Contributed Paper

Global reforestation and biodiversity conservation

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Abstract: The loss of forest is a leading cause of species extinction, and reforestation is 1 of 2 established interventions for reversing this loss. However, the role of reforestation for biodiversity conservation remains debated, and lacking is an assessment of the potential contribution that reforestation could make to biodiversity conservation globally. We conducted a spatial analysis of overlap between 1,550 forest-obligate threatened species' ranges and land that could be reforested after accounting for socioeconomic and ecological constraints. Reforestation on at least 43% (~369 million ha) of reforestable area was predicted to potentially benefit threatened vertebrates. This is approximately 15% of the total area where threatened vertebrates occur. The greatest opportunities for conserving threatened vertebrate species are in the tropics, particularly Brazil and Indonesia. Although reforestation is not a substitute for forest conservation, and most of the area containing threatened vertebrates remains forested, our results highlight the need for global conservation strategies to recognize the potentially significant contribution that reforestation could make to biodiversity conservation. If implemented, reforestation of ~369 million ha would also contribute substantially to climate-change mitigation, offering a way to achieve multiple sustainability commitments at once. Countries must now work to overcome key barriers (e.g., unclear revenue streams, high transaction costs) to investment in reforestation.

Keywords: Aichi biodiversity targets, Bonn Challenge, forest, post-2020, threatened vertebrate species

Reforestación Mundial y Conservación de la Biodiversidad

Resumen: La pérdida de los bosques es una de las causas principales de la extinción de especies y la reforestación es una de las dos intervenciones establecidas para revertir esta pérdida. Sin embargo, el papel de la reforestación en la conservación de la biodiversidad todavía se debate, además de que hay una falta de evaluación de la contribución potencial que podría dar la reforestación a la conservación mundial de la biodiversidad. Realizamos un análisis espacial del traslape de la distribución de 1,550 especies obligadas de bosque que se encuentran amenazadas y el suelo que podría utilizarse para reforestar después de considerar las restricciones socioeconómicas y ecológicas. El análisis predijo que la reforestación en al menos el 43% (~ 369 millones de ha) del área que se puede reforestar beneficiará potencialmente a los vertebrados amenazados. Esto es aproximadamente el 15% del área total en donde están presentes los vertebrados amenazados. Las oportunidades más grandes para conservar a las especies amenazadas de vertebrados se encuentran en los trópicos, particularmente en Brasil y en Indonesia. Aunque la reforestación no es un sustituto para la conservación de los bosques, y aunque la mayoría del área que contiene vertebrados amenazados todavía tiene flora original, nuestros resultados resaltan la necesidad de tener estrategias mundiales de conservación para reconocer la contribución potencialmente significativa que podría dar la reforestación a la conservación de la biodiversidad. Si se implementa, la reforestación de ~369 millones de ha también contribuiría significativamente a la mitigación del cambio climático, ofreciendo así una manera de cumplir varios compromisos de sustentabilidad a la vez. Los países ahora deben trabajar para sobreponerse a las barreras importantes (p. ej.: flujos inciertos de ingresos, costos elevados de las transacciones) que enfrentan las inversiones para la reforestación.

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Palabras Clave: bosque, especies amenazadas de vertebrados, objetivos de biodiversidad de Aichi, post 2020, Reto de Bonn

摘要: 森林丧失是物种灭绝的主要原因, 而造林则是已确立的扭转森林丧失的两种干预措施之一。然而, 造林对生物多样性保护的作用仍存在争议, 目前尚缺乏造林对全球生物多样性保护潜在贡献的评估。我们考虑了社会经济和生态制约因素, 对 1550 个森林特有濒危物种的分布范围内可以造林的土地进行了空间重叠分析。据预测, 在至少 43% (约 3.69 亿公顷) 的可造林土地上实施造林, 将有助于受威胁脊椎动物的保护, 大约占受威胁脊椎动物分布总面积的15%。保护濒危脊椎动物的最大机会在热带地区, 特别是巴西和印度尼西亚。虽然再造林不能代替森林保护, 而且受威胁脊椎动物大部分栖息地仍是森林, 但我们的结果强调了认识到造林对生物多样性保护潜在重要贡献的全球保护战略的必要性。如果实施造林计划, 约 3.69 亿公顷的再造林还将大大有助于缓解气候变化, 为同时实现多项可持续承诺提供了途径。各国现在应努力克服投资造林的主要障碍 (如不明确的收入来源、高昂的交易成本) 。 **【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 受威胁脊椎动物, 2020后框架, 爱知生物多样性目标, 波恩挑战, 森林

