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The role of different governance regimes in reducing native vegetation conversion and promoting regrowth in the Brazilian Amazon

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ABSTRACT

Area-based conservation measures, including protected areas (PA) and other effective area-based conservation measures (OECM), play an important role in biodiversity conservation. In the Brazilian Amazon, even though Conservation Units and Indigenous Lands have been shown to reduce deforestation, few studies have addressed *Quilombola* Territories, and none of the above-mentioned areas were evaluated according to their role in promoting native vegetation regrowth. Here, we used a matching analysis to show that Brazilian Amazon Indigenous Lands, *Quilombola* Territories, and two types of protected areas (Conservation Units of Restrict Use and Sustainable Use) contribute to reduced native vegetation conversion, when compared to their control areas. Indigenous Lands and Conservation Units of Restrict Use lost respectively 17 and five times less native vegetation cover than their unprotected control areas, between the years of 2005–2012. Similarly, *Quilombola Territories* had native vegetation loss rates 5.6 times lower than in matched controls. Importantly, our results demonstrate for the first time that between 2012 and 2017 Indigenous Lands and *Quilombola* Territories contributed two and three times more to native vegetation regrowth – a critical process for safeguarding biodiversity in many, if not all, parts of the world. Our results underscore the importance of areas beyond the formal protected areas system in conserving biodiversity and promoting forest regrowth.

1. Introduction

Lands governed by Indigenous Peoples and local communities have long been shown to have a positive effect in delivering environmental conservation outcomes (Hayes and Ostrom, 2003; Nelson and Chomitz, 2011; Renwick et al., 2017; Garnett et al., 2018; IPBES, 2019). Yet, several of these areas are not formally recognized for their contribution to biodiversity conservation. The Strategic Plan for Biodiversity 2011–2020 has, through Target 11, opened up for the possibility of including other areas beyond protected areas into the conservation

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agenda (CBD, 2018), through "other effective area-based conservation measures" (OECMs).

'OECMs' are geographically defined areas where biodiversity conservation is not necessarily the primary objective, but nonetheless, their primary objectives are compatible with also achieving positive, long-term in situ biodiversity conservation, as well as the conservation of associated ecosystem functions and services and other locally relevant values (CBD, 2018). Thus, many areas governed by Indigenous Peoples and local communities already providing benefits to biodiversity could be included into the conservation agenda by being recognized as OECMs, subject to the local condition of the area as well as the free, prior, and informed consent of the governance authority (Jonas et al., 2017; Alves-Pinto et al., 2021).

In Brazil, the formal system of protected areas is recognized under the Conservation Units National System (SNUC, Portuguese acronym), and includes the Conservation Units of Restrict Use (CURU; IUCN Categories I-IV), and Conservation Units of Sustainable Use (CUSU; IUCN Categories V-VI; SNUC; MMA, 2019). Further, other types of governance regimes might contribute to biodiversity conservation, such as Quilombola Territories (QT) and Indigenous Lands.

QTs, or maroon communities, are territories formed by descendants of African slaves in Brazil, which have established their own cultural, political, and subsistence system (Lopes et al., 2015). Many of these communities implement shifting cultivation and rely on extensive agriculture and extractivism (Malcher, 2017), yet lack of land regularization, land invasions, and expansion of intensive agriculture threatens their persistence (Comissão Pró-Índio, 2011; Adams et al., 2013). Even though these areas potentially contribute to biodiversity conservation by decreasing native vegetation conversion and increasing regrowth, only a handful of studies evaluating their effectiveness in doing so exist, and most are focused on forest formations (e.g., Comissão Pró-Índio, 2011; Adams et al., 2013; Nogueira et al., 2018). Indigenous Lands (IL) have been evaluated mostly with a focus on deforestation, and studies have found that they are capable of reducing forest conversion (e.g. Adeney et al., 2009; Nolte et al., 2013; Carranza et al., 2014; Pfaff et al., 2015). However, it remains unknown whether these areas contribute for the conservation of native vegetation in addition to forests, or whether they promote native vegetation regrowth.

