What influences the effectiveness of forest conservation interventions in tropical regions?

A systematic review

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Contents

Acknowledgement **v**

Executive summary **vi**

1 Introduction **1**

2 Paper selection and data extraction **3**

3 Synthesis of findings **5**
3.1 Main characteristics of the selected papers 5
3.2 Factors influencing the effectiveness of forest conservation interventions 6

4 Final remarks **14**

References **15**

Appendices **20**
Appendix A. Eligibility criteria 20
Appendix B. Boolean search string 21
Appendix C. List of the reviewed papers (N=47) 22
Appendix D. Geographic distribution of the reviewed papers by continent and region 25
Appendix E. Type of the interventions evaluated by the reviewed papers 26

List of boxes, figures and tables

Figure

1 Flow diagram to guide article selection 3
2 Main characteristics of the selected papers 5

Table

1 The influence of design and implementation factors on the effectiveness of forest conservation interventions 7
2 The influence of context factors on the effectiveness of forest conservation interventions 9

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Executive summary

Recent decades have witnessed a proliferation of policies and programmes to conserve forests in tropical countries based on a large and heterogeneous set of interventions. Their impact evaluations most frequently report statistically significant but still modest conservation results. Therefore, how to increase the effectiveness of interventions is an important empirical question.

The first generation of impact evaluations focused on estimating the average effects of conservation interventions. This was essential knowledge for inferring additionality and thus understanding *whether* and *by how much* interventions reduced forest loss compared to a counterfactual scenario. However, average estimations may mask substantial variation in treatment, thus preventing the generating of information on *where*, *how*, and *under what conditions* forest interventions may achieve better results.

After calls for taking impact evaluations to the next level, an emerging literature is implementing heterogeneity analysis. This provides robust evidence about the influence of different factors on the effectiveness of forest conservation interventions. Synthesizing and bringing such knowledge to policymakers is essential to guide the design and implementation of more effective forest interventions.

In this article, we present the first systematic review of the counterfactual-based studies exploring the heterogeneous effects of forest conservation interventions implemented across the tropics. Our goal was to synthesize current knowledge on how the level of effectiveness of forest interventions varies according to the design and implementation options that create heterogeneous treatments, as well as the characteristics from the context that moderate treatment effects.

We focused on English-language, peer-reviewed literature from two comprehensive, multidisciplinary, and expertly curated scientific databases (i.e., Scopus and Web of Science Core Collection). The review was restricted to scientific papers based on robust methods for causal inference (i.e., randomized controlled trials and quasi-experimental methods), and that also explore impact heterogeneity.

After screening 1,486 studies, we selected 47 papers conducting robust heterogeneity analysis, which revealed an emerging trend in the literature. Most papers were focused on understanding the role of context characteristics in the effectiveness of forest conservation interventions. In particular, they investigated whether effectiveness varied according to the threats faced by forests at the specific locations, measured using a diversity of indicators.

Based on our review, we found interventions generally achieve greater conservation results where forests are under higher deforestation pressure or risk. Therefore, if policymakers and practitioners want to optimize the use of public budgets for conservation, it would make more sense to prioritize the protection of forests under higher pressure. This apparent *trivial* recommendation is, however, hard to implement in practice, as these areas also generally attract development investments.

As the number of heterogenous assessments is limited, it is still difficult to draw other valid lessons about how and under what conditions interventions may be more effective. We thus renew the calls for more rigorous evaluations of forest conservation interventions that go beyond estimating average effects.

1 Introduction

Curbing tropical deforestation has moved to centre stage in the international climate agenda, and it is one of the main missions of the REDD+ mechanism (Pistorius 2012). Accordingly, recent decades have witnessed a proliferation of policies and programmes aimed at conserving forests in tropical countries (Chervier et al. 2022). These policies and programmes are based on a large and heterogeneous set of interventions, typically categorized into disincentives, incentives, and enabling measures (Börner and Vosti 2012). Despite the efforts, deforestation has persisted, and 17% of tropical moist forests disappeared between 1990 and 2019 (Vancutsem et al. 2021). This scenario could indicate, at first sight, that forest conservation interventions are failing to address causes of deforestation effectively and hence to prevent forest loss.

However, to make plausible conclusions about the effectiveness of forest conservation interventions, we need to focus on rigorous impact evaluations (Ferraro and Pattanayak 2006). These evaluations allow attributing the observed outcomes to an intervention by constructing a valid counterfactual – i.e., what would have happened in the absence of the intervention (White 2009). The conservation field still falls behind most other policy fields, such as health, education, and social protection, in terms of assessing the effectiveness of its interventions (Cameron et al. 2016). Yet, after many calls for robust assessments (e.g., Sutherland 2005; Ferraro and Pattanayak 2006; Pattanayak et al. 2010), the number of studies using counterfactual-based methods to evaluate conservation interventions increased significantly during the last two decades.

So, what do we know about the effectiveness of forest conservation interventions? Most of the counterfactual studies are case-based evaluations (e.g., Sims 2010; Alix-Garcia et al. 2012; Bauch et al. 2014; Ruggiero et al. 2019; Carrilho et al. 2022; Cisneros et al. 2022; Liu et al. 2022). Syntheses of their findings indicate forest interventions usually work better than no intervention at all (Börner et al. 2016, 2020). In other words, studies most commonly report statistically significant results in preventing forest loss but with moderate effect sizes (Börner et al. 2020).

The limited average success of the forest conservation interventions clearly suggests room for improvement. Besides indicating whether interventions worked, impact evaluations should generate knowledge on ways to improve them (Miteva et al. 2012). Yet, the first generation of impact evaluations focused on estimating the average effects of conservation interventions. This knowledge is indeed essential for inferring additionality and thus understanding *whether* and *by how much* interventions reduced forest loss as compared to a counterfactual scenario. However, average estimations may mask substantial variation in treatment effects (Sills and Jones 2018). This prevents the generating of information on *where*, *how*, and *under what conditions* forest interventions may achieve better results.

The magnitude of the impact of forest conservation interventions may vary for several reasons. First, and more obvious, the set of forest conservation interventions is heterogenous. Each intervention is expected to operate differently and, consequently, promote different levels of outcomes. For instance, evidence indicates that payment for environmental services (PES) has higher impacts than other intervention types (e.g., Protected Areas – PAs, Integrated Conservation and Development Projects – ICDPs), although the differences are small (Wunder et al. 2020). The type and the combination of the applied intervention should thus at least partially explain the level of success.

Second, the design and implementation of an intervention could vary substantially across locations. For instance, PAs may be designed with different degrees of land-use restrictions, varying from prohibiting most human uses (strictly protected) to allowing multiple uses (Dudley 2008). Furthermore, implementation can vary significantly according to, for example, the type of implementor, budget size, and the adopted management strategies (Nolte and Agrawal 2013; Herrera et al. 2019). Similarly, PES programmes may take different forms. For example, they can be implemented through individual or collective payments, in the form of cash or in-kind payments, for reducing activities (e.g., lowering forest conversion) or building environmental assets (e.g., planting trees) (Wunder 2005; Wunder et al. 2020). They can offer only conditional payments or combine them with non-conditional support to sustainable livelihood alternatives (e.g., technical assistance, free inputs). Differences in the design and implementation of the interventions are expected to create heterogeneous treatments, which, in turn, should cause heterogeneous outcomes.

Finally, the context for interventions will also shape outcomes. Several contextual factors may act as moderators of outcomes. By definition, moderators are exogenous factors unaffected by the interventions, but whose values influence the magnitude of the interventions' impact (Sills and Jones, 2018). This implies the same interventions may produce different levels of effectiveness across locations depending on the moderating factors to which they are exposed. Some factors may derive from local governance and institutional conditions. For instance, PES programmes operate better where property rights are well-defined (Wunder 2008). In those cases, implementors may invest in preparation phases to create adequate governance and institutional preconditions conducive to performance. Other moderating factors may be inherent to the locations and thus more difficult (or impossible) to be changed (e.g., biophysical and social context). Even so, understanding how these factors influence the effectiveness of forest policies and programmes is instrumental to prioritize intervention targeting (i.e., where it should be implemented).

After calls for taking impact evaluations to the next level (e.g., Miteva et al. 2012), there is an emerging literature implementing heterogeneity analysis. This is providing robust evidence about the influence of different factors on the effectiveness of forest conservation interventions (e.g., Alix-Garcia et al. 2012; Nolte and Agrawal 2013; Chervier and Costedoat 2017; Herrera et al. 2019; Delacote et al. 2022). To date, syntheses of impacts have pointed to global tendencies (e.g., Börner et al. 2016, 2020), but they have failed to capture the link between heterogeneous effects and the factors shaping outcomes. Synthesizing and bringing such knowledge to policymakers is essential to guide the design and implementation of more effective forest interventions.

In this article, we systematically reviewed scientific publications to assess the heterogeneous effects of forest conservation interventions implemented across the tropics using experimental or quasi-experimental methods. Our goal was to synthesize current knowledge on how the level of effectiveness of forest interventions varies according to: 1) the design and implementation options that create heterogeneous treatments; 2) the characteristics from the context acting as moderators of treatment effects.

