RESEARCH PAPER

TRAIL IMPACTS IN A TROPICAL RAINFOREST NATIONAL PARK

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ABSTRACT. Generally considered a sustainable economic activity, tourism can generate environmental deterioration due to a lack of planning. In this case, the edge effect is utilized to assess the degree of human interference in the environment. Although the Atlantic Forest is known as a hotspot because of its high species richness and endemism, it is also a threatened biome. In this context of anthropogenic pressure, our work assesses the edge-interior gradient in the regenerating forest based on the physical characteristics of vegetation and floristic composition, in addition to providing overall guidelines to effectively assist in its management. For this study, 30 plots of 25 m^2 (10 m x 2.5 m) equally distributed among the edges of trails and locations 20 and 40 m away from them were established, with the greatest length measured parallel to the edge of the tracks. Overall, 443 individuals of 122 species were investigated. More than 60 of them were endemic to Brazil, 13.3% were threatened and 9.1% were widely distributed species. Some species were present at all distances from the trails, others co-occurred, but the majority were exclusive to a single plot category. Differences in species diversity were also observed with an increasing trend in dominance at the edges of trails along with a decreased richness at the same distance.

KEYWORDS: trail disturbance, ecotourism, edge effect, forest fragmentation, habitat modification, Tijuca Forest

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INTRODUCTION

Tourism is an extremely important economic activity that experiences significant growth (Dushkova and Ignatieva 2020; Geffroy et al. 2015; Lu and Nepal 2009). Meanwhile, the same authors as well as Montagnini and Jordan (2005) give evidence that inadequate tourism administration aggravates environmental deterioration. Consequently, the utilization of public space together with ecotourism requires appropriate zoning (Pickering and Hill 2007; Sun and Walsh 1998; Walter 2013; Zaú 2014).

Trail impact is defined here as an alteration in any component of the environment, be it partial or total, that modifies interaction between species and the ecosystem dynamics. These disturbances directly or indirectly affect both man and the environment (Montagnini and Jordan 2005).

The Atlantic Forest is known for its elevated species diversity and endemism and is already an eminently threatened forest (e.g. Laurance 2009; Myers et al. 2000; Ribeiro et al. 2009; Teixeira et al. 2009). It is a hotspot biome that currently barely covers 12% of its original area with less than 20% of the fragments larger than 50 ha (Metzger 2009; Ribeiro et al. 2009). Brokaw (1985) indicates that subtle changes in the Atlantic Forest could provoke numerous diffuse transformations in the forestry dynamics. In this case, interconnected microclimatic alterations will occur every time when a natural or anthropogenic forest clearing is opened (e. g. Harper et al. 2005; Kapos 1989). The areas within these gaps of the canopy, as a result, have their solar incidence amplified (Nobis and Hunziker 2005).

Another problem concerns forest edges. Showed by Harris (1980) and Murcia (1995), the edge effect is a phenomenon that occurs at the interface of distinct biomes, and its study is used to evaluate the anthropogenic impact of trails or linear clearings for road and powerline infrastructure in a forest (e.g. Goosem 1997; Pohlman et al. 2007; Spellerberg 1998). According to the studies conducted in tropical forests, edges frequently show these effects due to differentiation and edge-interior vegetation gradients, especially in relation to microenvironmental conditions (Kapos 1989), vegetal structure, biotic composition, and its interactions (e. g. Bierregaard et al. 2001; Laurance and Yensen 1991). Unfortunately, environmental transformation along the lines integrated into ecotourism still lacks knowledge and clarity in understanding the dynamics as a whole (Zaú 2014).

Due to the lack of knowledge on the existence or magnitude of the impact of walking trails in the mentioned conditions, the objectives of this work were to evaluate the regenerating forest stratum, aiming to contribute to planning activities and management of conservation units. This paper seeks to answer the following questions: Are there trail-associated alterations in the shrubby/arboreal-regenerating stratum? What are the most appropriate indicators for efficiently evaluating and monitoring the impact of public use: vegetation physical parameters or species composition?

