MULTIVARIATE STUDY OF EDAPHIC FAUNA TO EVALUATED SOIL RECOVERY BY REFORESTATION

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Resumo: A conversão de sistemas nativos em sistemas agrícolas convencionais tendem a promover mudanças nas características naturais do solo. Estudos que mostrem essas mudanças, principalmente quando o sistema retorna ao seu estado original, são cada vez mais necessários. Neste sentido, este trabalho teve por objetivo avaliar se a fauna edáfica é uma ferramenta sensível para inferir sobre o estado inicial de recuperação do solo de uma área reflorestada anteriormente ocupada por plantio agrícola convencional. Os experimentos foram realizados no município de Foz do Iguaçu – PR considerando uma área descoberta, uma área degradada em fase de recuperação por reflorestamento e uma área sob Floresta Atlântica Nativa. Para este tipo de avaliação foram empregadas análises de qualidade biológica do solo por meio de indicadores da fauna edáfica através de armadilhas de pitfall. As amostragens dos organismos foram realizadas para a obtenção dos índices ecológicos de abundância e riqueza de fauna. Apesar da restauração não estar completa a fauna edáfica demonstrou que o processo está em andamento sendo que a área reflorestada está mais semelhante a floresta nativa do que a área descoberta. A análise multivariada também demonstrou que fauna edáfica é um bioindicador sensível para o monitoramento de áreas em recuperação sendo capaz de interpretar e comprovar o andamento da restauração.

Palavras – chave: Bindicadores, Monitoramento, Restauração, Floresta Nativa

Abstract: The conversion of native in conventional agricultural systems to promote changes in natural soil characteristics. Studies that show these changes, especially when the system returns to its original state, are increasingly necessary. Thus, this paper aimed at evaluating if the edaphic fauna is a sensitive tool to infer about the initial state of recovery of the soil in a reforested area formerly occupied by conventional agricultural plantation. The experiment was conducted in Foz do Iguaçu (PR) considering an uncovered area, a degraded area going through a process of recovery by reforestation and under Native Atlantic Forest area. For this evaluation, biological soil quality analyzes were used, through edaphic fauna indicators collected by pitfall traps. The sampling of organisms was performed to obtain ecological index of fauna abundance and richness. Despite the restoration not being completed, the edaphic fauna showed that the process is in progress, being the reforested area more similar to the native forest than the uncovered area. The multivariate analysis also revealed that the edaphic fauna is a sensitive bioindicator for the monitoring of recovery areas, being able to interpret and prove the ongoing process of restoration.

Keywords: Bioindicator, Monitoring, Degradation, Restoration, Native Forest.

INTRODUCTION

According to the most recent data from the Brazilian Institute of Geography and Statistics, the Atlantic Forest Biome comprehends 12.5% of Brazil's total area (SOS Mata Atlantica, 2013). The states of Paraná, Santa Catarina and part of Rio Grande do Sul stand out as the main states in coverage of this forest composition. However, part of this biome has been gradually substituted by agricultural and urban areas, reducing itself throughout the years. According to the Ministry of the Brazilian Environment (Prado et al., 2014), today there is only 27% of the original area under this biome.

The conversion of the natural ecosystems into agricultural ecosystems promotes changes in the natural soil characteristics. The soil production sustaining capacity is compromised by the different kinds of use and handling it undergoes (Cardoso et al., 2013). Among the main consequences of the change in the use of natural soil due to the human action is the reduction of the vegetal cover, organic matter, raise of compression and erosion of its superficial layers.

Data from the United Nations for Feeding and Agriculture (FAO, 2011) point that around 25% of the planet's soils are already degraded. Besides that, around 5% of the world's GDP is compromised due to this degradation (UNCCD, 2013).

One of the soil recovery methods consists of reforesting the area with native species. However, the degree of soil recovery must be evaluated to adopt decisions and interfere in the process if it is necessary. The use of bioindicators as the edaphic soil fauna, is an example of this. Changes in the fauna community are associated to the environmental changes.

