Global reforestation and biodiversity conservation

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Abstract

The loss of forest habitat is a leading cause of species extinction, and reforestation is one of two 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. Here, we conduct a spatial analysis of overlap between 1,550 forest-obligate threatened species’ ranges and land that could be reforested. We find that reforestation on at least 43% of the reforestable area could potentially benefit threatened vertebrate biodiversity. This
corresponds to ~ 369 Mha, or approximately 15% of the total area where threatened vertebrates occur. The greatest opportunities for conserving threatened vertebrate species are found in the tropics, particularly Brazil and Indonesia. While 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 in the amount of ~ 369 Mha would also contribute substantially to climate mitigation, offering a way of achieving multiple sustainability commitments at once. Countries must now work to overcome key barriers to investment in reforestation.

Introduction

The loss of biological diversity represents one of the most pressing environmental challenges of our time (Ceballos et al., 2017), with almost one fifth of all vertebrates classified as threatened (IUCN Red List 2018-2). Habitat loss and fragmentation are among the most significant threats to biodiversity, followed by over-exploitation, pressure from invasive species and pathogens, pollution, and climate change (IUCN, 2015; Maxwell et al., 2016). While habitat protection is essential to reducing the rate of species loss, reforestation should be considered as a complementary strategy (Wearn et al., 2012; Possingham et al., 2015; Venter et al., 2016; Newmark et al., 2017; Whitworth et al., 2018; Rocha 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 (UN CBD, 2011, 2012; Leadley et al., 2014, UN CBD 2018). Over the past eight years, 49 countries around the world have committed to restoring 150 million hectares (Mha) of degraded and deforested land by 2020, and 350 Mha 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. As noted in Newmark et al., 2017, extinctions from habitat loss are often delayed rather than immediate, as many species will tend to linger in forest fragments but be committed to extinction due to reduced and therefore non-viable population sizes. This time delay provides a window of opportunity for conservation through reforestation. Adding new forest can increase population sizes by expanding available 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 (Wright & Muller-Laudau, 2006; Brook et al., 2006; Newmark et al., 2017; Rocha et al., 2018). In addition to uncertainty regarding the local benefits of reforestation, lacking is an assessment of the potential contribution that reforestation could make to biodiversity conservation globally.

In this paper, we explore 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 identify the area of overlap to help prioritize locations where reforestation might provide the greatest benefit to threatened vertebrate biodiversity. With the CBD’s Strategic Plan for Biodiversity 2011-2020 nearing its end, our analysis is intended to help inform the role that forest restoration should play in the post-2020 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 the effort of 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, Griscom et al., 2017 modified a 1 km resolution map from the Atlas of Forest Landscape Restoration Opportunities (FLRO), which takes an estimate of potential forest cover (Bryant et al., 1997; FAO, 1999; Olson et al., 2001; Zomer et al., 2008; Minnemeyer et al., 2014), and excludes from this estimate existing forests (Hansen et al., 2003; Potapov et al., 2011) and areas incompatible with returning to forests, such as locations with dense rural populations and cropland (Sanderson et al., 2002; Bright et al., 2006; Pittman et al., 2010). Modifications to the FLRO map made by Griscom et al. (2017) included the removal of boreal ecoregions (due to albedo concerns), native grass-dominated ecosystems (to avoid adverse effects on non-forest biodiversity), and potential forest cover pixels with <25% tree cover and existing forest cover pixels with >25% tree cover (to better distinguish between forested and non-forested 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 using the IUCN Red List and BirdLife species range maps (BirdLife International and Handbook of the Birds of the World 2016; IUCN 2017). Data were obtained for mammals, amphibians, and birds only. Reptiles were excluded as they have not been comprehensively assessed. Species that only use forest habitat...
according to their IUCN Red List fact sheet coded habitat information (version 2018.1) were categorized as forest-exclusive (in other words, “forest-obligate” species). Species with conservation status Vulnerable, Endangered, or Critically Endangered were categorized as threatened. Species with Data Deficient status were omitted as their range maps may be less reliable (IUCN 2018). All polygons for which the species origin was not listed as Native and/or for which the species presence was listed as anything other than Extant or Probably Extant were removed. To aid analysis, we converted these vector data layers to 1 km grids (details in Supporting Information).

Spatial analyses
Both the species richness and reforestation opportunity maps are based on the World Cylindrical Equal Area Projection and a 1 x 1 km grid. The reforestation dataset was originally at a ~739 m resolution, and we resampled it to 1 km resolution using 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% overlaps with the ranges of threatened forest-obligate vertebrates. This corresponds to ~ 369 Mha, or approximately 15% of the total area containing threatened vertebrates. We also found that 25% (93 Mha) of this land corresponds to reforestation opportunities that overlap with the ranges of at least 5 forest-obligate threatened vertebrates, and 9% (35 Mha) corresponds to reforestation opportunities that overlap 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 overlap in Central and South America, Africa, and Southeast Asia (Fig. 1c).

