean original species richness across Amazonia (by 0.1° cell) is expected to decrease between 19% in the IGS to 36% in the BAU. As the projected deforestation is concentrated in southern and eastern Amazonia, the species were predicted to suffer higher impacts in these regions, with an average loss of estimated AOO of 58% (IGS) and 87% (BAU) (Supplementary Table 3). *Protium altissimum* (Aubl.) Marchand. is an example of a southern/eastern hyperdominant species that may be impacted by deforestation, with losses reaching up to 50% of its estimated AOO by 2050 (BAU) (Supplementary Fig. 6a; Supplementary Table 2). By 2050 between 1,802 (18%) and 3,512 (35%) species may lose sufficient AOO to become threatened according to the IUCN A4 criterion for IGS and BAU scenarios, respectively (Table 1; Supplementary Table 2). A total of 21–37% may be considered threatened when adding the IUCN B1 and D2 criteria (Supplementary Table 1). The correlation between the estimated loss of AOO by deforestation for 2050 and the population loss as estimated by ter Steege et al.[7] for 2050 was also significant but moderate for both IGS ($\rho = 0.46$) and BAU scenarios ($\rho = 0.54$) (Supplementary Fig. 3b,c; Supplementary Table 5).

Impacts of climate change

The average loss of AOO by 2050 was 47% in the representative concentration pathways (RCP) 2.6 scenario and 53% in the RCP 8.5 scenario (Supplementary Table 2). Mean species richness is expected to decrease between 30% in RCP 2.6 and 37% in RCP 8.5 (Fig. 2d,g; Supplementary Table 3). Climate change will impact the Amazonian lowland forest as a whole (Supplementary Fig. 7d,g; Supplementary Tables 2 and 3) and even northern/central Amazonian species occurring far from the 'Arc of Deforestation', such as the hyperdominant *Eperua falcata* Aubl. (Supplementary Fig. 6b), may be impacted by climate change in RCP 2.6 and RCP 8.5 scenarios (56–63%). The number of threatened species according to the IUCN A4 criterion was 4,320 (43%) for RCP 2.6 scenario and 4,588 (46%) for RCP 8.5 scenario (Supplementary Table 2). Adding the IUCN B1 and D2 criteria, the total number of species threatened may rise to 4,434 (44%) and 4,689 (47%).

Impacts of the combined scenarios

The best case combined scenario for 2050 (RCP 2.6 and IGS) resulted in an average loss of estimated AOO of 53%, followed by the intermediate scenarios RCP 8.5 and IGS (59%) and RCP 2.6 and BAU (60%), and the worst-case combined scenario (RCP 8.5 and BAU) with 65% (Table 1; Supplementary Table 2). Species richness dropped 43–58% (from best to worst) in the combined scenarios (Table 1; Supplementary Table 3; Fig. 2e,f,h,i). Species with a western distribution, such as *Iriartea deltoidea* Ruiz & Pav. (16–22% of AOO loss by 2050), may be less impacted by this interaction (Supplementary Fig. 6c; Supplementary Tables 2 and 4). By 2050 the loss of estimated AOO may vary between 8% and 28% inside and 40% and 60% outside the PAs. Mean species richness may vary between 639 and 995 species inside and 438 and 756 outside the PAs (Supplementary Fig. 4b,c) in 2050. The forest may have 1.0–1.6 million km^2 of its remaining area outside the network (Supplementary Fig. 5b,c), including areas with species richness reaching up to 1,986–2,188 species.

Some species may lose their entire estimated AOO, facing a high probability of extinction in Amazonia by 2050 (Supplementary Table 2). The number of species with 100% loss of AOO was higher in the combined scenarios that included the BAU deforestation

