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Characterization of soil fauna under the influence of mercury atmospheric deposition in Atlantic Forest, Rio de Janeiro, Brazil

Andressa Cristhy Buch[1,*], *Maria Elizabeth Fernandes Correia*[2], *Daniel Cabral Teixeira*[1], *Emmanoel Vieira Silva-Filho*[1]

1. *Departamento de Geoquímica, Universidade Federal Fluminense, Niterói, RJ 24020-007, Brazil. E-mail: andressabuch@hotmail.com*
2. *Embrapa Agrobiologia, BR 465 km 7, Seropédica, RJ 23890-000, Brazil*

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ABSTRACT

The increasing levels of mercury (Hg) found in the atmosphere arising from anthropogenic sources, have been the object of great concern in the past two decades in industrialized countries. Brazil is the seventh country with the highest rate of mercury in the atmosphere. The major input of Hg to ecosystems is through atmospheric deposition (wet and dry), being transported in the atmosphere over large distances. The forest biomes are of strong importance in the atmosphere/soil cycling of elemental Hg through foliar uptake and subsequent transference to the soil through litter, playing an important role as sink of this element. Soil microarthropods are keys to understanding the soil ecosystem, and for such purpose were characterized by the soil fauna of two Units of Forest Conservation of the state of the Rio de Janeiro, inwhich one of the areas suffer quite interference from petrochemicals and industrial anthropogenic activities and other area almost exempts of these perturbations. The results showed that soil and litter of the Atlantic Forest in Brazil tend to stock high mercury concentrations, which could affect the abundance and richness of soil fauna, endangering its biodiversity and thereby the functioning of ecosystems.

Introduction

Currently, seventeen countries are considered megadiverse, by containing 70% of the world's biodiversity. Brazil is the first for harboring between 15% and 20% of the biological diversity of the planet and the largest number of endemic species, the largest tropical forest (the Amazon) and two of the nineteen hotspots worldwide (the Atlantic Forest and the Cerrado). The Atlantic Forest Biome extending through fifteen Brazilian states (totalling approximately 1,105,000 km^2 of continental extension) is the fifth most endangered forest area of the planet. In the state of Rio de Janeiro, only 20% is preserved (INPE, 2013), although in a fragmented and localized way. The biodiversity of these biomes has been degraded due to anthropogenic activities such as industry, which emit pollutants, compromising the quality of atmospheric, aquatic and terrestrial ecosystems, leading to an accelerated loss of species. The mercury (Hg) stands out among the global pollutants due its ease of dispersion and toxicity, since it can stay in the atmosphere for about 0.5–2 years (Liang et al., 2014). Approximately 4070 tonnes of mercury is introduced in the Earth's atmosphere every year (Mason et al., 1994; UNEP, 2013). Environmental variables such as rainfall, temperature, wind and solar radiation can influence in the Hg enrichment in forest soils. According to Sigler and Lee (2006) the increase of soil and air temperature were directly associated to promote greater Hg deposition, while factors as solar

* *Corresponding author.*

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radiation and water vapor did not influence the deposition. Teixeira (2008, 2012) showed negative correlation between the wind speed and rainfall. Fire (Dicosty et al., 2006; Melendez-Perez et al., 2014) and CO_2 concentration (Natali et al., 2008) have been also reported to collaborate with the high Hg deposition in forests. Most of the Hg input to ecosystems is through atmospheric deposition (Niu et al., 2011) coming from anthropogenic and natural sources and may be deposited into a forest canopy in gaseous and aerosol forms (Lindberg et al., 2007). Forest canopies can uptake atmospheric Hg more rapidly than other landscapes due to their large leaf areas and rough surfaces (Risch et al., 2012). The dry deposition velocity to forests for the Hg species (in order of relative abundance—gaseous elemental, oxidized or reactive, and particulate of Hg) can be 2–5 times larger than in other vegetated or non-vegetated surfaces (Zhang et al., 2009). This trace element has been found in litter, in Brazil in Atlantic Forest (Silva-Filho et al., 2006; Teixeira et al., 2012), and in China in Subtropical Mixed Forest (Wang et al., 2009) in the largest concentrations reported worldwide.