The remainder of the paper is organized as follows: Section 2 presents the methodological strategies for study selection and data extraction; Section 3 reports our results, starting with the main characteristics of the selected papers, followed by the synthesis of the identified factors influencing the effectiveness of forest conservation interventions; and Section 4 provides concluding remarks.

2 Paper selection and data extraction

We restricted our review to the scientific papers that are based on robust methods for causal inference, i.e., randomized controlled trials and quasi-experimental methods, and that also explore impact heterogeneity. The studies included in our review could cover single or multiple interventions from one or more locations in tropical developing countries. The outcome variable had to be related to forest cover.

Aligned with Börner et al. (2020), we adopted a multiple-intervention approach. This means we considered any type of intervention aiming to conserve forests, which could include disincentives, incentives, and enabling measures. From a decision-making perspective, our goal is to contribute to the design of evidence-based forest policies and programmes. We thus exclude from our analysis any intervention not directly pursuing forest conservation goals, even if they might indirectly affect forest cover (e.g., conditional cash transfers to reduce poverty, delimitation of indigenous lands). The full eligibility criteria for paper selection are in Appendix A.

We used a Boolean search string on two comprehensive, multidisciplinary, and expertly curated scientific databases, i.e., Scopus and Web of Science Core Collection (WoS) (Appendix B). To test the comprehensiveness of the search string, we compared the search result with a test list of 10 papers previously identified as eligible for the review. This list originated from the authors' experience with the specialized literature, which included previous non-systematic searches. All 10 papers were found in both Scopus and WoS search results.

The searches occurred on the same day (18/07/2023), restricting the results to the papers published between 2000 and 2023. A total of 1,486 papers were found: 1,122 in Scopus, 682 in WoS, and 318 in both databases. The first author conducted two screening stages to assess articles' eligibility, evaluating (i) title and abstract and (ii) full text, as described in Figure 2. To ensure consistency and accuracy of inclusion/exclusion decisions, the second author assessed the eligibility of a randomly selected sample of 10% of the articles (N=149). The inclusion/exclusion decisions were then compared, showing a 99% rate of agreement: authors decided differently about only one article, and this disagreement was solved after discussion.

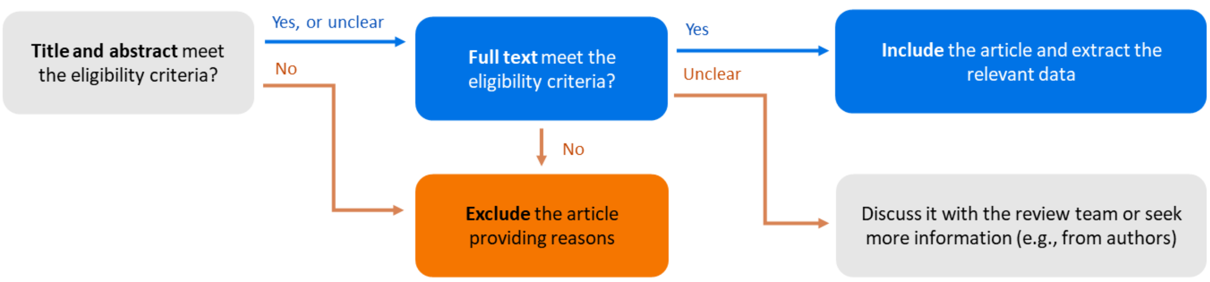

Figure 1. Flow diagram to guide article selection

The application of the screening stages resulted in the selection of 47 papers for data extraction (Appendix C). Three global analyses were included, although they cover other regions besides tropical developing countries. From each selected paper, we extracted information regarding the location, the type of evaluated interventions, the adopted outcome variable, and the evaluation methods employed for estimating average and heterogeneous treatment effects.

More importantly, we identified and registered the factors analysed by the authors that were potentially influencing the effectiveness of the forest conservation interventions. We then categorized their influence on effectiveness based on four broad categories: (i) positive (statistically significant) contribution to forest conservation; (ii) neutral (no significant effect); (iii) negative (statistically significant) contribution to forest conservation; and (iv) mixed results. We chose this broad categorization approach to standardize and compare the different types of results from the multiple methodological approaches adopted in the studies.

3 Synthesis of findings

3.1 Main characteristics of the selected papers

The 47 papers selected for data extraction analysed heterogeneous effects of forest conservation interventions implemented in different countries (Figure 2, item “a”, and Appendix D). Brazil was the country with the most assessments (N=11). PA is by far the most evaluated intervention type, accounting for ~72% of the papers (N=34), followed by PES (~ 17%, N=8) (Figure 2, item “b”, and Appendix E). This aligns with the results of a previous review showing PA and PES represent most forest conservation interventions with counterfactual-based evaluations (Börner et al. 2020).

The papers investigated the influence of different factors on the effectiveness of forest conservation interventions. Following our main goal, we classified the factors according to two broad categories: 1) design and implementation factors that created heterogeneous treatments; and 2) characteristics from the context acting as moderators of treatment effects (Figure 2, item “c”). Most papers analysed only the influence of context characteristics (~45%, N=21).

We identified three main types of methods in the analyses. In most papers (~72%%, N=34), authors calculated treatment effects in different subgroups with different levels of exposure to the factor of interest. For instance, using a combination of matching and regression techniques, Blackman (2015) estimated avoided deforestation effects among land parcels with two different land-use regimes (multiple use vs. strict protection) inside the same PA (the Maya Biosphere Reserve, in Guatemala). The author then tested whether the differences between treatment effects from the two groups were statistically significant, concluding that the multiple-use land regime avoided more deforestation than strict protection.

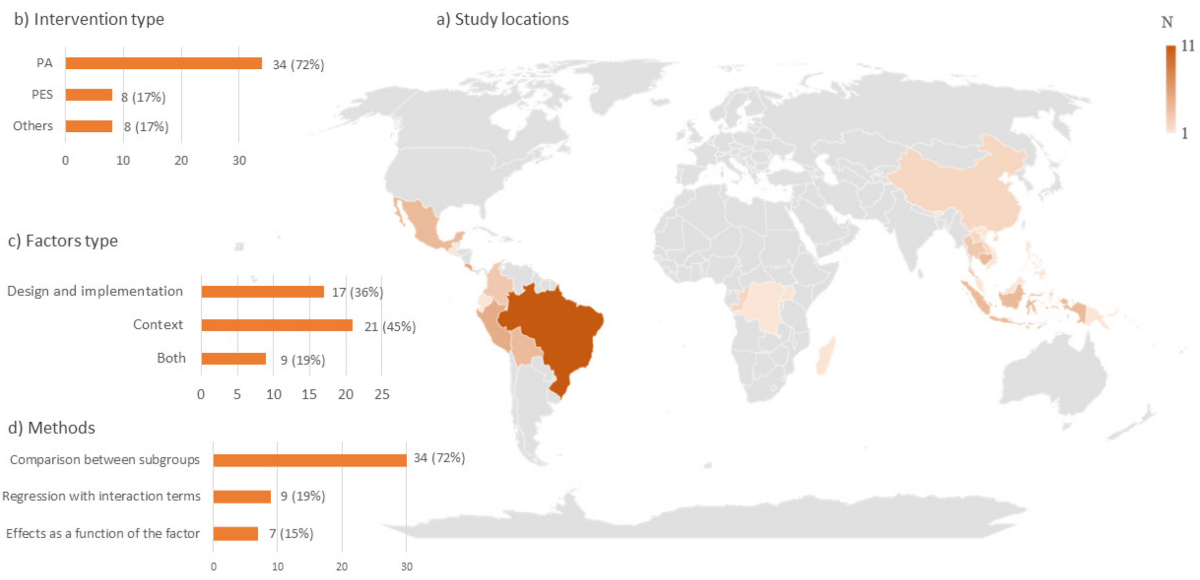

Figure 2. Main characteristics of the selected papers

Note: This figure shows: a) the geographic distribution of the reviewed articles by continent and region (global studies were not included in the map); b) the type of forest conservation interventions analysed by the studies; c) the type of the investigated factors influencing the effectiveness of the interventions; d) the methods authors used in the heterogenous analyses.

Source: Australian Bureau of Statistics, GeoNames, Geospatial Data Edit, Microsoft, Navindo, Open Places, OpenStreetMap, TomTom, Wikipedia, Zenrin, Da Platforma, Bing.

In the second type of method most employed in the heterogeneous analyses, the authors investigated how the factor of interest was influencing treatment effects. To that end, in regression models, they used an interaction term between the treatment and the presence of the factor (~19%, N=9). For example, Alix-Garcia et al. (2012) first employed a matching approach to estimate the effects of a Mexican PES programme on deforestation. Second, to understand how the programme impacts varied according to poverty levels, remoteness from roads, and the type of property (common vs. private), they ran post-matching Tobit regression using interaction terms between the treatment (i.e., PES) and those contextual variables. This allowed authors to compare the effects of the treatment alone with the effects of the treatment interacting with the variables of interest (e.g. PES x common properties).

