

Biomass and carbon stock estimation of an Atlantic Forest fragment

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Abstract

Carbon sequestration is a crucial ecosystem service, naturally mitigating and reducing the ever-growing threat from climate change. Large forests, such as the Atlantic Forest, are important carbon reservoirs removing carbon from the atmosphere and storing it in their biomass. The assessment of carbon stock from forests fragments helps to establish a better understanding of the carbon cycle and the potential of climate mitigation strategies. Thus, we estimated the biomass and carbon stock of an Atlantic Forest fragment located in the foothills of Pedra de Itaocaia. We used a non-destructive methodology based on climbing techniques and an allometric equation. We climbed seven trees in order to thoroughly measure them in whole and calculate the volume of arboreal compartments. We compared the measured volume obtained from the climb to an estimated tree cylindrical volume and established a correction factor of 0.65 between both (i.e. tree form factor). The tree form factor adjusts the allometric equation and allows carbon estimations without the need to climb all trees in the fragment. The biomass and carbon stock estimates obtained were 100.1 and 50.5 MgC/ha, respectively, which implies that the fragment is on an intermediary stage of regeneration at approximately forty years old. This allometric equation efficiently integrates structural features of forest fragments similar to the one of Pedra de Itaocaia, thus contributing to advance the knowledge about processes taking place in forest fragments situated in the Atlantic Forest. Carbon estimation is imperative for a better understanding of climate mitigation strategies that can revert the threat of climate change to ecosystems.

Keywords: Carbon sequestration; Allometric equation; Forest regeneration; Climate change mitigation.

Introduction

Climate change severely impacts ecosystems and biodiversity, however, with mitigation strategies in accordance with the Paris Agreement, risks can be reverted (MANES et al. 2021). Climate mitigation is essential to limit the magnitude of such threats and prevent irreparable consequences for natural and anthropogenic environments. The most effective method to mitigate climate change is through carbon sequestration, where forest regeneration plays a crucial role (LEWIS et al., 2019). The latest IPCC (2018) report stresses the need to implement one billion forest hectares to limit climate warming to a 1.5 °C increase until 2050.

The restoration of forest fragments would drastically reduce atmospheric carbon

concentration and help achieve this goal if all areas with regeneration potential were effectively accounted for (BASTIN et al., 2019). Actions to protect secondary forests in the Neotropics areas can store in the next 40 years a sufficient amount of carbon to offset industrial and fossil fuel emissions from the Latin American and Caribbean (CHAZDON et al., 2016). Quantifying and determining spatio-temporal patterns of forest biomass contributes to the understanding of the role of forests in the global carbon cycle, which in turn underpins estimates of the capacity of carbon storage (POORTER et al., 2016). The Atlantic Forest is considered a hotspot in the world and, according to estimates, 40 % of the species are endemic (MYERS et al., 2000). However, the great fragmentation affects about 91 % of the remaining fragments of the Atlantic

Forest (PÜTZ et al., 2014). Marques et al. (2016) report that forests store about a third of the total carbon in the non-geological world, where the restoration of the Atlantic Forest can triple the values of sequestration of this gas in regeneration areas in 60 years. Therefore, forest carbon storage is a relevant parameter to monitor ecosystems, evaluate impacts, estimate stages of ecological succession, and gauge the capacity of carbon storage as effective climate mitigation strategies.

Forest biomass is a mass of matter of biological origin from forest components. The components of forest biomass are the sum of the biomasses of the above-ground living components, which ranges from the base of the trunk to the crown of trees and shrubs; below-ground biomass, which is composed of live roots; dead biomass above ground, composed of litter (leaves, trunks and fallen branches) that has not yet been decomposed; and soil organic matter (SILVEIRA et al., 2008). Forest biomass can be estimated using allometric equations that determine the volume of tree individuals derived from measurements of their structure (BROWN et al., 1995; CHAVE et al., 2005) and calculate the carbon stock, which is estimated as 50 % of biomass (AZEVEDO et al., 2018). Most allometric equations require cutting and weighting the trees to determine the volume. A contrasting alternative, better-suited for the Atlantic Forest due to protective law, would be to climb the trees to measure them in whole (BRASIL, 2006). The thorough measurements from the climbing of few local trees allow the calculation of a correction factor that can be applied into forest inventories (containing tree's diameter, height, and wood density) and easily estimate carbon storage from forest fragments without the need to climb and measure every tree in the forest. Although less practical to estimate and often lacking in forest inventories, the wood density also plays an important role to explain differences with respect

to carbon estimates within a forest (CHAVE et al., 2005).

