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How Changes in Legally Demanded Forest Restoration Impact Ecosystem Services: A Case Study in the Atlantic Forest, Brazil

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Abstract

The recent change in Brazilian laws reduced the amount of area that is set aside for native vegetation restoration in rural private properties. However, we lack estimates of its impacts on the provisioning of key ecosystem services at local scales. Therefore, in a microwatershed in the Brazilian Atlantic Forest hot spot, we quantified the impact of the change from the Forest Code (1965) to the Native Vegetation Protection Law in Brazil (2012) on future native forest cover, biomass carbon stocks, and soil loss and sedimentation. We analyzed three scenarios: (a) the land use and cover as of 2016, (b) the Forest Code, 1965, and (c) the Native Vegetation Protection Law, 2012. In each scenario, we modeled soil loss and sedimentation (InVEST, Revised Universal Soil Loss Equation) and calculated the carbon stocks. The 2012 law implementation would increase forest cover (15.6%), decrease soil sedimentation (1.12%) and loss (1.13%), and increase carbon stock (5.4%). However, compared to the Forest Code, it would reduce the area for restoration and the potential for native forest cover growth, increase soil loss and sedimentation potential, and limit increases in carbon stocks at the landscape level. In both restoration scenarios, the potential percent increase in forest cover in the microwatershed owing to the laws is higher than the percent decrease in soil loss and sedimentation. These findings have the potential to elucidate the effect of laws on ecosystem services and be useful to those planning the creation, modification, and implementation of laws for forest restoration in private properties.

Keywords

Atlantic Forest, carbon, ecological restoration, landscape modeling, revised universal soil loss equation, soil management

Introduction

Degradation of biomes has compromised biodiversity conservation and provisioning of ecosystem services at global scales (Costanza et al., 2014). Tropical forests provide ecosystem services for millions of people worldwide (Beer et al., 2010; Millennium Ecosystem Assessment, 2005; Molnar, Scherr, & Khare, 2004). However, they have not been spared from degradation, with several instances worldwide of tropical forests that are currently fragmented and degraded (Achard et al., 2014; Haddad et al., 2015; Spracklen, Kalamandeen, Galbraith, & Spracklen, 2015; Tabarelli, Da Silva, & Gascon, 2004). The Brazilian Atlantic Forest, for example, has suffered vast devastation owing to urban and industrial growth and intensive farming, and currently, there is less than 16% of its original forest cover remaining, distributed in thousands of small and fragmented forest patches (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009).

Ecosystem restoration is currently a global priority to reverse degradation of biomes (Aronson & Alexander, 2013). Global and national commitments have been set with ambitious restoration targets (Bonn Challenge Latin America, 2017). In some countries, legal

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instruments ensure ecological restoration in degraded landscapes. This is the case in Brazil, where national laws have historically required rural landowners to conserve or restore the native vegetation in part of their lands (Soares-Filho et al., 2014; Sparovek, Berndes, Barreto, & Klug, 2012).

A law requiring native vegetation restoration in Brazil (Native Vegetation Protection Law) was established in 2012, replacing the Forest Code of 1965. This replacement brought significant changes in native vegetation conserved or restored in rural properties. Primarily, the 2012 law reduced the riverside area required to have forest buffers (called Areas of Permanent Preservation, hereafter APP) and stated that small rural properties[1] do not need to set aside a Legal Reserve of 20% (or 35%–80% when in the Amazon) for native vegetation conservation or sustainable use. With these and other changes, the Native Vegetation Protection Law will reduce, in comparison to the Forest Code, 58% of the area that would have been destined for ecological restoration in Brazil (Soares-Filho et al., 2014). Although we know the impact of these changes in terms of the number of hectares that will be restored in rural lands, we lack estimates of local changes in the provision of ecosystem services, such as carbon sequestration and soil erosion and sedimentation.

Carbon sequestration is an important ecosystem service provided by tropical forest restoration (Metzker, Sposito, Filho, Ahumada, & Garcia, 2012). Thus, a significant reduction in forest restoration in Brazil may affect both the provision of this service and the targets of greenhouse gases emissions committed by the country in international agreements. Forest restoration, especially as buffers along the riverside, plays an important role in retaining soil sediments, fertilizers, and pesticides contributing to the maintenance of water quality in waterbodies (Bernhardt et al., 2005) and avoiding siltation of rivers and water reservoirs (WWAP, 2018). Therefore, the reduction in the width of forest buffers caused by the change in law may have a direct impact on water quality-related ecosystem services. Although these effects are intuitive, there are few data quantifying these at the watershed scale.

