Litter dynamics in riparian zones of the Atlantic Rainforest under cocoa agroforestry (#58957)

First submission

Guidance from your Editor

Please submit by **3 Apr 2021** for the benefit of the authors (and your $200 publishing discount) .

Structure and Criteria
Please read the 'Structure and Criteria' page for general guidance.

Custom checks
Make sure you include the custom checks shown below, in your review.

Raw data check
Review the raw data.

Image check
Check that figures and images have not been inappropriately manipulated.

Privacy reminder: If uploading an annotated PDF, remove identifiable information to remain anonymous.

Files

Download and review all files from the materials page.

9 Figure file(s)
1 Table file(s)
1 Raw data file(s)

Custom checks

Field study

- Have you checked the authors field study permits?
- Are the field study permits appropriate?

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- Impact and novelty not assessed. Negative/inconclusive results accepted. *Meaningful* replication encouraged where rationale & benefit to literature is clearly stated.
- All underlying data have been provided; they are robust, statistically sound, & controlled.
- Speculation is welcome, but should be identified as such.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	***Example***
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult. I suggest you have a colleague who is proficient in English and familiar with the subject matter review your manuscript, or contact a professional editing service.*
Organize by importance of the issues, and number your points	*1. Your most important issue* *2. The next most important item* *3. …* *4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

Litter dynamics in riparian zones of the Atlantic Rainforest under cocoa agroforestry

Haialla Carolina Rialli Santos Brandão [1] , **Camila Andrade Coqueiro Moraes** [2] , **Ana Paula Silva** [2] , **José Francisco Gonçalves Júnior** [3] , **Renan de Souza Rezende** [4] , **Daniela Mariano Lopes da Silva** [Corresp. 5]

[1] Programa de Pós Graduação em Desenvolvimento e Meio Ambiente, Universidade Estadual de Santa Cruz, Ilhéus, Bahia, Brazil

[2] Universidade Estadual de Santa Cruz, Ilhéus, Bahia, Brazil

[3] AquaRiparia/Lab. de Limnologia, Departamento de Ecologia, Universidade de Brasília, Brasilia, Brazil

[4] Universidade Comunitária da Região do Chapecó, Chapecó, Santa Catarina, Brazil

[5] Departamento de Ciências Biológicas, Universidade Estadual de Santa Cruz, Ilhéus, Bahia, Brazil

Corresponding Author: Daniela Mariano Lopes da Silva
Email address: dmlsilva@uesc.br

Backgroud. The cultivation of cocoa in the tropics is developed mainly in the agroforestry system (AFS). In the Brazilian Atlantic Rainforest, this system is known as cabrucas and represents a high potential for biodiversity conservation and economic development. Studies of litter dynamics in AFS riparian zones are rare and therefore relevant to explaining the global importance of these areas for carbon balance and ecosystem services. The tree structure and composition of the cabrucas have been widely altered in time and space due to management practices. These modifications can change the litter supply pattern and affect the stream and aquatic communities' ecological process. Our objective was to estimate litter input and stock in riparian zones of cabruca cocoa agroforestry systems under management (MC) and abandonment (AC), and secondary forest (SF).

Methods. To estimate the litter dynamics, we evaluated the terrestrial production of litter (terrestrial input TI), the litter input for streams (litterfall/vertical - VI and lateral input - LI), and the litter stock in the stream bed (benthic stock - BS). Each compartment was sampled in specific collectors every 30 days from August 2018 to July 2019. Monthly, the litter was removed in the TI, VI, and LI compartments and the samples separated into fractions: leaf, branch, reproductive material, and miscellaneous.

Results. Terrestrial input was similar in all areas. However, the vertical input total was twice high in MC and AC than in the secondary forest, while lateral input was three times high in MC cocoa than in other areas. The benthic stock total was higher in SF than AC and three times higher than MC. We highlight the high contribution of reproductive parts in different inputs and stock of MC, the leaf in vertical input, and benthic stock in AC and branch and miscellaneous in SF. A pronounced temporal pattern was observed on litter input and stock at SF and AC by species phenology, while MC showed low temporal pattern variation by cocoa management. Despite differences in litter input and stock between areas related to vegetation structure, spatial and temporal patterns of litter input and stock in AC were closer to SF than MC. Therefore, we reinforce the importance of cabruca cocoa AFS for the conservation of landscape compared to other anthropic land uses.

Litter dynamics in riparian zones of the Atlantic rainforest under cocoa agroforestry

Haialla Carolina Rialli S. Brandão[1], Camila Andrade Coqueiro Moraes[1], Ana Paula Silva[1], José Francisco Gonçalves Júnior[2], Renan de Souza Rezende[3], Daniela Mariano Lopes da Silva*[1]

[1]Aquatic Biogeochemistry Lab, Department of Biological Sciences, Universidade Estadual de Santa Cruz (UESC), Ilhéus Bahia, Brazil.
[2]Limnology/Aquariparia Lab, Department of Ecology, IB, Universidade de Brasilia (UnB), Brasília, Distrito Federal, Brazil.
[3]Universidade Comunitária da Região do Chapecó, Avenida Senador Attilio Francisco Xavier Fontana, Engenho Braun 89809000 – Chapecó, SC – Brazil.

Corresponding Author:
Daniela Mariano Lopes da Silva
Universidade Estadual de Santa Cruz, Rodovia Jorge Amado km 16, Ilhéus, Bahia, Brazil
Email address: dmlsilva@uesc.br

Abstract

Backgroud. The cultivation of cocoa in the tropics is developed mainly in the agroforestry system (AFS). In the Brazilian Atlantic Rainforest, this system is known as *cabrucas* and represents a high potential for biodiversity conservation and economic development. Studies of litter dynamics in AFS riparian zones are rare and therefore relevant to explaining the global importance of these areas for carbon balance and ecosystem services. The tree structure and composition of the cabrucas have been widely altered in time and space due to management practices. These modifications can change the litter supply pattern and affect the stream and aquatic communities' ecological process. Our objective was to estimate litter input and stock in riparian zones of cabruca cocoa agroforestry systems under management (MC) and abandonment (AC), and secondary forest (SF).

Methods. To estimate the litter dynamics, we evaluated the terrestrial production of litter (terrestrial input TI), the litter input for streams (litterfall/vertical - VI and lateral input - LI), and the litter stock in the stream bed (benthic stock - BS). Each compartment was sampled in specific collectors every 30 days from August 2018 to July 2019. Monthly, the litter was removed in the TI, VI, and LI compartments and the samples separated into fractions: leaf, branch, reproductive material, and miscellaneous.

Results. Terrestrial input was similar in all areas. However, the vertical input total was twice high in MC and AC than in the secondary forest, while lateral input was three times high in MC cocoa than in other areas. The benthic stock total was higher in SF than AC and three times higher than MC. We highlight the high contribution of reproductive parts in different inputs and stock of MC, the leaf in vertical input, and benthic stock in AC and branch and miscellaneous in SF. A pronounced temporal pattern was observed on litter input and stock at SF and AC by species phenology, while MC showed low temporal pattern variation by cocoa management. Despite differences in litter input and stock between areas related to vegetation structure, spatial and temporal patterns of litter input and stock in AC were closer to SF than MC. Therefore, we reinforce the importance of cabruca cocoa AFS for the conservation of landscape compared to other anthropic land uses.

Introduction

Tropical ecosystems are notable for their biodiversity (Wright 2005), and Atlantic Rainforest corresponds to one of the most threatened tropical forests in the world (Winbourne et al. 2018, Taubert et al. 2018). High species richness, high endemism degree, and fragmentation make the Atlantic Rainforest biome a priority area for global biodiversity conservation (Canale et al. 2016, Martini et al., 2007). However, deforestation and the expansion of agriculture are substantial threats to terrestrial ecosystems (Bawa et al. 2004) and consequently to aquatic ecosystems.

Small forest streams (forest streams) are sustained by terrestrial plant litter (Tonin et al. 2019, - - Naiman et al. 2005, Vannote et al. 1980), and therefore highly sensitive to forest changes (Ferreira et al. 2018).

Changes in the structure and composition of forests for productive purposes can influence organic matter supply to streams (Wild et al. 2019, Ferreira et al. 2018, Delong and Brusven, 1994). Besides interfering in the contribution streams as dynamic components of the terrestrial carbon cycle (Tiegs et al. 2019, Stufin et al. 2015), and the provision of ecosystem services such as quality water and food (Ferreira et al. 2018). Thus, studies involving the litter dynamics in riparian zones (areas defined by Gregory et al. 1991 as an ecotone between terrestrial and aquatic ecosystems) of productive tropical systems are rare. These works could help understand the effects of anthropogenic changes on carbon cycling and climate change (Boyero et al. 2011, Stufin et al. 2015, Wright, 2005) and aquatic biota and ecological processes in streams (Ferreira et al. 2018).

It is argued that agricultural products in tropical forests must prioritize practices favorable to biodiversity (Martin et al. 2020). Agroforestry-based systems (AFSs) correspond to potential models that associate economic development with the conservation of tropical biodiversity (Scrhot et al. 2011, Cassano et al., 2009). In the Northeast of Brazil, a high remnant part of the Atlantic Rainforest is found in the cocoa AFS, where cocoa is grown (*Theobroma cacao* L.) (Piasentin et al. 2014). The agroforestry system for cocoa cultivation is inserted under forest trees' shade (dominant and codominant strata) and is surrounded by natural vegetation. Therefore, the cocoa agroforestry system may be causing less impact to related natural resources (Johns 1999, Sambuichi, 2002) when compared to other cultivation systems. The higher trees diversity of the agroforestry system (Sambuichi et al. 2012; Piasentin et al. 2014), is a consequence of diversity and natural heterogeneity of forests (Rolim and Chiarello 2004) representing high value for the conservation of local biodiversity (Schroth et al. 2011, Cassano et al. 2009, Faria et al. 2007). Also, the cabrucas represents an important ecological corridor among the remnants of the Atlantic Forest, enhancing the protection of biological communities (Faria et al.2007, Cassano et al., 2009).

The management cabruca system carried out by farm owners seems to be the factor that most influences this agroforestry arboreal communities attribute (Deheuvels et al. 2014, Sambuichi 2002). Recently, cabruca's tree component has shown a high degree of mischaracterization about native forests (Sambuichi 2002, Rolim and Chiarello 2004). The increase in market demand has generated pressures on production. Adopting more intensive management practices with the reduction of shade has been used (Deheuvels et al. 2014, Piasentin et al.2014, Johns, 1999), triggering new confirmations of cabruca in time and space (Sambuich et al. 2012, Rolim et al. 2017). On the other hand, the introduction of witches' broom in the late 80s and the decrease in commodity prices discouraged some owners, and several productive areas were abandoned (Rolim et al. 2017). Abandoned cabrucas have a high capacity to regenerate tree species' richness after abandonment (Sambuich et al. 2007). The remaining forest nearby works as seed sources favoring the recovery of the forest in abandoned cabrucas (Rolim et al. 2016). Therefore, the evaluation of cabrucas after the discontinuation of management practices is essential to understand the potential of these areas to restore ecological processes and ecosystem services provided by AFS cacao cabruca in the maintenance of tropical biodiversity.

