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Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of Brazilian Amazon municipalities

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ABSTRACT

The Brazilian Amazon harbours 70 % of the world's tropical forests and is essential to the country's economy because it maintains biodiversity, sustains the livelihoods of the indigenous people and local communities, and provides ecosystem services such as water production, soil stabilization, flood prevention, and climate regulation. In the last three decades, the Brazilian government has established a regional protected area (PA) network that currently covers approximately 48 % of the region. Despite their importance, some sectors of the Brazilian society have argued that the expansion of the PAs across the region hampers the local economic development, because they make less area available for non-forest economic activities such as large-scale agriculture, mining, and power generation. In this study, we analysed the relationship between local economic growth and PA coverage in 516 municipalities in the Brazilian Amazon from 2004 to 2014. We modelled the impact of the coverage of the three types of PAs (strictly-protected, multiple-use, and indigenous lands) on the (i) compound annual growth rate (CAGR) of the real gross domestic product per capita (GDP per capita), and (ii) real gross value added per capita (GVA per capita) of the agriculture, industry, services, and government sectors in each municipality. The models also considered the following control variables at the municipal level: area, age, per capita GPD in 2004 (or per capita GVAs in 2004), population growth rate between 2004 and 2014, education index, deforested area outside PA per capita, deforested area inside PA per capita, degraded area outside PA per capita, degraded area inside PA per capita, and presence of illegal mining within PA. We applied spatial Durbin error models (SDEM) to analyse the direct, indirect, and total impacts of the PAs on the local economic growth. We did not find a statistically significant relationship between the local economic growth and PA coverage in any of the three PA groups evaluated. Only the total impact of the GVA per capita of the industry was negatively correlated with the coverage of the strictly-protected PAs. Our findings do not support the arguments used by some interest groups of the Brazilian society that the social and environmental gains generated through the expansion of PAs across the region constrain the overall local economic growth.

1. Introduction

Set aside protected areas (PAs) is considered one of the most effective policies for ensuring biodiversity conservation across the world (Dudley et al., 2014; Johnson et al., 2017; Rodrigues et al., 2004). Recent assessments have concluded that when well-managed, PAs reduce habitat loss and maintain species populations (Watson et al., 2014). PAs also provide livelihoods for millions of people and maintain land carbon stocks, which helps to mitigate and regulate climate changes (Bertzky et al., 2012).

Brazil is one of the countries that most contributed with the recent expansion of PAs coverage around the world. Indeed, 74 % of the

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worldwide area spared for new terrestrial PAs during 2003–2009 was in Brazil (Jenkins and Joppa, 2009). Many of these new PAs were gazetted in the Brazilian Amazon. They had as goal to control the regional deforestation, which had reached its second highest rate in history in 2003 (Silva, 2005; Walker et al., 2009; Fearnside, 2005; Kirby et al., 2006). From 2004–2014, 845,000 km^2 of PAs were established in the region, including 315,000 km^2 of indigenous lands. The expansion of the regional PA system together with the intensification of law enforcement, improvement of monitoring systems, interventions in the soy and cattle supply chains, as well as support for forest-based economic activities, were major drivers of the regional decline in deforestation from 2004 to 2014 (Arima et al., 2014; Assunção et al., 2015; Le Tourneau, 2016; Nepstad et al., 2014, 2009; Pfaff et al., 2015).

Although political actions seeking the protection of the biodiversity in the Brazilian Amazon receive broad public support (MMA, 2012), certain groups of interest have been orchestrating a systematic campaign to change the country's advanced environmental legislation, including the way by which the country sets aside and maintains PAs (Abessa et al., 2019; Veríssimo et al., 2011). One of the most visible outcomes of these actions has been the high number of the PAs that have been degazetted, downsized, or downgraded in the country during the last years (Bernard et al., 2014; Marques and Peres, 2015; Pack et al., 2016). Currently, there are several legislative proposals under evaluation by the national parliament to allow mining and commercial agriculture within the PAs, where any such activity is currently prohibited. In parallel, anti-conservation movements are proposing new bills that seek to undermine the national PA system (Ferreira et al., 2014; Rocha, 2015; Villén-Pérez et al., 2018). Besides, the new Brazilian government is currently weakening the country's policies against deforestation, thereby threatening the rights of indigenous and extractive populations, and the conservation of the country's natural resources (Artaxo, 2019; Begotti and Peres, 2019; Kehoe et al., 2019). The major argument behind this political movement is that the Brazilian PAs constrain the local economic development because the space they take could be allocated for large-scale agriculture, mining, and power plants (Ferreira et al., 2010; de Miranda, 2009; Rodrigues, 2014).

The economic impacts of PAs on local economies have been widely discussed in the literature and they can be positive, negative, or neutral (Andam et al., 2010; Brockington and Wilkie, 2015; Hanauer and Canavire-Bacarreza, 2015; Oldekop et al., 2016; Sims, 2010; Upton et al., 2007; West et al., 2006). Positive impacts have been reported from several countries. For instance, in Costa Rica, PAs with tourism activities reduced rural poverty (Ferraro and Hanauer, 2014). In the western United States, non-metropolitan areas with national parks, wilderness, and other forms of protected public lands improved their economic performance (Rasker et al., 2012). In southwestern Australia, protected areas stimulated the local housing development sector, encouraged the local business growth, and received local government finances (Heagney et al., 2015). In Brazil, PAs ensured land use rights for the local communities, protecting them against the negative impacts of the expansion of the economic frontier (Silva et al., 2017; Veríssimo et al., 2011). On the other hand, negative impacts have also been reported, mostly from the sub-Saharan Africa. In this region, the governments that used a top-down approach to set aside PAs disrupted the local economies by imposing land uses that were not compatible with the traditional practices of the local communities (Derman, 1995; Fairhead and Leach, 2012; Gibson and Marks, 1995; Neumann, 1997). Finally, there are a few studies reporting a neutral relationship between PAs and local development. For example, Castillo-Eguskitza et al. (2017) showed that in Biscay, Spain, communities living inside a PA had better conservation features (native forest) and rural systems (forestry and primary economic sector) than those in the regions outside the PAs while maintaining similar socioeconomic and cultural conditions.

Differences on how PAs influence local development across countries are expected to be context-specific because countries have different laws on how PAs can be used and how they can be set aside. PAs can be classified in at least six categories, each one with its own set of goals and restrictions of use (IUCN et al., 2008; Jenkins and Joppa, 2009). Overall, PAs with many restrictions of usage are not always expected to produce direct economic gains, whereas PAs with fewer restrictions are expected to contribute directly to the local economic growth because they can attract and maintain a diverse set of economic activities over time (Cardoso, 2018). Regarding how PAs are set aside, some countries use a top-down approach with almost no feasibility studies and public consultation whereas others use a bottom-up approach in which detailed feasibility studies and broad stakeholder engagement are both mandatory. In general, PAs established by a bottom-up approach are more likely to minimize conflicts and produce local economic gains compared with PAs established using a top-down approach. Because conservation of biodiversity, and economic prosperity are two important goals for the sustainable development of a region (Sachs, 2015), national or sub-national studies documenting the synergies and trade-offs between these two societal goals are important for both researchers and land use policy-makers.