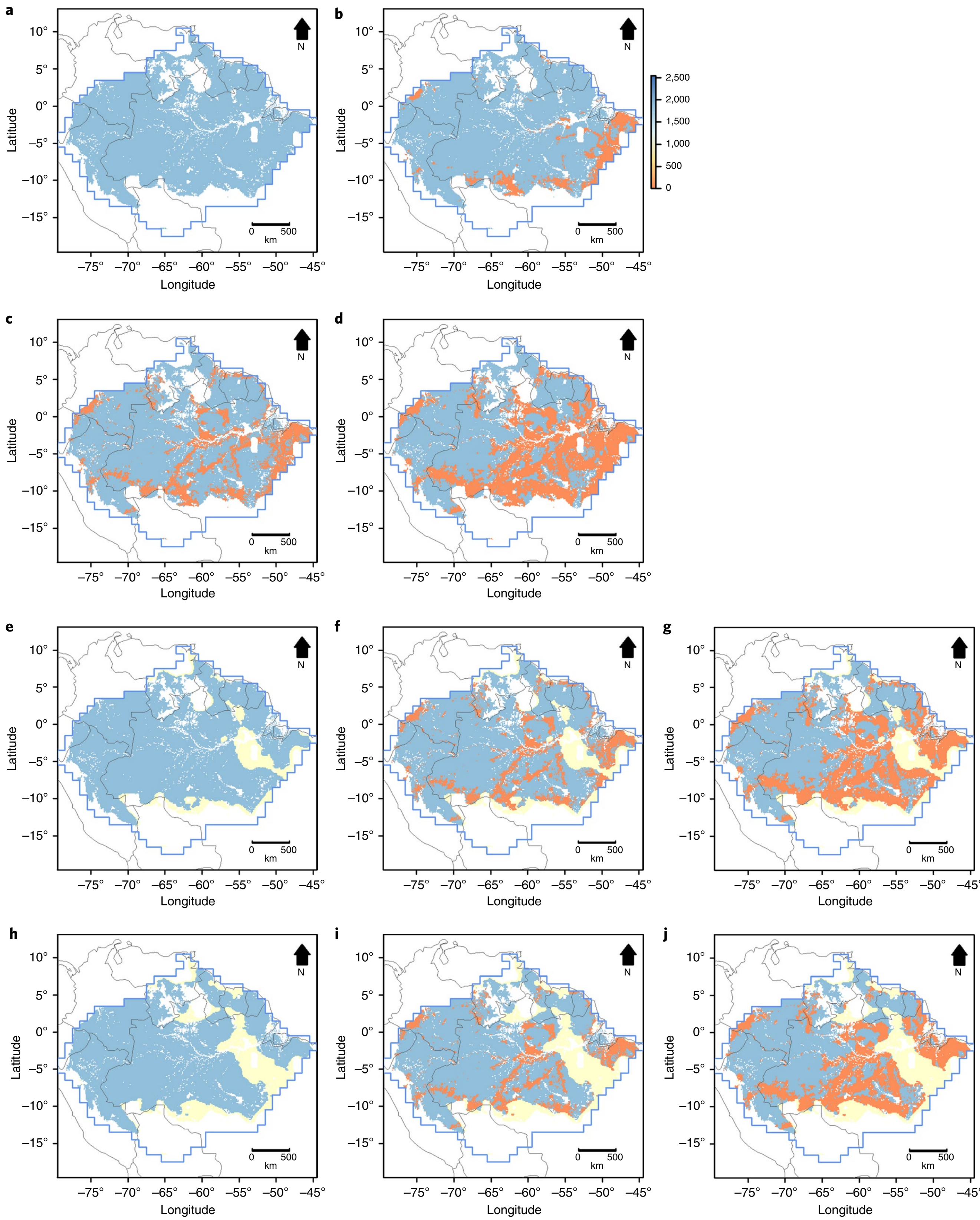

Fig. 1 | Loss by global change for *E. coriacea* (DC) SA Mori. a–j, Loss of *E. coriacea* (DC) SA Mori, the most common species in Amazonia[15]. **a**, Original AOO. **b**, Original AOO and deforestation by 2013 (refs. [6,53,54]). **c**, Original AOO and 2050 IGS deforestation[53,54]. **d**, Original AOO and 2050 BAU deforestation[53,54]. **e**, 2050 RCP 2.6 AOO. **f**, 2050 RCP 2.6 AOO and 2050 IGS deforestation. **g**, 2050 RCP 2.6 AOO and 2050 BAU deforestation. **h**, 2050 RCP 8.5 AOO. **i**, 2050 RCP 8.5 AOO and 2050 IGS deforestation. **j**, 2050 RCP 8.5 AOO and 2050 BAU deforestation. Colour scale indicates decrease in AOO from blue (forested area) to red (loss in AOO). Maps created with custom R script[55]. Credit: Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company, Arcworld.

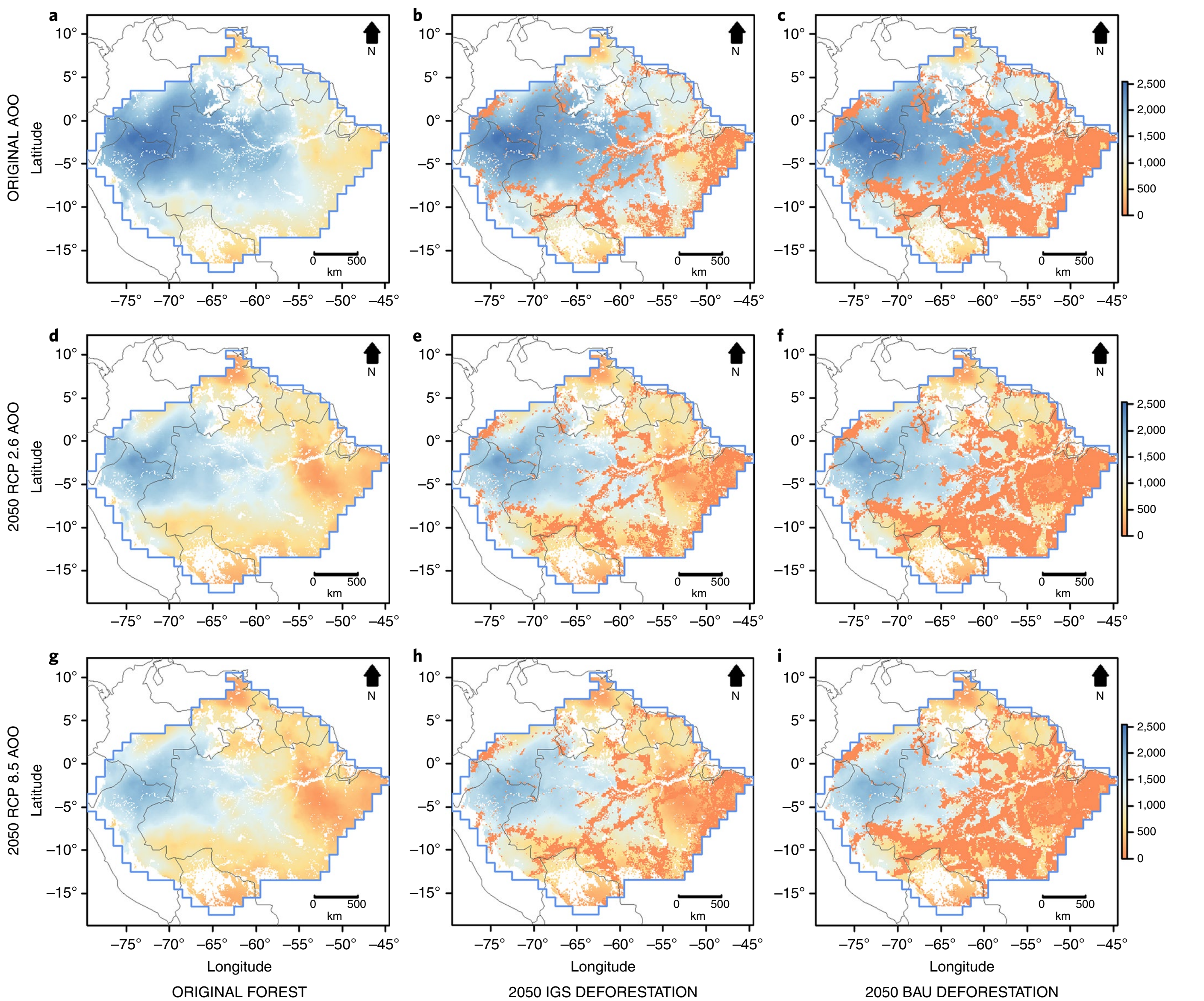

Fig. 2 | Amazonian species richness (number of species per grid cell) affected by global change and deforestation. a, Original AOO only. **b**, Original AOO and 2050 IGS[53,54]. **c**, Original AOO and 2050 BAU[53,54]. **d**, 2050 RCP 2.6 AOO only. **e**, 2050 RCP 2.6 AOO combined with 2050 IGS deforestation. **f**, 2050 RCP 2.6 AOO combined with 2050 BAU deforestation, **g**, 2050 RCP 8.5 AOO only. **h**, 2050 RCP 8.5 AOO combined with 2050 IGS deforestation. **i**, 2050 RCP 8.5 AOO combined with 2050 BAU deforestation. Colour scale as in Fig. 1. Maps created with custom R script[55]. Credit: Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company, Arcworld.

scenario (Supplementary Table 2). By 2050 the AOO of all species will be impacted by deforestation and climate change (Supplementary Table 2). The total number of threatened species according to IUCN A4, B1 and D2 criteria may vary between 4,872 (48.4%) and 4,993 (49.6%) from the best-case combined scenario to worst-case combined scenario (Table 1; Supplementary Table 2).

