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Land use policy as a driver for climate change adaptation: A case in the domain of the Brazilian Atlantic forest

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ABSTRACT

Brazil has a great potential for ecosystem-based adaptation to climate change and to disaster risk reduction, leveraged by the commitment of restoring 12 million hectares until 2030. This commitment is legally backed by the Native Vegetation Protection Law (NVPL), which defines the situations in which landowners must recover native vegetation in their land. In this paper, we discuss the role of land use compliance as a driver for adaptation in the Brazilian Atlantic forest domain based on the case of the State of Rio de Janeiro. We used high resolution satellite imagery (5 m pixel) to map the state's land use and land cover, delineate Areas of Permanent Preservation and calculate the environmental debt, i.e. the areas required for restoration in order to comply to the NVPL. We also related the distribution of the environmental debt to the socioeconomic conditions of the municipalities and examined potential funding sources for economic incentives to enhance feasibility of restoration in private lands. The state has 31% of native vegetation cover, and an environmental debt of 412,876 ha, correlated to Human Development Index ($R = -0.2952$, $p = 0.0043$) and vulnerability to poverty ($R = 0.3711$, $p = 0.0003$). The north-northwestern region hosts the hotspots both for environmental debt and vulnerability to poverty, therefore it should constitute a priority target for environmental and social policies. Compliance to this large environmental debt to abide to the regulatory policy NVPL will demand incentive mechanisms. Oil royalties are a potential funding source for programs of payment for ecosystem services, as 3% of those annual revenues could pay the restoration of 39% of the state's environmental debt per year over 20 years. Thus, policy mixes that combine existing regulatory and incentive mechanisms should ensure low-cost landscape restoration in tandem with new job opportunities in a restoration chain, and might represent a significant opportunity for the State of Rio de Janeiro.

1. Introduction

Recent anthropogenic emissions of greenhouse gases are the highest in history, with severe impacts in human and natural systems all across the globe. Climate change will amplify existing risks and create new ones, unevenly distributed, and generally greater for disadvantaged people (IPCC, 2014). Despite national commitments of reducing emissions, temperature will continue to rise, leading to the depletion of ecosystem services such as food and water provision (Rogelj et al., 2016). In this scenario, carbon mitigation will continue to be relevant, but alone will not suffice to halt or circumvent ongoing climate trends. Adaptation strategies are needed to increase resilience of vulnerable socio-ecological systems (Scarano, 2017).

Ecosystem-based adaptation to climate change (EbA) is the set of adaptation measures which take into account the role of ecosystem services (ES) in reducing the vulnerability of society to climate change (Magrin et al., 2014; Vignola et al., 2009). Within this approach, adapting requires a combination of policy instruments related to nature conservation and restoration with socioeconomic policies that foster livelihood diversification and, consequently, income generation and poverty reduction (Jones et al., 2012; Magrin et al., 2014; Scarano, 2017).

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Brazil has a great potential for EbA, leveraged by the commitment of restoring 12 million hectares until 2030, assumed in December 2016 by the national government in the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). Unlike many contributions announced by the UNFCCC parties, the one ratified by Brazil has national legal backing (Scarano, 2017). Brazil's Native Vegetation Protection Law – NVPL (Brasil, 2012) establishes the proportion of lands inside rural properties that must be maintained under protection and defines the situations in which landowners must recover native vegetation in their land (Brancalion et al., 2016). It establishes two main types of areas of restricted use: the Areas of Permanent Preservation (APP) and the Legal Reserve (LR). The APP comprises riparian areas, hilltops, slopes, high elevations and certain types of ecosystems; while the LR correspond to a proportion of the property (varying from 20 to 80% according to the biome where the property is inserted). In order to comply, landowners must restore all degraded areas inside riparian APP and LR, which constitutes the so-called "environmental debt" of a given property. The environmental debt of LR can also be settled outside its original property, through compensation and offset mechanisms such as environmental leaseholds or by purchasing areas with native vegetation in other properties (Brancalion et al., 2016).

Estimates are that for legal compliance rural landowners will need to restore 20 million hectares (Soares-Filho et al., 2014), which is nearly twice Brazil's commitment to the UNFCCC. Restoring those areas is essential to ensure water and food security in Brazil, once they provide key ecosystem services such as water flow regulation, soil fixation and pollination (Brancalion et al., 2016; Rey Benayas et al., 2009). At the same time, if well planned, landscape restoration has the potential to create jobs and improve livelihoods, enhancing society's resilience to climate change (Stanturf et al., 2015).

