Gregory Ramos Pitta

O balanço de carbono em paisagens tropicais
antropizadas

Carbon balance in human-modified tropical
landscapes

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Introdução Geral

Desde a Rio92 (CORDANI *et al.*, 1997) ao acordo de Paris na COP-24 (UNFCCC, 2018), passando pelos marcos dos protocolos REDD e REDD+ (PHELPS *et al.*, 2010), a comunidade científica, civil e tomadores de decisão se debruçam sobre o tema que interliga a ecosfera, economia e sociedade: lidar com a emissão de gases de efeito estufa na atmosfera e minimizar mudanças climáticas. O carbono é a moeda corrente ao quantificarmos emissões, estoques e impactos humanos, e realizar um balanço de carbono em paisagens tropicais é um desafio e uma necessidade. Focamos aqui no balanço para o carbono estocado na vegetação nativa, uma vez que essa vegetação abriga os maiores estoques acessíveis de carbono terrestre do planeta (FAHEY *et al.*, 2009).

Nos trópicos em particular, as florestas costumam conter elevados estoques de biomassa, e consequentemente, de carbono (FEARNSIDE, 2000; POTAPOV *et al.*, 2017). Tratando-se de estoques de carbono florestais, sabemos que quando a floresta é derrubada, o carbono estocado acima e abaixo do solo em folhas, galhos troncos e raízes é gradualmente liberado na atmosfera. Como consequência, o desmatamento passa uma das principais fontes de emissão de de carbono na atmosfera (VAN der WERF *et al.*, 2009). Portanto, evitar a supressão, fragmentação e degradação florestal adquire papel essencial nas metas de contenção das mudanças climáticas (GULLISON *et al.*, 2007).

Estimar os estoques de carbono contidos na vegetação representa em si uma tarefa complexa (GLOOR *et al.*, 2012). Essa tarefa necessita de dados de campo e alguma ferramenta de extrapolação, seja por modelagem, por sensoriamento remoto, ou combinação dessas técnicas (SCOLFORO *et al.*, 2015). Para algumas regiões do planeta, os esforços de mensuração dos estoques de carbono chegam tarde. No Brasil, por exemplo, restam em torno de 11% a 16% de cobertura vegetal na Mata Atlântica (RIBEIRO *et al.*, 2009), e pouco menos de 54% no Cerrado (STRASSBURG *et al.*, 2017). E se as tendências de aumento de desmatamento (INPE, 2017) se realizarem, podemos esperar um cenário parecido para a Floresta Amazônica nas próximas décadas, que já as taxas de desmatamento aumentaram em 29% no período entre 2012 e 2016 (FEARNSIDE, 2017).

Neste estudo, combinamos dados de inventários florestais (LIMA *et al.*, 2015) para modelar biomassa em função de variáveis ambientais e de estrutura da paisagem. A partir desse modelo, projetamos um cenário pré colonial, em que pressupomos pouca ou nenhuma influência antrópica nas formações florestais do estado de São Paulo antes da colonização européia (MELATTI, 2007). Assumimos ainda que os dados oriundos dos remanescentes florestais em estágio avançado de sucessão são boas *proxies* dos estoques de biomassa pré colonial. Esse cenário foi então usado como base para nossa estimativa de carbono atual e também para a estimativa de potencial de recuperação de biomassa no estado com a adequação ao Novo Código Florestal Brasileiro (BRASIL, 2012), levantamos, além do cenário de atendimento aos requisitos da lei, um cenário alternativo e ideal em que recuperamos a degradação dos fragmentos de vegetação existentes. Buscamos, no entanto, estabelecer mais do que estimativas particulares do balanço de carbono para São Paulo. Buscamos pôr em perspectiva, a situação de uma paisagem tropical antropizada, em que a vegetação remanescente está reduzida a ilhas (LAURANCE *et al.*, 2008), que abrange dois biomas hiper-diversos (SCOLFORO *et al.*, 2016) e se repete em outros estados do Brasil, assim como em outras regiões tropicais ao redor do mundo.

Apresento essa dissertação em um capítulo único, que acredito ser suficiente para contar a história de forma sucinta: de onde partimos, onde estamos e onde podemos chegar em termos de estoques de carbono no estado de São Paulo, Brasil. Finalmente, discuto as limitações dessa estratégia, a coerência das estimativas dos estoques de carbono com os esforços disponíveis na literatura e, finalmente, as implicações para a conservação e recuperação dos estoques de carbono.

Capítulo Único

Carbon balance in human-modified tropical landscapes

Abstract

Carbon pools around the globe are vanishing due to habitat conversion and degradation, making it essential the estimation of local carbon budgets. The research aimed to estimate the carbon balance of the natural vegetation of a tropical anthropized landscape. We estimate the amount of pre-existing tree biomass above the soil (pre-colonial scenario), how much was lost by human action (deforestation and fragmentation) and how much carbon could be recovered with the compliance to the New Brazilian Forest Code (NCFB). This balance is represented for the state of São Paulo, in its different stages (*e.g.* carbon inventory map for the original vegetation cover), and is based on field data to associate tonnage values with the estimated inventories. We estimated a pre-colonial above ground biomass (AGB) stock for São Paulo of 4.62 Gigatonnes, of which 87.3% (3.85 Gt) were lost. These losses were attributed to 90% (3.46 Gt) to deforestation, and 10% (0.39 Gt) to the effects of fragmentation. The legal vegetation deficits stipulated by the NCFB translate into a potential recovery of 0.11 Gt of AGB. If we were to reduce degradation in forest fragments as well, then the potential AGB recovery would triple (0.37 Gt). Our approach allowed the identification of current biomass hotspots and of regions with the greatest potential for carbon recovery. Finally, we discussed the viability of using compensation mechanisms to mitigate restoration costs. For our study area, 0.96 to 2.79 billion US\$ would be required to restore the legal deficit of vegetation, an amount that is feasible as long as carbon markets are willing to pay a minimum of 17.5 US\$ for ton of fixed carbon.

Key-words

1. Carbon balance 2. Atlantic Forest 3. Cerrado 4. São Paulo 5. Public policy

Introduction

Forest carbon stocks are particularly abundant in the tropics (GULLISON *et al.*, 2007), and much work has been put in estimating the status of current stocks (HUGHTON, 2005; ENGLUND *et al.*, 2017), which is a particularly difficult task given a series of uncertainties associated with methodology and precision of carbon estimates (MITCHARD *et al.*, 2013). Despite of these difficulties, it represents a paramount task, since forest carbon storage is one of the most accessible and dynamic pools of carbon on earth (FAHEY *et al.*, 2009). Thus, its estimation opens the possibility for developing a highly efficient strategy of carbon sequestration (CHAZDON *et al.*, 2016), contender of solid plan for counteracting climate change (IPCCC, 2018).

If we look at the forest carbon balance in any highly anthropized tropical landscapes - we make use of the São Paulo state in Brazil as a starting point here - human development associated with the evolution and dynamicity of its legal framework (MUELLER, 2016; CPI, 2016, 2018) led to a great loss of natural vegetation cover. In São Paulo, this sustained habitat conversion resulted in the very little amount of remaining natural vegetation seen today (RIBEIRO *et al.*, 2009; STRASSBURG *et al.*, 2017). In addition, the remaining habitats often correspond to isolated islands of disturbed vegetation (LAURANCE, 2008), which are affected by the surrounding landscape and fragmentation processes (MESQUITA *et al.*, 1999). Conserving the remaining natural vegetation is key to avoid extra emissions of carbon into the atmosphere, and restoration is thus an effective way to sink carbon from atmosphere, while enhancing ecosystem services and species preservation (REZENDE *et al.*, 2018).

Efforts to estimate carbon balances generally concentrate in relative short term emissions (past 10 to 20 years) resulting from deforestation (HANSEN *et al.*, 2013; PÜTZ, *et al.*, 2014; TYUKAVINA *et al.*, 2015). This approach does not take into account that the remaining vegetation is the result of a mix of deforestation and fragmentation processes. On the other hand, in eastern Brazil these processes started more than 500 years ago, when European colonization began (MORELLATO & HADDAD, 2000), and today those processes can be considered as having leveled off in the region (SOS-MA, 2018). If we can estimate what was the magnitude of the original carbon stocks that pre-date the first satellite images and advanced LIDAR

techniques (ASNER & MASCARO, 2014), we may understand how much we can do and expect in the coming years, both in terms of carbon emissions and sequestration from the atmosphere.

The New Brazilian Forest Code (NCFB) (BRASIL, 2012) opened new possibilities such as *ex situ* compensation (CRAs) (SOARES-FILHO *et al.*, 2016) and payments for ecosystem services (PES) (RUGGIERO *et al.*, 2018). The NCFB also defines minimum standards for natural vegetation, both in Legal Reserves (RL), and Permanent Preservation Areas (APP). Moreover, this new law strengthens the Rural Environmental Registry (CAR), a geo-referenced database of the boundaries, protected areas, and native vegetation occurrence in private rural properties. Brazil has also launched its EN+REDD, reinforcing its commitment to the reduction of deforestation and forest degradation (MMA, 2018). Therefore, we currently have at our disposal the tools needed to assess the current forest stocks define regeneration potential for carbon sequestration and to start thinking what is next (CPI, 2018).

Here we quantify the above ground carbon balance in the highly-modified tropical landscapes of the state of São Paulo, southeastern Brazil. With centuries of history of human impacts, this region combines high levels of habitat conversion and fragmentation with one of the most well-established economies and environmental legislations in the tropics. More specifically, we calculated the carbon balance by estimating pre-colonization carbon stocks, and then by subtracting the losses related to native vegetation loss and fragmentation processes. Besides the estimation of the current carbon stocks, we also quantify the state carbon potential recovery, based on local legislation requirements. Finally, we provide the regions with high priority to conserve carbon stocks (*i.e.* carbon hot-spots) and the regions with the highest carbon potential for ecological restoration.

Methods

Our study area was the state of São Paulo, southeastern Brazil, which has a total area of 28.4 million ha, 45.5 million inhabitants and over 257 billion US\$ of GDP in 2017 (IBGE, 2018). It is one of the most well-studied states of Brazil, resulting in extensive scientific databases available (LIMA *et al.*, 2015; FREITAS *et al.*, 2017a). Climate is stratified from the coast to the continental interior with more precipitation climates tending to be oceanic (Cfb) and tropical rainforest (Af) transitioning to humid subtropical (Cfa) and dryer tropical savanna (Aw), according to

Koppen's classification (ALVARES *et al.*, 2013). Precipitation decreases from the coast to the mainland, and temperature averages ranges from 10 °C on July to 24 °C in January (ALVARES *et al.*, 2013). Elevation varies from 0 m at the coastal line to 2,798 m at the highest point, but still remain under reasonable latitudinal restriction (OLIVEIRA-FILHO & FONTES, 2000). São Paulo includes almost 16 million ha (15%) of total original area of the Atlantic Forest domain (AF), and 7.5 million ha (4%) of the total original area of Cerrado, the Brazilian Savanna (IBGE, 2009).

We describe the the carbon balance of São Paulo, in terms of above ground biomass (AGB). Our operational biomass variable was stand basal area which is the most commonly estimate provided in our database of inventories. Based on the inventories that had both basal area (m²/ha) and AGB *per se* (Mg/ha), we built an equation to get AGB from basal area and vice-versa. Basal area is a good proxy for carbon estimations (SLIK *et al.*, 2010, BALDERAS TORRES & LOVETT, 2012), since both basal area and AGB are functions of tree diameter. Here, we found that basal area had a explanation power higher than 84% of the variation in AGB (Appendix 02).

The carbon balance considered in this study was composed by the following factors:

$$(1) \quad \text{Current AGB} = \text{Pre-colonial AGB} - \text{Losses of AGB},$$

where losses can be broken in:

$$(2) \quad \text{Losses of AGB} = \text{Deforestation AGB} + \text{Fragmentation AGB}.$$

Besides the estimation of the current AGB stocks, we also considered the long term potential of carbon recovery, given by:

$$(3) \quad \text{Potential AGB} = \text{Current AGB} + \text{FR} * (\text{Legal debt AGB}) + \text{Recovered AGB},$$

where FR is the average loss of carbon by fragmentation estimated for the study area, which is given by:

$$(4) \quad \text{FR} = \text{Fragmentation AGB} / (\text{Pre-colonial AGB} - \text{Deforestation AGB}).$$

Below, we present the steps used to obtain each of the factors of (1) and (3) that comprise the carbon balance. For simplicity, all factors were obtained in Gigatonnes which correspond to 10^{15} grams. All analysis were performed under R environment version 3.5 (R CORE TEAM, 2018), a full list of packages used is listed on Appendix 7.

Pre-colonial AGB

The estimate of the pre-colonial AGB was based on published forest biomass data obtained from the Neotropical Tree Communities database (TreeCo - <http://labtrop.ib.usp.br/doku.php?id=projetos:treeco:start>). Starting from TreeCo, we first filtered all inventories including biomass estimates conducted in the Atlantic Forest and Cerrado domains. We then performed an additional bibliographic search to retrieve any new and missing inventories in TreeCo, using the same protocols presented by Lima *et al.*, (2015). To standardize data compilation from each inventory (data collection methods, forest information, locality, etc.) we manually checked all forest inventories with coordinates that fell inside the study area or within a 25 Km buffer around the political limits of the state of São Paulo. We ended with 331 (details on Appendix 1) forest inventories (Table 1), that had an estimate of above-ground vegetation biomass (AGB) and their coordinates and forest descriptors verified.

Table 1: Descriptive statistics of the forest inventories compiled for São Paulo state, Brazil, along with their vegetation type, average above-ground biomass and total sampling efforts (N: number of individuals sampled and Effort: total area sampled) .