Finally, in ~15% of the papers (N=7), authors examined treatment effects as a function of the factor of interest. Chervier and Costedoat (2017), for example, first combined matching techniques with difference-in-difference estimation to assess the effects on deforestation of a collective PES programme implemented in Cambodia. They then used Partial Linear Model to express treatment effects as a non-parametric function of different moderators (i.e., slope, road accessibility, and population size). This means they calculated treatment effects conditioned on these respective moderators, which allowed them to observe, for instance, how avoided deforestation varied according to the properties' distance to roads.

3.2 Factors influencing the effectiveness of forest conservation interventions

Tables 1 and 2 summarize the main results extracted from the 47 reviewed articles regarding how different factors influenced the effectiveness of forest conservation interventions. First, the factors were classified according to the two aforementioned categories: 1) design and implementation factors that created heterogeneous treatments (Table 1); 2) characteristics from the context acting as moderators of treatment effects (Table 2). Second, each category holds subcategories characterizing the factors that influenced forest conservation effects. The tables are organized according to those factors identified in the reviewed articles. Therefore, if the article investigated the influence of multiple factors, the same article appears in more than one subcategory.

As explained in Section 2, we classified influence of the factors on forest conservation, as extracted from the reviewed papers, based on four broad categories. Appendix F presents the same results tables but with an additional column that provides more details on the heterogeneous effect found in each reviewed article.

3.2.1 Design and implementation factors (heterogenous treatments)

Starting with design and implementation, most studies investigated which PA type achieves better forest conservation results ("multiple use" or "strict protection") (Table 1, factor "a"). This is indeed a relevant empirical question. On the one hand, strict protection PAs could be more effective given that, by definition, they prohibit more (potentially damaging) human uses than multiple-use options (Locke and Dearden 2005). On the other hand, stricter restrictions might be harder to comply with, requiring more challenging institutional monitoring and enforcement capacities (Dudley 2008). Moreover, the literature on common pool resources indicates that permitting more uses and involving the communities in the management strategies could work better than relying on top-down decisions (Hayes and Ostrom 2005). Considering that PAs are the most popular conservation tool in the developing world, and they cover ~17% of Earth's land (Bingham et al. 2021), it is important to understand which combination of land-use restrictions may be more effective to conserve forests.

Table 1. The influence of design and implementation factors on the effectiveness of forest conservation interventions

Design and implementation	Influence on the effectiveness of conserving forests			
	Positive	**Neutral**	**Negative**	**Mixed results**
1.1 Management style				
a. Multiple-use vs. strict protection PA	Nelson and Chomitz (2011), Pfaff et al. (2014), Blackman (2015), Miranda et al. (2016), Sims and Alix-Garcia (2017), Pacheco and Meyer (2022), Soares-Filho et al. (2023)	Andam et al. (2013), Bruggeman et al. (2018), Koskimäki et al. (2021)	Pfaff et al. (2015b), Bonilla-Mejía and Higuera-Mendieta (2019), Kukkonen and Tammi (2019), Shah et al. (2021), Yang et al. (2021)	Ferraro et al. (2013)
b. Higher management capacity	Graham et al. (2021), Powlen et al. (2021), Soares-Filho et al. (2023)	Nolte and Agrawal (2013), Bruggeman et al. (2018)		
c. Imposing land-use restrictions	Holland et al. (2017)			
1.2 Type of implementor				
d. National vs. lower-level agencies	Herrera et al. (2019), Zhao et al. (2019)			
1.3 Intervention duration				
e. Older interventions	Miranda et al. (2016), Bruggeman et al. (2018), Tritsch et al. (2020)	Zhao et al. (2019)	Robalino et al. (2021), Black and Anthony (2022)	
1.4 Size of the intervention area				
f. Larger sizes	Liévano-Latorre et al. (2021)			

However, the available evidence in this regard seems to be inconclusive, as previously observed (e.g., Elleason et al. 2021). While several evaluations showed multiple-use areas were more effective (e.g., Nelson and Chomitz 2011; Blackman 2015; Pacheco and Meyer 2022), others found the opposite (e.g., Pfaff et al. 2015b; Bonilla-Mejía and Higuera-Mendieta 2019; Kukkonen and Tammi 2019). Still others detected no significant differences (e.g., Andam et al. 2013; Bruggeman et al. 2018). Importantly, for at least part of the evaluations that did find significant differences, other factors besides the differences in land-use restrictions might explain the results. For instance, Pfaff et al. (2014) stress that, in the Acre state of the Brazilian Amazon, multiple-use PAs were in sites that faced higher deforestation threats, which allowed them to avoid more deforestation than integral protection areas. In another evaluation, this time in Laos, authors showed that only the strictest protection areas were effective. However, they also admitted that governance problems could explain the ineffectiveness of multiple-use areas rather than the more flexible permissions in forest use (Kukkonen and Tammi 2019).

Regardless of the type of imposed land-use restrictions, some studies also provide evidence on the link between PA effectiveness and the level of management capacity of enforcement authorities. Indeed, implementers must guarantee PAs will receive proper investments and management capacity to avoid creating “paper parks” – i.e., a legally established but then neglected area, with no sufficient conditions to halt environmental degradation (Eyre 1990). Five studies tested the contribution of management capacity on PA effectiveness using different indicators (Table 1, factor “b”). For example, Powlen et al. (2021) found that Mexican PAs with high scores for management effectiveness had greater conservation effects than those showing low scores. In Brazil, PAs receiving support from the Amazon Protected Areas Program (ARPA) were more effective than no-supported PAs (Soares-Filho et al. 2023). Yet, in Bhutan, PAs with management plans did not perform significantly better than the rest of them (Bruggeman et al. 2018). Two studies found that national PAs, which authors assume to receive more resources and have higher management capacities, achieved better results than those implemented by local agencies, both in Brazil (Herrera et al. 2019) and China (Zhao et al. 2019) (Table 1, factor "d").

Two studies showed older PAs performed better in the Peruvian Amazon (Miranda et al. 2016), and Bhutan (Bruggeman et al. 2018) (Table 1, factor "e"). Authors argue that long-established PAs may have had more time to identify challenges and develop solutions (Miranda et al. 2016). Yet, in southwest China, no significant differences were detected between the effects of older and newer PAs (Zhao et al. 2019). Moreover, new PAs were more effective than old PAs in Cambodia. Interestingly, authors also showed effects decrease over time in both groups but more sharply in new PAs (Black and Anthony 2022). A PES assessment showed contracts signed later had greater effects than contracts signed earlier in Costa Rica (Robalino et al. 2021). The authors seem to believe the reason lies in the improvement of the implementer's environmental criteria to select participants, which implies the influence of the intervention 'age' on the effectiveness can be context-dependent. In the Congo basin, Tritsch et al. (2020) found that Forest Management Plans approved over a longer period were more effective than newer plans.

Only one study assessed the potential influence of the intervention area size on overall effectiveness. We might assume that protecting larger continuous areas is better since they would be less susceptible to edge effects and habitat loss due to fragmentation (Broadbent et al. 2008). Liévano-Latorre et al. (2021) showed that while the Colombian PA network had no overall impact in avoiding deforestation, they did find significant impacts after isolating the larger areas in the analysis (Table 1, factor "f"). Finally, in Ecuador, a 'forest-friendly' titling programme reduced deforestation only where the title came tied with land-use restrictions (Table 1, factor "c").

3.2.2 Context characteristics (moderators of treatment effects)

Deforestation risk

With respect to context characteristics, most papers investigated whether the effectiveness of forest interventions varied according to how threatened forests were at the specific locations. Forest conservation interventions are not usually randomly placed: they tend to be implemented in remote areas that are less suitable for agriculture, where opportunity costs are low (Joppa and Pfaff 2009; Delacote et al. 2022). In areas where the risk of deforestation and forest degradation is low, all things being equal, interventions are likely to produce minimal additional contributions to forest conservation. Likewise, in areas of low enforcement capacity (which is often the case across the tropical world) and high pressure for converting forests, forest conservation interventions might also be ineffective. To understand these interactions, researchers used different proxies accounting for deforestation pressure, including baseline or background deforestation rates, biophysical indicators of the land suitability for agriculture (e.g., slope, soil quality), proximity to deforestation drivers (e.g., cities, roads), demographic variables (population size), and economic indicators (e.g., agriculture income).