The main caveat is that restoration is costly. In the case of the Atlantic Forest biome, where most food production in Brazil takes place and also where the most capacity and tools are available (Scarano and Ceotto, 2015), conservative estimates point to an average cost of USD 5000 per hectare of forest restored by traditional techniques of direct planting (Brancalion et al., 2012b). The economic feasibility of restoration will require both public and private efforts in order to strengthen its economic chain, from the production of seedlings and inputs to the direct planting and management of degraded areas. Besides environmental benefits, this chain can enhance local economies, through the creation of new jobs and business opportunities (Silva et al., 2016).

In this paper we discuss the role of land use compliance as part of a subnational EbA strategy, by examining the case of the State of Rio de Janeiro, southeast Brazil. We analyze the distribution of the legal environmental debt in the state and discuss strategies to achieve compliance, considering both socioeconomic and environmental aspects. To perform this analysis we took the following steps: i) mapped the state's land use and land cover using high resolution satellite imagery (5 m pixel) and delineated riparian APP, based on the legislation; ii) calculated the environmental debt in APP of each municipality; iii) related the distribution of the environmental debt to the socioeconomic condition of the municipalities; and iv) examined potential funding sources for economic incentives to enhance feasibility of restoration in private lands.

2. Material and methods

2.1. Study area

The State of Rio de Janeiro (42°45′6"W; 22°25′39"S) comprises an area of 43,802 km^2 in Southeastern Brazil, an equivalent to the total area of the Netherlands or Switzerland, inserted in the Atlantic Forest biome, a biodiversity hotspot (Mittermeier et al., 2005) and one of the regions with the highest richness of terrestrial vertebrates in the world (Jenkins et al., 2013). The capital, Rio de Janeiro, is the fourth largest city in South America (United Nations, 2016), and together with its metropolitan region holds a total population of 12.3 million people, or 74% of the state's total population of 16.6 million people (IBGE, 2016)

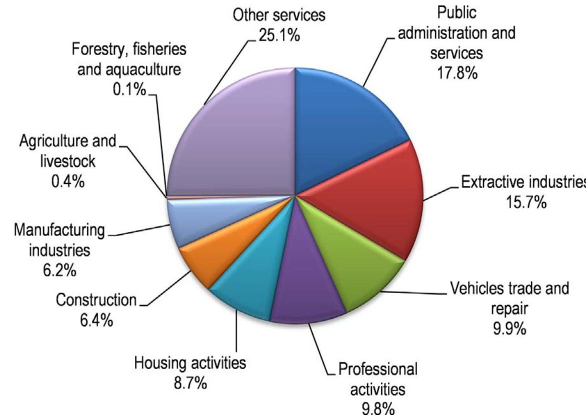

Fig. 1. State of Rio de Janeiro's gross domestic product (GDP) by gross value added (GVA). Data extracted from IBGE (2013a).

The economy of the State of Rio de Janeiro is strongly based in oil extraction. In 2015, the state produced 618 million barrels, which corresponded to 67% of Brazil's production (ANP, 2016) and 2% of global oil supply (IEA, 2016). It composes 16% of the state's gross domestic product, and moves a great part of the state's economy with its supply and processing chains (IBGE, 2013a). Rural activities such as agriculture, livestock and forestry compose less than 0.5% of the gross domestic product (Fig. 1).

Recently the state witnessed extreme climate events associated with the distribution of rainfall, which caused a series of casualties. Since 2012, a national-wide phenomena of a gradual and intense decrease in rainfall undermined significantly the water provision. This situation culminated in 2014, when, together with São Paulo, Rio de Janeiro faced a water supply collapse (Dobrovolski and Rattis, 2015; Marengo et al., 2015). In contrast, in 2011 and 2012 the region also faced major floods events, leaving more than 15,000 people homeless, businesses destroyed and plantations devastated (OECD, 2015). Recent studies indicate that water supply in Rio de Janeiro will be exhausted in 2030, when the metropolitan area of Rio de Janeiro will concentrate 95% of the state's water consumption due to a very uneven distribution of population and economic activity (COPPETEC, 2014). Avoidance of this scenario requires the development of adaptive mechanisms that enhance the state's resilience to extreme events.