The Atlantic Forest is a biodiversity hotspot due to a combination of high rates of faunistic and floristic endemism and ongoing loss of habitat. Due to the great diversity of arboreal species, it is inappropriate to use allometric equations previously developed for different biomes (e.g. for the Amazon forest) as is commonly seen in the literature. Using allometric equations from other areas can significantly increase errors given that in different areas distinct groups of species (with their respective allometric relationships) predominate (TANIZAKI, 2000). Hence, it is imperative to use allometric equations that encompass regional forest physiognomy and the main variables influencing forest structure variability to estimate forest biomass without the need for cutting trees down. In that sense, the aim of our study was to derive an allometric equation for an Atlantic Forest fragment in Pedra de Itaocaia (Rio de Janeiro), enabling biomass and carbon stock estimation from a forest inventory previously performed in the study area.

Material and methods

The methodology applied in this study was adapted from Tanizaki (2000). First, we climbed and measured the structure of seven trees to establish form factors and be able to develop an allometric equation to quantify aboveground biomass from the trees climbed. Afterwards, we applied the same allometric equation to a forest inventory to estimate biomass and carbon from the forest fragment area.

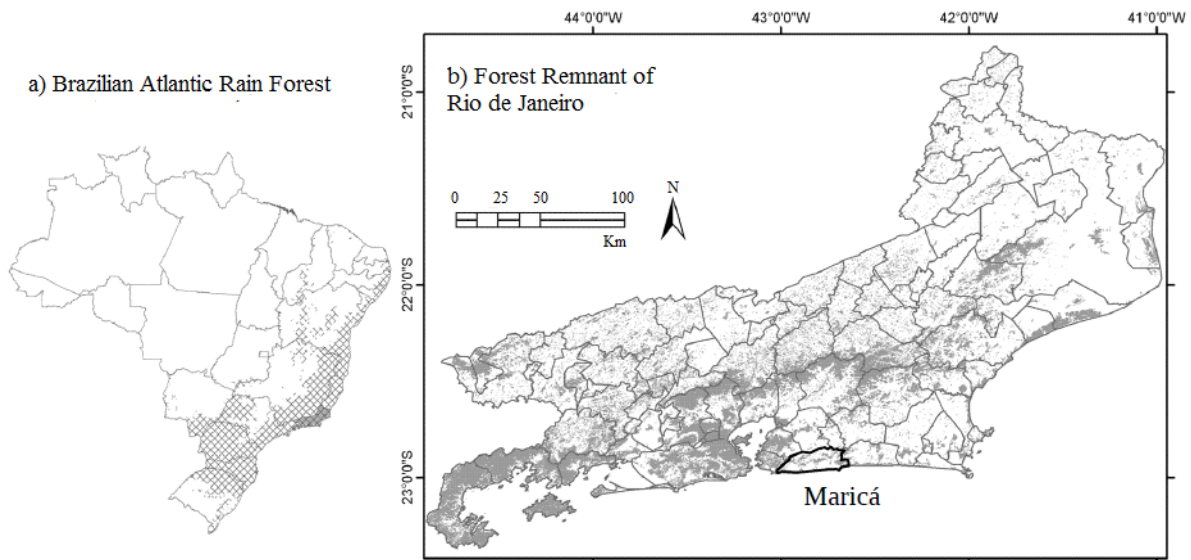
Study area

The study area corresponds to the perimeter known as Pedra de Itaocaia (22° 56' 06" S

and 42° 57' 49" W), located within the limits of the city of Maricá, Rio de Janeiro. The mean annual temperature is 23 °C and mean rainfall between 1000 mm/year and 1500 mm/year, within a sub-humid climate (BARBIERE & COENETO, 1999). Maricá is located at an altitude of about 5 meters and the main types of soils are argisol (70.82 %) and gleysol (16.87 %) (INDE, 2021).