Brazil is an important country for global tropical forest restoration, with large-scale programs being implemented (Holl, 2017; Pinto et al., 2014). Laws are an important mechanism to foster forest restoration in many parts of the world; thus, changes in them may directly affect local, national, and global targets for forest restoration (Soares-Filho et al., 2014). Changes in area brought under forest restoration will presumably affect forest ecosystem services, such as carbon sequestration and those related to avoiding soil erosion and sedimentation, which are key ecosystem services provided by forests (Bongers, Chazdon, Poorter, & Peñna-Claros, 2015; Mohammad & Adam, 2010). Estimating the impact of these changes on ecosystem services will be relevant when planning and discussing other mechanisms that affect forest restoration at the landscape scale. Thus, our objective was to evaluate, in a rural watershed, the impact on carbon sequestration, soil loss, and soil sedimentation caused by the change from the Forest Code to the Native Vegetation Protection Law in Brazil. Specifically, we quantified the area to be restored and the forest cover that would exist with each law and compared, through modeling, soil loss and sedimentation, and carbon stocks in these scenarios.

Methods

Study Sites

The study was conducted in a rural microwatershed, located within the Rio Piracicaba Basin (Figure 1), in the Brazilian Atlantic Forest, a hot spot for global biodiversity conservation and where most of the forest restoration initiatives occur in Brazil (Rodrigues et al., 2011). The Ribeirão Vermelho microwatershed, located in São Paulo State, South-East Brazil, comprises 7,515 ha, and has an altitude varying from 432.5 to 945.8 m (Figure 1). This microwatershed has 77 rural properties with an average size of 166.8 ha. Sugarcane is the main land use (Online Appendix S1) and Neosols together with Ultisols are the main soil classes (Online Appendix S2). Low intensity grazing and sugarcane are the most common land uses in south-eastern Brazil (Instituto Brasileiro de Geografia e Estatística, 2017).

Land Use and Land Cover Scenarios

We simulated three scenarios in the microwatershed: (a) the land use and cover as of 2016; (b) 100% of mandatory riparian forest restoration, according to the Forest Code, 1965 (Brazilian Law 4,771 of 1965); (c) 100% of riparian forest restoration, according to the Native Vegetation Protection Law (Brazilian Law 12,651 of 2012, also named the current 2012 law). For quantification of carbon stocks, we included, in Scenarios 2 and 3, the forests that should be restored as Legal Reserves (LR; 1,696.8 ha and 1,357.4 ha, respectively).

The width of the forest buffer along waterbodies in Scenario 2 (Forest Code, 1965) was variable according to the type and size of the waterbody and in Scenario 3 (2012 law), according to the type and size of the waterbody and the size of the rural property (Table 1). The microwatershed has been used for agriculture for many decades and deforestation is rarely seen currently. Thus, for Scenario 3, we considered that all properties had agricultural land use prior to July 2008. The amount of land that can continue to be cultivated in the APP