Improvements in measuring effectiveness by matching methods is an opportunity to address gaps in information regarding the role of different governance regimes for reducing native vegetation conversion and promoting native vegetation regrowth. Here, we evaluate the effectiveness of IL, QTs as well as more traditional forms of protection: CURU, and CUSU. We assess both their ability to reduce native vegetation loss, as well as their potential for promoting native vegetation regrowth in the Brazilian Amazon.

This evaluation has global importance considering Amazon's significance for biodiversity and the recent increasing deforestation and degradation rates, being 12% higher in 2021 when compared to the 2020 rates (INPE, 2021; Grantham, 2020). Further, nations are now engaging in the United Nations Ecosystems Restoration Decade, which will be a critical process for safeguarding biodiversity in many, if not all, parts of the globe. Brazil set an ambitious goal of restoring 4.8 million ha of native vegetation in the Amazon by 2030, and there are numerous initiatives promoting forest conservation, being some of them developed inside Indigenous Lands (Urzedo et al., 2020).

Concurrently, local communities in Brazil have been negatively impacted due to increasing land grabbing and invasion by miners, lack of enforcement to protect these areas, and increasing deaths of their population by Covid-19 (Ferrante and Fearnside, 2020; APIB, 2020). Scientific evidence showcasing the role of area-based measures (protected areas and OECMs), such as local communities, play in environmental conservation might contribute for the development of necessary legal and political reforms to support these areas and the people inhabiting them.

2. Methods

We evaluated four governance regimes in Brazil (hereafter "treatments"): i) Conservation Units of Restrict Use (CURU; MMA, 2019), ii) Conservation Units of Sustainable Use (CUSU; MMA, 2019), iii) Indigenous Lands (IL; FUNAI, 2019), and iv) *Quilombola* Territories (QT; INCRA, 2019). The control areas in the Brazilian Amazon consist mainly of rural settlements, non-destined public lands, and private lands. We evaluated each treatment in a separate analysis. Shapefiles were obtained from the following open-access databases: Conservation Units (MMA, 2019); Indigenous Lands (FUNAI, 2019); Quilombola Territories (INCRA, 2019). Even though the right for land for Quilombola and Indigenous Peoples was obtained in the Brazilian constitution in 1988, the process for territory regularization is lengthy and developed individually for each territory, and therefore there is not a single creation date for all of them (INCRA, 2021).

To assess the effectiveness of the above-mentioned areas (i.e., IL, QT, CURU, and CUSU), we used statistical matching , a quasi-experimental approach that controls for known biases in the location of the treatment units that could affect their performance. We looked at two different periods, 2005–2012 and 2012–2017. This division is to reflect national-level differences in overall patterns of native vegetation conversion rates: in the first period (2005–2012) conversion decreased continuously, going from 19,014 km^2 in 2005 to 4571 km^2 in 2012 (hereafter low - native vegetation conversion period), whereas to 6947 km^2 in 2017 (hereafter high - native vegetation conversion period) (INPE, 2021).

For each period, we compared land use change among years in treated areas to those observed in the counterfactual control areas identified through the matching process. We evaluated native vegetation conversion and regrowth using the *MapBiomas* database collection 3 land cover data for the Brazilian Amazon (Mapbiomas, 2019). For our analysis we re-classified all land cover classes into either native vegetation or non-native vegetation at 1 km^2 resolution, for the two periods. Native vegetation included land cover classes that referred to natural forest, forest formation, savanic formation, mangrove, natural non-forest formation, non-forest humid natural formation, non-forest natural formation (pixel value 0). Non-native vegetation included planted forests, pastures, agriculture, mosaic formations, urban infrastructure, and mining (pixel value 1). We resampled the *Mapbiomas* pixels from 30m^2 to 1 km^2 resolution. To do so, we conservatively considered that a group of 30m^2 pixels with less than 30% pixels classified as native vegetation were considered as a non-native vegetation 1km^2 pixel. As our goal was to evaluate the conversion of native vegetation, we excluded all non-native vegetation pixels in the first years of analysis (2005 for the first period and 2012 for the second period - Fig. 1). Thus, all pixels classified as native vegetation in the first year of analysis and as non-native vegetation in the last year of analysis (2012 for first period and 2017 for second period) were considered converted. The opposite was made to evaluate regrowth, excluding all native vegetation pixels from the first years of analysis, and considering all native vegetation pixels in the last year of analysis as restored areas.