Several studies report that ecological processes such as the high incorporation of organic matter in the soil in forests are maintained in AFSs cacau cabruca (Costa et al. 2018, Barreto et al. 2011, Fontes et al. 2014, Gama-Rodrigues et al.2010, Beer et al.1998). Nevertheless, differences in cabruca vegetation structures may affect the litter deposited amount in the riparian zone (Wild et al. 2019, Delong and Brusven, 1994) as well influence the litter input amount to streams (Gonçalves Júnior et al. 2014), and that may be especially true for AFS cocoa cabruca. Although all effects, there are few studies on AFS riparian zones of cocoa. Research shows that replacing the cabruca agroforestry systems in Northeast Brazil may change the carbon and nitrogen cycling of streams (Costa et al. 2017, Souza et al. 2017). According Costa et al (2018), the AFS cocoa cabruca presented the higher C input to streams and the higher CO_2 export from soils. The authors inferred that these variations were probably due to the vegetation cover. Thus, the current study aims to fill this inference cited in Costa et al (2016 and 2018) and assist with information to manage these important productive systems.

To understand the vegetation influences, it is essential to understand the role of the riparian zones of the AFS cacao cabruca and how the management implemented in these AFS areas can cause changes in the supply and stock of organic matter/litter the streams. It also checks how abandoned farming areas behave about the transition of environmental quality due to the successional stage. Information on ecological processes in riparian zones of this AFSs cacau cabruca is unprecedented and of great relevance for understanding the effects of carbon stock (Barreto et al. 2011), water production (Ferreira et al. 2018), and the consequences of biodiversity loss in ecosystems impacted by anthropogenic activities (Bawa et al. 2004). It was bearing in mind that the decomposition process in streams has been highlighted in the global carbon cycle's contribution (Stufin et al 2015, Boyero et al 2011, Battin et al 2009). Besides, streams terrestrial litter represents energy resources that support the trophic webs of aquatic ecosystems.

We aimed to assess the influence of different structural formations of AFS riparian plants under management and abandonment and secondary forest conditions on litter production (inputs terrestrial, vertical, and lateral) and litter stock in the riparian zone of streams. Therefore, this work was based on the premise that; i) Cabruca cocoa AFS areas tend to be more productive than native forest areas (Fontes et al. 2014); ii) Streams that run through a landscape of more productive areas tend to receive a higher amount of litter input (Gonçalves Júnior et al. 2014, França et al. 2009) and litter stock in streambeds (Webster et al. 1994, Lisboa et al. 2015); and iii) Tropical riparian systems are driven by precipitation and temperature due to litter productivity control (Tonin et al. 2017); iv) Variations in productivity pattern may occur due to the phytophysiognomies differences (Seena et al. 2017). Our first hypothesis is that cabruca cocoa AFS areas (managed and abandoned) will be more productive than secondary native forest areas, mainly in leaves litter part by the dominance of this fraction in the total litter. Our second hypothesis would be altered litter input to streams, riparian forests, and litter stock on streambeds over year among vegetation systems by phytophysiognomies differences.

Materials & Methods

Study area

The study was conducted in three riparian zones from different small watersheds (Fig. 1): secondary forest - SF (E 485415 / N 8397615), abandoned cabruca cocoa AFS - AC (E 481551 / N 8364478), and managed cabruca cocoa AFS - MC (E 448466 / N 8363187). All sites are located in the Atlantic Rainforest, southern Bahia, northeast Brazil, and have an Af-type climate according to Köppen classification (hot and humid with no defined dry season) with an annual average ranging between 1100 to 2200mm. The studied streams are second-order according to the Strahler classification system (Strahler 1952). The rainfall from 1 August 2018 to 30 July 2019 was obtained from the website of the Real-Time Climate Monitoring Program of the Northeast Region (PROCLIMA; http://proclima.cptec.inpe.br/) for the municipalities of Itacaré, Ilhéus, and Barro Preto. The daily precipitation for the three cities were described in Fig. 2. The secondary forest (SF) is located in a Conservation Unity (Serra do Conduru State Park – License 2017-013654/TEC/PESQ-0014). The vegetation is formed by a mosaic with different development stages, including secondary forests. It has a uniform canopy, above 25 m height, with few emerging individuals, epiphytes, large vines, and a dense understory (Costa et al. 2018, Martini et al. 2007). The predominant litter of the riparian zone were the following species: *Henrietta succosa* (DC.), *Symphonia globulifera* L.f., *Protium heptaphyllum* (Aubl.), *Cordia trichotoma* (Vell) Arráb. Ex Setud., *Brosimum rubescens* Taub., *Sloanea obtusifolia* (Moric.) Schum., *Andira* spp, *Albizia polycephala* Durraz., *Centrolobium robustum* (Vell.) Mart., *Inga affinis* DC., *Byrsonima sericea* DC, *Luehea divaricata* Mart. & Zuc., *Senna multijuga* (Rich.) H.S. & Barneby, *Pimenta pseudocaryophyllus* (Gomes) Landrum, *Scheffera morototoni* (Aubl.) Maguire et al., *Mimosa* sp, *Xylopia brasiliensis* Spreng., *Himtanthus bracteatus* Spreng., *Tapirira obtusa* (Benth.) J.D.Mitch., *Miconia* sp and lianas and were based on the description by Martini et al. 2007 for that same area of study. The monthly and annual average precipitation was 94 ± 43 mm and 1135 mm (database for the municipality of Itacaré) (Fig. 2)

The AC area has 73.38 ha and is located in the agroforestry farming system (Santa Cruz). The watershed showed a slope of around 5% and medium shading 70 % formed by old cocoa trees (since the abandoned of 20 years ago of the extractive area) among other species (like jackfruit, erythrina, imbaúba, and jequitibá trees; Argôlo 2009), distributed in a disorganized way. The monthly and annual average precipitation was 87 ± 41 mm and 1075 mm (database for the municipality of Ilhéus) (Fig. 2). The predominant litter was of the riparian zone following species: *Theobroma cocoa* L. *Artocarpus heterofophyllus* Lam., *Spondias mombin* L., *Miconnia* sp, *Tapirira obtusa (*Benth.) J. D. Mitch, Ziziphus *joazeiro* Mart, *Vataireopsis araroba* (Aguiar) Ducke, *Nectandra membranacea* (Sw.) Griseb, *Dialium guianense* (Aubl.) Sandwith, *Eritrina* sp, *Inga* sp*, Lecythis pisonis* Cambess, *Mimosa sp e Bauhinia forficata* Link and lianas and were based on the description of same study area of Costa et al. 2016, Souza et al. 2017 and Costa et al. 2018. The managed cabruca (MC) area is located at agroforestry farming system (Nova Harmonia) with a total area of 89.80 ha, distributed in cocoa production, a forest patch in its central portion, and two areas in the regeneration process (Santos et al. 2016). The cocoa area management only consists of pruning (every six months and the biomass is disposed of in the soil), cutting vegetation, and few liming events for soil correction. The planting has a 3x3m spacing and is intercropped with introduced shade trees (erythrina). The monthly and annual average precipitation was 87±41 mm and 1039 mm (database for Barro Preto's municipality) (Fig.2). The predominant litter was of the riparian zone following species: *Theobroma cocoa L.*, *Eritrina* sp, *Clitoria fairchildiana* R. A. Howa, *Cordia trichotoma* (Vell.) Arrab. ex Steud., *Senna multijuga* (Rich.) H. S. Irwin & Barneby*, Artocarpus heterophyllus* L.*, Spondias mombin* L.*, Ficus sp* and lianas and were based on the description of same study area of Costa et al. 2018 and Santos et al. 2016.

Litter production input and benthic stock

The methodology for collecting the litter input and stock was presented in several studies (Tonin et al. 2017, Bambi et al., 2016, Gonçalves Júnior et al. 2014, França et al. 2009). To understand the litter dynamics, the samples were collected in different compartments in a stretch of 100 m in each riparian zone and the sample design adopted for each of them was described in the supplemental information (Fig S1). The compartments evaluated the terrestrial production of litter (terrestrial input TI), the litter input for streams (litterfall/vertical - VI and lateral input - LI), and the litter stock in the stream bed (benthic stock - BS). Samples were collected every 30 days from August 2018 to July 2019.

The litter production was estimated by the TI deposited directly on the soil of the riparian zones. The ten collectors' average quantified it installed 1 m from the ground (n = 10, total area - 2.5m², 1 mm of mesh) distributed at 20 m equidistant, five on each bank of the stream (Fig S1). The VI (litterfall) evaluated the litter that fell directly from the riparian vegetation canopy. Along the sampled section, 27 buckets (total area - 1.9 m²) were installed, perpendicular to the stream, and placed at 1 m from the water surface. The buckets were arranged in three sections, approximately 30 m apart, and in each section, a set of 9 buckets was installed, with about 1m between them. The LI evaluated the indirect litter input to stream by stored in riparian zone soil through lateral route, moved by gravity action, bank slope, runoff, wind, or animals' action. It was estimated by ten nets (1 mm mesh) arranged at ground level (total area - 1.5 m²) with five on each margin (Fig S1). The total litter input for the streams was considered by the sum of the lateral and vertical inputs (Table S1). The BS represented the litter accumulated in the streambed and was estimated using the Surber® sampler (total area - 0.45m² and 0.25 mm mesh), with five sampling units 20 m equidistant (Fig S1).

Experimental procedure

Monthly, the litter was removed in the TI, VI, and LI compartments accumulated in collectors (nets and buckets). In the laboratory, the samples were sorted and separated into fractions: leaf, branch (corresponding to woody parts with dimensions less than 25 cm), reproductive material (flower and fruit), and miscellaneous (unidentified plant material and traces of animal material). After screening, the material was dried in an oven at 60° C for 72 hours and then weighed. The TI, VI, and BS were expressed in $g.m^{-2}$ (subsequently estimated by day - $g.m^{-2}.d^{-1}$), calculated considering the litter mass deposited in the collectors (M g). These results were corrected by the sampler area (A m^{-2}) and the exposure time (T = difference in days between the previous and the current collection), using the following formula: TI, VI, and BS = M / A / T.

The lateral input was calculated according to Elosegi, and Pozo (2005) and Pozo et al. (2009) by dividing twice the litter mass collected in a sampler (M g^{-1}) by the width of the collector (Lcolr m-1) multiplied by the average channel width (LACnal m^{-1}). These results were corrected by the number of days (T) of exposure to express the results per unit area of the riverbed ($g.m^{-2}$), using the following form: LI = 2M / Lcol x Lchanel / T. The data on the litter dynamics were expressed $g.m^{-2}$ (subsequently estimated by day - $g.m^{-2}.d^{-1}$). The annual productivity of riparian zones corresponded to the sum of the average monthly production of litter over the year studied (Table S1). The portion of the litter stored in the soil that input in the stream through the LI was measured by the difference between the total production of TI (which corresponds to 100%) and the total production of LI.

Statistical Analysis

We compare the leaf litter by litterfall and lateral input to streams, as also the terrestrial input and stock (benthic deposition in streambed) among secondary forest (SF), abandoned cabruca (AC), and managed cabruca (MC) areas by non-parametric bootstrapped confidence intervals. In a non-parametric bootstrapped analysis, the statistical differences were observed when the confidence intervals of different areas (SF, AC, and MC) do not overlap. Bootstrapped was robust against violations of common parametric assumptions, such as normal distribution and homogeneity of variances observed on inputs and stocks, and a simple and straightforward method that facilitates the interpretation of results (Efron and Tibshirani 1993; Johnson 2001). Ordinary non-parametric bootstrapped 95% confidence intervals were calculated using the BCa method using boot function and package and were based on 1,000 bootstrap replicates (Davison and Hinkley 1997; Canty and Ripley 2016).