Biome	Vegetation type (Samples)	Mean AGB (Mg/ha)	Total N	Sum of Effort (ha)
Atlantic Forest	Alluvial Forest (16)	242.35	24971	6.97
Atlantic Forest	Ombrophilous Dense Forest (126)	232.05	165146	123.02
Atlantic Forest	Ombrophilous Mixed Forest (8)	361.40	6343	3.5
Atlantic Forest	Pioneer Marine Forest (31)	159.65	41547	20.62
Atlantic Forest	Semideciduous Seasonal Forest (116)	161.13	139224	101.87
Savanna	Savanna Forest (Cerradão - 22)	142.29	75899	25.44
Savanna	Open Savanna (Cerrado - 12)	63.59	52619	11.47
TOTALS	331	194.63	505753	292.88

For each inventory, we obtained different abiotic and biotic co-variables related to energy, water availability, terrain structure, soil quality, forest conditions, and major landscape metrics calculated for 4×4 km landscapes (full list of variables, can be found at Appendix 3). We performed a variable selection procedure in an attempt to select the those co-variables that were the least correlated and that did not present collinearity between each other (CRABTREE, *et al.*, 2009). We tested the normality of co-variables (log-transforming them whenever needed) and the effects of possible interactions between co-variables. We only tested meaningful interactions that could, within reason, have biological function. Finally, we used a framework based on linear mixed-effects regression models (BATES *et al.*, 2015) to relate biomass estimates for each survey with co-variables (*i.e.* fixed-effects), while using survey methods, sampling effort and forest domains as random effects (BONAN, 1995; LIMA *et al.*, 2015). After the selection of the best random and fixed-effects model structure, we optimized the following model:

$$(5) \quad \text{AGB} \sim \text{Temperature} + \text{Humidity} + \text{Solar Radiation} * \text{Forest Disturbance Level} + \text{Fragment Size} * \text{Landscape Aggregation Index (at 4km)} + \text{Fragment Shape Index} + (1 | \text{Vegetation Type})$$

In this model, Forest Disturbance Level is an ordered and weighted ponderation from heavy, high, medium and low forest disturbance levels. Fragment

size is the normalized log-transformed area of the forest fragment. The Aggregation Index derived from the proportion of forest in a 4 km square landscape around the forest inventory (LIMA *et al.*, 2015). The Fragment Shape Index given by the perimeter area relationship of the forest fragment where the inventory was conducted.

Next, we overlaid a hexagonal grid (BIRCH & BEECHAM, 2007) to the study area and extracted the same explanatory co-variables of (5) to each hexagon (mean values at a spatial resolution of 2,500 ha). To simulate a pre-colonial scenario, we assumed that the whole study area had no major human-related interventions in vegetation conditions and landscape structure. Indigenous populations have been inhabiting the region for the past 8000 prior to european colonization (FIGUTI, 1993), those are still relatively small and very pontual interventions (MELATTI, 2007). In practice, we set all human-related co-variables (*i.e.* landscape metrics and forest disturbance level) to the best values found on our sample of forest inventories (Figure 1). Although there may have been climate changes in the past 500 years, we assumed that this changes were neglectable, so climate variables were left untouched.

Figure 1: Frequency distributions of the co-variables used on our AGB model in the overlaid hexagonal grid (total of 10,482 cells). All co-variables have been normalized. On the lower right corner are the best values from our TreeCo forest inventory sample, that we attribute to a pre-colonial scenario.

We extrapolated AGB values obtained using equation (5) over the grid with three different methodologies: (i) Linear Mixed Effects Model, with group random

effects, and spatial correlation between biomass observations, (BATES *et al.*, 2015), (ii) a Geographically Weighted Regression Model (BIVAND & YU, 2017), and (iii) Auto Kriging (HIEMSTRA *et al.*, 2008; GRÄLER *et al.*, 2016). Thus, we obtained three similar spatial representations of AGB distribution prior to heavy human interventions. The three methodologies were very similar in terms of the total biomass estimated and in their ranges (Appendix 4). For not having to choose one methodology over another (considering SCOLFORO *et al.*, 2015; HARRIS *et al.*, 2010), we opted to present the average of these three methodologies as the final estimates of above ground biomass.

Current AGB

To obtain current carbon we need to estimate losses related to deforestation, to attain this we masked the pre-colonial carbon estimates with the 2017 natural vegetation remnants from the classification provided by Mabiomas 3.0, classes 1 to 5 corresponding natural remnants of forests, savannas and mangroves (MAPBIOMAS, 2018). Fragmentation effects on carbon stocks were calculated on two steps. First, we considered edge-effects as a linear decreasing intensity of carbon loss from the edge of the forest fragments up to 120 m (DE-PAULA *et al.*, 2011; CHAPLIN-KRAMER, *et al.*, 2015). Next, we incorporated other fragmentation effects that can permeate to the core of the fragments and also are responsible for additional carbon loss (CHAPLIN-KRAMER, *et al.*, 2015; TYUKAVINA, *et al.*, 2015), such as selective logging, fire (NEPSTAD *et al.*, 1999), large tree mortality (LAURANCE *et al.*, 2000). To incorporate those effects we made use of the size of the fragment core (fragment area excluding edges up to 120 m) and long term estimates of the carbon loss (PÜTZ *et al.*, 2014). The first 5-10 years are usually known as the time needed for trees communities to pay biomass debts due edge creation in tropical forests (LAURANCE *et al.*, 1998; PÜTZ *et al.*, 2014), thus we assume that the forest fragments were isolated long enough to have leveled off their carbon losses.

Potential AGB

Based on current legislation requirements (BRASIL, 2012) and on available databases of private rural properties (SPAROVEK *et al.*, 2015; FREITAS *et al.*, 2017a; GUIDOTTI *et al.*, 2017) we calculated the legal deficits of forest area cover for the state of São Paulo. These calculations considered the Legal Reserve (RL) and Permanent Preservation Areas (APP) areas around rivers and water springs on rural properties. To attribute values of carbon per hectare we used the cell-specific pre-colonial AGB in order to estimate how much carbon can be restored in RL and APP. We assumed that restoration projects are generally lower than 50 ha (SMA-SP, 2018) in total implantation area, which roughly corresponds to the mean fragment size of the São Paulo state remnants (RIBEIRO *et al.*, 2015). Therefore, we used the average percentage of carbon loss from fragmentation in the study area (FR from equation 4) to correct the estimated value of AGB that could be stored in restored RLs and APPs.

We evaluated two potential long term scenarios of carbon stocks for the state of São Paulo: (i) a legal scenario, where all debts of forest area are restored in accordance to the legal compliance (RL and APP are both restored and are subject the same fragmentation effects from current forest fragments); (ii) an ideal scenario, where both RL and APP are fully restored and active measures (DIXON, *et al.*, 1993; ALBRECHT & KANDJI 2003) are taken increase the carbon storage potential of restored RL and APPs areas as well as existing forest fragments (CHAZDON *et al.*, 2016). In other words, these ideal measures should be capable of reducing edge-effects and the deterioration of the quality of the core forest (*i.e.* reversion of within-forest disturbance processes). Thus, this scenario represents a strategy that by increasing only the forest area required by law and by managing the future forest area to obtain carbon storages closer to the pre-colonial estimates. In this scenario, fragmentation effects are still present but are lessened (MURCIA, 1995; LAURANCE *et al.*, 1997).

Results

The first step of the São Paulo carbon balance was to estimate the amount of AGB prior to european colonization. The linear mixed effect model with best fit to our biomass data explained 56% of the variation in forest biomass (conditional R^2 *sensu* NAKAGAWA, *et al.*, 2013) (Table 2) and estimated a total of 4.62 Gigatonnes [SE +- 0.19] (10e15g) of above ground biomass for our pre-colonial scenario (*i.e.* no deforestation or fragmentation effects). Most of this biomass was concentrated along the mountainous regions in the state coast (up to 150 km inland) (Figure 1A), which correspond to the part of the state which is less seasonal in precipitation and thus mainly covered by lowland to high-altitude rainforests. On the other hand, the regions with lower biomass corresponded to more seasonal areas covered by savannas or on the transition between savannas and seasonal forests. AGB estimates per grid cell average 191 Mg/ha [SE +-7.97].

Table 2: Parameter estimates of the linear mixed-effects model with best fit to AGB data, used here to estimate the pre-colonial scenario AGB for the state of São Paulo.

Parameter	Estimate	Std. Error	Pr(> t)
Intercept	102.2236	(24.26)	0.00
Temperature	-1.1474	(0.66)	0.08
Humidity	3.2961	(1.19)	0.01
Radiation	0.8047	(0.59)	0.17
Forest Succession	5.2032	(0.62)	0.00
Fragment Size	34.8976	(15.72)	0.03
Aggregation Index (at 4km)	-0.7592	(0.25)	0.00
Fragment Shape Index	1.6715	-0.57	0.00
Fragment Size: Aggregation Index (at 4km)	-0.3432	-0.16	0.03
Radiation: Forest Succession	-1.2879	-0.52	0.01

The second step of the carbon balance was to calculate the amount AGB lost until present. Based on the 2017 vegetation cover and excluding areas of agriculture and silviculture, we found that only 16.7% of the original pre-colonial aboveground biomass remains (0.77 Gt) (Figure 1B). This estimate is smaller than to the total natural vegetation cover remaining in the state of São Paulo (21.3% in area). The AGB losses were mostly due to vegetation cover loss (3.46 Gt, or about 89.87% of the total AGB losses). The remaining losses were attributed to edge-effects and to the

deterioration of core natural vegetation quality (*i.e.* disturbances), accounting for 0.39 Gt (10.12% of the total AGB losses) (Figure 2). If we discount deforestation from the pre-colonial estimates (*i.e.* calculating FR in equation 4), then the fragmentation is responsible for losses of 34% of the carbon in the remaining vegetation fragments in 2017. Which concentrates on the more mountainous region around state parks: Serra do Mar, Carlos Botelho, Ilha bela, Intervales and Alto Ribeira. Hence, the current carbon balance for the state of São Paulo can be expressed as:

$$(5) \text{ Current AGB} = \text{Pre-colonial AGB} - (\text{Deforestation AGB} + \text{Fragmentation AGB})$$

$$0.77 \text{ Gt} = 4.62 \text{ Gt} - (3.46 \text{ Gt} + 0.39 \text{ Gt})$$

Figure 1: Estimates of the (A) pre-colonial and (B) remaining AGB for the state of São Paulo, Brazil. There are 10482 hexagonal cells and 260 hexagons missing estimations.

Figure 2: Estimates of AGB losses by type of effect: (A) habitat conversion and (B) forest fragmentation and degradation. In this map, colder tones indicate greater percentage of loss in Mg/ha in respect to the pre-colonial reference values. Fragmentation losses in B are inherently low due the extent of deforestation in A. Both maps combined result in the total AGB loss until 2017 (83.4% or 3.46 Gt).

We found no study providing pre-colonial estimates of AGB for São Paulo state, so we could not compare or validate our results with those from other researchers. However, we cross-checked our pre-colonial estimations and current estimates of AGB for São Paulo with other estimates available in the literature (AVITABILE, *et al.*, 2015; SANTORO *et al.*, 2015; ENGLUND *et al.*, 2017), which ranged between 0.95-1.13 Gt. Our estimates without fragmentation effects fall in the same range, especially regarding the study of Englund *et al.* (2017) (Figure 03), and the R-squared of the relationship between their estimates of current carbon stocks ranged from 91% to 68%.

Figure 3: Comparison between the current AGB stocks obtained in this study (x-axes) with the most recent literature AGB estimates for São Paulo (y-axes). Simple dispersion plots where each circle is one of the cells in Figure 1A. The results of the linear regression lines are given in red along with the amount of variance explained by the model (R^2). All values are given in Mg per ha.

We then estimated what could be the long term carbon balance under two different scenarios of AGB recovery: a legal compliance and an ideal one. The first scenario considers that all the area that should be restored due to legislation constraints would be fully restored (*i.e. de facto* legislation according to Freitas *et al.*, 2017a). Under this scenario, we estimated a total of 0.17 Gt of total deficit (Legal Reserve: 0.05 Gt; Permanent Preservation Areas: 0.12 Gt). These estimates assume that the restoration of these areas will be able to recover 100% of the pre-colonial AGB, which is not likely. If we take into account that in the long term that this areas

will be under fragmentation effects once they are restored, we can thus use the average of 34% of fragmentation-induced losses (FR) we estimated for the remaining forest fragments in the state of São Paulo to get a more conservative estimate of AGB recovery potential (Figures 4A, 5A):

$$(6) \quad \text{Potential AGB} = \text{Current AGB} + \text{FR} * (\text{Legal debt AGB})$$

$$0.88 \text{ Gt} = 0.77 \text{ Gt} + (1 - 0.342) * (0.17 \text{ Gt})$$

Therefore, under the legal compliance scenario we could expect a total increase over current stocks of 14.66%.

Considering the ideal scenario, where active restoration measures would also be put into place to mitigate the effects of the fragmentation and disturbance over the remaining forest fragments (LAURANCE, *et al.*, 2011; KUPFER, *et al.*, 2006), we could further add 0.225 Gt of carbon at forest edges and cores. In this scenario fragmentation effects are modelled to be halved in the 120 m of edges and absent of the core of forest fragments. In this implementation the fragmentation-induced losses (FR) becomes 14.9%. This means that we could potentially increase up to one half of the current carbon (Figures 4B 5B). In other words our potential AGB recovery in the optimistic scenario is:

$$(7) \quad \text{Potential AGB} = \text{Current AGB} + \text{FR} * (\text{Legal debt AGB}) + \text{Recovered AGB}$$

$$1.14 \text{ Gt} = 0.77 \text{ Gt} + (1 - 0.149) * (0.17 \text{ Gt}) + 0.225 \text{ Gt}$$

In this scenario, the expected increase in AGB would be three times higher than in the legal compliance scenario, reaching up to 48.27% over current carbon stocks. In both scenarios, seen in Figure 5, we have the regions that would have the greatest marginal gains in carbon stocks, which we refer as the hotspots of carbon potential.

Figure 4: Projected scenarios of potential AGB recovery: (A) The legal compliance scenario where recovery potential includes only legal obligation of RL and APP areas.; and (B) the ideal scenario, where recovery potential includes RL, APP and active measures to revert fragmentation processes. Stocks in Mg/ha, figures in the same scale.

Figure 5: Projected scenarios of the full potential of recovery of the AGB stocks in São Paulo state, represented here in percentage of increase over 2017 carbon stocks. (A) legal compliance scenario and (B) ideal, active effort scenario.

Finally, to help the visualization of our results in more practical manners, we present them aggregated by municipality or administrative units of management (UGRHs) (Figures 6 and 7). We are able to name the municipalities with highest legal forest area debt and their respective carbon potential, which are not the same municipalities that would have the greatest marginal increase in its carbon stocks by restoration (Table 3). Clustering the data by UGRIs, the west of the state is clearly the area with the highest potential for biomass increase, but today it retains only about 0.1 Gt of florestal carbon. Equally if we look at the lowest potential of recovery the coastal units store around 0.43 Gt of carbon.

Table 3: Ranked municipalities by area deficit and percentual increase in carbon stocks by complying to the NCFB.

