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Litter production and decomposition during succession in Atlantic Tropical Forest, Brazil

Achilles d Avila Chirol, Ana Luiza Coelho Netto

Universidade do Estado do Rio de Janeiro – Departamento de Geografia Física – e-mail: achilleschirol@gmail.com
Universidade do Federal do Rio de Janeiro - GEOHECO/UFRJ – e-mail: ananetto@globo.com

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Resumo

Os movimentos de massa são feições naturais do Ambiente de Mata Atlântica, trazendo diversas transformações na paisagem, tanto do ponto de vista ecológico como hidrológico. O presente trabalho observou como se dá a produção e decomposição da serapilheira em três áreas de deslizamento, levando em conta as características morfológicas de cada uma, que variam em tamanho e forma, sempre as comparando com uma área de floresta secundária tardia. Observou-se que as clareiras de maior porte apresentam condições menos favoráveis a decomposição, tem menor produção de serapilheira e maior propagação de efeito de borda, que pode ser visto a partir da maior produção e tempo de decomposição nas bordas. O efeito de borda pode ser observado também nas características estruturais da vegetação. A sucessão em clareiras é mais complexa que em áreas onde houve queimadas e até mesmo a introdução de pastagem, já que estas contam com condições pretéritas de solo, que não ocorrem nas clareiras, que tem a sua sucessão praticamente ocorrendo no saprolito. Em áreas tropicais isto é particularmente problemático, em função da importância que a dinâmica da decomposição tem nestes ecossistemas. A diversidade de habitats que são criados por estas clareiras pode estar fortemente associada à biodiversidade elevada típica destes ecossistemas, influenciando diretamente na dinâmica e resiliência.
Palavras-chave: Produção de serapilheira; ecologia de Floresta Atlântica, Cicatrizes por movimento de massa

Abstract

Landslides are natural features of the Atlantic rainforest environment, causing various changes to the landscape, both from ecological and hydrological viewpoints. This paper observed how litterfall production and litter decomposition works in three landslide areas, taking into account the morphological characteristics of each, which vary in size and shape, always comparing them to an area of a late secondary forest. It was found that the larger landslides show conditions less favorable to decomposition, have less litterfall and a greater spread of edge effect, that can be seen by higher litter production, higher decomposition time at the edges. The edge effect can also be perceived by the structural characteristics of the vegetation. The succession in landslides scars is more complex than in areas where there were burnings and even the introduction of pastures, since the latter have better soil conditions that do not occur in gaps whose succession practically occurs on saprolite. In tropical areas, this is a particular problem given the importance of decomposition dynamics in these

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ecosystems. The diversity of habitats created by these landslides gaps can be closely associated with the typical high biodiversity of these ecosystems, directly influencing their dynamics and resilience.
Keywords: Litter Production; Atlantic forest ecology; Landslides scar

I. INTRODUCTION

Gaps caused by landslides are natural features of steep forested slopes, namely, those of the Tijuca Massif, originally an area of Atlantic rainforest, as a result of the association between the biogeophysical elements of the environment, such as steep slopes, rainfall and heterogeneous deposits of soil. The direct consequence of these gaps is the disturbance to soil-biota relations and spread of edge effects to the adjacent forest. COELHO NETTO *et al*. (2007) emphasise that these phenomena are part of the evolutionary dynamics of the area, but due to urban spread around the Tijuca Massif, these events increase in scale and recur more often. It was found that more than 85% of the landslides in February 1996 (where in February there was a total rainfall of more than 300 mm) occurred in areas covered by grass or degraded forest, and only 2.8% in areas of conserved forest (CRUZ, 2000). Considering this situation, it is essential to understand how these areas recover from the functional viewpoint of their possible rehabilitation projects.

Litter dynamics is extremely important within the ecosystems (DAWOE *et al*., 2010, HOQUE *et al*., 2015, CHEN *et al*., 2017, LIU *et al*., 2018, FENGA *et al.*, 2019) and, by extension, in the functional rehabilitation of the landslide scars, because it is a major input of nutrients and because of the many hydrological roles acknowledged in literature played by the organic horizon on the forest floor (COELHO NETTO, 1987, LARSEN *et al.*, 1999, BRUINJNZEEL, 2004 and CHIROL *et al*., 2018). As DOUCHAUFOUR (1968) has already pointed out, tropical soils have a low CEC (cationic exchange capacity) and predominant clays 1:1, and most nutrients for vegetation come from decomposition. So decomposition and mineralisation are key processes in understanding these ecosystems (LODGE *et al.*, 1991, SILVER *at al.*, 2014, DALING *et al.*, 2016)

Litter production in the ecosystems varies according to a series of factors, and it is a mistake to attribute the deposition of material to one factor alone (LIU *et al.*, 2019). BRAY *et al.* (1964) and DENEV (1975) stress the altitude and direction of the slopes as important geographic variables in determining and explaining deposition. In general, it may be said that there is a negative correlation between rainfall and litter deposition, although a cause and effect relation between both is not always noticeable. MADGE (1965), KLINGE (1977), OLIVEIRA *et al.* (2000), MONTEZUMA (2005) and BARLOW *et al.* (2007) found higher rates in drier periods of the year

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During decomposition, the organic matter follows a sequence of changes including falling, leaching and immobilisation of nutrients in decomposed litter. In most of the ecosystems, this chain of events is guided by environmental elements, such as, for example, humidity, temperature and quality of the litter produced (OZALP *et al*. 2007 and ZALAMEA *et al*., 2016). PANDEY *et al*. (2007) point out that the relative humidity, maximum temperature, fungi population and actinomycetes are the main control factors for litter decomposition. The initial quality of litter is also very important, due to the concentration of cellulose, hemicellulose and lignin, nitrogen, phosphorus and potassium, which play a leading role in different ecosystems. SWIFT *et al*. (1979) also stress the importance of the physiochemical environment in regulating decomposition. As a result of the poor soils, tropical areas require mechanisms to optimise the use of the nutrients, among which OLIVEIRA *et al.* (2000) mentioned the following for Atlantic rainforest areas: (a) fast decomposition and release of nutrients from the litter; (b) etranslocation of phosphorus before leaf abscission; (c) large litter-related biomass of roots and in the topsoil; (d) efficiency of rainfall removing nutrients from the tree canopy.

The gaps addressed in this study differ from those associated with falling trees because of their varying size and shape, having a more intense edge effect and consequently a more complex succession process. In the light of the above, this paper proposes to analyse the relationship between litter production and decomposition and the biotic and abiotic environment in three different sizes and shapes of landslides scars, trying to figure out the effect of these on the Landscape. To do so, the litterfall production, soil litter, decomposition, vegetation structure and rainfall patterns were analysed.

