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# "The Environmental Impacts of Protected Area Policy"

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# The Environmental Impacts of Protected Area Policy

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**Abstract**

The world has pledged to protect 30 percent of its land and waters by 2030 to halt the rapid deterioration of critical ecosystems. We summarize the state of knowledge about the impacts of protected area policies, with a focus on deforestation and vegetation cover. We discuss critical issues around data and measurement, identify the most commonly-used empirical methods, and summarize empirical evidence across multiple regions of the world. In most cases, protection has had at most a modest impact on forest cover, with stronger effects in areas that face pressure of economic development. We then identify several open areas for research to advance our understanding of the effectiveness of protected area policies: the use of promising recent econometric advancements, shifting focus to direct measures of biodiversity, filling the knowledge gap on the effect of protected area policy in advanced economies, investigating the long-run impacts of protection, and understanding its equilibrium effects.

JEL codes: Q23, Q24, Q57, R14

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# 1 Introduction

In December 2022, almost 200 countries signed the Kunming-Montreal Global Biodiversity Framework that pledges to protect 30 percent of the earth's land and waters by 2030 and avert the potentially-catastrophic decline in a million species of animals and plants (Einhorn, 2022). This is a sizeable increase from the 15 percent of the planet's land and 7 percent of its oceans that are designated as a protected area now (Parks and Palmer, 2022).

This '30 by 30 target' highlights that protecting nature, forests, and biodiversity have gained prominence on the global agenda, not only as a climate-mitigation tool but also as a direct objective to protect the ecosystems the world depends on. The recent push for more protection is much needed given that habitat destruction stands out as one of the primary drivers of biodiversity loss, particularly in the context of the ongoing extinction crisis we currently face (Matthews et al., 2021, Chapter 14). There is a strong focus on slowing down global deforestation: the world has already lost a third of its forests, and deforestation continues at a rapid pace, though it has slowed down over the past two decades (Ritchie et al., 2021).

The 30 by 30 target, if met, could be an important element of progress amidst a looming biodiversity crisis. However, it also raises important questions: How effective have protected area policies been? Has nature flourished as countries protected more land? And why are certain areas protected but others are not?

This paper focuses on evaluating large government-led terrestrial protected area policies. This includes, among others, designated land under the US Endangered Species Act, the EU's Natura 2000 program, and Brazil's Forest Code. These policies deliberately designate land to become a protected area shielded from certain human activities.[1] We provide a brief conceptual framework around the economic trade-offs of protected areas, as well as practical challenges with data, measurement, and statistical identification. We then summarize the extant empirical estimates, which focus mostly on measures of vegetation or forest cover. We end with discussing areas in which we believe the literature could be productively expanded.[2]

# 2 Conceptual Framework

We begin our overview by providing a conceptual framework of how a policymaker interested in maximizing utilitarian social welfare would design a protected area policy. Clearly, the social planner must consider the costs and benefits of protecting land from economic development.[3]

The costs primarily stem from the economic losses incurred by reducing economic activity within the protected area. These could include reductions in farmers' incomes, losses from preventing construction

[1] We do not discuss related policies such as marine protection (e.g., Albers and Ashworth, 2022), community-based policies (e.g., Eisenbarth et al., 2021), payment for ecosystem services (e.g., Jayachandran et al., 2017), and offsetting schemes which necessitate developers to compensate for the destruction of a particular area by providing an alternative area (e.g., Taylor and Druckenmiller, 2022; Aronoff and Rafey, 2022).

[2] This paper complements important previous surveys focused on correcting for site selection (Joppa and Pfaff, 2010), spillover effects (Pfaff and Robalino, 2017), and the impacts of several conservation policies, including protected areas (Börner et al., 2020).

[3] Though we do not focus on equity issues here, as is standard in aggregated social welfare analysis, we note that such concerns can be important in practice, given that much protection occurs in poorer rural areas.

projects, and the consequences of lost access to foraging or subsistence use. The displacement of people and economic production to another area also entails economic costs because the activity—such as home construction—cannot occur in the preferred location. In some cases, there might even be a reduction (instead of an increase) in economic development in the region around the protected area. Therefore, protected area policies can create a potentially complicated spatial reallocation of economic activity.[4] Additionally, it is costly to implement and enforce such policies. Enforcement costs can be particularly substantial in remote locations or when protection limits economic activities that are susceptible to concealment, such as hunting.

The benefits derived from protected area policies primarily stem from the ecological gains achieved. Firstly, there exists a recovery effect: the reduction in already-ongoing economic activity following protection enables the recovery of the ecosystem and its biodiversity. Secondly, there are protection effects: preserving ecological integrity and biodiversity that would have been at risk from economic development absent protection. Thirdly, protecting an area might have positive spillovers on the ecological state of nearby areas. Finally, a protected area might increase the amenity value of land and attract tourism.[5]

The timing of costs and benefits also matters for understanding the effectiveness of protected area policy. The costs of restricting activities can be immediate and continue over the period of protection. Ecological benefits might arrive long after protection is established. The discount factor of the social planner determines the extent to which the optimal protection policy trades off immediate costs and future conservation benefits.

