Received: 10 May 2018 | Revised: 8 March 2019 | Accepted: 14 March 2019
DOI: 10.1111/conl.12646

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

LETTER

Restoration priorities to achieve the global protected area target

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Funding information
Australian Research Council Laureate Fellowship; University of Queensland Research Scholarship; EU H2020 programme, Grant/Award Number: H2020-MSCA-IF-2017-793212

Abstract
With much of Earth's surface already heavily impacted by humans, there is a need to understand where restoration is required to achieve global conservation goals. Here, we show that at least 1.9 million km^2 of land, spanning 190 (27%) terrestrial ecoregions and 114 countries, needs restoration to achieve the current 17% global protected area target (Aichi Target 11). Restoration targeted on lightly modified land could recover up to two-thirds of the shortfall, which would have an opportunity cost impact on agriculture of at least $205 million per annum (average of $159/$km^2$). However, 64 (9%) ecoregions, located predominately in Southeast Asia, will require the challenging task of restoring areas that are already heavily modified. These results highlight the need for global conservation strategies to recognize the current level of anthropogenic degradation across many ecoregions and balance bigger protected area targets with more specific restoration goals.

KEYWORDS
Aichi Target 11, conservation planning, ecoregions, ecosystem restoration, habitat conservation, human footprint, land conversion, representation

1 | INTRODUCTION

To address the ongoing decline in biodiversity, the United Nation's Strategic Plan for Biodiversity defined a set of targets (the "Aichi Targets") to be met by 2020 (UN CBD, 2010). Under Aichi Target 11, signatory nations agreed that 17% of terrestrial environments "especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas" (United Nations, 2013). This target sets a minimum standard that all signatory nations agree to for the conservation of biodiversity. The term "ecologically representative" is a measurable component of this target and has been interpreted to mean that 17% of each of the 867 terrestrial ecoregions should be in protected areas by 2020 (UNEP-WCMC & IUCN, 2016; Woodley et al., 2012).

While the overall area placed under formal protection has significantly increased since the Convention on Biological Diversity was first signed in 1992 (UNEP-WCMC & IUCN, 2016), human populations and national economies have continued to grow, expanding their extraction of natural resources (Millennium Ecosystem Assessment, 2005; Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015) and further converting intact land to human uses (Venter et al., 2016a). As a consequence, humans have extensively modified Earth's landscapes (Hansen et al., 2013; Watson et al., 2016), such that restoration is needed to abate severe environmental degradation, recover past ecosystem functions and reduce extinction debt (Haddad et al., 2015; Possingham, Bode, & Klein, 2015). However, it remains unclear to what extent and where restoration is required to meet Aichi Target 11.

Here, using recent, spatially explicit, fine-resolution data on human pressure (Venter et al., 2016b), we assess all terrestrial ecoregions to determine which have been converted to the extent that they fail to have enough suitable unprotected land remaining to reach the 17% protection target without restoration to enhance biodiversity. Within these ecoregions, we identify the priorities and agricultural opportunity cost for restoration on lightly modified land to achieve the protected area target. In addition, we identify those ecoregions for which the target may never be met as this would require challenging restoration of heavily modified land.

2 | METHODS

2.1 | Data

We classified the level of modification and suitability for conservation using the most recent human footprint dataset (Venter et al., 2016b), which measures direct and indirect anthropogenic pressures on the environment. As the human footprint score increases, there is an increase in human pressure and a deterioration in environmental conditions. The pressure variables include built environments, intensive agriculture, pasture lands, human population density, night-time lights, roads, railways, and navigable waterways. Following the original human footprint assessment (Sanderson et al., 2002), the pressures were placed on a 0–10 scale (with 0 being least pressure) and then summed to create the cumulative measure of the human footprint at the 1 km^2 resolution, which ranges from 0 to 50. A score of 4 is equivalent to pasture lands, representing an approximation of when anthropogenic land conversion has occurred to an extent that the land can be considered human-dominated and not suitable for protection (Watson et al., 2016). As such, land with a human footprint score of <4 is considered to have potential for protection, and land with a human footprint score of ≥4 is classified as converted and not suitable for protection as major reductions in the suitability for biodiversity are likely to have occurred (Di Marco & Watson, 2018). A score of 7 is equivalent to intensive croplands (Venter et al., 2016b); human footprint scores above 7 are heavily modified with human impacts such as built environments and roads present (Venter et al., 2016b).