The region is composed of forest fragments found in the vicinity of the Serra da Tiririca State Park (IGNÁCIO et al., 2015). The local vegetation is mostly composed of secondary formations of dense ombrophilous Atlantic Forest. The area was much altered due to anthropic perturbations and deforestation, followed by land abandonment. The area has been abandoned for 30 to 40 years without major anthropic influences (BARROS, 2008).

Figure 1. a) Brazilian Atlantic Forest; b) Forest Remnant of Rio de Janeiro. The area circled in black represents the Maricá municipality.



Source: Adapted from SOS Mata Atlântica/INPE (2021).

Form factor establishment

Starting at the base, the diameter of the trunk was measured from meter to meter to the base of the crown, including the traditional DAP, measured at about 1.3 m from the ground. At that moment, according to the structural structure of the tree, the branches were registered and the diameter of the base of each branch (Diameter of the Base of the Branch) was measured, as well as the length of each branch (Length of the Branch) estimated visually. As far as possible, the most representative branches were measured meter by meter from their respective bases, and their branches (secondary branches) were also recorded. The climb continues to assess viability towards the top of

the canopy. When the maximum possible limit is reached, the total height of the tree is recorded plus the remaining length towards the top: estimated visually and usually a few meters away.

In the second stage of the climbing process, a middle branch is selected and cut from the tree. Once on the ground, the branch is partitioned into thick branches (diameter greater than 2 cm) and thin branches, and the leaves detached from the branches. The three compartments (thick branch, thin branch, and leaves) are weighed and samples from each compartment are stored for further laboratory analysis (calculation of basic density and fresh density). In the case of branches, cylindrical samples of approximately 5 cm in length were

separated, in the case of leaves, samples of approximately 100 grams of leaves.

We climbed seven trees in whole to calculate their trunk and tree crown volume. To calculate trunk volume, we measured the trunk diameter in every meter up from the ground until the beginning of the tree crown, to calculate the volume of each trunk section and summed them. For the calculation of the tree crown's volume, we used a branch form factor (FF_B). The branch form factor is a ratio between the branches' estimated conical volume and the real volume obtained measuring their irregular form (TANIZAKI, 2000). To measure the branch's real volume, we cut out a big branch from each climbed tree and measured the volume according to the method of water displacement (Archimedes' principle). We estimated the conical volumes and used the branch form factor from each tree to calculate the volume of the branches that were not cut from the same tree. Therefore, the branch form factor (Eq. 1) for each tree represents the ratio of the branch's real volume (Eq. 2; which is a sum of three branch compartments of thick and thin branches and leaves) and its conical volume (Eq. 3; calculated using length and diameter at the branch base on cone volume formula). Finally, the total branch volume (i.e. tree crown volume) representing all of the branches from a given climbed tree is given by the sum of the conic volume of every branch multiplied by the branch form factor (Eq. 4). We used the trunk volume and tree crown volume to thoroughly calculate the trees' volume (i.e. real volume).

$$FF_B = V_{branch} / V_{conical} \quad (1)$$

$$V_{branch} = \sum(W_{fn} / D_{fn}), \text{ with } 1 \leq n \leq 3 \quad (2)$$

$$V_{conical} = \{(D_{branch}/2)^2 * \pi * L_{branch}\} / 3 \quad (3)$$

$$V_{treecrown} = \sum(V_{conical} * FF_B) \quad (4)$$

At which: FF_B , V_{branch} , $V_{conical}$, D_{branch} , L_{branch} , W_f , D_f , and $V_{treecrown}$ are, respectively, branch form factor, branch real volume, branch conical volume, branch diameter, branch length, fresh weight, and fresh density of the branch compartments assuming that n is the number of compartments (namely thick and thin branches and leaves), and total branch volume from a climbed tree.

We also measured the diameter at breast height (DBH) and total height (H) of the trees, used to calculate the tree's cylinder volume. Combining the real volume and the cylinder volume we were able to establish a tree form factor (FF_T). Similarly, the tree form factor represents the conversion from the tree's estimated cylinder volume to its real volume, which accounts for natural irregularities of the trunks, assuming that trees from the same area present similar shapes and structures. The tree form factor is calculated using a linear regression correlating the tree's cylinder volume and their real volume measured during the climb, eliminating the need to climb every tree in the region. We selected trees with great variability of sizes and shapes in order to generate an FF_T reflective of the region (TANIZAKI, 2000).