In short, a utilitarian planner would prioritize protecting plots with the highest difference between the present value of ecological benefits and economic costs.[6] Notably, meaningful protection occurs when the protected area changes the economic production activity in the area relative to what would have been produced without protection. In contrast, protecting land that never leads to changes in economic activity would be considered a wasteful expenditure of resources.[7]

Next, we discuss several key decisions policymakers make when protecting an area: site selection, the type and stringency of protections, ownership type, and enforcement.

**Site selection.** In reality, site selection is performed by policymakers who may weigh the costs and benefits of protection differently from a social planner. Policymakers might assign greater importance to local economic production, attach a lower value to the broader benefits derived from future increases in biodiversity, or benefit politically from "green glow" from the act of protection, even in areas where nature is not under development pressure (Grupp et al., 2023). Furthermore, when policymakers discount the future more

[4] For an example of how protected areas affect the distribution of land values in the United States, see Frank et al. (2021).

[5] Amenity, recreation, and tourism benefits of protected areas have been studied in Rasker et al. (2013), Robalino and Villalobos (2015), Naidoo et al. (2019), Sims et al. (2019), Walls et al. (2020), Wu et al. (2023), and Szabó and Ujhelyi (2023). While increased amenity values and tourism matter locally, our review focuses on ecological gains—the principal stated goal of large government-led protection policy.

[6] Metrick and Weitzman (1998) and Weitzman (1998) investigate the conceptual challenge for a policy maker deciding how to preserve biodiversity while operating under a constrained budget within the utilitarian social welfare framework. Anderson et al. (2016) present a theoretical analysis of protected area policies in a monocentric model with an agricultural sector that faces trade costs that increase with distance from a city; optimal protection occurs at the boundary where agricultural profits equal ecological value.

[7] Of note, protection can also serve as insurance against uncertain future pressures from economic development in some areas that are not yet apparent when the land is protected.

heavily than the social planner, it can lead to the protection of low-cost land (requiring few restrictions), limiting future ecological gains unless the pressure on the land changes substantially.

**Degree and type of limitation.** A protected area policy restricts economic activity to various degrees. The International Union for Conservation of Nature (IUCN) classifies protected areas into seven categories: strict nature reserve, wilderness area, national park, natural monument, habitats or species management area, protected landscape or seascape, and protected area with sustainable use of natural resources. The categories relate to differences in underlying policy goals: protecting specific habitats and species, conserving a national monument, or protecting nature while allowing some inhabitants to keep benefiting.[8] Different policy goals and the resulting array of restrictions interact with diverse ecological conditions, leading to potentially different impacts of protection depending on the region, type, and degree of protection (Dudley et al., 2010). Of note, many countries, such as Brazil, use their own systems of protected area categories that do not perfectly correspond to IUCN categories.[9]

**Land ownership status.** Policymakers have to consider the ownership status of the sites they contemplate protecting. Ownership can range from private property with clearly established property rights to informal or contested tenure status. Also, protected areas have been established on lands traditionally held in common by communities (Gandour and Mourão, 2023). The impacts of protected areas may vary with the underlying property rights.

**Monitoring and enforcement.** Lastly, policymakers face the critical task of monitoring and enforcing their protected areas, which is a challenging endeavor in many areas placed in remote and inaccessible locations. Recent advancements in remote sensing techniques, such as the innovative real-time satellite-based deforestation warning system in the Brazilian Amazon (DETER), have contributed to addressing such challenges (Assunção et al., 2023a). When there is spatial heterogeneity in monitoring and enforcement costs, a second type of site selection may emerge, involving the selection of varying levels of enforcement intensity for different areas.

In sum, we expect the interaction of these critical policy choices to potentially deliver a wide variety of potential treatment effects of protected areas.

[8] "Multi-use" or "mixed-use" protected areas allow limited usage of natural resources, see Nelson and Chomitz (2011).

[9] Brazil classifies protected areas into twelve categories instead of seven, see "*Guia SNUC-CNUC Módulo 1*" in `https://www.gov.br/mma/pt-br/assuntos/areasprotegidasecoturismo/plataforma-cnuc-1/manuais-1`.

# 3 Measurement and Identification

## 3.1 Data and measurement

The study of the impact of protected areas usually involves panel data with a high degree of spatial disaggregation. A crucial outcome to study from the perspective of traditional economic welfare criteria would be the ecological value of the land, but direct data on this is sparse, if not impossible, to obtain. Most studies focus data relatively readily available from satellite imagery—forest cover and vegetation 'greenness' (e.g., BenYishay et al., 2017; Assunção et al., 2023b). Occasionally, species counts data are available as a more direct measure of biodiversity outcomes, although coverage and consistency are orders of magnitude below satellite-based land-use data (Dornelas, 2018). Another set of relevant outcome data includes economic indicators such as land prices, house values, nightlights, asset holdings, poverty, inequality, and migration (e.g., Uchida et al., 2007; Eichman et al., 2010; Tumusiime and Sjaastad, 2014; Sims and Alix-Garcia, 2017; Geldmann et al., 2019; Frank et al., 2021).

Two data types are common in the literature: discrete and continuous land-use data. Discrete measures include the global Historical Land Dynamics Assessment project, MapBiomass for Brazil, and the Cropland Data Layers and the Land Change Monitoring, Assessment and Projection collection for the U.S.[10] Continuous measures of vegetation greenness include the normalized difference vegetation index (NDVI), the enhanced vegetation index (EVI), or vegetation continuous fields (VCF).[11] These discrete and continuous measures are often derived from satellite data, most commonly LANDSAT, which assembles a high-resolution remote sensing dataset starting in 1972. Using a continuous measure avoids classification errors in discrete categorical data, which are typically available at lower frequency (Alix-Garcia and Millimet, 2022; Torchiana et al., 2023); ultimately, the choice depends on the main focus of the study (e.g., deforestation or gradual greening of different types of vegetation cover).