In this study we analysed the relationship between local economic growth and PA coverage in 516 municipalities in the Brazilian Amazon from 2004 to 2014. Because Brazilian PAs were established with different management goals, we modelled the independent impacts of three PA groups (strictly-protected, multiple-use, and indigenous lands) on municipal economic growth, as measured by the compound annual growth rate of the gross domestic product per capita (CAGR of the GDP per capita) and of the gross value added per capita (CAGR of the GVA per capita) of the agriculture, industry, services, and government sectors. We examined these relationships at the municipals while controlling for the following variables: (a) municipality's area, (b) municipality's age, (c) GDP (or sectorial GVA) per capita in 2004, (d) estimated population growth between 2004 and 2014, (e) education index, (f) deforested area outside PA per capita, (g) deforested area inside PA per capita, (h) degraded area outside PA per capita, (i) degraded area inside PA per capita, and (j) presence of illegal mining within PA.

2. Material and methods

2.1. Study area

We analysed a total of 516 municipalities in the Brazilian Amazon and 571 PAs designated by 2014 (Fig. 1). The Brazilian Amazon was delimited according to the boundaries of the Amazonia biome, as defined by the Brazilian Institute of Geography and Statistics [IBGE, Instituto Brasileiro de Geografia e Estatística] (IBGE, 2004b). This region includes the states of Amazonas, Acre, Roraima, Amapá, Pará and Rondônia, and parts of Mato Grosso, Maranhão, and Tocantins. The Brazilian Amazon covers 4.3 million km^2 and has a population of 21.6 million people, 72 % of whom live in urban areas (da Silva et al., 2017).

The Brazilian Amazon has a PA network of around 2.2 million km^2 (Brazil, 2015), which can be divided into three groups: strictly-protected PAs, multiple-use PAs, and indigenous lands (Brasil, 2000, 2006; Rylands and Brandon, 2005). Strictly-protected PAs (biological reserves, IUCN category I; ecological reserves, IUCN category I; and national parks, IUCN category II) have the basic goal of protecting the ecosystems with minimal human interference, allowing touristic activities only within certain zones of the national parks. In contrast, multiple-use PAs seek to conciliate biodiversity conservation and sustainable use of natural resources. In the Brazilian Amazon, multiple-use PAs include two major sub-groups. The first sub-group includes extractive reserves (IUCN category VI) and sustainable development reserves (IUCN category VI), aiming to protect the livelihoods and culture of local extractive populations while promoting community-driven economic development. The second sub-group includes the national or state forests (IUCN category VI) with the goal of promoting multiple use

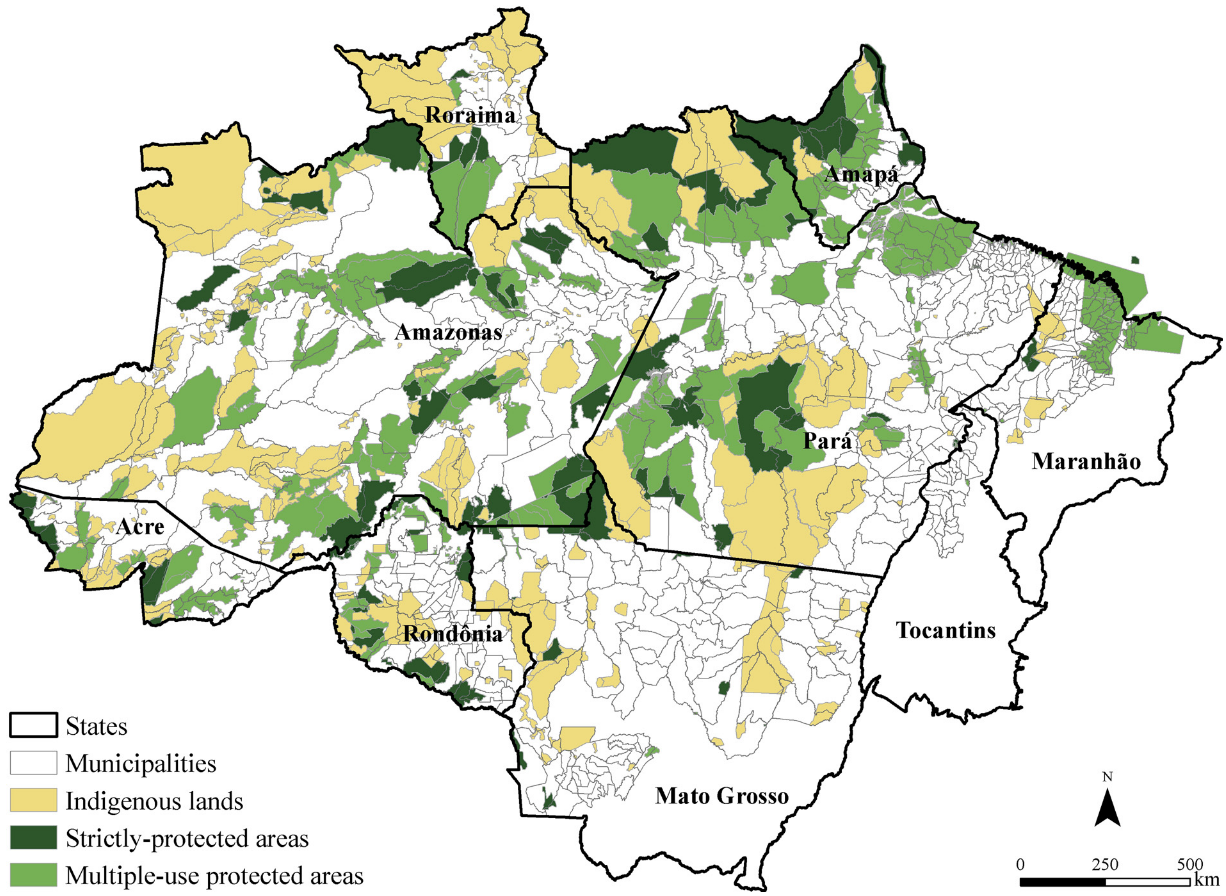

Fig. 1. Brazilian Amazon municipalities (n = 516) and protected areas (n = 571) established by 2014. The protected areas were divided into three groups: strictly-protected areas (n = 80), multiple-use protected areas (n = 185), and indigenous lands (n = 306).

of natural resources through commercial forest or mining concessions. Finally, the indigenous lands seek to guarantee the right of the Amerindians to the lands historically occupied by them, and maintenance of these indigenous people's livelihoods and cultural heritage (Brasil et al., 1988). Inside the indigenous lands, sustainable economic activities are allowed depending on the context and characteristics of the indigenous population (FUNAI, 2019; Paixão et al., 2015).

