Voluntary, permanent land protection reduces forest loss and development in a rural-urban landscape

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Voluntary, permanent land protection reduces forest loss and development in a rural-urban landscape

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Abstract

Voluntary, permanent land protection is a key conservation process in many countries. Concerns with the effectiveness of such decentralized processes exist due to the potential for 1) selection bias, i.e., the protection of parcels whose land cover would have been conserved in the absence of protection, and 2) local spillover effects, i.e., protection increasing the likelihood that adjacent parcels lose land cover due to additional conversion. We examine the validity of both concerns using a quasi-experimental approach and a dataset of 220,187 parcels and 26 years of protection and land-cover change in Massachusetts. We find that land acquisitions and conservation restrictions implemented by state, local, and non-governmental actors reduced forest loss and conversion to developed uses without increasing either type of land-cover change on adjacent parcels. Our results suggest that voluntary, permanent land protection can make significant contributions in protecting land cover in landscapes dominated by private ownership.

Introduction

The voluntary, permanent protection of land by multiple, decentralized actors is an important conservation process in many parts of the world. Over the past two decades, willing private landowners have transferred ownership or partial rights to millions of hectares of land to governments and conservation non-governmental organizations (NGOs), often in response to financial incentives (Parker & Thurman 2018). Here we consider such transactions “voluntary” if landowners have the option to not give up their land rights, and “permanent”, if the transaction does not oblige recipients to return the land rights in the future. Significant volumes of voluntary, permanent land protection (VPLP) transactions are occurring in Australia, Brazil, Canada, Chile, Colombia, Denmark, Finland, and the United States, and individual deals have been reported from at least 20 tropical countries (Nolte 2018). With rising global pressures on ecosystems, climate-induced species migrations, and growing societal discomfort with compulsory approaches to protection, the importance of VPLP is likely to increase.

In spite of the substantial growth in VPLP transactions, their actual effectiveness is rarely the subject of rigorous scholarly scrutiny. Empirical studies have examined different aspects of VPLP, including preferences of landowners (e.g., Knight et al. 2011; Bastian et al. 2017), spatial patterns of protection (e.g., Meyer et al. 2014), or effects of tax incentives (e.g., Parker & Thurman 2018). However, few ex-post analyses quantify the difference that VPLP have made for conservation outcomes. This contrast with a rapidly growing empirical literature on impacts of other conservation strategies, including 1) compulsory approaches, e.g., protected areas (see Oldekop et al. 2016 for a recent review) and regulatory zoning / enforcement (e.g., Wu & Cho 2007; Sims & Schuetz 2009; Börner et al. 2015; Nolte et al. 2017), 2) voluntary, non-permanent protection, such as payments for environmental services (PES) (see Börner et al. 2017 for a recent review) and alternative income generation strategies (e.g., Weber et al. 2011), 3) approaches that grant or clarify land rights, such as indigenous lands (e.g., Nolte et al. 2013; Blackman et al. 2017) or improvements in land-tenure security (Robinson et al. 2017), as well as 4) supply-chain interventions (see Lambin et al. 2018 for a recent review).

Whether VPLP transactions make a difference for conservation is not a trivial question. Observed conditions on protected lands are not a good proxy for impact for two reasons: First, impact is the difference between observed outcomes in the presence of an intervention and outcomes that would have occurred in its absence (Ferraro 2009). Protecting a property under low pressure will usually result in lower impact than protecting a similar property under higher pressure; it will also, on average, generate lower opportunity costs and thus be cheaper or less controversial. The coincidence of both has created a pervasive global bias in the allocation of stricter conservation towards low-pressure locations (Joppa & Pfaff 2009), which has been shown to lower the true effectiveness of parks, PES, and other voluntary, non-permanent conservation interventions (Ferraro et al. 2011; Mason & Plantinga 2013; Börner et al. 2017). This problem is likely to be even more pronounced when all transactions are voluntary, yet few empirical studies have accounted for possible bias in estimating the effectiveness of VPLP.