Generalized additive mixed models (GAMM) was used to explore the seasonal patterns in litter input (litterfall, lateral and terrestrial) and stock of the different litter fractions (leaves, branch, reproductive part, and miscellaneous) from 12 months as a predictor from a normal distribution (identity-link function) with sites as a random component of the models. In non-linear relationships, the additive models are suitable and a powerful tool to better represent reality. The amount of smoothing in an additive model is expressed as effective degrees of freedom (edf). High values of edf, lower were linearity on a curve and the variation over time (edf of 1 indicate a linear effect). The additive mixed models were fitted using the 'by' command in the 'mgcv' package in R. The validation was used to estimate the optimal amount of smoothing (Wood 2017). In this way, based on previous studies, the GAMMs could be the better approach from seasonal testing (Tonin et al. 2017, 2019). In this way, the temporal patterns of each response variable among sites may have proceeded visually. The residual spread within models among temporal sampling was measure using the varIdent function. Additional analytical protocol, details of residual tests, and model validation are available in Zuur et al. (2009).

Results

Litter annual productivity and fractions

In secondary forest (SF), the annual terrestrial input (TI) was 743.47 $g.m^{-2}.year^{-1}$ (7.43 $t.ha^{-1}.year^{-1}$). The lateral input (LI) was 215 $g.m^{-2}.year^{-1}$ (29%), while vertical input (VI) was 436.57 $g.m^{-2}.year^{-1}$. The annual benthic stock (BS) was 4,591.76 $g.m^{-2}.year^{-1}$. In abandoned cabruca cocoa (AC) the annual TI was 961.84 $g.m^{-2}.year^{-1}$ (9.61 $t.ha^{-1}.year^{-1}$). The LI that reached the stream was 130.24 $g.m^{-2}.year^{-1}$ (13%), and VI was 852, 6 $g.m^{-2}.year^{-1}$ while annual BS was 3.160,4 $g.m^{-2}.year^{-1}$. In managed cabruca (MC), the annual TI corresponded to 691 $g.m^{-2}.year^{-1}$ (6.91 $t.ha^{-1}$.year-1). The LI was 307.33 $g.m^{-2}.year^{-1}$ (44%), VI was 532.32 $g.m^{-2}.year^{-1}$, while the annual BS was 1.395,84 $g.m^{-2}.year^{-1}$.

The leaf was the most representative litter fraction, with a percentage higher than 60% in the TI and VI and 70% in the LI of the secondary forest and abandoned cabruca. In the managed cabruca the percentages of TI, VI and LI corresponded to 56%, 41% and 62%. In BS, leaves values were 61% in abandoned cabruca cocoa, 57% in managed cabruca, and 38% in secondary forest. The miscellaneous fraction was the second most abundant among the compartments, with the highest percentages observed in secondary forest and abandoned cabruca cocoa of BS (43% and 22%, respectively). The branches fraction shows the highest percentages in BS (secondary forest 19% and AC 16%) and TI (secondary forest 9% and abandoned cabruca cocoa 12%). Due to occurring sporadically and transiently, the reproductive fraction shows low percentages in all contributions and study areas, but they were more frequent in areas of managed cabruca (Table S1).

Spatial variation on riparian litter inputs and stream benthic stock

The total vertical input was twice times high in managed cabruca (MC; 0.51 $g.m^{-2}.d^{-1}$ – range 0.08 to 0.11 for mean and 95% confidence intervals) and abandoned cabruca cocoa (AC; 0.49 $g.m^{-2}.d^{-1}$ – range 0.15 to 0.31) than secondary forest (SF; 0.26 $g.m^{-2}.d^{-1}$ – range 0.08 to 0.10). The dry mass of leaf litter was three times high in abandoned cabruca cocoa than managed cabruca and secondary forest (Fig. 3a; Table S1). On the other hand, reproductive parts were three times high in managed cabruca than abandoned cabruca and four times high compared to the secondary forest (Fig. 3a; Table S1). Finally, the dry mass of branch and miscellaneous were also similar among the input in all riparian systems (Fig. 3a; Table S1).

Terrestrial input total was similar in all areas with the highest values on abandoned cabruca (0.08 $g.m^{-2}.d^{-1}$ – range 0.06 to 0.09) followed to managed cabruca (0.07 $g.m^{-2}.d^{-1}$ – range 0.05 to 0.10 for mean and 95% confidence intervals) and secondary forest (0.06 $g.m^{-2}.d^{-1}$ – range 0.05 to 0.07). Terrestrial input shows a similar dry mass of leaf litter, branch, and miscellaneous, but significantly high reproductive parts were found in managed cabruca compared to the secondary forest (Fig. 3b; Table S1). The reproductive parts in terrestrial input of abandoned cabruca AC were similar to managed cabruca and secondary forest (Fig. 3b).

The lateral input total was three times high in managed cabruca (0.15 $g.m^{-2}.d^{-1}$ – range 0.11 to 0.23 for mean and 95% confidence intervals) followed to secondary forest (0.06 $g.m^{-2}.d^{-1}$ – range 0.05 to 0.08) and abandoned cabruca (0.04 $g.m^{-2}.d^{-1}$ – range 0.03 to 0.06). Lateral input showed significantly higher leaf litter values, reproductive parts, and miscellaneous in managed cabruca than abandoned cabruca and secondary forest, but similar branches among areas (Fig.3c; Table S1).

Finally, the benthic stock total was higher in secondary forest (6.85 $g.m^{-2}.d^{-1}$ – range 5.38 to 8.94 for mean and 95% confidence intervals) than abandoned cabruca (4.82 $g.m^{-2}.d^{-1}$ – range 3.95 to 6.23) and three times higher than managed cabruca (2.24 $g.m^{-2}.d^{-1}$ – range 1.55 to 3.48). Dry mass of leaf litter was three times higher in abandoned cabruca than managed cabruca (Fig. 3d; Table S1**).** The leaf litter in benthic stock of secondary forest was similar to abandoned cabruca and managed cabruca (Fig. 3d). The highest values in benthic stock for branch and miscellaneous were observed in the secondary forest than in another area. On the other hand, reproductive parts were three times higher in the secondary forest than abandoned cabruca and four times higher than managed cabruca (Fig. 3d; Table S1).

Timing of litter inputs and stream benthic stock

Litterfall input has shown annual patterns on leaves productivity on secondary forest (by effective degrees of freedom – edf = 5.5; Fig. 4a) and abandoned cabruca areas (edf = 5.1; Fig. 4b), and a peak among November to February in both areas representing the rainy months. On the other hand, the leaves productivity in managed cabruca was more constant over time (edf = 1; values closer to 1 represent a low temporal variation; Fig. 4c). We also observed a branch peak in October in managed cabruca area (Fig. 4f). Reproductive parts have had sinusoidal patterns over time in abandoned cabruca (low peak in October, February, and July; Fig. 4h) and managed cabruca areas (high peak in August and February; Fig. 4i). No differences in seasonal patterns were observed on miscellaneous in all riparian areas and reproductive parts in secondary forest and branch and in abandoned cabruca (Fig. 4).

Over time, terrestrial input has shown a sinusoidal pattern on leaf productivity than other inputs (by edf). In the secondary forest, a peak was observed in October and March (Fig. 5a) and managed cabruca, a peak in September and March (Fig. 5c). These months correspond to the least rainy periods. However, more constant leave input over time was observed in abandoned cabruca, only peak in November (Fig. 5b). We also observed a variation in input patterns for the branch of AC (Fig. 5e), reproductivity parts in managed cabruca (Fig. 5i), and miscellaneous in abandoned cabruca (Fig. 5l) and managed cabruca (Fig. 5m). On the other hand, no seasonal patterns were observed for the branch of secondary forest (Fig. 5d) and managed cabruca (Fig. 5f), reproductivity parts of secondary forest (Fig. 5g) and abandoned cabruca (Fig. 5h), and finally, for miscellaneous of secondary forest (Fig. 5j).

Lateral input shows patterns in leaves productivity in the management cabruca area (edf = 1.9; Fig. 6c), with peaks among January to March, less rainy period. No differences among areas on the timing of litter inputs for branch, reproductivity parts, and miscellaneous litters parts (Fig. 6).

The leaves in the benthic stock in the secondary forest peaked in April, the month preceding the least rainy season (Fig. 7a), and the abandoned cabruca showed the lowest peak in November (the rainiest period) and the highest peak in February (the least rainy period). (Fig. 7b). No seasonal pattern was observed for managed cabruca leaves (Fig. 7c). We also found a temporal variation on reproductivity parts in managed cabruca (Fig. 7i) and miscellaneous in secondary forests (Fig. 7j). On the other hand, it was not observed seasonal patterns for the branch in all areas (Fig. 7d, e, and f). The reproductivity parts were significant only in the secondary forest and abandoned cabruca (Fig. 7g and 7h) and miscellaneous in abandoned and managed cabruca (Fig. 7l and 7m).

Annual productivity

The annual productivity in the riparian zone of abandoned cabruca managed cabruca, and the secondary forest was 18.14, 12.24, and 11.80 t. ha $^{-1}$ano $^{-1}$, respectively. In AC and managed cabruca, 56% of the litter was brought directly into the soil (TI) while 44% was directly in the streams (VI), while in the forest, the percentages of TI and VI were 63% and 37%. From litterfall to the soil in the managed cabruca, 66% of the litter input to streams was from the lateral contribution. This contribution corresponded to only 16% in abandoned cabruca and 37% in secondary forest. The litter stock at the secondary forest was three times higher than at managed cabruca. Abandoned cabruca has already stocked twice the litter compared to managed cabruca (Fig. 8)

Discussion

Management on regeneration and conservation of Atlantic Rainforest riparian zones

Our results highlight that the abandoned cabruca cocoa AFS (AC) has a higher vertical input of leaves and reproductive parts than secondary forest (SF). The presence of pioneer species could explain this due to the ecological succession process (Sambuichi et al. 2012, Sambuichi and Haridasan 2007, Rolim and Chiarello 2004) and an increased presence liana species (Schnitzer and Bongers 2011). These results were corroborated by spatial and temporal patterns of litter input and stock in abandoned cabruca and got closer to secondary forest behavior instead of managed cabruca cocoa AFS (MC). Therefore, abandoned cabruca or cabruca cocoa with poor anthropic management may present highly favorable conditions for the regeneration of tropical forests (Rolim et al. 2016). These areas can be used as strategic conservation areas for tropical forest remnants in Atlantic Rainforest riparian zones (Scroth et al. 2011, Sambuich et al. 2012, Cassano et al. 2009, Faria et al. 2007).