Ruivo et al. (2012), for example, in a study performed in Pará, applied the edaphic fauna as a bioindicator in Native and Agricultural Ecosystem Forests finding correlation between the fauna species and the physical traits of the soil. In a study carried out in China, Luo et al. (2013) concluded that the kind of vegetation and the successional stage of the reforesting cause variation in the distribution and abundance of the Coleoptera order.

In this sense, the aim of this paper was to evaluate if the edaphic fauna is a sensitive tool to infer about the initial recovery state of the soil of an forested area formerly occupied by conventional agricultural plantation.

MATERIAL AND METHODS

The study was conducted in the years 2012 and 2013 in Foz do Iguaçu, state of Paraná. According to the Köppen classification, the region's climate is characterized as tropical humid mesothermal with no defined dry season, with hot summers, offbeat frosts and rain during all the months of the year. The native vegetation is composite of Atlantic Forest. In the rural region the natural vegetation is compound of natural forest little remaining, capons and creeping plants.

The experiment was developed on Oxisol Udox with clayey texture (Soil Survey Staff, 2010) in three areas, being: one uncovered area, one degraded area in reforestation recovery stage and one native forest area.

Both the uncovered area (25°31'25''S and 54°32'57''W) and the degraded area in recovery stage (25°33'05''S and 54°31'35''W) were historically occupied by Atlantic Forest. The uncovered area has approximately 1 ha and does not have any kind of coverage since 2011; the recovery area, after the cutting off of the original native forest, had a history of use and management of soil under the conventional agricultural system with the cultivation of corn and soy beans. This was reforested in 0.25 ha in 2010, receiving five hundred seedlings of varied native species, among them the *Peltophorum dubium*, *Parapiptadenia rigida* (Benth.) Brenan, *Anadenthera colubrina* (Vell.) Brenan, *Annona sp*., *Albizia hasslerii* and *Schinus terebinthifolius Raddi*. The third area is Atlantic Forest vegetation (native) still preserved, being located beside the reforested area.

In all the areas soil biological quality analysis by means of edaphic fauna indicators were used. To do so, eight samples were established in transect form. The samples were taken

in the months of September, October and November of 2012 and May of 2013. They were obtained by the use of pitfall traps (Coleman et al., 2000).

In this method opened collectors are inserted, polypropylene glasses with 10 cm of height, put close to the soil. These were left for three days for the capture of edaphic fauna organisms. The collectors were filled ⅓ with a preservative 50% alcohol solution with some drops of detergent.

The organisms that fell into the trap were classified and counted at order level with the help of a binocular magnifying glass. With the results, the ecological abundance and richness index were calculated. Based on this, it was possible to calculate the abundance (N), which represents the total number of organisms; the richness (S), which represents the taxon number; Margalef diversity index (K), Pielou's evenness (e) and Berger Parker dominance (d) (Magurran, 1988). The Margalef diversity was calculated by the rations: K = S-1/logN, where S = richness and N = abundance. The evenness of Pielou was calculated by the formula: e =H/logS, where H = Shannon index (H= -Σ(pi log pi), being: pi = ni/S; (ni = density of each group). The Berguer Parker dominance was obtained by the ration: d = Nmax/N, where Nmax = maximum abundance of the same taxon.

For being sensitive, these fauna indicators were interpreted by means of multivariate statistics for evaluating the soil recovery level of the reforested area. The analysis used was the one of principal components (PCA), analysis of Cluster and meanings of the distances by Hotelling Bonferroni. The statistics program used was the one from the software Infostat, free version for students.

RESULTS AND DISCUSSION

The multivariate analysis of the principal components (PCA) for the studied areas showed that there was a separation between the principal components 1 and 2 (PC1 and PC2) (Figure 1). With the variability of 60%, the PC1 separated the reforestation area from the other studied areas; the PC2 separated the native forest area from the other ones responding for 40% of variability. This means that the composition of the edaphic fauna in the reforestation areas and native forest tend to become distant from the uncovered area.