On the field, we also obtained wood samples using a cylindrical borer and used them to calculate wood basic (D_b) and fresh density (D_f) from each tree with the relation between sample volume and their oven-dried weight.

Carbon stock estimation

In order to establish an allometric equation (Eq. 5) for the Atlantic Forest fragment, we used the tree form factor (FF_T) generated from the climbed trees. The estimation of biomass and forest carbon stock can be conducted through the application of an allometric equation to a forest inventory previously performed in the study area containing tree's structural measurements (diameter and height to calculate cylinder volume, and basic density) (CARVALHO, 2007). We used the allometric equation to calculate biomass and divided the biomass by 2 to calculate carbon stock since carbon is assumed to be 50 % of biomass (TIEPOLO et al., 2002).

$$AGB = V_{cylinder} * FF_T * D_b \quad (5)$$

At which: AGB , $V_{cylinder}$, FF_T , D_b are, respectively, aboveground biomass, cylinder volume, tree form factor, and basic density.

We measured the biomass from the seven climbed trees and, additionally, we evaluated the contribution of each tree component to the total tree's biomass (between trunk, thick, and thin branches and leaves).

The forest inventory adopted in this study was the one performed by Carvalho (2007) in a forest fragment undergoing an intermediate stage of ecological succession at Pedra de Itaocaia, classified by the author as a secondary forest growing on land abandoned for 30 to 40 years. This inventory assessed 56 trees in a transect area of 600 m² where the average values of DBH and H found were, respectively, 15.7 cm and 9.25 m (coefficient of variation of 56.3 % and 41.8 %).

In addition, trunk samples from 9 trees enabled the estimation of an average basic density value of 0.55 g cm⁻³ (coefficient of variation of 19.1 %).

Results

Form Factor Establishment

The 7 sampled tree individuals were very heterogeneous, with different sizes and therefore aboveground biomass storage potential (TABLE 1). The contributions of the aerial tree compartments (branches and leaves) sum up to 33 % of the total AGB. Variability was also observed among the basic density values, namely 0.52 g cm⁻³ on average.

Table 1. Main features of the trees climbed and the contributions of the different compartments to the AGB. Values shown for each of the 7 trees climbed are diameter at breast height (DBH, in centimeters), height (H, in meters), total aboveground biomass, and proportion of biomass in each tree component (trunk, thick and thin branches, and leaves), and fresh and basic wood density. Trees were sampled in Pedra de Itaocaia, Rio de Janeiro, Brazil.

Tree	DBH (cm)	H (m)	Aboveground Biomass				Density		
			Total (Kg)	% Trunk	% Thick branches	% Thin branches	% Leaves	Fresh (g/cm ³)	Basic (g/cm ³)
#1	9	8	10	85	5	5	6	0.86	0.35
#2	11.2	8	28	58	5	25	13	0.99	0.47
#3	16	15	100	84	9	5	3	0.95	0.61
#4	20.9	12	161	55	28	10	8	1.02	0.54
#5	39	21	917	62	30	5	4	1	0.58
#6	43	23	1696	69	18	4	9	0.86	0.55
#7	93	23	4843	59	32	3	6	0.9	0.53
Average	33.1	15	-	67	18	8	7	0.94	0.52
Coefficient of variation (%)	89	42	-	18	66	95	48	7	17

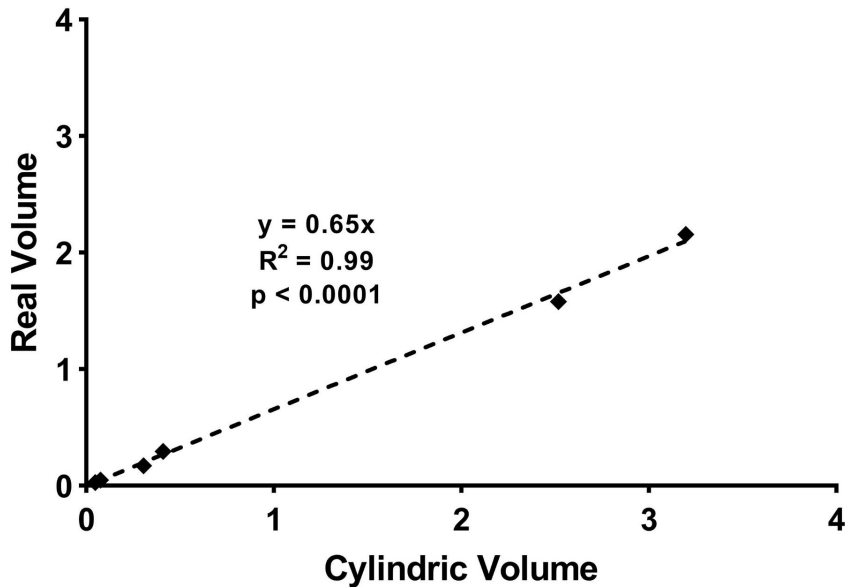
Source: Elaborated by the authors (2020).