Second, any conservation intervention that focuses on a subset of properties has the potential to affect outcomes on properties that were not subject to it. Such spillover effects, also termed leakage or slippage, can manifest through diverse channels and across different scales (Wu 2000; Alix-Garcia et al. 2012; Atmadja & Verchot 2012; le Polain de Waroux et al. 2017). Long-distance spillovers of environmental policies are commonly studied using economic models (Sohngen et al. 1999; Wu & Plantinga 2003; Searchinger et al. 2008), whereas local spillovers can be investigated directly using spatial data (e.g. Wu 2000; Sims & Schuetz 2009; Alix-Garcia et al. 2012). In the context of VPLP, local spillovers are of concern as they can undermine the provision of spatially dependent ecosystem services (e.g., contiguous scenic landscapes or connected habitats). Empirical work has shown that protection increases sales value of adjacent properties (Reeves et al. 2018), and some scholars argue that this phenomenon can undermine the cost-effectiveness of future protection efforts (Armsworth et al. 2006). Furthermore, if increased property values increased the likelihood of habitat loss, this could attenuate the net impacts of protection. Using data from three U.S. counties and a regression framework, McDonald et al. (2007) find proximity to protected areas to be associated with higher rates of development in two counties, but not the third. In a study of one U.S. county, Zipp et al. (2017) find protected open space to reallocate parcel subdivision within a small neighborhood, which reduces the net impacts of protection. These initial findings suggest a need for more large-scale empirical studies to identify where and under which conditions local spillovers occur.

Here we investigate the validity of both concerns in a setting spanning rural to urban land uses with a high incidence of VPLP. Our study area, Massachusetts, is an exemplar of the private land conservation movement in the United States, with 120 active land trusts (Land Trust Alliance 2016), substantial direct public funding ($53 million annually, 1998-2011) (The Trust for Public Land 2017), and tax incentives for charitable land donations. As with much of New England, Massachusetts experienced two centuries of deforestation, followed by 150 years of forest regrowth, and, since the 1980s, a slow but continuous loss of forest cover, mostly due to low-density development (Olofsson et al. 2016). VPLP occurs for diverse reasons, including species conservation, local recreation, the preservation of cultural landscapes, and, more recently, the maintenance of carbon stocks. It can involve full acquisition by NGOs or public actors or the transfer of partial rights (known as “conservation restrictions” in Massachusetts, and “conservation easements” elsewhere in the U.S). Using a rich parcel dataset from the entire state, we estimate whether protection helped slow down forest loss and development. We find that most types of protection significantly reduced land-cover change on protected parcels, without leading to an increase of land-cover change on adjacent, unprotected parcels. Our results suggest that VPLP can play an important role in protecting conservation values along rural-urban gradients in high-income countries.

Methods

Data

We use spatial boundaries of parcels from the public MassGIS system (Commonwealth of Massachusetts 2018). MassGIS aggregates parcel layers from 351 towns, 66% of which reflect recent conditions (2017 or 2018), while some date back to 2010. We include in our analysis all 220,187 parcels in the state with an area of no less than 1 ha (2.47 ac). The threshold ensures that parcels contain sufficient units of land-cover observations (pixels) to reliably observe change at 30m resolution. To ensure this size threshold does not affect results, we supplement the parcel-based analysis with a pixel-based analysis (see below).

All protection data – including spatial boundaries, years of protection, conservation actors (local, state, non-governmental), and instruments (full acquisition or conservation restriction) – come from a database maintained by the Harvard Forest and the Highstead Foundation, which aggregates multiple public sources and supplements them with information from private land trusts, and was last updated in 2018.

Land-cover change estimates are derived from a dataset developed by Oloffson et al. (2016), which uses Landsat time series and a spectral break detection algorithm to map annual changes in 12 land-cover categories across New England from 1985 to 2012 at 30m spatial resolution. For each parcel, we extract annual % forest cover (deciduous, coniferous, and mixed) and % developed land (commercial, high-density, and low-density). Oloffson et al.'s data is known to underestimate conversion of forests to low-density development, but this underestimation is not known to be spatially biased (P. Oloffson, personal communication, 2018). We therefore consider the data suitable for quantifying impacts in relative terms (observed outcomes as % of estimated pressure), but caution against interpreting rates of avoided land-cover change in absolute terms.