Introduction

The loss of biological diversity represents one of the most pressing environmental challenges of our time (Ceballos et al. 2017). Almost one-fifth of all vertebrates are classified as threatened (IUCN 2018). Habitat loss and degradation are among the most significant threats to biodiversity, followed by overharvesting, pressure from invasive species and pathogens, pollution, and climate change (IUCN 2015; Maxwell et al., 2016). Although habitat protection is essential to reducing the rate of species loss, reforestation should be considered a complementary strategy (e.g., Possingham et al. 2015; Venter et al. 2016; Whitworth et al. 2018). The UN Convention on Biological Diversity (CBD) calls for the restoration of 15% of degraded ecosystems (Aichi target 15) to improve ecosystem resilience, increase carbon stocks, and reduce biodiversity loss (e.g., UN CBD 2011, 2012; Leadley et al. 2014). Over the past eight years, 49 countries around the world have committed to restoring 150 million ha of degraded and deforested land by 2020 and 350 million ha by 2030 (Bonn Challenge 2019; New York Declaration on Forests 2019) to secure the services and biodiversity these ecosystems support.

However, the potential impact of reforestation efforts on biodiversity conservation remains debated. Extinctions from habitat loss are often delayed rather than immediate because many species linger in forest fragments but eventually are extirpated due to reduced and therefore nonviable population sizes (Newmark et al. 2017). This time delay provides a window of opportunity for conservation through reforestation. Adding new forest can increase population sizes by expanding habitat and allowing immigration from source populations. However, the rate at which species go extinct following habitat loss is uncertain, as is the suitability of secondary forest for old-growth specialist species (e.g. Wright & Muller-Laudau 2006; Brook et al. 2006; Rocha et al. 2018). In addition to uncertainty regarding the local benefits of reforestation, an assessment of the potential contribution that reforestation could make to biodiversity conservation globally is lacking.

We explored this potential by assessing the amount of overlap between a recent reforestation opportunities map (Griscom et al. 2017) and a threatened forest-obligate vertebrate species richness map (Betts et al. 2017). We identified the area of overlap to help prioritize locations where reforestation might provide the greatest benefit to threatened vertebrates. With the CBD's Strategic Plan for Biodiversity 2011–2020 nearing its end, we sought to describe the role forest restoration can play in the post-2020 CBD Biodiversity Framework. Our results also represent a starting point for exploring the potential synergies and trade-offs between biodiversity and other conservation objectives of reforestation (e.g., climate mitigation) at the global scale to ease achieving multiple international sustainability goals and commitments such as the UN Sustainable Development Goals and the Paris Agreement (Ripple et al. 2019).

Methods

Reforestation Data

Our global spatial data set of reforestation opportunities was obtained from Griscom et al. (2017 [https://zenodo.org/record/883444]). To calculate the extent of reforestation potential, they modified a 1-km resolution map from the Atlas of Forest Landscape Restoration Opportunities (FLRO). This map is based on an estimate of potential forest cover minus existing forests minus areas incompatible with returning to forests, such as locations with dense rural populations and cropland (Griscom et al. 2017). The modifications introduced by Griscom et al. (2017) include removal of boreal ecoregions (due to albedo concerns), native grass-dominated ecosystems (to avoid adverse effects on nonforest biodiversity), potential forest-cover pixels with <25% tree cover, or existing forest-cover pixels with >25% tree cover (to better distinguish between forested and unforested lands).

Species Data

We used a modified version of Betts et al. (2017) for our species richness maps (see below). In particular, we estimated forest vertebrate richness based on the International Union for Conservation of Nature (IUCN) Red List and BirdLife species' range maps (BirdLife International 2016; IUCN 2017). Data were obtained for mammals, amphibians, and birds only. Reptiles were excluded because they have not been comprehensively assessed. Species that use only forest according to their IUCN Red List fact sheet (version 2018.1) were categorized as forest-exclusive (i.e., forest-obligate species). Species with conservation status vulnerable, endangered, or critically endangered were categorized as threatened. Species with data deficient status were omitted because their range maps may be less reliable. All polygons for which the species origin was not listed as native or for which the species' presence was listed as anything other than extant or probably extant were removed. We converted these vector data layers to 1-km grids for analyses (details in Supporting Information).