Discussion

The combined losses by deforestation and climate change, suggest that Amazonian tree species may lose 53–65% of their estimated AOO by 2050. This would be enough to qualify 47–49% of all known Amazonian tree species as threatened according IUCN A4 criterion, including almost all (96%) of the hyperdominant species[3]. Adding the 425 species we found to be currently qualified as threatened under IUCN Criteria B1 and D2, the total proportion increases to 48–50% (Supplementary Table 2). There is a data void in the tropics[16] and the number of new species of flowering plants is expected to increase by 10–50% in Brazilian Amazonia alone[17]. Considering the limitation of our analyses for rare and, as yet, unknown species, the estimates of the number of species qualified as threatened are probably higher than we report here.

Our analyses were based on 49% of all known Amazonian tree species (10,071). However, this should not affect species richness patterns. We omitted only those species that were either too rare or did not have enough available records to produce significant models. Major ecological patterns are likely to be maintained because the most common species generally define large-scale patterns, and rare species are often too restricted to affect it[18]. Furthermore, rare species and species with low prevalence are probably over-predicted, compromising model accuracy and the reliability of the stacked SDMs (S-SDMs)[19], as used in our species richness analysis. S-SDMs tends to over-predict species

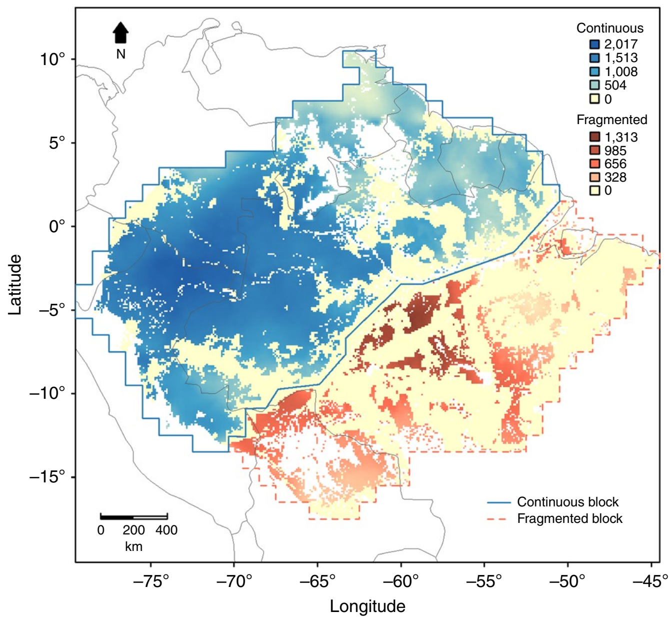

Fig. 3 | Only half of the Amazonian forest may remain in 2050 (worst-case combined scenario). Blue, a relatively intact Amazonian forest continuous block, composed of north-western and central Amazonia, the Guiana Shield and smaller part of south-western Amazonia (maximum number of species per grid cell is 1,393, with mean 578). Red, a largely degraded and fragmented Amazonian forest block composed of eastern, southern and a major part of south-western Amazonia (maximum number of species per grid cell is 898, with mean 142). Light yellow, forest loss. Map created with custom R script[55]. Credit: Base map source (country.shp, rivers.shp): ESRI (http://www.esri.com/data/basemaps, © Esri, DeLorme Publishing Company, Arcworld.

richness because they model environmental suitability, rather than the species' real range[20]. We believe that over-prediction effects were reduced by our SDMs, based on a conservative estimate of an environmental suitability model[15] (area slightly larger than species EOO, compatible with, for example, the IUCN Red List assessments, Supplementary Fig.1).

Deforestation is also expected to reduce populations of Amazonian tree species in the future[7]. We found deforestation in 2013 to be responsible for a 7% decline in the estimated AOO of the Amazonian tree species, and this may potentially reach 19–33% by 2050, considering our projected deforestation analyses. We compared our results of the estimated loss of AOO against estimated population loss as estimated by ter Steege et al.[7]. The correlations for historical deforestation by 2013 and the IGS projected deforestation scenario by 2050 were significant but moderate. For 2050 projections of the BAU scenario, the correlation was slightly higher. Although the correlations are mostly moderate, both estimates may be realistic. Area changes will first occur in the outskirts of the range where the population densities are lowest, thereby decoupling the two measures to some extent.

Despite that, the losses produced by climate change are expected to be higher. According to our climate change mitigation scenario (RCP 2.6) mean species richness may be reduced by almost one-third (30%) and estimated AOO may drop by almost a half (47%) by 2050. This scenario limits global warming below 2 °C[21]. Our BAU climate change scenario (RCP 8.5) shows higher emissions trends, close to those observed in 2000 (ref. [22]), and may drive the forest in more extreme climate conditions[23]. According to this scenario, the estimated AOO loss may increase up to 53% and mean species richness losses may reach 37%.

The interaction between deforestation and climate change may be the greatest threat to Amazonian biodiversity, especially for trees[24]. South-western, southern and eastern Amazonia are the regions most likely to be affected by the synergetic impacts of deforestation and climate change (Supplementary Fig. 7). Eastern Amazonia alone may suffer up to 95% of forest loss by 2050, followed by south-western (81%) and southern Amazonia (78%) (Supplementary Table 4). Adding the influence of fire to the synergy of deforestation and climate change, a 20–25% deforestation is already expected to be the tipping point for these regions to no longer support rainforest ecossystems[8]. By 2007 and 2010 southern/eastern Amazonia had already lost 12% and 5%, respectively, of its forests by regional fire during severe drought events[25]. Furthermore, deforestation has also influenced regional climate in Amazonia by affecting the water balance and water cycle in southern/eastern Amazonia due to land uses that follow deforestation, such as agricultural expansion[26].