Rank	Municipality with highest area deficit (ha)		Carbon Potential (Mg)	Municipality highest carbon potential % - (Mg)	
1	Teodoro Sampaio	107222	1111643	Santo Expedito	63571
2	Guararapes	8490	123678	Flora Rica	139255
3	Santo Antônio da Alegria	8056	824891	Ribeirão dos Índios	126674
4	Morro Agudo	7814	729432	Junqueirópolis	492682
5	Andradina	7227	773476	Pacaembu	304241
6	Rancharia	6775	626505	Alfredo Marconde	106171
7	Martinópolis	6609	634696	Severí-nia	73279
8	Castilho	6583	688505	Emilianópolis	114891
9	Euclides da Cunha Pta.	6527	665710	Santa Mercedes	137463
10	Pereira Barreto	6478	756706	Irapuru	169448

Rank	Pre-colonial Highest AGB (Mg/ha)	2017 Highest AGB (Mg/ha)	Highest Potential % increase over 2017 AGB. (Both scenarios)
1	São Bento do Sapucaí 380.68	Ilhabela 250.39	Santo Expedito 91.1 ~ 93.6
2	Campo Limpo Paulista 363.70	Pedro de Toledo 247.15	Flora Rica 87.3 ~ 91.1
3	Santo Antônio do Pinhal 339.69	Iporanga 241.37	Ribeirão dos Índios 86.4 ~ 90.8
4	São José do Barreiro 325.58	Ubatuba 237.50	Junqueirópolis 86.0 ~ 90.3
5	Bananal 314.69	Tapiraí 225.97	Pacaembu 85.7 ~ 89.9
6	Natividade da Serra 312.08	Eldorado 221.82	Alfredo Marconde 84.1 ~ 89.0
7	São Luiz do Paraitinga 310.92	Miracatu 217.68	Severínia 83.9 ~ 89.2
8	Redenção da Serra 309.66	São Sebastião 216.98	Emilianópolis 83.4 ~ 88.8
9	Paraibuna 308.66	Barra do Turvo 213.37	Santa Mercedes 83.3 ~ 88.3
10	Piedade 305.02	Itariri 211.89	Irapuru 83.1 ~ 88.2

Figure 6: Estimates of the carbon balance for São Paulo aggregated by municipalities. (A) Pre-colonial AGB; (B) Remaining AGB in 2017; (C) Potential of recovery in the legal compliance and (D) ideal, scenarios. Table presents the top 10 Municipalities according to the upper graphs. Potential percentual increase according to legal compliance (lower value) and ideal (higher value) scenarios.

Rank	Pre-colonial Highest AGB (Mg/ha)		2017 Highest AGB (Mg/ha)		2017 Highest Potential % increase over 2017 AGB
1	Mantiqueira	366.69	Litoral Norte	227.28	Peixe 63.7~76.4
2	Paraíba do Sul	290.48	Ribeira de Iguape	197.02	Aguapeí 62.3~75.3
3	Litoral Norte	281.75	Baixada Santista	190.62	P. Paranapanema 62.3~73.0
4	Alto Tietê	273.06	Mantiqueira	104.22	Baixo Tietê 59.2~73.6
5	Ribeira de Iguape	263.17	Alto Tietê	66.86	Turvo / Grande 51.1~69.8

Figure 7: Estimates of the carbon balance for São Paulo aggregated by main river basins (*i.e.* UGHRI). (A) Pre-colonial AGB; (B) Remaining AGB in 2017; Potential AGB recovery under (C) the legal compliance and (D) ideal scenarios. Table presents the top 5 UGHRI according to the upper graphs. Potential percentual increase according to legal compliance (lower value) and ideal (higher value) scenarios.

Discussion

Estimating carbon stocks and its potential of recovery is a important but complex task (GLOOR *et al.*, 2012), especially because 70% of terrestrial ecosystems are disturbed by man (LUYSSAERT, *et al.*, 2008). Hence, assessments of carbon storage anywhere else than in remotes area of the Amazon, Sub-Saharan Africa, or Southeast Asia (SAATCHI, *et al.*, 2011) must take into account human-induced carbon losses. Here we provide such assessment and, as far as we known, this is the first time anyone estimates the carbon storage prior to human intervention in a tropical anthropized landscape. Our approach provides a spatially explicit carbon carrying capacity that can be used as benchmark for calculating current carbon stocks and to set site-specific references for carbon restoration. Another implication is the inherent lower standard deviations generated by the modelling, than other spatial interpolators currently used (ENGLUND, *et al.*, 2017; AVITABILE, *et al.*, 2015) that allows for a greater precision than ever before attained in spatial carbon modelling. On that account, our approach could be readily used for other human-modified regions of the world, as long as there is well-curated forest inventories available.

However, estimating carbon stocks from centuries ago most likely have its limitations. For the Atlantic Forest, the available knowledge on forest structure does not go past beyond 70 years (LIMA, *et al.*, 2015). If old-growth forests currently available in São Paulo are not good proxies of forests 500 years ago, our pre-colonial estimates may be biased. For instance, large, hard-wooded tree species (*e.g.* *Aspidosperma polyneuron*, *Cedrela fissilis*, *Handroanthus* spp.) have a long history of selective logging particularly in seasonal forests on the west part of the state. In our sample, average AGB for seasonal forests were conspicuously low in comparison to other forest types (Table 1). Therefore, it is possible that our seasonal forest inventories may not have had enough time to recover and thus they may underestimate their carbon storage potential. This suggestion may be especially true because high-fragmentation levels, typical of this part of São Paulo state, are known to hinder the establishment/persistence of big trees (LAURANCE *et al.*, 2000). It should be noted, however, that if this bias do exist in our sample, it means that our pre-colonial carbon estimate (4.62 Gt) is actually a conservative one.

As with niche modeling (TOWNSEND, 2001), our approach indicates what should be the carbon stock where there is no data available. Thus, this should be seen

a baseline that can be used in carbon assessments and restoration planning. For São Paulo state, we found that current carbon estimates decurred from this baseline values were comparable to other published AGB estimates (ENGLUND *et al.*, 2017). The main differences between ours (0.77 Gt) and their estimates (1.05 Gt), is probably due to the fact that we specifically did not include silviculture or agriculture carbon and we did include fragmentation effects in our current estimates. In addition, our approach allows to break the sources of carbon loss into deforestation and types of fragmentation effects (edge-effects and core degradation). For example, model adjustments can and provide or test breakpoints where those effects become relevant (D'ALBERTAS *et al.*, 2018). Thus reinforcing that our approach can be used for multiple purposes regarding carbon estimates.

Regarding our results on the current carbon stocks for São Paulo, the most striking outcome was quite clear: we have lost almost all vegetation cover, and with that almost all carbon stock. This footprint is not new and is expected from the deforestation rates described elsewhere (RIBEIRO, *et al.*, 2009). The impressive 3.85 Gt AGB loss registered, however, is a novelty and quantifies the magnitude of human impacts. This quantity can be used to estimate the contribution of carbon emissions to climate change (MATTHEWS, *et al.*, 2009). To understand the magnitude of the above ground carbon loss for the São Paulo state, yearly the entire country of Brazil releases about 0.43 Gt of carbon (MCTIC, 2017). The total loss of vegetation carbon in São Paulo account for about four and a half years of current emissions of the entire country. This comparison further emphasizes the need for preservation of the remaining current vegetation carbon stocks.

Another compelling result is to know that today we have, proportionally, more natural vegetation standing than stored carbon for São Paulo state, a result that could be true for other tropical regions. The difference between the remaining natural vegetation cover (21.3%) and the current carbon stocks (16.7%) can be explained by the combination of: (i) fragmentation effects and (ii) the intrinsic spatial variability our pre-colonial scenario. If there were no fragmentation effects the standing forest conditions would be much closer to the undisturbed scenario and thus forest area and carbon stocks would be more proportional. In addition, the pattern of deforestation specific to São Paulo resulted in the concentration of the remaining carbon in a single region: the mountainous coastal forests (which originally had the highest concentration to begin with). Both these effects interact, and if deforestation had been

uniform throughout our study area, then the expected carbon stocks should be even smaller, around 14% of the original. Therefore, the observed higher than expected carbon stocks ultimately are the consequence of the clumpiness of the remaining fragments in the pre-colonial hotspots of carbon.

The magnitude of carbon loss due to the fragmentation effects (FR) found in this study (34%) is very close to the findings of Laurance *et al.*, (1998) for the amazon forest fragments, where at 100m of edges fragmentation loss of carbon rates were around 36%. We know that more than 80% of remaining fragments of the Atlantic Forest have less than 50 ha (RIBEIRO *et al.*, 2009) and thus where most of the fragmentation effects occur. Those forest fragments are subject to the highest total carbon loss, and are responsible for 72.21% of the carbon losses by fragmentation. On the other hand, it may be argued that the Cerrado domain is not subjected to the same fragmentation effects as a the Atlantic Forest domains. However, there are very few studies on Cerrado domain edges (COELHO, 2017), making it difficult to parameterize edge-effects in this type of vegetation, if they exist at all. Thus, our assumption of using percentual losses has inherent less impact in the Cerrado domain.

By providing estimates of current carbon stocks and carbon recovery potential, our approach allows to identify long term hotspots of carbon sequestration. For São Paulo, independently of the recovery scenario, these hotspots are mainly located in intensive sugarcane systems in the west of the state, and in the Paraíba valley region that has a long history related to coffee plantations. These areas were identified as hotspots because they have the greatest natural area deficits and/or they hold the highest marginal potential of carbon storage increase. Thus, our approach can be readily used for planning future restoration actions aiming at maximizing carbon sequestration (Appendix 05).

Based on our different scenarios of potential AGB recovery, we can also monetize the carbon net gain. By assuming the european allowance cost of 5 to 25 US\$ as proxy for value of an stored ton of carbon in 2018 (BUSSINES-INSIDER, 2019) and a biomass to carbon conversion rate of 0.5 (HOUGHTON *et al.*, 2001), then the carbon potential for the State of São Paulo would value between 0.28 and 1.38 billion US\$ only in our legal compliance scenario. If we consider the ideal scenario, these values would increase to 0.925 - 4.63 billion US\$. In this latter case carbon credit gains triple over the legal compliance scenario. Therefore, our approach

allows not only to value carbon gains but also to assess separately the of carbon or credit gains based on different restoration strategies or goals for a given locality.

These results naturally lead to the following question: Can carbon credits alone pay for restoration costs? The AGB recovery of 0.11 Gt under the legal compliance scenario would represent a total 958,117 ha of restored lands. Considering restoration costs of tropical vegetation ranging from 1000-3000 US\$ per ha (RODRIGUES *et al.*, 2009), total costs would range from 0.96 to 2.79 billion US\$ for the legal compliance scenario. Under the ideal scenario however, the total recovery potential is 0.37 Gt, but costs are harder to estimate. If we consider only costs of fencing the remaining forest fragments, we would need to fence over 550 thousand km of fragment edges in São Paulo. Considering the average cost of fencing at 2000 US\$ per km (SOARES-FILHO *et al.*, 2016), we would add a cost of approximately 1.1 billion US\$. Thus, our estimates for the ideal scenario would reach total costs of 2.06 to 3.89 billion US\$.

So, in terms of funding restoration costs using carbon market mechanisms, our results suggest that the legal compliance and ideal scenarios would be economically viable if markets are willing to pay at least 11.15 (ideal) and 17.5 (legal) US\$ for fixed carbon ton. The ideal scenario can be further more attractive if we consider other fencing alternatives (*e.g.* green fences of *Mimosa caesalpiniaefolia*) that should be cheaper (10 US\$ for km) providing ecosystem services, buffering for forest fragments and example of mitigation of edge effects (BRANCALION *et al.*, 2012; RUGGIERO *et al.*, 2018). Hence, besides providing spatially explicit carbon reference values and the contribution of fragmentation induced carbon loss, our approach can also supply projections economic feasibility of different strategies for carbon restoration.

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Discussão Geral e Conclusões

Neste trabalho estabelecemos o balanço de carbono para o estado de São Paulo, uma paisagem tropical altamente modificada pelo ser humano, com elevadas atividades agrícolas e demandas conflitantes pelo uso da terra e pela conservação (ADAMS *et al.*, 2007). Nesta paisagem, onde a supressão de vegetação nativa ocorre há pelo menos cinco séculos (MORELLATO & HADDAD, 2000), é crucial estabelecer parâmetros de referência para os estoques de carbono na vegetação em uma dada localidade (BIRCH *et al.*, 2010). Uma vez estabelecidos estes parâmetros, pudemos revisar as estimativas dos estoques atuais de carbono e evidenciar a situação crítica desse serviço ambiental. Finalmente, destacamos regiões com potencial para recuperação (*i.e.* hotspots de recuperação de carbono), juntamente com os potenciais de custos de restauração e uma breve análise de sua viabilidade econômica.

A modelagem de carbono utilizada neste estudo se mostrou um método relativamente simples, que gerou resultados mais precisos (*i.e.* menores intervalos de confiança) em relação às estimativas até então disponíveis (ENGLUND *et al.*, 2017), que foram feitas majoritariamente por sensoriamento remoto da cobertura vegetal (HANSEN *et al.*, 2013). A aquisição de informações oriundas de sensores remotos ainda é necessária no método utilizado aqui, mas associada apenas à variáveis como temperatura e umidade, que estão atualmente disponíveis com graus de precisão elevados (ALVARES *et al.*, 2013). Em particular, obter um mapa de cobertura vegetal nativa remanescente (MAPBIOMAS, 2018) é essencial para a boa execução desse método. A compilação e auditoria de dados de biomassa florestal publicados foi o fator limitante e que demandou um grande tempo para sua compilação (LIMA *et al.*, 2015). Eventualmente espera-se que bancos de inventários florestais com informações de biomassa se tornem mais comuns e prontamente disponíveis, facilitando a réplica do procedimento para demais localidades ao redor do globo.

Tendo em vista essas considerações, com os dados de inventários florestais disponíveis hoje seria possível prontamente produzir mapas similares para outras localidades. No contexto nacional, o TreeCo seria capaz de fornecer dados de biomassa com boa cobertura para reproduzir

esse estudo para Minas Gerais, Santa Catarina e Rio de Janeiro. Para Minas Gerais, essa metodologia poderia inclusive ser comparada com o estudo de Scolforo *et al.*, (2015). No contexto global, seriam necessários dados especializados de remanescentes florestais atuais. Alguns candidatos que já possuem numerosos inventários florestais tropicais já disponíveis são o Peru, Guiné Equatorial, Gabão, Uganda e boa parte do sudeste Asiático (AVITABILE *et al.*, 2015).