METHODOLOGY

Study Site

The investigated area is an Atlantic Forest fragment of Tijuca National Park (TNP) (22º55'-23º00'S, 43º11'-43º19'W, Rio de Janeiro, Brazil – Figure 1). It is located inside the urban city center of Rio de Janeiro and is currently the most visited National Park, in Brasil with more than three million visitors each year (Parque Nacional da Tijuca, 2017). Moreover, TNP is a Conservation Unit of Full protection with an area of about four thousand hectares, and an altitude range from 80 m up to 1,021 m (ICMBIO 2008). According to the Köppen classification, it is characterized by a Humid Tropical climate, with «Tropical Monsoon (Am)» up to an altitude of 500 m, and a «Temperate climate, without dry season (Cf)» above this altitude (Coelho-Netto et al. 2007). Mean annual precipitation generally exceeds 2,000 mm, while the mean temperature is 23.8 ºC and relative humidity is 72% (Zaú 2010). Furthermore, the Massif is formed by gneiss, granite and blocks with intensely leached soils and the predominance of latosol, lithosol and cambisol in the mid-upper part of the area, and podzolic soil in the lower part (Coelho-Netto et al. 2007).

Sampling Design And Data Collection

30 plots of 10 m x 2.5 m were established in the sector «A» of TNP for sampling shrubby/arboreal-regenerating components, which included all the individuals with the stem diameter at breast height (DBH, about 1.3 meters from soil) between 10 mm and 50 mm. The plots were always defined in the hillside stretch above the tracks with the greatest length measured parallel to their edge. The allocation of sampling units was based on a random raffle of pre-defined locations which were identified as feasible for sampling from the baseline cartographic analyses (Instituto Pereira Passos 2004). To avoid spatial pseudo replications (Hurlbert 1984) and minimize sampling distortion, the locations were situated at least 50 m away from rivers and water springs, roads and clearings. Ten plots were defined on the edge of trails (0 m), ten within 20 m of the trails, and ten within 40 m of the trails, with the last category considered as the forest's interior (Harper et al. 2005; Laurance et al. 2002).

Data Analysis

After collecting all the data, several variables were defined to run statistical analysis of each plot: height (m), basal area (mm^2; calculation done from DBH), the density of alive/dead individuals (individuals per m^2), number of tillers, width of the trail (m), declivity (º), slope/trail orientation and altitude (m). The statistics package «R» (R Development Core Team 2020) was used to form Venn's diagrams. Additionally, GraphPad Prism v.6 (Graphpad 2012) was applied to conduct normality and homoscedasticity tests, as well as for univariate statistics comparisons. In the latter, the variables with parametric characteristics had ANOVA counter measures, whilst the remaining were submitted to the non-parametric equivalent – Kruskal-Wallis «H» test. PAST v4.03 (Hammer et al. 2001) was used to compare data between the different sampled distances, estimate diversity and perform multivariate analysis.

RESULTS

Species Response

Overall, 122 different species distributed among 68 Genus and 34 Families were found from 443 investigated individuals. The species can be divided into two groups: A - *infrequent,* with 58 species that were observed at only one plot out of 30; and B - *frequent*, with 64 species. Taking both groups into account, 51 species were detected at the edge of trails (T0), 67 species – at 20 m (T20), and 68 species – in the forest's interior (T40). Some species were noticed at all distances, few others co-occur, but the majority are exclusive to a single plot category. In the *frequent* group, there was a total of two species from T0, five species from T20, and 11 species from T40 (Fig. 2).

Fig. 1. In the left: the location of the city of Rio de Janeiro with Tijuca National Park in red; In the right: Tijuca National Park boundaries. «X» marks the location of unit samples. Font: http://earth.google.com. 2022

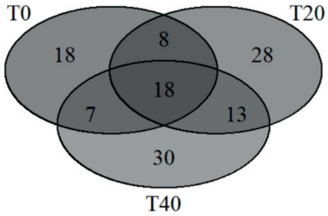

Fig. 2. Venn's diagram with all species found at each distance

The main species (n = 36), *Eriotheca pentaphylla (Vell. & K.Schum.)* A.Robyns, was dominant at T0 and T20 and appeared at only one plot of T40. The third (n = 23), 11th (n = 9), 19th (n = 7) and 20th (n = 7) most prevalent species, *Faramea occidentalis (L.) A.Rich., Erythroxylum citrifolium A.St.-Hil., Myrcia splendens (Sw.) DC.* and *Blepharocalyx salicifolius (Kunth) O.Berg*, respectively, were absent from T0. On the other hand, the 7th most frequent species (n = 12), *Bathysa stipulata (Vell.) C.Presl*, was found only at T0, whilst the 12th most prevailing species (n = 9), *Eugenia batingabranca Sobral*, appeared only at T20. The 13th (*Eugenia florida DC.*) and 15th (*Swartzia simplex (Sw.)* Spreng.) were absent from T40, and 14th (*B. mendoncaei*) was missing from T20 (Appendice). Finally, the 20 most common species represented 59.1% of all individuals (n = 262) and the standing dead individuals corresponded to 6.1% (n = 27).