Starting with the baseline/background deforestation rates, the evidence gathered here consistently shows larger conservation effects in areas exposed to high deforestation levels (Table 2, item 2.1). This was observed in assessments of a PES-like programme in Brazil (Cisneros et al. 2022), REDD+ projects from several locations (Guizar-Coutiño et al. 2022), Forest Management Plans in Congo (Tritsch et al.2020), as well as of PAs in Brazil (Pfaff et al. 2015a, 2015b), China (Yang et al. 2019), and across the globe (Yang et al. 2021). Similarly, a Brazilian initiative to limit deforestation from soy producers was more effective in properties with less forest cover than the minimum required by the Forest Code

Table 2. The influence of context factors on the effectiveness of forest conservation interventions

Context	Influence on the effectiveness of conserving forests			
	Positive	**Neutral**	**Negative**	**Mixed results**
2.1 Baseline/background outcomes				
a. Higher forest loss	Pfaff et al. (2015a, 2015b), Jayachandran et al. (2017), Jung and Polasky (2018), Yang et al. (2019, 2021), Tritsch et al. (2020), Cisneros et al. (2022), Guizar-Coutiño et al. (2022)			
b. Tree cover	Jayachandran et al. (2017)			
2.2 Biophysical (indicators for agricultural suitability)				
c. Flat lands vs. steeper slope areas	Ferraro and Hanauer (2011), Ferraro et al. (2011), Joppa and Pfaff (2011), Hanauer and Canavire-Bacarreza (2015), Chervier and Costedoat (2017), Yang et al. (2019, 2021)		Santika et al. (2017)	
d. High-quality soils	Yang et al. (2021)			
e. High rainfalls			Santika et al. (2017)	
f. High suitability for agriculture	Ferraro and Hanauer (2011)			
2.3 Location				
g. Proximity to cities or settlements	Ferraro and Hanauer (2011), Joppa and Pfaff (2011), Nelson and Chomitz (2011), Pfaff et al. (2014, 2015a), Hanauer and Canavire-Bacarreza (2015), Santika et al. (2017), Bonilla-Mejía and Higuera-Mendieta (2019), Tritsch et al. (2020), Yang et al. (2019, 2021)			Ferraro et al. (2011)
h. Proximity to roads	Pfaff et al. (2014), Pfaff et al. (2015a), Chervier and Costedoat (2017), Higuera-Mendieta (2019), Tritsch et al. (2020)	Alix-Garcia et al. (2012)		
i. Remoteness from markets		Cisneros et al. (2022)		
2.4 Demographic				
j. Greater population size			Chervier and Costedoat (2017)	
2.4 Socioeconomic				
k. Low poverty levels	Alix-Garcia et al. (2012)	Ferraro and Hanauer (2011), Ferraro et al. (2011)		

continued on next page

Table 2. Continued

Context	Influence on the effectiveness of conserving forests			
	Positive	**Neutral**	**Negative**	**Mixed results**
l. Higher agriculture income	Cisneros et al. (2022)t			
m. Higher income from timber products	Jayachandran et al. (2017)			
n. Higher presence of agricultural workers	Ferraro and Hanauer (2011)			
o. Small vs. large properties	L'Roe et al. (2016), Jung and Polasky (2018)			
2.5 Governance				
p. Interaction with other conservation policies	L'Roe et al. (2016), Montoya-Zumaeta et al. (2019), Heilmayr et al. (2020)	Montoya-Zumaeta et al. (2022)	Robalino et al. (2015), Sims and Alix-Garcia, (2017)	
q. Interaction with economic land concessions				Black and Anthony (2022)
r. Interaction with decentralization policies (not directly related with forest management)				Miteva and Pattanayak (2021)
s. Implementation in older municipalities	Bonilla-Mejía and Higuera-Mendieta (2019)			
t. Implementation in less violent contexts	Bonilla-Mejía and Higuera-Mendieta (2019)			
u. Higher community engagement	Wright et al. (2016)			
v. Common or public vs. private properties		Alix-Garcia et al. (2012), Yang et al. (2021)		Miteva et al. (2019)
w. Small vs. large properties	L'Roe et al. (2016), Jung and Polasky (2018)			

(Jung and Polasky 2018). In Uganda, PES effects were higher for farmers who had recently cut more trees but also for those with more tree cover at the baseline (Jayachandran et al. 2017).

Likewise, when looking to biophysical indicators, the papers reviewed most commonly found that forest interventions achieved higher effects in areas more suitable for agriculture and, therefore, where deforestation pressure was allegedly higher (Table 2, item 2.2). Slope was the biophysical indicator with most assessments. Overall, conservation effects were larger in flatter lands compared to steep slope areas. This was observed in participant properties of a Cambodian PES programme (Chervier and Costedoat 2017), and in several PA assessments, covering Costa Rica and Thailand (Ferraro and Hanauer 2011; Ferraro et al. 2011), Bolivia (Hanauer and Canavire-Bacarreza 2015), and China (Yang et al. 2019), besides global evaluations (Joppa and Pfaff 2011; Yang et al. 2021).

Three papers analysed heterogeneous effects using other biophysical indicators. Ferraro and Hanauer (2011) adopted a measure of the land's suitability for agriculture considering together, besides slope, other indicators such as soil quality and precipitation. The authors showed that protected land parcels in Costa Rica with high land suitability for agriculture displayed significantly higher levels of avoided deforestation. Similarly, Yang et al. (2021) detected higher conservation effects in PAs with high soil carbon stocks (a soil fertility indicator) in a global assessment. However, unlike the previous papers, Santika et al. (2017) find the community forest management scheme in Indonesia performed worse in areas with high agricultural values (lowland areas with high rainfalls).

The interaction between the potential for agriculture within the target areas and the effects of the conservation interventions was again confirmed when economic indicators were used. Ferraro et al. (2011) showed that, among Costa Rica's PAs, avoided deforestation achieved the highest effects where there was a higher percentage of agricultural workers (the adopted indicator for agricultural activity) (Table 2, factor "l"). Likewise, larger effects of a Brazilian PES-like programme were observed in areas with high levels of agricultural income (Table 2, factor "n") (Cisneros et al. 2022). In Uganda, larger PES effects were detected where the income from timber products was higher at the baseline. Although not an agriculture indicator, it is still a potential indication of higher deforestation pressure (Table 2, factor "m") (Jayachandran et al. 2017).

Furthermore, the reviewed studies indicate that effectiveness is generally larger in more accessible areas. More specifically, higher effects were observed in areas closer to cities, roads, or settlements than in remote locations (Table 2, item 2.3). Remoteness contributed to worse performance, for instance, of PAs in several locations (e.g., Ferraro and Hanauer 2011; Joppa and Pfaff 2011; Nelson and Chomitz 2011; Hanauer and Canavire-Bacarreza 2015; Pfaff et al. 2015a; Bonilla-Mejía and Higuera-Mendieta 2019), and logging concessions with Forest Management Plans in the Congo basin (Tritsch et al. 2020).

However, two papers showed there might be more complex, non-linear relationships between local effectiveness and proximity to cities and roads. When accessing the heterogeneous effects of a Cambodian PES programme, Chervier and Costedoat (2017) indeed found smaller effects in remote areas. However, the highest values for avoided deforestation were observed in the intermediate locations (around 200 minutes to roads), not in the closest-to-roads areas. Similarly, Ferraro et al. (2011) detected the highest avoided deforestation effects of Costa Rica's PA in the intermediate distances to the major city (~50 km), while the lowest values were observed in the most remote areas. Living relatively far from cities increases transportation costs, but it may also mean farmers are further removed from enforcement actions against the violation of environmental conservation rules; this may encourage them to convert forests (Ferraro et al. 2011). In other words, at least in some locations, the deforestation pressure may be higher in areas with intermediate values of accessibility. Yet, when assessing Thailand PA effects, Ferraro et al. (2011) found different results: higher avoided deforestation effects were observed in both the farthest and the closest distances to major cities, whereas the intermediate distances presented the lowest effects. As most papers effectuated binary comparisons (e.g., high vs. low accessibility levels), such non-linear interactions may be hidden in the reported results.

Chervier and Costedoat (2017) also observed nonlinearity in the relationship between PES effects in Cambodia and the communities' population size (Table 2, item 2.4). The maximum avoided deforestation effect was detected for the intermediate population size (~50 households): in both more and less densely populated communities, the effects tended to decrease. As the authors pointed out, since the programme offered equal collective payments, payments per head were possibly insufficient to trigger behavioural change where there were too many households. In the most sparsely populated communities, forests would perhaps remain relatively safe even if the programme had not taken place. However, this was the only heterogeneous assessment using a demographic explanatory variable. This impairs extracting broad lessons about how the effects may vary according to the population characteristics.

Socioeconomic characteristics

It is difficult to draw general conclusions about how poverty levels influence the effectiveness of forest conservation interventions, due to limited available evidence (Table 2, factor “k”). In Mexico, PES effectiveness was higher where the municipal poverty was classified as low to medium (Alix-Garcia et al. 2012). However, two assessments using different methods found no significant influence of baseline poverty levels on PA effectiveness in Costa Rica. Ferraro and Hanauer (2011) compared avoided deforestation effects between two subgroups, with high and low levels of baseline poverty. Although the point estimates were higher on the land parcels that fell into high levels of baseline poverty, the difference between the subgroups was statistically insignificant. In turn, using a non-parametric LOESS model to estimate effects as a function of baseline poverty, Ferraro et al. (2011) found no clear relationship between baseline poverty and avoided deforestation: avoided deforestation was relatively constant along most of the baseline poverty range.