For our matching analysis, we selected nine variables described in the literature that could influence the presence of the implementation of the treatment itself (Nolte et al., 2013; Ewers and Rodrigues, 2008; Joppa and Pfaff, 2010; Jusys, 2018): slope, elevation, flooding, precipitation, distance to nearest deforestation patch, distance to nearest city, distance to nearest road, distance to nearest river, and distance to nearest city (Table 1). Given the known effect of these variables on land use (e.g. areas with greater slope and more elevated are harder to be accessed and thus would present smaller values of land-use change), by including these nine variables in our analysis we ensure that any observed differences are due to management of the treated areas. The database used for roads only included the official ones, excluding logging, gold mining, and other types of unofficial roads, which have been linked to conversion (Barber et al., 2014).

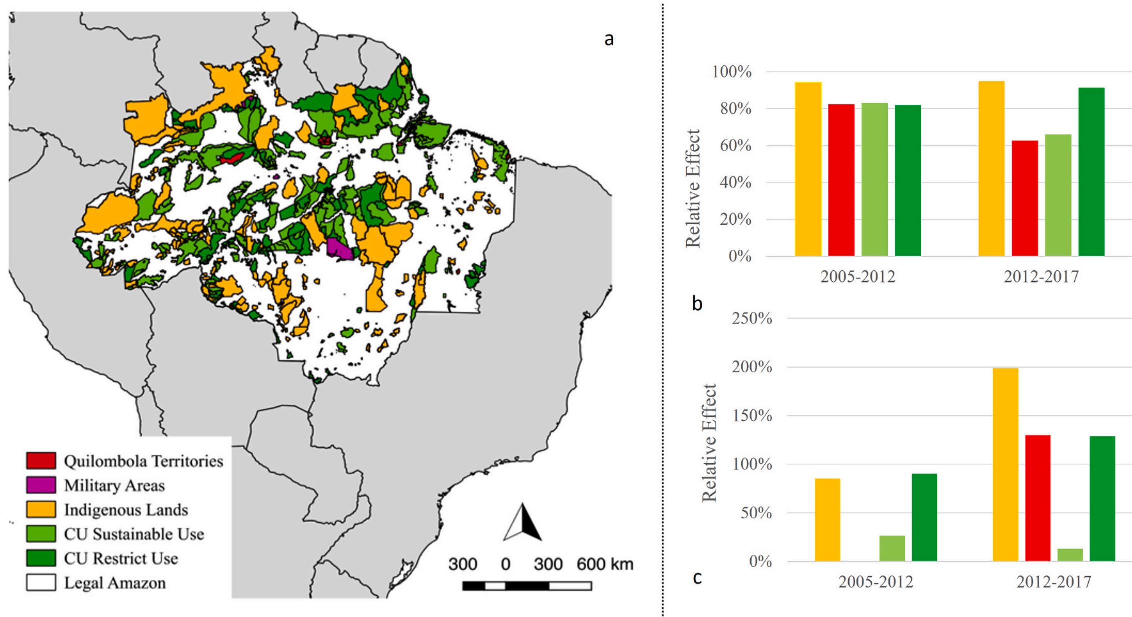

Fig. 1. (a) Location of Conservation Units (CURU and CUSU), Indigenous Lands (ILs), *Quilombola* Territories (QTs) in the Brazilian Amazon (Sources: MMA, 2019, INCRA, 2019, FUNAI, 2019, IBGE, 2019). (b) Histogram showing relative effect of avoided native vegetation conversion of each treatment for the periods of 2005–2012 and 2012–2017; (c) histogram showing relative effect of increased restoration of each treatment for the periods of 2005–2012 and 2012–2017.

Table 1
Confounding variables used in the matching analysis.