Analyzing floristic composition, we recognized a total of 110 species, with the other 12 being classified at the genus level. Furthermore, no exotic species were found and 70 species were endemic to Brazil, which corresponds to 63.6% of the total. Additi onally, we also identified two native species from the Amazon, which although they are native to Brazil, are not native to the Atlantic Forest biome: *Coupeia subcordata Benth*. ex Hook.f and *F. occidentalis* (L.) A. Rich. Also, based on Oliveira-Filho & Fontes (2000), nine supertramp species were recognized (n = 40): *Cabralea canjerana* (Vell.) Mart., *Endlicheria paniculata* (Spreng.) J.F.Macbr., *E. citrifolium, E. florida, Guapira opposita* (Vell.) Reitz, *Guarea guidonia* (L.) Sleumer, *Matayba guianensis Aubl., Maytenus communis Reissek, Roupala brasiliensis Klotzsch.* The average species density for each plot category was slightly different with 0.204 species/m² for the edge of trails, 0.268 species/m² for 20 m, and 0.272 species/m² for the interior of the forest (T40).

Six of the identified species were included in the IUCN Red List of Threatened Species (2017): two with «Lower Risk» which are «conservation dependent», three «Vulnerable» and one «Endangered». Also, two species were listed in IBAMA's National Official List of Threatened Species (MMA 2014): one was classified as «Vulnerable», and one as «Endangered» whose presence in this list is constant (Annex 1).

Descriptive And Univariate Analyses

The tracks referring to the studied sections of Tijuca National Park have a minimum width of 0.79 m and a maximum of 2.21 m. Therefore, their average width of 1.28 m (±0.34) shows 26% variation (n=30[1]).

In terms of physical characteristics, the studied shrub/arboreal-regenerating stratum reflects an evolved maturity stage of cover from the same community (Zaú 2010). The average altitude and slope inclination are typical attributes of the regional mountainous relief (Tab. 1; Fig. 3). However, no significant differences in the investigated characteristics were noticed when comparing the physical aspects of the studied segments and the environmental attributes between the assessed intervals (T0, T20 and T40). According to the Kruskal-Wallis H test for medians of abundances, we cannot say that there are significant differences between the three distances analyzed, despite the borderline value of «p» (H=5.084; Hc-tie corrected=5.964; p=0.0507).

In contrast, the Shannon diversity t-test applied for sample units at different distances, reveals significant differences when comparing T0 (the edge of trails) with T20 (t=-3.655; p≤0.001) and T40 (t=-2.939; p=0.004). However, no significant differences were found when comparing T20 and T40 (t=0.653; p=0.514).

Multivariate Analyses

The Non-Metric Multidimensional Scaling (NMDS) using Euclidean distance as a similarity measure for the abundance data of the total number of species in each plot category showed a valid result (stress=0.1567) (Fig. 4). The analysis produced a graphic representation of the first three axes (or coordinates), which «explain» about 86% of the distribution of sampling units in multidimensional space. Axes 1 and 2, which are graphically represented, «explain» 75% of the data distribution. Axis 3 (not graphically represented) «explains» another 11%, and other axes, not measured individually, are responsible for the remaining 14% of data variability. (Fig. 5).

The similarity analyses carried out from 9999 permutations do not allow us to state that there are significant differences between the sets of species and their abundance at various distances to the trails (T0; T20; T40) (ANOSIM with the measured distance by the Bray-Curtis index: R=-0.0042; p=0.5072; NPMANOVA with the distance measured by the Bray-Curtis index: F=1.034; p=0.3979). Additionally, no significant differences were identified in the floristic composition when examining the regenerating stratum at the three distances (Attachment 1).