Information about the location and characteristics of terrestrial and marine protected areas is available from comprehensive sources such as the World Database on Protected Areas (WDPA) or, for Europe, the Common Database on Designated Areas (CDDA).[12] Figure 1 shows the earth's protected areas, both terrestrial and marine, as of 2023.

[10]See `https://landchange.imk-ifu.kit.edu/hilda`, `https://brasil.mapbiomas.org/en`, `https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php`, and `https://www.usgs.gov/centers/eros/science/usgs-eros-archive-lcmap-continuous-change-detection-classification-ccdc`.

[11]For more details, see `https://www.usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index`, `https://www.usgs.gov/landsat-missions/landsat-enhanced-vegetation-index`, and `https://modis.gsfc.nasa.gov/data/dataprod/mod44.php`.

[12]For details, see `https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA` and `https://www.eea.europa.eu/data-and-maps/data/external/common-database-on-designated-areas`. Importantly, the WDPA data is based on the information provided by individual countries. The quality may vary substantially by country. For example, China has stopped providing relevant portions of its data to the IUCN (see `https://www.protectedplanet.net/country/CHN`).

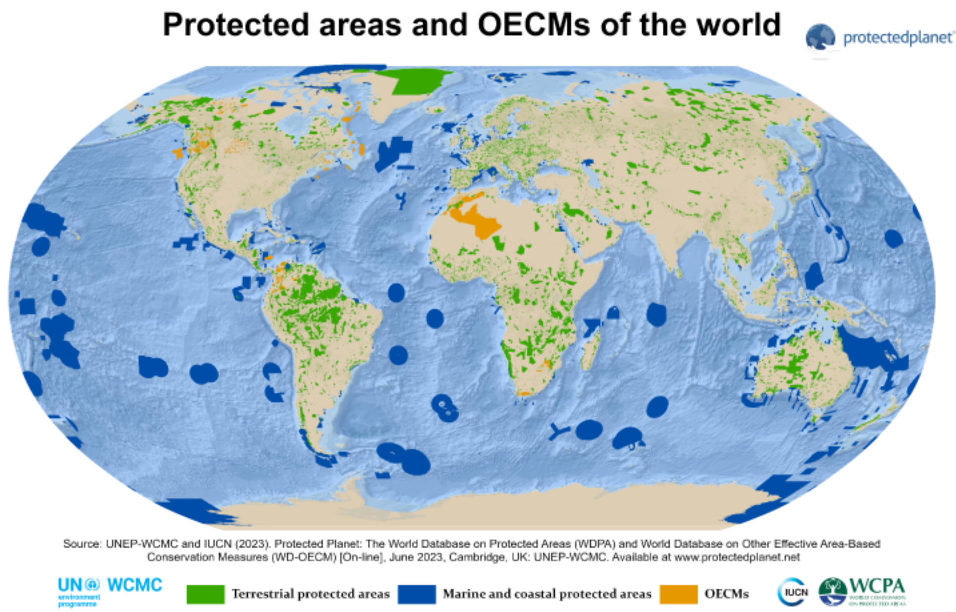


Figure 1: Source: UNEP-WCMC (2023). Protected areas map of the world in June 2023. Map plots terrestrial protected areas (green), marine and coastal protected areas (blue), and other effective area-based conservation measures (orange)

### 3.2 Commonly-used methods

Ideally, estimating the impact of a protected area policy involves comparing a region of interest where certain lands are under protection over time with other similar lands following a non-protected trajectory. Such a comparison naturally yields a valid causal interpretation. However, in practice, readily available data often lack the ideal comparable unprotected land. Consequently, when using observational data, researchers must carefully construct counterfactual areas for a proper comparison. The reliability of causal estimates depends crucially on the quality of these counterfactual areas.[13] In constructing causal estimates, researchers need to confront at least three important econometric challenges: selection bias, spillover effects, and heterogeneity in treatment effects.[14] Selection bias occurs because of the site selection issue. Protected area status is not randomly distributed across different areas; therefore, comparing a protected area with a non-protected area will result in estimates that suffer from selection bias. Spillover effects arise when economic activities relocate from protected to unprotected areas, potentially degrading biodiversity. Consequently, when comparing biodiversity within the protected area to an area influenced by this relocation, researchers may obtain biased estimates of protection effects. Finally, the effect of protection might vary by type of vegetation, type of

[13]For example, consider a region that is already completely deforested at the beginning of the study period, except for a protected area. In this case, it becomes impossible to find suitable comparable areas to measure the impact of protected area policy accurately. Noteworthy, the lack of good counterfactuals for causal estimates does not imply that the policy is ineffective.

[14]Section 4 discusses empirical evidence for each of these challenges.

economic restriction, enforcement stringency, the year in which the area is protected, the time since the area became protected, among other factors. This heterogeneity in potential effects makes it difficult to construct a meaningful average treatment effect (Vincent, 2016).