Our findings demonstrated the similarity in the litter stock capacity between secondary forest and abandoned cabruca reiterates the importance of streams for the metabolization of terrestrial carbon and its consequent contribution to the global carbon cycle (Tiegs et al. 2019, Battin et al. 2009, Stufin et al. 2015). Besides, it demonstrates the positive effect of SAF cacao cabruca on the carbon stock, mainly due to the high litter input and its potential to mitigate CO_2 (Costa et al. 2018, Gama- Rodrigues et al. 2010, Sambuichi et al. 2012). The effect of management in managed cabruca for a high contribution of the reproductive fraction may be resultant from exotic species (e.g., *Artocarpus heterophyllus, Spondias mombin,* and particularly in this study *Clitoria fairchildiana,)* used in providing shade for cacao trees (Sambuichi et al. 2012, Sambuichi and Haridasan 2007). However, how those anthropic alterations may preserve the plant community structure, the ecosystem functioning was little changed (Rezende et al. 2017a). Therefore, cabruca cocoa AFS may be an important strategy for conserving riparian zones on the landscape compared to other anthropic land uses.

Finally, a high and similar temporal variation on litter input and stock by species phenology in secondary forest and abandoned cabruca also corroborates the poor management of cabruca cocoa AFS with an important conservation strategy by Atlantic Rainforest riparian zones. On the other hand, litter input and stock on managed cabruca showed low temporal variation due to the most intensive anthropic management effect. The low temporal variation on managed cabruca could explain the perennial biology of cocoa with the release of new leaves at least three times a year (Almeida and Valle 2007, Mello and Gross 2013). The most intensive anthropic management effect may change the plant riparian communities structure affecting the ecosystem functioning over time (P. Bambi et al., unpublished manuscript, Ferreira et al. 2018, Delong and Brusven 1994). Anthropic management may also increase the temporal variation on reproductive material and leaf of terrestrial input.

In general, the dynamic litter changes are primarily caused by the absence of a natural riparian zone traditionally replaced by the cultivation system itself when establishing cocoa plantations on streams banks (Piasentin et al. 2014). The riparian zones with natural vegetation are essential for the structural and functional integrity of streams (Ferreira et al. 2018). Moreover, the results highlight that the tree configuration of cabruca had ecological implications for the functioning of AFSs streams on the amount of litter by input and stock. Other consequences may consider changes in litter quality, nutrient cycling, and community structure at the stream.

Spatial and Annual patterns on riparian litter inputs and stream benthic stock

Although we hope that both cabruca areas would be more productive in biomass deposition (Fontes et al. 2014, Dawoe et al. 2010) than the secondary forest, the abandoned cabruca was the most productive area with higher vertical litter input compared to other areas. High productivity in abandoned cabruca may be explained by riparian vegetation phytophysiognomy (Gonçalves et al. 2014, Rezende et al. 2017a) and successional stage by plant community recovery (Sambuichi et al. 2007, Rolim et al. 2016). High productivity in abandoned cabruca may increase the carbon

stock in soil compared to other areas (Gama-Rodrigues et al. 2010, Costa et al. 2018) and the rapid dynamics of nutrient cycling (Nair et al. 1999).
However, abandoned cabruca exhibited a similar pattern to the secondary forest in terms of balance with low total litter input and high retention capacity compared to managed cabruca by intensive management (Rolim et al. 2016). The intensive management may promote a plant species loss in cabruca (Piasentin et al. 2014, Sambuichi et al. 2012, Rolim and Chiarello 2004) due to the replacement of native shade tree species with high commercial value (Cassano et al. 2009, Piasentin et al. 2014). On the other hand, vertical input (VI) was twice as high in managed cabruca and abandoned cabruca compared to the secondary forest and other tropical areas under antrophic uses like riparian forest logging (P. Bambi et al., unpublished manuscript, Delong and Brusven 1994). Usually, the riparian vegetation near the stream is preserved (Ferreira et al. 2018). An increase of light availability through adjacent deforestation may also increase the plant productivity of vertical input (Rezende et al. 2017a). High VI increases the stream productivity and the supply of litter to the consumer community (P. Bambi et al., unpublished manuscript).
Vertical input (VI) has shown variations in leaves productivity in secondary forest and abandoned cabruca with higher inputs in rainy periods (November/2018 and February/2019), while managed cabruca presented low seasonality. Terrestrial input (TI) has shown a sinusoidal pattern in leaves productivity over time in secondary forest and managed cabruca, with higher inputs observed from September/2018 to March/2019, with fewer rainy months. Periods with rainfall concentration and intensity may represent a mechanism that explains the annual variations on the studied system (Lemes da Silva et al. 2017, Wantzen et al. 2008), despite the low seasonality of our areas (Martini et al. 2007). High rainfalls intensity also increase the leaves and branches input (Afonso et al. 2000, França et al 2009, Rezende et al. 2017a) by mechanical removal (Rezende et al. 2016, Gonçalves Júnior et al. 2014).
On the other hand, in managed cabruca, the seasonality was markedly represented for reproductive parts in vertical (VI) and terrestrial (TI) inputs. Vertical input shows the high peak in August/2018, February, and June/2019 in managed cabruca and terrestrial input higher peaks in September/2018. These peaks in managed cabruca may be justified by management and phenology of the shade species used in cocoa cultivation (Rolim et al. 2017, Piasentin et al. 2014, Sambuich et al. 2012). Consequently, high input of flowers and fruits in the tropical

streams may imply an acceleration in the decomposition process due to high nutritional quality and a possible increase in decomposers community (Rezende et al. 2019).

An increase in lateral input (LI) in managed cabruca could also be due to the cultivation management, including mowing and soil cleaning (Sambuichi et al. 2012, Mello and Gross 2013). The soil cleaning may facilitate leaching and transport from detritus to stream through runoff (Wantzen et al. 2008, Afonso et al. 2010). The high slope at the morphology of stream margins of managed cabruca also increases the LI (Lisboa et al. 2015, Wantzen et al. 2008). On the other hand, the high presence of root biomass and low slope at the morphology of stream margins in secondary forest and abandoned cabruca may increase the litter retention in the soil of riparian zones and minimize the transport to stream (Tank et al. 2010). In this case, cocoa's intensive management may change the stream ecosystem functioning by an increase in LI.

Lateral input shows annual patterns on leaves productivity in managed cabruca, with a peak from January to March. In Atlantic Rainforest, the beginning of summer (the period of most significant rain) tends to increase input (Tonin et al. 2017) due to runoff increase (Wantzen et al. 2008, Lisboa et al. 2015).

Despite the highest LI on managed cabruca, the total benthic stock (BS) was higher in the secondary forest than abandoned cabruca and three times higher than managed cabruca. The benthic stock reflects the ecosystem functioning, relating retention, transport, breathing, and the consequent stability in the ecosystem's energy balance (Elosegi and Pozo 2005, Tank et al. 2010). High BS in secondary forest suggests that the stock does not vary only according to input, because although the stream of managed AFS had a higher litter input, it did not have a high amount of stored litter (Bambi et al. 2016, Lisboa et al. 2015, França et al. 2009). Also, BS accumulation may be related to low decomposition coefficients and downstream transport (Gonçalves Júnior et al. 2014). The high amount of miscellaneous in the secondary forest stream represents organic matter's processing in the system itself. In small order streams, litter retention in the system favors processing in smaller fractions in the headwater streams instead of litter being transported downstream in the form of coarse particles (Bilby and Linkes, 1980).

On the other hand, the predominance of the cacao leaf in BS of cabruca cocoa AFS vegetation tends to be the potential energy source for the food base of the aquatic ecosystems of these areas. Previous studies have shown that the low litter decomposition of the soil in a cocoa system was related to a high concentration of lignin and cellulose in the cocoa leaves (Dawoe et al. 2010).

This condition can also be especially true for the decomposition of litter in aquatic ecosystems. Other studies report that higher concentrations of lignin and cellulose increase the decomposition time of litter stored in streams (Zhang et al. 2018, Lemes da Silva et al. 2017, Tank et al. 2010). Thus, changes in the litter chemistry influence colonization by aquatic invertebrates and micro-organisms (Rezende et al. 2017b), and consequently, affect the functioning of aquatic ecosystems (Ferreira et al. 2018). Leaves in BS show annual patterns on secondary forest (peak in April) and abandoned cabruca (lowest peak in November and the highest peak in February), and miscellaneous in secondary forest. Tonin et al. (2017) present a bimodal tendency to litter stock with a peak in summer or winter, a negative relationship between precipitation and stock, and a positive relationship between supply and stock). In the managed cabruca, the high contribution of the material reproductive system favored the high stock value of this area. At the same time, this fraction was not registered in the secondary forest and abandoned cabruca.

Conclusions

Our results point that despite the secondary forest and AFS showed similarities in terms of productivity, the litterfall to stream in AFS (abandoned and managed) was higher than the forest. However, only the stream of managed cabruca received a higher lateral input. On the order hand, a higher stock of litter occurred in the forest stream, followed by the abandoned and managed AFS. Although the management can influence the vegetation cover differences, some ecological processes such as the litter dynamics can be maintained in cabruca cocoa AFS. The high similarity of the secondary forest with the abandoned cabruca in terms of input and stock litter demonstrated the potential of these areas to provide favorable conditions for the restoration of ecological processes such as litter dynamics.

Although cabruca cocoa AFS is not a substitute for natural forests, these systems' structural complexity is more desirable from conservation than simplified farming systems or devoid of vegetation cover (Scroth et al., 2011). Indeed, the litter dynamics could present more marked differences if pastures or more intensified agricultural uses replaced the areas covered by cabruca cocoa AFS. These environmental changes could have effects on aquatic biota and ecosystem processes, compromising the ability of rivers to provide ecosystem services (Ferreira et al. 2018) Thus, the importance of cabruca cocoa AFS contribution to the local landscape of southern Bahia, Brazil, is emphasized, which play a significant role in the conservation of regional biodiversity (Faria et al. 2006, Cassano et al. 2009, Sambuichi et al. 2012). However, future investigations on the concentration of nutrients are necessary to elucidate the nutritional quality of this litter better and if it varies depending on the composition and structure of vegetation in these areas. Studies also assess whether the breakdown litter process and nutrient cycling in streams are affected by this agrosystem.

Acknowledgements

We are grateful to Mr. Hermann Rehem, owner of Nova Harmonia farm for granting us the license to collect data on his farm. We appreciate the support and partnership of the Aquariparia research group at the Universidade de Brasilia - UnB.

References

Afonso, A. A. O., Henry, R., and Rodella, R. C. S. M. 2000. Allochthonous matter input in two different stretches of a headstream (Itatinga, São Paulo, Brazil). *Brazilian Archives of Biology and Technology* 43: 335-43.

Almeida, A. A., and Valle, R. R. 2007. Ecophysiology of the cacao tree. *Brazilian Journal of Plant Physiology* 19: 425-448.

Argôlo, L. M. H. 2009. Avaliação de genótipos de *Heliconia* spp. sob cultivo a pleno sol e cabruca Master's thesis. Universidade Estadual de Santa Cruz,

Bambi, P., De Souza Rezende, R., Feio, M. J., Leite, G. F. M., Alvin, E., Quintão, J. M. B., Araújo, F., and Gonçalves Júnior, J. F. 2016. Temporal and spatial patterns in inputs and stock of organic matter in savannah streams of central Brazil. *Ecosystems* 20: 757-768.

Bambi, P., Tonin, A. M., Rezende, R. S., Vieira, F.C., Miranda, F.G.G. Boyero, L. Gonçalves Junior, J.F. 2020. Riparian forest logging increase plant litter and inputs to stream. (in press).