Our best-case combined scenario (RCP 2.6 and IGS) shows only a small reduction in the total number of threatened species compared to our worst-case combined scenario (RCP 8.5 and BAU). However, it makes a big difference in the level of threat, as the number of species listed as 'critically endangered' (CR) drops from 22% (RCP 8.5 and BAU) to 11% (RCP 2.6 and IGS). The worst-case combined scenario shows 'a half Amazonia' by 2050 where the original forest is divided into two blocks: one continuous with 53% of the original area and a severely fragmented one (Fig. 3). The severe fragmentation outside the continuous block may add to species loss[27], provoking alterations in tree-community composition[28]. Small forest fragments will also quickly lose species and biomass due to overhunting, causing a decrease in populations of large bodied animals[29] and further reducing species richness for trees that depend on these species for dispersal[30]. Big tree species are also largely affected by fragmentation due to influences of wind turbulence, desiccation and infestation by lianas, which are common effects observed near forest edges[31]. Such species have a strong influence on forest structure, composition and hydrology, and they also contribute to carbon storage[32].

Although the impacts in some Amazonian countries such as Guyana[33] may be lower and deforestation rates have declined compared to projected deforestation scenarios[7], the worst-case combined scenario, and also the intermediary combined scenario RCP 2.6 and BAU, cannot be discarded given the recent rising deforestation trends in Brazil, which holds the largest portion of the Amazonian rainforest[34]. Brazil joined the Paris Agreement in 2015 and pledged to cut its greenhouse gas emissions by 37%, reach zero deforestation and reforest 12 million ha by 2030[35]. However, Brazil still suffers from high deforestation rates[36] and a future reduction of this trend remains uncertain[37]. Deforestation has increased during the past 5 years at a rate of ~7,000 km^2 per year[38]. Furthermore, international negotiations on limiting global warming have failed[39] and recent Brazilian law changes may severely limit scientific research, including the monitoring of forest and biodiversity loss[40].

Other Amazonian countries, such as Colombia, showed a recent increase of fires within PA after demobilization of the guerilla[41]. Studies have pointed out positive correlations between coca cultivation and guerrilla activities within PAs[42] and reductions in deforestation in Colombia and Peru[43]. PAs contain tree populations that are safeguarded from deforestation and they have an important inhibitory effect on the deforestation of Amazonian forest in Brazil[44]. PAs are also effective in preventing deforestation fires, with fewer fires occurring within PAs compared to outside the protection area[45]. PAs are not immune to the impacts of climate change, however, and the absence of protected corridors may isolate species from suitable areas under different future climate conditions[14].

We found that inside the PA network mean species richness may drop to 639 species per grid cell and total habitat loss may reach 28%. Despite this, PAs may provide benefits for biodiversity, especially when they focus on governance quality and planning methods[46]. We found that areas outside the network had worse results, with mean species richness dropping down to 438 species per grid cell and total habitat loss reaching 60%. Amazonia may have about 50% of its forest outside the network, mostly in central and north-western Amazonia, and this unprotected area has grid cells with a high predicted number of species, which is important for biodiversity conservation and establishment of new PAs (Supplementary Fig. 5).

Tropical forests have major environmental roles by stabilizing atmospheric CO_2 (ref. [47]), regulating climate[48] and safeguarding biodiversity[49]. Tropical forests also provide benefits to the society (ecosystems services), and their losses are generally not compensated for by the development of other sectors, such as manufacturing and services, leading to unsustainable development pathways[50]. The true losses behind their degradation may be immeasurable. Biologists have warned for more than a century about the possible demise of the Atlantic forest[51], and yet only 12% of its original cover remains[52]. We must try to avoid that Amazonia will suffer the same fate.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, statements of code and data availability and associated accession codes are available at https://doi.org/10.1038/s41558-019-0500-2.