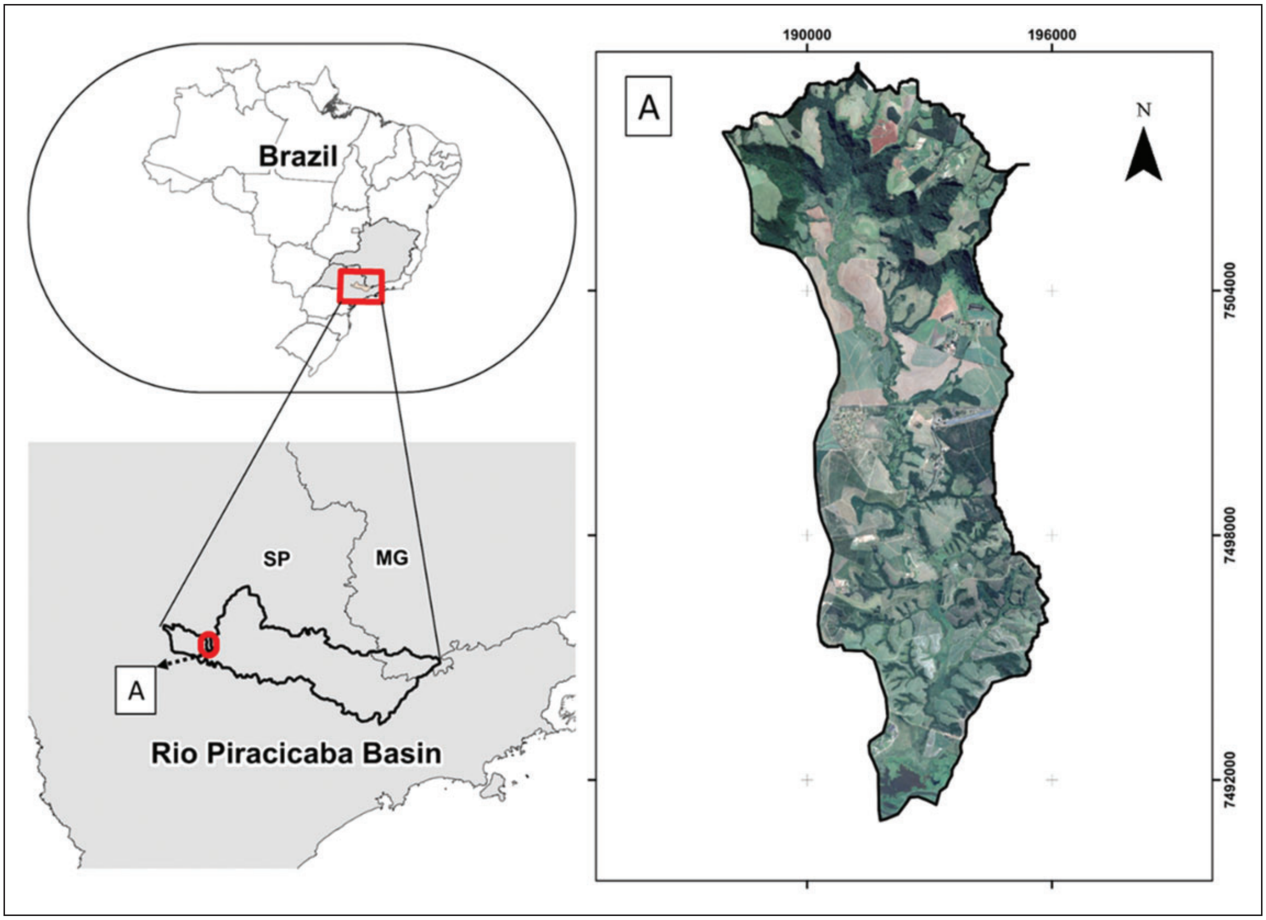

Figure 1. Ribeirão Vermelho (A) microwatershed located in São Pedro municipality, São Paulo State—SP, Southeast Brazil, in the Rio Piracicaba Basin and within the Brazilian Atlantic Forest.

Table 1. Width of Forest Buffers Used to Simulate Riparian Restoration for Scenarios 2 (Forest Code) and 3 (Native Vegetation Protection Law), in a Microwatershed in the Atlantic Forest, Brazil.

	Forest buffer width	
Waterbody type	Scenario 2 (Forest Code)	Scenario 3 (Native Vegetation Protection Law)
Water stream width < 10 m	30 m	5–50 m[a]
Naturals lakes and dams up to 20 ha	50 m	5–30 m[a]
Naturals lakes > 20 ha	100 m	5–30 m[a]
Springs	50 m	15 m
Artificial dams	15 m	15 m[b]

[a]According to property size (for details, see Online Appendix S3).
[b]Width of forest buffer for this type of waterbody was defined by the state environmental agency at the time of licensing the dam. As we did not have this information, we considered it to be the same as for the Scenario 2.

varies according to property size, measured in number of fiscal modules, which is the unit used in Brazil to categorize rural properties according to their sizes (for details, see Brancalion et al., 2016).

We used satellite images from 2016 to visually classify the 2016 land use and cover and map waterbodies. We obtained the digital elevation model (DEM) from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), with a 30×30 m spatial resolution. In addition, as an improvement before running the model, this layer was sampled and interpolated by a 2×2 m resolution layer, aiming for information at a smaller scale. The boundaries of the properties were obtained from a previous database used by the landowners to register their properties from the CAR (Rural Environmental Registration) platform.

We calculated the Legal Reserve deficit for Scenario 2 based on the amount of native forest cover that each property was required to have (20% in the Atlantic

Forest biome). For Scenario 3, we calculated 20% of Legal Reserve only for properties with more than four fiscal modules (1,357.4 ha in the Ribeirão Vermelho microwatershed, considering 16 ha as the size of one fiscal module). In addition, for Scenario 3 (2012 law), we considered the APP with native vegetation or those to be restored as part of the Legal Reserve, as foreseen in the Native Vegetation Protection Law. For estimating the Legal Reserve deficit, we did not consider the possibility of a property compensating for its deficit in another property within or outside the microwatershed, although this is legally possible. Based on these calculations, we quantified the demand for forest restoration and the native forest cover for each scenario, in each microwatershed.