II. METHODS AND MATERIALS

The sample plan took into consideration a control area and three different landslides (with the same age) divided into four domains: the top slope, middle slope, right edge and left edge, totalling 13 areas. There samples of litter production (3 collectors in each area, in a total of 39 collectors) and soil litter (3 points of samples in each area). The option to collect in the high and middle slope areas, called here domains 1 and 2, respectively, from within the landslides was because they were areas of more complex succession, due to water erosion dynamics, as already identified by GUARIGUATA (1990) and CHIROL *et al* (2018). The edge areas were chosen in order to have an idea of the spread of degenerative effects for the adjacent forest. The sampling period was from January to December 2007. All data was statistically treated, applying ANOVA when the data

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had normal distribution and Kruskall-Wallis when the data distribution was not normal. For Grouping was used the Scheffe test (parametric) and Dunn test (non-parametric).

Rainfall patterns

Rainfall data was collected from the Mayrink Chapel rainfall station belonging to SERLA. From the 2007 daily data monthly totals and the average between 1977 and 2007 were calculated. The daily precipitation was classified in four classes according to intensity, as proposed by FIGUEIRÓ *et al*, 2009: 1 – rainfall of 10 mm or less, with practically no cross-flow; 2 – rainfall of more than 10 mm and less than 50 mm, where the cross flow already occurs; 3 - rainfall of between 50 mm and less than 100 mm, which are heavy and cause surface flow; 4 – rainfall of more than 100 mm, which is an extreme event. This is important to see if there is a link between rainfall intensity and litterfall.

Survey of vegetation structure:

The vegetation structure was examined from plots of 50 m^2 in area (5m x 10m). This plot size was chosen as proposed by DE VUONO (2002) who claims that small plots are recommended for areas under initial succession. Also because of the successional stage of the landslide areas, a criterion was adopted to include PBH (perimeter at breast height) at 1.30m of height and diameter equal to 5 cm or more (DBH = 1.5). The height of each individual was also measured based on the finding of three observers. The DBH (diameter at breast height) was measured from the data using the formula DBH = PBH/π.

Litter production

To assess the litterfall production, square collectors were used 0.5 m each side (total area of 0.25 m^2), with a 2 mm bottom mesh for water to pass through, and around 1 m in height to prevent predation by fauna. Three collectors were placed per structure plot, spaced every 5 metres in the lower area of the plot and the deposited material were collected every 15 days.

The samples were collected every month and later oven-dried at 60^{o}C, until they achieved constant weight. They were then sorted into the component fractions: leaves, branches, reproductive material and waste; the last item consists of unidentified fragmented material. Next, each fraction was weighed on precision

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scales to three decimal places. It was therefore possible to calculate the monthly and annual productivity of the areas in the study.

Soil Litter

This was collected quarterly from a surface of $0.0625m^2$ (0.25m x 0.25m) with three samples per structure plot. The samples were separated in O_1 and O_2, and when also present in fine roots. The height of each layer will be registered at four points corresponding to the mid-point of each side of the collector. The collected material will be stored and oven-dried at a temperature of $60^{O}C$ until it reaches constant weight.

After drying, each component fraction of the inventory will be weighed on precision scales to three decimal places, and then the total inventory will be calculated in kg/ha.

Decomposition rate and renewal time

This was calculated according to the proposal by OLSEN (1963), based on the decomposition constant K, which is calculated using the formula K = P/A, and then the litter renewal rate, whose formula is Tr = 1/K. In this case K is the decomposition coefficient, P the produced litter and A the soil litter.

Study Area

The study areas are situated in the Tijuca Massif in Rio de Janeiro county, covering a total area of $118.7Km^2$ (11,870 ha) considering the continuous contour at the elevation of 40m as external boundary. This is one of the three mountainous physiographic units in the city of Rio de Janeiro (complemented by Pedra Branca and Mendanha massifs) (figure 1). The slopes of this massif are covered by vegetation, mostly the result of an advanced natural regeneration process, not excluding the influence of replanting begun in the 19^{th} century of native and exotic species to rehabilitate this landscape.

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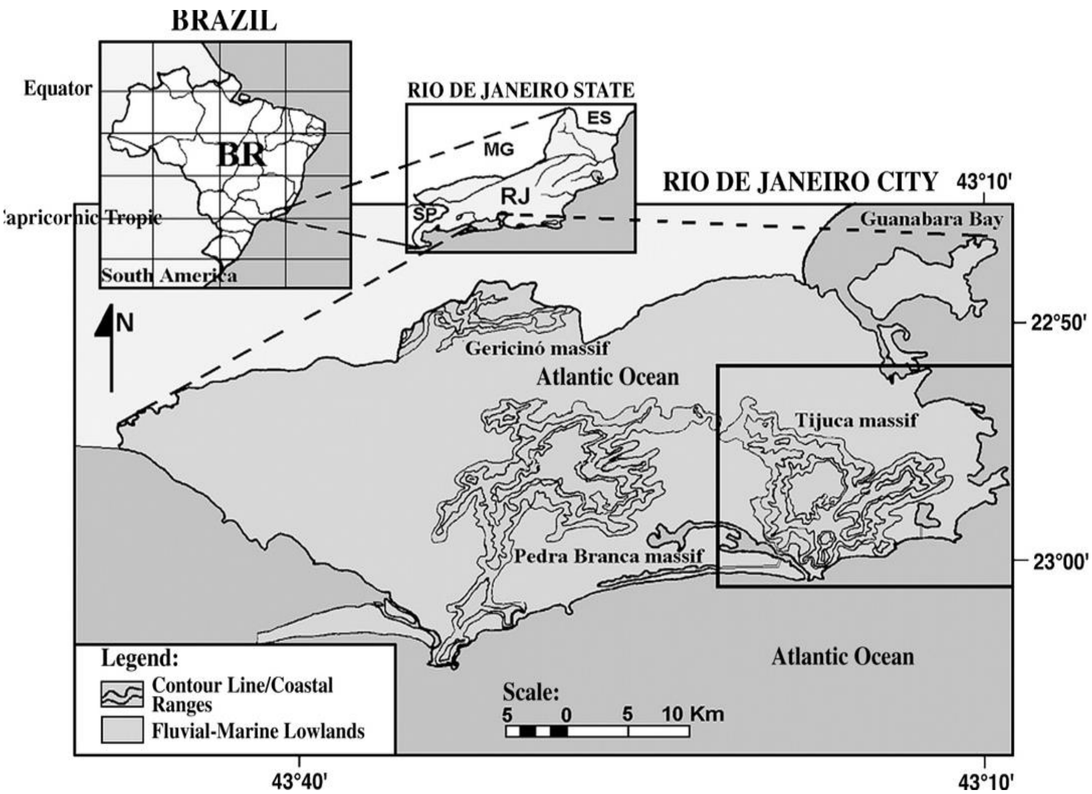

Figure 1: Location map of Tijuca Massif (limited by the 40 m a.s.l. contour level) in the municipality of Rio de Janeiro.