Table 1. Average physical characteristics of individuals from regenerating stratum and average environmental characteristics at the locations of sample units. Tijuca National Park, Rio de Janeiro, RJ. 2013. In which: H = height; BA = basal area; AD = absolute density; TD = tiller density; DD = density of dead individuals standing; Dcl. = slope declivity; Alt. = altitude; SD = standard deviation; CV = coefficient variation; n = number of sample repetitions

	H (m)	BA (mm)	AD (ind. m²)	TD (ind. m²)	DD (ind. m²)	Dcl. (º) 28	Alt. (m) 621
Average (±SD) =	3.35 (±1.27)	504.11 (±451.57)	0.62 (±0.20)	0.11 (±0.07)	0.02 (±0.03)	(±9)	(±114)
Minimum =	1.40	38.48	0.28	0.00	0.00	5	474
Maximum =	7.50	1,963.50	1.04	0.32	0.12	40	893
CV (%) =	38	90	32	69	164	31	18
n =	443	443	30	30	30	30	30

[1]Each mean was composed of six measurements.

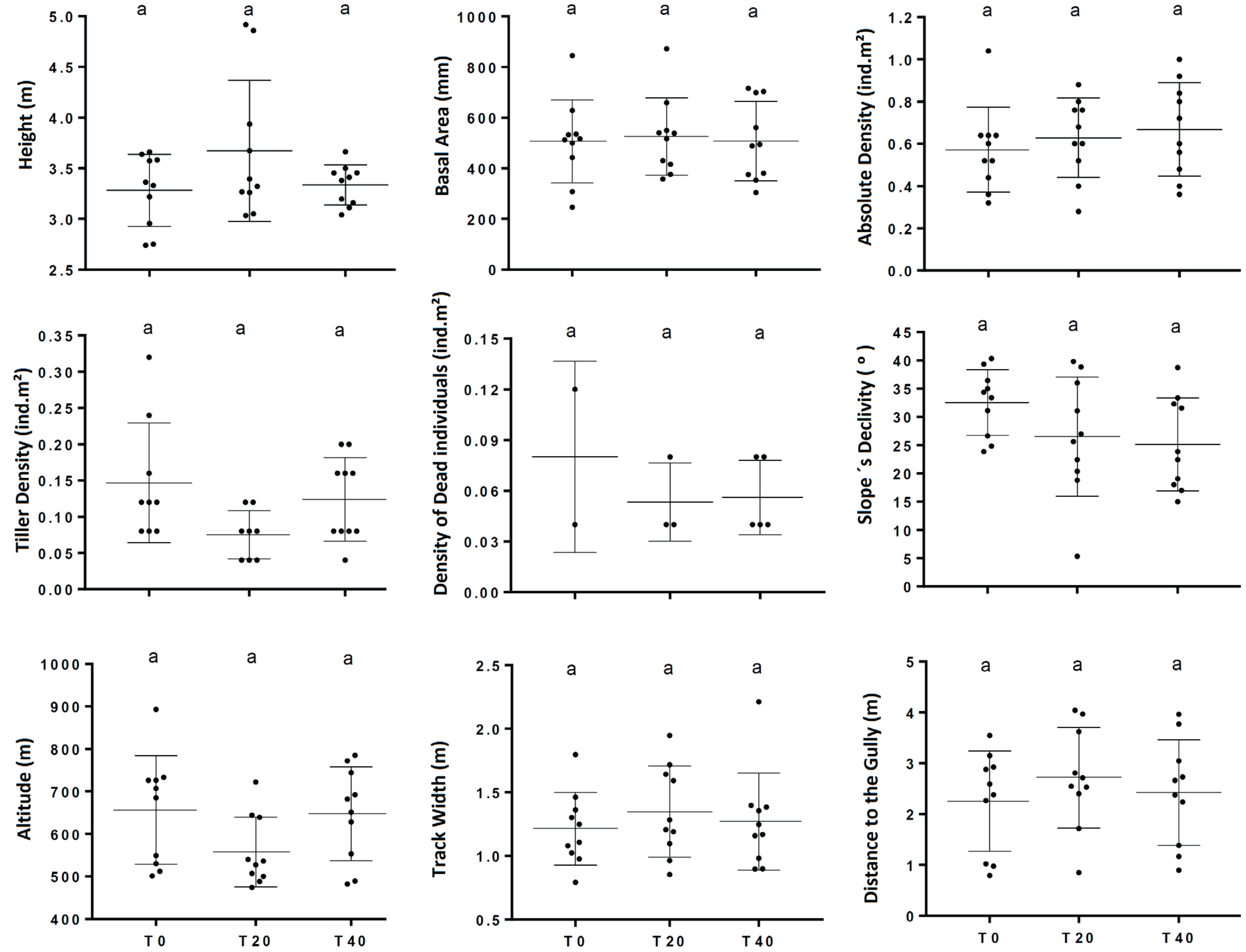

Fig. 3. Characteristics of individuals from regenerating stratum and average environmental characteristics at the locations of sample units. Tijuca National Park, Rio de Janeiro, RJ. 2013. In which: A) height (m); B) basal area (mm); C) absolute density (ind./m^2); D) tiller density (ind./m^2); E) density of dead individuals standing (ind./m^2); F) slope declivity (º); G) altitude (m); H) track width (m); I) distance to the gully (m)