Confounding variable	Description	Source
Distance to deforestation (km)	Euclidean distance to the nearest deforested patch.	Own analysis, based on Mapbiomas (Mapbiomas, 2019)
Distance to roads (km)	Euclidean distance to the nearest road, paved and unpaved.	Own analysis, based on DNIT (DNIT, 2019)
Distance to rivers	Euclidean distance to the nearest navigable rivers.	Own analysis, based on IBGE (IBGE, 2019)
Distance to cities	Euclidean distance to cities with more than 10,000 inhabitants.	Own analysis, based on IBGE (IBGE, 2019)
Slope (degrees)	SRTM-derived landform classes. 30 m resolution, resampled to 1 km.	Own analysis, based on Global SRTM Landforms (Theobald, 2015)
Elevation (m)	SRTM Digital Elevation Data 30 m was resampled to 1 km.	(Farr et al., 2007)
Flooding	Height Above the Nearest Drainage (HAND). 90 m resolution, resampled to 1 km.	(Nobre et al., 2011)
Mean annual precipitation (mm)	TerraClimate 2.5 arcsecond, resampled to 1 km.	(Abatzoglou et al., 2018)
State	Political limit of Amazonian States	IBGE (IBGE, 2019)
x and y (degrees)	Latitude and longitude	

We performed matching analysis using the *Matchit* package from R software version 3.5 (Ho et al., 2007). Matching works through constructing groups of controls that have similar attributes for the confounding factors as that of the treatment units (covariate balancing) (Andam et al., 2008; Ferraro and Hanauer, 2014). We identified control pixels that match treatment pixels in terms of potentially confounding variables based on a sampling approach to avoid spatial autocorrelation and due to the large number of potential control pixels when using a 1 km^2 resolution for the whole Amazon. Given that there is higher likelihood of identifying an appropriate match if more control areas are available (Rasolofoson et al., 2015) we tried to select 10 control pixels with the same characteristics (i.e., similar values for the confounding factors) for each treatment pixel. To account for any possible leakage from the treatment effect (Ewers and Rodrigues, 2008; Joppa and Pfaff, 2010), we excluded from the analysis a buffer area of 5 km around each treatment unit from which control pixels could not be drawn. Buffer exclusion reduces possible leakage effects from treated areas (Ewers and Rodrigues, 2008, Fig. 2). Buffer distance varies from 1 to 10 km in other studies (e.g. Andam et al., 2008; Rodríguez et al., 2013), and we decided on a 5 km distance to ensure that enough control points would be available for the analysis.

We used Propensity Score Matching (PSM), and nearest neighbour method without replacement for all the treatments, both for native vegetation conversion and restoration analysis (Supplementary Tables 1–3; Supplementary Tables 5–7). To stipulate a limit to the choice of control pixels, avoiding dissimilar and distant pixels being chosen, we used a *caliper* of 0.25 standard deviations of each matching covariate. Pixels that go beyond this limit were excluded from the analysis, limiting the distance to which control pixels can be matched to treatment pixels (Andam et al., 2008; Pfaff et al., 2015).

We evaluated the quality of the matched samples based on whether the treatment and control have similar characteristics according to the confounding factors (Ferraro and Hanauer, 2014; Schleicher et al., 2019). We then evaluated the balance of matched data based on the Absolute Standardized Difference in Means (SDM), and by considering the values for each covariate of treatment pixels before and after the matching.

To determine if there are differences in native vegetation conversion avoidance or regrowth inside treated areas compared to their respective controls, we performed a Fisher's test with only the matched pairs, considering a confidence interval of 95% (see Supporting Materials). We evaluated the *relative effect* of the treated area by calculating the difference between conversion or regrowth in the control and treatment pixels divided by the conversion or regrowth in the control sample. This allows us to compare changes to the baseline (Carranza et al., 2014), and the performance of each treatment. We also present results in terms of native vegetation conversion avoidance for each of the treatments, comparing treated sites to their respective control areas.

3. Results

We found that native vegetation conversion was lower inside all analyzed treatment types when compared to their matched control samples. During the low- native vegetation conversion period, IL avoided the conversion of 16,367 km^2 of native vegetation, equivalent to avoiding 94% of the loss expected without the presence of IL (Fig. 2). This means that native vegetation conversion in IL was 17 times lower than what was observed in the corresponding unprotected counterfactual (Supplementary Table 5; Fig. 1b). The same pattern was observed during the high- native vegetation conversion period analyzed, in which only 616 km^2 of native vegetation was converted inside ILs, whereas 11,713 km^2 were converted in its correspondent control areas, representing a relative effect of 95% (Supplementary Table 5; Fig. 1b).