Closely related to the question of poverty, two papers in Brazil indicate the size of target properties (small vs. large landowners) may influence conservation results (Table 2, factor “v”). Jung and Polasky (2018) showed the impacts of an initiative to limit deforestation from soy producers were stronger in small properties compared to large ones. Similarly, CAR only avoided deforestation among “smallholders” (i.e., 100–300 ha) according to L’Roe et al. (2016). Yet, as authors alerted, the explanation seems to derive from concurrent policies that affect properties of different sizes unequally.

Interaction with other policies and governance characteristics

Another theme covered in the literature reviewed was the influence of other policies and governance characteristics on the effectiveness of forest conservation interventions (Table 2, item 2.5). Regarding the interaction with other conservation policies, the reviewed papers presented mixed results (Table 2, factor “o”). From six assessments, three papers found positive interactions that contributed to enhancing conservation results. L’Roe et al. (2016) showed the Brazilian Environmental Registry for Rural Properties (“CAR” in the Portuguese acronym) avoided more deforestation when implemented together with a land titling programme in which compliance with environmental regulations helped obtain the title. Again in Brazil, the Amazon Soy Moratorium was effective in curbing deforestation only when combined with CAR and forest monitoring (Heilmayr et al. 2020). Likewise, a Peruvian PES-ICDP mixed approach amplified the conservation effects of a municipal PA (Montoya-Zumaeta et al. 2019). However, still in Peru, no significant effects of a REDD+ project were detected, not even when interacting with law enforcement (Montoya-Zumaeta et al. 2022). Moreover, two papers showed potentially negative interactions between concurrent conservation policies. In Costa Rica, PES and PA implemented separately achieved higher aggregated effects than when combined, which indicates a relationship of substitution between the interventions (Robalino et al. 2015). Similarly, in Mexico, PES and PA performed better overall alone than together (Sims and Alix-Garcia 2017).

Two papers assessed the influence of policies other than conservation (Table 2, factors “p” and “q”). Miteva and Pattanayak (2021) investigated the influence of decentralization policies at the district level (not directly related with forest management) on PA effectiveness in Indonesia. The authors found the impacts varied according to the adopted indicator: direct elections contributed to avoiding deforestation in PAs, while district splitting increased forest fragmentation inside PAs. District head change had non-significant forest impacts. In turn, Black and Anthony (2022) assessed the interactions between PA effects and economic land concessions in Cambodia. They showed PAs with concessions for agro-industrial activities had reduced conservation effects in comparison to non-concession PAs. Yet, this result was obtained only in one of the three evaluated time periods: non-significant differences were detected in the others.

Notably, two other papers showed the results of forest conservation interventions may be influenced by broader governance characteristics (Table 2, factors “r” to “t”). Bonilla-Mejía and Higuera-Mendieta (2019) found the Colombian national PAs avoided more deforestation in older and less violent municipalities. The authors assumed these attributes correlated with better municipal governance. Moreover, the findings of Wright et al. (2016) indicated that policies of decentralization of forest governance conserved more forest in Bolivia where the community was more engaged.

Finally, three papers investigated the role of property rights in shaping the effectiveness of conservation interventions (Table 2, factor “u”). Overall, the evidence is insufficient to state whether the effectiveness will be most likely greater in one type of tenure regime over the other. The type of property (common vs. private) did not significantly influence the effectiveness of PES in Mexico (Alix-Garcia et al. 2012), or of PAs (public vs. private) according to a global assessment (Yang et al., 2021). In the Yucatan Peninsula of Mexico, the impacts of PAs in common areas (*ejidos*) relative to private property seem to vary slightly according to the type of forest (dry or moist): dry broadleaf forests in ejidos had a 3% lower probability of being lost than in observationally similar private properties, while moist broadleaf forests had the same deforestation probability (Miteva et al. 2019).

4 Final remarks

We presented the first systematic review of the counterfactual-based studies exploring the factors influencing the level of effectiveness of forest conservation interventions. Our review confirms an emerging literature examining the heterogenous effects of forest conservation interventions. This provides important information about *how* and *under what conditions* forest interventions can contribute to reduce tropical deforestation.

As the only relatively consistent result in our review, effectiveness of forest conservation interventions is larger when forests are under higher deforestation pressure or risk, measured using a diversity of indicators. If policymakers and practitioners want to optimize the use of public budgets for conservation, it would thus make more sense to prioritize the protection of forests under higher pressure. This *trivial* recommendation is, however, hard to implement in practice, as these areas are generally also attracting development investments.

For all the other factors considered, especially those related to design and implementation characteristics, our review identified divergent results that cannot be generalized. This is partly due to the limited number of studies assessing some factors included in our review. All in all, a larger number of rigorous studies on the influence of context on the effectiveness of forest interventions would be needed to generate other valid lessons. This result might also be linked to the complex way different context characteristics interact and influence the effectiveness of forest conservation intervention, and the methodological difficulty to isolate the effect of a single factor. Finally, PA is by far the type of intervention targeted by the greatest number of heterogeneity analysis. The evidence base for PES and other intervention types is much weaker and results are even less generalizable. Again, this calls for more heterogeneity analysis that targets other types of forest interventions.

Our review also suggests the type of method used to assess heterogeneity might influence results. Specifically, methods that assess the level of effectiveness as a function of values taken by the contextual variable can detect more complex context-effectiveness relationships than methods based on a simple comparison between different subgroups with different levels of exposure to the factor of interest. The use of these methods should be prioritized whenever possible, particularly when a larger sample of observation units is available.

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Appendices

Appendix A. Eligibility criteria

To be included in our review, studies must have met the following criteria.

1. Study design
    - Included: Counterfactual-based studies that present a credible estimation of the effects of forest conservation interventions, and then explore the factors shaping the effects. By factor, we mean: i) design and implementation choices influencing the treatment, and ii) contextual characteristics acting as moderators of outcomes. Studies must have employed randomized controlled trials or quasi-experimental designs using methods for removing biases due to non-random assignment.
    - Excluded: Qualitative methods, before-after designs without a control group, before-after-control-impact studies that did not employ appropriate methods for removing biases due to non-random assignment, and any kind of evaluation that is not investigating moderators, or design and implementation choices shaping outcomes.
2. Type of interventions
    - Included: Policy, programme, or project aiming to conserve forests, regardless of the type of interventions applied, which can include disincentives, incentives, and enabling measures. Interventions can be implemented singly or in different combinations, by any institution, whether public, private, or non-governmental organization.
    - Excluded: Policy, programme, or project pursuing goals other than conserving forests, even if they might indirectly affect forest cover (e.g., conditional cash transfers to reduce poverty). Hypothetical forest conservation interventions (e.g., in Framed Field Experiments).
3. Outcomes
    - Included: Outcome variables must be related to forest cover, encompassing: i) forest cover per se, ii) deforestation, iii) reforestation, iv) forest fragmentation, and v) the occurrence of forest fires.
    - Excluded: Social and economic outcomes, and environmental outcomes not directly related to forest cover (e.g., species richness, carbon stocks).
4. Locations
    - Included: Tropical forests in developing countries, which englobes parts of Central and South America, Africa, India, Asia, and New Guinea. It includes any type of forest surrounding the Equator, and between the Tropic of Cancer and the Tropic of Capricorn inside any low- or middle-income country as per the World Bank classification (https://data.worldbank.org/).
    - Excluded: Forests from other parts of the globe (Europe, North America, Australia).
5. Publication type
    - Included: Scientific articles written in English and published in peer-reviewed journals.
    - Excluded: Articles in languages other than English, books, book chapters, conference papers, proceedings papers, editorials, letters, reports, and working papers. Please note: while these publication types were not included in the systematic review, some were used as references in the text of this paper.

Appendix B. Boolean search string

1. **Scopus** (data of access: 18/07/2023)
   - Initial search string:
     TITLE-ABS-KEY (*forest* OR "tree cover*") AND TITLE-ABS-KEY (impact* OR effectiveness OR heterogen*) AND TITLE-ABS-KEY (conserv* OR protect*) AND ALL ("random* control* trial*" OR "random* trial*" OR rct OR matching OR "propensity score" OR psm OR "regression discontinuity design" OR rdd OR did OR "difference-in-difference*" OR "difference in difference*" OR "synthetic control" OR scm OR "instrumental variable*" OR counterfactual OR "quasi-experiment*" OR "quasiexperiment*")

     Initial results: 1,350.

     <u>Filters applied:</u>
     a. Time period: 2000–2023.
     b. Source Type: Journal.
     c. Document type: Article, Review, Letter, Note.
     d. Language: English.
     e. Subjected area: to exclude « Medicine ».