Soil Loss and Sedimentation Calculation

To calculate soil loss and sedimentation metrics, we used the Sediment Delivery Ratio Model from InVEST (Sharp et al., 2015). We used this model to spatially determine soil loss and sedimentation to the nearest channel, and consequently, to infer the effect of these parameters in each land use and cover.

We used the same DEM spatial resolution (2×2 m) for layer results. The results return the amounts of eroded soil and sediments that reach the waterways, for each pixel. This model uses the Revised Universal Soil Loss Equation (RUSLE), in which the annual soil loss is indexed for each cell, according to Equation 1.

$$\text{RUSLE}\left(\text{Mg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}\right) = \text{R.K.LS.C.P} \qquad (1)$$

We obtained R values (rainfall erosivity—$\text{MJ}\cdot\text{mm}\cdot\text{ha}^{-1}\cdot\text{h}^{-1}\cdot\text{year}^{-1}$) for the municipality of the study area from the Research Group on Water Resources software (Moreira, Pruski, Cunha de Oliveira, Pinto, & Silva, 2006). The value is $7{,}155.0\,\text{MJ}\cdot\text{mm}\cdot\text{h}^{-1}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ for the Ribeirão Vermelho microwatershed (São Pedro, São Paulo State—SP). We used K parameter values (soil erodibility—$\text{Mg}\cdot\text{ha}\cdot\text{h}\cdot\text{MJ}^{-1}\cdot\text{ha}^{-1}\cdot\text{mm}^{-1}$) found in the literature, specific for each soil type, forming a mosaic within the microwatershed (Online Appendix S2). The InVEST model calculated the LS values (slope length, L, and steepness factor, S) automatically based on the DEM layer. The C (cropping management factor—0 to 1) and P (supporting practices factor—0 to 1) values were obtained from secondary data and scientific publications for each land use and cover (Online Appendix S2). To validate the P parameter, we used visually interpreted land cover from the satellite images, to identify the presence of contour lines, bare soils, and other aspects used to classify conservation practices.

Carbon Stock Quantification

For Scenario 1, we considered only the carbon stock from the land use and cover as of 2016. To quantify carbon stock for Scenarios 2 and 3, we included the carbon that would be added by native forest restoration and discounted the carbon stock from the land use replaced by forest restoration. In addition, we considered that forest restoration would be established in a single moment, just as the entire baseline (land use replaced by forest restoration) would be lost after that.

To include the carbon stocks to be increased owing to restoration in the LR for legal compliance (Scenarios 2 and 3), we used the mean carbon stock of land uses (not including forests) in Scenario 1 as the baseline. Once we had the area of the Legal Reserve deficit for each scenario, we added the amount of carbon that these areas would increase by forest restoration and discounted the carbon stock of an equivalent area, using the baseline carbon stocks as described. This was adopted because it would be very imprecise and arbitrary to allocate the deficit of the Legal Reserve in each property. In both the APP and Legal Reserve calculations, we considered that planted forests would increase biomass over a 30-year period, which is generally the time assumed in carbon forest projects (Rocha, 2008).

Carbon stock quantification was based on above- and belowground biomass compartments. We used secondary data for the carbon stocks of the land use and cover found in the microwatershed (Online Appendix S3). We considered that forest restoration would be planted exclusively with native tree seedlings, which is the main forest restoration technique in this region of the Atlantic Forest (Rodrigues et al., 2011). We used $4.1\,\text{MgC}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ as the mean annual carbon increment by forest restoration (Miranda, 2008).

Results

Changes in Forest Cover

The native forest cover at the Ribeirão Vermelho microwatershed is 23.9% (1,795.3 ha, Scenario 1). With the enforcement of the Forest Code (Scenario 2), forest restoration would occur in 336.6 ha (4.5% of the microwatershed, Figure 2) at Ribeirão Vermelho, increasing native forest area by 18.7% (Figure 3, Online Appendix S2). With the enforcement of the Native Vegetation Protection Law (Scenario 3), forest restoration would add 280.6 ha (3.7% of the microwatershed), increasing native forest area in Scenario 3 by 15.6%. Compared to the Forest Code, 1965, implementation of the Native Vegetation Protection Law, 2012 would potentially reduce the area to be restored by 16.6% in the Ribeirão Vermelho microwatershed.

In the entire microwatershed, 59 properties (76.6%) have a Legal Reserve deficit in Scenario 2 and 26 properties (36.7%) in Scenario 3. Forty properties (51.9%) are larger than four fiscal modules (larger than 64 ha), which requires them to have at least 20% of native forest cover in both Scenarios 2 and 3. If each property restored its legal reserve deficit within its boundaries (excluding the possibility of compensating in properties with more than 20% of native forest cover), we would have more than 50% of forest cover in Scenario 2, while in Scenario 3, it would be 45.7% (Figure 2). If we exclude the deficit of the Legal Reserve in the calculations, forest cover would be 28.4% in Scenario 2 and 27.6% in Scenario 3.