We assume that probabilities of protection and land-cover change are influenced by a parcel's potential returns from alternate uses, which in turn is a function of its physical properties (e.g., terrain, proximity to water), accessibility, and socio-economic setting (Irwin & Bockstael 2004). To control for key differences that might affect both protection and land-cover change, we compute a range of covariates for each parcel (discussed below and in Table 1). More details on data sources are provided in the Supporting Information.

Impact Estimation

We use quasi-experimental pre-matching followed by regression analysis to estimate the impact of voluntary, permanent protection of private lands on the loss of forest cover and undeveloped land. Ideally, matching emulates an experimental setup from observational data by identifying control groups of untreated (unprotected) parcels that, at the time of treatment, were as similar as possible to treated (protected) parcels in terms of observable confounders. By capturing key differences in terrain, water, accessibility, demographics, parcel size, and nearby protection (Table 1), we control for several well-known sources of selection bias that are of common concern in impact evaluations of conservation interventions. We minimize these differences with the use of pre-matching and then control for them explicitly using regression analysis. Because matching does not allow us to control for unobserved sources of bias (e.g., individual landowner preferences or scenic appeal), we conduct sensitivity checks to assess the vulnerability of our findings to the potential presence of unobserved confounders (see Supporting Information).

We conduct two distinct analyses. First, we measure the impact of protection on the loss of forest and undeveloped land within protected parcels (hereafter, “impact analysis”). Our treatment group consists of parcels that experienced an increase in protection coverage of > 80% between 1985 and 2006 (n=6,676, 1,120 km^2). We include only parcels protected before 2006 in order to have a reasonably long time period for the observation of post-protection outcomes. Our pool of potential controls includes all parcels that remained “unprotected” until the present (defined as having < 20% of their area protected, n=182,982, 9,527 km^2).

Second, we measure the impact of protection on the loss of forest and undeveloped land on nearby parcels (hereinafter, “spillover analysis”). Our treatment group consists of all unprotected parcels that experienced an increase in protection of at least 1% within a given radius (default: 200m) between 1985 and 2006 (n=29,296, 1,965 km^2), in which case the year of the greatest increase was defined as the treatment year. Our pool of potential controls includes all unprotected parcels that did not experience such an increase in nearby protection (n=144,332, 6,940 km^2). Because neighboring parcels are frequently contiguous, we conduct matching of 25% samples with 20 repetitions to reduce the likelihood of spatial autocorrelation. We present average results in the figures, and their distribution in the Supporting Information.

We measure outcomes as the average annual change in the land cover of interest (forest or undeveloped, as percentage of parcel area). For each treatment-control pair, the time period over which land-cover change is observed begins in the year in which the treatment parcel was protected (spillover analysis) or three years after (impact analysis), and ends in 2012, the last year for which land-cover data is available. The three-year offset in the impact analysis is added to reduce the influence of a small number of parcels with large land-cover losses that co-occurred with protection. We observe such losses in the case of conservation restrictions held by local governments and placed on parcels with new subdivisions and golf courses, which imply that protection was created specifically to accompany planned development. As our data does not allow us to separate such planned development restrictions from those we aim to study here (direct acquisitions or donations independent of development), we use an offset and implement a several alternative robustness checks (Supporting Information).

To account for possible selection bias, we use Mahalanobis nearest neighbor covariate matching (one neighbor, with replacement), and post-matching linear regressions. Regressions predict annual observed land-cover change as a function of all covariates and a continuous treatment variable (impact analysis: % of parcel protected, spillover analysis: % increase in protection within given radius). All observations are weighted by parcel area. To explore how threats and impacts vary as a function of location, we split matched samples at the 33% and 67% quantiles for each covariate and estimate impacts for each subgroup separately. Our default setting uses calipers of 1 standard deviation, which retains 70-75% of treated parcels (59-66% of area) in the impact analyses and 72-75% (62-67% of area) in the spillover analyses, respectively, dropping the remainder because of the absence of comparable controls.