The linear model which considered the cylinder and the real volumes of the climbed trees generated an FF_T of 0.58 ($R^2 = 0.998$). However, tree #7 presents a DBH of 93 cm, representing over 60 % of the total biomass gauged during the climbing process. Large-stature trees with a DBH superior to 70 cm can be excluded from the biomass predictive models for tropical

rainforests without compromising the final estimates (OVERMAN; WITTE; SALDARRIAGA, 1994). Therefore, we also calculated FF_T with the exclusion of the bigger tree, generating a new FF_T of 0.65 ($R^2 = 0.99$, $p < 0.0001$; FIGURE 1).

By considering the tree's structural characteristics (TABLE 1), the total biomass obtained with the FF_T of 0.58 differed only -10 % from the

Figure 1. Tree Form Factor established for the trees climbed. The tree form factor is based on the correlation of cylinder and real volume of 6 the climbed trees, excluding the bigger tree #7.



Source: Elaborated by the authors (2020).

biomass value measured through the climb [% difference = (estimated AGB – measured AGB)/measured AGB]. Moreover, when excluding the bigger tree #7, the new FF_T of 0.65 differed only 1 % from the AGB measured on the ground (TABLE 2).

Table 2. Comparison between the aboveground biomass estimated through the allometric equation using different FF_T . Values shown for each of the 7 trees are: aboveground biomass measured in the climb and estimated aboveground biomass using the two different FF_T . Trees were sampled in Pedra de Itaocaia, Rio de Janeiro, Brazil.

Tree	Aboveground Biomass (Kg)		
	Measured (climb)	Estimated (FFT 0,58)	Estimated (FFT 0,65)
#1	10	10.33	11.57
#2	28	21.47	24.07
#3	100	106.65	119.52
#4	161	128.87	144.43
#5	917	843.48	945.28
#6	1696	1064.94	1193.47
#7	4843	4800.29	5379.63
Total	7755	6976	7818

Source: Elaborated by the authors (2020).

Due to the smaller discrepancy between the AGB measured through the climb and the one obtained through the allometric equation, the FF_T value of 0.65 was adopted as the one that represents best the study area.

Carbon stock estimation

We applied the allometric equation to the forest inventory performed by Carvalho (2007). The total biomass was estimated by applying Eq. 5 with an FF_T value of 0.65 and basic density of 0.55 found by the author, similar to the value we calculated. We estimate the biomass stock estimated for Pedra de Itaocaia of 100.1 Mg ha^{-1} (i.e. 6.006 kg), with a potential for carbon stock reaching about 50.5 Mg ha^{-1} .

Discussion

Overall, the structural features of the trees were well distributed between the minimum and maximum DBH values representative of tree variability. Therefore, we were able to establish an FF_T that consistently reflects the structure of trees

from the study area, despite the small number of trees climbed. The exclusion of the bigger tree that was biasing the estimations led to a more adjusted FF_T value, very close to the real volume of the trees. This shows the strength of the methodology, allowing the FF_T value to be applied to a forest inventory in order to estimate carbon stocks.

Tropical forests present a great number of small individuals granting that the structural relationships existing between them accurately capture and represent the entirety of the vegetation (CHAVE; RIEIRA; DUBOIS, 2001). The contributions of the aerial tree compartments (branches and leaves) sum up to 33 % of the total AGB, which is in accordance with previous studies (TANIZAKI, 2000). Similar values were obtained by Cunha et al. (2009) in the Atlantic Rainforest located in the Desengano State Park, where foliar structures, branches, and bark represented up to 39 % of the AGB in two distinct forest fragments. This thorough measurement enabled the calculation of the FF_B and therefore the adjustment of the FF_T required to estimate the AGB taking into account the substantial proportions of aerial compartments (TANIZAKI, 2000).