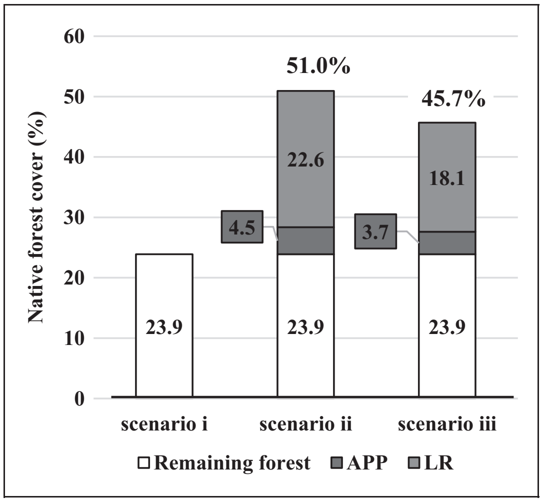

Figure 2. Native forest cover (%) in the Ribeirão Vermelho microwatershed, in the Atlantic Forest, Brazil, at the 2016 land use and cover (Scenario 1), and simulating the Forest Code, 1965 (Scenario 2) and the Native Vegetation Protection Law, 2012 (Scenario 3). Additions of native forests through restoration in Scenarios 2 and 3 are shared between APP and LR.

Soil Loss and Sedimentation

Estimated soil loss and sedimentation were the highest in the land use as of 2016 (Scenario 1) and the lowest for Scenario 2 (Figure 4, Online Appendixes S4 and S5). In the Ribeirão Vermelho microwatershed, soil loss would decrease by 3,626.1 $Mg \cdot year^{-1}$ (1.6%) from Scenario 1 to 2, and by 2,555.5 $Mg \cdot year^{-1}$ (1.13%) from Scenario 1 to 3 (Figures 3 and 4). From Scenario 2 to 3, soil loss increased by 1,070.7 $Mg \cdot year^{-1}$ (0.48%). Soil sedimentation decreased by 294.1 $Mg \cdot year^{-1}$ (1.7%) from Scenario 1 to 2, and by 195.3 $Mg \cdot year^{-1}$ (1.12%) from Scenario 1 to 3 (Figures 3 and 4). Between the Scenarios 2 and 3, soil sedimentation increased by 98.8 Mg. $year^{-1}$ (0.6%). The mean soil loss was 30.2 $Mg \cdot ha^{-1} \cdot year^{-1}$, 29.7 $Mg \cdot ha^{-1} \cdot year^{-1}$, and 29.9 $Mg \cdot ha^{-1} \cdot year^{-1}$ for Scenarios 1, 2, and 3, respectively. Thus, the difference from Scenario 1 to 3 was 0.3 $Mg \cdot ha^{-1} \cdot year^{-1}$.