Em um sentido mais amplo, os objetivos deste trabalho foram: (i) produzir resultados práticos, contextualizados e de fácil entendimento para o público geral; (ii) capacitar o aluno para produção científica e, ao mesmo tempo, (iii) instrumentalizá-lo com técnicas e conceitos que possam ser úteis também para o seu futuro como profissional no mercado de trabalho. Acredito que dentro das limitações de 24 meses, esses objetivos foram alcançados. Certamente existem pontos que poderiam ser trabalhados para aprimorar esse estudo caso houvesse mais tempo disponível, como a explicitação espacial dos custos de oportunidade para recomposição de estoques de carbono, locais com menor eficiência e maior potencialidade de regeneração espontânea (*i.e.* restauração passiva). Estas possibilidades parecem óbvias uma vez ditas, mas são considerações que apenas se mostram ao longo do processo já em andamento, com a troca de experiências com demais pesquisadores. Mas, acredito que o trabalho oferece uma contribuição substancial para o campo científico, técnicas e estimativa de carbono, para tomada de decisão pública e para, acima de tudo, instigar no leitor um imaginário de um futuro mais verde.

Resumo

Esta pesquisa consistiu em estimar o balanço de carbono da vegetação nativa de uma paisagem antropizada, ou seja, calcular a quantidade de biomassa arbórea acima do solo (AGB) preexistente (cenário pré-colonial), o quanto foi perdido pela ação humana (desmatamento e fragmentação) e que quantidade de carbono poderia ser recuperada com a adequação ao Novo Código Florestal Brasileiro (NCFB). Os fatores desse balanço são apresentados cartograficamente, e foram obtidos baseado em dados de campo para associar valores de tonelagem aos estoques estimados. A AGB pré-colonial estimada foi de 4.62 Gigatoneladas, dos quais 87.3% (3.85 Gt) foram perdidos até 2017. Essas perdas foram atribuídas em 90% (3.46 Gt) ao desmatamento, e 10% (0.39 Gt) à efeitos decorrentes da fragmentação. Os déficits em Reserva Legal e Áreas de Preservação Permanente estipulados pelo NCFB se traduzem em um potencial de recuperação de 0.11 Gt de AGB para São Paulo. Se reduzíssemos os efeitos da fragmentação esse potencial triplicaria (0.37 Gt). Os hotspots de biomassa atuais estão restritos às florestas costeiras (Ribeira do Iguape, Baixada Santista e Litoral Norte) e que as regiões com maior potencial de recuperação de carbono com a adequação ao NCFB são o Vale do Paraíba, Aguapeí e Pontal do Paranapanema. Finalmente, discutimos a eficácia dos mecanismos de compensação: seriam necessários 0.96 a 2.79 bilhões de US\$ para restaurar o déficit legal de vegetação, possível apenas se os mercados estiverem dispostos a pagar pelo menos 17.5 US\$ por tonelada de carbono fixado na vegetação.

Palavras chave: Balanço de Carbono, Mata Atlântica, Cerrado, São Paulo, Políticas Públicas

Abstract

The research aimed to estimate the carbon balance of natural vegetation in a tropical anthropized landscape. That is, to calculate the amount of pre-existing tree biomass above the soil (pre-colonial scenario), how much was lost by human action (deforestation and fragmentation) and how much carbon could be recovered with the adaptation to the New Brazilian Forest Code (NCFB). This balance is represented cartographically for the state of São Paulo, in its different stages (*e.g.* carbon inventory map for the original vegetation cover), and is based on field data to associate tonnage values with the estimated inventories. The estimated pre-colonial AGB for São Paulo was 4.62 Gigatonnes, of which 87.3% (3.85 Gt) were lost. These losses can be attributed to 90% (3.46 Gt) to deforestation, and 10% (0.39 Gt) to the effects of fragmentation. The vegetation deficits in Legal Reserve and Areas of Permanent Preservation stipulated by the NCFB translate into a potential recovery of 0.11 Gt of AGB. If we were to reduce degradation in forest fragments this potential AGB recovery would raise to 0.37 Gt. It was observed that current biomass hotspots are restricted to coastal forests (Ribeira do Iguape, Baixada Santista and Litoral Norte) and that the regions with the greatest potential for carbon recovery with adaptation to the NCFB are the Vale do Paraíba, Aguapeí and Pontal of Paranapanema. Finally, we discussed the effectiveness of compensation mechanisms, it would require 0.96 to 2.79 billion US\$ to restore the legal deficit of vegetation, feasible as long as carbon markets are willing to pay 17.5 US\$ for ton of fixed Carbon.

Key-words: Carbon Balance, São Paulo, Atlantic Forest, Cerrado, Public Policy

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Discussão Geral

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Anexos e Apêndices

Appendix 1: Tree community surveys and above ground biomass reference points.

The TreeCo database is an ongoing effort to compile and organize vegetation surveys for the Atlantic Forest (LIMA *et al.*, 2015) and other extra-Amazonian domains of Brazil. Starting with TreeCo we conducted complimentary a search for inventories of natural formations including basal area, above ground biomass, or carbon done in the Atlantic Forest and Cerrado domain in several online reference databases (BTDCAPES, Google Scholar, Web of Knowledge, SCIELO, SCOPUS, SPRINGERLINK, SCIDIR) adding all studies published until April 2017.

We selected only those inventories containing any type of tree biomass estimates (basal area, above ground biomass and/or carbon). Inventory basal area is a good proxy of the forest above ground biomass (SLIK *et al.*, 2010, BALDERAS TORRES & LOVETT, 2012), and is used throughout the analysis as the measure of biomass. Fifteen studies that only contained measurements of biomass or carbon had theirs values converted to basal area according to methods on Appendix 2. All forest surveys selected had their coordinates manually checked with google-earth suite to check it falls inside the reported forest fragment (Figure A1.1).

Our natural vegetation dataset contains 331 entries, which represented a total of 505,753 trees, covering 292.88 hectares. The total basal area recorded was 9,749.25 square meters. The forest types most sampled were Ombrophilous (38.07% of the entries) and Semi-Deciduous (35.05%) and the class with few surveys is the Cerrado *stricto sensu* (3.63%) and Mixed Ombrophilous (2.42%).

From each natural vegetation inventory retrieved during the search, we extracted qualitative and quantitative information and added them into the TreeCo database. We included all Atlantic Forest and Cerrado subtype formations listed by forest inventory authors, making small adjustments to standardize nomenclature. We limited our search to forest inventories done from 1990 onwards unless when the forest inventory was conducted inside conservation unities (at least 65 ha), assuming that the landscapes containing this forests tend to be more stable over time in terms of its forest cover. This led to the inclusion of surveys with the oldest forest inventory data acquired in 1979.

Figure A1.1: Location of the study area and the distribution of the forest inventories. The shaded grey corresponds to the Atlantic Forest limits, darker area represents the São Paulo state, each green dot represents one survey, and the red line is a 25km buffer of forest survey inclusion around the state.

The inventories used in the analysis use different criteria to include individuals in their sampling. Most of the used a minimum diameter at breast height (DBH) as their inclusion criterion, but other surveys used diameter at ground height (DGH) or a minimum height (H). To simplify the analysis, we first grouped the original dbh cutoff criteria into some major dbh classes 3 (2.8-3.2), 5 (4.8-5.0) and 10 centimeters. Then, we obtained an equivalent value of dbh for those surveys using criteria such as diameter at ground height or a minimum height criterions, using the following equations:

$$(A1.1) \quad DGH = 0.7814 + 1.269 \cdot DBH,$$

$$(A1.2) \quad DBH = 1.656e-01 + 1.087e-02 \cdot H.$$

This allometric relationships were obtained from data collected by Lima (2013) which contained measurements of DBH, DGH and H. The conversion between DBH and DGH presented above is in line with the conversion obtained using the equation of Gehring *et al.* (2008), but we decided to use ours equation because it was obtained from data collected in a stretch of Atlantic Forest of São Paulo state.

We classified all surveys according to four categorical classes of forest disturbance (*i.e.* heavy, high, medium and low disturbance levels), based on the information given by authors on the forest age and forest disturbance history □ intensity and timing of human disturbances within the fragment, such as logging, fire, livestock grazing, etc. This is a very general classification with lots of variation in forest structure and diversity within classes, but we were unable to refine it further due to a lack of more detailed information of site disturbance histories in most inventories. If authors did not provide information on the forest disturbances and/or stand age, the relative abundance of typical light-demanding Neotropical genera (*e.g.* *Baccharis*, *Cecropia*, *Celtis*, *Piptocarpha*, *Trema*, *Urera* and *Vernonanthura*) were used in a final attempt to classify forests according to their disturbance level.

We recorded total sampled area and sampling arrangement (*i.e.* contiguous or systematically/randomly distributed), assuming that randomly and systematically distributed sample units are equivalent for the estimation of forest biomass and richness (COCHRAN, 1977). Finally, we carefully cross checked references and data values to avoid inclusion of duplicated entries (*i.e.* different studies using the same data).

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Appendix 2: Basal area, Above Ground Biomass and Carbon relationships.

Studies reporting forest biomass estimates often use distinct methodologies. The most common forest biomass estimate is basal area (cross-sectional area of tree stems), which is obtained based on the DBH measurements of individuals inside a given area. Above ground biomass (AGB) and carbon (AGC) are more precise estimates of forest biomass, because they often take into account not only tree DBH but also tree height and species wood specific gravity. Estimates of AGB are generally obtained based on allometric equations, many of them being developed for specific types of forests or parts of the world. The surveys used in this study presented 13 different allometric equations, although many other were found in the TreeCo database (Table A2.1).

Table A2.1: List of allometric equations reported in the forest inventories, H denotes Height of the tree, DBH, diameter at breast height, WSG wood specific gravity. After the equation autho (*) indicates that the formula was used in a São Paulo forest inventory and in this study.

Allometric Equation	Author (Model)
$\exp(-2.289+2.649*\log(\text{DBH})-0.021*(\log(\text{DBH}))^2)$	Brown_1997
$\exp(-3.676+0.951*(\log((\text{DBH}^2)*\text{H})))$	Burger_&_Delitti_2008
$\exp((-3.068)+2.522*\log(\text{DBH}))$	Burger_&_Delitti_2008(b)
$\exp(-2.187+0.916*\log(\text{WSG}*(\text{DBH}^2)*\text{H}))$	Chave_et_al_2005(DryH)
$\text{WSG}*\exp(-1.449+2.148*\log(\text{DBH})+0.207*(\log(\text{DBH})^2)-0.0281*(\log(\text{DBH})^3))$	Chave_et_al_2005(Moist)
$\exp(-2.977+\log(\text{WSG}*(\text{DBH}^2)*\text{H}))$	Chave_et_al_2005(MoistH)
$\exp(-2.557+0.940*\log(\text{WSG}*(\text{DBH}^2)*\text{H}))$	Chave_et_al_2005(WetH)
$0.0673*(\text{WSG}*(\text{DBH}^2)*\text{H})^{(0.976)}$	Chave_et_al_2014(4)
$\exp(-4.15190+1.06068*\log((\text{DBH}^2)*\text{H}))$	Melo_&_Mantovani_1994
$\exp(-10.9520199234+2.0898526615*\log(\text{DBH})+0.8096162241*\log(\text{H}))/ (0.4839)$	Scolforo_et_al_2008(FES)
$\exp(-11.319842099+2.1415723631*\log(\text{DBH})+0.8134282561*\log(\text{H}))/ (0.4833)$	Scolforo_et_al_2008(FOM)
$21.297-(6.953*\text{DBH})+(0.74*(\text{DBH}^2))$	Tiepolo_et_al_2002
$0.6*\exp(-2.694+2.038*\log(\text{DBH})+0.902*\log(\text{H}))$	Velasco_&_Higuchi_2007

After compiling the AGB formulas, we used individual tree data from 43 plots from Brazil to estimate the relationships between different allometric equations to

estimate AGB. Tree species listings were crossed with a database of wood specific gravity (WSG) (CHAVE *et al.*, 2009; ZANNE *et al.*, 2009) and assigned WSG for each species. If a species had no WSG available, it was assigned the average of the genus (BAKER *et al.*, 2004; CHAVE *et al.* 2006). If at this taxonomic level still no WSG recorded, then the family average was assigned. If still any of those steps did not provide a wsg value, the average of the total sample was assigned (0.6555 g/cm³).

The TreeCo database also includes raw data from around 167 thousand trees measured in 43 permanent plots in Brazil (TreeCo, 2018). We used data regarding tree diameter at breast height (DBH), tree height (H) and wood specific gravity (WSG), trees with missing height measurement or on-field height guess had estimations of height provided by an allometric relationship of dbh and height (Figure 2). Three concurring models were tested to describe (Power model, Weibull model and Chapman-Richards model SCARANELLO *et al.*, 2012) along with equation 6a from Chave *et al.* 2014 which uses a coordinate grid of environmental stress to define such Height and DBH relationship). Using the Akaike information criterion the winning representation was the power model relationship below:

Height ~ a *DBH^b

Parameters:	Estimate	Std. Error	t value	Pr(> t)
a	2.614573	0.010210	256.1	<2e-16 ***
b	0.476434	0.001454	327.6	<2e-16 ***

Figure A2.1: Visual interpretation of our power model (b) reveals less dispersion along the 1:1 line than the estimation using Chave *et. al.* 2014 (a). Grey dots are individual trees, red line is the mean prediction of the estimated relationship.

For each plot we estimated the relationship of all allometric equations (Table 2) with the allometric equation proposed by Chave *et.al.* (2014) - see formula 7. We used a simple linear model to describe the relationship between each pair of allometric equation. We tested two types of linear regression, one weighted by the total sampling effort of each survey (in ha) and its logarithmic transformation. Neither weighting efforts returned a better fit. Figure A2.3 depicts all the relationships between allometric equations.

Figure A2.2: Linear relationships with between allometric equations and Chave *et al.* 2014 formula (7). Y is the natural logarithmic of the the Chave's formula value for aboveground biomass and X is the natural logarithmic of the aboveground biomass of each allometric equation. We present the resulting parameters of the regression (in blue), the associated R square of the relationship (in red), 1:1 line and fit lines are also displayed in each graph (grey line).