We estimated biomass stock for Pedra de Itaocaia of 100.1 Mg ha^{-1} , which is in accordance with the forest age. Carvalho (2007) assessed a biomass stock of 111 Mg ha^{-1} using the same forest inventory, which is 10 % higher than our estimation. Cunha et al. (2009), while studying a natural regeneration fragment of the Atlantic Rainforest of 40 years old, estimated a value of $158.14 \text{ Mg ha}^{-1}$, which also corroborates our findings. The forest fragment of Pedra de Itaocaia is considered to be small (≤ 50 hectares) and because of anthropogenic impacts and edge effects, the potential for carbon stocking is reduced, whereas bigger trees are replaced by smaller ones that manage to thrive in such circumstances: pioneer species that absorb less carbon and die more easily (RIBEIRO

et al., 2009). The bigger tree found in the study area does not match the period of abandonment of the forest fragment and therefore is probably a remnant that survived the previous deforestation. Including this tree in the AGB estimates nearly doubles the final results, reaching about 193 Mg ha^{-1} . This indicates that considering a large-stature tree that is not representative of the stage of the ecological succession of the system it composes might interfere with the estimates and lead to inaccurate extrapolations regarding the biomass stock in the fragment.

Tanizaki (2000) estimated AGB in different Atlantic Rainforest fragments in Rio de Janeiro. In the forest fragment of Pedra Branca, which was left fallow for 20 years, biomass was estimated at 30 Mg ha^{-1} – a relatively low value explained by land use and banana plantations in the area. In another forest fragment left fallow for 40 years in the city of Magé, characterized by intense edge effects and seasonal floods, the AGB was estimated at 60 Mg ha^{-1} . In two other forest fragments left fallow for 40 years, Mata do Caçador and Floresta Queimada in the city of Nova Friburgo, AGB was estimated in 150 Mg ha^{-1} and 250 Mg ha^{-1} respectively, in which despite similar values of DBH in both areas, a greater number of large-stature trees in the Floresta Queimada explains the discrepant results (TANIZAKI, 2000).

Secondary forests or fragments disrupted for various reasons accumulate less than 200 Mg ha^{-1} , and in some extreme cases even less than 100 Mg ha^{-1} . These values are consistent with data obtained in the Desengano State Park, where biomass estimates reached about $158.14 \text{ Mg ha}^{-1}$ (CUNHA et al., 2009). Estimates from the Parque Natural Municipal do Curió at the city of Parabambi are $212.39 \text{ Mg ha}^{-1}$, indicating a tropical forest in a good state of conservation (SILVA et al., 2018). However, it is expected that biomass stock estimated after adequate forest management is higher than natural regeneration

and abandonment. For example, Azevedo et al. (2018) in the well-managed Guapiaçu Ecological Reserve, estimated biomass of 39.88, 45.78, and 71.24 Mg ha⁻¹ for reforestation undertakings of 3, 5, and 7 years old, respectively, whereas the native forest presented a value of 273.35 Mg ha⁻¹. Thus, the AGB value of 100.1 Mg ha⁻¹ estimated for Pedra de Itaocaia reflects well its current stage of regeneration (initial to an intermediary) further to 30-40 years left fallow and subject to occasional anthropogenic impact. The importance of forest maintenance is evident since these systems are intimately related to several ecosystem services (CHAZDON & BRANCALION, 2019).

Conclusion

The allometric equation derived in this study efficiently integrates structural features of forest fragments similar to the one of Pedra de Itaocaia. The calculation of the FF_B enabled the adjustment of the FF_T based on the significative percent contribution of the branches relative to the total biomass. The exclusion of a tree with a great DBH did not compromise the predictive potential of the equation; on the contrary, its inclusion may entail an inaccurate extrapolation of biomass values in the study area. Overall, the information collected for and derived from this study contributes to advance the knowledge about processes taking place in the various floristic compositions and stages of the succession of forest fragments situated in the Atlantic Rainforest.