Our default analyses are based on parcels, as they constitute the key decision unit in private land protection. However, state-wide parcel boundaries were only available for post-treatment time periods (2010-18). Because we include parcel area in both sample definition and matching, protected parcels are less likely to be matched correctly to controls that might have originally been the same size and were subsequently sub-divided and developed. For this reason, the use of post-treatment parcel boundaries might lead to an underestimation of impact. We therefore supplement parcel-based analyses with corresponding pixel-based analyses that are not vulnerable to this type of bias.

We also conduct extensive robustness checks with alternative model specifications (see Supporting Information).

Results

Across all model runs, we find protected parcels to have significantly lower levels of forest loss and development than they would have experienced in the absence of protection (Figure 2). Our main results suggest that protection avoided about half of forest loss (-55% ± 30.8%) and about four fifths of development (-83% ± 27%).

Differences in impact are mostly driven by differences in pressure levels along rural-urban and income gradients rather than by differences in observed outcomes on protected parcels. For instance, protected parcels in high-income locations and parcels close to cities were exposed to significantly higher levels of development pressure (0.063 ± 0.015 and 0.078 ± 0.020 % loss / year, respectively) than parcels in low-income locations and parcels further away from cities (0.006 ± 0.009 and 0.008 ± 0.008, respectively). In contrast, the observed rates of development are remarkably similar (Figure 3).

We find significant impacts for both protection instruments (fee or conservation restrictions) and conservation actors (local, state, or NGO), but not for all combinations (Figure 4). For instance, impact of conservation restrictions on forest loss are only significant at the 10% level (p=0.08), and weak for local (p=0.80) and NGO-held restrictions (p=0.87). Not all subgroup impact estimates are robust (see Supporting Information).

Unprotected parcels that experienced an increase in nearby protection between 1985-2006 did not exhibit higher levels of forest loss or development than their pressure estimate (Figure 2). Sizes of estimated spillover effects are near zero for forest loss (p=0.50); for development, they point in the opposite direction (p=0.14). We did not find significant spillover effects (at the $\leq$ 0.05 level) for any locations along the rural-urban gradient (Figure 3). Our robustness checks confirm that spillovers of protection are either positive or absent (see Supporting Information).

Discussion

Our results suggest that voluntary, permanent land protection reduced forest loss and development in Massachusetts between 1985 and 2012. We find significant and robust evidence of reductions in both types of land-cover change on protected parcels. In addition, we find no evidence that protection increased nearby land-cover change. Taken together, these findings suggest that voluntary, permanent land protection delivered tangible conservation results in Massachusetts.

On average, percentage reductions in land-cover change were higher for development than for forest loss. This is consistent with expectations. In Massachusetts, most VPLP transactions extinguish development rights, while forest conversion is not always regulated by conservation restrictions and might even be desired to improve conservation outcomes (e.g., through the creation of early successional habitat). We also note that absolute land-cover change on protected parcels in Massachusetts varies very little as a function of pressure. Protection thus appears to deliver consistently low loss of land-cover change along the state's rural-urban gradients – which differs notably from findings from other world regions: in the Brazilian Amazon, for instance, forest loss inside protected areas has been found to be much higher where counterfactual pressure is high (e.g., Nolte et al. 2013b), likely as a result of imperfect enforcement (Robinson et al. 2010).

Our findings have at least two important policy implications. First, we show that differences in the impact of VPLP transactions in Massachusetts are largely driven by differences in pressure, not by differences in observed outcomes. This finding illustrates the caveats of relying on observed outcomes as estimates of "success" and underscores the need for a rigorous quantification of pressure. Data and methods now exist to develop counterfactual pressure estimates at decision-relevant spatial scales (parcels). If combined with empirically grounded and spatially disaggregated data on conservation costs (Armsworth 2014), such estimates can help conservation decision makers target investments to where they are likely to generate the highest conservation returns (Newburn et al. 2006). Their systematic inclusion in the allocation and evaluation of conservation interventions could enhance the targeting of a range of VPLP occurring in Massachusetts today, such as forest-based carbon credits, natural resources damage compensation programs, direct public land acquisitions, and environmental philanthropy.