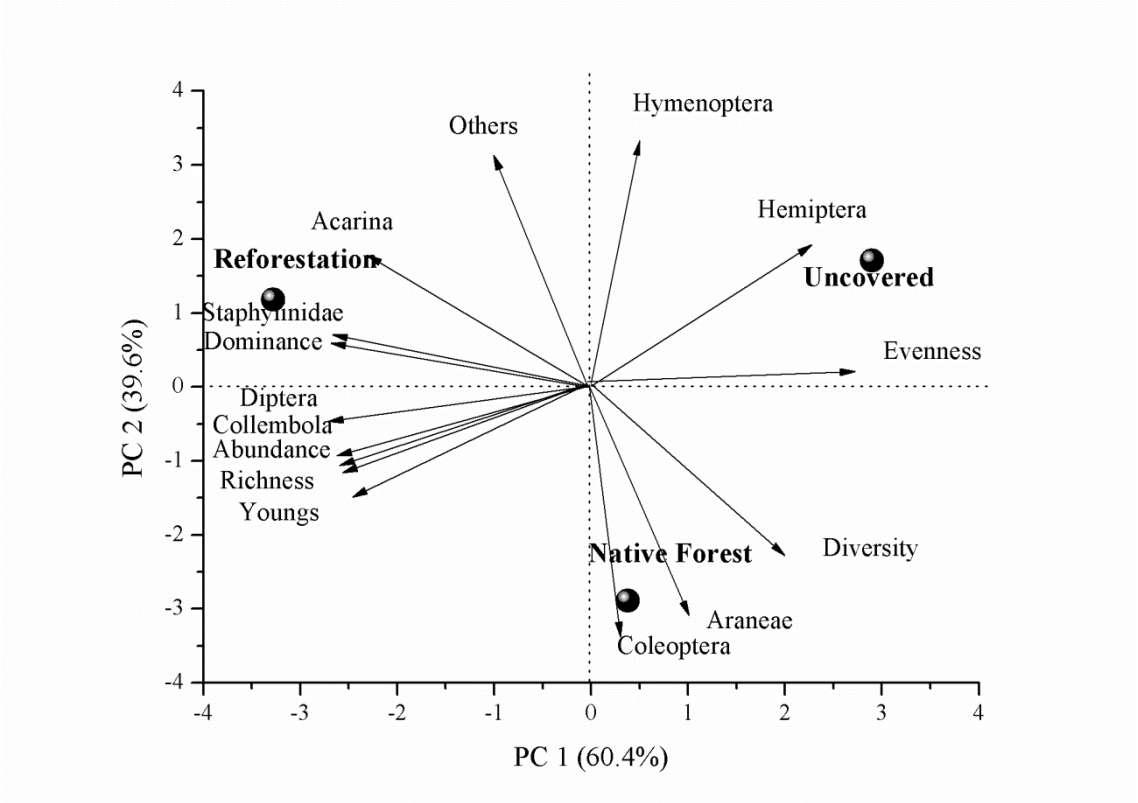

Figure 1. Principal Components Analysis (PCA) in Uncovered, Reforestation and Native Forest areas in Foz do Iguaçu, PR, Brazil.

The three areas positioned themselves in different quadrants, showing distance from the reforestation, the native forest and the uncovered area. This distance showed to be meaningful by the Hotelling Bonferroni test ($p<0.05$), which means that the soil organisms of the three areas are different.

Native forest area presented a higher number of Araneae and Coleoptera organisms and diversity index in meaningful quantities that indicate the soil richness of the studied region (Table 1). Edaphic fauna improves the fertility, macroporosity, mineralization of organic matter, structure, gas exchange, infiltration, water retention and increase in root exploration in the soil (Brévault et al., 2007). This happens because the litter formed on the forest ground serves as food and shelter for the fauna. This litter is also the precursor of the organic matter in the soil. Some orders of fauna feed on the litter while others feed on the organic matter (Fox et al., 2006). The order Aranae is made of predators while in the order Coleoptera some of the species are from this functional group. The predators are excellent environmental indicators, because they need a food net under them to support them. Besides, they regulate the preyed organisms for them not to increase the number in order not to cause environmental damage (Brévault et al., 2007). The presence or absence more specifically of these two orders is an indicator of the human intervention (Luo et al., 2013).

Table 1. Edaphic fauna distribution in Oxisol under: uncovered area, reforested and native forest; Foz do Iguaçu, PR, Brazil.