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References

- AZEVEDO, A. D.; CAMARA, R.; FRANCELINO, M. R.; PEREIRA, M. G.; LELES, P. S. S. Estoque de carbono em áreas de restauração florestal da Mata Atlântica. **Floresta**, v. 48, n. 2, p. 183-194. 2018.
- BARBIÉRE, E. B.; COE-NETO, R.; Spatial and temporal variation of the east fluminense coast and atlantic Serra do Mar, State of Rio de Janeiro, Brazil. In: KNOPPERS, B.; BIDONE, E. D.; ABRÃO, J. J. (eds). **ENVIRONMENTAL GEOCHEMISTRY OF COASTAL SYSTEM**, Rio de Janeiro, Brazil. Série Geoquímica Ambiental, v. 6, p. 47–56, 1999.
- BARROS, A. A. M. de. **Análise florística e estrutural do Parque Estadual da Serra da Tiririca, Niterói e Maricá, Rio de Janeiro, Brasil**. 2008. 218 p. Tese (Doutorado). Instituto de Pesquisas Jardim Botânico do Rio de Janeiro/ Escola Nacional de Botânica Tropical, Rio de Janeiro.
- BASTIN, J. F.; FINEGOLD, Y.; GARCIA, C.; MOLLICONE, D.; REZENDE, M.; ROUTH, D.; ZOHNER, C. M.; CROWTHER, T.W. The global tree restoration potential. **Science**, v. 365, n. 6448, p. 76-79. 2019.
- BRASIL. **Lei n. 11.428/2006**. Disponível em: http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2006/Lei/L11428.htm Acesso em: 16 abr. 2021.
- BROWN, F.; MARTINELLI, L. A.; THOMAS, W. W.; MOREIRA, M. Z.; FERREIRA, C. A. C.; VICTORIA, R. A. Uncertainty in the biomass of Amazonian forests: an example from Rondônia, Brazil. **Forest Ecology and Management**, v. 75, p. 175-189. 1995.

- CARVALHO, M. C. P. **Avaliação do estoque de carbono na biomassa arbórea de uma floresta secundária em Maricá, RJ.** 2007. Dissertação (Graduação em Ciências Biológicas). Universidade Veiga de Almeida, Rio de Janeiro.
- CHAVE, J.; RIERA, B.; DUBOIS, M. A. Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability. **Journal of Tropical Ecology**, v. 17, p. 79-96. 2001.
- CHAVE, J.; ANDALO, C.; BROWN, S.; CAIRNS, M.; CHAMBERS, J. C.; EAMUS, D.; et al. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. **Oecologia**, v. 145, p. 87-99. 2005.
- CHAZDON, R. L.; BRANCALION, P. Restoring forests as a means to many ends. **Science**, v. 365, n. 6448, p. 24-25. 2019.
- CHAZDON, R. L.; BROADBENT, E. N.; ROZENDAAL, D. M. A.; BONGERS, F.; ZAMBRANO, A. M. A.; AIDE, T. M.; POORTER, L. Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. **Science Advances**, v. 2, n. 5. 2016.
- CUNHA, G. M.; RODRIGUES, A. C. G.; RODRIGUES, E. F. G.; VELLOSO, A. C. X. Biomassa e estoque de carbono e nutrientes em florestas montanas da mata atlântica na região norte do estado do Rio de Janeiro. **Revista Brasileira de Ciência do Solo**, v. 33, n. 5. 2009.
- IGNÁCIO, A.; SCHNEIDER, A.; MATIAS, F.; CASTRO, P. F. **Trilhas: Parque Estadual da Serra da Tiririca.** Instituto Estadual do Ambiente, Rio de Janeiro. 384p. 2015.
- INFRAESTRUTURA NACIONAL DE DADOS ESPACIAIS (INDE). <https://visualizador.inde.gov.br/> Acesso: Abr. 2021.
- IPCC. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [MASSON-DELMOTTE, V.; ZHAI, P.; PÖRTNER, H. O.; ROBERTS, D.; SKEA, J.; SHUKLA, P. R.; PIRANI, A.; MOUFOUMA-OKIA, W.; PÉAN, C.; PIDCOCK, R.; CONNORS, S.; MATTHEWS, J. B. R.; CHEN, Y.; ZHOU, X.; GOMIS, M. I.; LONNOY, E.; MAYCOCK, T.; TIGNOR, M.; WATERFIELD, T. (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp. 2018.
- LEWIS, S. L.; WHEELER, C. E.; MITCHARD, E. T. A.; KOCH, A. Restoring natural forests is the best way to remove atmospheric carbon. **Nature**, v. 568, p. 25–28. 2019.
- MARQUES, M. C. M.; SILVA, A. C. L.; RAJÃO, H.; ROSADO, B. H. P.; BARROS, C. F.; OLIVEIRA, J. A.; FINOTTI, R.; AMORIM, S. N. A.; CERQUEIRA, R.; BERGALLO, H. G. Mata Atlântica: O desafio de transformar um passado de devastação em um futuro de conhecimento e conservação. In: PEIXOTO, A. L.; LUZ, J. R. P.; BRITO, M. A. **Conhecendo a Biodiversidade.** Brasília: MCTIC, CNPq, PPBio, p. 51-67. 2016.
- MYERS, N.; MITTERMEIER, R. A.; MITTERMEIER, C. G.; DA FONSECA, G. A. B.; KENT, J. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, n. 6772, p. 853-858. 2000.
- OVERMAN, J. P. M.; WITTE, H. J. L.; SALDARRIAGA, J. G. Evaluation of regression models for above-ground biomass determination in Amazon Rainforest. **Journal of Tropical Ecology**, v. 10, p. 207-218. 1994.