The Hg stock in litter to the horizon O (organic) in the soil is directly proportional to the quantity of produced litter (Silva-Filho et al., 2006), and this deposition is mainly related to weather, deposition in cold regions are weaker than in warm regions. Litter is one of the biggest sources of Hg accumulation in forest soils, affecting the terrestrial and aquatic trophic chain (Tabatchnick et al., 2012). The forest biome has a huge relevance in the elemental (Hg^0) atmosphere/soil cycling through leaf capture and posterior transference to soil by the litter (Grigal, 2002). The atmospheric deposition in forest areas can represent an important local sink in the biogeochemical cycle of this element (Lyman and Jaffe, 2012). Moreover, because it is a global pollutant, the effect of this sequestration could affect regional and even global background values.

Through litter decomposition the Hg is incorporated to the soil, which is considered as the environment that has the major biodiversity of the planet. Hundreds of thousands of species of invertebrates live in this environment, which have been playing important functions in the terrestrial ecosystems, fundamental for decomposition and mineralization processes of the organic matter and providing a series of environmental services for humans, with value estimated in hundreds of billions of dollars per year (Van Der Putten et al., 2004). Those services are being threatened by the ignorance of such animals and their importance, and by the progressive alteration of their natural habitats caused, among other factors, by soil contamination. Thus the soil edaphic fauna is a key tool to understanding the anthropogenic impacts in the environment. In this context, the qualitative and quantitative variations of the fauna can reflect the loss or diminishing of determined groups of the fauna, as well as, of the population and of specific species.

Due to the scarcity of studies assessing the ecological risk of atmospheric Hg deposition for edaphic fauna in tropical forest biomes, this work is based and focuses on the quantification of Hg levels in litter and soils, coming from atmospheric deposition, and the characterization of the fauna of two Units of Conservation of Atlantic Forest in the Rio de Janeiro state, Brazil.

1. Material and methods

1.1. Characterization of the forest areas

The study was performed in two Units of Forest Conservation (UFCs) of the state of Rio de Janeiro in Brazil, Três Picos State Park (Latitude: 22°35′52.24″S, Longitude: 43°14′21.15″O, altitude: 74 m) and Taquara Municipal Natural Park (Latitude: 22°30′ 8,76″S, Longitude: 42°51′21.95″O, altitude: 72 m). The first park is considered an urban forest and is located in an industrial zone at 12.4 km from a big petroleum refinery, which was activated fifty-two years ago and still works. The second park is inserted in a rural zone, away from industrial activities and at 18.2 km from the largest petrochemical complex in Brazil, which is under construction, beginning its functioning in 2016. The choice of these areas was based on the following factors: (1) the distance lower than 40 km of the possible Hg emission sources, since the largest rate of deposition occurs in these perimeter (Schroeder and Munthe, 1998); (2) the wind direction from the emitting source to the forests, South to North; (3) the similarity in the phytophysiognomy of the vegetation in the chosen altitudes, being both Lowland Rain Forest Dense; (4) the soils of the sampling of fauna and total mercury to the UFCs are of the same category, classified as Dystrophic Haplic Cambisol (Ta), according to EMBRAPA (2013); and (5) same geologic formation, being Santo Aleixo Unit, composed of garnet–hornblende–biotite granodioritic, rich in xenolits of paragneisse partially molten. This geology has no mercury in its composition (Guimarães, 1999).

According to the Köppen classification (1936), the climate in the region, for the two UFCs is Aw, hot and humid, with an average annual temperature of 24°C, and an average annual precipitation of 1299 mm in Taquara Municipal Natural Park (T), and 1473 mm in Três Picos State Park (P).