   - Final search string (after filters):
     TITLE-ABS-KEY (*forest* OR "tree cover*") AND TITLE-ABS-KEY (impact* OR effectiveness OR heterogen*) AND TITLE-ABS-KEY (conserv* OR protect*) AND ALL ("random* control* trial*" OR "random* trial*" OR rct OR matching OR "propensity score" OR psm OR "regression discontinuity design" OR rdd OR did OR "difference-in-difference*" OR "difference in difference*" OR "synthetic control" OR scm OR "instrumental variable*" OR counterfactual OR "quasi-experiment*" OR "quasiexperiment*") AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "le") OR LIMIT-TO (DOCTYPE , "no")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (SUBJAREA , "MEDI"))

     <u>Results: 1,122.</u>

2. **Web of Science Core Collection** (data of access: 18/07/2023)
   - Search string:
     TS= (*forest* OR "tree cover*") AND TS= (impact* OR effectiveness OR heterogen*) AND TS= (conserv* OR protect*) AND ALL= ("random* control* trial*" OR "random* trial*" OR rct OR matching OR "propensity score" OR psm OR "regression discontinuity design" OR rdd OR "difference-in-difference*" OR "difference in difference*" OR "synthetic control" OR scm OR "instrumental variable*" OR counterfactual OR "quasi-experiment*" OR "quasiexperiment*")

     Initial results: 711.

     <u>Filters applied</u>:
     a. Time period: 2000–2023
     b. Type of document: Article, article review.
     c. Language: English.

     <u>Results: 682.</u>

Appendix C. List of the reviewed papers (N=47)

Alix-Garcia JM, Shapiro EN, Sims KRE. 2012. Forest conservation and slippage: Evidence from Mexico's National Payments for Ecosystem Services Program. *Land Economics* 88(4):613–638. https://doi.org/10.3368/le.88.4.613

Andam KS, Ferraro PJ, Hanauer MM. 2013. The effects of protected area systems on ecosystem restoration: A quasi-experimental design to estimate the impact of Costa Rica's protected area system on forest regrowth. *Conservation Letters* 6(5):317–323. https://doi.org/10.1111/conl.12004

Black B, Anthony, BP. 2022. Counterfactual assessment of protected area avoided deforestation in Cambodia: Trends in effectiveness, spillover effects and the influence of establishment date. *Global Ecology and Conservation* 38:e02228. https://doi.org/10.1016/j.gecco.2022.e02228

Blackman A. 2015. Strict versus mixed-use protected areas: Guatemala's Maya Biosphere Reserve. *Ecological Economics* 112:14–24. https://doi.org/10.1016/j.ecolecon.2015.01.009

Bonilla-Mejía L, Higuera-Mendieta I. 2019. Protected areas under weak institutions: Evidence from Colombia. *World Development* 122:585–596. https://doi.org/10.1016/j.worlddev.2019.06.019

Bruggeman D, Meyfroidt P, Lambin EF. 2018. Impact of land-use zoning for forest protection and production on forest cover changes in Bhutan. *Applied Geography* 96:153–165. https://doi.org/10.1016/j.apgeog.2018.04.011

Chervier C, Costedoat S. 2017. Heterogeneous impact of a collective payment for environmental services scheme on reducing deforestation in Cambodia. *World Development* 98:148–159. https://doi.org/10.1016/j.worlddev.2017.04.014

Cisneros E, Börner J, Pagiola S, Wunder S. 2022. Impacts of conservation incentives in protected areas: The case of Bolsa Floresta, Brazil. *Journal of Environmental Economics and Management* 111:102572. https://doi.org/10.1016/j.jeem.2021.102572

Ferraro PJ, Pattanayak SK. 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *Plos Biology* 4:0482–0488. https://doi.org/10.1371/journal.pbio.0040105

Ferraro PJ, Hanauer MM. 2011. Protecting ecosystems and alleviating poverty with parks and reserves: "Win-win" or tradeoffs? *Environmental Resource Economics* 48:269–286. https://doi.org/10.1007/s10640-010-9408-z

Ferraro PJ, Hanauer MM, Sims KRE. 2011. Conditions associated with protected area success in conservation and poverty reduction. *In* Proceedings of the National Academy of Sciences of the United States of America. 108:13913–13918. https://doi.org/10.1073/pnas.1011529108

Graham V, Geldmann J, Adams VM, Negret PJ, Sinovas P, Chang, HC. 2021. Southeast Asian protected areas are effective in conserving forest cover and forest carbon stocks compared to unprotected areas. *Scientific Reports* 11:1–12. https://doi.org/10.1038/s41598-021-03188-w

Guizar-Coutiño A, Jones JPG, Balmford A, Carmenta R, Coomes DA. 2022. A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conservation Biology* 36:1–13. https://doi.org/10.1111/cobi.13970

Hanauer MM, Canavire-Bacarreza G. 2015. Implications of heterogeneous impacts of protected areas on deforestation and poverty. *Philosophical Transactions of the Royal Society B. Biological Sciences* 370. https://doi.org/10.1098/rstb.2014.0272

Heilmayr R, Rausch LL, Munger J, Gibbs HK. 2020. Brazil's Amazon soy moratorium reduced deforestation. *Nature Food* 1:801–810. https://doi.org/10.1038/s43016-020-00194-5

Herrera D, Pfaff A, Robalino J. 2019. Impacts of protected areas vary with the level of government: Comparing avoided deforestation across agencies in the Brazilian Amazon. *In* Proceedings of the National Academy of Sciences of the United States of America. 116:14916–14925. https://doi.org/10.1073/pnas.1802877116

Holland MB, Jones KW, Naughton-Treves L, Freire JL, Morales M, Suárez L. 2017. Titling land to conserve forests: The case of Cuyabeno Reserve in Ecuador. *Global Environmental Change* 44: 27–38. https://doi.org/10.1016/j.gloenvcha.2017.02.004

Jayachandran S, Laat J. De, Lambin EF, Stanton CY, Audy R, Thomas NE. 2017. Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation. *Science* 357(6348): 267–273. https://doi.org/10.1126/science.aan0568

Joppa LN, Pfaff A. 2011. Global protected area impacts. *In* Proceedings of the Royal Society B Biological Sciences 278:1633–1638. https://doi.org/10.1098/rspb.2010.1713

Jung S, Polasky S. 2018. Partnerships to prevent deforestation in the Amazon. *Journal of Environmental Economics and Management* 92:498–516. https://doi.org/10.1016/j.jeem.2018.11.001

Koskimäki T, Eklund J, Moulatlet GM, Tuomisto H. 2021. Impact of individual protected areas on deforestation and carbon emissions in Acre, Brazil. *Environmental Conservation* 48: 217–224. https://doi.org/10.1017/S0376892921000229

Kukkonen MO, Tammi I. 2019. Systematic reassessment of Laos' protected area network. *Biological Conservation* 229:142–151. https://doi.org/10.1016/j.biocon.2018.11.012

L'Roe J, Rausch L, Munger J, Gibbs HK. 2016. Mapping properties to monitor forests: Landholder response to a large environmental registration program in the Brazilian Amazon. *Land Use Policy* 57:193–203. https://doi.org/10.1016/j.landusepol.2016.05.029

Liévano-Latorre LF, Brum FT, Loyola R. 2021. How effective have been guerrilla occupation and protected areas in avoiding deforestation in Colombia? *Biological Conservation* 253:108916 https://doi.org/10.1016/j.biocon.2020.108916

Miranda JJ, Corral L, Blackman A, Asner G, Lima E. 2016. Effects of protected areas on forest cover change and local communities: Evidence from the Peruvian Amazon. *World Development* 78:288–307. https://doi.org/10.1016/j.worlddev.2015.10.026

Miteva DA, Ellis PW, Ellis EA, Griscom BW. 2019. The role of property rights in shaping the effectiveness of protected areas and resisting forest loss in the Yucatan Peninsula. *PLoS One* 14: 1–27. https://doi.org/10.1371/journal.pone.0215820

Miteva DA, Pattanayak, SK. 2021. The effectiveness of protected areas in the context of decentralization. *World Development* 142:105446. https://doi.org/10.1016/j.worlddev.2021.105446

Montoya-Zumaeta JG, Rojas E, Wunder S. 2019. Adding rewards to regulation: The impacts of watershed conservation on land cover and household wellbeing in Moyobamba, Peru. *PLoS One* 14:1–22. https://doi.org/10.1371/journal.pone.0225367

Montoya-Zumaeta JG, Wunder S, Rojas E, Duchelle AE. 2022. Does REDD+ complement law enforcement? Evaluating impacts of an incipient initiative in Madre de Dios, Peru. *Frontiers in Forests and Global Change* 5. https://doi.org/10.3389/ffgc.2022.870450

Nelson A, Chomitz KM. 2011. Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: A global analysis using matching methods. *PLoS One* 6. https://doi.org/10.1371/journal.pone.0022722

Nolte C, Agrawal A. 2013. Linking management effectiveness indicators to observed effects of protected areas on fire occurrence in the Amazon Rainforest. *Conservation Biology* 27:155–165. https://doi.org/10.1111/j.1523-1739.2012.01930.x