Although QT represent a small area of the Amazon territory, we found these to be almost as effective as the CURU in the low-native vegetation conversion period (relative effect QT = 82%; CURU = 83%, Fig. 1b), presenting native vegetation loss rates that were 5.6 times lower than its matched controls (31 km^2 converted inside treated areas against 176 km^2 converted in its corresponding counterfactuals) (Supplementary Table 5; Fig. 1b). Native vegetation conversion inside QTs increased slightly in the high- native vegetation conversion period (2012–2017 - 44 km^2 converted), whereas native vegetation conversion in control areas reduced (118 km^2) when compared to the first period analyzed. Yet, even in the latter period, QTs still lost 2.6 times less native vegetation than their matched control areas, representing a relative effect of 63% (Supplementary Table 5; Fig. 1b).

Both types of Conservation Units (CUSU and CURU) avoided native vegetation conversion in both periods evaluated, having similar relative effects in the low- native vegetation conversion period (CUSU = 0.83; CURU = 0.84; Fig. 1b). Yet, while 1428 km^2 was cleared inside CUSU and 8440 km^2 was cleared in their matched control areas, native vegetation conversion inside CURU was only 467 km^2 and 2591 km^2 in their correspondent controls. During the high- native vegetation conversion period, conversion inside CUSU doubled to 2970 km^2, whereas no change in the rate of loss was observed in their corresponding control areas (8780 km^2), reducing drastically the relative effect of CUSU (66%) in the second period evaluated. Conversely, the opposite pattern was observed for CURU, where native vegetation conversion inside CURUs decreased slightly (383 km^2) while it almost doubled in their corresponding control areas (4482 km^2) (Supplementary Table 5; Fig. 1b).

We evaluate here, for the first time, the ability of different governance regimes to contribute to native vegetation regrowth – a critical process in many places to reverse historic biodiversity loss. Between the years of 2005 and 2012 (low- native vegetation conversion period), CURU and IL had a positive performance in increasing native vegetation. Native vegetation regrowth was observed inside CURU 1.9 times more than in its correspondent control areas (276 km^2 inside treated areas and 145 km^2 in its control areas, relative effect = 90%). Native vegetation grew in 771 km^2 inside IL and in 416 km^2 in its matched control areas (relative effect = 85%) (Supplementary Table 10; Fig. 1c).

Regrowth inside CUSU was similar to that of their corresponding control areas (893 and 706 km^2 in and outside, respectively; relative effect 26%). QT were not evaluated for this period due to its low sample size. Between the years of 2012 and 2017, IL and CURU were ~3 and ~2 times more efficient in promoting restoration than their corresponding control areas, respectively (relative effect = 199% and 129% respectively). Although absolute numbers are low for QT (23 km^2 restored inside its areas compared to 10 km^2 in its respective control areas), it represents an increase in vegetation of 7.98% (Supplementary Table 10; Fig. 1c).

4. Discussion

Our results highlight that diverse governance regimes have important contributions to biodiversity conservation, being equal to or even more effective than formal protected areas both in avoiding native vegetation conversion and in promoting regrowth. We demonstrate, for instance, that IL and CURU have a higher contribution to curbing native vegetation conversion, but that QT and CUSU are also effective in doing so. Regarding native vegetation regrowth, IL, followed by QT and CURU, promoted the higher proportional amount of recovery.