Received: 13 June 2018; Accepted: 3 May 2019;
Published online: 24 June 2019

References

1. Crowther, T. W. et al. Mapping tree density at a global scale. *Nature* **525**, 201–205 (2015).
2. Cardoso, D. et al. Amazon plant diversity revealed by a taxonomically verified species list. *Proc. Natl Acad. Sci. USA* **114**, 10695–10700 (2017).
3. ter Steege, H. et al. Hyperdominance in the Amazonian tree flora. *Science* **342**, 1243092 (2013).
4. Huntingford, C. et al. Towards quantifying uncertainty in predictions of Amazon 'dieback'. *Philos. Trans. R. Soc. Lond. B* **363**, 1857–1864 (2008).
5. ter Steege, H. Will tropical biodiversity survive our approach to global change? *Biotropica* **42**, 561–562 (2010).
6. Hansen, M. C. C. et al. High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–854 (2013).
7. ter Steege, H. et al. Estimating the global conservation status of over 15,000 Amazonian tree species. *Sci. Adv.* **1**, e1500936 (2015).
8. Lovejoy, T. E. & Nobre, C. Amazon tipping point. *Sci. Adv.* **4**, 2340 (2018).
9. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **15**, 365–377 (2012).
10. Cowling, S. A. et al. Contrasting simulated past and future responses of the Amazonian forest to atmospheric change. *Philos. Trans. R. Soc. Lond. B* **359**, 539–547 (2004).
11. Feeley, K. J. & Rehm, E. M. Amazon's vulnerability to climate change heightened by deforestation and man-made dispersal barriers. *Glob. Chang. Biol.* **18**, 3606–3614 (2012).
12. Pecl, G. T. et al. Biodiversity redistribution under climate change: impacts on ecosystems and human well-being. *Science* **355**, eaai9214 (2017).
13. Mayle, F. E., Burbridge, R. & Killeen, T. J. Millennial-scale dynamics of southern Amazonian rain forests. *Science* **290**, 2291–2294 (2000).
14. Feeley, K. J. & Silman, M. R. Disappearing climates will limit the efficacy of Amazonian protected areas. *Divers. Distrib.* **22**, 1081–1084 (2016).
15. Gomes, V. H. F. et al. Species distribution modelling: contrasting presence-only models with plot abundance data. *Sci. Rep.* **8**, 1003 (2018).
16. Feeley, K. J. & Silman, M. R. The data void in modeling current and future distributions of tropical species. *Glob. Chang. Biol.* **17**, 626–630 (2010).
17. Pimm, S. L., Jenkins, C. N., Joppa, L. N., Roberts, D. L. & Russell, G. J. How many endangered species remain to be discovered in Brazil? *Nat. Conservacao* **8**, 71–77 (2010).
18. Pos, E. T. et al. Are all species necessary to reveal ecologically important patterns? *Ecol. Evol.* **4**, 4626–4636 (2014).
19. van Proosdij, A. S. J., Sosef, M. S. M., Wieringa, J. J. & Raes, N. Minimum required number of specimen records to develop accurate species distribution models. *Ecography* **39**, 542–552 (2015).
20. Calabrese, J. M., Certain, G., Kraan, C. & Dormann, C. F. Stacking species distribution models and adjusting bias by linking them to macroecological models. *Glob. Ecol. Biogeogr.* **23**, 99–112 (2014).
21. IPCC *Climate Change 2013: The Physical Science Basis* (eds Stocker, T. F. et al.) (Cambridge Univ. Press, 2013).
22. Peters, G. P. et al. The challenge to keep global warming below 2°C. *Nat. Clim. Change* **3**, 4–6 (2012).
23. Diffenbaugh, N. S. & Field, C. B. Changes in ecologically critical terrestrial climate conditions. *Science* **341**, 486–492 (2013).
24. Brodie, J., Post, E. & Laurance, W. F. Climate change and tropical biodiversity: a new focus. *Trends Ecol. Evol.* **27**, 145–150 (2012).
25. Brando, P. M. et al. Abrupt increases in Amazonian tree mortality due to drought-fire interactions. *Proc. Natl Acad. Sci. USA* **111**, 6347–6352 (2014).
26. Silvério, D. V. et al. Agricultural expansion dominates climate changes in southeastern Amazonia: the overlooked non-GHG forcing. *Environ. Res. Lett.* **10**, 104015 (2015).
27. Taubert, F. et al. Global patterns of tropical forest fragmentation. *Nature* **554**, 512–519 (2018).
28. Laurance, W. F. et al. Rapid decay of tree-community composition in Amazonian forest fragments. *Proc. Natl Acad. Sci. USA* **103**, 19010–19014 (2006).
29. Bicknell, J. & Peres, C. A. Vertebrate population responses to reduced-impact logging in a neotropical forest. *For. Ecol. Manage.* **259**, 2267–2275 (2010).
30. Bello, C. et al. Defaunation affects carbon storage in tropical forests. *Sci. Adv.* **1**, e1501105 (2015).
31. Laurance, W. F., Delamônica, P., Laurance, S. G., Vasconcelos, H. L. & Lovejoy, T. E. Rainforest fragmentation kills big trees. *Nature* **404**, 836 (2000).
32. Feldpausch, T. R., Jirka, S., Passos, C. A. M., Jasper, F. & Riha, S. J. When big trees fall: damage and carbon export by reduced impact logging in southern Amazonia. *For. Ecol. Manage.* **219**, 199–215 (2005).
33. MacDicken, K. et al. *Global Forest Resources Assessment 2015: How Are the World's Forests Changing?* (FAO, 2016).
34. Fearnside, P. M. Business as usual: a resurgence of deforestation in the Brazilian Amazon. *Yale Environment 360* 1–6(18 April 2017).
35. Tollefson, J. Forests in spotlight at Paris climate talks. *Nature News* (1 December 2015).
36. Moutinho, P., Guerra, R. & Azevedo-Ramos, C. Achieving zero deforestation in the Brazilian Amazon: what is missing? *Elementa (Wash DC)* **4**, 000125 (2016).
37. Tollefson, J. Stopping deforestation: battle for the Amazon. *Nature* **520**, 20–23 (2015).
38. PRODES Projeto. *Mapeamento do desmatamento da Amazônia com Imagens de Satélite* (Instituto Nacional de Pesquisas Espaciais, 2018).
39. Christopher, J. US withdrawal from the COP21 Paris Climate Change Agreement, and its possible implications. *Sci. Prog.* **100**, 411–419 (2017).
40. Bockmann, F. A. et al. Brazil's government attacks biodiversity. *Science* **360**, 865–865 (2018).
41. Armenteras, D., Schneider, L. & Dávalos, L. M. Fires in protected areas reveal unforeseen costs of Colombian peace. *Nat. Ecol. Evol.* **3**, 20–23 (2018).
42. Dávalos, L. M. in *The Origins of Cocaine: Colonization and Failed Development in the Amazon Andes* 1st edn (eds Gootenberg, P. & Dávalos, L. M.) 19–52 (Routledge, 2018).
43. Hanauer, M. & Canavire Bacarreza, G. *Civil Conflict Reduced the Impact of Colombia's Protected Areas* (Inter-American Development Bank, 2018).
44. Soares-Filho, B. et al. Role of Brazilian Amazon protected areas in climate change mitigation. *Proc. Natl Acad. Sci. USA* **107**, 10821–10826 (2010).
45. Adeney, J. M., Christensen, N. L. & Pimm, S. L. Reserves protect against deforestation fires in the Amazon. *PLoS ONE* **4**, e5014 (2009).
46. Watson, J. E. M., Dudley, N., Segan, D. B. & Hockings, M. The performance and potential of protected areas. *Nature* **515**, 67–73 (2014).
47. Houghton, R. A., Byers, B. & Nassikas, A. A. A role for tropical forests in stabilizing atmospheric CO_2. *Nat. Clim. Change* **5**, 1022–1023 (2015).
48. Bonan, G. B. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science* **320**, 1444–1449 (2008).
49. Gibson, L. et al. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* **478**, 378–381 (2011).
50. Carrasco, L. R., Le Nghiem, T. P., Chen, Z. & Barbier, E. B. Unsustainable development pathways caused by tropical deforestation. *Sci. Adv.* **3**, 1–10 (2017).
51. Dean, W. *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest* (Univ. of California Press, 1997).
52. Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J. & Hirota, M. M. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biol. Conserv.* **142**, 1141–1153 (2009).
53. Soares-Filho, B. S. et al. Modelling conservation in the Amazon Basin. *Nature* **440**, 520–523 (2006).
54. Soares-Filho, B. S. et al. *LBA-ECO LC-14 Modeled Deforestation Scenarios, Amazon Basin: 2002–2050* (Oak Ridge National Laboratory Distributed Active Archive Center, 2013).
55. R: a Language and Environment for Statistical Computing v3.4.3 (R Foundation, 2018).

Acknowledgements
V.H.F.G, H.t.S. and R.P.S. were supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico grant no. 407232/2013-3—PVE—MEC/MCTI/CAPES/CNPq/FAPs. R.P.S. is also supported by Programa Professor Visitante Nacional Sênior na Amazônia—CAPES. I.C.G.V. is supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico grant no. 308778/2017-0—CNPq. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal Nível Superior—Brazil (CAPES)—Finance Code 001. We thank S. Mota de Oliveira for constructive comments on the manuscript.