2.2. Mapping

We mapped land use and land cover through supervised classification of RapidEye imagery (5 m resolution) of the year 2012, comprising the classes I) native forest formation; II) native non-forest formation; III) silviculture; IV) built areas; V) anthropic areas and VI) water. Total native vegetation cover is given by the sum of classes I and II, respectively forests (sensu IBGE, 2012) and all other native vegetation types (i.e high-altitude fields, inselbergs and sandy coastal plains – see Scarano (2009) for description of the vegetation types of the Atlantic forest biome). For a better understanding of the distribution of this class, we crossed the results of this mapping with the official databases of protected areas (MMA, 2017) in order to calculate the amount of native vegetation located inside protected areas.[1]

Regarding non-natural classes, silviculture comprises all tree monocultures, predominantly *Eucalyptus spp*. and *Pinus spp*. Built areas were extracted from Brazil's official continuous cartography (IBGE,

[1] Here we adopted the term protected areas as a synonym for conservation units, while APP and RL can be framed as Other Effective Conservation Measures (OECM).

2013b) and used as a proxy for urban areas, in order to subsidize APP calculations (see supplementary material for calculation details). Anthropic areas comprise agriculture, pastures, roads, mining and degraded areas.

Vector checking and editing were performed in the scale of 1:10,000, capturing polygons ≥0.3 ha. Map validation was made through 8122 randomized checkpoints, which were compared to high resolution satellite imagery from Google Earth, similarly to Cohen et al. (2010), and reached an accuracy of 97%.

The official hydrology base of the State of Rio de Janeiro in the scale of 1:25,000 (IBGE and SEA, 2006) was adjusted on the RapidEye images. Adjustments comprised two situations: i) rivers over 10 m wide represented as lines were digitized as polygons in order to allow the calculation of its APP; ii) rivers and waterbodies which had their courses altered along time were updated. We calculated riparian APP according to the marginal strip width values stipulated in the NVPL (see supplementary material for calculation details). Absolute environmental debt was calculated as the sum of the areas occupied by land use classes III, IV and V inside APPs, and relative environmental debt corresponds to the absolute debt divided by the total area of APP.

2.3. Socioeconomic data

We analyzed the relationship between environmental debt and socioeconomic conditions of the municipalities by spatial cluster analysis, using as social indicators the human development index (HDI) and the rate of vulnerability to poverty (PPOB), defined as the percentage of population with average monthly income up to BRL 255 (~USD 77) in August 2010 (PNUD et al., 2013). In order to identify possible hotspots for social and environmental conditions, we compared the patterns of distribution of those variables using Anselin Local Moran's I, which identifies spatial clusters of features with high or low values at $p < 0.05$.

In order to analyze potential funding sources for economic incentives to restoration, we compiled data on annual production of the State's economic activities from the Brazilian Institute for Geography and Statistics (IBGE, 2013a) and the National Oil Agency (ANP, 2016). Maximum restoration costs were projected based in the average price of USD 5000 per hectare, estimated by the Atlantic Forest Pact (Brancalion et al., 2012b).

3. Results and discussion

3.1. Land use and land cover

The State of Rio de Janeiro has 31% of native vegetation cover, of which 29% are forest remnants and 2% are non-forest natural ecosystems. The estimate of natural cover is higher than the one widely used to the Atlantic Forest (SOS Mata Atlântica and INPE, 2015), most likely due to the higher resolution of the satellite imagery used for the present study, which allowed the detection of more areas of native cover. Two thirds of the state are covered by non-natural areas, of which 4% corresponds to built areas, 1% to silviculture and 63% to other types of anthropic areas such as pastures, croplands, mining and degraded areas. Water covers 2% of the state's surface (Fig. 2).

Native vegetation is concentrated in the southern and central areas of the state, which correspond to the more rugged relief areas of the Serra do Mar Ridge. These remnants play a key role in biodiversity conservation, as this ridge presents very high levels of species richness in a global scale, and holds the highest level of endemism for several taxonomic groups in the Atlantic Forest (Jenkins et al., 2013). Only 41% of total native cover is located inside protected areas (PA), of which 25.7% are inside full protection public PA (13.5% under state, 10.8% federal and 1.4% municipal administration), 14.6% are inside sustainable use public PA (7.7% under federal, 6.0% state and 0.9% municipal administration) and 0.5% inside private PA. As with most protected areas in Brazil, those in Rio de Janeiro still lack land-tenure regularization (Bernard et al., 2014; Rocha et al., 2010). Therefore, a significant part of those remnants is probably inside private properties.