To address these difficulties, researchers have used different econometric techniques. Many papers account for selection using some combination of standard methods, such as (i) controlling for observable land characteristics, including climate and soil characteristics, agricultural productivity, and distance to relevant markets; (ii) difference-in-differences regression to control for time-invariant unobservables and time trends that affect treatment and control areas similarly; and (iii) spatial regression discontinuity to control for unobservables that are highly unlikely to vary around park boundaries (see, e.g. Turner et al., 2014; Anderson et al., 2016). Few studies have used instrumental variables techniques to deal with endogenous siting of protected areas; an example is Sims (2010), who use proximity to major rivers as an instrument.

Most prevalent is the use of matching on observables to address the selection bias (e.g., Andam et al., 2008; Ferraro et al., 2013; Abman, 2018). Matching is often combined with a difference-in-differences approach to estimate the causal average treatment effect of protection in an area (e.g., Cheng et al., 2023; Keles et al., 2023). As discussed in Joppa and Pfaff (2010), naive estimates without careful matching can result in substantial upward biases in estimated treatment effects, as protected areas with low risk of development are compared to control areas with higher economic pressures. To deal with the heterogeneity of treatment effects, researchers often compare the effects of protection between regions with observable differences in the factors that affect the effectiveness of protection, such as economic pressure, protection type, and enforcement pressure—see Section 4.2 for a discussion of empirical studies.

Rico-Straffon et al. (2022) and Grupp et al. (2023) apply noteworthy recent econometric advances from de Chaisemartin and D'Haultfœuille (2020) and Callaway and Sant'Anna (2021) that are robust to estimation bias stemming from the staggered introduction of protection. These estimators are especially useful when treatment effects are heterogeneous across year of protection *and* time since protection, as commonly-used two-way fixed effects estimators are biased in that setting. Grupp et al. (2023) also apply recent non-parametric methods of Wager and Athey (2018) for heterogeneous treatment effects estimation. Importantly, this method uses a causal random forest algorithm to test which dimensions of heterogeneity matter most and estimates the associated conditional average treatment effects. Causal forests have the advantage that machine learning tools estimate treatment effect heterogeneity in potentially complex multivariate settings. Combining the use of machine learning with prior knowledge based on economic theory and institutional details can lead to a balanced approach in which researchers zoom in on differences that are statistically and theoretically relevant.

# 4 What Is The Empirical Evidence So Far?

We now summarize the empirical evidence of the impacts of protected areas on deforestation and other related outcomes. This review does not attempt to encompass all studies in this vast literature.[15] We begin by summarizing average treatment effects of protected areas, including evidence for the nonrandom location of protected areas. We then investigate the evidence on heterogeneous effects (importantly, how estimates vary with economic pressure on the land), spillovers outside protected areas boundaries, and the strategic complementarities between protected areas and other policy interventions. It is important to note from the outset that these studies have focused on the short-run impacts, as opposed to long-run effects, in virtue of data limitations (a point we discuss further below, in Section 5).

## 4.1 Empirical estimates of the impact of protected areas

The estimated effects of protected areas on deforestation and vegetation cover tend to be modest in magnitude. Furthermore, these effects are frequently, though not always, statistically insignificant—i.e., precise zeros. As a result, the literature on protected areas has been critical of the current efficacy of such policies to restore biodiversity and prevent deforestation (Herrera et al., 2019; Maxwell et al., 2020).

**Global estimates.** Several studies provide global estimates. Joppa and Pfaff (2011) use data on 147 countries and highlight the importance of matching, which reduces treatment effects by more than half. They find a modest 4 percentage point increase in natural vegetation, on average, following protection. Abman (2018) studies protected areas in 71 countries and concludes that deforestation would have been 2.3% greater, on average, during 2001–2012 without protection. Geldmann et al. (2019) report no difference in the human pressure index between protected and matched unprotected areas across the globe. In tropical areas, they even find increased human pressure relative to matched unprotected areas. Wade et al. (2020) report similar forest loss trends in protected and unprotected forests. Maxwell et al. (2020) find that despite increased protected surface globally, the coverage of threatened species and habitats has not increased substantially.[16]

**Regional estimates.** Some regional studies have found somewhat larger estimates. In Costa Rica, about 10% of the protected forests would have been deforested without conservation measures (Andam et al., 2008). In Thailand, increasing protection coverage locally from zero to 100% increases forest cover by 7 percentage points, alongside higher local consumption and reduced poverty, largely due to tourism (Sims, 2010).

However, effects in other countries have been smaller. In the Brazilian Amazon, protected areas reduced the deforestation rate by approximately 2 percent (Pfaff et al., 2015b). In Indonesia, protection preserved

[15] To provide a glimpse of the volume of research, a Google Scholar search for "impacts of protected areas on deforestation" yielded 248,000 results (with 21,100 publicly available papers after 2010), including papers published in various academic disciplines such as biology, ecology, geography, and economics. (Search conducted on May 30th, 2023.)

[16] Many empirical studies report impacts in percentage terms, but do not report them in terms of total area affected. Given that total areas matter for biodiversity and ecological services such as carbon storage, we recommend researchers report both percentage changes and total areas.

just an additional 1.1% of forest cover (Shah and Baylis, 2015). Effects on the deforestation rate in Chile (Arriagada et al., 2016), China (Cheng et al., 2023), Indonesia (Gaveau et al., 2014), Mexico (Honey-Roses et al., 2011) and Peru (Miranda et al., 2016) were small and statistically insignificant. Many of these studies found that failing to correct for location bias would more than double the estimated impacts.