Author contributions
V.H.F.G. conceived the study. V.H.F.G., I.C.G.V. and H.t.S. designed the study. V.H.F.G. carried out the GBIF data collection. H.t.S checked the species list. V.H.F.G. carried out the analyses and wrote the R scripts. V.H.F.G. and H.t.S wrote the manuscript. I.C.G.V and R.P.S provided comments and feedback.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information is available for this paper at https://doi.org/10.1038/s41558-019-0500-2.

Reprints and permissions information is available at www.nature.com/reprints.

Correspondence and requests for materials should be addressed to V.H.F.G.

Peer review information: *Nature Climate Change* thanks Luke Gibson and other, anonymous, reviewer(s) for their contribution to the peer review of this work.

Methods

Species and collections. We focused our analysis on the most recent checklist of lowland Amazonian trees that can reach 10 cm stem diameter at breast height (dbh)[56]. We downloaded species collections from Global Biodiversity Information Facility (GBIF, www.gbif.org) using the 'gbif' function from R package 'dismo' (August 2017). For each species, we downloaded the Amazonian occurrences and also all occurrences in the Neotropics to avoid problems in SDM related to modelling with partial geographic ranges[57]. We assigned all single collections at species level, ignoring intraspecific levels. We followed Gomes et al.[15] using a new conservative pipeline to remove inconsistencies and outliers from collection data. Imprecise georeferences were also removed[58–60]. Since sample size is a relevant aspect of model accuracy, species with less than six records (here defined as locations or a single occurrence per 0.1° cell) were not used to produce SDMs[19]. All species with a small number of collections (<6) were tested with a large plot dataset from Steege et al.[7] to identify poor collected species. Species with a small number of collections and not present in the large plot dataset were listed as threatened according IUCN D2 criterion[61].

Deforestation, PAs and indigenous territories. Deforestation was based on historical deforestation up to 2013 (refs. [6,53,54]) and projected deforestation for 2050 (historical deforestation plus the predicted deforestation)[53,54] at 10 × 10 km resolution, using IGS and BAU (Supplementary Fig. 2a–c). We gathered the spatial data of Amazonian PAs and indigenous territories from the World Database on Protected Areas (Supplementary Fig. 8) (April 2018, https://www.protectedplanet.net)[62], and updated with data from Red Amazónica de Información Socioambiental Georreferenciada - RAISG (January 2019, http://raisg.socioambiental.org/)[63].

Amazonian base map. To produce an Amazonian lowland forest base map we followed ter Steege et al.[7] and eliminated cells with more than 50% water, areas originally without forest and areas above 500 m of elevation at 10 × 10 km resolution. The base map consists of 47,038 0.1° cells, or 5.7 million km^2 (Supplementary Fig. 9). We followed ter Steege et al.[3] and divided the area into six regions: Guiana Shield (GS), north-western Amazonia (WAN), south-western Amazonia (WAS), southern Amazonia (SA), eastern Amazonia (EA) and central Amazonia (CA).

Species AOO. We estimated AOO based on environmental suitability[15]. For that, we assessed environmental suitability by constructing SDM using MaxEnt v.3.3.3k[64,65]. We downloaded 19 environmental variables data from WorldClim[66] at 0.16° resolution, which were produced by means of average monthly interpolated climate data. We resampled all variables to 0.1° (approximately 10 × 10 km) spatial resolution, using the function 'resample' from R package 'raster'[67]. The original environmental suitability for species was based on average climate data for 1950–2000 (ref. [66]). Future environmental suitability for species for 2050 (averages for 2041–2060) was based on two representative concentration pathways (RPCs), RCP 2.6 and RCP 8.5 (ref. [68–70]), using seven global climate model (GCM) projections[66], from the IPCC Fifth Assessment Report (AR5), BCC-CSM[71], CCSM4 (ref. [72]), HadGEM2-ES[73], IPSL-CM5A-LR[74], MIROC-ESM[75], MPI-ESM-LR[76] and MRI-CGCM3 (ref. [77]). These RCPs represent increasing projections of global warming from 0.4 to 2.6 °C by 2050, with mean range of 1 °C (RCP 2.6) and 2 °C (RCP 8.5), and radiative forcing of 2.6 and 8.5 W m^{-2}, corresponding to atmospheric CO_2 concentration of 450 to 750 ppm CO_2eq^{-1} (refs. [78–80]). They reflect trends of CO_2 emissions based on improvements of governance (RCP 2.6) and absence of climate change polices (RCP 8.5).

We based the selection of the variables on their biological relevance and on their scores using a Spearman's rank correlation coefficient threshold of $|\rho| > 0.7$ (ref. [81]). Precipitation variables based on temperature, and temperature variables based on precipitation, were also removed. For temperature, we selected isothermality, temperature seasonality and maximum temperature of warmest month for temperature; for precipitation, we selected annual precipitation, wettest month precipitation and driest month precipitation. Finally, we cropped the environmental variables to the extent of the Neotropics[57].

We corrected the SDMs for geographical sampling bias by employing a target-group background method, producing a background file based on bias according survey efforts of Amazonian tree species collections[15,56,82]. We used only product, threshold and hinge features of MaxEnt[83,84]. MaxEnt's logistical output was transformed into binary maps with a 10% training presence threshold, and a convex hull was used around the species records to estimate their EOO. We then estimated the AOO of the species by restricting the environmental suitability as modelled by MaxEnt to the EOO plus a buffer of 300 km (refs. [15,85]). We produced SDM maps for all species, considering all three climate scenarios: 'original forest', '2050 RCP 2.6' and '2050 RCP 8.5'. For the 2050 scenarios (RCP 2.6 and RCP 8.5) we considered only grid cells predicted by all seven IPCC AR5 GCMs. We then produced three S-SDMs maps by stacking all SDMs maps for each of the three climate scenarios in order to assess species richness (defined as the number of species per grid cell based on their original estimated AOO) by adding the predicted species in each grid cell[86,87].