Spatial Analyses

Both species richness and reforestation-opportunity maps were based on the World Cylindrical Equal Area Projection and a 1 × 1 km grid. The reforestation data set originally had a ~739-m resolution, and we resampled it to 1-km resolution with the nearest neighbor method. All geospatial analyses on the reforestation and species richness data were done in ArcGIS 10.4.

Results

Out of the total area that could be reforested, 43% overlapped with the ranges of threatened forest-obligate vertebrates. This corresponded to ~369 million ha, or approximately 15% of the total area containing threatened vertebrates. Twenty-five percent (93 million ha) of this land corresponded to reforestation opportunities that overlapped with the ranges of at least 5 forest-obligate threatened vertebrates, and 9% (35 million ha) corresponded to reforestation opportunities that overlapped with the ranges of at least 10 forest-obligate threatened vertebrates, out of a maximum potential (in any given cell) of 22 forest-obligate threatened vertebrates. Reforestation potential and threatened forest-obligate vertebrate species distributions primarily overlapped in Central and South America, Africa, and Southeast Asia (Fig. 1c). Opportunities for conserving 10 or more species together were most common in Indonesia and the Brazilian Amazon, roughly around the so-called arc of deforestation along the southeastern edge of the Amazon. Much of the potentially reforestable land that did not overlap with the ranges of any threatened forest-obligate vertebrates (i.e. 57%) occurred in the Northern Temperate Zone (Fig. 1c).

Discussion

Our results suggest that reforestation opportunities and threatened vertebrate biodiversity overlap primarily in the tropics, including in places where a high number of threatened forest-obligate vertebrate species are concentrated. This is not surprising, given that tropical forests contain a higher total number of forest-obligate vertebrate species than temperate or boreal forests (Supporting Information) and that most of the forest loss over the past approximately 30 years has taken place in the tropics (Song et al. 2018). Deforestation rates accelerated in the Amazon in the 1970s, followed by Southeast Asia in the 1990s, and most recently the Congo Basin (Rosa et al. 2016).

In the reforestable area that does not overlap with threatened forest-obligate vertebrate species ranges (primarily the Northern Temperate Zone), most deforestation took place hundreds of years ago. In Europe forests were cleared on a large scale before the industrial revolution, and the amount of forest is now on the rise due to land abandonment since the mid-twentieth century (FAO 2011; Kaplan et al. 2009; Navarro & Pereira, 2012). In the United States, most deforestation took place in the 19th century, and the amount of forest has been relatively stable since the early 1900s (Smith et al. 2009). However, it is conceivable that forest-obligate vertebrate species in these locations are still vulnerable to disturbances dating back hundreds of years (e.g., Halley et al. 2016). Chen and Peng (2017) estimate that forest-dwelling mammals and amphibians destined for extinction due to deforestation in the 1500s exist in several locations, including in Europe and the eastern United States. Thus, although reforestation should be prioritized in the tropics, where forest-obligate vertebrates species are closest to extinction, reforestation outside the tropics may help reduce the number of species that eventually become threatened. Because IUCN threat statuses are a species-level variable, the lack of threatened species also does not preclude reforestation potentially helping conserve threatened forest-obligate subspecies or extremely endangered populations of forest-obligate species.

Although reforestation is not a substitute for the conservation of existing forest and most of the area containing threatened forest-obligate vertebrates is forested (Hansen et al. 2013), the amount of opportunity area for conserving threatened vertebrates through reforestation is substantial in absolute terms. Three hundred and sixty nine million hectares is approximately the size of India and Vietnam combined. Moreover, reforestation opportunities that could potentially benefit at least 10