Barreto, P.A., Gama-Rodrigues, E.F., Gama-Rodrigues, A.C., Fontes, A.G., Polidoro, J.C., Moço, M.K.S., Machado, R.C. and Baligar, V.C., 2011. Distribution of oxidizable organic C fractions in soils under cacao agroforestry systems in Southern Bahia, Brazil. *Agroforestry systems* 81::213-220. DOI: 10.1007/s10457-010-9300-4

Battin, T.J., Kaplan, L.A., Findlay, S., Hopkinson, C.S., Marti, E., Packman, A.I., Newbold, J.D. and Sabater, F., 2008. Biophysical controls on organic carbon fluxes in fluvial networks. *Nature geoscience*, 1(2):95-100.

Bawa, K.S. et al. Tropical ecosystems into the 21st century. Science.(2004) 306: 227-228.

Beer, J., Muschler, R., Somarriba, E., Kass, D. 1998. Shade management in coffee and cacao plantations. *Agroforestry Systems* 38: 139-164.

Boyero, L., Pearson, R.G., Gessner, M.O., Barmuta, L.A., Ferreira, V., Graça, M.A., Dudgeon, D., Canale, G.R., Peres, C.A., Guidorizzi, C.E., Gatto, C.A.F. and Kierulff, M.C.M., 2016. Pervasive defaunation of forest remnants in a tropical biodiversity hotspot. *PloS one* 7(8): 41671.

Canty, A. J., and Ripley, B. 2016. Boot: Bootstrap R (S-Plus) functions.

Cassano, C. R., Schroth, G., Faria, D., Delabie, J. H. C., and Bede, L. 2009. Landscape and farm scale management to enhance biodiversity conservation in the cocoa producing region of southern Bahia, Brazil. *Biodiversity Conservation* 18: 577-603. DOI: 10.1007/s10531-008-9526-x

Costa, E. N. D., De Souza, M. F. L., Marrocos, P. C. L., Lobão, D., and Silva, D. M. L. 2018. Soil organic matter and CO2 fluxes in small tropical watersheds under forest and cacao agroforestry. *PloS one* 13 (7). DOI 10.1371/journal.pone.0200550.

Costa, E. N. D., Souza, J. C., Pereira, M. A., Souza, W. F.L., Souza, M. F. L., and Silva, D. M. L. 2017. Influence of hydrological pathways on dissolved organic carbon fluxes in tropical streams. *Ecology and Evolution* 1: 1-12.

Davison, A. C., and Hinkley, D. V. 1997. *Bootstrap methods and their application.* Cambridge University Press, Cambridge, England.

Dawoe, E. K.; Isaac, M. E.; Quashie, A. S. J. 2010. Litterfall and litternutrient dynamics under cocoa ecosystems in lowland humid Ghana. *Plant and Soil* 330: 55-64.

Deheuvels, O., Rousseau, G. X., Quiroga, G. S., Franco, M. D., Cerda, R., Mendoza, S. J. V., and Somarriba, E. 2014. Biodiversity is affected by changes in management intensity of cocoa-based agroforests. *Agroforestry Systems* 88: 1081-1099.

Delong, M. D. and Brusven, M. A. 1994. Allochthonous input of organic matter from different riparian habitat of an agricultural impacted stream. *Environmental Management.* 18: 59-71.

Efron, B., and Tibshirani, R. 1993. *An introduction to the bootstrap*. Chapman & Hall, New York, USA.

Elosegi, A., and Pozo, J. 2005. Litter input. Pages 3-11 *in* Graça, M. A. S., Bärlocher, F., and Gessner, M. O., editors. *Methods to study litter decomposition: a practical guide*. Springer, New York, USA.

Faria, D., Laps, R. R., Baumgarten, J., and Cetra, M. 2007. Bat and bird assemblages from forests and shade cacao plantations in two contrasting landscapes in the Atlantic Forest of southern Bahia, Brazil. *Biodiversity and Conservation* 15: 587-612.

Ferreira, V., Boyero, L., Calvo, C., et al. 2018. A Global assessment of the effects of eucalyptus plantations on stream ecosystem functioning. *Ecosystems* 22: 629-642.

Fontes, A. G., Gama-Rodrigues, A. C., Gama-Rodrigues, E. F., Sales, M. V. S., Costa, M. G., and Machado, R. C. R. 2014. Nutrient stocks in litterfall and litter in cocoa agroforests in Brazil. *Plant and Soil* 383: 313-335.

França, J. S., Gregório, R. S., D'Arc De Paula, J., Gonçalves Júnior, J. F., Ferreira, F. A., and Callisto, M. 2009. Composition and dynamics of allochthonous organic matter inputs and benthic stock in a Brazilian stream. *Marine and Freshwater Research* 60: 990-998.

Gama-Rodrigues, E. F., Nair, P. K. R., Nair, V. D., Gama-Rodrigues, A. C., Baligar, V. C., and Machado, R. C. R.. 2010. Carbon storage in soil size fractions under two cacao agroforestry systems in Bahia, Brazil. *Environmental Management* 45: 274-283.

Gonçalves Júnior, J. F., Rezende, S., Gregorio, R. S., and Valentin, G. C. 2014. Relationship between dynamics of litterfall and riparian plant species in a tropical stream. *Limnologica* 44: 40-8.

Gregory, S. V., Swanson, F. J., Mckee, W. A., Kenneth, W., Swanson, J., and Cummins, K. W. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. *BioScience* 41: 540-551.

Johns, N. D. 1999. Conservation in Brazil's chocolate forest: the unlikely persistence of the traditional cocoa agroecosystem. *Environmental Management* 23: 31-47.

Johnson, R. W. 2001. An introduction to the Bootstrap. *Teaching Statistics* 23: 49-54. https://doi.org/10.1111/1467-9639.00050

Lemes da Silva, A. L., Lisboa, L. K., Siegloch, A. E., Petrucio, M. M., and Gonçalves Júnior, J. F. 2017. Connecting the litterfall temporal dynamics and processing of coarse particulate organic matter in a tropical stream. *Marine and Freshwater Research* 68: 1260-1271.

Lisboa, L. K., Da Silva, A. L. L., Siegloch, A. E., Gonçalves Júnior, J. F., and Petrucio, M. M. 2015. Temporal dynamics of allochthonous coarse particulate organic matter in a subtropical Atlantic rainforest Brazilian stream. *Marine and Freshwater Research* 66: 1-7.

Martin, D.A., Osen, K., Grass, I., Hölscher, D., Tscharntke, T., Wurz, A. and Kreft, H., 2020. Land-use history determines ecosystem services and conservation value in tropical agroforestry. *Conservation Letters*, 13(5): 12740.

Martini, A. M. Z., Fiaschi, P., Amorim, A. M., and Paixão, J. L. 2007. A hot-point within a hot-spot: a high diversity site in Brazil's Atlantic Forest. *Biodiversity and Conservation* 16: 3111-31288.

Mello, D. L. N., and Gross, E. 2013. *Guia de manejo do agroecossistema cacau cabruca*. Editora Instituto Cabruca, Ilhéus, Brazil.

Naiman, R. J., Décamps, H., and Mcclain, M. E. 2005. *Riparian ecology, conservation, and management of stream side communities.* Elsevier Academic Press, Burlington, USA.

Nair, P. K. R., Buresh R. J., Mugendi D. N., and Latt C. R. 1999. Nutrient cycling in tropical agroforestry systems: Myths and science. Pages 1-31 *in* Buck, L. E, Lassoie, J. P., and Fernandes, E. C. M., editors. *Agroforestry in sustainable agricultural systems: Advances in agroecology.* CRC Press, Boca Raton, EUA.

Piasentin, F. B., Saito, C. H., and Sambuichi, R. H. R. 2014. Local tree preferences in the cacao-cabruca system in the southeast of Bahia, Brazil. *Ambiente & Sociedade* 17: 55-78.

Pozo, J., Elosegi, A., Díez, J., and Molinero, J. 2009. Dinámica y relevancia de la materia organia. Pages 141-168 *in* Elosegi, A., and Sabater, S. *Conceptos y técnicas en ecología fluvial.* Fundación BBVA, País Vasco, Espanha.

Rezende, C. L., Scarano, F. R., Assad, E. D., Joly, C. A., Metzger, J. P., Strassburg, B. B. N., Tabarelli, M., Fonseca, R. A., and Mittermeier, R. A. 2018. From hotspot to hopespot: an opportunity for the Brazilian Atlantic Forest. *Perspectives in Ecology and Conservation* 16: 208-214.

Rezende, R. S., Graça, M. A. S., Santos, A. M., Medeiros, A. O., Santos, P. F., Nunes, Y. R. F., and Gonçalves Júnior, J. F. 2016. Organic matter dynamics in a tropical gallery forest in a grassland landscape. *Biotropica* 48: 301-310.

Rezende, R. S., Medeiros, A. O., Gonçalves Júnior, J. F., Feio, M. J., Gusmão, E. P., de Andrade Gomes, V. Â., Calor, A. and Almeida, J. D. S. D. 2019. Patterns of litter inputs, hyphomycetes and invertebrates in a Brazilian savanna stream: a process of degradative succession. *Journal of Tropical Ecology* 35: 297-307.

Rezende, R. S., Sales, M. A., Hurbath, F., Roque, N., Gonçalves Júnior, J. F., and Medeiros, A. O. 2017a. Effect of plant richness on the dynamics of coarse particulate organic matter in a Brazilian Savannah stream. *Limnologica* 63: 57-64.

Rezende, R. S., Santos, A. M., Medeiros, A. O., and Gonçalves Júnior, J. F. 2017b. Temporal leaf litter breakdown in a tropical riparian forest with an open canopy. *Limnetica* 36: 445-459.

Rolim S. G., and Chiarello A. G. 2004. Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. *Biodiversity and Conservation* 13: 2679-2694.

Rolim, S. G., Sambuichi, R. H. R., Schroth, G., Nascimento, M. T., and Gomes, J. M. L. 2017. Recovery of forest and phylogenetic structure in abandoned cocoa agroforestry in the Atlantic Forest of Brazil. *Environmental Management* 59: 410-418.

Sambuichi, R. H. R. 2002. Fitossociologia e diversidade de espécies arbóreas em cabruca (Mata Atlântica raleada sobre plantação de cacau) na região sul da Bahia, Brasil. *Acta Botanica Brasiliensis* 16: 89-101.

Sambuichi, R. H. R., and Haridasan, M. 2007. Recovery of species richness and conservation of native Atlantic Forest trees in the cacao plantations of southern Bahia in Brazil. *Biodiversity and Conservation* 16: 3681-3701.

Sambuichi, R. H., Vidal, D. B., Piasentin, F. B., Jardim, J. G., Viana, T. G., Menezes, A. A., and Baligar, V. C. 2012. Cabruca agroforests in southern Bahia, Brazil: tree component, management practices, and tree species conservation. *Biodiversity and Conservation* 21: 1055-1077.

Santos, E. R. M., Araujo, Q. R., Faria Filho, A. F., Vieira, R. B., Assunção Neto, J. F., and Cabral, L. C. C. 2016. Aspectos geoambientais dos recursos hídricos das propriedades rurais do Projeto Barro Preto, Bahia, Brasil. Pages 121-138 *in* Bruck, M. M. E., Lorandi, R., editors. *Métodos e técnicas de pesquisa em bacias hidrográficas*. Editus, Ilhéus, Brazil.