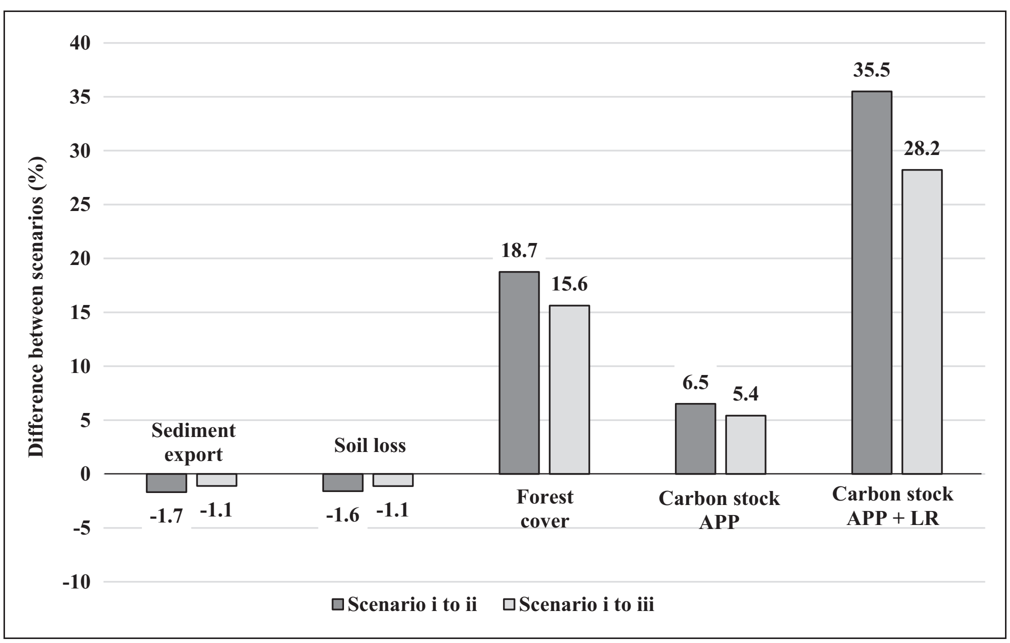

Figure 3. Percent change from Scenario 1 (2016 land use and cover) to Scenario 2 (Forest Code, 1965) and from Scenario 1 to 3 (Native Vegetation Protection Law, 2012) in the Ribeirão Vermelho microwatershed, in the Atlantic Forest, Brazil. Sediment export, soil loss, and forest cover are considered only for changes in land use and cover in Areas of Permanent Protection (APP) while the carbon stock is considered for restoration in APP and both APP and LR.

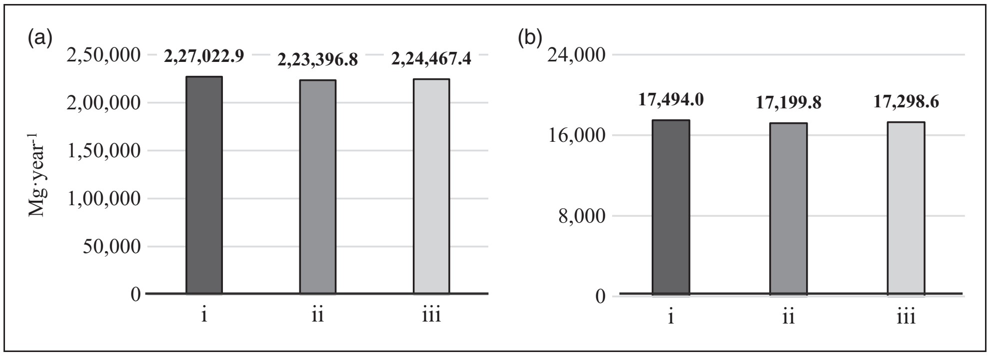

Figure 4. Soil loss (a) and sedimentation (b) values in the Ribeirão Vermelho microwatershed, in the Atlantic Forest, Brazil, for the land use and cover as of 2016 (Scenario 1), simulation of the Forest Code, 1965 (Scenario 2), and of the Native Vegetation Protection Law, 2012 (Scenario 3). Only restoration of Areas of Permanent Protection was considered (no inclusion of Legal Reserve deficits).

Carbon Stocks

The carbon stored in the above- and belowground biomass in the land use as of 2016 at the Ribeirão Vermelho microwatershed is 462,360 Mg of C. From this, 11,320 Mg would be replaced by restoration of the APP in Scenario 2 and 9,491 Mg by restoration of the APP in Scenario 3. Thus, carbon stocks 30 years after implementation of APP restoration would be 492,441.4 Mg for Scenario 2 and 487,381.8 Mg for Scenario 3. This would increase carbon stocks by 6.5% in Scenario 2 and 5.4% in Scenario 3, in comparison with that at the land use and cover as of 2016 (Figure 3). In both scenarios, the landscape would reach the 2016 carbon stock level 8 years after forest restoration implementation (Figure 5).

When we include restoration of LR in the calculations, the amount of carbon stocks replaced by forest restoration would be 74,653 Mg for Scenario 2 and 59,721 Mg for Scenario 3. After 30 years of restoration, carbon stocks would increase by 35.5% in Scenario 2 and 28.2% in Scenario 3 for Ribeirão Vermelho, in relation to that with the land use as of 2016 (Figure 3).