1.2. Physico-chemical analysis of the soil

For each UFC 20 sub-samples of soil of 20 cm depth were collected, with the aid of a Dutch auger, forming a composite sample of 500 g of soil. The analysis was performed in the Brazilian Agricultural Research Corporation — EMBRAPA — Agrobiologia, following the methods of physico-chemical analysis of the soil described in Nogueira and Souza (2005).

1.3. Characterization and quantification of accumulated litter

For quantification and characterization of accumulated litter, eight litter samples were collected using a square mold of 0.5 m^2, randomly placed in forest areas. The samples were dried in the lab oven at 65°C, and posteriorly separated and classified according to their stages of fragmentation: (1) layer of leaves non-fragmented (L portion); (2) layer of leaves fragmented (F portion); and (3) layer of humus, advanced stage of decomposition (H portion).

1.4. Analysis of mercury

For the determination of total Hg concentration in litter and soil, the samples were prepared by mechanical grinding.

After being homogenized, approximately 1.0 g of each sample was submitted to an acidic extraction in a 3:1 of $HCl:HNO_3$ solution. Cold Vapor Atomic Absorption Spectrophotometry (CVAAS) was used for Hg determination, after Hg^{2+} reduction to volatile Hg^0 with $SnCl_2$, according Lechler et al. (1997).

1.5. Sampling methods of soil fauna

The sampling of the soil microarthropods was carried out during the month of November 2013. Three sampling methods of soil fauna were employed for each UFC in sixteen collection points distributed every 2 m. The first method aimed to sample the mesofauna (invertebrates 100 μm–2 mm in length), and the methodology of sampling and extraction was based on the technique described by Aquino and Correia (2006), using modified Berlese–Tullgren funnels. Samples of litter and soil were collected at 0–10 cm of depth. The second method employed, consisted in the use of pitfall traps (Mommertz et al., 1996), with the aim to sample meso and macrofauna more active, resident in the soil–litter interface. The pitfall traps consisted of plastic recipients (diameter = 8 cm; height = 12 cm) buried in the ground with its rim at surface level, containing 100 mL of preservative solution, alcohol (70%). The traps remained in the field for 7 days. The last method used was TSBF (Tropical Soil Biology and Fertility), developed by Anderson and Ingram (1993), to collect the macrofauna (invertebrates larger than 10 mm in length) (Aquino and Correia, 2005). This principle constitutes in the hand-sorting of litter and soil at 0–10 cm and 10–20 cm of depth, at the exact moment of sampling and separation of soil horizons. Specimens collected, in the three sampling methods, were quantified and identified in the laboratory in petri dishes under binocular microscope, at the level of taxonomic groups and families. Only the more predominant taxonomic groups in the samples were identified at the family level. The percentage proportion of the families was estimated by the sum of the specimens found in litter and soil samples, performed by the three sampling methods.

1.6. Ecological index

The calculation of the ecological indexes was measured according to the total number of individuals to estimate the abundance, and the richness of organisms to estimate the Shannon diversity index (H) (Magurran, 1988) and equitability of Pielou (e) (Begon et al., 1996).

1.7. Statistical analysis

The results of ecological indexes were subjected to analysis of variance and average comparison, between each UFC, through the application of the Tukey test at $p < 0.05$. Posteriorly, the data of fauna and chemical–physical properties of soil and litter, including the concentration of mercury were analyzed by multivariate statistical analysis by Principal Component Analysis (PCA), as a linear ordering technique, used to understand the differences between fauna in the UFCs correlating with environmental variables. The analysis was performed by the software CANOCO version 4.5.

2. Results and discussion

2.1. Physico-chemical characterization of the soil

The chemical characteristics of the soil are important functional indicators, because it synthesizes the process of decomposition and mineralization of organic matter, which occurs in forests, mainly in the soil (Pessoa et al., 2012). Soils of the tropical regions are generally very acids and have low fertility, showing relatively high potential of nutrient lixiviation. The high production of biomass of these forests and its maintenance require large amounts of nutrients. Part of these nutrients, after a certain development phase of the forest, is supplied by cycling process, whose dynamics and magnitude of contribution change with the forest ecosystem (Gama-Rodrigues et al., 2008).