Second, previous concerns about negative local spillover effects of protection may require greater scrutiny. Our evidence suggests that spillover effects are largely negligible, and, if they exist, more likely positive than negative. A possible explanation for this phenomenon might be that protection increases informal, voluntary conservation by surrounding landowners. However, our finding contrasts with those of earlier studies in the U.S., which find protection to generate negative local spillovers in other locations in the U.S. (McDonald et al. 2007; Zipp et al. 2017). We also do not include in our analysis possible long-range spillovers effects that tend to be more difficult to identify empirically. More exploration of the possible mechanisms that drive positive spillovers is thus an important area of future empirical research.

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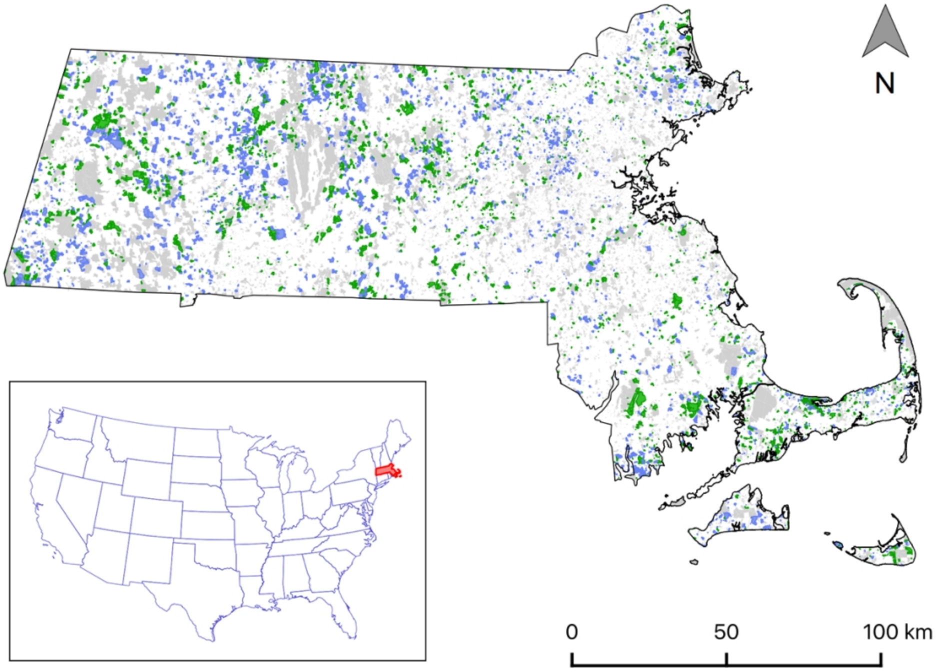

Figure 1: Protection of land between 1985 and 2006 in Massachusetts in the form of fee title acquisitions (green) and conservation restrictions (blue). Grey areas were protected either before 1985 or after 2006 and thus excluded from the analysis. Inset shows the location of Massachusetts within the U.S.