Regarding legal compliance, the percent native cover of the state (31%) is above the minimum threshold of 20% established for LR in each property in the Atlantic Forest, according to NVPL. The mechanisms of environmental compensation provided by the NVPL allow landowners to compensate their LR deficit outside their properties, through environmental leaseholds, purchasing either areas with native vegetation or Environmental Reserve Quotas (CRA) (Brancalion et al., 2016; Brasil, 2012). Considering the application of those mechanisms, the environmental debt of LR in Rio de Janeiro may be largely compensated inside the state.

3.2. Distribution of the environmental debt

The State of Rio de Janeiro has an estimated environmental debt of 412,876 ha in APP, heterogeneously distributed along the state (Fig. 3, Table S4). The North-Northwestern region (N-NW) is the most affected, with a cluster of 19 municipalities highly degraded, which together comprise 38% of the state's total debt.

The distribution of the environmental debt relates to the socioeconomic conditions of the municipalities. We found that municipalities with higher relative environmental debt have lower HDI ($R = -0.2952$, $p = 0.0043$) and higher vulnerability to poverty ($R = 0.3711$, $p = 0.0003$). Cluster analysis shows that the N-NW region hosts the hotspots both for environmental debt and vulnerability to poverty (Fig. 4A and B), indicating that this area should constitute a priority target for both environmental and social policies.[2]

By paying off this debt with forest restoration, the state would contribute to 3.4% of the Brazil's National Determined Contribution of restoring 12 million hectares until 2030 (Brasil, 2015). Regarding costs, restoring the environmental debt of the state by direct planting would require a total investment of about USD 2.1 billion, or USD 103 million per year considering the deadline of 20 years established by the NVPL.

This estimate of annual restoration costs to landowners so as to overcome the legal environmental debt inside the APPs corresponds to 18% of the total value of annual production of agriculture and livestock in the state (IBGE, 2013a,b), which suggests the unfeasibility of this process. Thus, in order to expect compliance, we believe three alternatives should be looked into: (a) how could restoration costs be reduced?; (b) if farming is unproductive and farmers cannot afford restoration, can other interested parties pay for it?; and (c) should unproductive municipalities switch to other main economic activities? These alternatives are not mutually exclusive and they can all operate simultaneously. Furthermore, in some municipalities the negative balance between production and restoration cost is even greater, considering that agriculture and livestock production are concentrated in few areas and most municipalities present a land use pattern of low productivity in rural areas (IBGE, 2015).

3.3. Restoration feasibility

The feasibility of restoration begins with an optimization of the allocation of resources. The recent excitement with the potential for natural regeneration of tropical forests (Chazdon et al., 2016; Poorter et al., 2016) echoes previous studies conducted in the State of Rio de Janeiro (Rezende et al., 2015), which suggest that some portion of the existing environmental debt can be restored at low costs. Inside areas

[2] Thus, our approach is complementary to the "green poverty" approach (municipalities with extensive green cover, high poverty and high exposition to climate change) of Kasecker et al. (2017) that defined priority municipalities for EbA policies based on incentives for conservation and livelihood improvement in Brazil. In our case, by detecting clustered municipalities that combine environmental debt and poverty, we propose EbA action based on incentives for restoration and livelihood improvement.