There is a striking lack of analysis of the impact of protected areas on vegetation cover in advanced economies such as the European Union and the United States. A notable exception is Grupp et al. (2023), who use a doubly-robust estimator that corrects for site selection and trends in covariates. They find that Europe's protected area policies have not contributed to the EU's gradual greening. The average treatment effect is a precise zero because protected areas do not green more than matched unprotected areas.

**Evidence of site selection.** Why are these effects so small? One important reason is that protected areas are typically (though not always) established in remote areas with low levels of deforestation pressure. Politicians tend to select land that is least costly to protect and, therefore, not necessarily the most beneficial for biodiversity.

One particular example is the siting of protected areas in the European Union, where 26% of the land is currently protected, but protection seems to have happened in areas with low risk of increased current or future economic development (Grupp et al., 2023). Joppa and Pfaff (2009) conducted the most comprehensive global analysis of the spatial distribution of protected area networks that we are aware of and find that protected areas are often situated in remote and high-elevation regions, located away from centers of human population and economic activity. Moreover, this pattern of site selection tends to be more pronounced for protected areas with higher levels of protection compared to those with lower protection statuses.

Yet, not all protected areas are placed in remote locations. For example, Assunção and Gandour (2018) highlight the intentional siting of protection in high-risk areas within the Brazilian Amazon following the Action Plan for the Prevention and Control of Deforestation in Legal Amazon (PPCDAm) in 2004. Politics may also influence the placement of protected areas. Mangonnet et al. (2022) use a regression discontinuity approach in the Brazilian Amazon, and find that protected areas are 26—32% more likely to be located in municipalities controlled by opposition mayors to protect the municipalities controlled by mayors aligned with the incumbent political coalition from economic costs.

## 4.2 Evidence for heterogeneous effects

Average treatment effects of protected area policies are typically small but can hide a substantial amount of heterogeneity. Several factors may influence treatment effects, most notably whether placement is in regions with high deforestation pressure (as proxied, e.g., by agricultural productivity or distance to cities and roads), the type of protection (strict, less strict, indigenous), and the type of government (federal vs. local; weak vs. strong enforcement).[17]

[17] Most papers focus on heterogeneity in the impact of protection across space, but effects can vary over time, for example if there is a shift of the politics of conservation. This happened, for example, in Mexico between the 1990s and the 2000s

**Economic pressure.** While negligible protection effects are estimated in low-pressure areas, the impacts are higher and statistically significant in high-pressure areas. Protected areas in high-pressure regions of the Brazilian Amazon have average effects on deforestation rates that are 2 to 10 times greater than those in low-pressure areas (Pfaff et al., 2015b). Assunção and Gandour (2018) proxy deforestation pressures in protected cells within the Brazilian Amazon using the alert intensity of the Brazilian satellite-based monitoring system (DETER) within a 50km radius. They find that protection reduces forest clearing more in locations with higher deforestation pressures—an increase of one standard deviation in the intensity of neighborhood alerts increases the difference in clearings for unprotected and protected cells by approximately 26% of the sample mean difference. Kere et al. (2017) find that recently-implemented protected areas are more effective at avoiding deforestation than older ones, corroborating the evidence that new protected areas are placed in areas with greater economic pressure from agriculture. Other evidence that protection is more impactful in areas with economic pressure comes from Costa Rica. Avoided deforestation is greater when areas are closer to the capital, near national roads, and situated on lower slopes (Pfaff et al., 2009).

**Protection type and land ownership status.** Evidence regarding the effectiveness of different types of protection and land tenure is ambiguous. Nolte et al. (2013) and Amin et al. (2019) find that strictly protected areas and protected areas on indigenous lands avoided more deforestation than sustainable use areas—which permit some local deforestation—in the Brazilian Amazon. Bonilla-Mejía and Higuera-Mendieta (2019) find similar results for the Colombian Amazon. Ferraro et al. (2013) investigate the impacts of different types of protected areas in Bolivia, Costa Rica, Indonesia, and Thailand. Their findings reveal that, on average, strict protection is more effective at preventing deforestation compared to other types, but the differences in magnitudes are small, possibly a result that is driven more by where strict protection was assigned rather than regulatory strictness *per se*.

Estimates of the impacts of protection by type could be confounded by differences in the risk of deforestation or other concerns about nonrandom siting of different protection and management regimes. Blackman (2015) tackle this problem through matching. He finds that, in Guatemala, mixed-use protection has reduced deforestation more than strict protection. Sims and Alix-Garcia (2017) introduce an important innovation: they present marginal impacts of protection types that vary with an index that captures the predicted risk of deforestation. This is a promising approach for further studies of protection-type heterogeneity. Conditional on deforestation pressure, they find that biosphere reserves—a combination of strict protection areas with mixed-use buffer zones, with participation from local communities—were more effective than mixed-use and strict protected areas.

Other studies find no evidence that effectiveness varies with protection type or land ownership status. BenYishay et al. (2017) do not find evidence that indigenous land demarcation increases forest cover.[18] Rico-

(Blackman et al., 2015; Pfaff et al., 2017).