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Appendix 3: Co-variables for AGB modeling

For our pre-colonial carbon estimation we evaluated several co-variables capable to help explaining the observed carbon stocks in the forest inventories. We evaluated these variables for their normality and correlation within other co-variables, and selected those least correlated. Some variables were obtained from the original publication, while others, such as climatic, soil, landscape and ecological data, were obtained from georeferenced datasets.

Climate Co-variables

We extracted air temperature, annual rainfall and monthly precipitation, all with 100 m of resolution (ALVARES *et al.*, 2013). From monthly precipitation we computed rainfall seasonality (*sensu* WALSH & LAWLER, 1981). We also extracted the climatic water deficit at resolution of 5000 m (CHAVE *et al.* 2014), and the 19 Bioclimatic variables from WorldClim at resolution of 1000 m; (HIJMANS *et al.* 2005). Data extraction was done in R (R Core Team, 2018) using package *raster* (HIJMANS, 2017).

Soil

To estimate our pre-colonial carbon stocks we needed a map of the vegetation types prior to human intervention. To this end we used the 2009 vegetation map from Brazil elaborated by the Brazilian Institute of Geography and Statistics (IBGE, 2009), which includes a preterit vegetation classification, that delimits the reported limits of ecotones. We also made use of the the soil maps produced by IBGE, and adjusted the naming scheme to match the forest surveys.

Soil Co-variables

Forest surveys soil reports provided by the authors were checked against soil maps at state level (DOS SANTOS *et al.*, 2011). Soil information was manually checked and classified, giving priority to the classification provided by the authors of the original publication. Each survey had its soil type defined at the best resolution possible, following the IBGE and Rossi (2017) classification. We generated an index of soil suitability for plant growth Where to obtain the soil suitability for plant

growth, we had assess to used a database of nearly 6000 soil profiles from Brazil (MUNIZ *et al.*, 2011). After classifying each profile using the same soil classification from Rossi 2017, profiles were ordered in terms of its suitability for plant growth according to: depth, fertility, drainage, and aluminium toxicity (PEREIRA & LOMBARDE NETO, 2004). For each of these soil attributes were ranked from 0 (very inapt for plant growth) to 4 (very apt for plant growth). Therefore, the soil aptitude variable used in this study is a compound index varying from 0 (very inapt) to 16 (very apt).

Terrain Co-variables

We gathered NASA Shuttle Radar Topography Mission data sets from year 2000 with the resolution of 1 arc degree. Georeferenced to WGS84 and grouped the geo-tifs into 4x4 arc degree files. Along the height we calculated the slope with GDAL-QGIS "slope" function ranging from 0 to 90 degrees. Aspect of the terrain, with GDAL-QGIS "aspect" function, attributing North to 1 and 359 and south to 180 in a 360 scale, and 0 to pixels without aspect.

Vegetation Co-variables

Fragment size

Fragment size is a good proxy for habitat availability for species and a proxy of the proportion of the fragment susceptible to landscape effects transitioning to fragment core areas (Putz, *et al.*, 2014). Fragment size was extracted from the original publications and checked with Google Earth Pro (© Google Inc.). The smallest vegetation fragment had only 0.55ha and the larger fragments (>50.000 ha) were rare.

Processing and selection of explanatory variables included in the model

Forest disturbance level was the only categorical explanatory variable we had, but since categories are ordered we attributed arbitrary values for each category. These values were: 15 for very heavy, 40 for high, 70 for medium and 100 for low disturbance levels. We standardized all explanatory variables prior to analysis (*i.e.* (observed – mean)/standard deviation), so that all variables had a similar range of variation, making their estimated effects comparable.

The selection of explanatory variables was based on their performance on previous similar studies (unpublished data, R.A.F. LIMA) and on the absence of

strong correlation or collinearity with other explanatory variables. We selected as candidate variables humidity and mean annual temperature, as they are basic climatic variables, and measure seasonality. While we tested other landscape metrics (such as perimeter area relationships, fractal mandelbrot index), the metric with least collinearity was the aggregation index, which provides a simple measure of patch aggregation (MCGARIGAL *et al.*, 2012). In this index values close to one represent high aggregation, while higher values represent greater disaggregation. The regression model containing all the pre-selected candidate environmental and human-related variables was tested for collinearity and all condition indices were considered quite low (BELSLEY, 1991).

Linear mixed-effect models

We performed a model selection procedure to find the best fixed and random effects structure to explain the variation of biomass in our study area. Candidate models had different combinations of abiotic and biotic co-variables and interactions between them. To avoid problems with the interpretation of individual coefficients, only those interactions with a clear biological meaning, were included such as the interactions of solar incidence with Forest Disturbance Level. The model with best fit to data contained only one random effect (*i.e.* vegetation type) that improved overall model fit. Model selection was based on the Akaike information criterion (AIC) and AIC values greater than 2 between models were considered as an indicative of difference in models fit (HU, 2007). We tested the significance of the chosen model based on the comparison of a "null" model containing only random effects (no fixed effects), using Chi-squared statistics. We also obtained the conditional (pseudo) R^2 , which may be seen as the variance explained by the full model (fixed + random effects NAKAGAWA & SCHIELZETH 2013).

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Appendix 4: Interpolation of AGB in a pre-colonial scenario

For our extrapolation of above ground biomass stocks prior colonization we applied a 25 km buffer around the São Paulo state, and overlaid an hexagonal grid (BIRCH *et al.*, 2010). Whenever a hexagon felt partially inside the study area its center was moved inside the study area (Figure A5.1.).

Figure A5.1: Detail at coastal and island region of São Paulo, red lines represent the interior of continental margins and black hexagons the result of a simple overlay of the hexagonal grid. The snapping of hexagons to the continental margin to keep proportional area.

This hexagonal grid at a 2.500ha was used for the spatial extraction of the co-variables used on the extrapolation of our linear mixed effects model (1 in methods section) and building of the pre-colonial scenario. The spatial representation of the co-variables use displayed on Figure A5.2:

Figure A5.2: Spatial representation of the variable used in the pre-colonial scenario (A) Phytophysiognomies delimitation; (B) Normalized relative humidity; (C) Normalized Direct incident Solar Radiation; (D) Normalized mean annual temperature. Data from ALVARES *et al.*, (2013) and NASA, (2018).

Applying (5) with the co-variables depicted on figure A5.2 along three different methodologies (BATES *et al.*, 2015; HIEMSTRA *et al.*, 2008; GRÄLER *et al.*, 2016; BIVAND & YU, 2017) to estimate Above Ground Biomass for our pre colonial scenario, results can be seen on Figure A5.3. Mean standard errors on Figure A5.4.

Validation was achieved by applying the same resolution and hexagonal grid to the rasters provided by recent literature (AVITABILE *et al.*, 2015; SANTORO *et al.*, 2015; ENGLUND *et al.*, 2017).

Figure A5.3. AGB distribution prior to heavy human interventions by three methodologies. (A) Linear Mixed Effects Model, with group random effects and spatial correlation; (B) Geographically Weighted Regression Model; and (C) Auto Kriging.

Figure A5.4 Spatial representation of the mean standard errors resulting from the combination of the three methodologies used to obtain the pre-colonial scenario.

Figure A.5.5 Representation in the same color scale and at 2,500ha scale of the works on carbon estimation from (A) Englund *et al.* 2017 (B) Avitabile *et al.* 2015 (C) Saatchi *et al.* 2011

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Appendix 5: Municipal data table

Municipality	AGB Mean (Mg/ha)	Legal Vegetation Area deficit (ha)	AGB Pre- Colonial (Mg)	AGB Remaining 2017 (Mg)	AGB Potential Recovery
					Legal compliance (Mg)
Águas da Prata	255.49	607.08	3658159.04	511106.97	102332.22
Águas de Lindóia	266.73	230.1	1600580.69	92824.72	40390.44
Águas de Santa Bárbara	147.64	1169.88	6025949.8	382938.95	114698.49
Águas de São Pedro	150.12	8.3	48013.86	2800.28	884.74
Adamantina	163.11	3077.41	6731839.21	84115.34	330077.17
Adolfo	148.71	819.45	3140792.18	58152.97	120727.47
Aguai	191.25	2311.92	9051474.23	403220.1	285585.13
Agudos	138.23	4949.13	13361834.04	1169107.39	448365.52
Alambari	222.04	405.88	3529850.71	175268.39	59392.73
Alfredo Marconde	161.2	689.27	1919915.53	10153.13	73279.98
Altair	145.96	1334.76	4613898.59	194758.23	128947.31
Altinópolis	136.8	3011.34	12729993.62	1424587.26	283183.08
Alto Alegre	173.24	1047.32	5512446.44	139753.21	119333.07
Alumínio	266.71	215	2249829.79	332776.14	37602.26
Alvinlândia	168.31	415.1	1437403.1	238485.16	45989.48
Álvares Florence	150.32	1068.33	5432018.78	148081.65	107122.57
Álvares Machado	158.12	1569.99	5467313.59	47670.85	162892.32
Álvaro de Carvalho	180.34	936.27	2760016.72	199465.2	111132.95
Americana	203	210.06	2717475.13	73666.06	28146.61
Américo Brasiliense	139.77	387.47	1723453.06	102008.55	36489.86
Américo de Campos	255.79	2413.39	9710864.88	559805.68	403619.93
Amparo	168.08	1084.56	5410651.8	194258.64	136638.1
Analandia	150.47	1456.61	4918748.74	568501.99	143072.82
Andradina	162.27	7227.09	15584375.66	329510.75	773476.54
Angatuba	174.17	3712.15	17908836.77	1336089.48	418602.9
Anhembi	208.35	1887.72	15333126.97	1003773.89	262073.67
Anhumas	144.14	1964.32	4620728.01	138668.87	180214.92
Aparecida	299.52	741.91	3593114.55	404637	146074.58
Aparecida d'oeste	166.03	1248.51	2981938.93	66120.04	136224.4
Apiáí	284.21	1804.99	27579026.59	15308723.82	354534.94
Araçariguama	239.92	292.97	3522599.32	772927.03	45110.49
Araçatuba	170.66	4743.97	19913169.82	358427.33	535783.59
Araçoiaba da Serra	225.85	497	5798752.92	379018.3	73992.38
Aramina	158.84	420.48	3233827.03	90175.14	43878.92
Arandu	144.11	311.88	4110387.85	183990.59	37469.04
Arapeí	304.12	928.25	4734125.11	1374834.21	185784.38
Araraquara	147.26	3140.8	14831266.32	745791.01	316622.65
Araras	204.83	2996.73	13154347.14	379247.12	400115.7
Arco-íris	169.86	1318.21	4478599.64	121796.75	147463.59
Arealva	131.26	2582.52	6651355.46	269524.68	225002.75
Areias	284.53	1133.02	8725974.78	1375403.76	261818.25
Areiópolis	154.98	153.55	1330330.17	16048.1	15799.74
Ariranha	173.92	381.82	2310039.76	35609.8	43630.16
Artur Nogueira	202.62	252.48	3586966.81	71454.34	33699.58

Aruja	265.55	55.32	2582493.02	408549.94	9993.93
Aspásia	167.98	218.73	1155810.62	19988.13	24179.14
Assis	141.53	1624.94	6526369.05	464955.64	148404.01
Atibaia	261.39	537.05	12474357.64	1691862.19	91380.4
Auriflama	158.87	3097.48	6880323.28	156597.68	328636.86
Avaí	148.19	1874.11	8020476.41	505764.6	178891.03
Avanhandava	148.88	1624.23	5074903.73	113515.03	158032.76
Avare	150.73	3866.9	18360722.88	1055545.59	371088.17
Bady Bassitt	177.66	215.63	1947967.36	22534.48	25210.75
Balbinos	173.74	761.4	1570779.29	36216.99	87084.12
Bálsamo	167.29	222.77	2521836.91	95492.58	24371.18
Bananal	314.69	3353.24	19372151.91	8480919.57	653330.76
Barão de Antonina	191.33	522.15	2951098.16	73071.35	66757.05
Barbosa	147.42	772.35	3024994.38	74937.17	74923.61
Bariri	177.34	2404.15	7824265.39	153715.24	283983.68
Barra Bonita	200.03	473.67	3000918.64	25594.72	62437.23
Barra do Chapéu	286.32	643.42	11659386.53	3448473.06	121914.54
Barra do Turvo	288.17	814.31	28942072.61	21429208.3	149997.79
Barretos	126.34	3082.11	19758812.81	793445.02	274205.79
Barrinha	137	261.07	2006569.47	49627.12	24081.1
Barueri	273.21	8.55	1729126.55	131496.33	1532.67
Bastos	158.41	452.22	2670693.71	81653.99	46377.76
Batatais	160.08	2241.46	13603513.42	777793.15	236211.42
Bauru	153.05	1879.43	10295842.2	683450.35	182138.41
Bebedouro	133.8	1305.51	9106160.26	275164.35	114706.37
Bento de Abreu	166.51	2285.7	5045177.66	111307.69	250738.18
Bernardino de Campos	184.35	1244.87	4484545.77	123490.61	150950.84
Bertioga	219.21	301.65	10640814.04	8656695.81	61878.58
Bilac	172.18	659.35	2706534.26	40769.24	74621.82
Birigui	172.7	2536.31	9150336.27	130010.87	288724.9
Biritiba Mirim	276.56	859.91	8775435.67	3964764.43	159679.12
Boa Esperança do Sul	144.91	3422.21	10009776.42	586193.74	325640.79
Bocaina	162.57	1990.75	5917155.86	343717.32	212283.43
Bofete	205	2116.52	13399662.54	1296775.21	298504.89
Boituva	224.62	618.02	5558339.15	143299.4	90505.41
Bom Sucesso de Itararé	301.16	352.09	3988352.94	1246097.56	70021.79
Bon Jesus dos Perdoes	275.43	59.23	3013537.69	1019514.67	10658.46
Borá	147.4	590.19	1742443.04	60793.38	56328.88
Boracéia	189.13	833.78	2285145.85	36183.35	103646.18
Borborema	148.61	2626.33	8203419.95	156197.55	250224.05
Borebi	130.43	2905.37	4522648.67	326988.73	244409.95
Botucatu	181.23	3888.09	26895679.23	2067884.43	476037.31
Bragança Paulista	240.95	1601.59	12367045.7	772091.67	253838.65
Brauna	171.79	1028.25	3363182.68	74094.33	116287.09
Brejo Alegre	168.41	754.23	1756036.71	18400.11	83771.26
Brodosqui	136.36	1202.31	3813063.42	127986.02	102467.67
Brotas	158.14	3109.18	17397851.38	1209495.29	332811.6
Buri	175.89	3456.84	21036462.99	2010671.53	413279.05
Buritama	172.48	1253.2	5660842.93	147638.86	173087.5
Buritizal	148.27	711.63	3950157.84	244427.25	69731.08
Cabrália Paulista	140.54	1147.74	3365397.28	240523.15	108678.97
Cabreúva	245.42	734.62	6384304.78	2202707.87	117826.04
Caçapava	274.96	1731.01	10180615.35	674186.88	318530.89
Cachoeira Paulista	261.05	2008.85	7517692.47	377823.5	345107.25