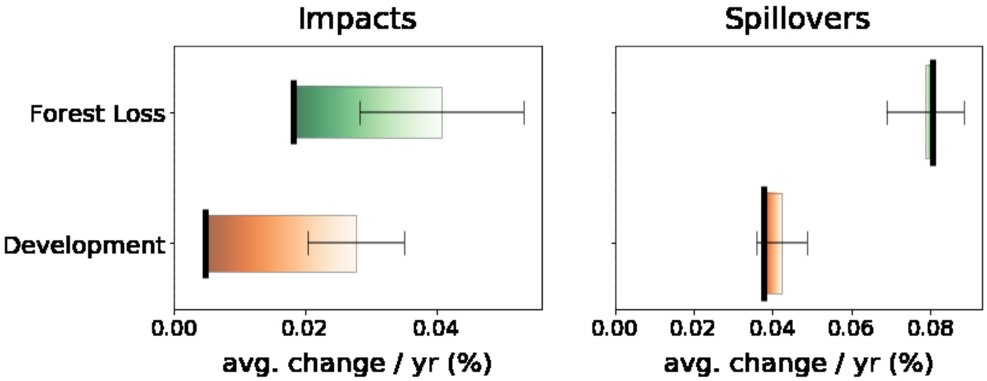

Figure 2: Estimated effects of voluntary, permanent land protection in Massachusetts (1985-2006) on forest loss and development (1985-2012) on protected ("Impacts") and nearby parcels ("Spillovers"). In this figure and all following, 1) all values refer to average annual land-cover change (as percentage of parcel area), 2) magnitudes of estimated effects are represented by rectangle widths, with bold black lines indicating predicted rates of land-cover change on treated parcels, the opposite end indicating predicted rates of land-cover change in the absence of treatment (counterfactual), and shading added to indicate direction of effect, 3) error bars indicate 95% confidence intervals around the effect estimate, 4) bar height is proportional to the total area of parcels in the matched treatment group; bar area is therefore proportional to total area of avoided (or increased) land cover change.