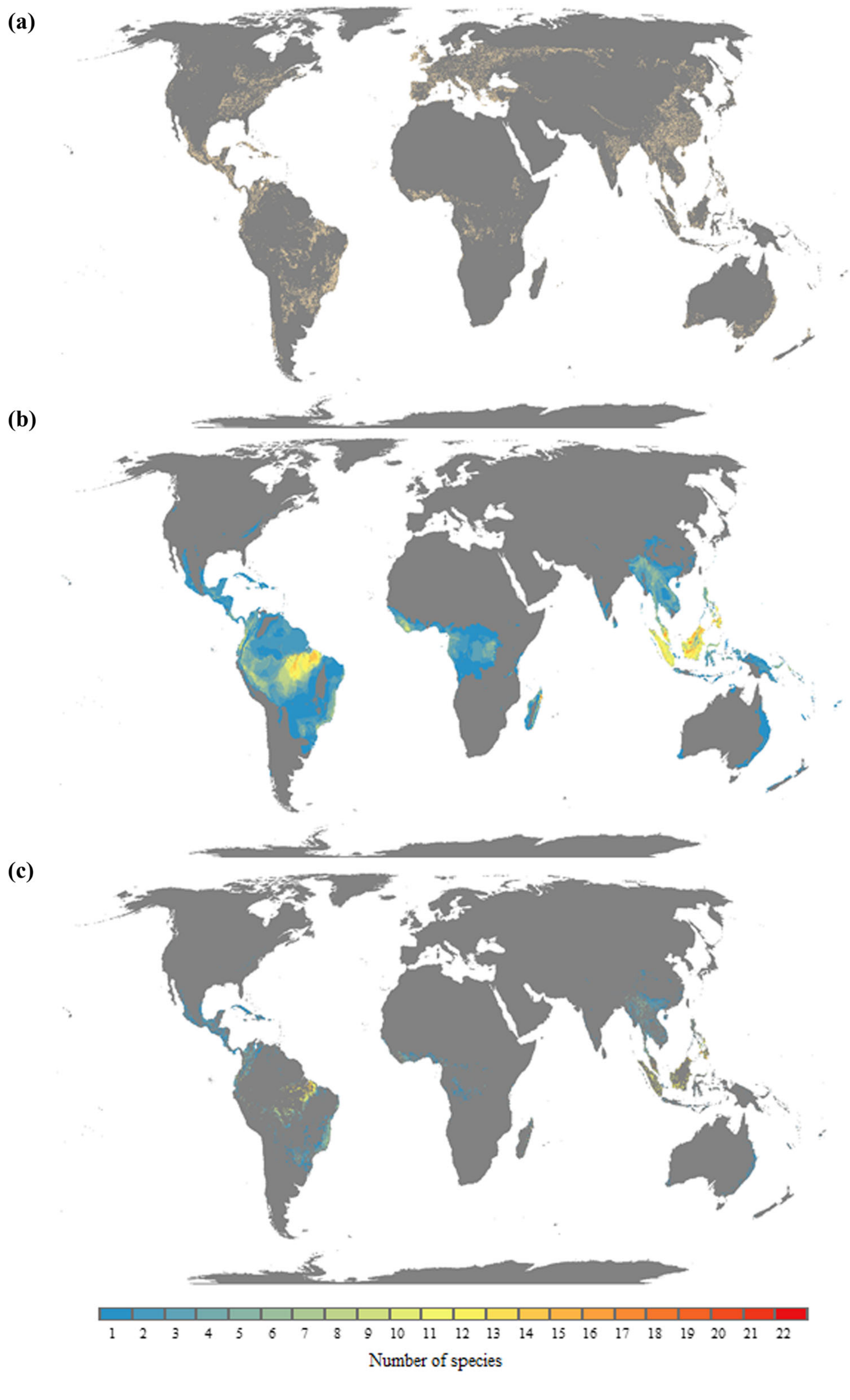

Figure 1. (a) Areas of reforestation opportunity from Griscom et al. (2017), (b) International Union for Conservation of Nature threatened forest-obligate vertebrate species richness, and (c) threatened forest-obligate vertebrate species richness in areas that could be reforested.

threatened vertebrate species encompass roughly one-tenth of this area. This congruence between reforestation opportunity and threatened vertebrate species richness is encouraging because tropical nations such as Brazil may need to invest substantially in reforestation to significantly reduce the loss of vertebrate species (Rosa et al. 2016). In the Brazilian Amazon, >80% of extirpations expected to occur due to habitat loss over the last few decades are still to come (Wearn et al. 2012). Even a small amount of reforestation can go a long way toward stemming the loss of species. Newmark et al. (2017) estimated that regenerating 6,452 ha of forest in the Atlantic Forest would create over 251,000 ha of restored contiguous forest. This in turn would enhance species persistence by a factor of 13 per location, or 5,102 years, on average, compared with individual forest fragments. Reforestation within the 369 million ha could, moreover, potentially benefit threatened mammals, birds, and amphibians less strongly dependent on forest (Supporting Information) and threatened species belonging to other animal classes (e.g., forest-dwelling reptiles). Although our study is intended to provide a broad overview of the overlap between reforestation potential and threatened forest biodiversity, future studies could look at which individual species would benefit most from reforestation.