Taxon	**Reforested**	**Native Forest**	**Uncovered**

	Organisms Numbers		
Orthoptera	12	11	12
Collembola	618	546	384
Hemiptera	10	13	108
Hymenoptera	78	75	79
Coleoptera	174	246	58
Diptera	349	214	56
Acarina	27	13	15
Araneae	9	19	12
Youngs	37	34	23
Others	18	6	15
Abundance	1,342	1,177	874

The PCA revealed that the area under reforestation linked to the order Acarina beyond the dominance index (Figure 1). This result indicates that the process of recovery of soil is not completed yet. What can be explained by the lower age of reforestation that, in these three years, didn't promote enough time to express the maximum tree growth. Being so, we didn't reach the maximum level of soil coverage by the litter and, consequently, a better incorporation of organic matter. Moreover, the architecture of the plants didn't reach its potential of live protection against the climatic variations.

The changes that occurred in the edaphic environment during the years in which the area soil stayed under the agricultural use were enough to alter the organisms of the fauna. The soil use modifies the natural ecosystem causing a change in the quantity, composition and development of soil organisms according to the kind of intensity of the adopted practice. The exotic species introduction, common practice in the agricultural systems, affects the more sensitive organisms like the order Collembola (Bolger et al., 2013). The organisms of the edaphic fauna are influenced by the condition in which the soil is found, being this: organic matter, water content and presence of heavy metals coming from fertilizers used during the agricultural practices (Debeljak et al, 2007).

Nevertheless, the reforestation shares with the native forest a higher number of species such as: Young, Collembolas, Dipterous and richness and abundance index (Figure 1 and Table 1). This result suggests that the process of recovery is happening. The reforestation with plant diversity helps the increase density and diversity of the edaphic fauna (Birkhofer et al., 2011; Salamon et al., 2011; Laossi et al., 2008). According to Sautter (1991) the total soil recovery happens in three distinct stages. In the initial stage it's easily observed elements of the Collembola and Acari species, as found in the present study. In initial stage of soil recuperation it's more common to find species with dispersive abilities like the Dipterous. In a second stage, the variety of edaphic species will depend on the availability of food, habitat and soil coverage. And the third phase of recovery can be noticed when the species can survive to seasonal variations. The edaphic fauna plays an important role in the restoration of soil through the regulation of energy flows and matter that pass by trophic levels (Cardoso et al., 2013).

The use of various native species constitutes an adequate method or restoration, affecting the abundance of organisms and species as the Collembola through the quality of the litter formed and the soil physical condition (Moghimian et al., 2013). The reforestation

increases the soil permeability, promotes a humid microclimate by the steam of the evapotranspiration besides reducing the superficial flow (Pagano, 2013).

The uncovered area promoted more quantity of the order Hemiptera and Hymenoptera (Figure 1 and Table 1). In the order Hemiptera it's possible to find, in the majority, insects considered pests in grass. The lack of plants reduces the soil coverage, exposing these insects. The soil organisms are extremely sensitive to temperature variation, humidity, litter content and organic matter. Some of these animals, like the Collembolas and young forms, have bodies fragile to dehydration ad impacts coming from rain drops. The order Hymenoptera, in its turn, can indicate environmental disorders (Ribas et al., 2012).

In agricultural systems, the edaphic fauna plays a pest regulator role. However, in the lack of food and shelter in the form of organic matter, these organisms decrease significantly increasing the pests that consume live plants. Soils disturbed by anthropic action decrease the number of species and groups (Mendes et al., 2011). Uncovered soils enter in a process of compaction, because they decrease the content of organic matter coming from the plants and leave it susceptible to the impact of rain drops (Wingeyer et al., 2015). The compaction of soil causes negative effects in the fauna decreasing its abundance (Beylich et al., 2010).

In spite of the difference among the areas, the Cluster analysis by Mahalanobis distance revealed that the soil of the area in reforestation is more similar to the native forest, becoming distant from the degraded area (Figure 2). This result shows that the reforestation area is in an intermediate to advanced stage in the process of soil recovery.

