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Recognizing the equity implications of restoration priority maps

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Recognizing the equity implications of restoration priority maps

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Bill Schultz^{1,*}, Dan Brockington^{2,3}, Eric A Coleman⁴, Ida Djenontin^{5,6}, Harry W Fischer⁷,
Forrest Fleischman⁸, Prakash Kashwan⁹, Kristina Marquardt⁷, Marion Pfeifer¹⁰, Rose Pritchard¹¹
and Vijay Ramprasad^{12,13}

- ¹ Department of Political Science, Florida State University, Tallahassee, FL 32306, United States of America
 - ² Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, Barcelona 08193, Spain
 - ³ Institució Catalana de Recerca i Estudis Avançats, Barcelona 08010, Spain
 - ⁴ Department of Political Science, Florida State University, Tallahassee, FL 32306, United States of America
 - ⁵ Grantham Research Institute on Climate Change and the Environment, The London School of Economics, WC2A 2AE London, United Kingdom
 - ⁶ Department of Geography, Penn State University, State College, PA 16801, United States of America
 - ⁷ Department of Urban and Rural Development, Swedish University of Agricultural Sciences, PO Box 7012, SE-750 07 Uppsala, Sweden
 - ⁸ Department of Forest Resources, University of Minnesota, St. Paul, MN 55108, United States of America
 - ⁹ Department of Environmental Studies, Brandeis University, Waltham, MA 02453, United States of America
 - ¹⁰ SNES, Newcastle University, NE1 7RU Newcastle Upon Tyne, United Kingdom
 - ¹¹ Global Development Institute, University of Manchester, M13 9PL Manchester, United Kingdom
 - ¹² Center for Ecology, Development and Research, Dehradun, Uttarakhand 248006, India
 - ¹³ Department of Environmental Studies, Ashoka University, Sonapat 131029, India
- * Author to whom any correspondence should be addressed.

E-mail: wbs15@fsu.edu

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Abstract

A growing number of studies seek to identify global priority areas for conservation and restoration. These studies often produce maps that highlight the benefits of concentrating such activity in the tropics. However, the potential equity implications of using these prioritization exercises to guide global policy are less often explored and articulated. We highlight those equity issues by examining a widely publicized restoration priority map as an illustrative case. This map is based on a prioritization analysis that sought to identify places where restoration of agricultural land might provide the greatest biodiversity and carbon sequestration benefits at the lowest cost. First, we calculate the proportion of agricultural land in countries around the world that the map classifies as a top 15% restoration priority. A regression analysis shows that this map prioritizes restoration in countries where displacing agriculture may be most detrimental to livelihoods: countries that are poorer, more populated, more economically unequal, less food secure, and that employ more people in agriculture. Second, we show through another regression analysis that a similar pattern appears sub-nationally within the tropics: 5 km × 5 km parcels of land in the tropics that are less economically developed or more populated are more likely to be top 15% restoration priorities. In other words, equity concerns persist at a subnational scale even after putting aside comparisons between the tropics and the Global North. Restorative activity may be beneficial or harmful to local livelihoods depending on its conceptualization, implementation, and management. Our findings underline a need for prioritization exercises to better attend to the risks of concentrating potentially negative livelihood impacts in vulnerable regions. We join other scholars calling for greater integration of social data into restoration science.

1. Introduction

Ecosystem restoration seeks to recover degraded ecosystems through interventions like assisted natural regeneration, tree planting and species reintroduction [1, 2]. The New York Declaration on Forests, the Bonn Challenge [3], and the UN Decade on Ecosystem Restoration [4] illustrate the high profile of restoration in global environmental discourse. When implemented effectively, restoration may provide a variety of benefits [5]. These benefits include carbon sequestration, habitat protection, improving the availability of resources that support local livelihoods [1, 2, 6, 7], erosion control, flood reduction, and pollination [8–12]. However, these benefits are not guaranteed [13–15], there may be spatial disparities in their distribution, and there may be negative impacts of restoration as well [16, 17].

A growing number of studies seek to identify restoration and conservation priorities spatially [18–24]. The maps these studies produce may be used by policymakers to inform decision-making [25]. Such studies can be valuable for improving the effectiveness of environmental policy [24, 26], identifying spaces with climate mitigation potential [18, 20, 27], and identifying synergies between biodiversity conservation and carbon sequestration goals [28–30]. These studies can also be useful for weighing the costs and benefits of land use change in different areas [19, 21].

However, these prioritization analyses and the maps they produce have attracted criticism. For example, a study of global tree restoration potential [18] was criticized for projecting tree restoration onto grasslands [31, 32]. Wyborn and Evans discuss how mapping exercises might oversimplify complex decision-making problems or crowd out information about local contexts [23]. Meyer and Pebesma point out that accuracy assessments of some global ecological maps are disputable, and that such maps may rely on inadequate reference data [33]. In contrast, others contend that despite such problems, the outputs of these prioritization exercises provide broader context for local decisions and help encourage global co-ordination [25].

To date, there are few empirical analyses of the equity issues raised by the data and processes commonly used to produce global priority maps. We argue that a better understanding of equity in this area is crucial, on both normative and feasibility grounds [34]. We understand equity as an ethical requirement to take fair and just steps to support the sustainability of socio-ecological systems [35]. Four dimensions of equity are often underscored in environmental planning [35–37]. First, procedural equity requires that decision-making procedures are inclusive and democratic, with effective participation of relevant voices. Second, distributional equity speaks to how resources, costs, responsibilities, and benefits are allocated and shared. Third, recognitional equity

requires acknowledging and respecting diverse rights, values, and identities. Finally, contextual equity refers to the consideration of historical and structural socio-cultural, economic, and policy contexts.

Our study focuses most on distributional equity concerns, which have been at the forefront of environmental justice debates for decades, and are possibly easier to demonstrate quantitatively [36]. We provide an illustrative analysis of a recent, well-publicized priority mapping exercise [21] that exemplifies the challenges faced by other studies in this literature. First, we show that an output map from this study concentrates top priority restoration areas in countries that are poorer, more densely populated, more reliant on agriculture, and more food insecure. Though restoration and conservation interventions may support local livelihoods [10], they can also have negative impacts on the poor [38–40]. Restoration can involve the loss of agricultural lands [21]. It may lead to increased competition for remaining land [41, 42], the displacement of customary land uses [11, 43], or the displacement of communities themselves [44]. It can also increase the risk of detrimental human-wildlife interactions [45, 46]. A prioritization analysis that leads policymakers to concentrate restoration in lower-income countries could have serious distributional consequences depending on subsequent decisions about design, implementation, and monitoring.