In our study, we analysed all PAs that were established by 2014 under the management of the official authorities (federal, state, and municipal levels). Other areas, such as the *quilombola* lands (Afro-Brazilian communal territories), and private lands with a legally defined environmental conservation function (e.g. riparian forests or private reserves) were not included. When there was a spatial overlap between the PAs, we corrected it by excluding the overlapping part from one of the PAs. In these cases, the criteria adopted was to maintain the PA with the most restrictive category in the following order: strictly-protected PA > multiple-use PA > indigenous land.

2.2. Data sources

All information used in this analysis was obtained from available public sources. Data about the GDP per capita, GVA per capita, estimated population, and boundaries (shapefile format) for each municipality were obtained from the databases of the IBGE (2018a, b, 2010a). Digital maps of the PAs (shapefile format) are from the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2017, 2016). The education index of each municipality, which combines the proportion of children and young people in school and the education level of the adult population, was taken from the 2010 Human Development Index of the Brazilian municipalities (United Nations Development Program, UNDP, 2013). The location of the cities (shapefile format) are from IBGE/DGC (2015). The official figures of cumulative deforested area within the municipalities (outside and inside PAs) were taken from the Satellite Monitoring System of the Brazilian Amazon Forest (Sistema de Monitoramento da Floresta Amazônica Brasileira por Satélite, PRODES) conducted systematically by the National Institute for Space Research [INPE, Instituto Nacional de Pesquisas Espaciais] (INPE, 2015). The official figures of degraded forest area within the municipalities (outside and inside PAs) were taken from the Satellite Monitoring System of Forest Degradation of the Brazilian Amazon (Mapeamento da degradação florestal na Amazônia Brasileira, DEGRAD) carried out until 2016 by the National Institute for Space Research [INPE, Instituto Nacional de Pesquisas Espaciais] (INPE, 2019). Data on the presence of illegal mining within PA (measured as the number of occurrences up to 2014) were obtained from the database organized by the Amazon Geo-Referenced Socio-Environmental Information Network (RAISIG, 2019).

Spatial datasets (PA polygons, municipality polygons, and city points) were first standardized and entered in a Geographic Information System (GIS) environment in ArcGIS 10.6 software (ESRI, 2018). Then, we generated the data required for all the subsequent statistical analyses using the following steps: First, we used the IBGE's maps to create the shapefile of the Brazilian Amazon municipalities by overlapping the maps of the Brazilian municipalities with the map of the Brazilian ecological regions (or biomes). Second, we created a shapefile of Brazilian Amazon PAs from the WDPA data, including the correction for the PA overlaps. Third, we intersected the map of the municipality's boundaries with the maps of the PAs to calculate the municipality areas and the proportion of each PA type (strictly-protected, multiple-use, and indigenous lands) in each municipality. Fourth, for each municipality, we gathered the following information from public databases:

GDP (and sectorial GVA) per capita (2004–2014), population in 2010, age, education index, deforested area outside and inside PA per capita (up to 2014), degraded area outside and inside PA per capita (up to 2014), and presence of illegal mining within PA. All the information was organized in a final database for the analyses. We used equal area projection (Projection: Albers Equal Area Conic; Datum: South America, 1969) in all the shapefiles and maps.

2.3. Analysis

In our models, the dependent variables were the local economic growth as measured by the CAGR of the GDP per capita and the growth of specific economic sectors as measured by the CAGR of the GVA per capita for each one of the four main economic sectors: agriculture, industry, services, and government. This approach is used for comparisons of economic performance at local level (Fagerberg and Verspagen, 1996; Gordon, 2012; Klasen and Lamanna, 2009; Mo, 2001; Romer, 1986; Scully, 1988; Persson and Tabellini, 1994). We calculated the CAGR for the period between 2004 and 2014 – the period where the number of the PAs in the Brazilian Amazon increased most rapidly – by following three steps: 1) We divided the GDP (or GVAs) per capita of the final year in the time-series (2014) by the GDP (or GVAs) per capita of the initial year of the time-series (2004); (2) then, we raised the result to the power of 1 divided by the total length of the period (10 years); and (3) finally, we subtracted 1 from the result. We estimated the GDP and GVAs per capita in thousands of Brazilian Reais (R$). The 2004 GDP and GVAs per capita were converted to 2014 GDP and GVAs per capita values by considering Brazil's national inflation by using the Broad National Consumer Price Index [Índice Nacional de Preços ao Consumidor Amplo, IPCA], an official Brazilian inflation index (IBGE, 2018c), as the deflator.

We used as predictor variables the percentage of the municipality areas covered by the three PA groups (strictly-protected, multiple-use, and indigenous lands). Because several other factors can influence economic growth at the local level, our models included variables that are usually associated with economic growth such as the municipalities' area (log-transformed), age, 2004 GDP (or GVAs) per capita (log-transformed), population growth (overall rate from 2004 to 2014), and education index (Table 1). In the Brazilian Amazon, informal economy is an important but unknown component of the local economy (Silva et al., 2017). Hence, we also included deforested area outside PA per capita, deforested area inside PA per capita, degraded area outside PA per capita, degraded area inside PA per capita, and presence of illegal mining within PA as proxies of the intensity of the local informal economic activities. We chose these indicators because although deforestation, forest degradation and mining in the region is not always illegal, most of the informal economic activities in the rural Brazilian Amazon seems to include the illegal use of natural resources. Of course, informal economy also includes several community-based economic activities that the Brazilian state currently cannot control, such as small-scale fisheries that supply to the most of the local markets, and extraction and commercial use of non-timber forest products. However, such economic activities are more difficult to assess at regional level (Almeida et al., 2001; Antunes et al., 2016; Cleary, 1993; Kauano et al., 2017; Simmons et al., 2007).

We followed the protocol of data exploration described by Zuur et al. (2010). Box plot and Cleveland dot plots were used to visualize the CAGR values. We retained all the values in the analyses even when some municipalities presented growth rates above or below the regional trend (Fig. A.1 to A.5). We log-transformed the CAGR values for all the subsequent analyses. We added 1 to the CAGR values due to the presence of negative rates. Cleveland dot plots were also used to visualize the predictor and control variables. We found that some municipalities had a high GDP and GVAs per capita in 2004, and some municipalities had very large areas (Fig. A.6 and A.7). Therefore, these five variables were also log-transformed. Variance inflation factors (VIFs) were used to determine the presence of collinearity in the predictor and control variables. We found no strong collinearity (all VIFs < 4; Table A.1), and thus all variables were used in the subsequent analyses.