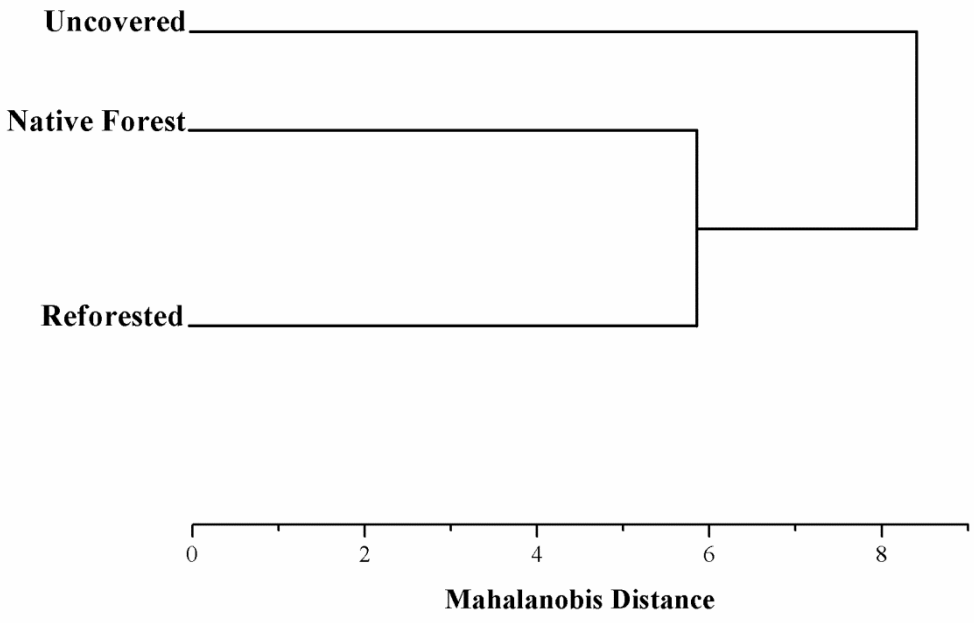

Figure 2. Analysis of Cluster in Uncovered, Reforestation and Native Forest areas in Foz do Iguaçu, PR, Brazil.

This way, according to the species found in the reforested area, the present study showed that, although a full biological soil recovery hasn't happened yet, the process is in progress, what seems to comply with the goals of the adoption of reforestation as a regenerator of degraded soils. Areas where there is a total removal of the surface layer, the edaphic fauna restructures itself in a slow and gradual form, as the vegetation develops and offers suitable conditions for this fauna to reestablish (Araújo et al., 2015).

The eigenvectors showed that, in general, all the organisms identified took part in the differentiation of the areas (Table 2). However, it was possible to notice that the groups Dipterous, Collembola, Youngs and the index of Dominance, Abundance, Richness and Evenness in a higher proportion exerted differentiation in the areas of PC1, responding for the separation of the reforested area from the other ones. Inversely, the groups Hymenoptera, Coleoptera, Orthoptera, Aranae, other less frequent orders and the Diversity index were the principal responsible for the separation for the environments in PC2, between Native Forest and Uncovered Area. These results seem to indicate such groups as more specific bioindicators when compared to the others that promoted the proportional separation in both components. It's important to understand that the changes happened in soil are felt in a different way by the edaphic organisms (Cardoso et al., 2013).

Table 2. Eigenvalues of edaphic fauna in Oxisol under: uncovered area, reforested and native forest; Foz do Iguaçu, PR, Brazil.

Variables	**Eigenvalues**	
	PC 1	**PC 2**
Diptera	-0.32	-0.06
Coleoptera	0.04	-0.39
Hymenoptera	0.06	0.39
Collembola	0.30	0.13
Araneae	0.12	-0.37
Orthoptera	-0.01	0.40
Acarina	-0.27	0.21
Hemiptera	0.26	0.23
Young	-0.29	-0.18
Others	-0.12	0.37
Richness	-0.30	-0.14
Abundance	-0.31	-0.11
Dominance	-0.31	0.07
Diversity	0.24	-0.27
Evenness	0.32	0.02

CONCLUSIONS

Although the restoration is not complete the edaphic fauna showed that the process is in progress and the reforested area is more similar to the native forest than the uncovered area.

The edaphic fauna showed to be a sensitive bioindicator for monitoring the recovery areas.

The multivariate study of the edaphic fauna was able to interpret and prove the progress of the recovery.

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