Second, we show that similar distributional equity concerns persist at a subnational scale: areas within tropical countries that are less developed or more populated are more likely to be top restoration priorities. Even when cross-national comparisons between the Global South and the Global North are set aside, using extant prioritization analyses to guide policy still risks concentrating any negative impacts of restoration on communities that are less prepared to bear them.

Though our empirical analyses highlight distributional equity, we emphasize that priority setting analyses also raise potential procedural, recognitional, and contextual equity concerns. Proponents of restoration mapping may suggest that their outputs are not concrete proposals, but rather starting points for debate [25]. However, this argument sidesteps the threat such analyses pose to fair decision-making. Priority-setting exercises may shape future policy implementation, yet they often do not incorporate information on the values and interests of communities who would be most affected by restoration [37]. These communities are often overlooked in subsequent steps of the restoration policymaking process as well [47, 48]. This raises interrelated procedural and recognitional equity concerns, which may reinforce distributional consequences in the future. Meanwhile, a failure to consider aspects of the local social context, such as land tenure security, risks creating a misleading picture of global restoration

priorities. This is problematic on contextual equity grounds. In sum, our study reinforces calls for better integration of social data into restoration science.

2. Methods

2.1. Exploring a single map in-depth

As a case study into the equity issues underlying global prioritization analyses, we explore Strassburg *et al*'s restoration priority map [21]. We selected this prioritization analysis and one of its output maps for a few reasons. First, it is a well-publicized global prioritization study¹³. Moreover, it was published in a high-impact journal, represents a clear methodological improvement, and exemplifies important tensions in this literature. We emphasize that our intent is not to critique this study in particular. We are responding to calls for deeper exploration of equity issues in the prioritization literature raised by Strassburg *et al* themselves, as well as other recent studies [49].

Strassburg *et al* [21] developed a multi-criteria algorithm for optimally choosing areas for restoration while accounting for biome-specific characteristics of different parcels of land. They use this algorithm to assign restoration priority levels to 'converted lands' around the world (i.e. lands used for crops or pasture). Specifically, they break down the world's surface into 5 km × 5 km 'planning units.' Within each planning unit, they map land cover in 300 m × 300 m cells to both identify agricultural lands and estimate the distribution of ecosystem types to which those agricultural lands should be restored. These authors focus on complete land use change, wherein agricultural lands are entirely converted to a natural ecosystem, making opportunity costs easier to define.

Strassburg *et al* [21] consider two benefits of restoring agricultural land: carbon sequestration and maintaining natural habitat. They estimate the opportunity costs of restoration based on projected profits from livestock or crop production, and they estimate implementation costs globally based on restoration projects in Brazil's Atlantic Forest [22]. Based on these spatial estimates of costs and benefits, the authors use simulations to classify planning units around the world into different restoration priority levels (top 5%, 6%–10%, 11%–15%, etc) under a range of scenarios. These different scenarios assign priorities to minimize costs, maximize carbon storage, maximize biodiversity protection, or combinations of the three. We focus on the restoration priority map for one of their scenarios, visualized in figure 1(e) of Strassburg *et al* [21], which identifies priority sites for restoration that maximize carbon sequestration and habitat protection whilst minimizing costs.

2.2. Initial descriptive analysis

We begin with some descriptive analysis of Strassburg *et al*'s [21] restoration priority map. We follow an approach outlined by Strassburg *et al* to produce a map that identifies agricultural ('converted') land around the world at a 300 m resolution (see our supporting information for more detail). A cell is classified as being either converted cropland or pastureland (1), or not (0). We then use the priority levels from the map in figure 1(e) of Strassburg *et al*'s [21] study to classify converted lands by their restoration priority level and calculate the proportion of high priority (global top 15%) agricultural lands that are in the tropics.

Additionally, we estimate the proportion of agricultural land in each Food and Agriculture Organization (FAO) member country that would need to be restored if a global restoration initiative targeted the planning units classified as a top 15% priority by this map. Our estimates assume the complete restoration of all agricultural land cells, as did the original prioritization analysis.

2.3. National-level regression analysis

We use ordinary least squares (OLS) linear regressions to explain variation in the proportion of agricultural land in a country that is classified as a top 15% restoration priority (the dependent variable; 'top priority land'). Our primary regression model includes the following explanatory variables: population, wealth (gross domestic product, GDP), economic inequality (Gini index), governance (democracy and human rights scores), and a country's land area (added as a control)¹⁴. We include population and wealth in this model to explore whether more populated or less wealthy countries tend to contain more top priority land. We include a measure of economic inequality given past research investigating the relationship between inequality and conservation policymaking [48]. The Gini index is a well-established indicator of economic inequality that measures the dispersion of income in a country, such that a low score indicates a highly equal income distribution while a high score indicates a highly unequal income distribution.

To see the logic for our inclusion of two governance measures, consider that some countries may pursue restoration and conservation in more coercive ways than others, or may be more likely to infringe on communities' rights and implement environmental policies without consideration of local livelihoods. National-level measures of the incidence of conservation-induced displacement, for example, are not readily available, so we can only proxy for

¹³ For instance, it was referenced in an article of the New York Times [83], and as of 8 February 2022, the study had an Altmetric score of 1867.

¹⁴ Though land area is of less substantive interest, it may still be important to include in our models. Larger countries tend, for instance, to have a greater GDP and a greater population. They may also tend to contain more top priority land, simply by virtue of their size.

these inclinations indirectly. Measures of the extent of liberal democracy—characterized by the protection of individual liberties and limits on state authority [50]—and the extent of human rights protection are some of the better proxies available at a cross-national scale. A previous analysis of the interactions between inequality, democracy and the legal designation of protected areas in a global sample of 137 countries shows that, *ceteris paribus*, the relationship between inequality and protection varies depending on the strength of democracy: in relatively democratic countries inequality is associated with less land in protected areas, whereas in relatively undemocratic countries the reverse is true [48].