Schnitzer, S. A., and Bongers, F. 2011. Increasing liana abundance and biomass in tropical forests: emerging patterns and putative mechanisms. *Ecology Letters* 14: 397-406.

Schroth, G., Faria, D., Araujo, M., Bede, L., Van Bael, S. A., Cassano, C. R., Oliveira, L. C., and Delabie, J. H. C. 2011. Conservation in tropical landscape mosaics: the case of the cacao landscape of southern Bahia, Brazil. *Biodiversity and Conservation* 20: 1635-1654.

Seena, S., Carvalho, F., Cássio, F., and Pascoal, C. 2017. Does the developmental stage and composition of riparian forest stand affect ecosystem functioning in streams? *Science of the Total Environment* 609: 1500-1511.

Souza, J. C. S., Pereira, M. A., Costa, E. N. D., and Silva, D. M. L. 2017. Nitrogen dynamics in soil solution under different land uses: Atlantic forest and cacao–cabruca system. *Agroforestry Systems* 92: 425-435.

Sutfin, N. A., Ellen E. W., Kathleen, A. D. 2015. Banking carbon: a review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems. 2019. *Earth Surface Processes and Landforms* 41: 38-60.

Tank, J. L., Rosi-Marshall, E. J., Griffiths, N. A., Entrekin, S. A., and Stephen, M. L. 2010. A review of allochthonous organic matter dynamics and metabolism in streams. *Journal of the North American Benthological Society* 29: 118-146.

Taubert, F., Fischer, R., Groeneveld, J., Lehmann, S., Müller, M.S., Rödig, E., Wiegand, T. and Huth, A., 2018. Global patterns of tropical forest fragmentation. *Nature*, 554(7693): 519-522.

Tonin, A. M., Boyero, L., and Bambi, P., Pearson, R. G., Correa-Araneda, F., and Gonçalves Júnior, J. F. 2019. High within-stream replication is needed to predict litter fluxes in wet–dry tropical streams. *Freshwater Biology* 65: 688-697. DOI:10.1111/fwb.13459

Tonin, A. M., Gonçalves Júnior, J. F., Bambi, P., et al. 2017. Plant litter dynamics in the forest-stream interface: precipitation is a major control across tropical biomes. *Scientific Reports* 7: 10799. DOI: 10.1038/s41598-017-10576-8

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.

Wantzen, K. M., Yule, C. M., Mattooko, J. M., and Pringle, C. M. 2008. Organic matter processing in tropical streams. Pages 43-64 *in* Dudgeon, D., editor. *Tropical stream ecology.* Elsevier, Amsterdam, Netherlands.

Webster, J., Covich, A., Tank, J., and Crockett, T. 1994. Retention of coarse organic particles in streams in the southern Appalachian Mountains. *Journal of the North American Benthological Society* 13: 140-150.

Wild, R., Gücker, B. and Brauns, M., 2019. Agricultural land use alters temporal dynamics and the composition of organic matter in temperate headwater streams. *Freshwater Science*, 38(3):.566-581.

Winbourne, J. B., Feng, A., Reynolds, L., Piotto, D., Hastings, M. G., and Porder, S. 2018. Nitrogen cycling during secondary succession in Atlantic Forest of Bahia, Brazil. *Scientific Reports* 8: 1-9.

Wood, S. N. 2017. *Generalized Additive Models: An Introduction with R.* Chapman & Hall/CRC, Boca Raton, EUA.

Wright, S.J., 2005. Tropical forests in a changing environment. *Trends in ecology & evolution*, 20(10):.553-560.

Zuur, A. F., Ieno, E. N., Walker, N., Saveliev, A. A., and Smith, G. M. 2009. *Mixed Effects Models and Extensions in Ecology with R.* Springer-Verlag, New York, EUA.

Figure 1

Location of the study area

(SF) Secondary Forest, (MC) Managed cabruca and (AC) Abandoned cabruca

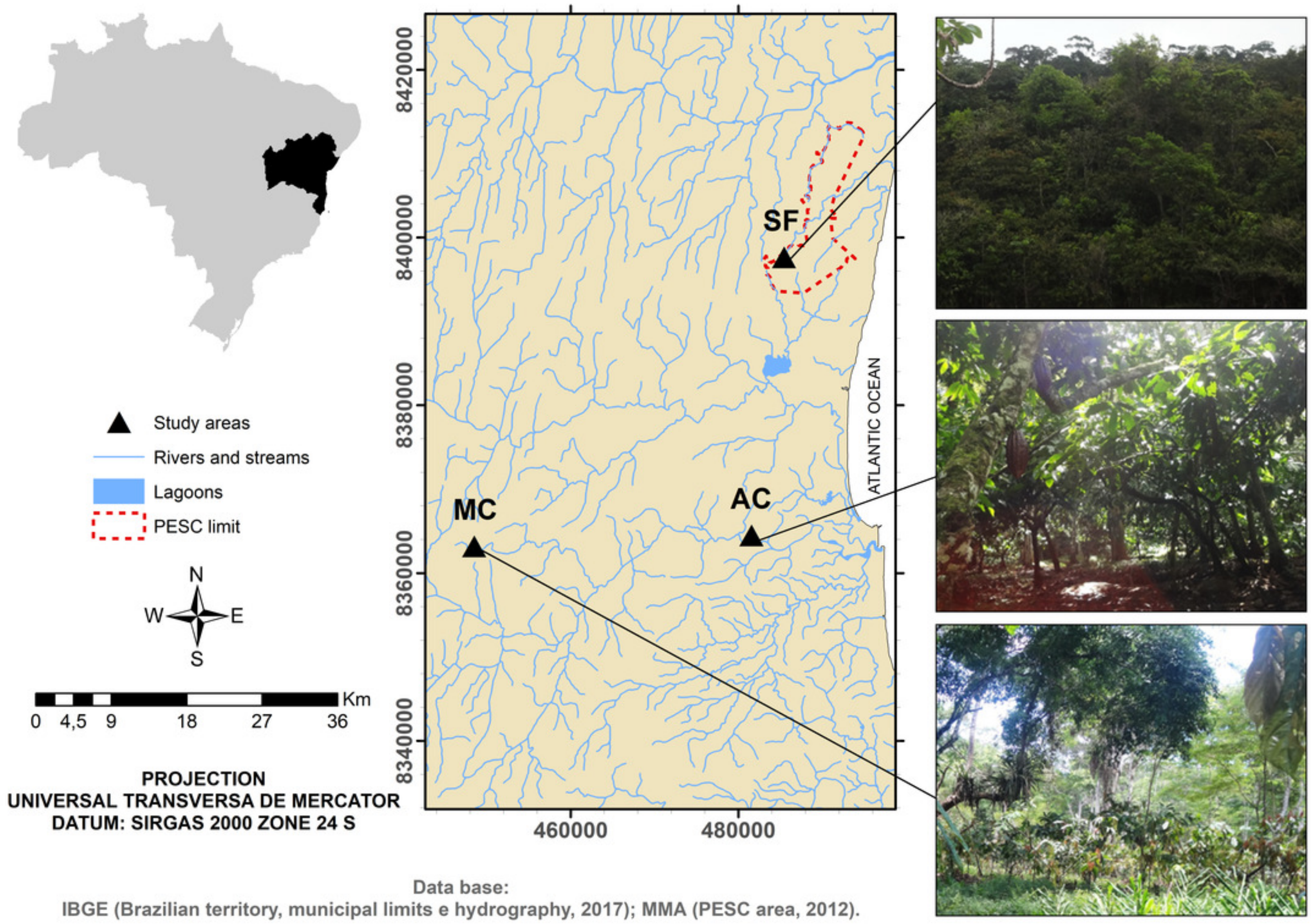

Figure 2

Daily precipitation in study areas

(SF) Secondary Forest, (MC) Managed cabruca and (AC) Abandoned cabruca

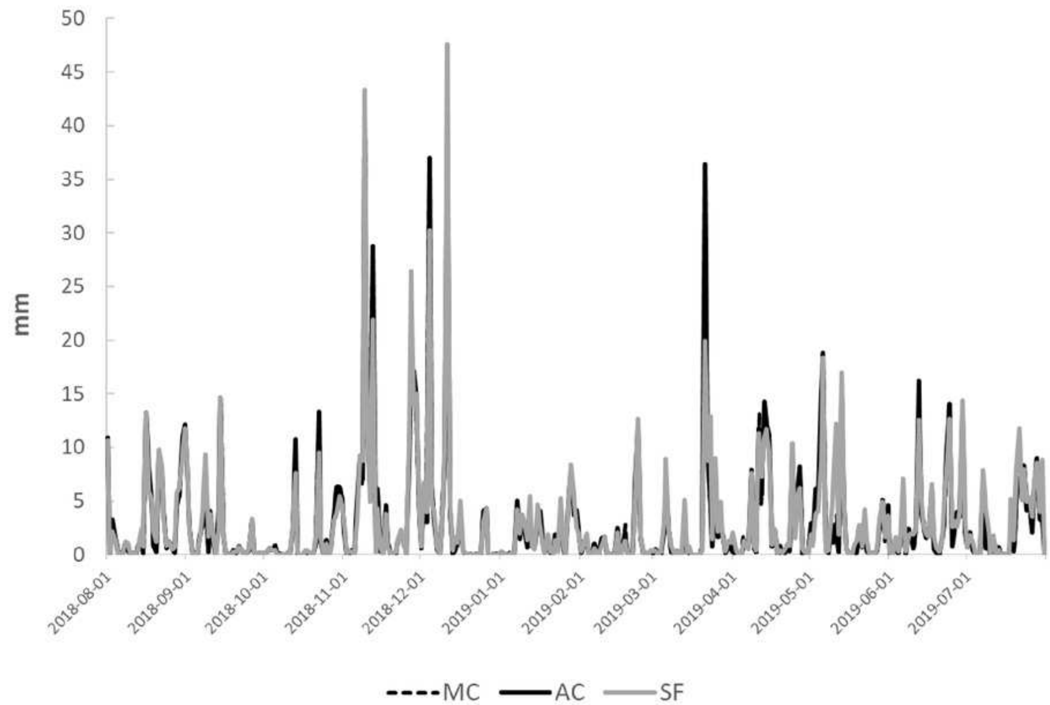

Figure 2. Daily rainfall of the small watersheds. Secondary Forest – SF, Managed cabruca – MC and Abandoned cabruca - AC).

Figure 3

Spatial variation of litter inputs and stream benthic stock in secondary forest, abandoned cabruca and managed cabruca.

Black circles represent the variations mean of litterfall (a), terrestrial (b) and lateral (c) inputs, as also litter stock (d) among litter fractions (leaves, branch, reproductive part and miscellaneous). The variation (circles are means) and confidence intervals where upper and lower limits of 95% was performed by nonparametric bootstrapped analysis. Different numbers indicate significant difference among means whether lines do not overlap (different means among areas).