The physico-chemical results of the soils did not show relevant differences among the parameters evaluated, showing similarity in the values for the two UFCs (Table 1).

2.2. Accumulated litter

The litter changes its structure during the decomposition process, serving as food and habitat to microarthropods, besides being a regulatory element of the own fauna. The average values of accumulated litter were similar to the two UFCs, being of 5 ± 0.34 Mg/ha for Três Picos State Park (P) and 5.13 ± 0.19 Mg/ha for Taquara Municipal Natural Park (T). Similar values were found by Mateus et al. (2013) in studies performed in areas of Atlantic forest in the state of Rio de Janeiro, reporting accumulated litter of 5.15 ± 1.51 Mg/ha. Research of Espig et al. (2009) reported that in various forest formations of tropical regions the amount of accumulated litter ranged between 4.0 and 25.3 Mg/ha/year.

Regarding the stage of decomposition of litter, the UFCs also presented similar values for non-fragmented leaves (L) being 1.44 ± 0.25 Mg/ha for P and 1.71 ± 0.32 Mg/ha for T, as well as for fragmented leaves (F) with values of 2.63 ± 0.38 Mg/ha for P and 2.93 ± 0.21 Mg/ha for T. On the other hand, P showed slightly higher values of the humus layer, referring to advanced stage of decomposition (H) of 0.94 ± 0.14 Mg/ha, whereas in T average values of 0.40 ± 0.11 Mg/ha were observed.

2.3. Mercury concentration in litter and soil

Forest soils are considered efficient storage pools for atmospheric Hg, retaining up to 90% or more of deposited Hg, in mineral soil layers and litter (Gong et al., 2014). The average storage of total Hg concentration in litter was 240 ± 18 ng/g for T, being six times higher than in P (Table 2). This high concentration is possibly associated with the mercury atmospheric deposition once that in the regional geology of the UFCs, the source material is exempt of mercury in its composition. According to recent studies Hg deposition through literfall in tropical forests can be greater than temperate and boreal areas where deciduous vegetation is frequently dominant, since there are evidences that Hg accumulates with increasing foliar age, and canopies of tropical forests tend to be more efficient filters of atmospheric Hg than temperate forest canopies (Millhollen et al., 2006; Silva-Filho et al., 2006; Gong et al., 2014). In temperate

Table 1 – Physico-chemical characteristics of soils, of the Units of Forest Conservation (UFCs). M: moisture; P: Três Picos State Park; T: Taquara Municipal Natural Park.

UFC	pH	Al (cmolc/dm^3)	Mg (cmolc/dm^3)	Ca (cmolc/dm^3)	H + Al (cmolc/dm^3)	K (mg/L)	P (mg/L)	M (%)	C (%)	N (%)	Sand (%)	Silt (%)	Clay (%)
P	3.97	1.48	0.12	0.02	9.06	27	1.58	17.61	1.42	0.18	50	15	35
T	4.14	1.69	0.10	0.01	9.24	30	1.68	19.57	1.5	0.16	53	15	32

M: moisture; P: Três Picos State Park; T: Taquara Municipal Natural Park.

forests the stored total mercury concentrations ranged between 2.6–58 ng/g (Grigal, 2002; Sheehan et al., 2006) and in boreal of 40–70 ng/g, values that tend to be smaller than in tropical forests, being 52–205 ng/g (Almeida et al., 2005; Niu et al., 2011; Teixeira et al., 2012; Zhou et al., 2013). However, the relative importance of vegetation type and morphophysiological characteristics to mercury stock within forested systems is not well known.