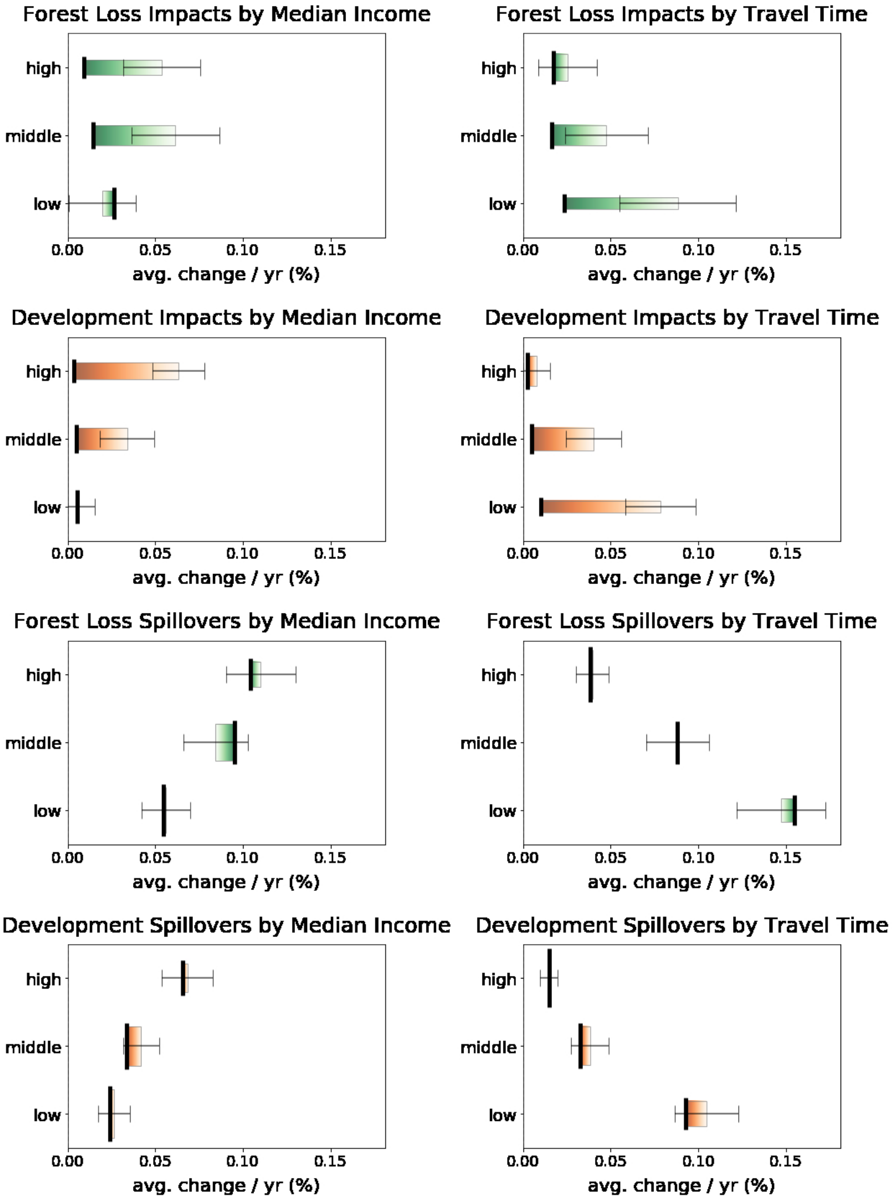

Figure 3: Estimated effects for selected subgroups of protected parcels. Subgroups are formed by splitting matched treatment groups at the 33% and 67% quantiles for the respective covariate. Legend as in Figure 2.

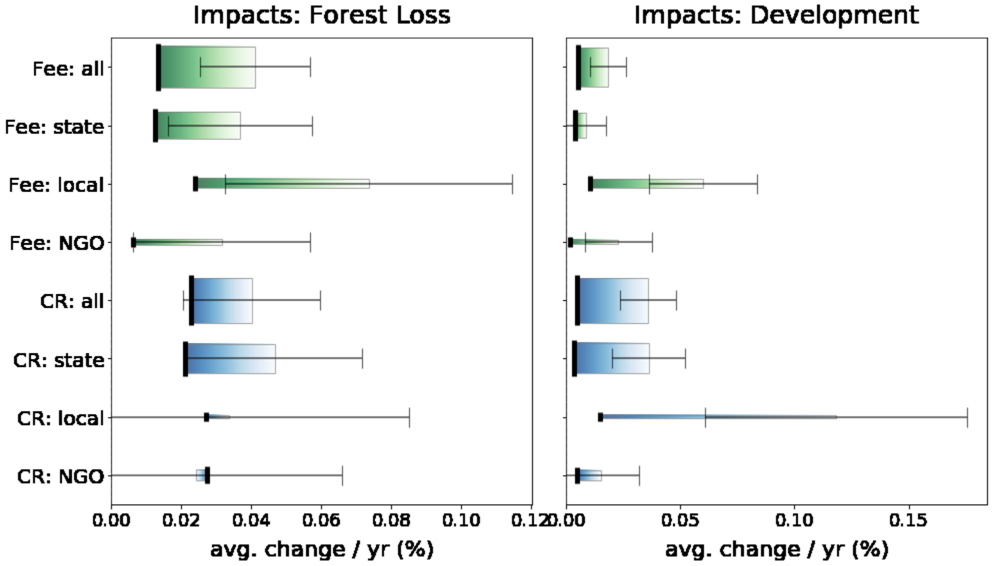

Figure 4: Estimated effects for protected parcels held in fee (green) or as conservation restrictions (CR, blue), for all actors and disaggregated by actors (state, local, and non-governmental). Legend as in Figure 2

Table 1: Covariates used in matching, with justification. IHS: inverse hyperbolic sine transformation. Data source and further details can be found in the Supporting Information and Table S1.
** variables that can be considered time-invariant within the study period,*
*** time-variant variable for which no earlier data source was available.*

Covariate	Unit	Year	Justification for Selection
Slope	degree	2017*	Key driver of agricultural potential and suitability for development
Wetland coverage	% of parcel area	2018*	Creates both physical and legal obstacles to conversion
Proximity to coastal waters	% ocean area within 2.5km radius	2009*	Increases attractiveness to development and thus the cost of protection
River and lake frontage	meters (IHS)	2017*	Increases attractiveness to development and thus the cost of protection
Travel time to major cities	minutes (IHS)	2007*	Key driver of accessibility to markets, workplaces, and amenities
Median income, (block group)	USD	1990	Affects local development pressure and land prices
Population density (block group)	km^{-2} (IHS)	1990	Affects local development pressure
Parcel size	hectares (log)	2010-2018**	Affects economies of scale and transaction costs of protection
Coverage of land cover of interest	% of parcel area	Year of protection (1985-2006)	Caps the quantity of forest or undeveloped land that can be lost
Nearby protection	% protected area within given radius (default: 200m)	Year of protection (1985-2006)	Accounts for local spillover effects, which can be positive or negative