Discussion

In relation to the land use as of 2016, the Brazilian Native Vegetation Protection Law, if fully implemented, will increase forest cover and consequently, increase carbon stocks, and reduce soil loss and sedimentation. However, compared to the previous legislation (Forest Code, 1965), the implementation of the 2012 law would reduce the area to be restored and the potential for native forest cover growth, as previously documented (Garcia et al., 2013; Soares-Filho et al., 2014), and would reduce the potential increase in carbon stocks and increase soil loss and sedimentation at the landscape level. These results corroborate the increase in the provision of ecosystem services at the landscape level with forest restoration (Bongers et al., 2015; Mohammad & Adam, 2010; Viani, Braga, Ribeiro, Pereira, & Brancalion, 2018). Our results demonstrate that the 2012 changes in the Brazilian forest law will affect not only the forest cover but also their provision of key ecosystem services on private properties. If implemented, the 2012 law would result in 16.6% less forest cover than with the implementation of the 1965 law. It is lower than the 58% area estimated for all of Brazil (Soares-Filho et al., 2014) and the 83% found for the Posses microwatershed, in Extrema, Minas Gerais State—MG, where all properties are smaller than four fiscal modules (Rotta, Viani, & Rosário, 2017). According to the 2012 law, properties smaller than four fiscal modules do not need to achieve the 20% of native forest cover usually required as the Legal Reserve in the Brazilian Atlantic Forest, and additionally they can continue agricultural land use in a greater APP width (Brancalion et al., 2016). Thus, our results possibly underestimate the impact of the change in the law on forest cover, and consequently ecosystem services, because we studied a microwatershed with large property sizes.

Compared to the land use and cover in 2016, increases in forest cover in the forest law Scenarios 2 and 3 would reduce soil loss and sedimentation. This was expected, because forests, especially riparian forests, provide soil stabilization, sediment retention, and waterbody protection (Studinski, Hartman, Niles, & Keyser, 2012; Sweeney & Newbold, 2014). However, the percentage increase in soil loss and sedimentation (Figure 3), from the 2016 scenario to those simulating full implementation of forest laws (both Scenarios 2 and 3), would be smaller than the percentage increase in native forest cover in the microwatershed (Figure 2). For instance, from the 2016 land use and cover to that simulating APP restoration according to the 2012 law, we found an increase of 3.7% in native forest cover in Ribeirão Vermelho. However, this 3.7% increase in forest cover