We may consider that the rocky substratum of Tijuca Massif dates from Pre-Cambrian and is part of the large mobile strip that formed the rocks of Southeast Brazil, as a result of the tectonic faults of the Lower Tertiary. It is essentially made up of gneisses, mainly facoidal gneiss and biotite gneiss, with isolated patches of granite in its eastern portion (COSTA, 1986).

The climate of Tijuca Massif, according to the Koppen classification is high altitude tropical (Cf) with temperatures varying from maximum average values of 25ºC in February to a minimum of 19ºC in June, resulting in an annual average of 22ºC. The maximum temperature may reach 35ºC during the summer and the minimum around 10ºC in the winter season. Average annual rainfall oscillates between 2,000 and 2,500mm, and may peak at 3,300mm in very wet years and drop to a minimum of 1,600mm in very dry years. Most rainfall is concentrated in the first four months of the year. The heaviest rainfall occurs in summer as direct response to the impact caused by the Atlantic polar front, altering the habitual dynamics of the atmosphere (COELHO NETTO, 1985).

According to Coelho Netto et al (2007), the area is within the Rio de Janeiro metropolis, thereby directly under the influence the city's changing vectors and pressures.

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Laboratory area 1: Vista do Almirante landslide scar

The origin of all landslides under study is related to the extreme inputs occurring during the extremely heavy and long-lasting rainfall in February 1988 (954.4 mm in 21 consecutive days). The Vista do Almirante landslide scar shows residual-colluvial soils in the upper and recent deposits in the lower portion, where the landslide material was deposited. In the upper portion, the shallow soils, associated with the slope morphology, prevent major accumulation of moisture, slowing down succession. In the lower portion, however, recolonisation occurred faster, thanks to a gentler slope that permitted major accumulation of organic matter, associated with the organic debris carried in the movement and deeper soils. The narrowness of the scar (0.6 ha) helped its recovery by pioneer and initial secondary species throughout. The unequal revegetation process is because of aspects of the scar's morphology. The surroundings consist of late secondary forest at an advanced state of regeneration with understory dominated by the jussara palm (*Euterpe edulis*).

Laboratory area 2: Vista Chinesa landslide scar

It covers a total area of 1.8 ha, and its top lies at the foot of the road close to the watershed of the basin, and its base is situated on the valley bottom of a channel of a first order tributary of the Macacos River. This landslide carried a large volume of mobilized soil of around 12,480 m^3 with an average depth varying from 1.3 to 1.5 m. (SILVA FILHO, 1992).

NEGREIROS *et al*, 2009 observed three well-defined morphological domains that reflect the different positions on the slope. They are: (a) High slope: The upper part of the scar, which extends from the road to the first slope failure. (b) Middle Slope: The central part of the scar, extending from the first to the second slope failure. It also consists of the steeper stretch and erosion activity, with outcrops of weathered and unaltered rock in the transition with the lower-slope domain. (c) Low-Slope: This is the base of the scar, extending from the second slope failure of the profile to the river channel. It consists of the stretch where the mobilized material was deposited in the landslide. Made up of an extensive soil package, with a larger ravine in the middle, this area has accelerated spontaneous revegetation, with formation of continuous canopy and accumulated litter.

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Laboratory Area 3: Gabião landslide scar

This gap-scar is also associated with the February 1988 events and partly reproduces the morphology of the Vista Chinesa landslide scar, but on a smaller scale (1.2 ha of area). ROCHA LEÃO *et al.* (1996) identified three morphological domains, as follows: 1 – The top part with steep gradient and no concave features, which hinders gullying; 2 – The central part, characterized by the presence of an extremely steep sloping segment, with exposed soils, crust formation and sealed surfaces; 3 – The lower zone with the second slope failure, smaller gradients and where the landslide material was deposited.

Control area: Pai Ricardo forest

This was chosen to be the control area in the study. There is a stretch of well-conserved forest called Pai Ricardo's forest, where a fragment of late secondary forest resists, covering 200 ha of woodland. In this same stretch of forest a structural survey of the vegetation was carried out, where large trees are predominant, characteristic of this environment, with basal areas of 36.62 m^2/ha in the slope environment, as observed by BASILE (2004).

III. RESULTS AND DISCUSSION

Rainfall patterns

As can be seen from table 01, the year 2007 had a very different rainfall pattern compared with the mean between 1977-2007, with below average in March, August and September, and heavier rainfall in May and December. From October all months had higher monthly totals than the mean between 1977 and 2007. On the other hand, the months with least rainfall were far below average, principally March, which is still part of the wettest season. The total rainfall was very close to the average, but its distribution was quite different, some months with rainfall varying widely from the average.

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Table 01: Rainfall daily classes, total Rainfall and mean rainfall (1977-2007) at the Capela Mayrink Station 2007

	up to 10 mm	Between 11 and 50 mm	Between 51 and 100 mm	> 100 mm	2007 rainfall	mean rainfall (1977-2007)
Jan	15	6	0	0	187	201,1
Feb	3	1	0	1	147,9	181,9
Mar	6	0	0	0	15,8	195,8
Apr	7	1	0	1	172,6	205,2
May	12	3	0	2	367	162,5
Jun	4	3	0	0	74,8	131,5
Jul	5	4	0	1	258,9	146,9
Aug	11	0	0	0	50	131,3
Sep	4	2	0	0	57,9	207,3
Oct	5	2	1	1	270,4	163,4
Nov	10	6	1	0	268,1	203,7
Dec	10	4	1	1	364,6	229,5
Total	92	32	3	7	2235	2129,8

When analysing the precipitation, not only was May the month with most total rainfall, but it also had the highest number of days with precipitation above 100mm and the second with the highest number of events altogether. January was the month with most events, but all under 50mm. August, despite the low total volume of rainfall, had a significant number of events, but all with low intensity. November also had a total volume above average, and most of this volume was concentrated in five events with rainfall between 50 and 100mm.

Vegetation structure

Table 02 shows the structural data and some aspects call our attention, such as the high rate of dead trees in the internal domains of the gaps. As already mentioned by Guariguata *et al* (2001), pioneer formations prevail, whose fast life cycle can cause this pattern. The values of a basal area are also lower for the domains inside the landslide areas, also a reflection of their successional stage. The left edge of the Gabião area has the lowest value of basal area among the edges, and in this area a large number of fallen trees can be found, which emphasizes the degree of this area's degeneration. Domain 2 of Vista Chinesa (laboratory area 2) has the smallest basal area as a result of predominant grasses and presence of the *Tibouchina granulosa* (*Melastomaceae)* in the area. The lowest total density of trees is found in Gabião domain 2, where there are a few individuals of fast-growing pioneer species (like C*ecropias sp.*) and pteridophytes of the genus *Gleichenia*.