[18] Baragwanath and Bayi (2020) find that the granting of property rights in Amazonian indigenous areas is more crucial than demarcation alone. A regression-discontinuity design yields that granting property rights reduces deforestation levels by 75%; there is no effect in territories without full property rights.

Straffon et al. (2022) find that the less strict multi-use protected areas do not result in more deforestation than in the more strictly protected areas in the Peruvian Amazon. Kere et al. (2017) show that protected areas in the Brazilian Amazon slowed down deforestation, regardless of the type of protected-area governance. Pfaff et al. (2015a) estimate a wide range of impacts in the Brazilian Amazon depending on the region, time period, and type of protection, and they do not find a consistent ranking of protection types based on their impact. Overall, the ambiguity in these results depends on the spatial correlation in economic/agricultural pressure and the chosen strictness of protection (Pfaff et al., 2014; Assunção and Gandour, 2018).[19]

**Enforcement pressure.** Given the practical difficulties of measuring effective enforcement, the vast majority of the studies consider the (ex-ante) type of protection—strict versus less strict—as a good proxy for different levels of enforcement. An alternative approach is to look at the retraction of protection. When protection is retracted, we expect to see an increase in deforestation only when there is economic pressure to deforest in the area and enforcement is high. Tesfaw et al. (2018) focus on Rondônia State in the Brazilian Amazon (a state where economic pressure is strong), and find that reductions in ineffective protected areas cause no additional deforestation. Keles et al. (2023) extend these results to the entirety of the Brazilian Amazon and find that when protected areas shrink, deforestation increases only in protected areas with high economic pressure and strong enforcement.[20] This demonstrates that interactions of dimensions of heterogeneity also matter—in this case, economic pressure and enforcement intensity.

Contrary to the findings in most regions, the effects in Europe show a surprising lack of heterogeneity. There is no meaningful heterogeneity across countries, year of first protection, time after protection, or along any other climatic, soil, or land characteristics (Grupp et al., 2023); treatment effects are consistently small. This suggests that Europe has protected land with limited opportunity costs.

### 4.3 Evidence for spillover effects

When protected areas are established, economic activity may change in surrounding areas. Such spillover effects can go in different directions—leakage (more deforestation in nearby unprotected areas) or blockage (less deforestation in nearby unprotected areas). The existing evidence on spillovers is mixed and highlights their complexity and variation. Evidently, without direct impacts of protected area policies, one would expect no spillover effects.

Fuller et al. (2019) investigate deforestation spillovers from protected areas in 71 countries and find evidence of heterogeneous effects. Of the protected areas that effectively restricted deforestation rates, 11.8% showed leakage, and 54.8% featured blockage. At a regional level, we see a mixed picture. Some

[19] Herrera et al. (2019) focus on the type of protection at the government level, and estimate that federally protected areas lower deforestation in the Brazilian Amazon. For state- and local-level protection, results vary substantially and lack robustness. Explanations include different site selection and management practices.

[20] Somewhat relatedly, protected areas have avoided more deforestation in countries with a stronger "rule of law" index, signaling less corruption, better property rights, and stronger institutions (Abman, 2018).

studies find negligible leakage, such as in Brazil (Soares-Filho et al., 2010) and in Costa Rica (Andam et al., 2008). Other studies report large positive leakage effects. Assunção and Gandour (2018) find that protected areas in Brazil effectively protect vegetation within their boundaries, but deforestation is redirected to nearby unprotected areas, leaving region-wide deforestation unaffected. Robalino et al. (2017) study Costa Rica and find that protected areas facing greater threats of deforestation show greater leakage. These tend to be close to roads and far from park entrances and so experience high agricultural returns and limited ecological tourism. The authors do not find evidence for leakage in locations with lower agricultural returns or higher tourism returns. Yet other studies find evidence of blockage, or negative leakage. Strict protection in Brazil led to a reduction in deforestation in nearby unprotected areas, especially near roads and cities (Herrera, 2015; Amin et al., 2019). Federal protection seems to influence migration patterns, encouraging out-migration from and discouraging in-migration to regions with protected areas, possibly due to reduced labor demand caused by the restrictions in local economic activities. Also, municipalities with a large share of protected land experienced reduced growth of unofficial roads, likely due to smaller anticipated profitable opportunities in the future (Herrera, 2015).[21]

## 4.4 Interactions of protected areas with other policies

Protected areas can interact with other policies, influencing their effectiveness at mitigating deforestation. Protected areas and 'blacklist policies' reinforce each other. Assunção et al. (2023b) examine the *Priority List* policy between 2008-2010, which is a blacklist policy that targets monitoring and enforcement efforts to combat deforestation in highly-deforested municipalities in the Brazilian Amazon. This policy reduced deforestation by 40% in blacklisted municipalities and their neighbors. The study suggests that combining the blacklist policy with protected areas strategically can further contribute to reducing deforestation. Anderson et al. (2016) find similar synergies between protection policies and the Priority List.

There are also complementarities between protection and payments for ecosystem services (PES)–subsidies to landowners to protect nature (Sims and Alix-Garcia, 2017). Protected areas and PES can both reduce deforestation—by 20–25% in Mexico. Strict protection avoids deforestation more and PES resulted in more poverty alleviation, suggesting that both policies can be combined to balance the goals of conservation and supporting local livelihoods.[22]

Although not directly focused on protected areas, Assunção et al. (2023a) emphasize the importance of monitoring in enhancing the effectiveness of environmental policies. A 50% increase in monitoring and law enforcement, as measured by the intensity of alerts in the DETER system, decreases deforestation by 25% in the Brazilian Amazon. This monitoring system has also had the unanticipated consequence of increasing forest regeneration, as demonstrated by Gandour et al. (2023).