We used five ordinary least squares regressions (OLS) on the relationship between the proportions of different PA types and the economic growth (CAGR of the GDP per capita and CAGR of the GVA per capita of the agriculture, industry, services, and government sectors) of Brazilian Amazon municipalities from 2004 to 2014 (Table A.2 to A.6, Fig. A.7 to A.12). The control variables (Table 1) were also included in the fitted OLS regressions. We verified the spatial dependence of the residuals of the fitted OLS regressions using a Moran's I test and applying Lagrange Multiplier tests. To apply these tests, we built a weighted distance matrix (Table A.7) based on contiguity neighbours' graph (queen-style) (Fig. A.13). The Moran's I tests showed significant spatial dependence for all models (Table A.8), and the Lagrange Multiplier test diagnostics indicated that a spatial error simultaneous autoregressive model to be more appropriate for the observed spatial autocorrelation in the models (Table A.9). As a consequence, we applied spatial error models (SEM) and spatial Durbin error models (SDEM), using the same weighted distance matrix as the spatial dependence evaluation. A likelihood ratio test between the SEMs and the SDEMs was used to verify if the spatial autoregressive error specification was internally consistent (Arbia, 2014). The SEMs (Table A.10 to A.14) were fitted only for evaluating the error specification, considering that the SDEMs (Tables A.15 to A.19) improved our interpretation because this procedure considers the autocorrelation of the variables in the neighbouring municipalities. This procedure is important because it assesses the neighbouring impacts, in which indirect impacts (spatial spillovers) interact with direct impacts (own municipality), producing a total (overall) impact (e.g. an indirect impact may nullify a significant positive direct impact on growth level and produce an insignificant or negative total impact) (LeSage and Fischer, 2008). For all models (OLSs, SEMs, and SDEMs), we tested for normality using a Jarque-Bera test and for heteroskedasticity using a studentized Breusch-Pagan test. Finally, we evaluated the SDEM impacts (direct, indirect, and total) by generating 1000 simulations in a Markov Chain Monte Carlo (MCMC) process. All the analytical procedures used here were based on the spatial econometrics methods described by Le Sage and Fischer (2008), LeSage and Pace (2009); Bivand et al. (2013a), and Arbia (2014).

We used the R-platform (R Core Team, 2018) for all the statistical analyses. The R scripts used were adapted from Zuur et al. (2010); Bivand et al. (2013a); Bivand and Piras (2015) and Arbia (2014). The R packages used in our study were "rgdal" (Bivand et al., 2018), "sp" (Pabesma and Bivand, 2005), "lattice" (Sarkar, 2008), "spdep" (Bivand et al., 2013b; Bivand and Piras, 2015), "coda" (Plummer et al., 2006), "tseries" (Trapletti and Horninik, 2018), "lmtest" (Zeileis and Hothorn, 2002), and "ggplot2" (Wickham, 2016).

3. Results

The GDP per capita across the municipalities ranged from R$ 1,910 to R$ 94,820 (mean of R$ = 8,170) in 2004 and from R$ 3,770 to R$ 86,600 (mean of R$ = 13,400) in 2014 (Table A.20). The estimated regional population was 17,962,134 in 2004 and 21,282,131 in 2014 (Table A.20). Over the entire study period, the annual CAGR of the GDP ranged from -5.51 % to 23.66 % (mean = 5.56 %) (Table A.21, Fig. 2b). The CAGR of the GVA per capita of the agriculture ranged from –16.84 % to 30.31 % (mean = 4.40 %), of the industry ranged from –18.12%–55.04% (mean = 5.87 %), of the services ranged from -3.19%–24.42% (mean = 6.87), and of the government ranged from 0.18%–22.79 % (mean = 6.12) (Table A.22, Fig. 2c–f). The regional PA coverage in 2014 was 47.9 %, of which 9.6 % were strictly-protected, 16.0 % were multiple-use, and 22.3 % were indigenous lands (Table A.21, Fig. 2a). Most of the municipalities (72.48 %) had some PA coverage within their territories.

The SDEM on the log of CAGR of the GDP per capita had an R^2 of

Table 1
The explanatory variables used to evaluate the interactions between the economic growth of Brazilian Amazon municipalities and the proportion of protected areas coverage from 2004 to 2014.

Explanatory variables	Description
Strictly-protected areas (%)	Percentage of strictly-protected area (PA) coverage in each municipality in 2014. This variable was used to evaluate the hypothesis that strictly-protected PAs have a negative or no association with the economic growth of Brazilian Amazon municipalities.
Multiple-use PAs (%)	Percentage of multiple-use PA coverage in each municipality in 2014. This variable was used to evaluate the hypothesis that multiple-use protected areas have a positive association with the economic growth of Brazilian Amazon municipalities.
Indigenous lands (%)	Percentage of indigenous land coverage in each municipality in 2014. This variable was used to evaluate the hypothesis that indigenous lands have a negative or no association with the economic growth of Brazilian Amazon municipalities.
Municipality area	Municipality area in km^2. Municipality area was included to consider the differences in municipality size in the models. This variable was included because larger municipalities are expected to have a higher economic growth.
Municipality age	Municipality age in 2014. Municipality age was included to evaluate the prediction that old municipalities have had more time to create a government capable of organizing their development, and consequently have a higher economic growth.
Population growth	Population growth was defined as the difference between the municipalities' populations in 2004 and 2014 divided by the population in 2003. The values were log-transformed before the calculation: Population growth = *(log(population 2014) – log(population 2003))/ log (population 2003)*. The expectation is that municipalities with a higher population growth have a bigger work force and consequently have a higher economic growth.
Education index	The education sub-index variable of the 2010 Municipal Human Development Index was used by considering that education level of a population is positively correlated with economic growth.
Deforested area outside PA per capita	Cumulative deforested area (km^2) up to 2014 per capita in the municipality and outside PAs. Deforestation is associated with the traditional expansion of the economic frontier in the developing regions, and it can also be associated with informal economic activities in the Brazilian Amazon. This variable was included because municipalities with greater cumulative deforested area outside PAs are expected to have a higher economic growth.
Deforested area inside PA per capita	Cumulative deforested area (km^2) up to 2014 per capita inside PAs settled in the municipality. This variable was included because municipalities with greater cumulative deforested area inside PAs are expected to have a higher economic growth.
Degraded area outside PA per capita	Cumulative forest degraded area (km^2) up to 2014 per capita in the municipality and outside PAs. Forest degradation could be an indicative of timber extraction and also be associated with the expansion of the economic frontier. Then, it could be associated with informal economic activities in the Brazilian Amazon. This variable was included because municipalities with greater forest degraded area outside PAs are expected to have a higher economic growth.
Degraded area inside PA per capita	Cumulative forest degraded area (km^2) up to 2014 per capita inside PAs settled in the municipality. This variable was included because municipalities with greater forest degraded area inside PAs are expected to have a higher economic growth.
Presence of illegal mining within PA	Presence of illegal mining within PA in the municipality (number of occurrences up to 2014). The formal GDP only captures a portion of the local economic activity and an important share of the economic activities at the local level is informal or illegal. The illegal mining within PAs (mainly gold mining) could help understanding the variability of local economic performance and its association within PAs. This variable was included because municipalities with greater number of illegal mining inside PAs are expected to have a higher economic growth.
GDP per capita 2004	GDP per capita in 2004 was used because the value in the initial year is an important factor to consider in growth models. The assumption is that municipalities with a lower initial per capita GDP have a higher economic growth.
Agriculture GVA per capita 2004	This variable was utilized because the value in the initial year is an important factor to consider in growth models. The assumption is that municipalities with a lower initial agriculture GVA have a higher economic growth in this sector.
Industry GVA per capita 2004	This variable was utilized because the value in the initial year is an important factor to consider in growth models. The assumption is that municipalities with a lower initial industry GVA have a higher economic growth in this sector.
Services GVA per capita 2004	This variable was used because the value in the initial year is an important factor to consider in growth models. The assumption is that municipalities with a lower initial services GVA have a higher economic growth in this sector.
Government GVA per capita 2004	This variable was used because the value in the initial year is an important factor to consider in growth models. The assumption is that municipalities with a lower initial government GVA have a higher economic growth in this sector.