Where appropriate, we log transform variables before including them in our analysis. See our supporting information for more detail on our national-level analysis, data sources (SI sections 1, 2, 4 and table S2), and for a full results table based on our primary regression model (table S3). After estimating our primary model, we estimate four additional regression models that each replace GDP and the Gini index with various alternative economic measures (and also omit the governance measures). The alternative economic measures are: (a) the percent of farms smaller than 5 ha (as a proxy for the prevalence of smallholder farming); (b) a measure of food availability (the percent of an average person's daily caloric needs that can be met by food availability in a country); (c) the percent of a country's citizens employed in agriculture; and (d) a country's average radiance at night (average 'nighttime lights'), which is increasingly used as an indicator of national economic production [51], especially production linked to the manufacturing and service sectors [52–54]. Again, see our supporting information for more detail on data sources, and for a full regression table including each of these additional models (table S4).

2.4. Subnational-level regression analysis

Finally, we analyze approximately 820 000 planning units (parcels) from FAO member countries with at least 20% of their land area in the tropics. Parcels were only included in our sample if they also had a restoration priority level assigned and if they contained at least 10% agricultural land. We first analyze the entire sample of parcels that meet our criteria. Then, to help address possible spatial dependence concerns [55], we repeat our analysis on a randomly chosen 5% of parcels, decreasing the likelihood that remaining parcels will be close together. A similar strategy has been applied, for instance, in work examining the impacts of protected areas [56–58].

Our dependent variable here is binary: whether a parcel is classified as a top 15% priority ($Y = 1$) or not ($Y = 0$). We explain variation in this measure using both logit regression models and linear probability models (LPMs), though we focus on the linear probability model results for ease of interpretation.

Our first explanatory variable is a parcel's level of development, based on nighttime lights data. Nighttime lights data can provide reasonable estimates of economic development at local scales [51, 54], though it becomes especially difficult to link nighttime lights to specific components of development (e.g. urbanization, infrastructure growth, manufacturing sector activity, etc). Nighttime lights are therefore more useful in this analysis as a summary measure of overall economic and infrastructure development [51]. Additionally, note that nighttime lights data struggle to measure the light emissions produced by poorer rural households in lower-income countries [59, 60]. It may be more appropriate to treat these data as measures of development related to sectors of the economy aside from rural smallholder agriculture, rather than presuming they provide a complete picture of local variation in wealth.

Our second explanatory variable is the average population density of a planning unit. To adjust for skew in the distribution of both explanatory variables, as well as an established non-linear relationship between nighttime lights and economic development, we add a constant of 0.01 to both and then log transform them before fitting our models [54, 61]. Our supporting information provides more detailed discussion of our parcel-level data, measurement and transformation choices, and modeling choices (SI appendix sections 1–4). It also includes parcel-level summary statistics (table S5).

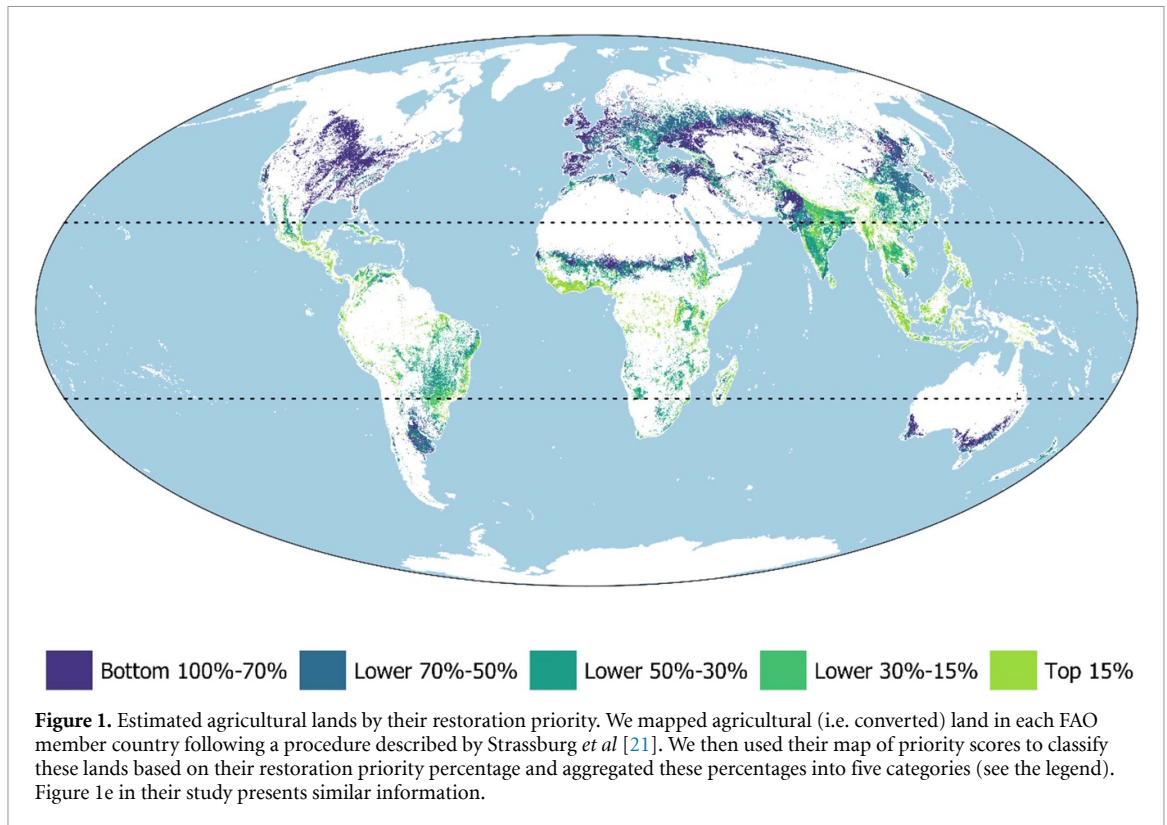
We conduct this analysis within a multilevel modeling framework, estimating random country-level intercepts. We also include additional control variables for mean nighttime lights and total population at a country level (both logged and mean-centered). For computational reasons, we approximate multilevel logit models using a generalized additive modeling (GAM) approach (see SI 4, tables S6 and S7).