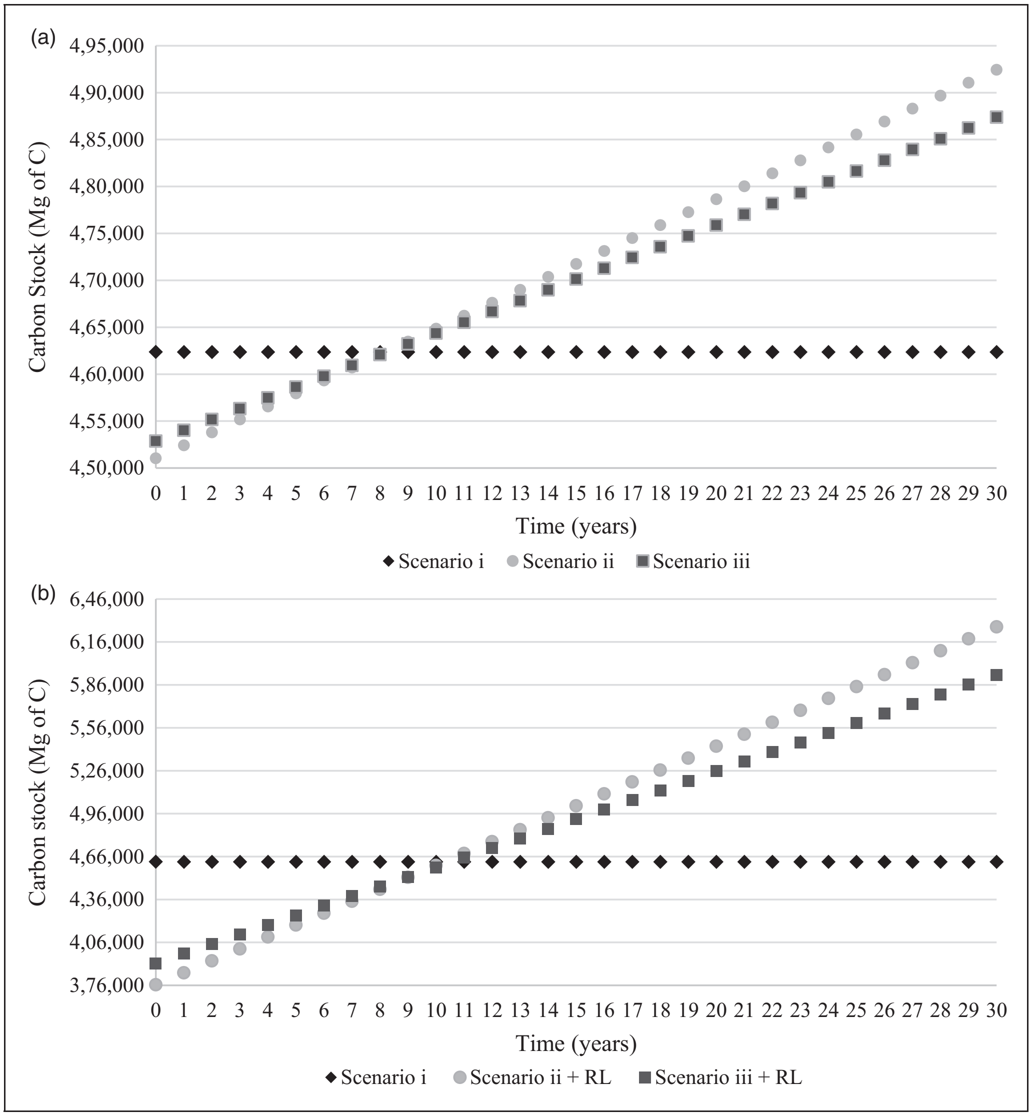

Figure 5. Carbon stock over a period of 30 years after forest restoration in the Ribeirão Vermelho microwatershed in the Atlantic Forest, Brazil, for the 2016 land use and cover (Scenario 1), simulation of the Forest Code, 1965 (Scenario 2), and of the Native Vegetation Protection Law, 2012 (Scenario 3). (a) Only restoration of Areas of Permanent Protection was considered (no inclusion of Legal Reserve deficits). (b) LR was included.

would reduce soil loss or sedimentation by only 1.1% (Figure 3). This means that reestablishment of forest cover through restoration may have a limited effect on reducing the amount of soil loss per area, and other factors such as land use type and adoption of soil conservation practices may be the major drivers of soil loss in agricultural landscapes (Online Appendixes S4 and S5). Thus, this reinforces the importance of integrating forest restoration and good farming practices when the main goal is to reduce soil loss and sedimentation in agricultural landscapes.

When we accounted for carbon stocks in the APP plus LR, the percentage increase in the carbon stock was higher than the increase in forest cover (Figure 3) and more than 5 times higher than when only forest restoration in the APP was accounted for (Figure 5). This highlights the importance of forest restoration in LR for establishing carbon pools in the Brazilian Atlantic Forest hot spot, a degraded and fragmented biome (Ribeiro et al., 2009).

In all scenarios, we considered more than 20% native forest cover, which is the minimum value to maintain a high potential for natural regeneration in these landscapes (Gao, Zhong, Yue, Wu, & Cao, 2011). Most of the properties had Legal Reserve deficits in simulations with both laws. Thus, all scenarios, considering APP and Legal Reserve cover, would maintain the potential for natural regeneration as well as the minimum levels of forest cover considered to be required to maintain biodiversity and ecological functions at a landscape level (24%–33%, Banks-Leite et al., 2014). Thus, for the landscape studied, changes in the forest law do not seem to limit ecological functioning. However, the impact of changes in the Brazilian forest law on forest cover, soil loss and sedimentation, and carbon stocks would probably be more pronounced in microwatersheds with lower levels of native forest cover. The current Brazilian Atlantic Forest has less than 16% of forest cover remaining and most of it is concentrated in the mountain range of the Atlantic Coast (Ribeiro et al., 2009), in landscapes not used or suitable for agriculture. Therefore, most of the agricultural landscapes in the Atlantic Forest have forest cover levels lower than that of the studied microwatershed. Thus, we presume the impacts on provision of ecosystem services because of changes in the Brazilian forest law would be more pronounced for the whole Atlantic Forest biome than for the specific microwatershed we studied. We recommend conducting similar studies in landscapes with very low forest cover to test this assumption.

Finally, we conclude that changes from the Forest Code, 1965 to the Native Vegetation Protection Law in Brazil, 2012 would not only reduce the area to be restored and the future forest cover but would also negatively affect the carbon stocks and increase soil loss and sedimentation at the landscape level. These results are useful for those drafting, changing, and implementing the laws for tropical forest restoration in private properties. Changes in forest cover and in the area legally demarcated for restoration affect provision of ecosystem services. Thus, we advocate that studies that measure and simulate changes in the provision of ecosystem services, like the one presented, should be demanded worldwide when discussing laws and policies that affect forest restoration in private properties.

Implications for Conservation

Changes from the Forest Code, 1965 to the Native Vegetation Protection Law in Brazil, 2012 would not only reduce the area of forest restoration and the potential for forest cover growth, but it would also increase soil loss and sedimentation and limit increases in carbon stocks at the landscape level. Despite this potential negative impact of the change in the Brazilian forest law on key ecosystem services, effects on forest cover were greater than on soil loss and sedimentation at the landscape level.

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Note

1. According to Federal Law no 11,326/2006, small properties in Brazil are those smaller than four fiscal modules, with one module being 5 to 110 ha across different regions.

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