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Pfaff A, Robalino J, Herrera D, Sandoval C. 2015a. Protected areas? Impacts on Brazilian Amazon deforestation: Examining conservation – development interactions to inform planning. *PLoS One* 10:1–17. https://doi.org/10.1371/journal.pone.0129460

Pfaff A, Robalino J, Sandoval C, Herrera D. 2015b. Protected area types, strategies and impacts in Brazil's Amazon: Public protected area strategies do not yield a consistent ranking of protected area types by impact. *Philosophical Transactions of the Royal Society B Biological Sciences* 370. https://doi.org/10.1098/rstb.2014.0273

Powlen KA, Gavin MC, Jones KW. 2021. Management effectiveness positively influences forest conservation outcomes in protected areas. *Biological Conservation* 260. https://doi.org/10.1016/j.biocon.2021.109192

Robalino J, Sandoval C, Barton DN, Chacon A, Pfaff A. 2015. Evaluating interactions of forest conservation policies on avoided deforestation. *PLoS One* 10:1–16. https://doi.org/10.1371/journal.pone.0124910

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Santika T, Meijaard E, Budiharta S, Law EA, Kusworo A, Hutabarat JA, Indrawan TP, Struebig M, Raharjo S, Huda I, et al. 2017. Community forest management in Indonesia: Avoided deforestation in the context of anthropogenic and climate complexities. *Global Environmental Change* 46:60–71. https://doi.org/10.1016/j.gloenvcha.2017.08.002

Shah P, Baylis K, Busch J, Engelmann J. 2021. What determines the effectiveness of national protected area networks? *Environmental Research Letters* 16. https://doi.org/10.1088/1748-9326/ac05ed

Sims KRE, Alix-Garcia JM. 2017. Parks versus PES: Evaluating direct and incentive-based land conservation in Mexico. *Journal of Environmental Economics and Management* 86:8–28. https://doi.org/10.1016/j.jeem.2016.11.010

Soares-Filho BS, Oliveira U, Ferreira MN, Marques FFC, de Oliveira AR, Silva FR, Börner J. 2023. Contribution of the Amazon protected areas program to forest conservation. *Biological Conservation* 279. https://doi.org/10.1016/j.biocon.2023.109928

Tritsch I, Le Velly G, Mertens B, Meyfroidt P, Sannier C, Makak JS, Houngbedji K. 2020. Do forest-management plans and FSC certification help avoid deforestation in the Congo Basin? *Ecological Economics* 175:106660. https://doi.org/10.1016/j.ecolecon.2020.106660

Wright GD, Andersson KP, Gibson CC, Evans TP. 2016. Decentralization can help reduce deforestation when user groups engage with local government. *In* Proceedings of the National Academy of Sciences of the United States of America 113:14958–14963. https://doi.org/10.1073/pnas.1610650114

Yang H, Viña A, Winkler JA, Chung MG, Dou Y, Wang F, Zhang J, Tang Y, Connor T, Zhao Z, et al. 2019. Effectiveness of China's protected areas in reducing deforestation. *Environmental Science and Pollution Research* 26:18651–18661. https://doi.org/10.1007/s11356-019-05232-9

Yang H, Viña A, Winkler JA, Chung MG, Huang Q, Dou Y, McShea WJ, Songer M, Zhang J, Liu J. 2021. A global assessment of the impact of individual protected areas on preventing forest loss. *Science of the Total Environment* 777. https://doi.org/10.1016/j.scitotenv.2021.145995

Zhao H, Wu R, Long Y, Hu J, Yang F, Jin T, Wang J, Hu P, Wu W, Diao Y, et al. 2019. Individual-level performance of nature reserves in forest protection and the effects of management level and establishment age. *Biological Conservation* 233:23–30. https://doi.org/10.1016/j.biocon.2019.02.024

Appendix D. Geographic distribution of the reviewed papers by continent and region

Continent	N	%
North America		
Mexico	4	8.51
Central America		
Costa Rica	6	12.77
Guatemala	1	2.13
South America		
Brazil	11	23.40
Peru	5	10.64
Bolivia	4	8.51
Colombia	3	6.38
Ecuador	1	2.13
Africa		
Congo/Republic of the Congo	2	4.26
Democratic Republic of the Congo	1	2.13
Uganda	1	2.13
Madagascar	1	2.13
Asia		
China	2	4.26
Cambodia	4	8.51
Indonesia	4	8.51
Thailand	3	6.38
Laos	2	4.26
Bhutan	1	2.13
Malaysia	1	2.13
Philippines	1	2.13
Viet Nam	1	2.13
Oceania		
Papua New Guinea	1	2.13
Global	**4**	**8.51**

Note: The "global" category encompasses three global assessments of PAs (Joppa and Pfaff 2011; Shah et al. 2021; Yang et al. 2021), plus one PA assessment of multiple locations from Latin America, Africa, and Asia of which it was not possible to identify all countries (Nelson and Chomitz 2011).

Appendix E. Type of the interventions evaluated by the reviewed papers

Intervention type	N	%
Disincentives		
PA	34	72.34
Rural environmental registry	1	2.13
Soy moratorium	2	4.26
Incentives		
PES	8	17.02
Community forest management	1	2.13
Enabling measures		
Forest Management Plan	1	2.13
Land titling	1	2.13
Others		
Multiple interventions under the REDD+ umbrella	1	4.26
Decentralization of forest governance	1	2.13

Note: Three papers evaluated more than one intervention type.

Appendix F. Result tables with observations

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	Neutral	Negative	Mixed results	
1.1 Management style					
a. Multiple-use vs. strict protection PA	Blackman (2015) (1), Miranda et al. (2016) (2), Nelson and Chomitz (2011) (3), Pacheco and Meyer (2022) (4), Pfaff et al. (2014) (5), Sims and Alix-Garcia (2017) (6), Soares-Filho et al. (2023) (7).	Andam et al. (2013) (8), Bruggeman et al. 2018) (9), Koskimäki et al. (2021) (10)	Bonilla-Mejía and Higuera-Mendieta (2019) (11), Kukkonen and Tammi (2019) (12), Pfaff et al. (2015b) (13), Shah et al. (2021) (14), Yang et al. (2021) (15)	Ferraro et al. (2013) (16)	The effects of multiple-use areas were larger in assessments of Guatemala's Maya Biosphere Reserve (1), Peru (2), Brazil (4, 5, 7), Mexico (6), and several locations in Latin America, Africa and Asia (3). No significant differences between the effects of multiple-use and strictly protected was detected in Costa Rica (8), Bhutan (9), and the Brazilian state of Acre (10). Other studies indicate strictly protected worked better in Colombia (11), Laos (12), in the Brazilian Amazon (13), and across the globe (14, 15). Another paper found that in Costa Rica, Sumatra, and Thailand strictly protected areas were more effective than less strictly protected areas, but, in Bolivia, difference was statistically insignificant (16).
b. Higher management capacity	Graham et al. (2021) (1), Powlen et al. 2021) (2), Soares-Filho et al. (2023) (3)	Nolte and Agrawal (2013) (4), Bruggeman et al. (2018) (5)			In Southeast Asia, PAs that had completed METT (Management Effectiveness Tracking Tool) assessments were more effective than those that had not (1). In Mexico, PAs with high scores for management effectiveness had greater effects than those with low scores (2). In Brazil, PAs receiving support from the Amazon Protected Areas Program (ARPA) were more effective than no-support PAs (3). Yet, in the Amazon basin, no significant differences were observed between PAs with high and low METT scores (4). In Bhutan, PAs with management plans did not perform significantly better than the rest of them (5).
c. cImposing land-use restrictions	Holland et al. (2017)				In Ecuador, a 'forest-friendly' titling programme reduced deforestation only where the title came tied with land-use rules.

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Appendix F. Continued

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	**Neutral**	**Negative**	**Mixed results**	
1.2 Type of implementor					
d. National vs. lower-level agencies	Herrera et al. (2019) (1), Zhao et al. (2019) (2)				Federal PAs were more effective than those implemented by state-level agencies in Brazil (1). In southwest China, national PAs were more effective than provincial PAs (2).
1.3 Intervention duration					
e. Older interventions	Bruggeman et al. (2018) (1), Miranda et al. (2016) (2), Tritsch et al. (2020) (3)	Zhao et al. (2019) (4)	Robalino et al. (2021) (5), Black and Anthony (2022) (6)		Older PAs performed better in Bhutan (1) and the Peruvian Amazon (2). Forest Management Plans approved over a longer period were more effective than newer plans in Congo's logging concessions (3). In southwest China, no significant differences were detected between the effects of older and newer PAs (4). PES contracts signed later had greater effects than contracts signed earlier in Costa Rica (5). New PAs were more effective than older PAs in Cambodia. Effects decrease over time in both groups but more sharply in new PAs (6).
1.4 Size of the intervention area					
f. Larger sizes	Liévano-Latorre et al. (2021)				Larger PAs worked better in Colombia.