The high and consistent performance of ILs in avoiding conversion observed in our analysis corroborates similar findings from Peru (Schleicher et al., 2017), Bolivia, and Colombia (Blackman and Veit, 2018), as well as earlier studies in the Brazilian Amazon, particularly

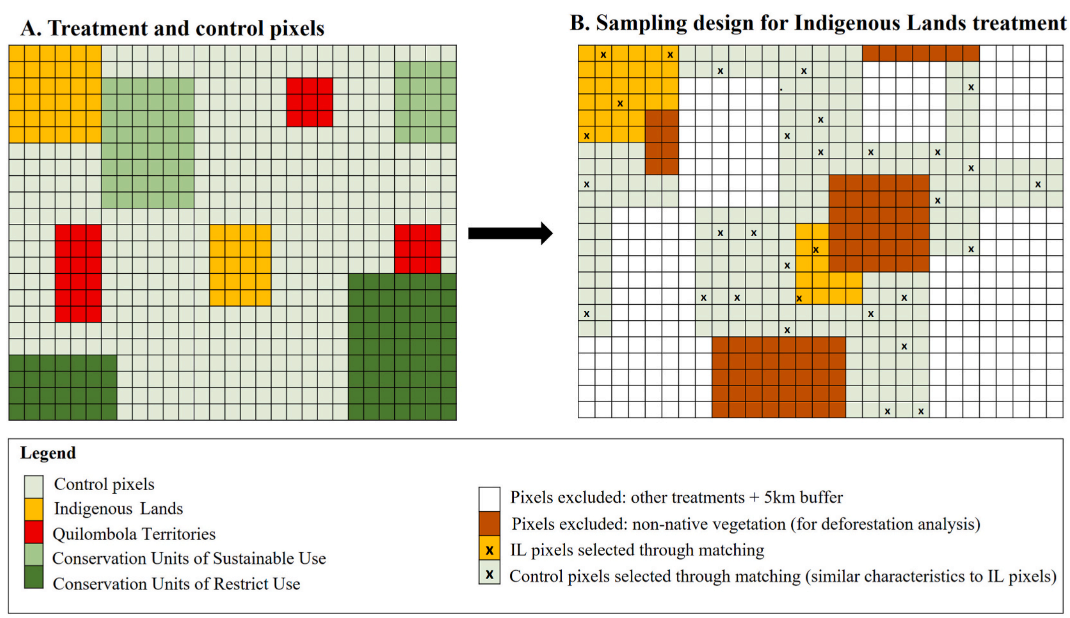

Fig. 2. Schematic figure illustrating treated and control areas, considering the four treatments analyzed (A), and pixels excluded and selected in the sampling procedure for Indigenous Lands evaluation (B). We excluded pixels that were under any other type of treatment (e.g. Quilombola Territories), that were inside the buffer of 5 km, and the ones that were not classified as native vegetation (for the native vegetation conversion analysis). The pixels selected (marked with an "x") were the ones that had similar characteristics regarding the nine confounding variables included in the study between treatment and control areas.

within a high threat agricultural frontier (Soares-Filho, 2010; Nolte et al., 2013). The mechanisms through which these areas promote positive conservation outcomes, nevertheless, might vary according to different management systems, governances and cosmologies (Carneiro da Cunha and de Almeida, 2009). Different approaches will lead to distinct relations between societies and their territories and promote diverse degrees of biodiversity conservation. Further, the time of creation of each conservation area might also interfere, as observed by Kere et al. (2017), who found that recently created Conservation Units in the Brazilian Amazon were more effective than the older ones.

It is important to keep in mind that we have used vegetation data as derived via satellites to evaluate effectiveness of the areas in curbing native vegetation conversion. Although these are informative of the condition of the environment and its threats, it is only one measure of loss and does not consider other degrading threats such as poaching, or the presence of invasive species found to be high in the Amazon (Harfoot et al., 2021). Future studies could consider different types of response variables, such as on-the-ground based species populations or communities as well as reducing threat which has revealed often more complex patterns (Barnes et al., 2016; Geldmann et al., 2018; Geldmann et al., 2019). In addition, here we could not differentiate the types of uses that compose the control area: rural settlements, private areas and non-destined public lands have different governances, and which might influence the results (Alencar et al., 2016).

Native vegetation regrowth in the Amazon can be a result of different processes. Some of it is a result of natural regrowth after land abandonment due to the implementation of swidden systems (Uhl, 1988). Swidden systems, or slash-and-burn areas, are plots used for agricultural production by local communities and are periodically deforested and left to regrowth after agricultural production. Notably, regrowth that is a result of swidden fields or slash-and-burn agricultural systems usually occur on a small scale (Uhl, 1988), and thus might have been overlooked in this work because we resampled data to 1 km^2 resolution. Likewise, other small-scale regrowth or restoration initiative might not have been captured in this work.