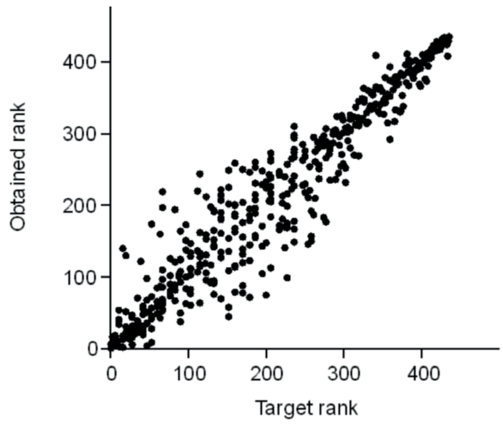

Fig. 4. Shepard stress plot of Non-Metric Multidimensional Scaling (NMDS) from the Euclidian distance, considering abundance data of the regenerating stratum in each sample unit (n=10 per distance), at the edge of trails (0 m); 20 and 40 m of the trails. Stress = 0.1567. Tijuca National Park, Rio de Janeiro, RJ. 2013

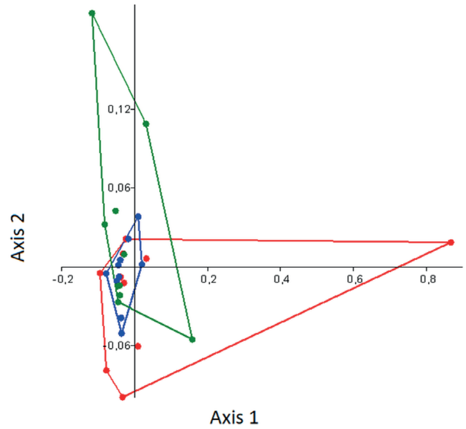

Fig. 5. Non-Metric Multidimensional Scaling (NMDS) from the Euclidian distance, considering abundance data of the regenerating stratum in each sample unit (n = 10 per distance) where in red are values from the edge of trails; in blue for 20 m; and in green for the interior of the forest. Stress = 0.1567; Axis 1 = 0.5435; Axis 2 = 0.2107; Axis 3 = 0.1079. Tijuca National Park, Rio de Janeiro, RJ. 2013

Despite this, we observed a difference between the curves of species accumulation at the edge of trails (T0) and at the distances T20 and T40 (Fig. 6). Differences were also found in the Shannon (H') and Brillouin alpha diversity indices when comparing the abundance of individuals of different species at various distances from the trails (Fig. 7).

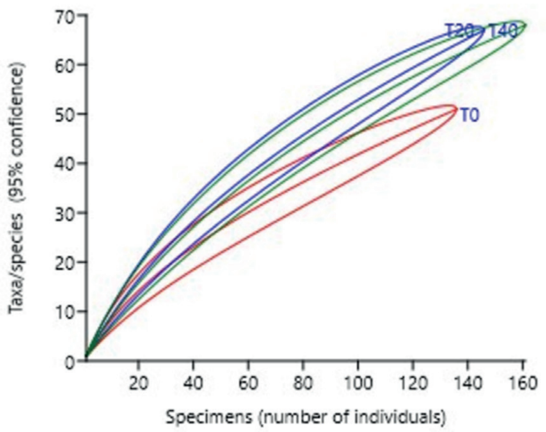

Fig. 6. Rarefaction or accumulation curves of the number of individuals by the number of species at different distances from the trails (T0 in red; T20 in blue; T40 in green). The center curves for each color represent the data for each distance. Polygons of the same colors bordering the center lines represent 95% confidence intervals. Tijuca National Park, Rio de Janeiro, RJ. 2013

DISCUSSION

Based on the analysis of physical variables, no harmful impact on the vegetation structure was detected at the regenerating stratum of the studied stretches as a consequence of the park's public use. However, the lack of differences could be integrated with a larger set of variables, which can occasionally diverge from the examined parameters.