Following previous global analyses (Hoekstra, Boucher, Ricketts, & Roberts, 2005), we used global biomes (n = 14) and ecoregions (n = 827) as the basis of our analysis for the classification of ecological representativeness (Olson & Dinerstein, 2002). We used the publicly available ecoregion boundary shapefile (World Wildlife Fund, 2012). Any rock and ice, lake, and Antarctic ecoregions or ecoregions <5,000 km^2 were omitted from the analysis following established practice (UNEP-WCMC & IUCN, 2016; Venter et al., 2014; Watson et al., 2016), which left 712 terrestrial ecoregions.

We used the World Database on Protected Areas (IUCN UNEP-WCMC, 2017) to determine the extent of the global protected area estate. We included terrestrial protected areas irrespective of their IUCN classification and excluded proposed protected areas (Hanson, 2016). We classified countries using the Database of Global Administrative Areas (GADM, 2015) based on the unique country codes and their development status with the Human Development Index (United Nations Development Programme, 2015).

To quantify the restoration's potential impact on agricultural production systems, we utilized the annual agricultural opportunity cost layer from Venter et al. (2014), which was based on the approach developed in Naidoo and Iwamura (2007). This opportunity cost layer is a high-resolution map that estimates gross economic benefits from agricultural land by integrating crop productivity, livestock density and prices. Places with no opportunity cost have been estimated using regularized spline interpolation with tension (Venter et al., 2014). Values were converted to 2015 U.S.$ and resampled at 1 km^2 resolution.

2.2 | Analysis

At a 1 km^2 resolution and global extent, terrestrial cells were classified into three categories, (i) protected, (ii) suitable for protection (areas outside the protected area estate with human footprint <4), or (iii) converted (areas outside the protected area estate with human footprint ≥4). For each ecoregion, we calculated the percentage of protected, suitable for protection and converted cells. We identified ecoregions with >83% converted cells to have insufficient suitable land to make up the protection target without restoration and termed these as ecoregions with a shortfall. We measured the shortfall to achieve the protected area target as the difference in area between 17% and the sum of the percentage of protected and suitable for protection land in the ecoregion (i.e., 17% −(i)–(ii)). We aggregated these shortfalls by biogeographical realm, biome, and country. We compared our identified ecoregions to the ecoregions that are *crisis* ecoregions due to recent rapid habitat conversion (Watson et al., 2016).

Restoration thresholds are levels in environmental condition that are barriers to restoring degraded systems (Suding, Gross, & Houseman, 2004), beyond which restoration is challenging (McDonald, Gann, Jonson, & Dixon, 2016). Land areas that have crossed restoration thresholds are less likely to recover, so areas that are relatively less modified should be prioritized for restoration (Bestelmeyer, 2006; Yoshioka, Akasaka, & Kadoya, 2014). We, therefore, classified the converted cells within ecoregions with a shortfall into two categories: lightly modified (human footprint scores of 4–7 inclusive), or heavily modified (human footprint scores >7). We applied the restoration threshold concept to identify restoration opportunities and challenges to achieve the protection target within the ecoregions with a shortfall.

We calculated the least opportunity cost on agricultural production at a 1 km^2 resolution that the restoration of the lightly modified land would impact within the ecoregions with a shortfall. These costs were aggregated globally and by biogeographic realm. Additionally, we constructed a cost curve by determining the cumulative percentage of the shortfall could be restored of the lightly modified land by increments of $100/ha/pa (in 2015 $U.S.). We considered the percentage of the required restoration overall, and by biogeographical realm, that could be achieved on land with agricultural opportunity cost of < $500/ha/pa as a cost threshold to determine the restoration that could be achieved at a moderate cost.

3 | RESULTS

3.1 | Global shortfall of land suitable for protection

Our analysis shows that 190 (27%) ecoregions (Table S1 in supplementary material) have >83% of their land converted, with an overall global shortfall of suitable land to meet the Aichi Target 11 of 1.9 million km^2 (1.4% of the included Earth's terrestrial area). The ecoregions with insufficient suitable land span all seven biogeographical realms, 12 biomes and 114 countries (Figure 1, ecoregions colored orange, red, and dark red). Four ecoregions with shortfalls are also considered *crisis* ecoregions (namely *Sulaiman Range alpine meadows*, *Madagascar subhumid forests*, *Madagascar lowland forests*, and *Huon Peninsula montane rain forests*) due to recent rapid habitat conversion (Watson et al., 2016). We also found that 24 ecoregions were almost entirely converted, having <2% suitable land remaining (Table S1 in supplementary material).

Strikingly, more than three-quarters of the estimated shortfall of suitable land is in just two of the seven biogeographical realms, *Indomalayan* and *Palearctic* (Figure 2a). The highest concentration of ecoregions with shortfalls occurs in the *Indomalayan* realm, where over half (58%) are too converted to have sufficient land to meet Aichi Target 11. The *Palearctic* realm has a much lower proportion of ecoregions with insufficient suitable land (27%), but, given its size, it has the largest areal shortfall (827,000 km^2) of any realm.

At a biome level, the ecoregions with the greatest shortfalls identified in our analysis are found within the tropical and temperate forest biomes (Figure 2b). By area, most (55%) of the shortfall falls into two of the 14 biomes, *Tropical and subtropical moist broadleaf forests* and *Temperate broadleaf and mixed forests*. However, considering the number of ecoregions, over half (57%) of the ecoregions within the *Tropical and subtropical dry broadleaf forests* biome have a shortfall of suitable land; this biome also has the highest percentage shortfall of its area (6%). *Tundra* and *Boreal forests/taiga* are the only biomes whose entire set of ecoregions have sufficient suitable area to meet Aichi Target 11.

The ecoregions that we found with insufficient suitable land are found in 114 countries, the majority (65, or 57%) of which are defined as either "low human development" (32%) or "medium human development" (25%) nations. Almost half (48%) of the ecoregions with shortfalls are spread across multiple countries, with eight ecoregions each spread across more than five countries.

3.2 | Restoration priorities

Restoration actions are a necessity to meet Aichi Target 11 for the 190 ecoregions that cannot achieve 17% protection within their remaining suitable land. We found that for 126 of these ecoregions (66% of the 190) the 17% target can be met by restoring only lightly modified land (Figure 1, orange ecoregions). In contrast, the challenging task of restoring heavily modified land is necessary for the other 64 ecoregions (34% of the 190) (Figure 1, red and dark red ecoregions). An example of such a region is the *Sichuan Basin evergreen*

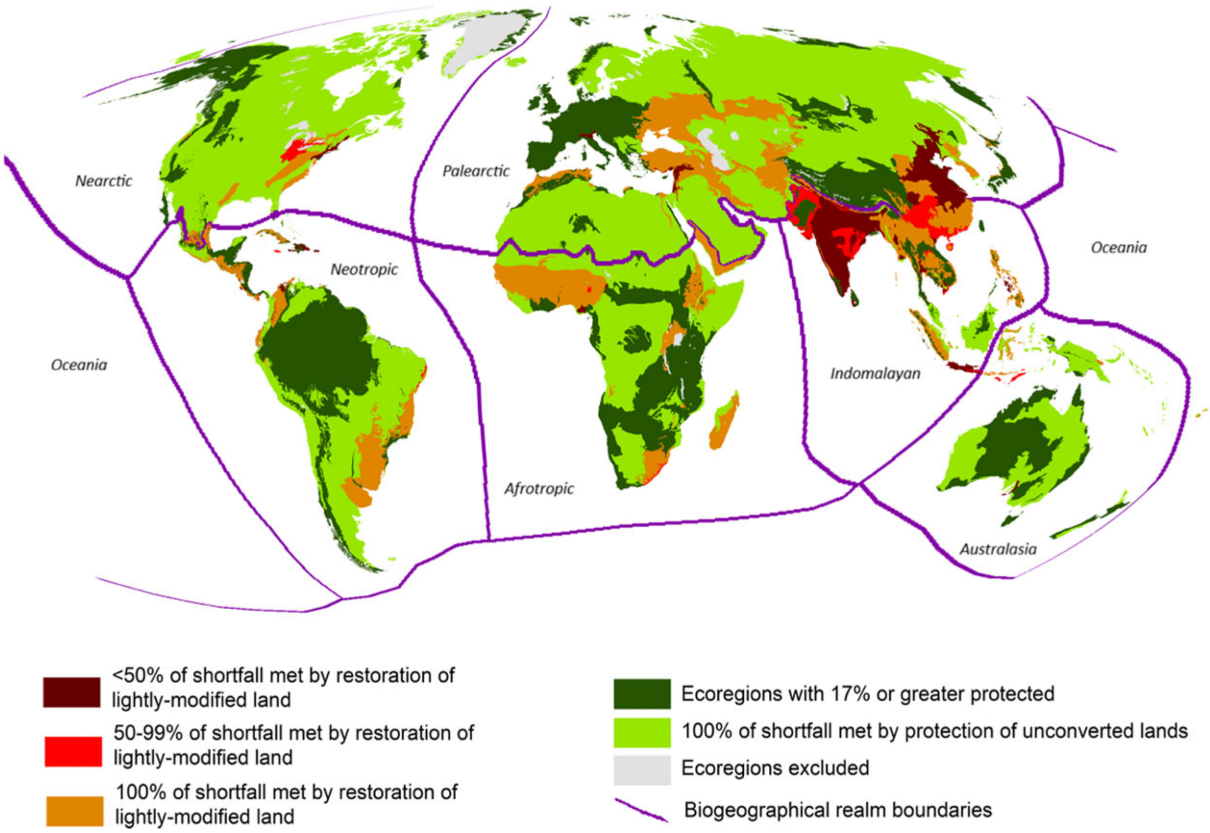

FIGURE 1 Global map displaying the ecoregions classified by levels of conversion and protection. The dark red, red and orange shaded regions are the ecoregions do not have enough suitable land available for protection to reach the Aichi Target 11 of 17% protected area without restoration (shortfalls). The orange regions are ecoregions that can regain these shortfalls through restoration of lightly-modified land. The red and dark red regions are ecoregions that have been converted to an extent that will demand restoration on heavily-modified land to meet their Aichi Target 11 of 17% protected area. The dark green regions are ecoregions that have 17% or greater protected area coverage. The light green regions are ecoregions that have sufficient suitable unprotected land to meet Aichi Target 11 without restoration. The grey regions are ecoregions that have been excluded from the analysis. The purple lines are the boundaries of the biogeographical realms

broadleaf forests ecoregion that has >98% of its area heavily modified.

Targeted restoration on lightly modified land has the potential to recover, in terms of area, the majority (1.3 million km^2, 67%) of the 1.9 million km^2 shortfall to meet Aichi 11. The restoration opportunities differ across the biogeographical realms and biomes (Figure 2). The *Afrotropic*, *Neotropic*, and *Oceania* realms have the greatest potential to recover their shortfalls of suitable land as >90% of the restoration required could be implemented on lightly modified land. Conversely, in the *Indomalayan* realm, 54% of the required restoration to meet Aichi Target 11 is on heavily modified land. There are sufficient restoration opportunities present in the *Temperate Conifer Forests*, *Temperate Grasslands, Savannas & Shrublands*, *Montane Grasslands & Shrublands* biomes to recover their shortfalls to at least 99% on lightly modified land. Whereas the restoration opportunities within the *Tropical and Subtropical Dry Broadleaf Forests* biome are very limited with >70% of the restoration required is on highly modified land.

3.3 | Opportunity costs

The restoration of the 1.3 million km^2 of lightly modified land has an estimated agricultural opportunity cost of at least $205 million per annum with an average least cost of $159/km^2 (Table 1). Over 80% of this cost would fall in the *Palearctic, Indomalayan,* and *Neotropic* realms (Table 1).

Most of the restoration of lightly modified land required to meet the 17% ecoregional targets (93%, 1.2 million of 1.3 million km^2) can be achieved in areas with an agricultural opportunity cost of <$500/ha/pa (Figure 3a). However, the opportunity cost of restoring habitat in the *Nearctic* realm is generally higher and only 51% of the restoration opportunities can be realized in areas with an agricultural opportunity cost of <$500/ha/pa (Figure 3b). Conversely, in the *Afrotropic*, *Indomalayan*, *Oceania*, and *Palearctic* realms 95% or greater

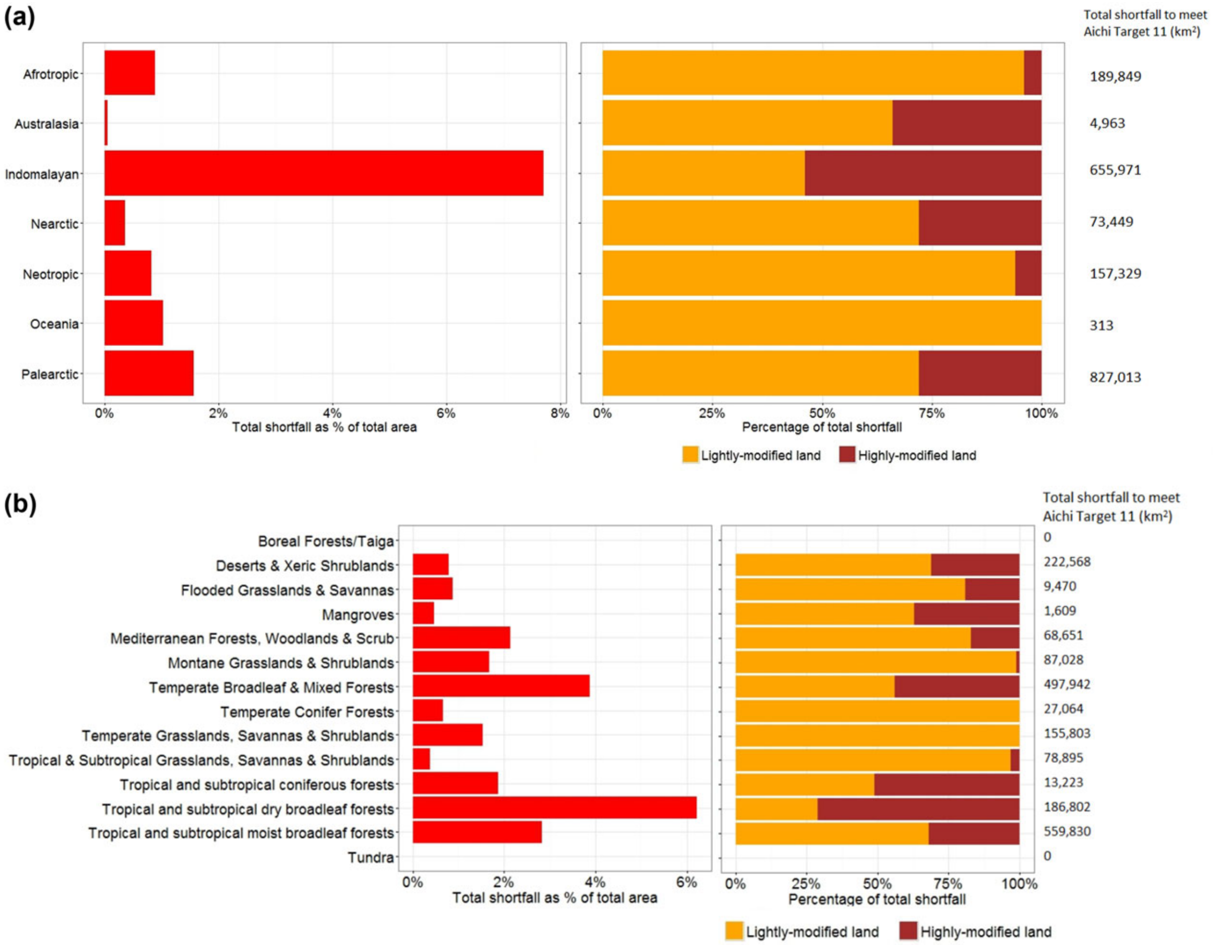

FIGURE 2 The total shortfall in area to meet Aichi Target 11 (red bars), and the potential to address the shortfall by restoring lightly modified lands (yellow bars) or highly modified lands (maroon bars), aggregated by biogeographic realms (a) and biomes (b)

of the restoration opportunities can be realized in areas with an agricultural opportunity cost of <\$500/ha/pa (Figure 3b).

4 | DISCUSSION

Restoration efforts, especially those aimed at enhancing local biodiversity persistence, are critical to ensuring global protected area targets are met. Even if all remaining suitable land is protected, we show that 190 ecoregions across 114 nations will not meet the 17% target and, as such, there is a need for urgent targeted restoration.

More aggressive and ambitious approaches to restoration and protected area establishment are needed in those ecoregions that our analysis identifies as having a shortfall of suitable land (Figure 1, ecoregions colored orange, red, and dark red). Additionally, future global conservation targets need to include restrictions on the conversion of remaining habitat alongside the expansion of protected areas. As human populations continue to grow and the use of natural resources increases, constraints on the amount of area that can be cultivated, urbanized, or modified are imperative to avoid further biodiversity losses.

Our analysis shows that at least 1.9 million km^2 need to be restored to achieve Aichi Target 11, which is consistent with the target outlined within the Bonn Challenge, a global restoration effort to commit 1.5 million km^2 of deforested and degraded land to restoration by 2020 and 3.5 million km^2 by 2030. The total pledges to the Bonn Challenge surpassed 1.5 million km^2 in May 2017 (Bonn Challenge, 2017) with the majority of the commitments coming from Africa (IUCN, 2016). Large commitments have been made by Ethiopia, Democratic Republic of the Congo, Kenya, and Malawi (326,000 km^2) (IUCN, 2016), an area 14 times greater than their combined shortfalls identified in our analysis. Interestingly, our analysis demonstrates that these countries currently can meet their protection targets with available suitable land and restoring small amounts of lightly modified land. This highlights an interesting aspect of the *Afrotropic* realm: much of the realm is currently suitable for protection (Figure 1) and where there is restoration required it is highly cost-effective (restoration can be placed in areas with an

TABLE 1 Summary breakdown by biogeographical realm of the area and percentage of area for the total shortfall to meet Aichi Target 11, lightly modified lands, highly modified lands, and the total and average least opportunity cost of potential agricultural output on lightly modified land

Biogeographic realm	Total shortfall of suitable land to meet Aichi Target 11 (km^2)	Total shortfall of suitable land to meet Aichi Target 11 (% of total area)	Restoration opportunities on lightly modified land (km^2)	Restoration opportunities on lightly modified land (% of total shortfall)	Gap remaining that can only be met on highly modified land (km^2)	Gap remaining that can only be met on highly modified land (% of total shortfall)	Total annual least opportunity cost of potential agricultural output on lightly modified land (rounded to nearest $'000)	Average annual least opportunity cost on lightly modified land ($/$km^2$)
Afrotropic	189,849	0.9%	182,671	96.2%	7,178	3.8%	14,180,000	78
Australasia	4,963	0.1%	3,279	66.1%	1,684	33.9%	841,000	256
Indomalayan	655,971	7.7%	303,696	46.3%	352,275	53.7%	48,362,000	159
Nearctic	73,449	0.4%	52,802	71.9%	20,647	28.1%	23,720,000	449
Neotropic	157,329	0.8%	148,258	94.2%	9,072	5.8%	50,919,000	343
Oceania	313	1.0%	313	100.0%	-	-	24,000	76
Palearctic	827,013	1.6%	593,398	71.8%	233,615	28.2%	66,648,000	112
Total	1,908,886	1.4%	1,284,416	67.3%	624,470	32.7%	204,693,000	159

agricultural opportunity cost of <$500/ha), but this situation is likely to rapidly change in the future (Esch et al., 2017). Land use change scenarios project major deforestation and conversion of other natural land for crop and pasture production across the *Afrotropic* realm and in particular in the Democratic Republic of the Congo (Esch et al., 2017). This suggests that there is urgency in both protecting and restoring land in this region before the opportunity to act is lost.

The situation in the *Indomalayan* realm is now critical, where over half the ecoregions require restoration to achieve Aichi Target 11, and most of the required restoration is of highly modified land. Alarmingly, land use scenarios also predict continued deforestation and conversion of other natural land in the realm (Esch et al., 2017). The realm is predominantly tropical forest, which hosts some of the highest levels of biodiversity and concentrations of threatened species in the world (Jenkins, Pimm, & Joppa, 2013). Land conversion in Southeast Asia has been one of the major determinants of global biodiversity decline in recent decades (Sodhi, Koh, Brook, & Ng, 2004) and we show that expanding protected areas in the region would be largely insufficient to achieve a representative protection of its biodiversity. Considering the extent of habitat conversion and the rates at which natural habitat is being lost, the restoration and subsequent protection of lightly modified land in this region is an immediate priority. However, for 35 ecoregions in the realm, this will have to be coupled with the restoration of some highly modified land in the long term to achieve ecoregional representation. There have been few commitments in Asia for the Bonn Challenge (with <20% of the pledges) (IUCN, 2017), but encouragingly commitments are in three countries with substantial protection shortfalls (India, Indonesia, and Pakistan). Thus, while there are major challenges to achieving restoration in this realm both now and into the future, the commitment to act by governments is a conservation opportunity.

There are several caveats to our analysis that should be considered when interpreting and applying the results. While we used an established threshold to define habitat degradation using the human footprint (Jones et al., 2018), which is in line with empirical demonstrations of human impact on terrestrial mammals globally (Di Marco et al., 2018), it can be still considered generic. The exact threshold for habitat degradation may vary across ecosystem types, yet the evidence base for these potential regional variations does not yet exist. As the human footprint is updated using more fine scale and regionally specific datasets, we encourage regional spatial assessments to build on the framework we develop and employ here. Furthermore, we recognize that any successful restoration process is dependent on other influential factors that have not been considered in this analysis (Hanson, Buckingham, Dewitt, & Laestadius, 2015). For example, motivation for restoration action is required by local decision makers and land owners, and capacity and resources need to be

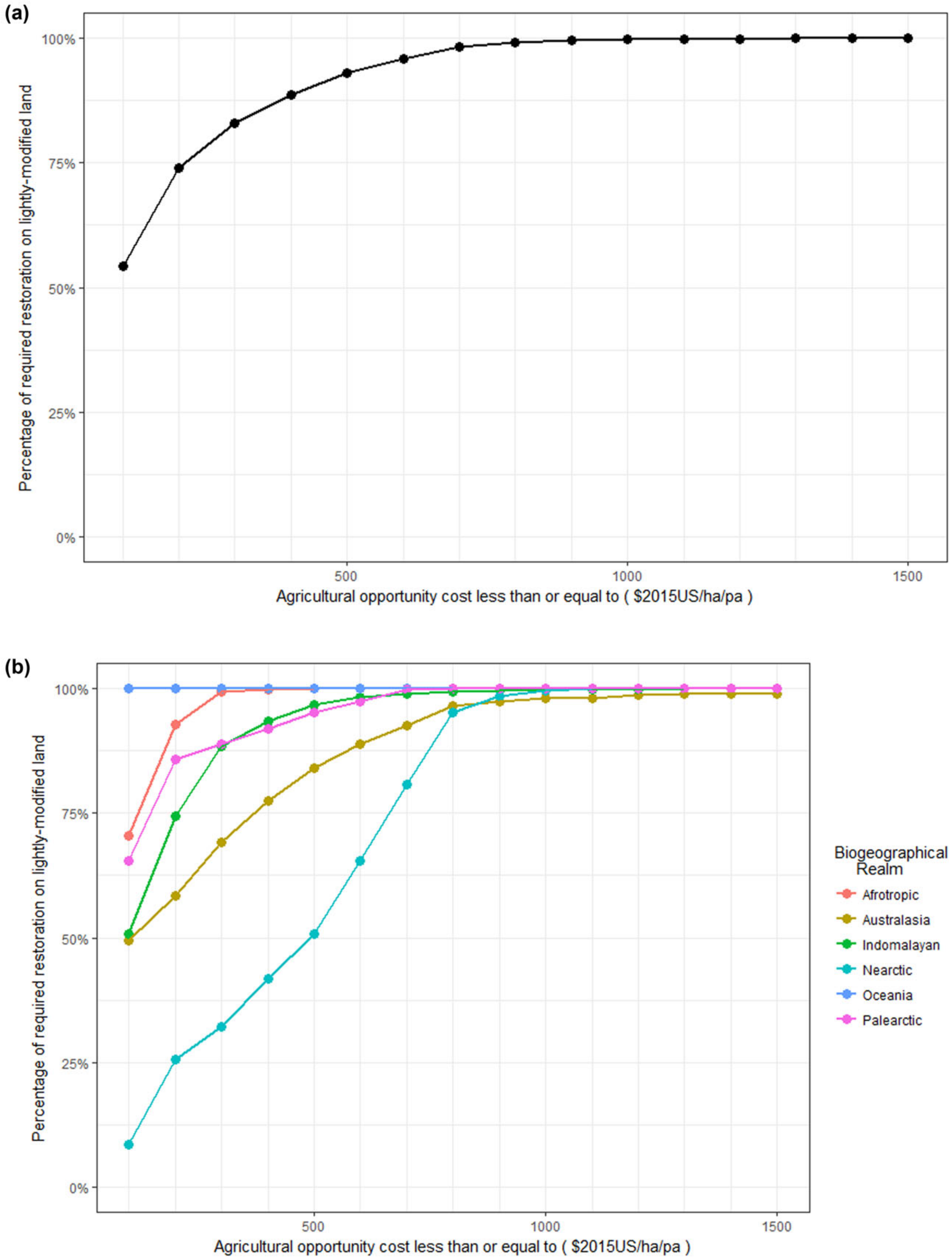

FIGURE 3 Cost curves of the percentage of the required restoration to address the shortfall available on lightly modified land by the annual opportunity cost of potential agricultural output in 2015 U.S.$/ha/pa aggregated globally (a) and by biogeographical realm (b)

mobilized and sustained over a long period, to ensure success. In addition to the ecological and market conditions we have considered, other enabling conditions include social, institutional, and governance factors that are entwined with effective protected area management (Oldekop, Holmes, Harris, & Evans, 2016).

There are significant knowledge gaps in how we achieve effective restoration outcomes for most ecosystems across Earth. As such, creative restoration solutions that are oriented towards an adaptive management philosophy are needed for sustaining the coexistence of both people and nature. Opportunities are being presented by the global reduction in the total agricultural land despite growth in production (Poore, 2016). This abandoned pasture land presents a potential source for a portion of the land required for the vital restoration. Other opportunities include the implementation of land stewardship schemes with payment for ecosystem services (Bullock, Aronson, Newton, Pywell, & Rey-Benayas, 2011) and biodiversity carbon farming incentives (Evans et al., 2015). For the extremely converted ecoregions, in addition to urgently protecting what remains, we recommend actions aimed at enhancing heterogeneity across agricultural lands (Benton, Vickery, & Wilson, 2003) to maintain moderate levels of biodiversity.

There are risks associated with the protection and restoration of land that are currently used for agriculture. For example, protection in one area can displace resource extraction or land conversion to other, less well protected areas (Pressey, Weeks, & Gurney, 2017). Such "leakage" effects can result in net detrimental impacts to biodiversity. It is essential that protection and restoration be appropriately planned and implemented in ways that minimise impacts on food production or resource extraction (Bode, Tulloch, Mills, Venter, & Ando, 2015). Ecoregions that are extensively converted and would require substantial restoration to meet Aichi Target 11 may be at high risk of causing such adverse, unintended effects. In these cases, it may be better to employ efforts to increase protection of other ecoregions and adopt lower targets for ecoregions in the interest of avoiding displaced losses.

Significant restoration efforts are essential for meeting conservation targets in many ecoregions, and we present a clear map of where global restoration priorities are to achieve a representative protected area network. As humanity continues to expand its footprint and conservationists call for bolder protected area targets, this analysis shows that a balanced approach around protection and restoration efforts needs to occur so strategic targets can best achieve long-term biodiversity conservation aspirations.

ACKNOWLEDGMENTS

We thank all the participants of the Social Equity and Restoration workshop that was funded by Australian Research Council Laureate Fellowship. BM is supported by the University of Queensland Research Scholarship. HPP supported by Australian Research Council Laureate Fellowship. MDM acknowledges support from the EU H2020 programme (H2020-MSCA-IF-2017-793212)

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Mappin B, Chauvenet ALM, Adams VM, et al. Restoration priorities to achieve the global protected area target. *Conservation Letters*. 2019;e12646. https://doi.org/10.1111/conl.12646