Opportunities for conserving 10 or more species together are most common in Indonesia and the Brazilian Amazon, roughly around the “arc of deforestation” along the southeastern edge of the Amazon. Much of the potentially reforestable land that does not overlap with the ranges of any threatened forest-obligate vertebrates (i.e. 57%) occurs in the Northern temperate zone (Fig. 1c).

**Discussion**

Our results suggest that reforestation opportunities and threatened vertebrate biodiversity overlap primarily in the tropics, and including in the 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 do temperate or boreal forests (see Supporting Information) and that most of the forest loss over the past ~30 years has taken place in the tropics (Song et al., 2018). Deforestation rates accelerated in the Amazon in the 1970s, followed by South East Asia in the 1990s, and most recently the Congo Basin (Rosa et al., 2016).

In the reforestable area which 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, 2001; Kaplan et al., 2009; Navarro & Pereira, 2012). In the USA, 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 (see e.g. Halley et al., 2016). Chen and Peng (2017) estimate that forest-dwelling mammals and amphibians committed to extinction due to deforestation in the 1500s exist in several locations including Europe and the Eastern USA. Thus, while 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 of conservation concern. Since IUCN threatened status is a species-level variable, the lack of threatened species also does not preclude reforestation potentially helping conserve threatened forest-obligate sub-species 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 threatened vertebrate species encompass roughly a tenth of this area. This congruence between reforestation opportunity and threatened vertebrate species richness is encouraging, as tropical nations such as Brazil may need to substantially invest in reforestation to significantly reduce the loss of vertebrate species (Rosa et al., 2016). In the Brazilian Amazon, more than 80% of extinctions expected to be incurred 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 towards stemming the loss of species: Newmark et al., 2017 estimate 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 to individual forest fragments.

Reforestation within the 369 Mha could, moreover, potentially benefit threatened mammals, birds and amphibians less strongly dependent on forest (see Supporting Information), and threatened species belonging to other animal classes (e.g. forest-dwelling reptiles). While 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 to 40 years to regenerate naturally (see below) (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 via national schemes (e.g. Nationally Determined Contributions or UN REDD+ projects) are already close to 300 Mha (Lewis et al., 2019), 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 amongst the countries where most of this type of reforestation is planned. 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 that there may be a threshold of forest cover, patch size or patch density that is needed for these species to be supported (Chazdon, 2014). Reforestation decisions must be informed by detailed assessments of local environmental and socio-economic 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 now a major cause of species loss across the tropics (Maxwell et al., 2016; Symes et al., 2018), with substantial declines in bird and mammal populations in hunted forests (Benitez-Lopez et al., 2017). The presence of areas in Indonesia where threatened forest-obligate vertebrate species richness exceeded 10 for example is likely due to the high rates of forest loss (Margono et al., 2014) as well as the high rates of exploitation (Symes et al., 2018). While a forest-obligate species will ultimately be doomed to extinction without its habitat, conserving tropical forests will not be enough if other threats are not abated as well. Another limitation of our analysis is that it assumes that all areas identified as being reforestable are, in fact, reforestable. While the reforestation potential map generally omits areas with intense land use (e.g. cropland), grazing lands in forested ecoregions are included. As noted in Griscom et al., 2017, reducing the need for pasture is contingent on increased efficiency of beef production and/or dietary shifts to reduce beef consumption. In some contexts, increasing tree cover can also increase fire risk, reduce water supplies, or lead to crop damage by wildlife (Chazdon and 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 analysis emphasizes the importance of quantifying the benefits of reforestation.

In addition to biodiversity conservation, 369 Mha represents an enormous opportunity for climate mitigation. To mitigate the effects of climate change, we need to not only curb emissions (which includes protecting existing forest) but also remove CO₂ from the atmosphere. Reforesting the 369 Mha would result in an additional land uptake of ~5.5 PgCO₂e/yr by 2030, which is roughly equivalent to half the amount of CO₂, CH₄ and N₂O being emitted currently from land use change (IPCC, 2014; Le Quéré et al., 2015; Griscom et al., 2017). Our estimate is approximate, however, as 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 (Table S1). We therefore assume that our reforestation pixels follow the same spatial distribution as in Griscom et al., 2017, 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 (Table S9). 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 assumes 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 might be 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 which releases stored CO₂ is released 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 that progress could at once be made towards achieving global biodiversity and climate goals.

As noted in Ding et al., 2017, climate funds represent a promising source of financing for conservation given reforestation’s potential for CO₂ sequestration. However, global public climate finance in 2015 was $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 $300-400 billion per year (Credit Suisse et al., 2014; Buchner et al., 2015). Reasons for restoration projects not being funded may include unclear revenue streams, the lack of an investment track record, the risk of projects failing, and high transaction costs (Wuethrich 2007; Suding 2011; Godefroid et al., 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 policy actions 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 that 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, as noted in Rosa et al., 2016, the most commonly employed action to prevent species extinctions is to protect habitat. While 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 recently done (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.

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Fig. 1. (a) Griscom et al. 2017 reforestation potential; (b) IUCN threatened forest-obligate vertebrate species richness; (c) Threatened forest-obligate vertebrate species richness in areas that could be reforested.
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