[21] Further evidence and discussion of spillover effects can be found in the survey by Pfaff and Robalino (2017).

[22] Cheng et al. (2023) find that protected areas increase local employment in service-based activities, but decrease employment overall. Souza-Rodrigues (2019) estimates that the impacts of protected areas *within* private property in the Brazilian Amazon are substantial, with costs for local farmers being ten times higher than hypothetical land use taxation for the same amount of forest protection. These studies highlight the need for complementary policies to mitigate these effects.

# 5 Open Areas for Research

The literature on protected areas is rich, policy-relevant, and full of evidence on the direct and indirect effects of protected areas. Next, we highlight several dimensions in which substantial progress can be made.

**Econometric methods.** Recent methodological advances can help deepen our understanding of protected area policies. These policies have been gradually expanding over the last decades, which gives the policy a staggered adoption design. de Chaisemartin and D'Haultfœuille (2020) show how such staggered policy adoption can severely bias average treatment effects when estimating a two-way fixed effects model if the model does not correctly weigh the different treatment cohorts. Callaway and Sant'Anna (2021) develop an estimator allowing for heterogeneous treatment effects across the staggered cohorts and time. Their estimator, therefore, seems very suitable to identify changes in the site selection process across cohorts and the dynamics related to the regeneration of biodiversity outcomes. Further, they provide accessible estimation routines that report the evolution of the outcome variables among treated and untreated units and test for pre-treatment parallel trends. Future studies could also aim for advances in the use of instrumental variables to address nonrandom site selection, improve the performance of bias-correcting matching techniques, and expand the use of robustness analysis to highlight sensitivity to choices regarding sample selection, matching variables, and outcome variables for land use and biodiversity.

Advances in causal machine learning models allow for estimating further heterogeneity in treatment effects, across dimensions such as land, soil, and climate characteristics. The methods developed in Wager and Athey (2018) seem adequate to expand the scope of empirical work on protected areas, presenting a potential method to identify the determinants of heterogeneous treatment effects. Methods that allow testing where causal effects of protection are more pronounced could lead to a better understanding of the drivers behind site selection. Such methods should be carried out alongside tests for heterogeneous treatment effects along dimensions motivated by economic theory.

**Shifting focus to biodiversity outcomes.** Much research is motivated by the biodiversity benefits of protected areas, but the outcome variables in almost all studies are more narrow—a measure of forest cover, a discrete land use category, or a continuous vegetation greenness index. Deforestation is a critical concern in and of itself, and increased forest cover is likely correlated with increased biodiversity but is not a direct measure of biodiversity or ecological value.

Interesting work focuses on better relating alternative land use data to biodiversity outcomes. Ecologists (e.g., Gregory et al., 2021) emphasize the importance of connecting protected areas through corridors, which presents trade-offs between economic and ecological connectivity. Conservation policies worldwide have usually prioritized protecting large areas of natural vegetation, though some countries establish numerous smaller unconnected sites. In light of these, Sims (2014) studies if wildlife sanctuaries and national parks in Thailand reduce forest fragmentation, measured as average and maximum forest patch size. Protected areas significantly increased forest cover (+19%), forest patch size (+25%), and maximum forest patch size (+21%). This is the first paper that studies the causal impacts of protected areas on forest fragmentation using quasi-experimental methods.[23] While it might sound intuitive that protecting a single contiguous large area is better for biodiversity than protecting several small areas, empirical support for this statement is lacking (Fahrig et al., 2022).[24] Overall, there is substantial scope for more research to establish the link between protected-area policy and fragmentation, but it is difficult to relate land use data to biodiversity without explicit measurement.

Researchers are limited in what they can measure about biodiversity for several reasons. First, despite several efforts (see, e.g., the recent review by Dasgupta, 2021), biodiversity is hard to define and summarize in a set of outcome variables. It is also challenging to collect data on the number of species and the number of individuals of those species in a given location. Perhaps for that reason, to the best of our knowledge, few government agencies systematically gather biodiversity or ecological indicators in relation to their protected area policies.[25] Second, the species count data that are available are scattered, not uniformly measured across space and time, and often do not contain the numbers of observations and locations needed for large-scale statistical analysis. More specifically, the critical difficulty for empirical causal analysis is to obtain good indicators both inside parks and in similar counterfactual areas.

Notwithstanding these challenges, there are promising improvements in more direct measures of biodiversity. There are several databases of animal tracking data, such as the Global Biodiversity Information Facility, Movebank, the PanEuropean Common Bird Monitoring Scheme, eBird, eButterfly, and the European Bird Census Council.[26] Animal movement researchers attach GPS to animals and record their movements over a few months to one year. Movement counts serve as an indirect measure of species abundance; many of the tracked animals are indicator species. Data on birds are especially useful because birds are highly sensitive to environmental changes and are therefore excellent indicators for ecosystem health (Fraixedas et al., 2020). The bioTIME dataset is another important step forward. It collects time series of species counts, with over 12 million records featuring almost fifty thousand species over 600 thousand distinct geographic locations (Dornelas, 2018).[27] This is an improvement over the animal tracking databases listed above, which are not time-varying in a consistent manner as in bioTIME. As a consequence of these efforts, there have been several recent studies that measure biodiversity/species counts directly. Among them, it is worth mentioning Cazalis et al. (2020) and Wauchope et al. (2022), which estimate mixed impacts of protected area policies on

[23]For a review of the existing economics literature on the drivers and impact of habitat fragmentation, as well as a discussion of potential policy and market-based mechanisms, see Albers et al. (2018).