- POORTER, L. F.; BONGERS, T. M.; AIDE, A. M.; ZAMBRANO, P. A.; BALVANERA, J. M.; BECKNELL, V.; et al. Biomass resilience of Neotropical secondary forests. **Nature**, v. 530, p. 211–214. 2016.
- PÜTZ, S.; GROENEVELD, J.; HENLE, K.; KNOGGE, C.; MARTENSEN, A. C.; METZ, M.; HUTH, A. Long-term carbon loss in fragmented Neotropical forests. **Nature communications**, v. 5, n. 1, p. 1-8. 2014.
- RIBEIRO, M. C.; METZGER, J. P.; MARTENSEN, A. C.; PONZONI, F. J.; HIROTA, M. M. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. **Biological Conservation**, v. 142, p. 1141-1153. 2009.
- SILVA, L. C.; ARAÚJO, E. J. G.; CURTO, R. A.; NASCIMENTO, A. M.; ATAÍDE, D. H. S.; MORAIS, V. A. Estoques de biomassa e carbono em unidade de conservação no bioma mata atlântica. **Biofix**, v. 3, n. 2, p. 243-251. 2018.
- SILVEIRA, P.; KOEHLER, H. S.; SANQUETTA, C. R.; ARCE, J. E. O Estado Da Arte Na Estimativa De Biomassa E Carbono Em Formações Florestais. **Floresta**, v. 38, n. 1, p. 185-206. 2008.
- SOS MATA ATLÂNTICA/INPE. **Atlas dos remanescentes florestais da Mata Atlântica – Relatório técnico**. <http://mapas.sosma.org.br/dados/> Acesso em: 16 maio, 2021.
- MANES, S.; COSTELLO, M. J.; BECKETT, H.; DEBNATH, A.; DEVENISH-NELSON, E.; GREY, K.; JENKINS, R.; KHAN, T. M.; KIESSLING, W.; KRAUSE, C.; MAHARAJ, S. S.; MIDGLEY, G. F.; PRICE, J.; TALUKDAR, G.; VALE, M. M. Endemism increases species' climate change risk in areas of global biodiversity importance, **Biological Conservation**, v. 257. 2021.
- TANIZAKI, K. **Impacto Do Uso Da Terra No Estoque E Fluxo De Carbono Na Área De Domínio Da Mata Atlântica: Estudo De Caso, Estado Do Rio De Janeiro**. 2000. Tese (Doutorado). Instituto de Geociências. Universidade Federal Fluminense, Niterói.
- TIEPOLO, G.; CALMON, M.; FERETTI, A. R. Measuring and monitoring carbon stocks at the Guaraqueçaba climate action project, Paraná, Brazil. In: **Proceedings of the International Symposium on Forest Carbon Sequestration and Monitoring** (pp. 11-15). Taipei: Taiwan Forestry Research Institute. 2002.