Data analysis. To estimate the impacts of deforestation and climate change on Amazonian tree species we produced ten different scenarios. First, we modelled the species' original environmental suitability. We tested which models were significantly different from random expectation using bias corrected null-models[15,88]. Models not significantly different were excluded from further analysis. We then estimated the species' original AOO for forested grid cells (Fig. 1a) and the losses of all deforestation and climate change scenarios over the species' original estimated AOO. This produced ten maps for each species (Fig. 1), starting with the historical deforestation for 2013 (Fig. 1b) and two projected deforestation scenarios for 2050 (IGS and BAU) (Fig. 1c,d). Then, we estimated the impacts of climate change by 2050 (RCP 2.6 and RCP 8.5) (Fig. 1e,h). Furthermore, we calculated the impacts of four combined scenarios of deforestation and climate change on the species' original AOO for 2050, one best-case combined scenario (RCP 2.6 and IGS), two intermediates combined scenarios (RCP 2.6 and BAU, RCP 8.5 and IGS) and a worst-case combined scenario (RCP 8.5 and BAU) (Fig. 1f,g,i,j). We also tested if the estimated loss of AOO by deforestation was correlated with population loss as estimated by ter Steege et al.[7] We then assigned categories of threat for all species according to IUCN A2, A4, B1 and D2 criteria, and three categories: critically endangered, endangered and vulnerable, based on geographic range losses, in the form of the estimated AOO and restricted number of locations (Supplementary Text). Finally, we analysed the estimated loss of AOO and the decrease in species richness inside and outside the Amazonian PA network using the S-SDM maps. All calculations and analyses were performed with R v.3.4.3 (ref. [55]), including the R packages 'raster' v.2.6–7 (ref. [67]), 'dismo' v.1.1–4 (ref. [89]), 'gstat' v.1.1–6 (ref. [90]), 'maptools' v.0.9–2 (ref. [91]), 'rgdal' v.1.2–16 (ref. [92]), 'rgeos' v.0.3–26 (ref. [93]), 'rJava' v.0.9–9 (ref. [94]) and 'speciesgeocodeR' v.1.0–4 (ref. [95]).

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All data used can be freely downloaded from GBIF (http://www.gbif.org) and WorldClim (http://www.worldclim.org) and are also available from the corresponding author upon request. A full list of species used can be found in Supplementary Table 1.

Code availability

The R code used for calculations and analyses is available from the corresponding author upon request.

References

56. ter Steege, H. et al. Towards a dynamic list of Amazonian tree species. *Sci. Rep.* **9**, 3501 (2019).
57. Raes, N. Partial versus full species distribution models. *Nat. Conserv.* **10**, 127–138 (2012).
58. Zizka, A. & Antonelli, A. Species geocoder: an R package for linking species occurrences, user-defined regions and phylogenetic trees for biogeography, ecology and evolution. Preprint at https://doi.org/10.1101/032755 (2015).
59. Maldonado, C. et al. Estimating species diversity and distribution in the era of Big Data: to what extent can we trust public databases? *Glob. Ecol. Biogeogr.* **24**, 973–984 (2015).
60. Boyle, B. et al. The taxonomic name resolution service: an online tool for automated standardization of plant names. *BMC Bioinforma.* **13**, 14–16 (2013).
61. IUCN Standards and Petitions Subcommittee. *Guidelines for Using the IUCN Red List Categories and Criteria v.13* (IUCN, 2017).
62. *The Global Database on Protected Areas Management Effectiveness* (UNEP-WCMC, IUCN, 2018); www.protectedplanet.net
63. *Amazonia socioambiental - Protected areas and indigenous territories* (Rede Amazônica de Informação Socioambiental Georreferenciada, 2017); https://www.amazoniasocioambiental.org/en/maps/
64. Phillips, S. J., Anderson, R. P. & Schapire, R. E. Maximum entropy modeling of species geographic distributions. *Ecol. Modell.* **190**, 231–259 (2006).
65. Phillips, S. J., Dudík, M. & Schapire, R. E. A maximum entropy approach to species distribution modeling. In *Proc. 21st Int. Conf. Machine Learning* (eds Carla Brodley) 83 (ACM Press, 2004).
66. Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* **25**, 1965–1978 (2005).
67. Hijmans, R. J. & van Etten, J. raster: geographic data analysis and modeling v2.5-8 (CRAN, 2016); https://CRAN.R-project.org/package=raster
68. van Vuuren, D. P., Eickhout, B., Lucas, P. L. & den Elzen, M. G. J. Long-term multi-gas scenarios to stabilise radiative forcing: exploring costs and benefits within an integrated assessment framework. *Energy J.* **27**, 201–233 (2006).
69. van Vuuren, D. P. et al. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Clim. Change* **81**, 119–159 (2007).
70. Riahi, K., Grübler, A. & Nakicenovic, N. Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technol. Forecast. Soc. Change* **74**, 887–935 (2007).

71. Xiao-Ge, X., Tong-Wen, W. & Jie, Z. Introduction of CMIP5 experiments carried out with the climate system models of Beijing Climate Center. *Adv. Clim. Chang. Res.* **4**, 41–49 (2013).
72. Yeager, S., Karspeck, A., Danabasoglu, G., Tribbia, J. & Teng, H. A decadal prediction case study: late twentieth-century north Atlantic Ocean heat content. *J. Clim.* **25**, 5173–5189 (2012).
73. Jones, C. D. et al. The HadGEM2-ES implementation of CMIP5 centennial simulations. *Geosci. Model Dev.* **4**, 543–570 (2011).
74. Swingedouw, D., Mignot, J., Labetoulle, S., Guilyardi, É. & Madec, G. Initialisation and predictability of the AMOC over the last 50 years in a climate model. *Clim. Dyn.* **40**, 2381–2399 (2013).
75. Watanabe, S. et al. MIROC-ESM 2010: model description and basic results of CMIP5-20c3m experiments. *Geosci. Model Dev.* **4**, 845–872 (2011).
76. Giorgetta, M. A. et al. Climate and carbon cycle changes from 1850 to 2100 in MPI-ESM simulations for the Coupled Model Intercomparison Project phase 5. *J. Adv. Model. Earth Syst.* **5**, 572–597 (2013).
77. Tatebe, H. et al. The initialization of the MIROC climate models with hydrographic data assimilation for decadal prediction. *J. Meteorol. Soc. Jpn* **90**, 275–294 (2012).
78. van Vuuren, D. P. et al. The representative concentration pathways: an overview. *Clim. Change* **109**, 5–31 (2011).
79. IPCC *Climate Change 2014: Mitigation of Climate Change* (eds Edenhofer, O. et al.) 413–510 (Cambridge Univ. Press, 2014).
80. IPCC *Climate Change 2014: Mitigation of Climate Change* (eds Edenhofer, O. et al.) 3 (Cambridge Univ. Press, 2014).
81. Dormann, C. F. et al. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **36**, 27–46 (2013).
82. Phillips, S. J. & Dudík, M. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* **31**, 161–175 (2008).
83. Boucher-Lalonde, V., Morin, A. & Currie, D. J. How are tree species distributed in climatic space? A simple and general pattern. *Glob. Ecol. Biogeogr.* **21**, 1157–1166 (2012).
84. Merow, C., Smith, M. J. & Silander, J. A. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography* **36**, 1058–1069 (2013).
85. Syfert, M. M. et al. Using species distribution models to inform IUCN Red List assessments. *Biol. Conserv.* **177**, 174–184 (2014).
86. Algar, A. C., Kharouba, H. M., Young, E. R. & Kerr, J. T. Predicting the future of species diversity: macroecological theory, climate change, and direct tests of alternative forecasting methods. *Ecography* **32**, 22–33 (2009).
87. Distler, T., Schuetz, J. G., Velásquez-Tibatá, J. & Langham, G. M. Stacked species distribution models and macroecological models provide congruent projections of avian species richness under climate change. *J. Biogeogr.* **42**, 976–988 (2015).
88. Raes, N. & ter Steege, H. A null-model for significance testing of presence-only species distribution models. *Ecography* **30**, 727–736 (2007).
89. Hijmans, R. J., Phillips, S., Leathwick, J. & Elith, J. dismo: species distribution modeling v1.1-4 (CRAN, 2016); https://CRAN.R-project.org/package=dismo
90. Pebesma, E. & Heuvelink, G. Spatio-temporal interpolation using gstat. *RFID J.* **8**, 204–218 (2016).
91. Bivand, R. & Lewin-Koh, N. maptools: tools for reading and handling spatial objects v0.9-2 (CRAN, 2017); https://CRAN.R-project.org/package=maptools
92. Bivand, R., Keitt, T. & Rowlingson, B. rgdal: bindings for the 'geospatial' data abstraction library v1.2-16 (CRAN, 2017); https://CRAN.R-project.org/package=rgdal
93. Bivand, R. & Rundel, C. rgeos: interface to geometry engine v0.3-26 (CRAN, 2017); https://CRAN.R-project.org/package=rgeos
94. Urbanek, S. rJava: low-level R to Java interface v0.9-9 (CRAN, 2017); https://CRAN.R-project.org/package=rjava
95. Zizka, A. speciesgeocodeR: prepare species distributions for the use in phylogenetic analyses v1.0-4 (CRAN, 2015); https://CRAN.R-project.org/package=speciesgeocoder