3. Results

3.1. Targeting the tropics for restoration

Figure 1 shows estimated converted (agricultural) lands around the world, classified by their restoration priority level [21]. As explained above, these priority levels were assigned based on an efficiency criterion (maximizing environmental benefits while minimizing economic costs). Of all the 5 km × 5 km planning units around the world classified as a top 15% priority, we find that approximately 85% are located in the tropics. Importantly, this prioritization analysis is not unique in that regard—due to its high concentrations of biodiversity and carbon sequestration potential [20, 28], other analysts also identify the humid tropics as a place where climate change mitigation strategies could be most efficiently concentrated [18, 27, 62]. We return to this issue below.

Next, for every FAO member state, we calculated the proportion of its agricultural land classified as



a top 15% restoration priority (i.e. that would be restored under a hypothetical global 15% initiative guided by this map). We provide a sample of these estimates in table 1. Our supplementary information includes an extended version of this table (table S1) and a color-coded map that visualizes these estimates for every FAO member state (figure S1). Indeed, many tropical countries would need to restore substantial portions of their agricultural land to natural ecosystems, whereas most countries outside the tropics would not.

3.2. The national implications of a prominent restoration map

Results from our primary national-level regression model (table S3), visualized in panel (a) of figure 2, show that countries have less of their agricultural land classified as a top 15% restoration priority (‘top priority land’) if they are wealthier, less populated, and have less economic inequality. Panel (b) visualizes the additional results for our regression models that use alternative economic measures (table S4). It shows that countries have more top priority restoration land if they have higher employment in the agricultural sector and if farms are smaller (less than 5 ha). Countries have less top priority land if they have more food availability (% daily dietary energy available), or if they are brighter at night (a proxy for economic development).

3.3. Subnational implications within the tropics

On average, 5 km × 5 km parcels of land in a tropical country that are darker at night are more likely

Table 1. Agricultural land to restore under a global 15% plan following Strassburg *et al* [21].

Country	Proportion of agricultural land to restore
Equatorial Guinea	99.6%
Philippines	96.7%
Nicaragua	87.2%
Nepal	83.9%
Indonesia	82.5%
El Salvador	62.4%
Uganda	34.1%
Tanzania	31.5%
Brazil	16.7%
India	12.6%
Malawi	10.6%
New Zealand	1.4%
United States	0.1%
Ukraine	0.1%
Germany	<0.1%

If Strassburg *et al* [21] map from figure 1(e) of their study was followed to implement a 15% global restoration target, the estimates in this table represent the percent of agricultural land that 15 select countries would need to restore to a natural state. We selected countries for this table based on the expertise of members of our research team and with an eye towards representing different continents.

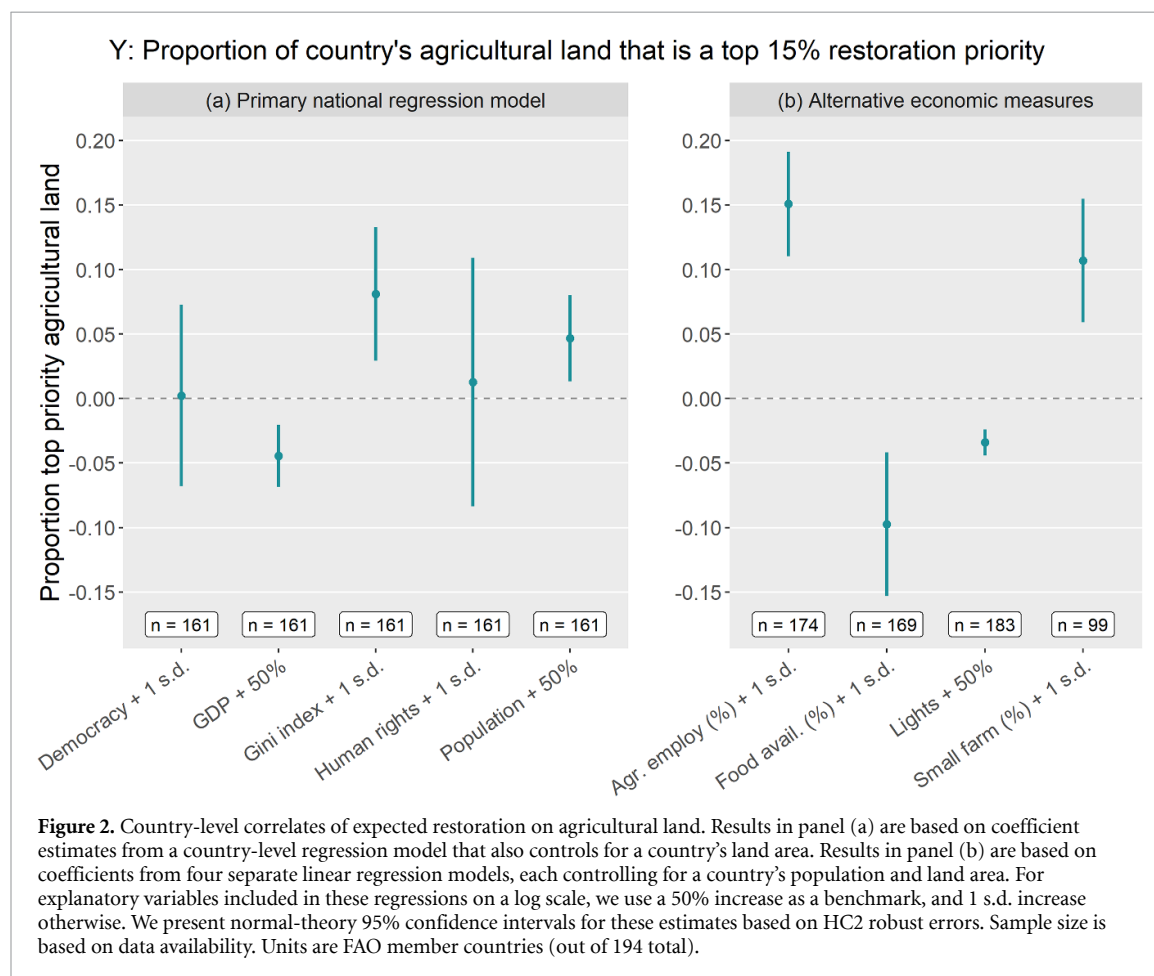
to be top 15% restoration priorities. For instance, per the linear approximations in Model 1 of table 2, when (logged) parcel lights increase by one standard deviation (+1.65), the probability that a parcel is a top 15% restoration priority declines by 3.47%. Further, the average within-country difference between the brightest and dimmest (logged) parcel light value

Table 2. Parcel level regression results (tropical countries).