Given that some forest-dependent vertebrate species can be lost in a matter of years and it takes tropical forests approximately 30–40 years to regenerate naturally (Chazdon 2008; Lennox et al. 2018), the window of opportunity for reducing biodiversity loss in the tropics through reforestation is narrowing. Encouragingly, commitments to the Bonn Challenge or national schemes (e.g. nationally determined contributions or UN REDD+ projects) are already close to 300 million ha, with large commitments from countries with high threatened vertebrate species richness such as Brazil and Indonesia. However, 45% of total commitments involve large monoculture plantations for income generation, and Brazil and Indonesia are among the countries where most of this type of reforestation is planned (Lewis et al. 2019). Planting monocultures can be highly detrimental to biodiversity (Hua et al. 2016), and the greatest biodiversity gains would likely be achieved through natural regeneration (Chazdon 2008).

Our results should be interpreted with caution. Global land-use patterns and natural limits on potential canopy density mean that over 70% of all reforestation opportunities described here would be most suited to reforestation involving a mix (or mosaic) of forest, planted trees, and other land uses, such as agroforestry or small-holder agriculture (WRI 2019). Natural regeneration is only possible when the state of land degradation is low and forest patches and seed dispersers still occur in the area to supply and distribute a diversity of seeds (Chazdon 2008). Forest regeneration in mosaic landscapes is also most effective for conservation when it permits enlargement of existing forest fragments or creation of biological corridors linking formerly isolated fragments. Moreover, many forest-interior species do not find adequate habitats in mosaic landscapes, which means there may be a threshold of forest cover, patch size, or patch density needed for these species to be supported (Chazdon 2014). Reforestation decisions must be informed by detailed assessments of local environmental and socioeconomic conditions (e.g., cost, cultural norms) (Guariguata et al. 2019).

A further caveat to our analysis is that patterns of extinction risk are not solely driven by deforestation. Hunting is a major cause of species loss across the tropics (Maxwell et al. 2016; Symes et al. 2018); declines in bird and mammal populations in hunted forests are substantial (Benitez-Lopez et al. 2017). The presence of areas in Indonesia where threatened forest-obligate vertebrate species richness exceeds 10 for example is likely due to high rates of forest loss (Margono et al. 2014) and high rates of exploitation (Symes et al. 2018). Although forest-obligate species will ultimately go extinct without habitat, conserving tropical forests will not be enough if other threats are not abated as well. Another limitation of our analysis is that it is based on the assumption that all areas identified as reforestable are reforestable. Although the reforestation potential map generally does not contain areas with intense land use (e.g., cropland), grazing lands in forested ecoregions are included. Reducing the need for pasture is contingent on increased efficiency of beef production or dietary shifts to reduce beef consumption (Griscom et al. 2017). In some contexts, increasing tree cover can also increase fire risk, reduce water supplies, or lead to crop damage by wildlife (Chazdon & Brancalion 2019). Moreover, the reforestation potential map does not account for land ownership or cultural drivers of land use. Given that not all areas identified as having reforestation potential may ultimately be reforested, our results emphasize the importance of quantifying the benefits of reforestation.