0.37 (adjusted R^2 = 0.34), indicating a good fit between the data and the model. The SDEM on the log of GVA per capita of the government sector had an R^2 of 0.57 (adjusted R^2 = 0.55), of the services sector an R^2 of 0.40 (adjusted R^2 = 0.38), of the industry sector an R^2 of 0.35 (adjusted R^2 = 0.32), and of the agriculture sector an R^2 of 0.43 (adjusted R^2 = 0.40) (Tables A.15 to A.19).

Overall, we did not find any significant impact (direct, indirect, or total) on the CAGR of the GDP per capita and on the coverage of any PA group when all the control variables were kept constant (Table 2). However, when evaluating the economic growth by sectors, we found a significant relationship between strictly-protected PA coverage and the total impact of the CAGR of the industry-associated GVA (Table 3).

All the control variables had statistically significant total impacts on CAGR of the GDP per capita, with the exception of the municipalities' age, deforested area outside PA per capita, deforested area inside PA per capita, degraded area outside PA per capita and presence of illegal mining within PA (Table 2). The area of the municipality was positively correlated with the CAGR of the GVAs corresponding to the agriculture, industry, and services sectors (Table 3). Population growth was negatively correlated with the CAGR of the GVAs corresponding to the agriculture, services, and government sectors (Table 3). On the other hand, the education index was positively correlated with the CAGR of the GVAs corresponding to the industry and services sectors (Table 3).

The deforested area (outside and inside PA), forest degraded area (outside and inside PA) and illegal mining within PA were not significantly associated with the CAGR of the GDP per capita (Table 2). The deforested area outside PA per capita was positively correlated with the CAGR of the GVA of the government sector, but the degraded area outside PA per capita was negatively correlated with the same variable. The degraded area inside PA per capita was positively associated with the CAGR of the GVA of the services sector. The presence of illegal mining within PA had a negative association with the CAGR of the GVA of the agriculture sector (Table 3).

We found that heteroskedasticity was not a restriction for the SDEM on the log of CAGR of the GDP per capita (studentized Breusch-Pagan test; BP = 29.99, df = 26, p-value = 0.27) and of the CAGR of the GVA per capita of the industry sector (studentized Breusch-Pagan test; BP = 27.87, df = 26, p-value = 0.36). In contrast, the SDEM residuals were not normally distributed for all the models. All the SDEMs were able to deal with the spatial dependence observed on the OLS residuals (Table A.23). The likelihood ratio test between the SEM and the SDEM suggests that the spatial autoregressive error specification is internally consistent for the CAGR of the GDP per capita and the CAGR of the GVA per capita of the agriculture sector (Table A.24).