[24]The debate is coined SLOSS: Single Large Or Several Small areas.

[25]Examples of agencies collecting biodiversity data include the U.S. National Park Service (see e.g.: `https://www.nps.gov/im/vital-signs.htm`); the U.S. National Forest Inventory, which collects information about tree species diversity (see `https://www.fia.fs.usda.gov/`); the recently initiated Mexican National Biodiversity and Ecosystem Degradation Monitoring System (see Garcia-Alaniz et al., 2017); and the Catalogue of Life China Annual Checklist (see `https://data.casearth.cn/thematic/Catalogue_of_Life_China`).

[26]See `https://www.gbif.org/`, `https://www.movebank.org/cms/movebank-main`, `https://pecbms.info/`, `https://ebird.org/home`, `https://www.e-butterfly.org/` and `https://www.ebcc.info/`.

[27]See `https://biotime.st-andrews.ac.uk/` for more details.

different bird species.[28] Continued and improved biodiversity data collection opens up an avenue to address the knowledge gap on how land protection and land fragmentation affect biodiversity beyond forest cover.

**Geographical coverage.** Many papers have studied the environmental and economic impacts of protected areas in tropical forests or in developing countries. But important gaps remain. There has been hardly any research on how protected areas have affected biodiversity, or vegetation cover specifically, in rich economies such as Europe or North America—perhaps because of fewer concerns about enforcement and because of the difficulty of establishing credible counterfactuals for land that is not at immediate risk of development. Rare exceptions include studies for the European Union (Grupp et al., 2023), for Russia (Jones and Lewis, 2015), and for the U.S. (Frank et al., 2021). As these continents have expansive forested and natural areas, it seems paramount to study which policies are most effective at protecting them, and estimate credible inputs for benefit-cost calculations.

**Dynamics of protected area policies.** Empirical research has focused on the immediate effects of protecting areas, given today's economic pressures or lack thereof. However, land that is "low-risk" today might face development pressure in the future, and protection policies might anticipate that. Alternatively, some of today's low-pressure protected areas might have faced threats of ecological fragmentation in the past. A promising direction for research would be to assess how changes in development pressure over time affect the effectiveness of protected areas. For example, long panels of protected areas and land-use outcomes over at least several decades are well-suited for difference-in-differences estimators that allow for treatment effect heterogeneity in years since protection. This could reveal that protecting areas initially has limited effectiveness but a growing impact in the following decades.

**Equilibrium effects.** As discussed previously, protection has potentially complicated spatial effects through leakage, blockage, and displacement effects. Further understanding the mechanisms behind the changes that protected areas cause in the spatial equilibrium is necessary to understand the potential economic costs of more ambitious conservation policies. This seems especially relevant in light of conservationists' aim for large connected protected areas that link different ecological systems. Such large connected areas could strongly change the current spatial economic equilibrium, possibly causing changes in inequality, regional poverty, urbanization, and migration (Morgan et al., 2022).

# 6 Conclusion

Protecting nature is critical to avert a looming biodiversity crisis, but many studies suggest that protected area policy has had modest, if any, effects on preserving vegetation cover and avoiding deforestation. Pro-

[28]Recently, new empirical applications in economics using birds diversity data have emerged, though not directly related to protected area policies. Madhok (2023) estimates that infrastructure expansion (e.g., transport, irrigation, and mining projects) accounts for 20% of total bird species losses in India between 2015 and 2020; Liang et al. (2020) estimates pollution effects on reductions of bird abundance; and Noack et al. (2021) studies the impact of farm size on bird species diversity.

tection often happens in areas under minimal pressure from economic development, and statistical analysis must account for this selection bias. The magnitude of the effect of protection varies greatly with contextual factors such as economic development pressure, location, governance type, property rights, and enforcement. Protected areas located in regions under high levels of deforestation pressure tend to have significantly higher impacts; the evidence on other factors is subtle and mixed, as is the evidence on spillover effects—leakage and blockage.

We have the following suggestions for academic research. First, evaluating protected areas often requires an econometric estimator that can handle a staggered policy introduction in combination with matching and heterogeneous treatment effects—recent methodological advances are well-suited for this purpose but have so far only been applied to protected area policy sporadically. Second, our understanding of protected area policy would be enhanced by studying a broader set of outcome variables than vegetation cover and deforestation alone. Third, there is a lack of evidence on the effectiveness of protected areas in advanced economies. Fourth, assessing the long-term impacts of the protected areas, as opposed to the immediate effects, can provide a better picture of the benefits of these policies. Finally, researchers could work on estimating the equilibrium effects of protected area policies. Policy-relevant academic research emphasizes the importance of assessing ecological benefits, economic costs, and the overall effectiveness of conservation policies. Incorporating these insights into conservation strategies and policy design is crucial to ensure the successful preservation of natural ecosystems at both local and global scales.

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