In addition to biodiversity conservation, 369 million ha represents an enormous opportunity for climate mitigation. To mitigate the effects of climate change, emissions need to be curbed (which includes protecting existing forest) and CO_2 needs to be removed from the atmosphere. Reforesting the 369 million ha would result in an additional land uptake of ~5.5 Pg CO_2e/year by 2030, which is roughly equivalent to half the amount of CO_2, CH_4, and N_2O emitted currently due to land-use change (IPCC 2014; Le Quéré et al. 2015; Griscom et al. 2017). Our estimate is approximate, however, because it is based on the relationship between the maximum potential extent of reforestation implementation and the associated maximum additional mitigation potential in Griscom et al. (2017).We therefore assumed our reforestation pixels follow the same spatial distribution as in that study, despite variation between temperate and tropical climate domains in plantation and natural forest growth rates and the proportion of future reforestation estimated to be allocated to plantations (Griscom et al. 2017). The allocation estimates are based on current plantation extent and therefore do not reflect aforementioned plans to drastically increase the area of plantations. Another source of uncertainty is the model of carbon uptake itself, which is based on the assumption that plantations sequester more carbon than natural forests. The maximum additional mitigation potential estimate in

Griscom et al. (2017) also includes adjustments for baseline reforestation and double counting with other land-based mitigation strategies (e.g., wetland restoration).

The difference in sequestration potential between natural and plantation reforestation strategies hinges on which species are planted and their carbon sequestration rates, the number of plantation harvests, emissions from timber products, and the persistence of naturally regenerating forests. A long maturing natural forest could sequester 40 times more carbon than a young plantation that is harvested once and releases stored CO_2 back into the atmosphere (Lewis et al. 2019; Fagan et al. 2019). The humid tropics, where most of the reforestable areas containing a high number of threatened vertebrate species occur, also represent places where natural regeneration could restore very high carbon stocks, compared with drier regions (Lewis et al. 2019). This congruence means progress could be made at once toward achieving global biodiversity and climate goals.

Climate funds represent a promising source of financing for conservation given reforestation's potential for CO_2 sequestration (Ding et al. 2017). However, global public climate finance in 2015 was US$128 billion, of which only $7 billion was used to fund land-use projects and only a fraction of those funds went to restoration. In contrast, global conservation (including restoration) funding needs are estimated to range from $300 to 400 billion/year (Credit Suisse et al. 2014; Buchner et al. 2015; Ding et al., 2017). Reasons for restoration projects not being funded may include unclear revenue streams, lack of an investment track record, risk of projects failing, and high transaction costs (Wuethrich 2007; Godefroid et al. 2011; Sunding 2011; Ding et al. 2017). One solution to reducing these costs for applicants would be to standardize requirements and procedures associated with accessing finance across different funds (Amerasinghe et al. 2017; Ding et al. 2017). Other solutions to increasing restoration financing might include greater support for risk-mitigation mechanisms that boost private-sector investment and implementation of national policies that signal to funders the importance of restoration. Governments should, for instance, explicitly acknowledge restoration as part of their nationally determined contributions and set targets for restoration finance (Ding et al. 2017).

Our results highlight the need for global conservation strategies to recognize the potentially significant contribution reforestation could make to biodiversity conservation. Included in the CBD's Strategic Plan for Biodiversity 2011–2020 is the restoration of degraded ecosystems to avoid biodiversity loss. However, the conservation of threatened species is not directly mentioned as an aim in the text of Aichi target 15. The focus is instead on ensuring ecosystem resilience and maintaining carbon stocks. Similarly, the conservation of threatened species is a stand-alone objective (Aichi target 12), with no associated action. However, the most commonly employed action to prevent species extinctions is to protect habitat (Rosa et al. 2016). Although habitat protection remains vital for avoiding further biodiversity loss, there is perhaps more opportunity for biodiversity conservation globally through reforestation than previously realized. Moreover, considering the current extent and rate of forest habitat conversion and the expected shifts in species range distributions due to climate change (Hermes et al. 2018), one might argue, as others have (Mappin et al. 2019) that restoration, in addition to protection, should be a priority. In the post-2020 Biodiversity Framework, targets could be revised so that the role of restoration in stemming biodiversity loss, in addition to ensuring ecosystem resilience, mitigating climate change, and providing other ecosystem services, is made more apparent. Clarifying relationships between the existing targets would also facilitate implementation and help identify common funding mechanisms.

Details about the method behind our threatened forest-obligate vertebrate species richness estimate (Appendix S1), a map of total forest-obligate vertebrate species richness (Appendix S2), and estimates of the total numbers of forest-dependent species (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Supporting Information

Details about the method behind our threatened forest-obligate vertebrate species richness estimate (Appendix S1), a map of total forest-obligate vertebrate species richness (Appendix S2), and estimates of the total numbers of forest-dependent species (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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