4. Discussion

By using the best data available, reliable spatial econometric

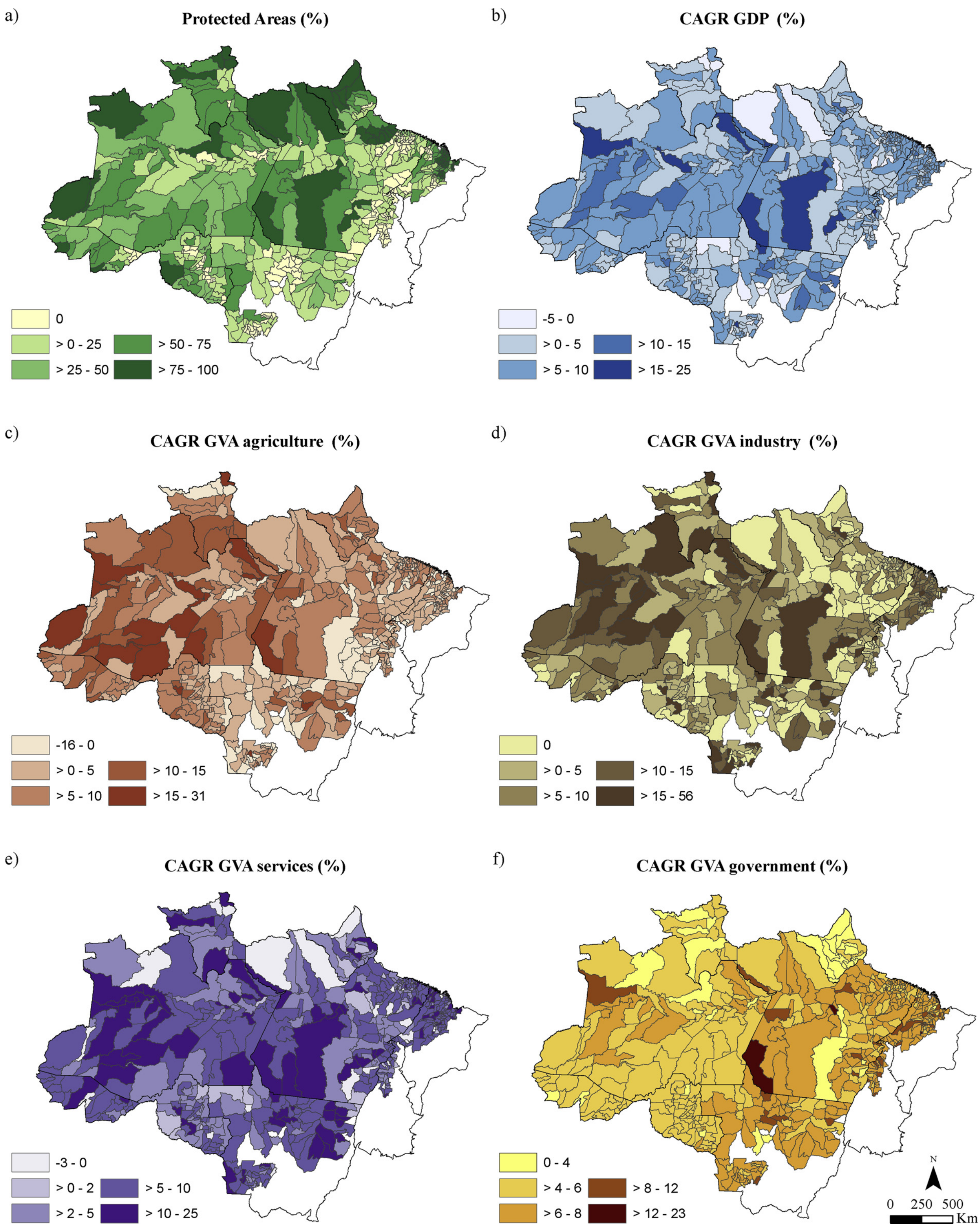

Fig. 2. (a) Percentage of the protected areas designated by 2014 in the Brazilian Amazon municipalities. Percentages for the period from 2004 to 2014 of the (b) compound annual growth rate (CAGR) of the local gross development product (GDP), (c) CAGR of the agriculture sector gross added value (GVA) per capita, (d) CAGR of the industry sector GVA per capita, (e) CAGR of the services sector GVA per capita, and (f) CAGR of the government sector GVA per capita.

methods, and considering key control variables, we demonstrated that the economic growth of the municipalities in the Brazilian Amazon have overall neither increased nor decreased with changes in the coverage of strictly-protected PAs, multiple-use PAs, and indigenous lands from 2004 to 2014. The same general pattern was found when the economic growth was analysed by sectors, albeit with the following one exception: The growth of the industry sector showed a negative association with the total impact of the strictly-protected PAs coverage. Hence, overall, our results do not support the arguments used by some sectors within the Brazilian society that social gains (e.g. protection of the rights of the local communities and indigenous people) and environmental gains (e.g. biodiversity protection and provision of services

Table 2
Impacts of the spatial Durbin error model (SDEM) results on the log of the compound annual growth rate (CAGR) of the gross development product (GDP) per capita in the 516 Brazilian Amazonian municipalities from 2004 to 2014. The impacts were obtained by a Markov chain Monte Carlo (MCMC) process using 1000 randomizations.

	Direct Estimate	Std. Error		Indirect Estimate	Std. Error		Total Estimate	Std. Error	
CAGR GDP									
Strictly protected areas	−0.00013	0.00015		0.00007	0.00028		−0.00005	0.00026	
Multiple-use protected areas	−0.00001	0.00008		0.00006	0.00012		0.00005	0.00010	
Indigenous lands	0.00000	0.00010		−0.00006	0.00017		−0.00006	0.00015	
Municipality area (log)	0.00413	0.00180	*	0.00191	0.00245		0.00604	0.00207	**
Age	−0.00001	0.00002		−0.00004	0.00005		−0.00005	0.00005	
GDP per capita 2004 (log)	−0.02960	0.00342	***	0.00564	0.00556		−0.02396	0.00526	***
Population growth	−0.02626	0.00400	***	−0.00113	0.00783		−0.02738	0.00839	***
Education index	0.07070	0.02045	***	0.01013	0.03303		0.08083	0.03201	*
Deforested area outside PA per capita (log)	0.01736	0.02239		0.00329	0.04221		0.02065	0.04489	
Deforested area inside PA per capita (log)	−0.12559	0.15090		0.41845	0.32026		0.29286	0.31937	
Degraded area outside PA per capita (log)	0.10016	0.08080		−0.27764	0.16231		−0.17748	0.16122	
Degraded area inside PA per capita (log)	0.09485	0.14066		0.56682	0.24897	*	0.66167	0.26035	*
Presence of illegal mining within PA (log)	0.00152	0.00294		−0.00010	0.00553		0.00142	0.00522	

Significance: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

to the local, regional and global population) generated from the expansion of the PAs across the region constrain the local economic growth.

A general explanation for the lack of relationships between the overall economic growth and PAs coverage at local level is that the economic activities across the Brazilian Amazon are spatially highly concentrated. For example, our results showed that 50.3 % of the regional GDP was concentrated in 10 municipalities that altogether covered an area of roughly 90,000 km^2 (only 2 % of the total area) and contained 33.2 % of the regional population in 2014. This highly spatial concentration of the economic activities at the municipal level in the Brazilian Amazon can be attributed to the following factors: large municipal areas, low human density, and high urbanization. In fact, most of the municipalities across the region are large (76 % are above 1000 km^2, compared with the mean size of 716 km^2 for all Brazilian municipalities), had low human densities in 2014 (the Brazilian Amazon had a human density of 4.92 people/km^2 whereas the statewide Brazilian human density was 22.42 people/km^2 in 2010), and had a high urbanization ratio (72 % of the regional population was living in the urban areas in 2010). In the last four decades, the regional population has shifted from mostly rural to mostly urban areas (IBGE, 2010b). This trend continues, and the regional urban population is expected to be approximately 80 % of the total regional population by 2030. Excluding the municipalities in the southern Brazilian Amazon, whose economy is based on large-scale commercial agriculture, this fast and chaotic urbanization process is leading to a high concentration of economic activities around relatively small urban areas (Becker, 2005). Hence, establishment of PAs, even large ones, far away from the major urban centres results in little impact, if any, on the local economies.

We found that the growth of industry sector is negatively influenced by the coverage of strictly-protected PAs. The industry is the only economic sector that diverged from the general pattern of no significant relationship between the economic growth and PA coverage. A potential explanation for this finding is that the industrial sector across most of the municipalities in the Brazilian Amazon is based on the basic processing of timber, non-timber forest products, and minerals (Pattanayak and Sills, 2001), whose extraction are not allowed within the strictly-protected PAs. However, this hypothesis need to be tested with more refined studies at local level. The existence of this negative correlation could help to explain the reaction against PAs by the industry sector. For example, some representatives of this sector such as illegal gold miners and loggers may mobilize disproportional political support given their connections with politicians, including electoral campaign finance. News media reports and recent cases of corruption investigation show the connection between politicians and environmental criminals in the Brazilian Amazon (Pailler, 2018). This contrast with opinion pools that reveals that the majority of Brazilians support the conservation of the Amazon (Imazon, 2018).