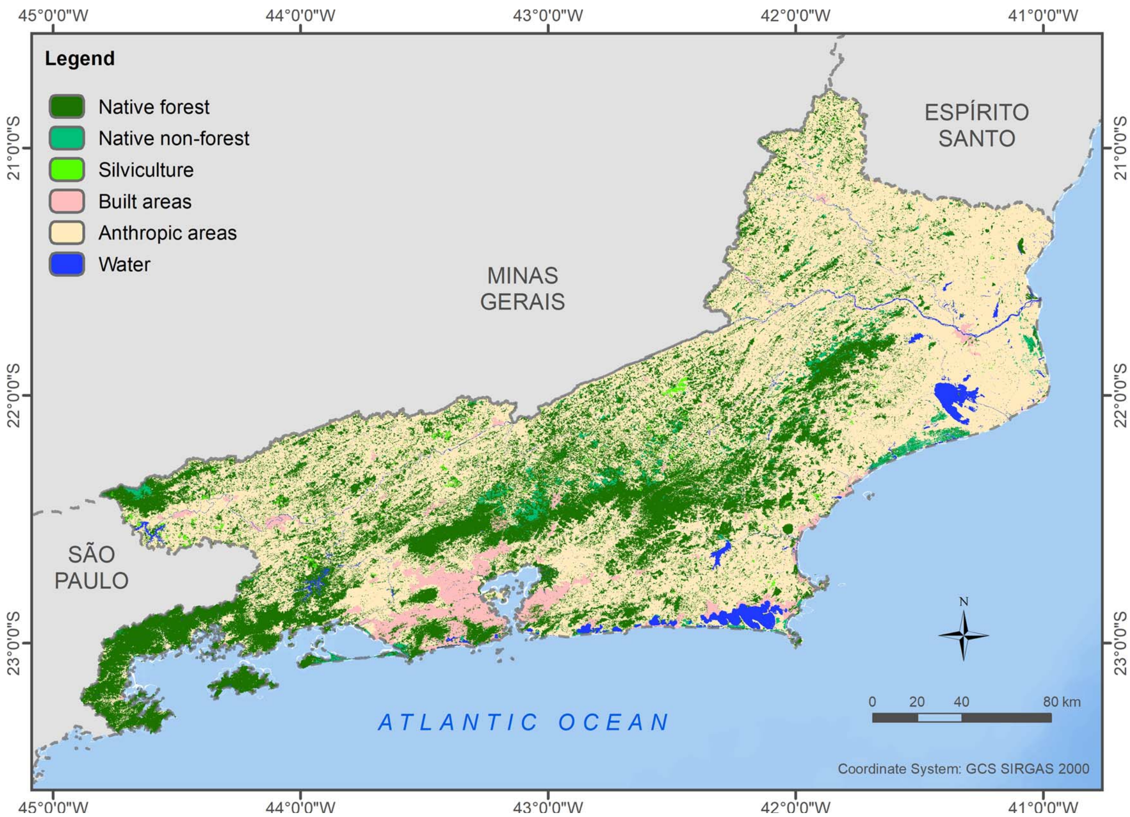

Fig. 2. Land use and land cover in the State of Rio de Janeiro, southeastern Brazil, mapped with RapidEye 5 m resolution images.