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Appendix F. Continued

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	**Neutral**	**Negative**	**Mixed results**	
2.1 Baseline/background outcomes					
a. Higher forest loss	Cisneros et al. (2022) (1), Guizar-Coutiño et al. (2022) (2), Jayachandran et al. (2017) (3), Jung and Polasky (2018) (4), Pfaff et al. (2015b) (5), Pfaff et al. (2015a) (6), ritsch et al. (2020) (7), Yang et al. (2021) (8), Yang et al. (2019) (9)				Larger effects were detected in areas exposed to high deforestation levels. This was consistent in assessments of a PES-like programme in Brazil (1), REDD+ projects from multiple continents (2), Forest Management Plans in Congo (7), as well as assessments of PAs in Brazil (5, 6), China (9), and across the globe (8). Similarly, a Brazilian initiative to limit deforestation from soy producers was more effective in properties with less forest cover than the minimum required by the Forest Code (4). In Uganda, PES effects were higher for those farmers who recently had cut more trees (3).
b. Tree cover	Jayachandran et al. (2017)				In Uganda, PES effects were higher in the locations with more tree cover at the baseline.
2.2 Biophysical (indicators for agricultural suitability)					
c. Flat lands	Chervier and Costedoat (2017) (1), Ferraro et al. (2011) (2), Ferraro and Hanauer (2011) (3), Hanauer and Canavire-Bacarreza (2015) (4), Joppa and Pfaff (2011) (5), Yang et al. (2021) (6), Yang et al. (2019) (7)		Santika et al. (2017) (8)		Overall, effects were higher in flatter lands compared to steep slope areas. This was observed in participant properties of a Cambodian PES programme (1), in several PA assessments from Costa Rica and Thailand (2, 3), Bolivia (4), China (7), and across the globe (5, 6). Yet, Indonesia's community forest management scheme performed worse in the lowlands (8).
d. High-quality soils	Yang et al. (2021)				Higher effects were detected in PAs with high rates of carbon in their soils (an indicator of soil fertility) in a global assessment.
e. High rainfalls			Santika et al. (2017)		A community forest management scheme in Indonesia performed worse in areas with high rainfalls.
f. High suitability for agriculture	Ferraro and Hanauer (2011)				In Costa Rica, PA effects were higher in areas with high suitability for agriculture. The indicator considers multiple factors such as soil, precipitation, climate, and slope.

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Appendix F. Continued

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	**Neutral**	**Negative**	**Mixed results**	
2.3 Location					
g. Proximity to cities or settlements	Ferraro and Hanauer (2011) (1), Hanauer and Canavire-Bacarreza (2015) (2); Joppa and Pfaff (2011) (3), Nelson and Chomitz (2011) (4), Pfaff et al. (2015a) (5), Pfaff et al. (2014) (6), Santika et al. (2017) (7), Tritsch et al. (2020) (8), Yang et al. (2021) (9), Yang et al. (2019) (10), Bonilla-Mejía and Higuera-Mendieta (2019) (11)			Ferraro et al. (2011) (12)	Overall, the effects were higher in areas with small or intermediate distances from cities or settlements. Remoteness contributed to worse performance of PAs in multiple locations (1, 2, 3, 4, 5, 6, 8, 10, 11, 12). Similarly, Indonesia's community forest management worked better in areas closed to agricultural settlements (7). Congo's Forest Management Plans worked better in non-remote areas (8). In Thailand, higher effects of PAs were observed in both the farthest and closest distances to major cities (11).
h. Proximity to roads	Chervier and Costedoat (2017) (1), Pfaff et al. (2015a) (2), Pfaff et al. (2014) (3), Higuera-Mendieta (2019) (4), Tritsch et al. (2020) (5)	Alix-Garcia et al. (2012) (6)			Overall, the effects were higher in areas with small or, at most, intermediate distances from roads. Remoteness from roads contributed to worse performance of PES in Cambodia (1), Congo's Forest Management Plans (5), and PAs in Brazil and Colombia (2, 3, 4). No significant variation in PES effects were found across different levels of road density in Mexico (6).
i. Remoteness from markets		Cisneros et al. (2022)			Proximity to markets did not affect the effects of a PES-like programme in Brazil.
2.4 Demographic					
j. Greater population size			Chervier and Costedoat (2017)		Higher effects of a PES programme in Cambodia were observed for intermediate population size. In more densely populated places, it decreased.

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Appendix F. Continued

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	**Neutral**	**Negative**	**Mixed results**	
2.5 Socioeconomic					
k. Low poverty levels	Alix-Garcia et al. (2012) (1)	Ferraro et al. (2011) (2), Ferraro and Hanauer (2011) (3)			In Mexico, PES effectiveness was higher where poverty was classified as low to medium (1). Yet, there was no clear relationship between poverty levels and PA effectiveness in Costa Rica (2, 3).
l. Higher agriculture income	Cisneros et al. (2022)				Larger effects of a Brazilian PES-like programme were found in areas with high levels of agricultural income.
m. Higher income from timber products	Jayachandran et al. (2017)				In Uganda, PES effects were higher for those with higher baseline revenue from timber products.
n. Higher presence of agricultural workers	Ferraro and Hanauer (2011)				In Costa Rica, PA effects were higher with a higher percentage of agricultural workers.
2.6 Governance					
o. Interaction with other conservation policies	Heilmayr et al., 2020 (1), L'Roe et al. (2016) (2), Montoya-Zumaeta et al. (2019) (3)	Montoya-Zumaeta et al. (2022) (4)	Robalino et al. (2015) (5), Sims and Alix-Garcia, (2017) (6)		The Amazon Soy Moratorium was effective only when implemented together with the Brazilian Environmental Registry for Rural Properties (CAR) and forest monitoring (1). Again in Brazil, CAR avoided more deforestation when implemented together with a land titling programme (2). In Peru, a PES-ICDP mixed approach amplified the effects of a municipal PA (3). Yet, still in Peru, no significant effects of a REDD+ project in Peru were detected, not even when interacting with law enforcement (4). In Costa Rica, PES and PA implemented separately achieved higher aggregated effects than when combined (5). Similarly, in Mexico, PES and PA overall performed better alone than together (6).

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Appendix F. Continued

Design and implementation	Influence on the effectiveness of conserving forests				Obs.
	Positive	**Neutral**	**Negative**	**Mixed results**	
p. Interaction with economic land concessions				Black and Anthony (2022)	PAs with concessions for agro-industrial activities had reduced effects in comparison to non-concession PAs in Cambodia. Yet, this occurred only in one of the three evaluated time periods: non-significant differences were detected in the others.
q. Interaction with decentralization policies (not directly related with forest management)				Miteva and Pattanayak (2021)	The impacts of decentralization at the district level on PA effectiveness varied in Indonesia according to the indicator used. Direct elections contributed to avoiding deforestation in PAs. Yet, district splitting increased forest fragmentation inside PAs. District head change had non-significant impacts.
r. Implementation in older municipalities	Bonilla-Mejía and Higuera-Mendieta (2019)				Colombian national PAs worked better in older municipalities (with assumed better governance).
s. mplementation in less violent contexts	Bonilla-Mejía and Higuera-Mendieta (2019)				Colombian national PAs worked better in low-violent municipalities.
t. Higher community engagement	Wright et al. (2016)				In Bolivia, the decentralization of forest governance performed better with greater community engagement.
u. Common or public vs. private properties		Alix-Garcia et al. (2012) (1), Yang et al. (2021) (2)		Miteva et al. (2019) (3)	The type of property did not significantly influence the effectiveness of PES in Mexico (1), or of PAs according to a global assessment (2). In the Yucatan Peninsula of Mexico, the impacts of PAs in common areas (ejidos) relative to private property varied according to the type of forest (dry or moist).
v. Small vs. large properties	Jung and Polasky (2018) (1), L'Roe et al. (2016) (2)				A Brazilian initiative to limit deforestation from soy producers worked better in small properties than in large ones (1). Brazil's Rural Environmental Registry only avoided deforestation among 'smallholders'. Yet, the explanation seems to derive from concomitant policies unequally affecting properties of different sizes (2).

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Recent decades have witnessed a proliferation of forest conservation interventions in tropical developing countries. Impact evaluations most frequently report statistically significant but modest conservation results. As tropical deforestation has persisted, how to increase the effectiveness of interventions is an important empirical question. In this article, we reviewed the English-language, peer-reviewed literature about the heterogeneous impacts of forest conservation interventions. Our goal was to synthesize the experimental and quasi-experimental evidence about how two main factors shaped forest conservation outcomes: 1) the design and implementation characteristics that create heterogeneous treatments; and 2) the characteristics of the context that act as moderators of treatment effects. After screening 1,486 studies, we selected 47 papers conducting robust heterogeneity analysis, showing an emerging trend in the literature. We found interventions generally achieve greater conservation results where forests are under higher deforestation pressure or risk. This implies the protection of forests that are most under threat should be prioritized. As the number of heterogenous assessments is limited, it is still difficult to draw other valid lessons about how and under what conditions interventions may be more effective. We thus renew the calls for more rigorous evaluations of forest conservation interventions that go beyond estimating average effects.

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