In the last decades, several science-based models to promote sustainable development across the region have been proposed. These models have in common the assumption that the traditional regional development model based on continuous deforestation to produce commodities would not improve the living standards of the regional population in the long-term (da Silva et al., 2017; Nobre et al., 2016). This assumption is based on global studies that demonstrated that although real per capita GDP increases as the amount of agricultural land expands, this income growth is not durable, and GDP per capita declines at some point in the long run with further expansion of the agricultural lands (Barbier, 2019). Moreover, the conversion of forests into pastures and agricultural land is not a guarantee for future economic growth, since forest loss has been associated with reduced rainfall in southern Amazonia and this will likely affect agricultural production as well as the hydroelectric power production in the region (Aragão et al., 2018; Leite-Filho et al., 2019). Another point that could be considered is the role that education can play to increase the regional development. The education has been one of the most important indicators of economic development, where the higher the education is, the higher the economic growth (Nowak and Dahal, 2016; Pastor et al., 2018). Thus, as expected, we found that the education index had a positive relationship with the gross development product (GDP), which indicates that if efforts are made to improve the level of science and technology in the sustainable use of Amazonian natural resources and agribusiness, economic and environmental gains can be achieved.

Most of the development models proposed to the Brazilian Amazon advocate a mix of policies that combine the intensive use of the areas that have been already deforested (approximately 20 % of the region or roughly 860,000 km^2) and the outright conservation of remaining forests. The intensification of the land use can be done through the generation of industrial and service centres around mid-sized cities as well as the use of technology to increase the agriculture output in the deforested areas that are currently unproductive (Vieira et al., 2008). Support for the hypothesis that economic spatial intensification can lead to a reduction of conflicts between conservation and expansion of agricultural productivity comes from two pieces of evidence. First, we found no significant correlation between the growth of the agriculture sector and PA coverage expansion. Second, recent studies showed some evidence of decoupling between agriculture production and deforestation (Macedo et al., 2012; Thaler, 2017; Zalles et al., 2019).

In addition to increase the economic output caused by the efficient use of the lands that have been deforested, the region also needs that

Table 3
Impacts of the spatial Durbin error model (SDEM) results on the log of the compound annual growth rate (CAGR) of the gross value added (GVA) per capita in the 516 Brazilian Amazonian municipalities from 2004 to 2014. The GVA values analysed represent the following four main sectors that constitute the GDP of the Brazilian municipalities: agriculture, industry, services, and government. The impacts were obtained by a Markov chain Monte Carlo (MCMC) process using 1000 randomizations.

	Direct Estimate	Std. Error		Indirect Estimate	Std. Error		Total Estimate	Std. Error	
CAGR GVA Agriculture									
Strictly protected areas	0.00012	0.00025		0.00069	0.00048		0.00082	0.00048	
Multiple-useprotected areas	0.00007	0.00013		−0.00006	0.00021		0.00001	0.00018	
Indigenous lands	0.00000	0.00016		−0.00021	0.00029		−0.00021	0.00028	
Municipality area (log)	0.00899	0.00285	**	0.00874	0.00399	*	0.01773	0.00357	***
Municipality age	0.00000	0.00004		−0.00006	0.00008		−0.00006	0.00010	
GVA agriculture per capita 2004 (log)	−0.01991	0.00295	***	0.00702	0.00530		−0.01289	0.00552	*
Population growth	−0.05167	0.00631	***	−0.01586	0.01291		−0.06753	0.01427	***
Education index	−0.13625	0.03003	***	0.11905	0.04650	*	−0.01719	0.04593	
Deforested area outside PA per capita (log)	0.03975	0.04007		−0.16218	0.07929	*	−0.12244	0.08633	
Deforested area inside PA per capita (log)	−0.10660	0.24592		0.45408	0.53662		0.34748	0.55253	
Degraded area outside PA per capita (log)	0.26838	0.13312	*	−0.09292	0.27912		0.17546	0.28855	
Degraded area inside PA per capita (log)	−0.04548	0.23162		0.67146	0.42579		0.62598	0.46678	
Presence of illegal mining within PA (log)	−0.00546	0.00476		−0.01540	0.00939		−0.02087	0.00936	*
CAGR GVA Industry									
Strictly protected areas	−0.00047	0.00041		−0.00122	0.00075		−0.00169	0.00071	*
Multiple-useprotected areas	0.00020	0.00021		−0.00016	0.00033		0.00004	0.00027	
Indigenous lands	−0.00042	0.00026		0.00064	0.00046		0.00022	0.00043	
Municipality area (log)	0.01539	0.00485	**	0.00021	0.00648		0.01560	0.00539	**
Municipality age	−0.00003	0.00006		−0.00014	0.00013		−0.00017	0.00015	
GVA industry per capita 2004 (log)	−0.04271	0.00358	***	0.00489	0.00630		−0.03783	0.00630	***
Population growth	−0.02125	0.01042	*	−0.00683	0.02099		−0.02809	0.02272	
Education index	0.27044	0.05365	***	0.05978	0.08330		0.33022	0.07808	***
Deforested area outside PA per capita (log)	−0.00796	0.05944		0.00651	0.11120		−0.00145	0.11876	
Deforested area inside PA per capita (log)	−0.33363	0.40604		0.56511	0.85552		0.23148	0.85341	
Degraded area outside PA per capita (log)	−0.13626	0.21826		−0.02977	0.43980		−0.16603	0.43979	
Degraded area inside PA per capita (log)	0.15381	0.37948		−0.18334	0.67187		−0.02953	0.70851	
Presence of illegal mining within PA (log)	0.01269	0.00792		−0.00837	0.01505		0.00431	0.01437	
CAGR GVA Services									
Strictly protected areas	−0.00005	0.00018		−0.00060	0.00034		−0.00065	0.00034	
Multiple-useprotected areas	−0.00008	0.00009		0.00016	0.00015		0.00008	0.00013	
Indigenous lands	−0.00019	0.00011		0.00019	0.00021		0.00000	0.00020	
Municipality area (log)	0.00644	0.00216	**	−0.00006	0.00298		0.00638	0.00259	*
Municipality age	−0.00004	0.00003		−0.00006	0.00006		−0.00010	0.00007	
GVA services per capita 2004 (log)	−0.02647	0.00306	***	0.00383	0.00564		−0.02264	0.00589	***
Population growth	−0.03757	0.00468	***	0.00713	0.00961		−0.03044	0.01061	**
Education index	0.10517	0.02944	***	0.02172	0.04774		0.12689	0.04621	**
Deforested area outside PA per capita (log)	−0.00045	0.02647		0.00679	0.05157		0.00634	0.05662	
Deforested area inside PA per capita (log)	−0.16000	0.17931		0.77367	0.39125	*	0.61367	0.40167	
Degraded area outside PA per capita (log)	−0.07492	0.09610		0.00525	0.20121		−0.06967	0.20786	
Degraded area inside PA per capita (log)	0.33459	0.16779	*	0.53779	0.30869		0.87237	0.33735	**
Presence of illegal mining within PA (log)	0.00170	0.00345		−0.00324	0.00683		−0.00154	0.00678	
CAGR GVA Government									
Strictly protected areas	−0.00007	0.00006		0.00000	0.00012		−0.00007	0.00012	
Multiple-useprotected areas	0.00001	0.00003		0.00003	0.00005		0.00004	0.00004	
Indigenous lands	0.00007	0.00004		−0.00007	0.00007		0.00000	0.00007	
Municipality area (log)	−0.00094	0.00072		0.00189	0.00104		0.00095	0.00097	
Municipality age	−0.00002	0.00001		0.00000	0.00002		−0.00001	0.00003	
GVA government per capita 2004 (log)	−0.03566	0.00361	***	0.01461	0.00424	***	−0.02105	0.00255	***
Population growth	−0.01449	0.00161	***	0.00175	0.00328		−0.01275	0.00366	***
Education index	−0.01077	0.00745		0.03358	0.01210	**	0.02280	0.01266	
Deforested area outside PA per capita (log)	0.02406	0.00920	**	0.03747	0.01796	*	0.06153	0.01971	**
Deforested area inside PA per capita (log)	0.10617	0.06143		−0.09660	0.14072		0.00957	0.14692	
Degraded area outside PA per capita (log)	0.02733	0.03299		−0.21521	0.07084	**	−0.18788	0.07416	*
Degraded area inside PA per capita (log)	−0.03060	0.05785		0.19761	0.10773		0.16701	0.11958	
Presence of illegal mining within PA (log)	0.00200	0.00118		−0.00130	0.00236		0.00070	0.00238	