nature research

Corresponding author(s): Vitor H. F. Gomes

Last updated by author(s): May 9, 2019

Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see Authors & Referees and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
☒	☐	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☒	☐	A description of all covariates tested
☒	☐	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. F, t, r) with confidence intervals, effect sizes, degrees of freedom and P value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's d, Pearson's r), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	We gathered species data by downloading species collections from Global Biodiversity Information Facility (GBIF, www.gbif.org) using the 'gbif' function from R package 'dismo' version 1.1-4. Environmental layers were downloaded from WorldClim (http://http://www.worldclim.org). Amazonian protected areas and indigenous were downloaded from Protected World Database of Protected Areas (https://www.protectedplanet.net), and updated with data from Red Amazónica de Información Socioambiental Georreferenciada - RAISG (http://raisg.socioambiental.org/).
Data analysis	All calculations and analyses were performed with R version 3.4.3, including the R packages 'raster' version 2.6-7, 'dismo' version 1.1-4, 'gstat' version 1.1-6, 'maptools' version 0.9-2, 'rgdal' version 1.2-16, 'rgeos' version 0.3-26, 'rJava' version 0.9-9 and 'speciesgeocodeR' version 1.0-4.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:
- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

All data used can be freely downloaded from GBIF (http://www.gbif.org), WorldClim (http://http://www.worldclim.org), Protected World Database of Protected Areas (https://www.protectedplanet.net), Red Amazónica de Información Socioambiental Georreferenciada - RAISG (http://raisg.socioambiental.org/) and are also available from the corresponding author upon request. A full list of species used can be found in Supplementary Table 1.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We quantified the combined effects of deforestation and climate change of 10,071 Amazonian tree species. We modelled species original environmental suitability, which we call estimated area of occupancy (AOO), based on species distribution model, but constrained by the known extent of occurrence (EOO) of the species. Then, we quantified losses produced by historical deforestation by 2013, two deforestation scenarios for 2050, two climate change scenarios for 2050, and their interactions. We also asked to what extent the Amazonian protected area network may prevent habitat loss and the decline in species richness. Finally, we analysed our data according the criteria of the IUCN Red List of Threatened Species to assess the species' threat status.
Research sample	We focused our analysis on the group of Amazonian tree species that can reach 10 cm stem diameter at breast height, using the most recent Amazonian checklist. We downloaded species collections from GBIF database to produce species distribution models.
Sampling strategy	Sample sizes followed species collections available in GBIF database. We used a cleaning pipeline to check collections for inconsistencies, including geographical outliers. This procedure may reduce species sample.
Data collection	Data collection was based on species natural history collections available in GBIF database. We used the 'gbif' function from R package 'dismo' version 1.1-4 to download species collections.
Timing and spatial scale	We used all collections ever record available in the GBIF database. We based the analyses on species original environmental suitability and then we calculated the impacts of the deforestation and climate change for historical deforestation by 2013 and deforestation for 2050. The original environmental suitability of the species was based on averaged climate data (environmental layers) for 1950-2000 from WorldClim. The environmental suitability of the species for 2050 was based on averages for 2041-2060 from WorldClim, for two representative concentration pathways (RPCs), RCP 2.6 and RCP 8.5. Our spatial scale was based on 0.1 degree resolution (approx. 10x10 km), for all 5,7 millions Km2 of Amazonian lowland forest.
Data exclusions	We excluded species with available records below <6 because they are likely to produce inacurate models, especially when considering the size of Amazonia area. We also excluded from all analyses species with an environmental suitability model non-significantly different from a bias corrected null model. Finally species with no estimated area of occupancy within Amazonia were also removed.
Reproducibility	All attempts to replicate the experiment were successful.
Randomization	Samples randomization does not apply within the context of this experimental design. But we used bias corrected null-models though, to test which species' models were significantly different from random expectation. We generated 99 null-models for each species by randomly drawing the same number of species collections localities without replacement from the same spatial grid as the environmental layers. Then, we used an upper one-sided 95% confidence interval to determined species AUC probability value against those generated by the null distribution. We used only species ranked 95 or above. The probability of an equally good random model is less than 5% in this scenario.
Blinding	Investigators were not blinded during data acquisition and analysis. It is not feasible to do so within the context of this experimental design. The investigators checked inconsistences in the natural history collections data of the species downloaded from GBIF using a cleaning pipeline.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology
☒	☐ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging