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Original Article

Conservation of Nature

Litter Dynamics in a Forest Dune at Restinga da Marambaia, RJ, Brazil

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ABSTRACT

Restingas are extremely degraded, tropical sandy ecosystems and are poorly studied in terms of nutrient cycling. The present study aimed to evaluate litter dynamics in a forest dune at Restinga da Marambaia, RJ. Litterfall was collected monthly using two parallel transects installed 200 m apart from each other with 15 litter traps (0.25 m^2), over two consecutive years. The litterfall was sorted into leaves, twigs, flowers, fruits, and refuse. Litter decomposition was evaluated by the ratio between litterfall and litter layer on the soil surface, which was estimated every four months by quadrats (0.25 m^2) placed next to the litter traps. The average annual litterfall was low (6.8 t ha^{-1} $year^{-1}$), mostly constituted by leaves (70%), with the greatest deposits occurring during the rainy season. The decomposition rate was low (0.85) and the turnover time was long (439 days). This litter dynamic contributes to the nutrient economy.

Keywords: litter, nutrient cycling, sandy coastal plain, tropical forest.

1. INTRODUCTION

Restingas are marginal habitats that occur in sandy coastal plains and belong to the Atlantic Rainforest complex. Restingas used to cover about 79% of the Brazilian coast (Menezes et al., 2010) and most of Rio de Janeiro State coast, but the majority of these ecosystems are in some way altered, totally or partially degraded, due to occupation over the last five centuries (Rocha et al., 2007). These authors identified 21 restinga remnants in the Rio de Janeiro State, totaling 105.29 ha, and highlighted that the most common causes of degradation are removal of vegetation to establish property developments, planting of exotic species and changes to the original substrate.

In restingas, plants are exposed to marine and fluvial-marine influence, heat, flooding, drought, wind, salinity and low natural soil fertility. Thus, plants community formation is based on positive ecological interactions between a few species (Scarano et al., 2001). For example, bromeliads are called keystone species because they contribute to the increasing diversity in restingas (Cogliatti-Carvalho et al., 2001). In Restinga da Marambaia, which is located in the municipality of Rio de Janeiro, the terrestrial bromeliads dominate the dense herbaceous layer on the floor of a forest dune. The aboveground biomass of such bromeliads involves a high concentration of nutrients (Souza et al., 2016) which improves soil fertility in the area by leaf litter (Pereira et al., 2005).

Litterfall is the primary process by which nutrients are transferred from aboveground vegetation, through the breakdown of organic material which releases mineral nutrients into the soils in forms available to plants and microorganisms (Vitousek & Sanford, 1986). There is incipient information about different aspects of nutrient cycling in restingas, where both litterfall and litter decomposition are low (Moraes et al., 1999; Pires et al., 2006; Bonadiman, 2007; Castanho & Oliveira, 2008; Paula et al., 2009; Pereira et al., 2012).

The low rates of litter decomposition in restingas are due to the high concentrations of cellulose and lignin (Pereira et al., 2012) and high lignin:N ratio and C:N ratio (Castanho & Oliveira, 2008). This feature, which is observed in coriaceous textured leaves, is a strategy to reduce evapotranspiration losses. Such processes allow the slow return of nutrients into the soil, which minimizes losses from the soil-plant system by leaching and maximizes the use of nutrient absorption by plants (Pires et al., 2006; Bonadiman, 2007; Paula et al., 2009). The high nutrient translocation before the leaves senescence in restingas is another evident strategy of the nutrient economy or high efficiency of nutrient use (Moraes & Domingos, 1997). Studies that focus on the dynamics of nutrient cycling in restingas permit an understanding of ecosystem functioning, which can support decisions not only for their conservation and preservation, but also with a view to their rehabilitation.

The present study aimed to evaluate the litterfall and decomposition along two consecutive years, in a forest dune at restinga da Marambaia, Rio de Janeiro, Brazil. We considered the hypothesis that (1) there are differences between the years in terms of litterfall and decomposition; (2) litter dynamics in the forest dune is slow in comparison to other forest ecosystems in the Atlantic Rainforest biome.

2. MATERIAL AND METHODS

Restinga da Marambaia presents approximately 49.40 km^2, distributed in the municipalities of Rio de Janeiro, Itaguaí and Mangaratiba in Rio de Janeiro State (Roncarati & Menezes, 2005). The area is in a relatively good state of preservation, because it is located within a military area and has restricted access. The macroclimate of the region is classified as Aw (Tropical Rainy) with a rainy summer and dry winter according to Köppen (Alvares et al., 2013). Monthly total precipitation and average temperature data was provided by INMET 6th District of Rio de Janeiro (Figure 1). According to this data, the total rainfall was 1,062.2 mm and 1,233.1 mm from September 1999 to August 2000 (Year1) and from September 2000 to August 2001 (Year2), respectively, while the average annual temperature was 24.2 °C and 25.3 °C, respectively.

This study was conducted in a forest dune situated on a slope at the east end of Marambaia (23°03'S; 43°36'W), lying approximately 800 m from the ocean and 300 m from Sepetiba Bay. This forest grows on the top of a single dune with about 30 m height, covering about 527 ha and corresponding to approximately 10.7% of the total area of Restinga da Marambaia. The vegetation profile in the dune varies from shrub, located in the lower third,

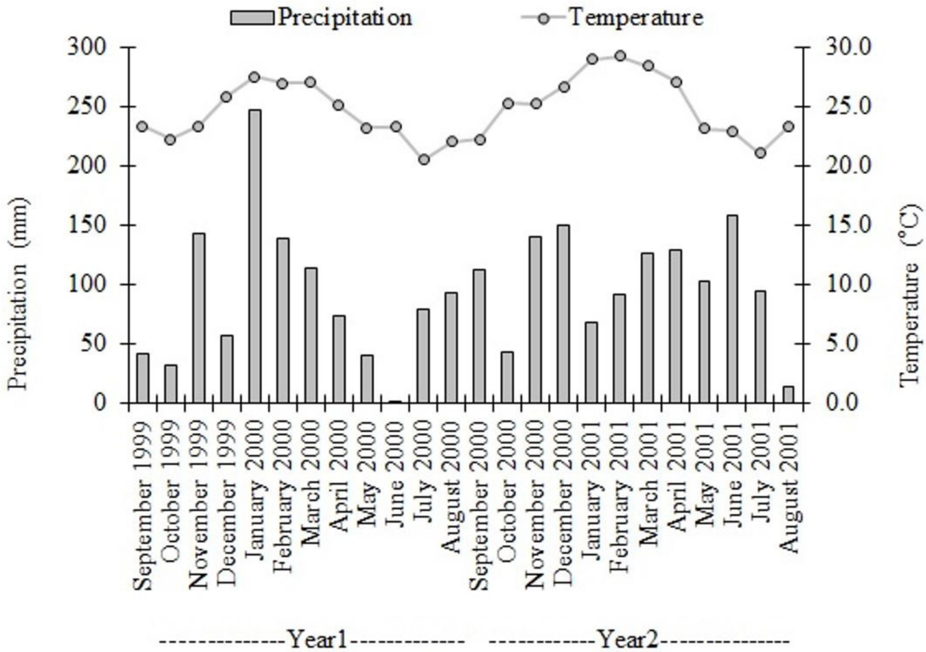

Figure 1. Monthly precipitation and temperature distributed over Year1 and Year2 at Restinga da Marambaia, Rio de Janeiro, Brazil.

to an arboreal community which predominates in the upper third (Fraga et al., 2010).

The forest dune presents an average height of 8 m on the slope facing the ocean, and an average height of 15 m on the slope facing Sepetiba Bay. The herbaceous layer is dense and dominated by bromeliads. The tree layer presents 53 tree species belonging to 25 families, with Myrtaceae being the family with the largest number of species (*Eugenia arenaria*, *E. copacabanensis*, *E. ovalifolia*, *E. sulcata*). The tree species of greatest importance are *Ocotea notata* (34.06), *Maytenus obtusifolia* (25.80), *Byrsonima sericea* (19.69), *Cupania emarginata* (17.18), *Aspidosperma parvifolium* (16.20), *Eugenia ovalifolia* (15.23), *Erythroxylum ovalifolium* (14.91), *Marlierea schottii* (11.27) and *Pseudopiptadenia contorta* (10.13).

The soil belongs to the Quartzipsamment order (Menezes et al., 2005). Soil fertility increases in the upper third of the dune, in comparison to the lower third, which presents the highest aluminum content and lowest nutrient content (Fraga et al., 2010). Regarding the topsoil chemical attributes (0-0.10 cm) in the upper third of the dune, Fraga et al. (2010) obtained the following results: K^+: 29.67 mg kg^{-1}; Ca^{2+}: 3.27 cmol$_c$ kg^{-1}; Mg^{2+}: 1.62 cmol$_c$ kg^{-1}; Na^+: 0.14 cmol$_c$ kg^{-1}.

In August/1999, we installed a total of 30 litter traps, 15 traps each along two parallel lines (transects) perpendicular to the sea line and separated from each other by 200 m, in the forest dune. We located transects in the upper third of the dune, facing the ocean. The litter traps were distributed at intervals of 10 m along each transect. The traps were made of wooden 0.5 m × 0.5 m quadrats (0.25 m^2) with 1 mm^2 nylon mesh and held 10 cm off the ground (Arato et al., 2003). The contents of the litter traps were collected monthly in Year1 and Year2 and placed in paper bags. These bags were dried in a fan forced oven (65 °C, 48 h) in the laboratory after each collection (Correia et al., 2016).

Afterwards, the litterfall was sorted into five fractions: leaves, small twigs (≤ 2 cm in diameter), flowers, fruits, and refuse (small < 2 mm, miscellaneous plant and animal debris and frass) (Pereira et al., 2012), and then weighed. The dry mass obtained monthly (g m^{-2} month^{-1}) was transformed into t ha^{-1} month^{-1}. The litterfall was evaluated according to the equation: LF = (Σ AL x 10,000) / TA; where: AL = annual average of litterfall (t ha^{-1} year^{-1}); ML = monthly litterfall (t ha^{-1} month^{-1}); TA = trap area (m^2) (Lopes et al., 2002).

The total small litter lying on the forest floor was removed within a 0.5 m × 0.5 m quadrat (0.25 m^2) (Patricia & Morellato, 1992) made of PVC tubes. Sampling (n = 15 samples / transect) was performed next to the litter traps, every four months in Year1 and Year2, at the end of September, December, March and June. This material was dried and weighed similarly as for litterfall.

The rate of litter decomposition indirectly represents the rate at which litter nutrients return to the soil and become available again for plants (Vital et al., 2004). This rate (K) was obtained by the equation of dynamic equilibrium (Olson, 1963): K = L / X, where L = annual small litterfall; X = small litter lying on the forest floor. This methodology was also used in other studies (Arato et al., 2003; Vital et al., 2004; Pires et al., 2006). The average time needed to complete renewal of litter accumulated on the forest floor (tr) was determined by: tr = 1 / K (Hopkins, 1966).

Factorial ANOVA was performed to evaluate statistical differences between the years in terms of total litterfall and fractions (t ha^{-1} ano^{-1}). In this analysis, we considered the dry mass as the dependent variable, and the year and month as the independent or predictor variables. Levene's test was employed to evaluate the homogeneity of variances, which was rejected. Afterwards, we performed the Mann-Whitney U non-parametric test with the aim of identifying the differences between the years, and months (t ha^{-2}) in terms of total litterfall and fractions, in each year. For this purpose, we calculated the mean dry mass between transects. We also employed the statistical analysis of a generalized linear model in order to evaluate the association between climatic variables (precipitation, temperature, the independent or predictor variables), and the fractional and total litterfall deposits (dependent variables). In all the statistical analyses, which were performed with STATISTICA software version 8.0., we considered $p < 0.05$ as the level for significance.

3. RESULTS AND DISCUSSION

In the forest dune, we observed significant interaction between year and month for leaf (p = 0.000000), twig (p = 0.006861), refuse (p = 0.000000), and total litterfall (p = 0.000000) deposits. There was an isolated significant effect for both the year (p = 0.002100) and month (p = 0.000000) for flower deposits. In contrast, there was no significant impact from either the year or month in relation to fruit deposits.

Leaf, flower, and total litterfall deposits were significantly higher during Year1, whereas refuse deposits were significantly lower in Year1, when comparing the years (Table 1). There were no significant differences between the years in terms of twig and fruit deposits.

The average total litterfall was approximately 6.6 t ha^{-1} $year^{-1}$ (Table 1). This value is close to the average litterfall in South American tropical forests that grow in white sand and poor soils which is 5.4 t ha^{-1} yr^{-1}, which is lower than in ferralsols where the average litterfall is 7.1 t ha^{-1} yr^{-1} (Chave et al., 2010). The total litterfall in non-flooding restinga forests is lower than in the Atlantic Rain Forests (Table 2).

This pattern is a consequence of the lower fertility of the soil in restingas (low clay and organic matter content, low cation exchangeable capacity values and high aluminum saturation values), in comparison with

Table 1. Annual deposits (t ha^{-1} yr^{-1}) of total litterfall and fractions and the relative contribution (%) in Year1 and Year2, in a forest dune at Restinga da Marambaia, Rio de Janeiro State, Brazil.

Litter	Deposits	Relative contribution	Deposits	Relative contribution	Deposits	Relative contribution
	Year1		Year2		Average	
Leaves	5.3A (0.8)	75	4.6B (0.9)	74	4.9 (0.8)	75
Twigs	1.1A (0.5)	15	1.0A (0.4)	16	1.0 (0.4)	16
Flowers	0.2A (0.2)	3	0.1B (0.1)	2	0.2 (0.1)	2
Fruits	0.2A (0.2)	3	0.2A (0.1)	3	0.2 (0.2)	3
Refuse	0.2B (0.1)	4	0.3A (0.1)	5	0.3 (0.1)	4
Total	7.0A (1.0)	100	6.2B (1.0)	100	6.6B (0.9)	100

Mean values, with standard deviation in parenthesis, followed by the same letter in a line indicate no statistical difference between the years (Mann-Whitney U test, $p < 0.05$).

Table 2. Total annual litterfall (t ha^{-1} year^{-1}) and relative contribution of leaves (%) in some Brazilian tropical forests.

Ecosystem/Local	Total annual litterfall	Contribution of leaves	Study
Non-flooding Restinga forest			
Ilha do Cardoso, SP	3.9	75	Moraes et al. (1999)
Ilha do Mel, PR	5.1	75	Pires et al. (2006)
Restinga da Marambaia, RJ	6.6	75	This study
Average	5.2	75	
Seasonally flooded Restinga forest			
FF1, Restinga da Marambaia, RJ	11.3	71	Paula et al. (2009)
FF2, Restinga da Marambaia, RJ	10.8	67	
FF3, Restinga da Marambaia, RJ	11.1	64	
Restinga da Marambaia, RJ	7.6	58	Pereira et al. (2012)
Ubatuba, SP	7.7	-	Assis et al. (2011)
Average	9.7	65	
Atlantic Rain Forest			
Ilha do Cardoso, SP	6.3	70	Moraes et al. (1999)
Guarujá, SP	7.9	64	Varjabedian & Pagano (1988)
Ilha Grande, RJ	10.7	-	Oliveira (2004)
Rio de Janeiro, RJ	7.5	64	Oliveira et al. (2005)
Ilha da Marambaia, RJ	7.9	66	Pereira et al. (2008)
Recife, PE	10.1	67	Espig et al. (2009)
Ubatuba, SP	8.8	-	Assis et al. (2011)
Average	8.5	66	

the soil in Atlantic Rain Forests (Assis et al., 2011). Thus, leaching of cations from the soil is more intensive in restingas, which limits primary productivity and, consequently, litter deposits. In addition, non-flooding restinga forests also present lower litterfall than in flooding restinga forests. This is probably a result of hydric stress in the non-flooding restinga, which limits vegetation growth in this ecosystem.

The production of litter is a function of primary productivity. Therefore, it depends fundamentally on the structure of the tree community (Clark et al., 2001). When comparing the non-flooding restinga forests to each other, the higher annual total litter deposits in the dune forest in Marambaia is due to the taller tree community, which ranges from 8 to 15 m. On the other hand, the tree community in Ilha do Cardoso is lower and ranges from 4 to 7 m (Moraes et al., 1999), whereas in Ilha do Mel the average height is 3 m, with the tallest trees reaching a maximum of 5 m (Pires et al., 2006).

The contribution of leaves to total litterfall was higher, followed by twigs, whereas the others fractions together represented only 9% of the total litterfall, in both Year1 and Year2 (Table 1). This result corroborated the pattern commonly observed in the literature. According to the Table 2, the contribution of leaves ranges from 58 to 75%. The variation in terms of the relative contribution of leaves, and other litter fractions in the total annual litterfall, is due to differences between ecosystems in terms of the forest structure, which is a consequence of the successional stage or degree of disturbance, as well as the climatic conditions of the site, such as precipitation and atmospheric moisture (Barbosa & Faria, 2006).

Total litterfall deposits and its fractions were continuous throughout Year1 and Year2 (Figure 2). In tropical rain forests without a severe drought period, the processes of senescence and emergence of new leaves occurs throughout the year (Morellato et al., 2000). However, in Year1 significant differences between the months occurred, within Year1, in terms of leaf ($p = 0.000000$), twig ($p = 0.000984$), flower ($p = 0.000355$), fruit ($p = 0.000000$), and total litterfall ($p = 0.000000$) deposits. On the other hand, no differences in refuse deposits ($p = 0.651100$) was observed between the months, in Year1.

In Year1, leaf deposits were significantly higher ($p < 0.05$) in September/1999 and January/2000 (0.70 and 0.74 t ha^{-1} month^{-1}, respectively). The same

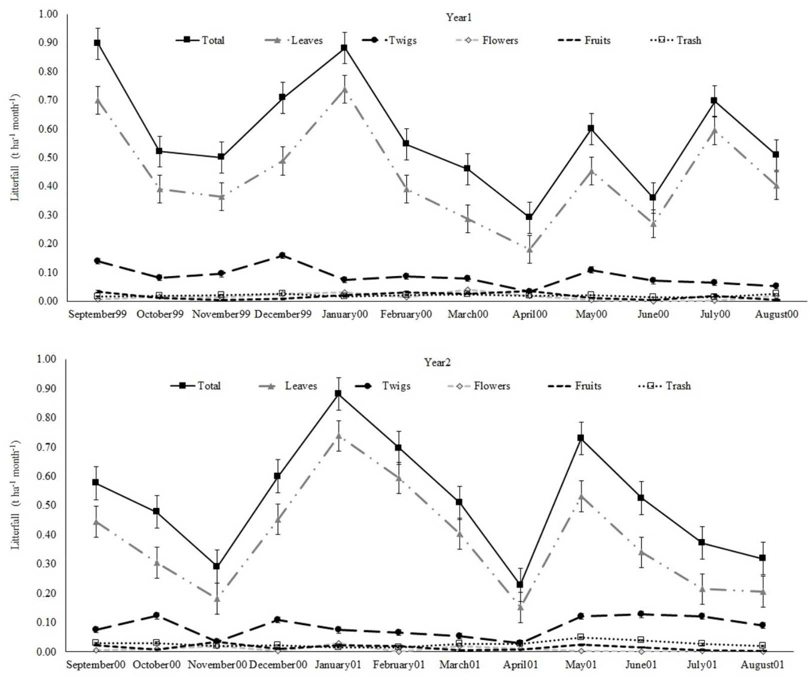

Figure 2. Annual distribution of litterfall (total and fractions, t ha^{-2} $month^{-1}$) over Year1 and Year2, in a forest dune at Restinga da Marambaia, Rio de Janeiro State, Brazil.

pattern of higher deposits during the rainy season occurred for twigs (December/2000: 0.16 t ha^{-1} $month^{-1}$), flowers (March/2000: 0.04 t ha^{-1} $month^{-1}$), fruits (September/2000: 0.03 t ha^{-1} $month^{-1}$), and total litterfall (September/1999 and January/2000: 0.90 and 0.88 t ha^{-1} $month^{-1}$, respectively). In contrast, there were no significant differences between the months in terms of refuse deposits in Year1. In Year2, there were significant differences between the months, for leaf ($p = 0.00$), twig ($p = 0.000403$), flower ($p = 0.001162$), fruit ($p = 0.049027$), refuse ($p = 0.000253$), and total litterfall ($p = 0.00$) deposits.

The highest leaf (January and February/2001), flower (January/2001), fruit (November/2001), and total litterfall (January/2001) deposits were observed in the rainy season, in Year2 (Figure 2). On the other hand, the highest twig (June/2001) and refuse (May/2001) deposits occurred in the middle of the dry season of the same year. These results indicated that litterfall was higher during the rainy season. This pattern was also observed in the non-flooding restinga forests in Ilha do Cardoso (Moraes et al., 1999), Ilha do Mel (Pires et al., 2006) and in seasonally flooding restinga forests in Marambaia (Paula et al., 2009). In non-flooding and flooding restinga forests in Ilha do Mel, the production of new leaves and senescent leaf deposits occurred continuously over two years of observation, but both conditions were more marked during the rainy season (Marques & Oliveira, 2004).

Similarly, it was expected that litter deposits would have been greater in Year2, due to higher annual precipitation and monthly average temperature (1,231.1 mm and 25.3 °C, respectively) values, in comparison with Year 1 (1,062.2 mm and 24.2 °C, respectively). However, we observed the opposite, because the total litterfall, influenced by both leaf and flower fractions, was higher in Year1. The absence of a pattern in the leaf deposits was also verified in non-flooding and flooding restinga forests in Ilha do Mel, when comparing two consecutive years in each type of forest (Marques & Oliveira, 2004). These authors indicated that other factors such as day length influenced litterfall.

The generalized linear model analysis in Year1 indicated a significant impact of both precipitation and temperature on leaf deposits ($p = 0.000148$, and p = 0.016070, respectively). Although precipitation significantly influenced total litterfall deposits (p = 0.003277), this pattern was not verified for temperature (p = 0.249819). Temperature significantly influenced flower deposits (p = 0.004725), whereas precipitation did not influence deposits of this fraction (p = 0.293811). On the other hand, neither precipitation nor temperature showed a significant impact on twig (p = 0.068439 and p = 0.105603, respectively), fruit (p = 0.868651 and p = 0.117804, respectively), or refuse (0.675173 and p = 0.269565, respectively) deposits.

According to the generalized linear model analysis for Year2, temperature significantly influenced leaf (p = 0.000009), twig (p = 0.002344), flower (p = 0.002303), refuse (p = 0.001086), and total litterfall (p = 0.001836) deposits, whereas precipitation did not influence deposits of these fractions (p = 0.472579, p = 0.369232, p = 0.909823, and p = 0.093873, respectively) or total litterfall (p = 0.531493). Neither precipitation nor temperature showed a significant impact on fruit deposits (p = 0.153749 and p = 0.882278, respectively).

Therefore, in the present study, temperature seemed to have a more decisive impact on litterfall, in comparison to precipitation. This result may occur in areas without a severe drought period, where variations in day length and temperature throughout the year have a greater impact than precipitation on phenology (Morellato et al., 2000).

In the forest dune in Restinga da Marambaia, the litter lying on the forest floor tended to be less in December/1999 and greater in March/2000, in Year1. However, in Year2, lower values occurred in June/2001, whereas higher values were observed in December/2000 (Table 3). The average annual litter lying on the forest floor estimated was 9.8 t ha^{-1} yr^{-1} and 7.4 t ha^{-1} yr^{-1} in Year1 and Year2, respectively, The decomposition rate (K) was 0.74 and the time needed to complete renewal of litter accumulated on the forest floor (tr) was 1.35 years (489 days), in Year1. However, in Year2, the value of K was 0.95 and tr was 1.05 years (382 days).

This result of faster litter decomposition was probably due to both higher annual precipitation (1,233.1 mm) and monthly average temperature (25.3 °C) in Year2, in comparison with Year1 (1,062.2 mm and 24.2 °C, respectively). In tropical forests, warmer, more humid climatic conditions favor the activity of the decomposing biota, which increases the rate of litter decomposition (Powers et al., 2009; Campo & Merino, 2016).

Considering the average values calculated between Year1 and Year2, K and tr were 0.85 and 1.20 years (439 days), respectively. In tropical forests, the K values are generally higher than 1.00, indicating that the turnover time of litter in these ecosystems occurs in less than one year (Golley et al., 1978), featuring a rapid process of decomposition and intense nutrient cycling (Olson, 1963). The results indicated that the litter turnover in the present study was slower than in a non-flooding restinga forest (K = 0.92; tr = 398 days) in Ilha do Mel (Pires et al., 2006) and in a fragment of Atlantic Rain Forest (K = 1.02; tr = 357 days) in Rio de Janeiro (Oliveira et al., 2005).

The differences between tropical forests in terms of the decomposition rate are mainly due to the activity of microbial decomposers, whose populations are regulated by the soil predator invertebrates and by soil saprophagous invertebrates, that breakdown the litter (Swift et al., 1979). In addition, climatic conditions (particularly precipitation and temperature), edaphic conditions (aeration, temperature, moisture and pH), and the litter characteristics influence the activity of the decomposing microbiota (Swift & Anderson, 1989). The litter characteristics are closely related to the palatability of the organic material available to decomposers (Maharning et al., 2009), which varies according to plant species (Villela & Proctor, 2002). Litter with higher palatability consists of easily degradable compounds (Milcu & Manning, 2011), with low phenolic

Table 3. Litter lying on the ground (t ha^{-1} yr^{-1}) at forest dune at Restinga da Marambaia, Rio de Janeiro State, Brazil.

Year1	Sep/1999	Dec/1999	Mar/2000	June/2000	Average
	10.1	9.2	10.2	9.6	9.8
Year2	**Sep/2000**	**Dec/2000**	**Mar/2001**	**June/2001**	**Average**
	7.4	9.0	7.9	5.2	7.4

substance content and high N (Maharning et al., 2009) and other nutrient contents (Pinto & Marques, 2003; Barbosa & Faria, 2006).

In restingas, the slower decomposition (Bonadiman, 2007) is influenced by the low nutrient quality of the litter (Castanho & Oliveira, 2008; Pereira et al., 2012). Therefore, the return of nutrients to the soil is gradual (Bonadiman, 2007) and the nutrient demand of plants is met through litter mineralization (Correia & Andrade, 2008). Additionally, such elements present high efficiency of use because they are internally translocated from mature to new leaves before their senescence (Moraes & Domingos, 1997). Further, slower decomposition would increase the organic layer and mineral soil carbon storage in these forest ecosystems, which could function as relevant soil carbon sinks (Campo & Merino, 2016).

Thus, slower decomposition combined with low litter production indicates that there is a synchronism between these processes, which is advantageous for the plant community in these ecosystems (Pires et al., 2006) because it minimizes the leaching of nutrients from the sandy soil with low fertility in such ecosystems (Moraes et al., 1999; Assis et al., 2011; Camara et al., 2016). This dynamic is responsible for the high plant diversity in restingas, despite the low fertility of the sandy soils (Castanho & Oliveira, 2008) and the other extreme abiotic conditions, which include heat, flooding, drought, wind, and salinity (Scarano et al., 2001).

4. CONCLUSIONS

Litterfall was higher in the Year1, in comparison to Year2.

Litter deposits were higher in the rainy season in both years, and were mainly influenced by temperature, and less influenced by precipitation.

The rate of decomposition and the turnover time of litter was faster in the Year2 than in Year1.

The litter dynamic (deposits and decomposition) was slower in the forest dune in comparison to other forest ecosystems in the Atlantic Rainforest biome.

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