Significance: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

the remaining forests can contribute to the regional economy. Among the several policies tested to date to promote both forest conservation and socio-economic development, establishment of PAs is considered as one of the most effective. The major reason is that PAs reduce social conflicts, deforestation, and waste of natural resources caused by illegal activities because the gazettement of these areas sets limits on the types of economic activities that can be developed within them as well as who is accountable for their management (Blankespoor et al., 2017; Kauano et al., 2017; Nolte et al., 2013). However, PAs require financial resources to be implemented and thus fulfil their social, economic, and environmental goals. In Brazil, PA implementation remains a challenge. For example, the most recent assessment of the management quality of the federal PAs in the Brazilian Amazon –a subset of the PAs analysed here– indicated that only few of them could be considered to have met the minimum requirements to be considered fully operational (WWF et al., 2017). Besides, a recent audit by the *Tribunal de Contas da União* (TCU) pointed out that only 4 % of the region's strictly-protected PAs and multiple-use PAs had an adequate management. The audit also found suboptimal use of the economic, social, and environmental potential of the areas (e.g. national parks without public use, national forests without community forest management or forest concessions, and biological reserves without research) (TCU, 2013). The situation of the indigenous lands is not any different from the other two groups of PAs because FUNAI (National Indigenous Foundation), the government agency responsible for the support to indigenous people, is underfunded and understaffed to fulfil its commitments (Phillips, 2017).

Implementing economic activities within PAs, such as the use of non-timber forest resources, forest concessions, tourism concessions, and payment for ecological services, can generate local and regional economic gains (Fraga et al., 2015; ICMBio, 2019, 2018, 2017, 2014; Lima and Peralta, 2017; Young and Medeiros, 2018). There are several studies demonstrating that non-timber forest products are an important economic activity for the populations living inside PAs (Ball and Brancalion, 2016; Guariguata et al., 2017; Robinson, 2016; Pereira et al., 2018). Similarly, if properly implemented, forest concessions in national and state forests could generate 1.8 million cubic meters of wood per year based on a conservative scenario (Pereira et al., 2018). Besides, forests can also generate revenues related to carbon stocks. For example, Junior et al. (2018) demonstrated that the strictly-protected and multiple-use PAs in Amazon have the potential to prevent deforestation of 143,000 km^2 and the release of approximately 9 billion tons of carbon-equivalent into the atmosphere; these services, in turn, could generate revenues of ca. 35 billion dollars if markets for such services existed. Finally, to every dollar that Brazil invested in tourism within PAs, it received US$ 7 in economic benefits (Souza et al., 2018).

Despite their potential to contribute to local economies, the successful implementation of economic activities in PAs depends of several other factors that are beyond the control of PA management authorities. For example, in relation to the forest sector, although the Brazilian forest policy has focused on sustainable forest management and the responsible institutions were strengthened over time (Bustamante et al., 2018), logging has been declining significantly in recent years (Veríssimo and Pereira, 2014; Young and Medeiros, 2018). The investment conditions for logging concessions in the Amazon are still not attractive, especially considering the lack of regional infrastructure (Azevedo-Ramos et al., 2015). Despite the potential of national forests to generate revenues, only 6 of the 34 existing national forests in the Amazon have a forestry concession in progress (SFB, 2019). In general, PAs in the Brazilian Amazon have not been adequately implemented and their potential to contribute to the local economies still remains to be fully realized (de C. Dias et al., 2016).

One caveat of our study is that it is based on the GDP per capita measured by official sources. In summary, it represents only a part of the total local economy. Although we used proxies to control the impact of the informal economy on our analyses, the impact of establishing PAs on local informal economies still needs to be assessed by combining field surveys and modelling. It is possible that in municipalities where the informal economy is based on the extraction of natural resources, the intensity of the informal economic activities would decline with the expansion of PAs and their implementation. The main reason is that the designation of PAs brings more and better law enforcement by governments, which consequently constrain illegal activities (Joppa et al., 2008; Kauano et al., 2017; Watson et al., 2016). On the other hand, it is also possible that PAs can foster informal rural economic activities. For instance, in those municipalities where the informal economy is currently limited due to lack of land security and government support, new PAs can increase local informal economies by ensuring that local populations have the right to use their lands, are protected against newcomers, and have access to social programs (Pinho et al., 2014; Simmons, 2004; Veríssimo et al., 2011).

Our study shows that there is no support for the hypothesis advanced by some interest groups in the Brazilian society that PA expansion in the Brazilian Amazon can constrain the growth of the local economies. In contrast, we found that in general there is no correlation between economic growth and PA coverage at municipal level. There is evidence that policies combining land use intensification in areas that have already been deforested and the establishment as well as implementation of PA in the remaining forests is a promising path to promote sustainable development across the region if the current financial and institutional bottlenecks are removed. To understand the synergies and trade-offs between PAs and local economies in different socio-economic contexts is a promising research agenda that can shed some light on the complex transitions that societies in tropical countries need to manage if they want to move towards a more sustainable development trajectory.

Research data for this article

All information used in this analysis was obtained from available public sources and the sources are cited on the paper. All the information was organized in a final database for the analyses and will be made available on request.

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Declaration of Competing Interest

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Appendix A. Supplementary data

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