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Vista do Almirante gap has a curious structural pattern at the edges: most of the individuals are classified in the DBH classes above 2.5 cm. This pattern differs from that found by GUARIGUATA *et al* (2001) in the literature for local climax areas, in the same way as the control area in the present study, where most trees have DBH under 5.0 cm and individuals of all sizes. This pattern encountered may be more associated with a high rate of individuals in the *Palmae* family on the edges, corresponding to more than 60% of the plant community, than a possible edge effect from the gap area. The individuals in this sampled family have an above 3.0 cm DBH, and its dominance is reflected in the absence of smaller individuals.

The large number of dead trees detected on the left edge of Gabião landslide is a possible indicator of the spread of edge effects, as already observed by NEGREIROS *et al.* (2009) in Vista Chinesa gap. The edge effect will also be noted in other parameters, as in litter production and soil characteristics, both in Gabião and Vista Chinesa landslide scar gaps. There are fewer dead trees in the Vista do Almirante, which would be expected because of its smaller and more elongated shape. The statistical tests applied corroborate this finding.

Table 01: Mean DBH, Mean Height, Basal area and % of dead trees in al landslide scar and control area (Pai Ricardo)

Area	Mean DBH (cm)	Mean Height (m)	Basal Area (m^2/ha)	% of Dead Trees
PR	4,66 (± 7,14) a	8,53 (± 6,91) ab	28,9	0
VA-D1	4,93 (± 3,30) ab	4,41 (± 2,47) ab	18,6	10
VA-D2	7,31 (± 3,46) ab	7,50 (± 4,05) b	13,8	12
VA-RE	8,76 (± 8,08) a	6,67 (± 4,61) ab	61,6	7
VA-LE	6,35 (± 4,18) a	5,23 (± 4,47) b	30,6	9
VC-D1	3,07 (± 1,91) b	3,57 (± 0,98) ab	13,5	3
VC-D2	3,13 (± 1,03) c	2,06 (± 0,33) a	2,4	50
VC-RE	7,34 (± 6,97) ab	4,70 (± 3,64) ab	18,5	25
VC-LE	9,73 (± 6,31) a	7,21 (± 3,81) b	33,2	10
GB-D1	4,69 (± 3,50) ab	3,56 (± 2,10) ab	12,7	33
GB-D2	9,31 (± 6,18) b	5,62 (± 4,45) ab	11,2	0
GB-RE	5,04 (± 5,78) a	4,13(± 3,17) ab	48,5	9
GB-LE	4,93 (± 3,93) b	3,73 (± 2,22) ab	12,2	15

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB –Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

The Vista do Almirante domain 2 has the best quality structural data in relation to the middle slope of all gaps, but this does not mean that the area has a condition close to that of the control area. The proportion

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of dead trees is very high and the distribution pattern of the DBH classes is quite different from the control area, with most of the individuals in the class between 5 and 10 cm. But the pattern is as expected by GUARIGUATA *et al* (op. Cit.) for areas of up to 20 years succession, with canopy cover, something that does not occur in the other areas of the middle slope. Gabião landslide has a very low tree density, and Vista Chinesa offers the lowest general average of a basal area, and the tree density is only high due to the large number of multiple trunks, a result of the number of Lent-season trees on the site. This place has the lowest values for all structural data in all of the study areas.

One of the reasons for the difference in pattern found between the gaps and part of the literature lies in the nature of how these gaps emerged. Most of the papers (BROWN *et al*, 1989, GUARIGUATA *et al.* 2001, DEWALT *et al*, 2003, SAYNES *et al.* 2005 and STONER *et al.*, 2009 and CORREIA *et al.* 2016) address succession in areas where the topsoil has some structuring, unlike the gaps, even more so in the middle slope, where various studies (NEGREIROS *et al* 2009 and CHIROL et al. 2018) show stronger water erosion dynamics. This entire set of aspects makes succession more complex and difficult.

It is necessary to differentiate the Vista Chinesa upper slope areas (domain 1) from the others. As a result of introducing *Bambusa vulgaris* (*Poaceae*), which dominates the area, the basal area distribution is more concentrated in the smaller classes and the height is more homogeneous. In the other gaps the composition is completely different, with the presence of pioneer species, such as the Lent-season tree, which has now given rise to a high concentration of multiple trunks. Although Vista Chinesa domain 1 is at a slightly more advanced stage, both are close to that proposed by GUARIGUATA et al (2001), and already have a more closed canopy than the middle slope.

Litterfall Production

As can be seen in figures 02, 03 and 04, the edge areas are those showing most productivity, especially those in the Vista Chinesa landslide. They all have a production of more than 10,000 kg/ha/year, except for the right edge of the Gabião laboratory area. Another interesting aspect is that the edges have a higher proportion of branches in the material produced compared to the other areas, which is to be expected because of the spread of the edge effect, mainly caused by the wind (SCHESSL *et al* 2008). The domains 1 of all laboratory areas have production values close to that of the control area (PR), but the proportion of leaves in all of them is less, which distinguishes the characteristics of the material produced.

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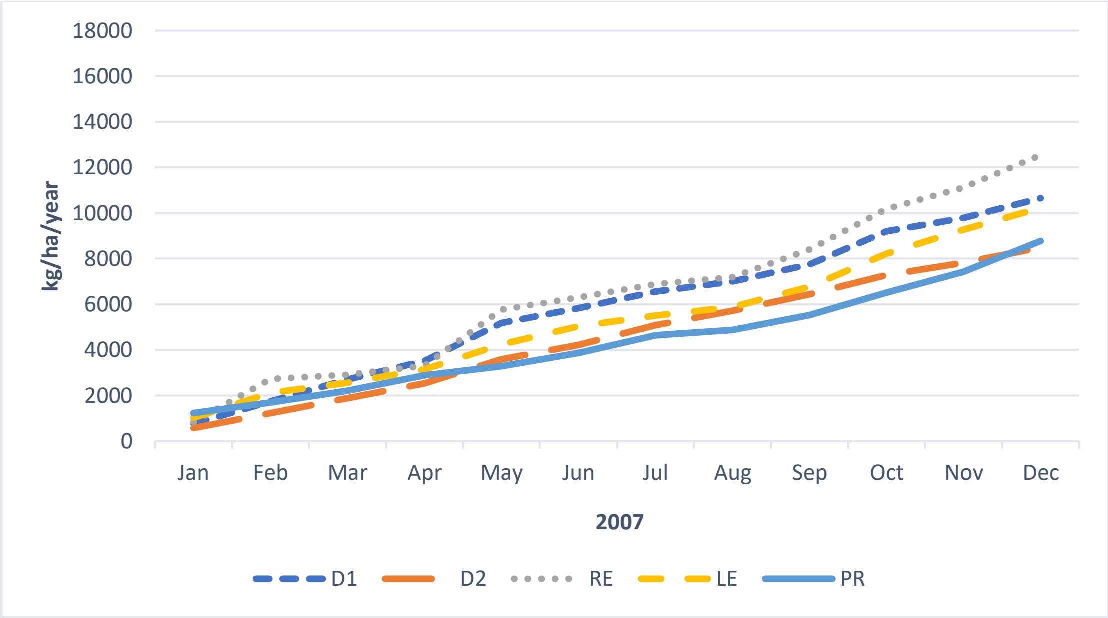

Figure 02: Monthly Litterfall Production at the Vista do Almirante and Control Area.

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB – Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

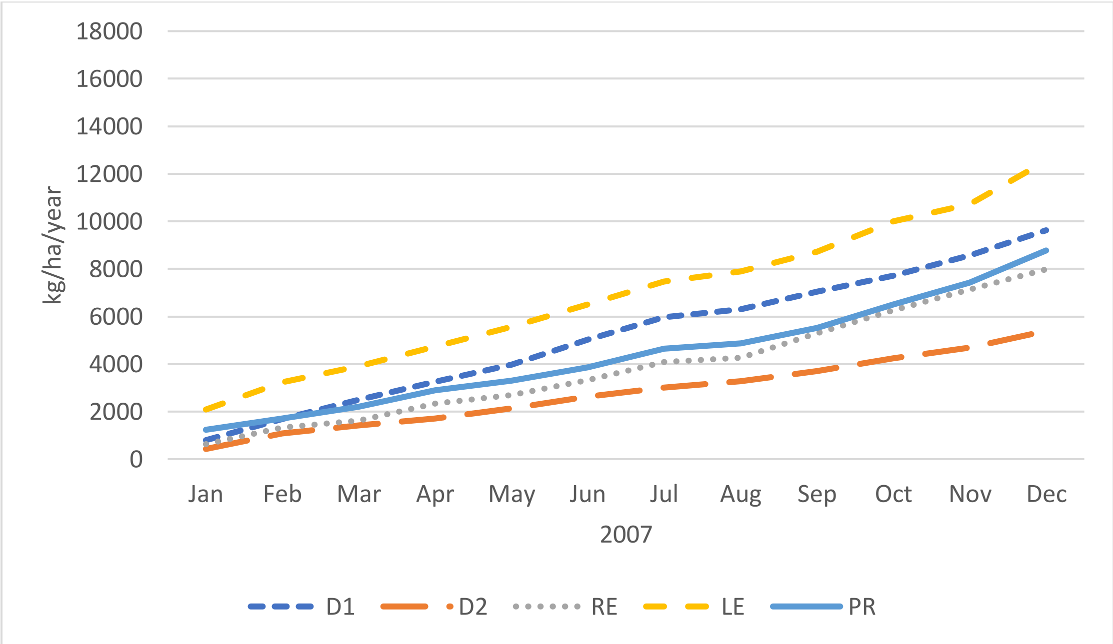

Figure 03: Figure 02: Monthly Litterfall Production at the Gabião landslide and Control Area.

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB – Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

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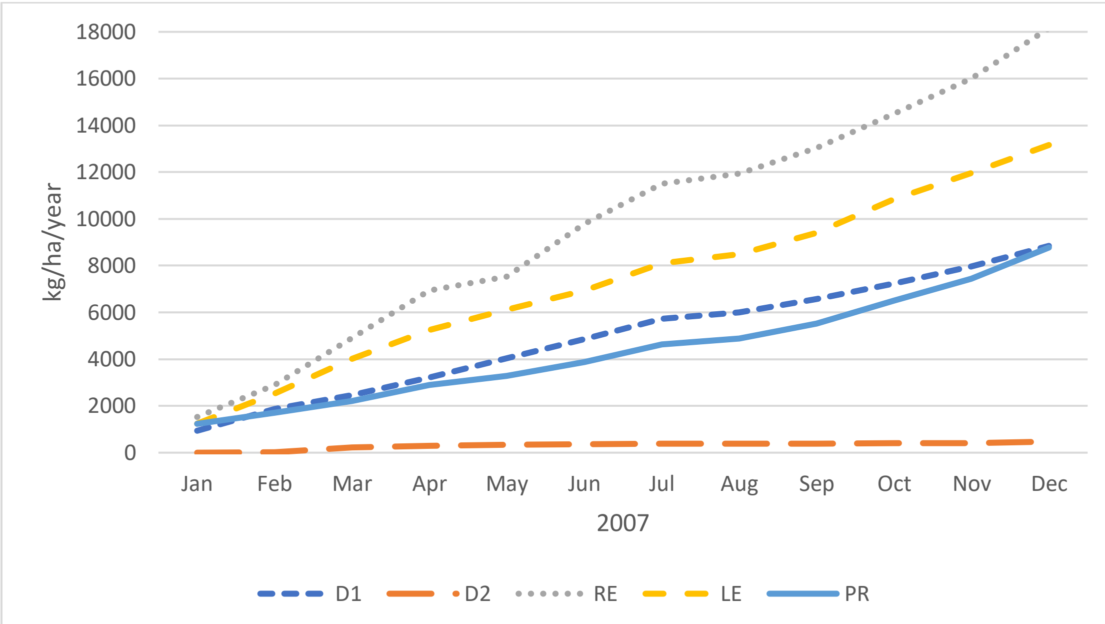

Figure 04: Figure 02: Monthly Litterfall Production at the Vista Chinesa and Control Area.

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB –Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

The area with the lowest total production of litter is Vista Chinesa domain 2. The predominance of grasses and the low tree density determine this pattern, since most of the decomposition occurs with the material still standing, which is typical of grasses.

It is worth noting that there is no apparent marked seasons for litter production in the Atlantic rainforest in Southeast Brazil. Production may respond to specific inputs from climate, as we can see in the Vista do Almirante areas, where in May, the month with the highest number of events over 100mm (2), productivity was considerably greater.

Another important aspect is that, contrary to expectations, the months with highest rainfall are those with greatest production, particularly in Vista do Almirante. One of the possible causes for this pattern may be the characteristics of extreme events that are accompanied by stronger winds, which may cause a larger volume of fallen branches.

One of the major challenges in analysing litter is its relation to precipitation. In Atlantic rainforest areas, the results vary considerably (VARJABEDIAN et al, 1988, BOREM et al. 2002, NUNES et al, 2007, FERREIRA *et al,*

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2015) and some areas with seasonality have been observed (Northeast Zona da Mata, SCHESSL et al, 2008) while in others it does not occur. Therefore the aim is not only to find the total volume of the month, but also categorise the events based on rainfall intensity.

In Vista do Almirante an interesting pattern was found, since the month with greatest production, and highest proportion of branches, was precisely May (except for the left edge), the month when most events of more than 100mm occurred. The action may not be by water alone, but also winds associated with such extreme events, which also cause a higher proportion of branches in the production. But this pattern was not found in other areas. A possible explanation is that rainfall is extremely variable over time and space, and Vista do Almirante is the area closest to the Mayrink Chapel station. But for all areas the months with lowest rainfall were August and March, which are characterised by low productivity in most of the areas.

Another important aspect is that in all edges a higher proportion of branches was found in the production compared to the other areas. This result is expected since the incoming sunlight and wind degenerate the vegetation and increase the proportion of branches in the litter (SCHESSL *et al* 2008). It is interesting to also note that, except for the right edge of Gabião, the edges were the areas with greatest productivity of those studied, far higher than those in the gaps.

In general, productivity inside the landslides (domains 1 and 2) is lower than found in the control area. The only exception was Vista do Almirante domain 1, which showed higher values than that of Pai Ricardo. The lowest productivity was found in Vista Chinesa domain 2 that had higher values than Pai Ricardo. The lowest productivity was found in Vista Chinesa domain 2 lower than 500 kg/ha/year.

Soil Litter Storage

The difference in decomposition rates among rainforests can be attributed to the quality of the material, the type of vegetation covering, fauna activity in the soil and environmental conditions, especially temperature and humidity (ARATO et al., 2003). Generally the larger soil litter storages will be in the edge areas (table 03), mainly as a result of the higher branch production in those areas and of the leaf characteristics with a larger specific leaf surface, which slows down decomposition. But the most significant result comes from crossing production and the soil litter, which gives the constant K of decomposition and renewal time of 14 years, which shows complete maladjustment of the decomposing subsystem in this area. Even if considering a system where the largest part of the organic matter is decomposed as it stands, since it is a domain where grasses are

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predominant, this result reflects a maladjustment of the ecological functions in this area. The difference in decomposition rates can be attributed to the quality of the material, the type of vegetation covering, fauna activity in the soil and environmental conditions, especially temperature and humidity (ARATO *et al.*, 2003). BROWN et al (1990) have already stressed the important role of the decomposing subsystem for tropical forests, and there is practically no turnover in this area. At the same time the area with the shortest time of residence is Vista do Almirante domain 2, a result to be expected from the observations of GUARIGUATA et al, 2001. The comparison between the two domains shows how these systems operate in different ways, and indicate how size and shape are important controls in succession in gaps.

Also in relation to the decomposition time of the litter, the left edges also had much higher values than for the control area, between three to six years. This result is more an indication of the propagation of the edge effect, which occurs regardless of the extent of the gap, since it may be a reflection of the high branch production on all edges. Another consequence is that the edges (in all landslides) showed a higher litter storage than the other areas. It is worth stressing that production was higher in the edges of Vista Chinesa, the largest landslide scar, which shows the importance of the size and shape of the gap for its regeneration process. The control area presents a K value within the range expected in Atlantic Forest (PINTO *et al.* 2009 and FERREIRA *et al,* 2015)

Table 03: Litter Storage at the study sites.

		Leafs (kg/ha)	Branches (kg/ha)	Reproductive parts (kg/ha)	Residues (kg/ha)	total (kg/ha)
VA	D1	2763,0	6193,1	575,5	7779,2	17310,9
	D2	743,8	303,9	0,0	614,8	1662,6
	RE	3453,6	2294,8	342,1	7128,6	13219,0
	LE	13287,4	11793,9	1196,5	20052,8	46330,6
GB	D1	2823,0	4326,7	205,9	3786,0	11141,5
	D2	2075,5	1931,5	116,4	4522,1	8645,5
	RE	2305,3	1530,6	7,0	2224,6	6067,5
	LE	10359,8	9436,1	738,1	12249,8	32783,9
VC	D1	1957,4	2149,3	5,5	3239,8	7351,9
	D2	2948,8	2044,3	16,0	1677,8	6686,9
	RE	1968,4	7853,1	0,0	8179,3	18000,7
	LE	8335,0	21165,5	21,5	28442,1	57964,2
	PR	5051,2	2075,3	21,6	2366,5	9514,5

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB –Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

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Table 04: K value and Renewal Time at the study sites

	K	TR
VA-D1	0,62	1,62
VA-D2	5,12	0,20
VA-RE	0,94	1,06
VA-LE	0,22	4,53
GB-D1	0,86	1,16
GB-D2	0,64	1,56
GB-RE	1,31	0,77
GB-LE	0,38	2,61
VC-D1	1,20	0,83
VC-D2	0,07	14,12
VC-RE	0,99	1,01
VC-LE	0,23	4,41
PR	0,92	1,09

PR – Pai Ricardo (control area); VA –Vista do Almirante landslide scar; VC – Vista Chinesa landslide scar; GB –Gabião landslide scar; D1 – Domain 1 (upper slope); D2 – Domain 2 (middle slope); RE – Right Edge; LE – Left Edge

IV. CONCLUSION

The landslides are truly successional mosaics, where various successional stages exist. The speed of decomposition, one of the most important processes in tropical forests, is a good indicator of the "quality" of this succession. Landslides size and shape are important factors in succession, bearing in mind that all the scars are the same age, but have very different successional patterns, mainly on the middle slope, where water erosion dynamics is more intense and rehabilitation more complex. These landslides affects the litterfall production and litter decomposition, as observed also by SILVA et al, 2018 in Amazonic Forest, and also have an impact in the ecosystem as whole. FENGA et al, 2019, also found that an increase in the basal area affects positively the soil organic matter and consequently the succession.

Litter production is not linear through the year nor has marked seasons. The litterfall seems to respond more to specific environmental conditions than to the major annual cycles. The Pai Ricardo Forest (control area) showed a higher productivity compared to the landslides scar areas and smaller than the edges, as a decomposition time of 1 year. The total litterfall is within the expected for Atlantic Forest (PAGANO, 1989, BOREM *et al*. 2002, OLIVEIRA *et al.* 2000 and MONTEZUMA, 2005). Also, as pointed by LIU *et al.* (2019), mean annual temperature and forest age are key drivers that affect litterfall, and the Atlantic Forest at the Tijuca's Massif is a late secondary forest, which may cause some patterns.

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When comparing the findings in literature (CELENTANO *et al.*, 2011, AIDE *et al.*, 2013, CHAZDON, 2014), the succession in landslides scars is more complex than in areas where there were burnings and even the introduction of pastures, since the latter have other soil conditions that do not occur in gaps whose succession practically occurs on saprolite. In tropical areas, this is a particular problem given the importance of decomposition dynamics in these ecosystems. Management of these areas is complicated due to the complexity of forest succession. ZARIN *et al*. (1995) have already mentioned that some chemical properties of the soil, namely carbon, for example, may take up to 1,000 years to recover. But the real issue is urban occupation and increasing recurrence of these events.