As it was noticed in other studies (e.g. Giulietti et al. 2005; Guedes-Bruni et al. 2009; Murray-Smith et al. 2009; Myers et. al. 2000; Oliveira-Filho and Fontes 2000) and evidenced in this investigation, high floristic diversity is common in multifaceted ecosystems such as the Atlantic Forest. Although certain distinction in the investigated physical components was found, floristic composition implies a relative impact. Shannon diversity «t» tests, Rarefaction Curves and Alpha Diversity Analyzes for Shannon (H') and Brillouin indices, comparing the abundance of individuals of different species at various distances from the trails (T0, T20, T40) suggest that there are differences in the sets of species that are found in the vicinity of the trails compared to the other distances. The NMDS corroborates this result as it showed different distributions for each plot category regardless of the overlap among the three distances (Fig. 4). Furthermore, 18 unique species were found in the edge plots, i.e., ten species less than at 20 m and 12 species less than in the forest interior.

Table 2. Permutation index of species diversity indicators of the regenerating stratum (dap ≥ 1.0 ≤ 5.0 cm) for various distances from the edge. Tijuca National Park, RJ

Permutation index	T0	T20	Perm p(eq)	T0	T40	Perm p(eq)	T20	T40	Perm p(eq)
Taxa S	51	67	0.02*	51	68.00	0.06	67	68	0.95
Individuals	136	146	<0.00*	136	161.00	<0.00*	146	161	<0.00*
Dominance	0.06	0.03	<0.00*	0.1	0.04	0.01*	0.0	0.0	0.16
Shannon H	3.4	3.9	<0.00*	3.4	3.8	0.01*	3.9	3.8	0.57
Evenness e^H/S	0.6	0.7	<0.00*	0.6	0.6	0.24	0.7	0.6	0.22
Simpson Index	0.94	0.97	<0.00*	0.9	1.0	0.01*	1.0	1.0	0.16
Menhinick	4.4	5.5	0.03*	4.4	5.4	0.07	5.5	5.4	0.76
Margalef	10.2	13.2	0.01*	10.2	13.2	0.05*	13.2	13.2	1.00
Equitability J	0.86	0.92	<0.00*	0.9	0.9	0.08	0.9	0.9	0.21
Fisher alpha	29.6	47.94	0.05*	29.6	44.4	0.1	47.9	44.4	0.72
Berger-Parker	0.16	0.07	<0.00*	0.2	0.1	0.02*	0.1	0.1	0.10

The reduced dominance, together with the verified high species richness, are characteristics of a complex ecosystem in a well developed or mature successional stage (Tab. 2). Conversely, considering all distances, Chao 2 richness estimator indicates the existence of 187 species (SD = ±20.9), with a minimum of 166 species, which confirms the richness elevation model found in this study. Moreover, Jackknife 1 shows a value of 172.7 (SD = ±7.4), Jackknife 2 displays 193.3 and the Bootstrap value is 145.6.

The most frequent species from this study (Eriotheca pentaphylla) dominated in T0 and T20 and was present

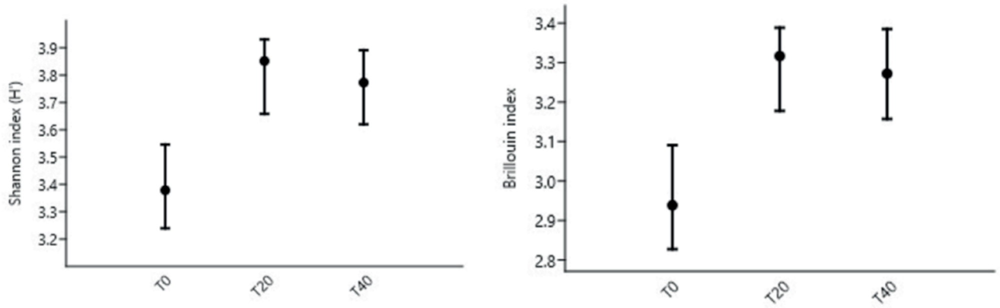

Fig. 7. Shannon (H') and Brillouin alpha diversity indices comparing the abundance of individuals of different species at various distances from the trails (T0, T20, T40). Tijuca National Park, Rio de Janeiro, RJ. 2013

at only one plot of T40. According to Fischer (1997), this could be due to its silky fibers, which promote high wind (aerodynamic) and water dispersion (lasts up to seven days floating), and maintain humidity in seeds. This could increase survival rates and intensify the number of individuals within the forest. Furthermore, the third most prevalent species was absent from the edge of trails, while the 7th most frequent species existed solely at the edge. No individuals of the 20th most frequent species were found at T40, where Simpson's dominance index is 1.6 times smaller than at the edge of trails. The value at the edges is approximately 2.2 times greater than at a 20 m distance. This can be attributed to trampling next to trails, which may impact plant tissue and result in a general decline in the reproduction of plants and their abundance (Wolf and Croft 2014). Additionally, as described by Pickering and Hill (2007), depending on the resistance and resilience of plants to trampling, the impact can extend even to modifications in the species richness (Bassett et al. 2005; Spellerberg 1998; Wolf and Croft 2014).

Machado (2012) found that there is a substantial difference when comparing the edges above and below roads at the same park. According to his study, as well as the study of Lugo & Gucinski (2000), the areas below roads are characterized by elevated water and sediments flow and higher light incidence, causing a notorious proliferation of exotic species, lower density, and greater dominance. On the other hand, Lugo and Gucinski (2000) explain that the presence of exotic species can be minimized by increasing management during the first years of settlement or by benefiting the development of mature vegetation, thus reducing local disturbance. Consequently, it is indispensable to extend these management techniques to tracks.

Moreover, as Forman and Alexander (1998) claim for roads, fauna tends to avoid linear openings, which act as a barrier and separate populations. Openings also affect the hydrological runoff of a forest, leaching out soil and generating high sedimentation downhill (Forman and Alexander 1998). Spellerberg (1998) and Pickering and Hill (2007) also cited a derivative impact of roads and trails on the transfer of spores along the openings, which increases the risk of pathogenic dispersal and could affect the most threatened species. Visitors can potentially also play the role of dispersers, disseminating seeds along tracks (Pickering and Mount 2010). This could explain the results we found for dominance, which has a slightly higher value at the edge (1.6 - 2.2 times) than in the other two plot categories (interior and T20, respectively).

Besides, the amount of light that penetrates the canopy and reaches the ground can affect ecological dynamics (Bréda 2003; Brokaw 1985). In this context, canopy openings in forest ecosystems can lead to changes in local microclimate (Pohlman et al. 2007), erosion, light availability and, consequently, growth, productivity, water consumption and composition of flora (e.g. Bréda 2003; Kunert et al. 2015). Hence, the assessment of canopy opening should also be included in the analysis of environmental impacts.

CONCLUSION

In conclusion, we did not find any evidence that proves differences in terms of structure when evaluating the regenerating tree and shrubby vegetation. However, differences in species diversity were identified when comparing the edges of trails (T0) with other distances further away (T20 and T40). This implies a disparity in species composition and distribution at the edges and therefore indicates at least a relative impact of trails in the studied site. Additionally, an increasing trend in species dominance was found in sector «A» trails of TNP for the sub-forest layer at the edges of trails with a corresponding decrease in species richness at the same distance. However, we perceive that in order to discern the effects of anthropogenic origin in complex and dynamic environments more accurately, there must be a more profound knowledge of fauna and flora richness, with the species composition being a key analysis in these types of studies. Also, seedlings and trees (DAP <10 mm and >50 mm) should be taken into account in order to have wide-ranging results on forestry composition and its impacts.

The current research also acknowledges that it is fundamental to have an accurate record of daily hikers of each track separately. Subsequently, we suggest that other sectors and segments with a large number of visitors and/or great environmental instability should be thoroughly and frequently examined and monitored. We also point out the importance of recovery and/or constant management of certain segments, possibly in alliance with hikers themselves (i.e. through an eventually developed app). This is especially crucial after heavy rain or strong wind, as some stretches we passed presented fallen trunks, marshes, intense erosion and exotic species (notably jackfruit – Artocarpus heterophyllus Lam., Dracaena fragrans (L.) Ker-Gawl., Bambusa vulgaris Schrad ex Wendl., and Coffea Arabica L.). In general, the emphasis of conservation should be on the greatest forest remnants, as suggested by Ribeiro et al. (2009).

Finally, we believe it is crucial to rigorously consider the Conservation Unit's management plan. Furthermore, in order to perpetuate the prevailing status of the regenerating forest stratum, we suggest that the actual number of visitors on the park's trails should not be increased without an accurate investigation of their carrying capacity. The width of trails should also be preserved and new activities should not be incorporated into the trails without more detailed surveys on their impact.

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