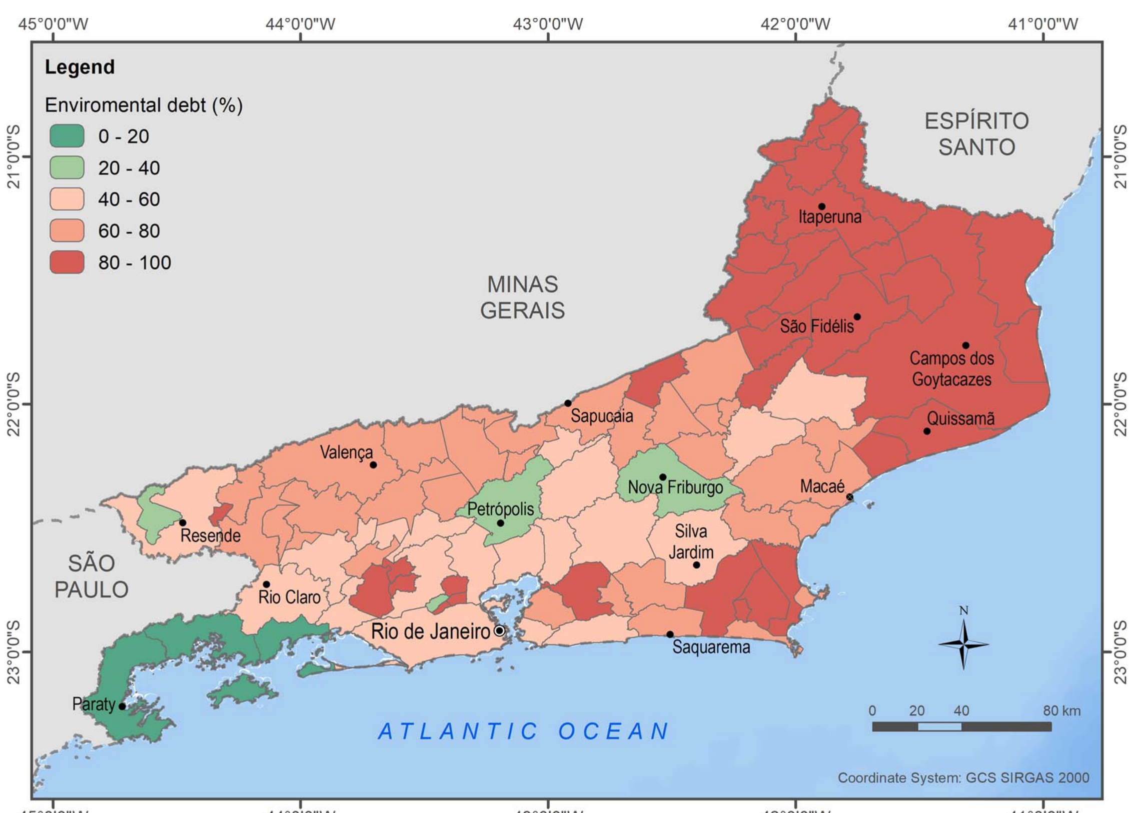

Fig. 3. Relative environmental debt in Areas of Permanent Preservation (APP) per municipality in the State of Rio de Janeiro, Southeast Brazil.

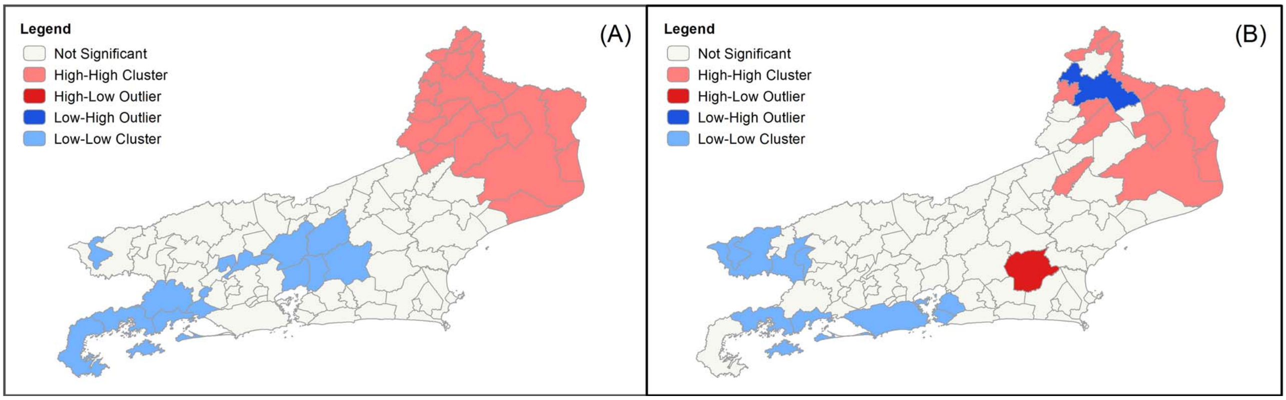

Fig. 4. Results of cluster analysis for environmental debt (A) and vulnerability to poverty (B), indicating low–low clusters for both indicators in the North-Northwest region on the State of Rio de Janeiro.

with high potential for natural regeneration, restoration costs for one hectare can decline to USD 440, when no intervention is necessary, or USD 760, when the area requires management of exotic grass and fences to isolate areas from disturbance − costs that range from 34% to 50% of the costs of direct planting all individuals (MMA, 2014). Identifying those areas with a higher potential for natural regeneration is essential to guide restoration planning, also considering that regeneration areas may require different levels of intervention, including exotic species management and enrichment with native species, in order to accomplish the desired level of ecosystem restoration (Brancalion et al., 2012a; Crouzeilles et al., 2017).

While the technical component of the strategy guarantees the best allocation of resources in order to achieve biodiversity and ecosystem services restoration at reduced costs, the social component is fundamental for engaging landowners. Engagement is not only key to enable restoration, but also to guarantee the perpetuation of restored areas along time, as the long-term effectiveness of rules in a socioecological system relies directly on users' willingness to monitor one another's harvesting practices (Ostrom, 2009). The definition of the best strategies to engage landowners in restoring their properties will depend on the regional context, considering characteristics of land use, social dynamics and economic activities taking place on the areas with environmental debt. Alternatives to increase economic attractiveness include mixed plantings; exploitation of non-wood forest products; payment for ecosystem services (PES); improvement of production systems, and long-term credit facilities at attractive rates (Brancalion et al., 2012b).