Cafelândia	171.65	4528.28	15803719.41	886518.99	512550.03
Caiabu	161.32	1269.8	4047117.19	58371.01	134864.57
Caieiras	276.88	111.64	2661357.72	764919.97	20284.99
Caiuá	156.04	2778.87	8385047.63	212227.45	284746.93
Cajamar	274.16	170.17	3512117.31	801862.2	30645.04
Cajati	274.36	762.47	12465256.56	8286154.91	130925.14
Cajobi	164.74	781.6	2894182.96	49799.44	84804.54
Cajuru	165.16	2140.99	10888274.64	871977.46	234797.81
Campina do Monte Alegre	175	723.11	3222158.39	177441.96	86448.65
Campinas	247.77	2480.22	19735394.9	545078.84	408789.05
Campo Limpo Paulista	363.7	172.81	10879367.02	4193825.96	44291.25
Campos do Jordão	273.01	56.53	1929538.7	209104.14	10187.89
Campos Novos Paulista	126.51	1881.91	6126411.26	283567.6	158785.67
Cananéia	224.3	333.67	29677759.69	25960128.16	56312.64
Canas	250.32	379.94	1315996.99	41168.92	63798.6
Cândido Mota	178.97	2009.16	10688460.04	126913.39	236522.87
Cândido Rodrigues	156.45	88.02	1094895.77	11933.61	8955.35
Canitar	189.68	201.83	1093683.98	8670.43	25188.28
Capão Bonito	240.12	3882.31	39412457.45	12960597.19	624714.38
Capela do Alto	227.89	361.33	3867030.05	288171.04	54667.92
Capivari	206.92	1962.72	6714890.41	114123.1	268457.87
Caraguatatuba	281.78	1543.14	13764402.86	9667949.51	274064.11
Carapicuíba	275.35	0.11	961633.29	30516.81	19.59
Cardoso	163.66	3160.55	10423074.72	378266.37	342450.5
Casa Branca	175.62	3878.45	15198547.42	901973.19	451393.69
Cássia dos Coqueiros	161.54	363.68	3107348.48	246765.76	37814.6
Castilho	146.85	6583.96	15585448.64	704589.79	688505.43
Catanduva	170.29	1021.25	4967838.05	66552.14	114627.3
Catigua	170.44	561.16	2477519.28	49288.39	62999.85
Cedral	174.4	581.36	3424177.94	46475.27	66365.83
Cerqueira César	140.59	961.46	7081495.1	331215.07	91959.36
Cerquillo	220	322.9	2815477.51	41983.71	47020.01
Cesário Lange	245.19	396.48	4670830.43	95298.33	63889.85
Charqueada	172.71	1167.1	3045083.68	71956.34	130641.07
Chavantes	191.98	667.19	3611144.89	54380.85	88522.47
Clementina	169.92	748.12	2871653.09	45629.22	83621.88
Colina	124.54	1256.85	5281360.92	171225.79	111592.13
Colômbia	97.8	2468.53	7141997.69	574900.64	133567.19
Conchal	196.15	381.53	3594113.4	119475.28	49244.9
Conchas	236.89	1659.38	11096414.44	349129.58	261389.06
Cordeirópolis	199.93	537.75	2752556.65	34739.92	70774.8
Coroados	171.96	1045.76	4240659.79	80945.35	118449.51
Coronel Macedo	208.36	1463.07	6349732.8	183525.98	196514.14
Corumbataí	190.5	1116.19	5290616.74	374364.1	139789.06
Cosmópolis	203.76	460.95	3148345.96	102943.52	61773.74
Cosmorama	144.63	1075.89	6386908.16	223630.28	102283.15
Cotia	278.34	49.12	9039752.64	3419990.4	9031.76
Cravinhos	148.16	1371.97	4613006.46	119076.13	133113.56
Cristais Paulista	150.16	1009.44	5794019.97	469792.75	99612.88
Cruzália	175.24	337.97	2616245.33	10819.22	38452.32
Cruzeiro	256.44	1795.47	7824827.39	1806282.13	295624.56
Cubatão	259.22	0.78	3588611.35	2700967.92	156.84
Cunha	299.62	3823.38	42159986.14	8539968.5	743175.57
Descalvado	175.37	2339.48	13237298.94	1046501.63	269624.33

Diadema	285.61	0.01	893721.94	34398.47	4.14
Dirce Reis	170.5	520.35	1517661.21	69908.92	58431.4
Divinolândia	244.48	580.45	5452497.99	240169.34	91843.71
Dobrada	143.79	595.06	2164347.99	27984.99	58774.85
Dois Córregos	165.47	1739.69	10445870.13	413560.69	193109.96
Dourado	178.61	745.01	3687047.62	304207.97	89870.98
Dracena	157.74	2739.3	7698732.62	190213.78	284028.96
Duartina	147.96	1177.2	3904762.41	218794.58	118781.28
Dulcinópolis	168.64	344.53	1312665.08	16844.22	38199.71
Dumont	141.77	280.97	1575719.89	22889.08	26246.86
Echaporã	117.8	2444.94	6081543.17	333158.67	199922.15
Eldorado	263.47	3498.31	43653312.18	36752217.82	595674.37
Elias Fausto	222.73	825.46	4471526.09	85510.98	121002.73
Elisiário	171.16	482.29	1586662.78	30027.4	54338
Embaúba	166.4	275.97	1383840.5	28782.13	30186.74
Embu	280.74	6.22	1948652.15	256552.03	1146.94
Embu-Guaçu	285.02	112.23	4387712.93	1529542.24	21195.24
Emilianópolis	159.17	1095.42	3546931.98	19742.8	114891.99
Engenheiro Coelho	198.49	233.35	2182715.64	54993.02	30462.09
Espírito Santo do Pinhal	238.12	2120.87	9303133.52	591833.21	332477.46
Espírito Santo do Turvo	160.44	1457.15	3050641.21	100199.36	154423.39
Estiva Gerbi	201.8	295.8	1487568.75	42081.95	39219.49
Estrela do Norte	151.82	2360.81	3985525	78487.69	236841.36
Estrela do Oeste	172.31	1525.19	5103526.74	155814.79	172987.03
Euclides da Cunha Paulista	152.66	6527.18	8794097.58	537521.33	665710.86
Fartura	196.64	1569.04	8444654.8	316450.65	206227.05
Fernando Prestes	158.28	273.08	2698018.82	43321.88	27897.54
Fernandópolis	172.54	3079.59	9505846.33	266727.45	349175.6
Ferno	172.41	503.76	1736710.12	99583.75	58125.4
Ferraz de Vascon	287.14	19.97	855029.35	83289.36	3810.01
Flora Rica	158.84	1331.78	3578521.35	22556.98	139255.45
Floreal	176.16	771.67	3586240.62	94077.91	89642.3
Flórida Paulista	162.2	3555.2	8514827.38	109134.65	379185.02
Florínia	181.12	661.36	4102021.3	59983.81	78977.62
Franca	153.3	1337.33	9300825.02	878940.47	134403.39
Francisco Morato	268.41	11.97	1321366.09	157356.52	2100.8
Franco da Rocha	260.13	67.74	3483582.62	639278.69	11585.64
Gabriel Monteiro	169.9	790.3	2346705.78	39365.5	88414.61
Gália	178.92	1948.4	6385421.1	718248.58	229338.94
Garça	183.69	3190.89	10221421.31	745417.51	386509.27
Gastão Vidigal	177.05	620.78	3192121.41	72377.36	72349.3
Gavião Peixoto	134.63	462.11	3284660.68	124938.86	40672.2
General Salgado	175.14	2671.2	8630779.98	259627.43	306764.06
Getulina	173.78	3632.13	11734597.78	400524.69	415334.53
Glicério	161.63	1685.36	4431444.9	57813.54	181786.43
Guaíçara	158.93	779.77	4285776.54	84293.1	83689.08
Guaimbê	175.58	1125.77	3817977.21	157065.75	130212.27
Guaíra	128.55	6340.91	16152945.97	418810.21	552338.76
Guapiaçu	295.33	403.12	12028605.29	3950248.7	79562.04
Guapiara	164.47	1419.06	5353342.59	163013.24	151717.19
Guará	150.82	1583.51	5462311.18	134704.06	158255.42
Guaraçaí	162.25	4690.94	9212440.44	383220.28	498039.52
Guaraci	159.97	1511.83	10201740.98	176418.03	161114.64
Guarani do Oeste	168.48	608.6	1429163.65	27949.7	67540.97

Guarantã	175.21	2718.61	8096609.15	597284.74	313936.5
Guararapes	223.53	8490.65	34935760.58	4258963.79	1236782.3
Guararema	169.97	696.28	2501335.48	45626.3	77972.62
Guaratinguetá	281.15	1488.32	7612072.08	1105379.14	276048.61
Guareí	204.96	2138.12	11621988.23	853486.55	297325.88
Guariba	104.84	596.76	2826286.15	41811.24	41460.27
Guarujá	258.08	12.93	3534418.3	1725849.99	2536.19
Guarulhos	222.2	70.82	7080327.35	2113623.39	9845.03
Guataporá	123.42	1917.51	5107648.38	207613.56	152392.57
Guzolandia	153.61	1832.97	3896323.34	110645.78	182420.71
Herculândia	165.14	2307.81	6028189.05	63188.46	250121.55
Holambra	214.32	139.5	1390584.96	40241.65	19854.19
Hortolândia	214.26	62.45	1335434.29	3010.5	8795.12
Iacanga	156.1	2904.51	8543025.1	348910.54	297173.64
Iacri	166.2	1472.3	5386969.96	123214.77	161108.15
Iaras	128.63	1361.99	5174291.68	372528.81	114997.79
Ibaté	172.62	1026.35	4997566.49	373036.21	119712.1
Ibirá	173.11	776.94	4699853.12	87740.49	88475.89
Ibirarema	177.71	830.55	4030328.96	51301.69	97354.37
Ibitinga	148.88	2811.84	10227420.07	286221.22	271554.74
Ibiúna	278.96	524.35	29556832.2	12457651.69	95445.18
Icém	145.58	1638.23	5305914.38	229074.64	159177.67
Iepê	161.63	2103.47	9588187.78	327818.15	246657.01
Igarçu do Tietê	205.39	218.68	1984496.06	11347.61	29611.64
Igarapava	155.04	1457.44	7218151.21	403411.16	151471.99
Igaratá	269.62	1228	7919797.99	1641811.41	217502.42
Iguaçu	240.59	1744.73	46764105.08	39464100.06	296836.98
Ilha Solteira	160.55	5464.56	10604751.2	178435.9	629854.98
Ilhabela	293.57	0.07	9825365.06	8380301.35	13.25
Indaiatuba	235.37	795.98	7297054.77	231282.62	131727.02
Indiana	153.79	536.11	1989671.2	49139.3	54051.29
Indiaporã	167.35	1162.38	4671030.61	131293.37	129285.37
Inúbia Paulista	163.85	565.73	1415704.1	62218.82	61086.53
Ipaucu	195.46	943.37	4113458.79	140464.77	126043.51
Iperó	230.6	293.67	3928226.17	547307.91	45700.66
Ipeúna	189.42	960.29	3613736.06	171959.84	119727.5
Ipiruá	145.46	381.56	1981083.69	71207.14	36340.7
Iporanga	268.62	822.51	31138925.02	27980123.5	145938.65
Ipuã	149.83	3233.79	6965492	160910.42	317692.23
Iracemópolis	200.85	468.21	2334759.71	37246.93	61893.05
Irapuã	156.75	542.17	4035747.61	194458.62	56233.39
Irapuru	161.08	1599.64	3438283.42	45967.77	169448.89
Itaberá	153.81	3389.46	16681042	1087527.34	345636.84
Itaí	160.25	4412.57	17823682.88	685484.19	461096.44
Itajobi	156.73	1422.44	7848958.35	178495.89	144378.74
Itaju	168	1176.09	3847024.48	91325.17	130973.24
Itanhaém	247.41	300.86	14805292.67	12222732.12	49373.21
Itaóca	258.54	1305.25	4710472.67	2051703.31	219704.76
Itapecerica da Serra	285.36	33.45	4319269.94	1285419.93	6257.55
Itapetininga	199.97	4853.43	35824781.47	2709706.93	637177.25
Itapeva	158.38	4559.11	28893182.55	2727485.48	473327.35
Itapevi	274.15	16.25	2515761.64	407725.24	2947.9
Itapira	242.08	3592.83	12513635.16	578556.12	577466.99
Itapirapuã Paulista	268.95	1270.51	10920927.84	3450082.77	228742.94