	Dependent variable			
	Top 15% priority planning unit? (0/1)			
	LPM (1)	LPM (2)	Logit (3)	Logit (4)
Parcel lights (log)	−0.021*** (0.0004)	−0.020*** (0.002)	−0.139*** (0.003)	−0.133*** (0.012)
Parcel population (log)	0.012*** (0.0003)	0.011*** (0.001)	0.085*** (0.002)	0.073*** (0.010)
Country lights (log)	0.051*** (0.016)	0.048** (0.019)	0.411** (0.164)	0.359** (0.154)
Country population (log)	−0.075*** (0.016)	−0.067*** (0.021)	−0.670*** (0.176)	−0.415** (0.175)
Constant	0.240*** (0.052)	0.256*** (0.057)	−2.093*** (0.518)	−1.673*** (0.455)
Random sample (5%)	No	Yes	No	Yes
GAM	No	No	Yes	Yes
sd (constant)	0.318	0.327	3.117	2.599
Countries	97	89	97	89
Observations	837 468	41 860	837 468	41 860

Note: ** $p < 0.05$ *** $p < 0.01$.

This table presents coefficients from two multilevel linear probability models and two multilevel logit models (estimated using a generalized additive modeling approach). All models include a country-level random intercept and country-level controls for development and population (logged and mean-centered). Models 1 and 3 are fit for all parcels that satisfy our inclusion criteria (in a tropical country, at least 10% agricultural land, and a non-missing restoration priority score), while Models 2 and 4 are fit on a dataset produced by randomly sampling 5% of these parcels. Coefficients for the linear probability models represent average changes in $\Pr(Y = 1)$ associated with $X + 1$. Coefficients for the logit models instead represent changes in log odds.



is 7.03. Model 1 therefore suggests that the brightest parcels in an average tropical country are approximately 14.7% less likely to be top restoration priorities than the dimmest parcels. Moving to the result for population, our analysis shows that more populated parcels are more likely to be top restoration priorities. A one standard deviation increase in logged population (+2.55) is associated with a 3.06% increase in the probability of being a top restoration priority, while the average within-country range of logged population (8.46) implies a 10.15% increase.

4. Discussion

We provide an illustrative case study of a prioritization analysis that sought to locate the restoration of agricultural land in areas where it would provide the greatest ecological benefits (in terms of habitat protection and carbon storage) at the lowest cost [21]. We show that the map produced by this analysis concentrates top priority restoration areas in the global tropics. Moreover, we show that many tropical countries have substantial portions of their agricultural land classified as a top restoration priority, while countries outside the tropics largely do not. It is worth emphasizing that countries at the top of table 1, for example, would not be able to restore so much agricultural land—food needs, employment needs, and the cultural value of agricultural lands would clearly prohibit it. Moreover, earning the cooperation of decision-makers in many countries with a restoration initiative that involves substantial loss of agricultural land would require a complicated political process, as would developing a program to compensate communities whose livelihoods are displaced [24]. Similar compensation programs have struggled in the past [63–65], and it is not clear how an initiative to substantially increase restoration in the tropics would overcome this hurdle.

Of course, many other analysts also point out the possible benefits of concentrating restoration and conservation interventions in the tropics. For instance, Bastin *et al* argue that loss of forest habitat in the tropics presents the greatest threat to global potential canopy cover [18]. Similarly, Walker *et al* seek to map the global distribution of carbon storage opportunities, and in particular the distribution of *unrealized* opportunities for carbon storage [27]. These authors argue that a majority of unrealized carbon storage potential is found in tropical regions. Lewis *et al* provide a commentary which argues that expanding natural forest restoration in the Tropics and Subtropics is essential to fighting climate change, given the quick pace at which trees grow and sequester carbon, and this region's cheaper land prices [62].

Our regression analyses help better illustrate the distributional equity issues that such arguments raise. First, our national level regression results imply that countries with more agricultural land classified as a

top restoration priority are also those whose populations are most dependent on agriculture. While the restoration of nature can facilitate human well-being, these benefits may not outweigh the costs incurred where activities like farming are the main source of food security and income. Plans that do not explicitly call for restoring agricultural land could still threaten communities in highly populated, agriculturally reliant countries due to increased competition for land or land-use displacement [11, 41, 42].

This finding may seem obvious, in that the economies of tropical countries are known to be relatively more dependent on agriculture. However, that obviousness raises a troubling question: why have the possible negative impacts of concentrating restorative activity in lower-income countries been an infrequent consideration in priority setting analyses?

Second, our subnational regression analyses suggest that areas of the tropics with relatively fewer livelihood opportunities besides agriculture (i.e. with less light-emitting economic activity) are also more likely to be targeted for restoration. Again, it could also be argued that this finding is not surprising. Unpopulated parcels, or those with a low population, may represent existing natural ecosystems that need less restorative activity. Meanwhile, parcels that are brighter at night may represent areas where expensive infrastructure is more concentrated, leading to higher restoration opportunity costs. However, again, this supposed obviousness is part of our point. Prioritization analyses may often locate restoration and conservation priorities in places where these activities raise greater social equity concerns. Seemingly rational prioritization criteria may obscure equity issues that need to be discussed more openly.

More broadly, we reiterate that restoration interventions have the potential to benefit or harm local livelihoods depending on their consideration of social equity [35–37, 66]. This includes the distributional concerns that we highlight above, but also inter-related procedural and recognitional concerns regarding whose interests are acknowledged and incorporated into restoration decision-making. Additionally, it includes contextual concerns regarding how interventions are adapted to their circumstances.

In turn, whether it is problematic to allow optimization exercises to guide global restoration priorities also depends on their engagement with these issues. For example, it depends on analysts' decisions about what constitutes 'restoration.' Mapping exercises often estimate the benefits of restoration by assuming complete land use change [19, 21, 22]; e.g. restoring a pasture entirely to natural forest. However, it is also possible to integrate restoration into existing agrarian landscapes, which requires less displacement of local land uses [10, 67, 68]. Making an informed choice between complete and partial land use change requires weighing the different social impacts of these strategies, as well as their relative

contributions to carbon storage and biodiversity protection. Extant prioritization analyses often do not provide sufficient information on these tradeoffs. As another example, prioritization analysis also requires making decisions about how the human population of an area should influence its status as a restoration or conservation priority. While Strassburg *et al* [21] focus on restoring agricultural land, other studies rule out crop lands, grazing lands, and areas of human habitation *ex ante* on the grounds of equity and feasibility [27, 69].

Relatedly, it is important to critically evaluate the data inputs to global environmental assessments [70]. The various decisions we highlight above should, on equity grounds, consider the interests and welfare of affected communities [35, 71], but omitting relevant social data makes doing so impossible. Moreover, restoration and conservation prioritization analyses may not properly account for the spatial distribution of various costs [72–74], the extent of feasible land area [69], or important spatial variation in the probability of success [75]. Information on land tenure, local socio-economic conditions, and the priorities of government officials may be important to understanding restoration's true costs in a given locale, or the probability that its intended benefits will materialize [14, 76]. But prioritization studies do not commonly include this information in their analyses.

As we point out above, Strassburg *et al* call attention to several of the issues we discuss, including the large proportion of agricultural land in some countries that is classified as a top 15% restoration priority [21]. They also discuss the need for deeper consideration of equity issues. Our exploration of one of their output maps takes this call further. Incorporating more social data into prioritization analyses will help re-orient those who create such maps towards a broader conceptualization of sustainability [35, 49] and aid in the search for compromise solutions between opponents and supporters of global mapping exercises. Ideally, prioritization analyses should provide opportunities for affected communities to participate in the mapping process, helping these analyses to better consider local knowledge, experiences, and aspirations. Examples include mapping done through the Restoration Opportunities Assessment Methodology [77, 78], as well as a recently developed systems approach to evaluating tree-restoration interventions which incorporates indicators of social and wellbeing outcomes alongside indicators of biodiversity and climate change mitigation [79]. Participatory mapping processes can be further strengthened with land tenure diagnostic tools [80]. Assessing the tradeoffs that restoration may imply under varying governance and land use arrangements should become a more foundational aspect of restoration planning [79].

In conclusion, we underscore the importance of engaging in critical discussions about the goals

of prioritization maps. Recent defenses of restoration mapping move in the right direction by laying out some possible benefits of these exercises more precisely [25]. But there is also a need for more discussion about whether these benefits outweigh the possible consequences of prioritization exercises: first, a risk of concentrating restoration in regions where possible negative livelihood impacts would be the most severe [39, 43, 44, 81, 82]; and second, a risk of crowding-out other strategies for identifying more just and pragmatic policy goals [23] or undermining the ability of local stakeholders to participate in land use decisions [47]. Both consequences point to a need for complementary, bottom-up approaches to setting restoration priorities.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Author contributions

E C, F E, and P K conceived the study. B S led the writing process and conducted the analyses. All authors contributed to writing and the development of our arguments.

Conflict of interest

We have no competing interests to disclose.

ORCID iDs

Bill Schultz  <https://orcid.org/0000-0002-6180-6679>

Eric A Coleman  <https://orcid.org/0000-0002-5315-7111>

Prakash Kashwan  <https://orcid.org/0000-0001-5540-5994>

Rose Pritchard  <https://orcid.org/0000-0002-6174-3460>

References

- [1] Gann G D *et al* 2019 International principles and standards for the practice of ecological restoration *Restor. Ecol.* **27** S1–S46
- [2] Besseau P, Graham S and Christophersen T 2018 *Restoring Forests and Landscapes: The Key to a Sustainable Future* Global Partnership on Forest and Landscape Restoration
- [3] Fagan M E, Reid J L, Holland M B, Drew J G and Zahawi R A 2020 How feasible are global forest restoration commitments? *Conserv. Lett.* **13** e12700

- [4] Aronson J, Goodwin N, Orlando L, Eisenberg C and Cross A T 2020 A world of possibilities: six restoration strategies to support the United Nation's Decade on Ecosystem Restoration *Restor. Ecol.* **28** 730–6
- [5] Meyfroidt P et al 2022 Ten facts about land systems for sustainability *Proc. Natl Acad. Sci.* **119** e2109217118
- [6] Griscom B W et al 2017 Natural climate solutions *Proc. Natl Acad. Sci.* **114** 11645–50
- [7] Lamb D, Erskine P D and Parrotta J A 2005 Restoration of degraded tropical forest landscapes *Science* **310** 1628–32
- [8] Aradottir A L and Hagen D 2013 Ecological restoration: approaches and impacts on vegetation, soils and society *Adv. Agron.* **120** 173–222
- [9] Das S 2017 Ecological restoration and livelihood: contribution of planted mangroves as nursery and habitat for artisanal and commercial fishery *World Dev.* **94** 492–502
- [10] Erbaugh J T, Pradhan N, Adams J, Oldekop J A, Agrawal A, Brockington D, Pritchard R and Chhatre A 2020 Global forest restoration and the importance of prioritizing local communities *Nat. Ecol. Evol.* **4** 1472–6
- [11] Malkamäki A, D'Amato D, Hogarth N J, Kanninen M, Pirard R, Toppinen A and Zhou W 2018 A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide *Glob. Environ. Change* **53** 90–103
- [12] Adams C, Rodrigues S T, Calmon M and Kumar C 2016 Impacts of large-scale forest restoration on socioeconomic status and local livelihoods: what we know and do not know *Biotropica* **48** 731–44
- [13] Coleman E A et al 2021 Limited effects of tree planting on forest canopy cover and rural livelihoods in Northern India *Nat. Sustain.* **4** 1–8
- [14] Fleischman F et al 2020 Pitfalls of tree planting show why we need people-centered natural climate solutions *Bioscience* **70** 947–50
- [15] Holl K D and Brancalion P H S 2020 Tree planting is not a simple solution *Science* **368** 580–1
- [16] Wilson K A, Davis K J, Matzek V and Kragt M E 2019 Concern about threatened species and ecosystem disservices underpin public willingness to pay for ecological restoration *Restor. Ecol.* **27** 513–9
- [17] Shackleton C M, Ruwanza S, Sanni G K S, Bennett S, De Lacy P, Modipa R, Mtati N, Sachikonye M and Thondhlana G 2016 Unpacking Pandora's box: understanding and categorising ecosystem disservices for environmental management and human wellbeing *Ecosystems* **19** 587–600
- [18] Bastin J-F, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner C M and Crowther T W 2019 The global tree restoration potential *Science* **365** 76–79
- [19] Brancalion P H S et al 2019 Global restoration opportunities in tropical rainforest landscapes *Sci. Adv.* **5** eaav3223
- [20] Cook-Patton S C et al 2020 Mapping carbon accumulation potential from global natural forest regrowth *Nature* **585** 545–50
- [21] Strassburg B B N et al 2020 Global priority areas for ecosystem restoration *Nature* **586** 724–9
- [22] Strassburg B B N et al 2019 Strategic approaches to restoring ecosystems can triple conservation gains and halve costs *Nat. Ecol. Evol.* **3** 62–70
- [23] Wyborn C and Evans M C 2021 Conservation needs to break free from global priority mapping *Nat. Ecol. Evol.* **5** 1322–4
- [24] Jung M et al 2021 Areas of global importance for conserving terrestrial biodiversity, carbon and water *Nat. Ecol. Evol.* **5** 1–11
- [25] Chaplin-Kramer R et al 2022 Conservation needs to integrate knowledge across scales *Nat. Ecol. Evol.* **6** 118–9
- [26] Schmidt-Traub G 2021 National climate and biodiversity strategies are hamstrung by a lack of maps *Nat. Ecol. Evol.* **1**–3
- [27] Walker W S et al 2022 The global potential for increased storage of carbon on land *Proc. Natl Acad. Sci.* **119** e2111312119
- [28] Soto-Navarro C et al 2020 Mapping co-benefits for carbon storage and biodiversity to inform conservation policy and action *Phil. Trans. R. Soc. B* **375** 20190128
- [29] Possingham H P, Bode M and Klein C J 2015 Optimal conservation outcomes require both restoration and protection *PLoS Biol.* **13** e1002052
- [30] Dinerstein E et al 2020 A “Global Safety Net” to reverse biodiversity loss and stabilize Earth's climate *Sci. Adv.* **6** eabb2824
- [31] Grainger A et al 2019 Comment on “The global tree restoration potential” *Science* **366** eaay7976
- [32] Veldman J W, Aleman J C, Alvarado S T, Anderson T M, Archibald S, Bond W J 2019 Comment on “The global tree restoration potential” *Science* **366**
- [33] Meyer H and Pebesma E 2022 Machine learning-based global maps of ecological variables and the challenge of assessing them *Nat. Commun.* **13** 1–4
- [34] Kashwan P, Biermann F, Gupta A and Okereke C 2020 Planetary justice: prioritizing the poor in earth system governance *Earth Syst. Gov.* **6** 100075
- [35] Leach M, Reyers B, Bai X, Brondizio E S, Cook C, Díaz S, Espindola G, Scobie M, Stafford-Smith M and Subramanian S M 2018 Equity and sustainability in the anthropocene: a social–ecological systems perspective on their intertwined futures *Glob. Sustain.* **1** 1–13
- [36] Friedman R S, Law E A, Bennett N J, Ives C D, Thorn J P R and Wilson K A H J 2018 How just and just how? A systematic review of social equity in conservation research *Environ. Res. Lett.* **13** 53001
- [37] Pritchard R, Sauls L A, Oldekop J, Kiwango W and Brockington D 2022 Data justice and biodiversity conservation *Conserv. Biol.* **36** 1–10
- [38] Agrawal A and Redford K 2009 Conservation and displacement: an overview *Conserv. Soc.* **7** 1–10
- [39] Gerber J-F 2011 Conflicts over industrial tree plantations in the South: who, how and why? *Glob. Environ. Change* **21** 165–76
- [40] Andersson K, Lawrence D, Zavaleta J and Guariguata M R 2016 More trees, more poverty? The socioeconomic effects of tree plantations in Chile, 2001–2011 *Environ. Manage.* **57** 123–36
- [41] Latawiec A E, Strassburg B B N, Brancalion P H S, Rodrigues R R and Gardner T 2015 Creating space for large-scale restoration in tropical agricultural landscapes *Front. Ecol. Environ.* **13** 211–8
- [42] Melick D, Yang X and Xu J 2006 Seeing the wood for the trees: how conservation policies can place greater pressure on village forests in southwest China *Plant Conservation and Biodiversity* (Berlin: Springer) pp 385–97
- [43] Ramprasad V, Joglekar A and Fleischman F 2020 Plantations and pastoralists: afforestation activities make pastoralists in the Indian Himalaya vulnerable *Ecol. Soc.* **25**
- [44] Henrique K P and Tschakert P 2019 Contested grounds: adaptation to flooding and the politics of (in) visibility in São Paulo's eastern periphery *Geoforum* **104** 181–92
- [45] Sharma P et al 2020 Mapping human–wildlife conflict hotspots in a transboundary landscape, Eastern Himalaya *Glob. Ecol. Conserv.* **24** e01284
- [46] Ghoddousi A, Buchholtz E K, Dietsch A M, Williamson M A, Sharma S, Balkenhol N, Kuemmerle T and Dutta T 2021 Anthropogenic resistance: accounting for human behavior in wildlife connectivity planning *One Earth* **4** 39–48
- [47] McCarthy J and Thatcher J 2019 Visualizing new political ecologies: a critical data studies analysis of the World Bank's renewable energy resource mapping initiative *Geoforum* **102** 242–54
- [48] Kashwan P 2017 Inequality, democracy, and the environment: a cross-national analysis *Ecol. Econ.* **131** 139–51
- [49] Allan J R et al 2022 The minimum land area requiring conservation attention to safeguard biodiversity *Science* **376** 1094–101

- [50] Lindberg S I, Coppedge M, Gerring J and Teorell J 2014 V-Dem: a new way to measure democracy *J. Democr.* **25** 159–69
- [51] Asher S, Lunt T, Matsuura R and Novosad P 2021 Development Research at High Geographic Resolution: an analysis of night-lights, firms, and poverty in India using the SHRUG open data platform *World Bank Econ. Rev.* **35** 845–71
- [52] Ghosh T, L Powell R, D Elvidge C, E Baugh K, C Sutton P and Anderson S 2010 Shedding light on the global distribution of economic activity *Open Geogr. J.* **3** 147–60
- [53] Smith B and Wills S 2018 Left in the dark? Oil and rural poverty *J. Assoc. Environ. Resour. Econ.* **5** 865–904
- [54] Weidmann N B and Schutte S 2017 Using night light emissions for the prediction of local wealth *J. Peace Res.* **54** 125–40
- [55] Mets K D, Armenteras D and Dávalos L M 2017 Spatial autocorrelation reduces model precision and predictive power in deforestation analyses *Ecosphere* **8** e01824
- [56] Nolte C, Agrawal A, Silvius K M and Soares-Filho B S 2013 Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon *Proc. Natl Acad. Sci.* **110** 4956–61
- [57] Ferraro P J, Hanauer M M, Miteva D A, Canavire-Bacarreza G J, Pattanayak S K and Sims K R E 2013 More strictly protected areas are not necessarily more protective: evidence from Bolivia, Costa Rica, Indonesia, and Thailand *Environ. Res. Lett.* **8** 025011
- [58] Zhao H et al 2019 Individual-level performance of nature reserves in forest protection and the effects of management level and establishment age *Biol. Conserv.* **233** 23–30
- [59] Gibson J, Olivia S and Boe-Gibson G 2020 Night lights in economics: sources and uses 1 *J. Econ. Surv.* **34** 955–80
- [60] Keola S, Andersson M and Hall O 2015 Monitoring economic development from space: using nighttime light and land cover data to measure economic growth *World Dev.* **66** 322–34
- [61] Bruederle A and Hodler R 2018 Nighttime lights as a proxy for human development at the local level *PLoS One* **13** e0202231
- [62] Lewis S L, Wheeler C E, Mitchard E T A and Koch A 2019 Restoring natural forests is the best way to remove atmospheric carbon *Nature* **568** 25–28
- [63] Pelletier J, Horning N, Laporte N, Samndong R A and Goetz S 2018 Anticipating social equity impacts in REDD+ policy design: an example from the Democratic Republic of Congo *Land Use Policy* **75** 102–15
- [64] Poudel M, Thwaites R, Race D and Dahal G R 2015 Social equity and livelihood implications of REDD+ in rural communities—a case study from Nepal *Int. J. Commons* **9** 177
- [65] Duchelle A E, De Sassi C, Jagger P, Cromberg M, Larson A M, Sunderlin W D, Atmadja S S, Resosudarmo I A P and Pratama C D 2017 Balancing carrots and sticks in REDD+ implications for social safeguards *Ecol. Soc.* **22**
- [66] Wells H B M, Kirobi E H, Chen C L, Winowiecki L A, Vågen T-G, Ahmad M N, Stringer L C and Dougill A J 2021 Equity in ecosystem restoration *Restor. Ecol.* **29** e13385
- [67] Djenontin I N S, Zulu L C and Etongo D 2020 Ultimately, what is forest landscape restoration in practice? Embodiments in sub-Saharan Africa and implications for future design *Environ. Manage.* **68** 619–41
- [68] Chazdon R L, Cullen J L, Padua S M and Padua C V 2020 People, primates and predators in the Pontal: from endangered species conservation to forest and landscape restoration in Brazil's Atlantic Forest *R. Soc. Open Sci.* **7** 200939
- [69] Gopalakrishna T, Lomax G, Aguirre-Gutiérrez J, Bauman D, Roy P S, Joshi P K and Malhi Y 2022 Existing land uses constrain climate change mitigation potential of forest restoration in India *Conserv. Lett.* **15** e12867
- [70] Scoones I 2022 Livestock, methane, and climate change: the politics of global assessments *Wiley Interdiscip. Rev. Clim. Change* e790
- [71] Pritchard R 2021 Politics, power and planting trees *Nat. Sustain.* **4** 932
- [72] Iacona G D et al 2018 Standardized reporting of the costs of management interventions for biodiversity conservation *Conserv. Biol.* **32** 979–88
- [73] Ifekhar M S, Polyakov M, Ansell D, Gibson F and Kay G M 2017 How economics can further the success of ecological restoration *Conserv. Biol.* **31** 261–8
- [74] Nolte C 2020 High-resolution land value maps reveal underestimation of conservation costs in the United States *Proc. Natl Acad. Sci.* **117** 29577–83
- [75] Wilson K A, Carwardine J and Possingham H P 2009 Setting conservation priorities *Ann. New York Acad. Sci.* **1162** 237–64
- [76] Fleischman F D 2014 Why do foresters plant trees? Testing theories of bureaucratic decision-making in central India *World Dev.* **62** 62–74
- [77] Maginnis S, Laestadius L, Verdone M, DeWitt S, Saint-Laurent C, Rietbergen-McCracken J and Shaw D M 2014 *A guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing forest landscape restoration opportunities at the national or sub-national level: working paper (road test edition)* Int. Union Conserv. Nat.
- [78] Hanson C, Buckingham K, DeWitt S and Laestadius L 2015 *The restoration diagnostic: a method for developing forest landscape restoration strategies by rapidly assessing the status of key success factors* World Resources Institute
- [79] Pfeifer M et al 2021 A systems approach framework for evaluating tree restoration interventions for wellbeing and ecological outcomes in rural tropical landscapes *Phil. Trans. R. Soc. B* (<https://doi.org/10.1098/rstb.2021.0111>)
- [80] McLain R, Lawry S, Guariguata M R and Reed J 2021 Toward a tenure-responsive approach to forest landscape restoration: a proposed tenure diagnostic for assessing restoration opportunities *Land Use Policy* **104** 103748
- [81] McElwee P 2009 Reforesting “bare hills” in Vietnam: social and environmental consequences of the 5 million hectare reforestation program *Ambio* **38** 325–33
- [82] Andersson K P, Gibson C C and Lehoucq F 2006 Municipal politics and forest governance: comparative analysis of decentralization in Bolivia and Guatemala *World Dev.* **34** 576–95
- [83] Einhorn C 2020 Restoring farmland could drastically slow extinctions, fight climate change (The New York Times) (available at: www.nytimes.com/2020/10/14/climate/biodiversity-farmland-extinction.html)