Landslides scars may play an important role in the diversity in Atlantic Forest. DENSLOW (1987) wrote about the importance of tree gaps in the diversity of tropical forests, as these create different ecological niches that will be occupied by different species, so these landslides, that greatly change soils (ZARIN *et al.*, 1995, and CHIROL *et al.*, 2018) and microclimate (MONTEZUMA, 2005) (compared to treefall gaps), may even have a greater impact on biodiversity, as biophysical diversity is related in several ways to biological diversity (RESTREPO *et al.* 2003 and GEERTSEMA *et al.*, 2007). Future studies are also required to progress in research on the Atlantic rainforest and revegetation in landslides, mainly with regard to hydrological conditioning factors, since they play a key control role in the successional dynamics of these areas.

V. References

AIDE, T.M., CLARK, M.L., GRAU, H.R., LÓPEZ-CARR, D., LEVY, M.A., REDO, D., BONILLA-MOHENO, M., RINER, G., ANDRADE-NÚÑEZ, M.J., MUÑIZ, M., 2013. Deforestation and reforestation of Latin America and the Caribbean (2001–2010). **Biotropica** nº45, pág. 262–271. 2011

ARATO, H.D.; MARTINS, S.V.; FERRARI, S.H.S. Produção e decomposição de serapilheira em um sistema agroflorestal implantado para recuperação de área degradada em Viçosa – MG. **Revista Árvore**, v.27, n.5, p.715-721, 2003.

BARLOW J, GARDNER T A, FERREIRA L V, PERES C A Litter fall and decomposition in primary, secondary and plantation forests in the Brazilian Amazon. **Forest Ecology and Management** 247, pág. 91-97 (2007)

BASILE R.O.N.C.; **Estrutura da Floresta Atlântica de encostas e arquitetura de raízes arbóreas: Maciço da Tijuca – RJ**. Tese de Mestrado, P.P.G. em Geografia/UFRJ. 114 páginas. (2004)

BRAY; J. R.; GORHAM; E. Litter production in forests of the world. **Advance Ecological Research** 2, pág. 101-157. (1964)

BROWN, S. & LUGO, A. Effects of forest clearing and sucession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Island; **Plant and Soil** 124, pág. 54-64. (1990)

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.8, n.2, p. XX – XX, 11/2020
DOI: http://dx.doi.org/10.5380/raega.v49i0.66383

BRUIJNZEEL L. A. Hydrological functions of tropical forests: not seeing the soil for the trees? **Agriculture, Ecosystems and Environment** 104 pág. 185–228 (2004)

CELENTANO, D., ZAHAWI, R.A., FINEGAN, B., OSTERTAG, R., COLE, R.J., HOLL, K.D., Litterfall dynamics under different tropical forest restoration strategies in Costa Rica. **Biotropica** nº43, pág. 279–287. (2011)

CHAZDON, R.L.; **Second Growth: The Promise of Tropical Forest Regeneration in an**

Age of Deforestation. University of Chicago Press, Chicago. (2014)

CHEN H. Y. H.; BRANT A. N.; SEEDRE M.;BRASSARD B.W.; TAYLOR A.R.; The Contribution of Litterfall to Net Primary Production During Secondary Succession in the Boreal Forest; **Ecosystems** (2017) nº20, pág. 830–844 (2017)

CHIROL, A. A.; COELHO NETTO, A. L. ; Perez, D V . Relações solo-fauna durante sucessão florestal em áreas de clareiras por movimento de massa em Mata Atlântica. **Revista de Geociência do Nordeste - REGNE**, v. 4, p. 01-26, 2018

COELHO NETTO, A.L. Overlandflow production in a Tropical rainforest Catchment: the role of litter cover, **Catena** v.14, p.213 231. (1987)

COELHO NETTO, A.L., **Surface Hydrology and soil erosion in a tropical rainforest drainage basin, Rio de Janeiro**. PhD Thesis University of Leuven, Belgium, 181p. (1985)

COELHO NETTO A,L; AVELAR A.S; FERNANDES M.C.; LACERDA W.A. Landslide susceptibility in a mountainous geoecosystem, Tijuca Massif, Rio de Janeiro: The role of morphometric subdivision of the terrain; **Geomorphology** Vol. 87, issue 3, 15 pag. 120-131 (2007)

Correia G. G. S.;, Martins S.V.; Neto A.M.; Silva K.A; Estoque de serapilheira em floresta em restauração e em floresta atlântica de tabuleiro no sudeste brasileiro. **Revista Árvore**, Viçosa-MG, v.40, n.1, p.13-20, (2016)

COSTA, N. M. da, (1986) **Geomorfologia estrutural dos Maciços litorâneos do Rio de Janeiro, RJ**, Rio de Janeiro, P.P.G. em Geografia /UFRJ, Dissertação de Mestrado, 108p. 1986.

DALLING, J.W.; HEINEMAN, K.; GONZÁLEZ, G.; OSTERTAG, R.; Geographic, environmental and biotic sources of variation in the nutrient relations of tropical montane forests. **Journal of Tropical Ecology**, nº 32, pág. 368–383. 2016

DAWOE, E.K., ISAAC, M.E., QUASHIE-SAM, J., 2010. Litterfall and litter nutrient dynamics

under cocoa ecosystems in lowland humid Ghana. **Plant Soil** nº330, pág. 55–64. (2010)

DE VUONO, Y.S; **Inventário fitossociológico** in: SYLVESTRE LS; ROSA MMT(org) Manual metodológico para estudos botânicos na Mata Atlântica. EDUR, pág. 51-65 (2002)

DENEV; D. The return of nutrient elements to the soil by leaf fall in Young poplar plantations. **Forestry Abstracts** 37 (8), pág 448-453 (1975)

DENSLOW, J. S.; Tropical rain forest gaps and tree species diversity. **Annual Review of Ecology and Systematics**. nº 18, pág 431-451(1987)

DUCHAUFOUR, P.H. **Pèdologie, sol, vegetation, environment**. Ed. Masson, Paris; 287 páginas (1968)

FENGA C.;, WANGA Z.; MA Y.; FUA S.; CHEN H. Y. H.; Increased litterfall contributes to carbon and nitrogen

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
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DOI: http://dx.doi.org/10.5380/raega.v49i0.66383

accumulation following cessation of anthropogenic disturbances in degraded forests **Forest Ecology and Management** nº432, pág. 832–839 (2019)

FERREIRA, M.L. & UCHIYAMA, E.A.; LITTERFALL ASSESSEMENT IN A FRAGMENT OF SECONDARY TROPICAL FOREST, IBIÚNA, SP, SOUTHEASTERN BRAZIL, **Revista Árvore**, Viçosa-MG, v.39, n.5, p.791-799, 2015

FIGUEIRÓ, A. S.; COELHO NETTO, A. L. IMPACTO AMBIENTAL AO LONGO DE TRILHAS EM ÁREAS DE FLORESTA TROPICAL DE ENCOSTA: Maciço da Tijuca Rio de Janeiro - RJ. **Mercato**r (UFC), v. 8, p. 187-200, 2009.