The state already has a specific legislation concerning PES, and three main programs running, all focused in restoration and conservation inside rural properties. According to official data (CEIVAP, 2015; INEA, 2015a, 2015b), those programs cover an area of 7772 ha designated for conservation and 1314 ha for restoration, which together account for less than 0.3% of the surface of the state. The expansion of those programs relies on finding alternative sources of financing, which may include the private sector. Since the State of Rio de Janeiro produces 67% of the oil production of the country (ANP, 2016), the oil sector is an obvious candidate. Moreover, since the oil industry is one of the two sectors with the highest demand for water in the state (OECD, 2015), and responds for a significant part of the state's carbon emissions, incentives to restoration schemes could compensate or offset carbon, water and biodiversity budgets of the sector.

The neighboring State of Espírito Santo already uses oil revenues − so-called 'royalties', i.e. the financial compensation due to the federative entities in function of the production of petroleum, natural gas and other fluid hydrocarbons (Brasil, 2010) − to fund restoration. In 2008, the state approved a law that redirects 3% of total oil royalties to restoration. Those resources are used by the government to support a state-wide program of PES, which stimulates landowners to restore by paying an amount of USD 820 − 2700 per hectare restored, depending on the restoration technique applied, plus an additional bonus of USD 70 as an annual reward (Sossai et al., 2016). If applied in Rio de Janeiro, a similar program would have an annual budget of around USD 40 million, based in 3% of last year's royalties collected by the state government (Cruz et al., 2016), not considering the amounts collected by the municipalities. That amount covers the annual costs of planting 39% of the environmental debt in APP of the state, considering a period of 20 years.

Implementing in the State of Rio a program similar to that of Espírito Santo would require a modification in the state's budget, a sensitive issue considering the current economic crisis the state is going through. The tax revenue of the state and of the vast majority of municipalities currently depends heavily on production in this sector. With the drastic drop in international oil prices, there was a sharp fall in the tax revenues (de Oliveira, 2017). Once the state's economy has reestablished itself, designating a small percentage of these resources for restoration would represent an important switch in the application of royalties revenues towards a safer and healthier environment for future generations. At the same time, this innovation would contribute to mitigate the actual impacts of this sector in producing regions, which was the original purpose of the creation of the Brazilian royalties' legislation in 1953 (Brasil, 1953; Seabra et al., 2015).

The injection of resources through mechanisms like PES could strengthen the restoration chain in degraded municipalities − from the production and commercialization of inputs to the execution of the restoration in the field − stimulating the generation of jobs and boosting the economy, while improving the provision of ecosystem services. This dynamics would be especially beneficial in the hotspot of the N-NW region of the state, which concentrates at the same time the greater indices of environmental liabilities and poverty. Regarding biodiversity, restoring those areas in the N-NW region of the state could help improving ecological connectivity between the blocks of forest remnants located in the north of Rio de Janeiro and the south of Espírito Santo, which host critically endangered species like the northern muriqui monkey (*Brachyteles hypoxanthus*), the largest primate of the Americas (Cunha et al., 2009).

Because riparian vegetation plays a key role in sediment retention and protecting streams from nonpoint source pollutants (Dosskey et al., 2010), we can expect that restoring this vegetation debt will also have a relevant impact in water quality in the state. A recent study conducted in the Atlantic Forest indicated that APPs restoration can improve water quality and increase watershed resilience during dry season (Pires et al., 2017).

4. Conclusions

Restoring the environmental debt in APP is the first step to enhance water and food security in Rio de Janeiro, contributing to the adaptation of the state to climate change. Adaptation will require not only landscape restoration, aiming the provision of ecosystem services, but also the improvement of social conditions, allowing the access to these services by the entire population. Thus, policy mixes that combine existing regulatory and incentive mechanisms, which may ensure low-cost restoration in tandem with new job opportunities in an active restoration chain, represent a significant opportunity for the State of Rio de Janeiro.

The vast scientific knowledge and technical expertise on the restoration of the Atlantic Forest, as well as the good repertoire of policies applicable to this theme, will not be sufficient to pay off the environmental debt if there is no adherence of the population in the field. The capacity for local self-organization to establish the supply, production and consumption chains for the restoration will be essential and will depend on the stimulus and sense of opportunity of local actors.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landusepol.2018.01.027.

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