Itápolis	147.18	3100.53	14673556.13	436526.73	300371.12
Itaporanga	236.89	2090.86	12053672.9	417535.31	323873.21
Itapuí	194.34	666.64	2706059.37	19976.14	85257.47
Itapura	160.18	3120.6	4913637.74	132955.59	341144.54
Itaquaquetuba	246.65	9.11	2028469.12	73591.48	1527.56
Itararé	160.89	2279.11	16157013.01	2140634.55	232482.55
Itariri	285.52	335.05	7814424.42	5799342.35	62095.31
Itatiba	259.98	1356.98	8366646.71	550634.2	232563.51
Itatinga	161.01	2736.89	15754727.48	1120859.11	286364.1
Itirapina	168.56	2640.19	9515933.7	912540.49	303740.08
Itirapuã	172.12	460.07	2768561.91	331179.34	51282.89
Itobi	189.98	965.36	2629308.24	52598.37	122053.49
Itu	236.47	1894.8	15136954.29	1389734.53	286610.65
Itupeva	291.9	564.44	5868143.59	392489.55	112269.14
Ituverava	158.3	3055.99	11033427.73	332374.12	316674.09
Jaborandi	103.15	1037.74	2835979.53	69294.69	72507.21
Jabuticabal	112.91	1544.26	7993506.93	110279.72	120064.54
Jacareí	276.19	2760.82	12697630.93	845860.45	505549.8
Jaci	174.41	455.33	2524190.47	81285.23	52171.01
Jacupiranga	256.02	1516.63	18115422.09	13471400.47	253852.9
Jaguariúna	236.85	409.51	3371591.11	79201.48	64212.41
Jales	170.91	1037.07	6308339.62	184162.89	116806.49
Jambeiro	299.24	1306.59	5484852.01	445371.88	256850.15
Jandira	275.93	0.16	484075.4	20734.77	29.92
Jardinópolis	141.39	1543.62	7114266.73	255281.66	145786.08
Jarinu	262.43	294.55	5456419.86	569139.13	50619.28
Jaú	195.42	2743.39	13463967.34	143856.83	352252.36
Jeriquara	156.46	431.82	2205743.61	164106.5	45104.32
Joanópolis	272.7	569.47	10185339.62	2271082.74	100384.18
João Ramalho	138.4	2012.33	5752713.94	166649.63	185022.01
José Bonifácio	160.01	4285.78	13742846.12	293146.82	440760.03
Júlio Mesquita	177.57	671.29	2271175.95	199136.79	78381.42
Jumirim	222.48	213.03	1256148.65	26136.62	31208.18
Jundiá	270.58	534.54	11686748.84	2668880.33	94844.89
Junqueirópolis	159.71	4692.9	9323254.49	105542.79	492682.99
Juquiá	262.32	1712.87	21538514.25	16776855.3	292332.21
Juquitiba	283.29	87.08	14770541.41	9795788.09	16117.35
Lagoinha	297.13	988.65	7623081.01	855449.61	192991.39
Laranjal Paulista	233.85	1786.76	9050173.4	120313.16	271976.84
Lavínia	164.32	4015.78	8848832.74	228989.94	431710.5
Lavrinhas	263.01	1176.58	4385572.46	1154168.51	201111.95
Leme	206.94	2368.69	8364823.99	210603.86	325740.85
Lençóis Paulista	136.49	2606.38	10991150.54	369973.1	230635.78
Limeira	194.19	1674.46	11265359.15	294860.63	213368.65
Lindóia	272.7	233.77	1330782.37	55013.13	41730.73
Lins	170.73	2027.86	9743600.06	429189.81	229069.56
Lorena	269.05	3163.09	11166075.7	944145.78	565381.67
Lourdes	175.63	604.86	2013772.3	99592.44	69877.73
Louveira	257.72	89.8	1426812.96	109007.75	15275.6
Lucélia	163.63	1734.95	5144674.71	147853.04	186925.54
Lucianópolis	164.25	1168.96	3131014.28	165289.07	126131.5
Luís Antônio	152.16	2510.12	9093486.46	1912944.45	246897.03
Luisiania	170.45	963.96	2847727.51	84050.03	108051.42
Lupercio	172.75	852.98	2663744.02	213327.57	98252.36

Lutécia	136.98	2530.09	6504079.99	250507.38	228531.04
Macatuba	154.98	940.54	3498765.89	52206.55	97484.15
Macaubal	174.28	640.28	4345523.26	155146.14	72604.91
Macedonia	170.49	1991.98	5605586.49	123591.13	223479.45
Magda	162.48	1267.19	5070593.38	347400.87	135734.85
Mairinque	248.27	284	5187494.63	728196.45	44999.84
Mairiporã	279.91	52.72	8977446.21	3252566.42	9723.26
Manduri	181.61	697.99	4155056	163906.85	83771.89
Mangaratiba	265.33	0	1320191.18	760503.58	0
Marabá Paulista	153.97	6250.73	14101941.6	371592.25	634146.98
Maracaí	170.94	1651.75	9105210.26	143100.51	181732.52
Marapoama	171.13	310.06	1951769.92	41187.83	34930.52
Mariópolis	161.32	905.42	2985945.54	25276.04	96126.43
Marília	172.11	5575.69	20116433.09	949298.81	630828.17
Marinópolis	167.56	457.64	1302452.82	24819.63	50528.23
Martinópolis	144.42	6609.91	18138154.38	680936.21	634696.39
Matão	145.36	2009.88	7640800.71	509465.69	187792.31
Mauá	288.77	4.47	1828348.42	228105.76	855.05
Mendonça	150.79	539	2955039.19	109469.45	53425.95
Meridiano	155.93	1296.05	3519883.73	179553.97	134887.39
Mesópolis	164.67	1270.87	2481275.65	52623.36	137648.01
Miguelópolis	148.49	3773.47	12277968.73	213516.83	367260.15
Mineiros do Tietê	184.77	705.87	3919169.08	72631.34	62103.82
Mira Estrela	167.74	684.74	3635678.35	97928.47	75989.23
Miracatu	271.24	990.58	27151415.44	21789348.99	177506.73
Mirandópolis	163.54	6084.08	15007775.81	458244.22	652144.2
Mirante do Paranapanema	148.71	6439.3	18413890.3	353470.83	629649.32
Mirassol	172.73	401.98	4220341.66	113444.86	46045.47
Mirassolândia	145	647.47	2409843.62	92390.69	61619.56
Mococa	180.97	3997.87	15466593.17	907854.04	478637.44
Mogi das Cruzes	280.85	2133.02	20014116.66	5164603.53	393404.16
Mogi Guaçu	201.57	4486.34	16354805.68	977700.75	583681.43
Mogi Mirim	205.33	1203.3	10304780.74	209602.62	162787.54
Mombaça	206.18	1050.53	2737815.92	61706.28	142620.33
Monçães	175.96	604.56	1831348.37	43761.03	69942.96
Mongaguá	249.02	26.95	3541313.68	2909781.91	4650.25
Monte Alegre do Sul	261.81	376.78	2913555.71	286927.16	65300.88
Monte Alto	160.91	820.22	5584373.23	120993.98	87730.89
Monte Aprazível	169.91	882.85	8194043.47	191400.7	98511.93
Monte Azul Paulista	167.1	1165.4	4421099.49	80466.32	127853.81
Monte Castelo	158.95	911.78	3718169.2	124006.54	95395.11
Monte Mor	210.17	1275.85	5071556.54	68526.51	176707.61
Monteiro Lobato	301.09	1036.8	9997150.3	3102536.33	204522.64
Morro Agudo	141.41	7814.48	19618000.6	587616.33	729432.41
Morungaba	258.19	699.04	3793891.26	350756.21	118754.58
Motuca	117.16	596.3	2669401.27	131311.54	44851.76
Murutinga do Sul	162.19	1540.51	4035263.54	86843.52	164038.43
Nantes	153.87	1248.01	4396906.42	158563.62	175150.04
Narandiba	150.66	2522.58	5393286.24	339460.62	251901.16
Natividade da Serra	312.08	2245.02	25994531.67	7287070.77	452644.08
Nazaré Paulista	275.29	224.83	8983931.03	2430994.61	39560.89
Neves Paulista	180.81	523.78	4179319.4	105875.16	62425.64
Nhandeara	172.78	1050.26	7569493.92	283240.89	119834.55
Nipoã	174.86	392.85	2424271.03	52773.55	44973.91

Nova Aliança	157.6	362.23	3429216.5	111647.43	37492.24
Nova Campina	239.05	873.18	9211885.69	2325089.5	143804.96
Nova Canaã Paulista	167.31	504.04	2064241.28	41591.81	55550.69
Nova Castilho	170.35	823.12	3127627.32	109509.81	90946.5
Nova Europa	139.23	347.31	2244823.17	87292.35	31019.17
Nova Granada	150.93	1987.33	8033664.57	298488.14	195752.77
Nova Guataporanga	158.92	152.12	542181.78	3899.38	15919.07
Nova Independência	157.76	2259.68	4182891.06	109440.15	234475.61
Nova Luzitânia	173.32	254.4	1277305.81	42887.49	28875
Nova Odessa	205.8	128.36	1492040.34	13639.98	17412.87
Novais	168.44	273.14	1977343.34	44305.41	30360.18
Novo Horizonte	168.82	2102.15	15725347.56	752002.76	229448.57
Nuporanga	159.4	1516.39	5534274.39	182691.1	159719.48
Ocaçu	138.34	1585.42	4155048.56	263170.93	147770.6
óleo	189.45	512.75	3736460.28	139266.99	64419.42
Olímpia	157.45	2823.48	12668656.54	330026.81	289527.62
Onda Verde	152.11	797.95	3691182.89	164244.08	77844.73
Oriente	174.45	1113.15	3795776.2	179084.33	127929.49
Orindiúva	161.45	1168.33	4006539.54	55898.57	124084.22
Orlandia	151.51	1834.16	4488711.1	151995.17	182845.72
Osasco	274.58	8.3	1780542.59	78296.96	1471.6
Oscar Bressane	159.06	1195.92	3509979.96	116795.81	123925.71
Osvaldo Cruz	164.46	1353.54	4081749.59	157161.97	146678.56
Ourinhos	185.79	903.28	5507039.79	75697.84	110613.55
Ouro Verde	156.85	2045.19	4166620.15	145129.23	211178.41
Ouroeste	166.27	1940.38	4768159.97	208280.86	212107.65
Pacaembu	161.54	2864.39	5484040.97	59483.3	304241.1
Palestina	145.93	2907.12	10130819.02	225288.42	283936.49
Palmares Paulista	171.58	379.91	1405679.9	25290.98	42866.35
Palmeira do Oeste	168.18	1433.03	5371823.99	121514.11	157967.36
Palmital	178.63	1866.34	9810820.99	73993.78	219225.37
Panorama	140.77	2695.15	4967212.31	162925.35	281865.94
Paraguaçu Paulista	123.69	3874.44	12385226.98	389699.59	321854.11
Paraibuna	308.66	3481.99	24996204.46	5067749.25	697763.62
Paraíso	169.51	414.08	2635390.15	48537.71	46229.76
Paranaparema	159.19	3666.14	16241272.46	881358.56	393033.97
Paranapuã	166.67	906.88	2316554.79	34158.69	99474.85
Parapuã	163.51	1734.39	5982061.57	125779.28	186684.06
Pardinho	199.04	623.83	4198469.5	249763.93	78772.58
Pariquera-Açu	254.32	721.79	9187976.27	5629562.56	120240.09
Parisi	166.43	385.48	1392150.28	31977.08	42577.91
Patrocínio Paulista	147.46	1600.21	8850271.64	1196430.12	155754.83
Paulicéia	151.14	2519.23	5653042.36	225731.01	279603.53
Paulínia	217.65	258.05	3036043.72	65502.99	37303.35
Paulistânia	142.57	1402.78	3651757.39	273453.7	139259.98
Paulo de Faria	163.56	3785.07	12119371.98	260218.29	412129.74
Pederneiras	147.26	3710.73	10750756.02	586334.33	351188.22
Pedra Bela	263.07	253.96	4146285.78	377190.19	43390.28
Pedranópolis	170.81	1248.02	4445785.57	108581.2	139771.26
Pedregulho	150.22	1760.79	10563273.48	1154654.02	170759.52
Pedreira	254.66	754.13	2783046.77	143370.02	126741.02
Pedrinhas Paulista	176.87	384.17	2713788.17	7818	41484.8
Pedro de Toledo	280.59	196.3	18820559.37	16577454.51	35969.71
Penápolis	159.04	2938.35	11264247.68	221045.27	304519.73

Pereira Barreto	160.35	6478.32	15697375.33	358757.13	756706.48
Pereiras	248.4	690.94	5508849.46	78951.7	113159.94
Peruíbe	251.52	278.67	8182459.52	6079479.38	45646.48
Piacatu	167.61	1485.81	3911007.47	175081.86	163870.27
Piedade	305.02	448.96	22693204.78	5056064.43	90601.54
Pilar do Sul	275.01	1262.68	18802832.69	3933135.53	232388.03
Pindamonhangaba	288.87	5328.55	21125478.43	4389265.98	1019391.15
Pindorama	154.25	673.89	2878020.85	59103.73	69433.15
Pinhal	261.97	492.55	2871811.55	102952.89	84586.56
Pinhalzinho	250.12	320.9	3867691.3	228565.89	52226.33
Piquerobi	157.36	3604.03	7589523.69	120764.61	373623.01
Piquete	273.27	873.27	4822418.5	1552986.06	151483.52
Piracaia	266.39	737.12	10247889.49	2104766.57	127246.8
Piracicaba	178.57	6337.35	24483527.4	586288.92	713162.63
Piracununga	186.33	2015.03	13550185.92	644468.2	245151.54
Pirajui	185.83	6075.15	20955304.17	1086830.38	735539.07
Pirajuí	171.59	911.69	3385857.16	88275.1	103253.07
Pirangi	172.86	553.22	3735664.63	54440.08	62984.07
Pirapora do Bom Jesus	254.46	160.19	2750391.49	921669.96	27896.18
Pirapozinho	150.83	3570.01	7287178.45	159409.62	352252.62
Piratininga	141.32	1670.09	5619012.99	344502.46	152796.81
Pitangueiras	134.26	1394.53	5760482.04	79593.49	125910.81
Planalto	150.82	2055.73	4347719.41	222054.55	205016.93
Platina	143.6	1400.27	4725547.39	133540.21	131637.94
Poá	282	3.65	466916.76	17968.85	689.69
Poloni	175.98	262.64	2371819.41	57312.62	30476.2
Pompéia	171.92	4680.52	13535194.5	472651.85	528803.58
Pongáí	170.93	848.19	3136961.66	88660.94	95500.42
Pontal	141.55	1822.07	5032761.59	100469.99	169896.37
Pontalinda	169.55	1353.84	3558399.58	152683.39	150803.35
Pontes Gestral	150.77	417.93	3266851.38	113212.16	41821.46
Populina	165.07	3167.35	5211459.21	150073.96	344868.7
Porangaba	247.37	836.71	6593432.5	204613.01	136139.15
Porto Feliz	210.27	2308.33	11698691.13	324513.94	318925.02
Porto Ferreira	144.47	1032.2	3530207.44	116472.17	96597.22
Potim	302.02	506.08	1350179.09	32843.47	100765.87
Potirendaba	163.35	451.65	5601721.2	123902.65	49688.11
Pracinha	161.94	376.29	1018223.16	9965	40127.6
Pradópolis	106.03	317.86	1776758.72	43995.09	24101.15
Praia Grande	242.31	12.28	2728399.58	2011596.9	1935.29
Pratânia	169.65	568.98	3037142.92	147627.31	63509.43
Presidente Alves	165.53	1441.71	4767290.03	319498.14	159397.56
Presidente Bernardes	149.16	3998.34	11240912.17	327836.95	391875.87
Presidente Epitácio	153.93	4540.84	19757843.79	567647.84	534510.04
Presidente Prudente	161.04	2606.54	9056626.82	127903.24	276280.2
Presidente Venceslau	157.03	5620.12	11846261.42	214051.82	580957.95
Promissão	159.05	2546.4	12424566.97	325239.89	272264.25
Quadra	246.91	639.49	5064241.31	127411.6	104066.18
Quatá	146.45	2854.85	9558329.44	426894.8	278540.82
Queiroz	172.03	1310.81	4027711.01	128435.26	148426.57
Queluz	261.82	1458	6549114.26	1847560.56	253994.03
Quitana	155.43	2242.33	4981830.2	213528.88	231765.18
Rafard	215.99	813.53	2850742.09	49314.78	115400.3
Rancharia	134.32	6775.59	21299878.02	945949.18	626505.29