Some assisted and active restoration initiatives are nevertheless known in and outside Indigenous Lands (Guerra et al., 2020). Indigenous Peoples have, in Latin America, been collecting and managing seeds for different purposes, and a network of seed programmes are being established to support management of seeds for restoration (Urzedo et al., 2021). In Brazil, there are more than 24 networks supporting Indigenous Peoples on supplying seeds for restoration. One example is the Xingu watershed Network (Redes Sementes do Xingu, 2021). Further, the Fundação Nacional do Indio, the federal institution responsible for protecting and promoting Indigenous Peoples' rights in Brazil, has invested R$ 2,5 million (~US$460k) in the acquisition of seedlings, seeds, and other inputs for restoration projects inside Indigenous Lands between 2012 and 2019 (Germano and Scaramuzza, 2020).

Even though Quilombola Territories are generally small areas scattered in the territory, the results found in this study are of considerable importance. First, those territories evaluated in this study are those which have been formally registered within the Government: there are thousands of other areas still to be registered (INCRA, 2021). Therefore, as a whole, they might eventually cover a larger area in the Amazon and in the rest of Brazil. Second, it is important to consider the overall role in conservation systems of relatively small but numerous areas across landscapes and how they can be better recognized and supported through being identified as OECMs (Alves-Pinto et al., 2021). Finally, recognizing the contribution of these areas may encourage those responsible for other areas that are working towards conservation.

Our analysis showcases the role of different governance types in halting native vegetation conversion and promoting native vegetation regrowth in the Brazilian Amazon. These results can contribute to the recognition of Brazilian OECMs, which are likely to play an important role for biodiversity conservation in the next decade (2021–2030 - Open-Ended Working Group on the Post-2020 Global Biodiversity Framework, 2020). Additionally, we show that Indigenous Peoples and local communities should have a prominent role in the next decade that is considered the United Nations Decade of Ecosystem Restoration.

Yet, changes in environmental policies resulting in increased conversion, fires and local communities' invasion by miners and ranchers (Blackman and Veit, 2018) have been observed, and will likely impact the ability of QT, IL, and Conservation Units to promote biodiversity conservation. These threats represent an existential crisis that damages the communities' biocultural diversity and their links to their territories. Irrespectively of their contribution to conservation, it is necessary to ensure full respect for local communities and Indigenous Lands international and national rights (Smith et al., 2016; Jonas et al., 2017), and by assuring local communities full and effective participation in decision making processes (Magnusson et al., 2018). Thus, more executable actions of this type are possible if there is also political will.

5. Conclusion

Based on a robust quasi-experimental analysis, we go beyond forests formations and demonstrate that Indigenous Lands and Quilombola Territories in the Brazilian Amazon contribute to reduced native vegetation conversion, when compared to control areas. Our results also show for the first time that between 2012 and 2017 Indigenous Lands and Quilombola Territories contributed to native vegetation regrowth, a critical process for safeguarding biodiversity. The results obtained demonstrate that different governance regimes and potential OECMs can be equal to or even more effective than formal protected areas both in avoiding native vegetation conversion and in promoting regrowth. Even though the mechanisms through which these areas promote positive conservation outcomes might vary (e.g. management systems, governance, cosmologies, or existence of local initiatives), our findings contribute to the recognition of potential Brazilian OECMs. These are likely to play an important role in biodiversity conservation in the next decade (2021–2030), suggesting in turn that Indigenous Peoples and local communities should have a prominent role and participation in the next UN decade, including Decade of Ecosystem Restoration, and must have their rights assured.

Data availability

The authors declare that the main data supporting the findings of this study are available within the article and its Supplementary information files. Extra data are available from the corresponding author upon request.

Credit authorship contribution statement

HAP led the conception and design of the study with considerable input from JG, AB and BS, HA-P, CC and JG to the analysis, or interpretation of data, HA-P, JG, HJ, MPG, AB, JW, AL and BS have drafted the work or substantively revised it.

Declaration of competing interest

There are no competing interests to declare.

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Appendix A. Supplementary data

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