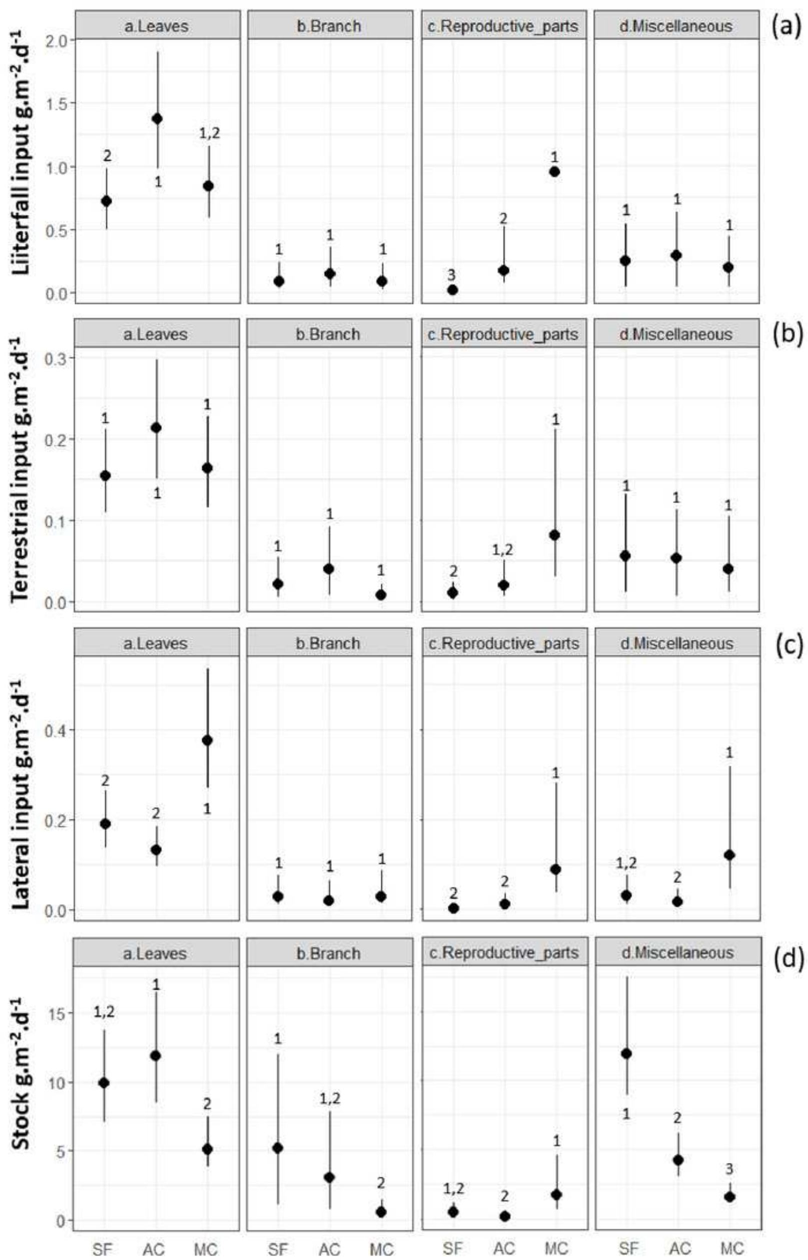

Figure 3. Spatial variation of litter inputs and stream benthic stock in secondary forest (SF), abandoned cabruca (AC) and managed cabruca (MC). Black circles represent the variations mean of litterfall (a), terrestrial (b) and lateral (c) inputs, as also litter stock (d) among litter fractions (leaves, branch, reproductive part and miscellaneous). The variation (circles are means) and confidence intervals where upper and lower limits of 95% was performed by nonparametric bootstrapped analysis. Different numbers indicate significant difference among means whether lines do not overlap (different means among areas).

Figure 4

Seasonality of litterfall input in secondary forest, abandoned cabruca cocoa and managed cabruca.

Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

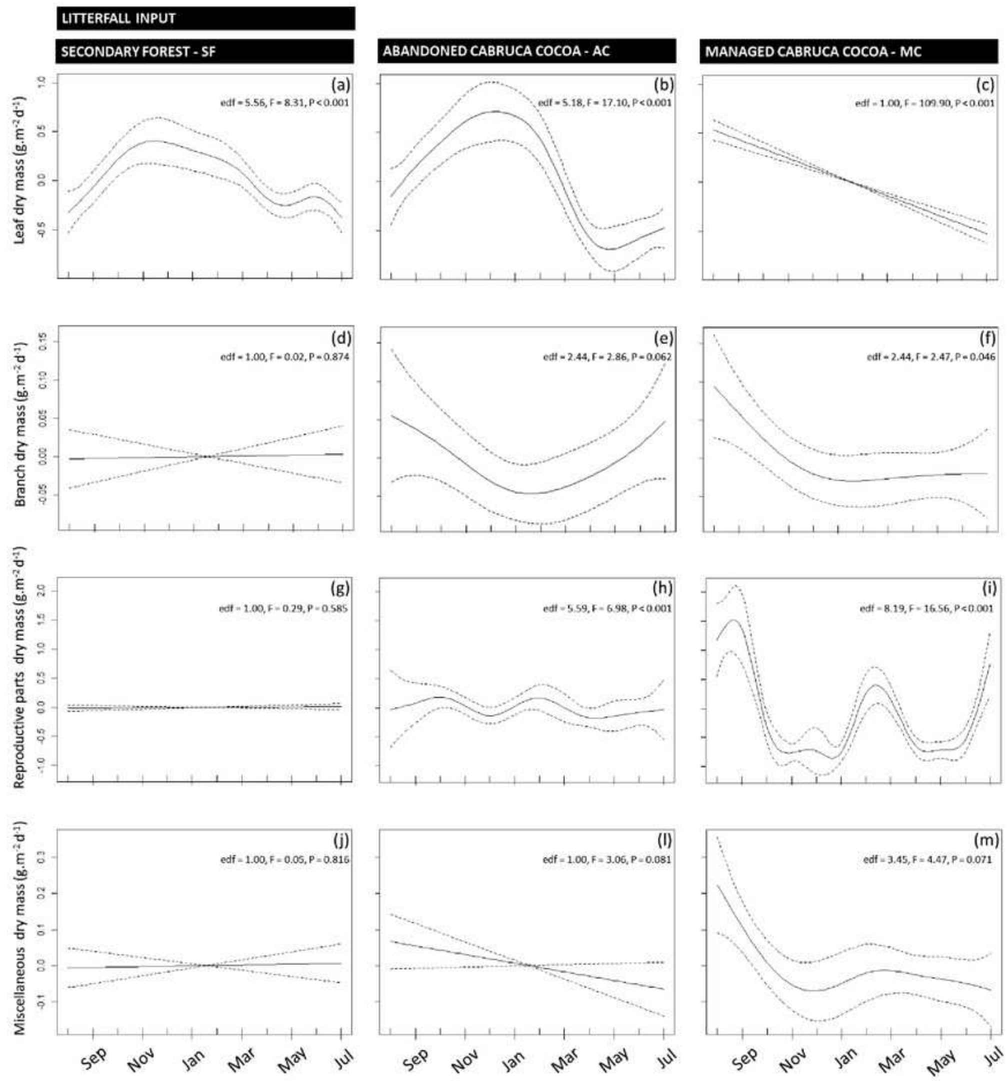

Figure 4. Seasonality of litterfall input at secondary forest, abandoned cabruca cocoa and managed cabruca cocoa areas. Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

Figure 5

Seasonality of terrestrial inputs in secondary forest, abandoned cabruca and managed cabruca

Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

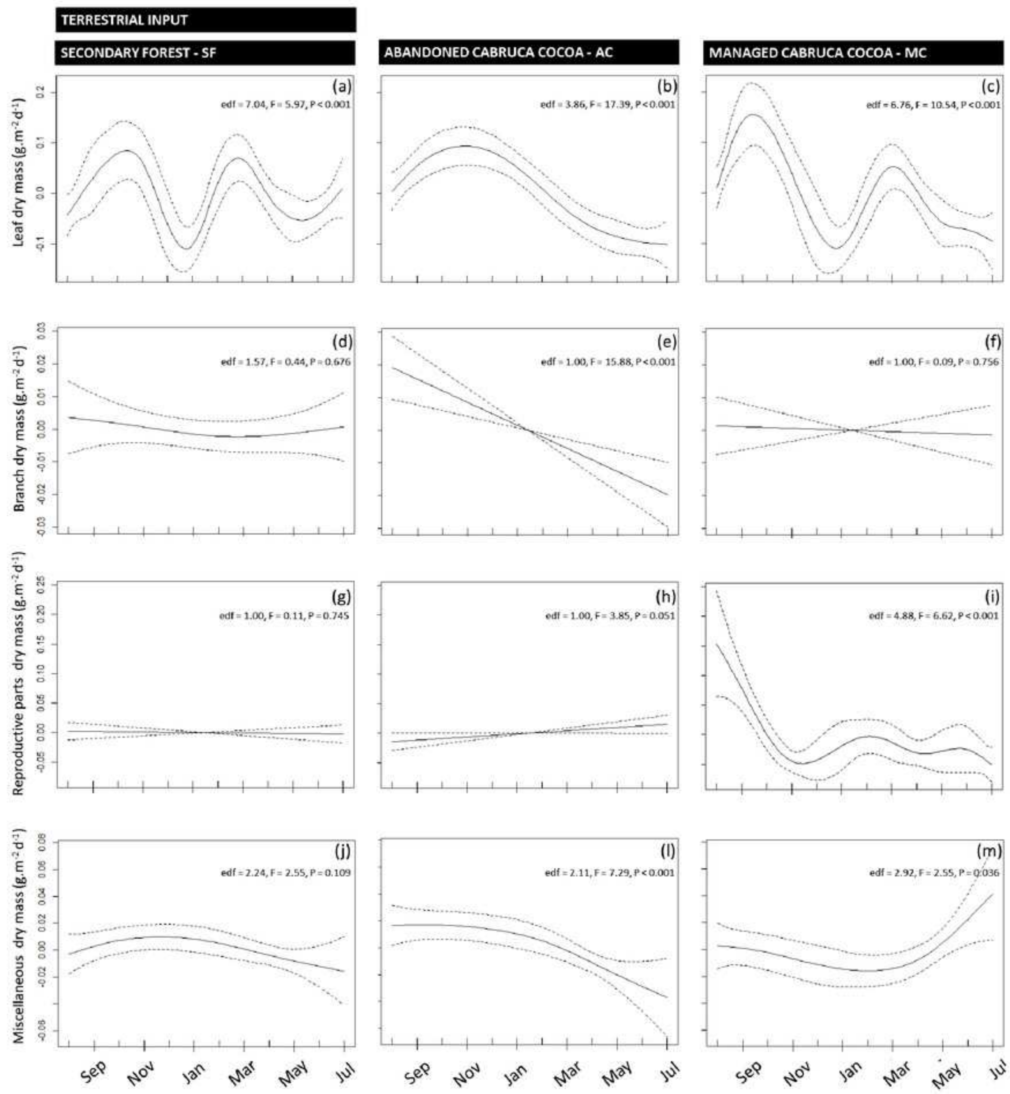

Figure 5. Seasonality of terrestrial inputs in secondary forest, abandoned cabruca cocoa and managed cabruca cocoa areas. Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

Figure 6

Seasonality of lateral input in secondary forest, abandoned cabruca and managed cabruca

Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

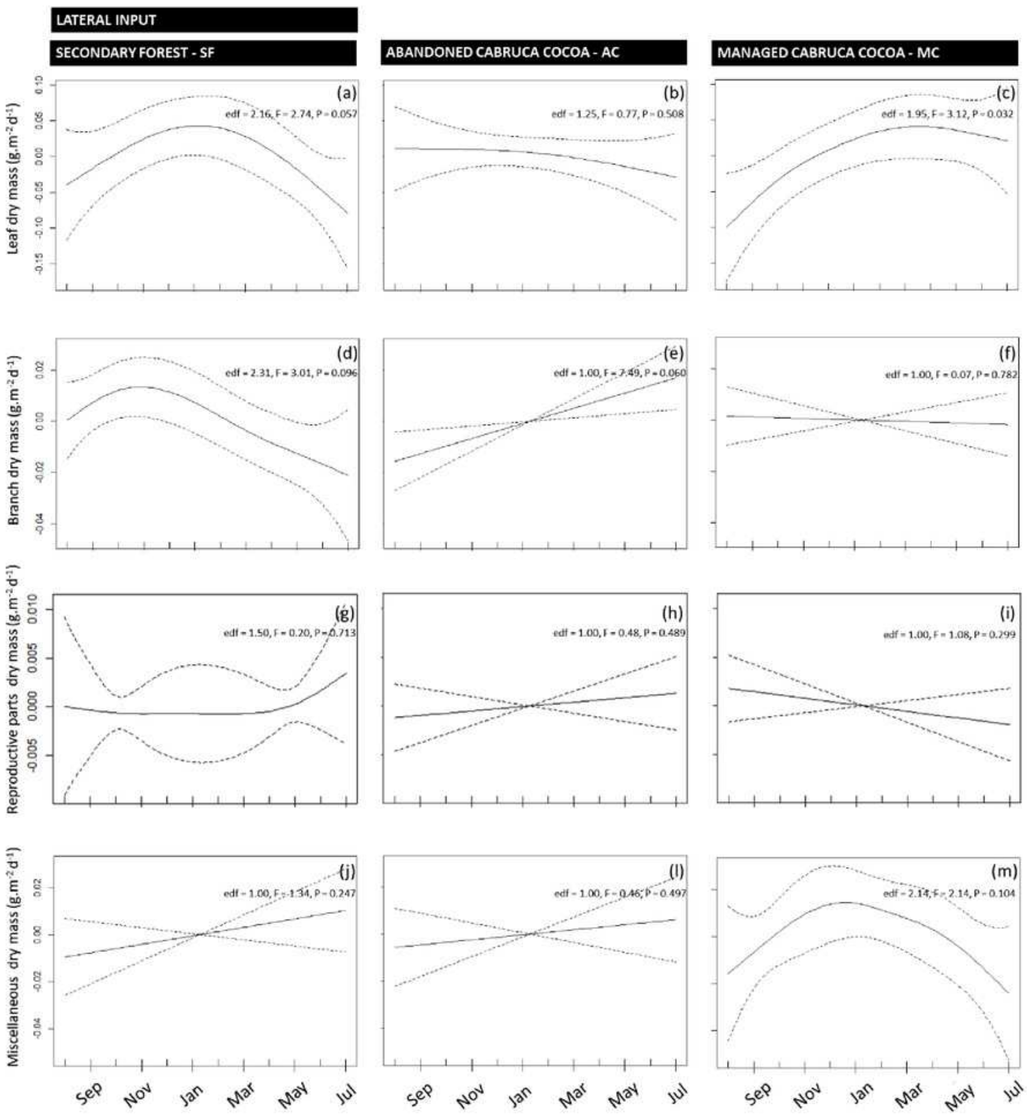

Figure 6. Seasonality of lateral input in secondary forest, abandoned cabruca cocoa and managed cabruca cocoa areas. Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

Figure 7

Seasonality of litter stock in secondary forest, abandoned cabruca and managed cabruca

Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

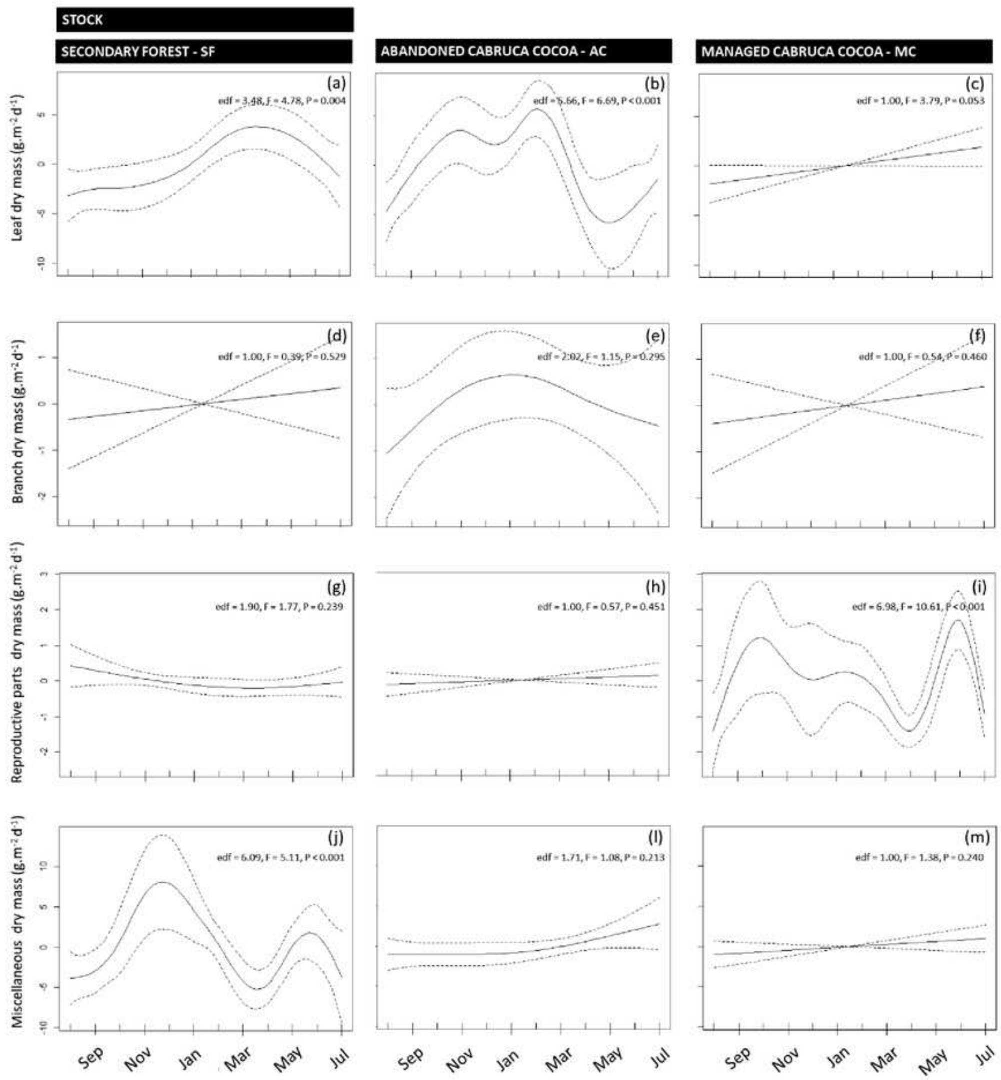

Figure 7. Seasonality of litter stock in secondary forest, abandoned cabruca cocoa and managed cabruca cocoa areas. Leaves (a to c), branch (d to f), reproductive part (g to i) and miscellaneous (j to m). In figure we also observe the F values, P values and the effective degrees of freedom (edf) from GAMM analysis. Continuous lines are the smoothers from GAMM and, upper and lower dotted lines the 95% confidence intervals from each model.

Figure 8

Average litter contribution ($g.m^{-2}$) in terrestrial input (TI), vertical (VI) and lateral input (LI) and in the benthic stock (BS) in riparian zone.

Secondary forest (SF - n = 12), Abandoned cabruca (AC - n = 11) and Managed cabruca (MC - n = 11)

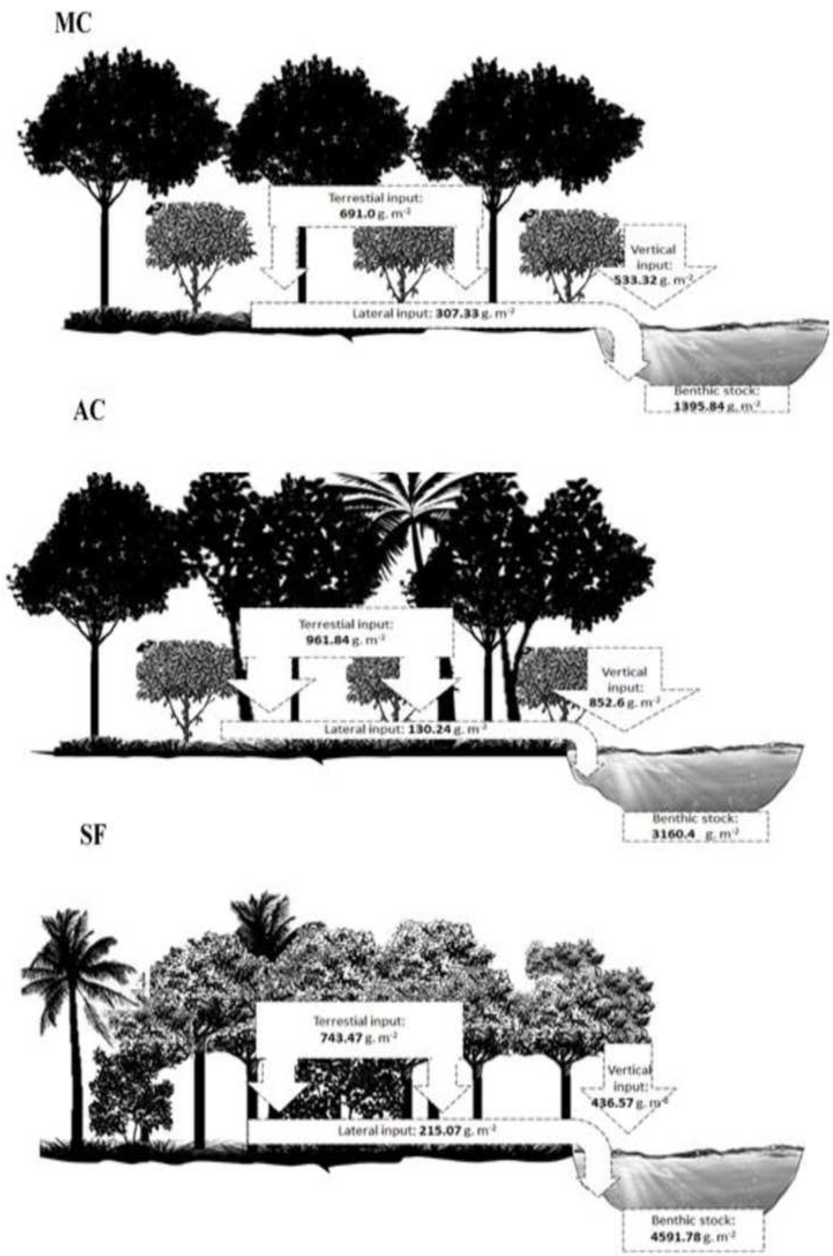

Figure 8. Average litter contribution (g.m^{-2}) in terrestrial input (TI), vertical (VI) and lateral input (LI) and in the benthic stock (BS) in riparian zone. SF - secondary forest (n = 12), AC- abandoned cabruca (n = 11) and MC - managed cabruca (n = 11)