Redenção da Serra	309.66	1594.92	9551138.18	1297445.02	326259.5
Regente Feijó	159.97	1302.05	4205972.3	105096.76	135249.69
Reginópolis	152.94	1652.55	6281646.42	354143.69	165720.54
Registro	248.42	2489.14	17785243.98	9096931.29	407210.47
Restinga	165.17	950.82	4066709.18	369827.61	103663.73
Ribeira	265.94	492.39	8887089.25	4642143.47	86817.95
Ribeirão Bonito	156.2	1040.82	7367936.71	590459.85	113920.6
Ribeirão Branco	301.23	2090.26	21025934.64	6180346.74	418453.59
Ribeirão Corrente	150.03	378.63	2236625.11	195528.78	37019.37
Ribeirão do Sul	177.4	815.48	3609040.2	89180.04	94155.33
Ribeirão dos Índios	158.73	1213.72	3139728.2	26199.6	126674.5
Ribeirão Grande	287.38	452.57	9559806.09	5414809.87	88386.25
Ribeirão Pires	285.53	10.33	2834445.69	817306.66	1973.91
Ribeirão Preto	139.8	1834.94	9084059.53	195847.21	165568.8
Rifaina	144.95	396.88	2482934.56	243557.68	40352.61
Rincão	123.58	1194.68	3874658.75	157766.15	99422.85
Rinópolis	166.99	1772.45	5983646.47	238093.37	194967.65
Rio Claro	181.29	1675.82	9017513.3	358094.12	203387.53
Rio das Pedras	214.93	1101.95	4872397.65	57551.79	152591.31
Rio Grande da Serra	287.01	7.99	1053636.63	448749.76	1507.44
Riolândia	169.2	2358.95	10672476.75	377549.24	261996.68
Riversul	175.62	1999.67	6767005.06	337078.51	240046.51
Rosana	159.91	4777.72	11826364.01	537151.62	538938.82
Roseira	289.41	1035.92	3744700.21	579031.85	198950.02
Rubiácea	167.73	1430.36	3941182.36	92106.74	157571.65
Rubinéia	148.48	1115.16	3490676.65	38576.74	143808.32
Sabino	163.57	546.33	5093942.98	219998.4	60121.15
Sagres	161.84	1011.19	2409407.53	39200.24	107733.78
Sales	156.4	389.86	4825181.9	369701.07	48375.79
Sales Oliveira	148.86	1158.13	4518378.51	169925.48	113429.46
Salesópolis	291.36	1060.6	12413104.54	4417255.1	205463.76
Salmourão	164.13	883.32	2833796.19	176283.28	95510.52
Saltinho	220.79	581.74	2222999.6	33989.17	84178.34
Salto	239.78	295.09	3217639.08	92361.18	46004.5
Salto do Pirapora	264.08	653.66	7390851.18	569479.54	111083.68
Salto Grande	181.35	560.86	3435697.5	74208.36	66856.22
Sandovalina	146.93	2875.74	6690246.84	167939.49	286308.32
Santa Adélia	154.18	935.85	5098496.17	107025.87	93908.08
Santa Albertina	165.87	1466.16	4544262.68	69929.66	163637.84
Santa Bárbara d'Oeste	175.43	1177.46	4776633.99	27853.09	137156.81
Santa Branca	293.52	2588.02	8090587.48	895670.36	500886.08
Santa Clara do Oeste	165.52	1539.48	3016179.37	59795.69	170453.59
Santa Cruz da Conceição	163.33	497.26	2433373.55	109959.78	53744.63
Santa Cruz da Esperança	163.15	503.42	2427582.26	221233.86	54036.38
Santa Cruz das Palmeiras	191.46	660.87	5663144.28	301729.43	81165.8
Santa Cruz do Rio Pardo	178.5	5679.96	19959380.38	686519.86	642305.97
Santa Ernestina	141.44	499.1	1908801.82	43702.98	49055.42
Santa Fé do Sul	153.16	809.01	3201367.97	130428.24	82926.2
Santa Gertrudes	207.23	474.13	2030881.91	22475.05	64768.89
Santa Isabel	273.58	1181.82	9888388.36	1966604.37	211244.67
Santa Lucia	127.21	648.79	1937634.86	86204.34	56333.95
Santa Maria da Serra	142.67	683.77	3675092.38	211809.47	68482.17
Santa Mercedes	158.28	1318.41	2633586.78	24614.73	137463.6
Santa Rita do Oeste	166.22	1371.82	3503394.98	58772.55	149990.08

Santa Rita do Passa Quatro	153.86	1939.44	11582101.56	799415.66	206116.6
Santa Rosa de Viterbo	117.76	894.67	3403705.84	209998.58	69337.88
Santa Salete	167.59	273.65	1332838.93	41851.21	30172.51
Santana da Ponte Pensa	159.53	529.4	2069908.71	44887.19	56325.54
Santana de Parnaíba	274.96	196.05	5051828.97	985503.39	35509.3
Santo Anastácio	156.02	2675.17	8616230.49	163448.24	273866.46
Santo André	269.82	39.44	4685513.52	1998975.4	7422.55
Santo Antônio da Alegria	157.42	8056.47	20563244.14	737830.85	824891.94
Santo Antônio de Posse	127.55	661.54	3943272.52	406796.44	55932.02
Santo Antônio do Aracanguá	225.79	481.79	3482379.13	78427.75	72484.35
Santo Antônio do Pinhal	339.69	306.9	4487073.89	1102262.09	67805.73
Santo Expedito	160.45	601.47	1499369.94	6171.62	63571.18
Santópolis do Aguapeí	167.85	820.12	2147927.12	50289.96	90628.14
Santos	265.79	128.09	6972631.98	4872911.67	30256.18
São Bento do Sapucaí	380.68	608.85	9563191.29	1905889.68	151898.2
São Bernardo do Campo	286.99	36.14	11674370.17	5501810.81	7797.21
São Caetano do Sul	271.71	0	416538.51	1245.82	0
São Carlos	168.03	3039.57	19166306.47	1790864.84	344155.16
São Francisco	169.55	506.61	1269714.21	22317.09	56620.73
São João da Boa Vista	228.63	2952.79	11804049.96	538936.03	455262.84
São João das Duas Ponte	172.87	772.47	2224679.29	60959.61	87980.75
São João de Iracema	168.06	1012.09	3002080.15	161027.1	113641.91
São João do Pau d'Alho	159.24	852.86	1872046.66	25545.62	89362.24
São Joaquim da Barra	153.95	2500.73	6356222.76	184473.69	251519.13
São José da Bela Vista	162.81	1528.73	4512376.25	245111.57	163491.58
São José do Barreiro	325.58	1210.61	18606107.07	8790737.94	227049.67
São José do Rio Pardo	209.45	2193.93	8763704.83	237434.99	304942.1
São José do Rio Preto	163.36	504.56	7031597.92	94090.13	55495.14
São José dos Campos	276.74	5240.44	30437837.62	5367431.7	959620.49
São Lourenço da Serra	285.19	42.87	5342336.05	3050743.94	8069.28
São Luiz do Paraitinga	310.92	2755.11	19189710.18	4756621.37	563711.27
São Manuel	168.64	2391.5	10950522.7	364012.9	265882.28
São Miguel Arcanjo	254.57	2941.97	23663099.31	4193483.83	487821.88
São Paulo	264.93	350.71	40383005.46	8935360.72	67678.82
São Pedro	150.25	3062.08	9283748.81	633735.17	303142.57
São Pedro do Turvo	162.41	2497.84	11874993.71	815904.29	267432.88
São Roque	263.78	250.73	8113633.49	1711179.18	40357.8
São Sebastião	268.35	11.49	11279069.18	9120151.63	2269.82
São Sebastião da Grama	245.03	1301.01	6174769.5	344731.21	209858.22
São Simão	129.91	2502.79	8016563.28	601695.37	222825.14
São Vicente	263.2	5.05	4599959.71	2729052.99	907.56
Sarapuí	221.68	1106.92	7842539.16	495200.72	163948.83
Sarutaiá	210.17	455.54	2962640.3	171076.31	62941.28
Sebastianópolis do Sul	167.06	284.45	2824821.8	125359.41	30440.49
Serra Azul	151.14	1285.36	4272734.57	303087.55	127923.42
Serra Negra	267.17	1232.62	5399239.91	314724.77	216646.64
Serrana	145.54	752.42	1844046.56	52205.17	70935.3
Sertãozinho	143.12	911.02	5772593.84	126115.87	85585.03
Sete Barras	254.6	1849.67	26809891.59	21430239.4	302065.29
Severínia	165.14	975.93	2317117.54	24331.05	106171.96
Silveiras	281.19	1549.07	11636227.86	1830685.4	280698.3
Socorro	266.52	2280.41	11935523.8	526690.71	399715.03
Sorocaba	256.35	422.51	11499614.84	544330.25	68852.06
Sud Mennucci	156.69	5402.1	9271102.73	245895.74	564171.22

Sumaré	210.13	298.34	3196685.26	10495.95	41184.67
Suzanápolis	271.51	6.04	591427.59	30622.3	1076.28
Suzano	207.81	3059.58	10663954.84	1193755.59	344993.09
Tabapuã	168.27	815.05	5811591.73	140926.18	90529.84
Tabatinga	145.61	861.65	5347589.64	261486.98	81524.74
Taboão da Serra	279.48	0.07	580091.27	26048.75	13.6
Taciba	153.96	3374.08	9383475.44	387852.06	348394.64
Taguaí	195.59	815.13	2838616.38	63442.26	103216.84
Taiacu	169.17	181.39	1803958.46	29697.79	19900.72
Taiúva	131.56	233.67	1740790.34	20768.31	21618.44
Tambaú	156.96	1924.11	8821224.06	663694.75	207411.37
Tanabi	145.64	1716.57	10855103.45	296280.83	163760.57
Tapiraí	280.84	207.9	21195378.64	17053837.37	39113.97
Tapiratiba	215.07	1327.41	4727635.16	207632.91	188440.2
Taquaral	120.09	66.55	637899.77	10109.18	5207.23
Taquaritinga	154.94	1700.12	9214796.37	169064.15	176643.89
Taquarituba	176.96	1441.52	7922233.23	171519.68	172347.41
Taquarivaí	151.16	379.15	3524625.86	221555.21	37860.85
Tarabai	146.17	1366.13	2872863.97	58242.83	132608.14
Tarumã	178.46	1719.75	5403801.75	68271.91	202820.59
Tatuí	235.53	1344.15	12366589.83	325347.11	207056.12
Taubaté	292.72	3128.13	18301561.89	1851532	621086.36
Tejupa	200.09	1359.31	5909528.64	352080.19	181916.37
Teodoro Sampaio	149.7	10722.22	23332412.26	5339065.03	1111643.93
Terra Roxa	140.57	1069.23	3090120.29	76562.15	99033.13
Tietê	212.65	1571.84	8359163.85	151403.41	221829.57
Timburi	204.5	668.48	4031613.2	281364.97	114431.35
Torre de Pedra	216.1	291.25	1537458.92	107236.88	40024.61
Torrinha	170.77	1172.58	5326982.47	268051.95	130176.47
Trabiju	183.22	345.9	1149385.63	61360.73	42257.37
Tremembé	293.21	1508.54	5649443.99	754807.46	297568.83
Três Fronteiras	152.44	561.72	2337971.08	37762.77	56262.26
Tuiuti	239.76	303.78	3026970.01	124820.65	48455.14
Tupã	163.35	3078.98	10263035.68	267004.49	332311.03
Tupi Paulista	159.75	945.51	3891679.18	26277.15	99228.62
Turiúba	172.26	686.76	2626699.61	74169.52	78420.59
Turmalina	168.27	789.99	2469478.64	91339.12	87382.07
Ubarana	149.22	1533.61	3127672.39	64690.75	153809.24
Ubatuba	283.47	39.14	20293763	17002701.56	7670.61
Ubirajara	138.06	1394.76	3896578.82	247105.65	134190.55
Uchoa	171.1	819.2	4306838.84	98353.15	92475.45
União Paulista	170.85	233.09	1343894.69	45419.14	25728.19
Urânia	168.53	623.2	3532233.22	73461.97	69103.38
Uru	171.71	1037.51	2548967.65	79045.21	117504.97
Urupês	171.4	473.82	5572288.08	131248.25	53530.72
Valentim Gentil	148.37	560.33	2234387.75	119001.82	54824.55
Valinhos	294.38	444.25	4352482.66	183349.56	83661.36
Valparaíso	166.03	6150.38	14255753.36	542220.03	667226.48
Vargem	254.87	306.78	3636618.81	354779.45	54189.23
Vargem Grande do Sul	201.9	1356.43	5398036.26	184357.81	181947.46
Vargem Grande Paulista	272.54	1.44	911361.41	132920.47	256.29
Várzea Paulista	271.96	14.32	953519.07	98829.61	2566.57
Vera Cruz	182.25	1495.43	4517601.75	251820.41	179325.28
Vinhedo	281.81	165.03	2300957.31	134013.62	30335.44

Viradouro	140.08	560.07	3068489.54	56786.23	51776.24
Vista Alegre do Alto	174.59	421.89	1665386.53	15255.97	48450.41
Vitória Brasil	171.59	169.82	861249.94	17347.56	19176.75
Votorantim	298.34	403.91	5489282.25	665485.03	80918.63
Votuporanga	150.01	1339.02	6313860.03	232634.65	135316.27
Zacarias	147.18	1858.29	4698914.33	90695.75	208826.27

Appendix 6: List of studies containing forest inventories

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Appendix 7: List of R packages used

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