GEERTSEMA M., POJAR J.J.; Influence of landslides on biophysical diversity — A perspective from British Columbia. **Geomorphology** nº89 pág. 55–69 (2007)

GUARIGUATA M.; Landslide Disturbance And Forest Regeneration In The Upper Luquillo Mountains Of Puerto Rico. **Journal of Ecology** nº78, pág. 814-832 (1990)

GUARIGUA, M.R; OSTERTAG R.; Neotropical secondary forest succession: changes in structural and functional characteristics. **Forest Ecology and Management** nº148, pág. 185-206 (2001)

HOQUE, M.M.; KAMAL A.H.M.; IDRIS M.H.; AHMED O.H.; HOQUE A.T.M.R.; BILLAHA M.; Litterfall production in a tropical mangrove of Sarawak, Malaysia. **Zoology and Ecology,** Vol. 25, No. 2, pág. 157–165 (2015)

KLINGE, H. Preliminary data on nutrient release from decomposing leaf litter in a neotropical rain forest. **Amazoniana** vol. 6 nº(2), pág. 193-202 (1977)

LARSEN, M.C., TORRES-SANCHEZ, A.J., CONCEPCION, I.M., Slopewash, surface runoff and fine litter transport in forest and landslide scars in humid-tropical steeplands, Luquillo Experimental Forest, Puerto Rico, **Earth Surf. Process. And Landforms** 24, pág. 481-502. (1999)

LIU X.; TAO ZHOU T.; LUO H.; XU P.; GAO S.; LIU J.; Models ignoring spatial heterogeneities of forest age will significantly overestimate the climate effects on litterfall in China**, Science of the Total Environment** nº661, pág. 492–503, (2019)

LODGE, D.J.; SCATENA, F.; ASBURY, C.; SANCHEZ, M.; Fine litterfall and related nutrient inputs resulting from Hurricane Hugo in subtropical wet and lower montane rain forests of Puerto Rico. **Biotropica**, nº 23, 336–342. 1991

MADGE, M.; Leaf fall and litter disappearance in a tropical Forest. **Pedobiologia** 5; pág. 5273-5288 (1965)

NUNES, F P; PINTO, M T C Produção de serapilheira em mata ciliar nativa e reflorestada no alto São Francisco, Minas Gerais **Biota Neotropica** v7 (n3) (2007)

NEGREIROS, A. B.; COELHO NETTO, A. L. Reabilitação Funcional de Clareira de Deslizamento em Encosta Íngreme no Domínio da Floresta Atlântica Rio de Janeiro (RJ). **Revista Brasileira de Geomorfologia**, v. 10, p. 85-93, 2009.

OLIVEIRA R.R.; COELHO NETTO, A. L. Processos interativos homem-floresta na evolução da paisagem da Ilha Grande, RJ. **Geo UERJ** v. 8, p. 29-38, 2000.

MONTEZUMA, R. C. M. (2005) **Produção e reabilitação funcional do piso florestal em clareira de deslizamento – PARNA Tijuca, Rio de Janeiro**; Tese de Doutorado, PPG em Geografia/UFRJ, 290 pág.

OZALP M, CONNER W H, LOCKABY G.; Above-ground productivity and litter decomposition in a tidal freshwater forested wetland on Bull Island, SC, USA. **Forest Ecology and Management** 245 pág. 31–43 (2007)

PAGANO, S.N.; Producão de folhedo em mata mesófila semidecídua no município de Rio Claro, SP. **Rev. Brasil.**

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.8, n.2, p. XX – XX, 11/2020
DOI: http://dx.doi.org/10.5380/raega.v49i0.66383

Biol. 49, 633–639. (1989)

PANDEY R.R., SHARMA G., TRIPATHI S.K, SINGH A.K.; Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in northeastern India. **Forest Ecology and Management** 240 pág. 96–104 (2007)

PINTO, S.I.C.; MARTINS, S.V.; BARROS, S.F.; DIAS, H.C.T. Ciclagem de nutrientes em dois trechos de floresta estacional semidecidual na Reserva Florestal Mata do Paraíso em Viçosa, MG, Brasil. **Revista Árvore**, v. 33, n. 4, p. 653-663, 2009.

RESTREPO C, PETER VITOUSEK P; NEVILLE P Landslides significantly alter land cover and the distribution of biomass: an example from the Ninole ridges of Hawai'i Kluwer. **Plant Ecology** 166 pág. 131–143 (2003)

ROCHA LEÃO, O. M.; BALESDANT, F.C.; CRUZ, E. S. ; COELHO NETTO, A.L.; Reativação Erosiva Em Cicatriz De Movimento De Massa, Maciço Da Tijuca, Rj. **Sociedade & Natureza**, Uberlândia-MG, v. 8, n.15, p. 259-263, 1996.

SAYNES V, HIDALGO C, ETCHEVERS J D; Julio E. CAMPO J E.; Soil C and N dynamics in primary and secondary seasonally dry tropical forests in Mexico. **Applied Soil Ecology** nº29, 282–289 (2005)

SCHESSL M.; WILKILANE L. S.; GOTTSBERGER G.; Effects of fragmentation on forest structure and litter dynamics in Atlantic rainforest in Pernambuco, Brazil. **Flora** nº203 215–228 (2008)

SILVA, W. B.; PÉRICO, E.; DALZOCHIO, M. S.; MÁRIO SANTOS M.; CAJAIBA R. L.; Are litterfall and litter decomposition processes indicators of forest regeneration in the neotropics? Insights from a case study in the Brazilian Amazon, **Forest Ecology and Management** nº429, pág. 189–97(2018)

SILVA FILHO, E.P. **Movimentos de massa na vertente sul do Maciço da Tijuca,RJ: casos de fevereiro de 1988 nas estradas Dona Castorina e Vista Chinesa**. P.P.G. em Geografia /UFRJ, 272 pág. (1992)

SILVER, W.L.; HALL, S.J.; GONZÁLEZ, G. Differential effects of canopy trimming and litter deposition on litterfall and nutrient dynamics in a wet subtropical forest. **Forest Ecology and Management**, nº332, pág. 47–55. 2014

STONER, K.E.; SANCHEZ-AZOFEIFA, G.A.; Ecology and regeneration of tropical dry forests in the Americas: Implications for management. **Forest Ecology and Management** 258 903–906 (2009)

SWIFT, M.J.; HEAL, O W.; ANDERSON, J.M.; **Decomposition in terrestrial ecosystems**, University of California Press, Berkley and L.A. (1979)

ZALAMEA, M.; GONZÁLEZ, G.; LODGE, D.J. Physical, chemical, and biological properties of soil under decaying wood in a tropical wet forest in Puerto Rico. **Forests**, no7, pág. 168. 2016

ZARIN, D. J., JOHNSON, A.J, Nutrient Accumulation during primary succession in a Montane Tropical Forest, Puerto Rico, **Soil Sci. Soc. Am. Journal,** 59; pág. 1444-1452 (1995)