In the soil, for three depths evaluated, the difference of average mercury concentrations between the UFCs was not as expressive as in litter. Nevertheless, in T the values were three times larger than in P, being the decreasing values according to the depth (Table 2). This decrease in the Hg concentration in accordance with increasing depth was also reported by Zhou et al. (2013) and Wang et al. (2009) being larger the Hg levels in the upper layer (±263.1 ng/g) than in the lower layers (±83.9 ng/g), suggesting a strong chemical affinity of this trace element with organic matter, in addition to being adsorbed on mineral surfaces, iron and aluminum oxy-hydroxides (Seigneur et al., 1998; Hissler and Probst, 2006; Richardson et al., 2013; Burns et al., 2014).

Arising from atmospheric deposition, the higher levels of mercury described in this study in the T, may be related to the proximity of anthropogenic sources in the region, small industries and big oil refinery, whereas in P anthropogenic influence is much smaller. However, we cannot fail to mention, that this region possibly will suffer a large increase of deposition of Hg, because it is located close to a large petrochemical complex (the Brazil's largest), which will become operational as from 2016.

2.4. Soil fauna

2.4.1. Sampling methods of soil fauna and Ecological índex

The abundance of soil fauna differed significantly ($p < 0.05$) between the two UFCs in litter and soil for sampling by Berlese, showing for P an abundance of mesofauna almost twice bigger than in T. The population of the taxonomic groups of Acari and Collembola was higher when compared to the twenty-four other groups found in the Berlese and Pitfall methods, in soil and litter, representing an average of 90% of the total population of the mesofauna sampled in P, and in T representing an average of 70% (according Table 3). In P the Acari group was on average represented by suborders Oribatida (58%), followed by Mesostigmata (19%), Prostigmata (14%), and Astigmata (4%) and 5% was represented by other suborders present in less than 1%. In T the suborders Oribatida (50%), followed by Mesostigmata (30%), Prostigmata (11%), and Astigmata (4%) prevailed and 5% was represented by other suborders, present in less than 1%. The Oribatida mites usually have little ability to respond to environmental changes in the short-term, and their populations decrease rapidly when the habitats are modified; such characteristic may allow its use to detect environmental degradation (Behan-Pelletier et al., 1993).

Table 2 – Average Hg concentration in the litter and soil of the Units of Forest Conservation (UFCs).

UFC	Hg (ng/g)			
	Litter	Soil (0–10 cm)	Soil (10–20 cm)	Soil (20–30 cm)
P	40 ± 2	50 ± 4	40 ± 7	20 ± 3
T	240 ± 18	140 ± 9	120 ± 15	80 ± 8

P: Três Picos State Park; T: Taquara Municipal Natural Park.

In the Collembola group the families were identified, where on average 64% corresponded to the sum of Entomobryidae with Isotomidae in both UFCs. Additionally in P, 20% corresponded to Poduridae, 10% to Sminthuridae and 6% was represented by other families, present in less than 1%. In T 26% corresponded to Poduridae, 7% to Sminthuridae and 3% was represented by other families, present in less than 1%. In forest soils, in Germany, the density of Isotomidae was significantly reduced in disturbed sites, whereas Entomobryidae did not decline in population, suggesting that the first family has greater sensitivity to environmental changes (Maraun et al., 2003). The presence or absence of certain species may be related to changes in pH, availability of nutrient and water and the presence of pollutants such as heavy metals (Cassagne et al., 2003; Santamaría et al., 2012). According to Das and Joy (2009) the litter quality is closely related to the abundance and distribution of Collembola.

The third largest taxonomic group identified in T, in the Berlese and Pitfall methods, was Hymenoptera representing 7% of the total fauna, being exclusively belonging to the family Formicidae. Already in P was sampled less than 1.5% in these methods, contrary to TSBF method where the average population was 11%. The specimens of Hymenoptera found in the three methods in P belonged to six subfamilies of Formicidae, being Myrmicinae (42%) as the most abundant, followed by Formicinae (18%), Ponerinae (11%), Ecitoninae (8%), Dolichoderinae (3%), Ectatominae (2%) and 16% was not known or was represented by other families present in less than 1%. The specimens of the sampling methods in T were represented by 67% of Myrmicinae, 13% of Ecitoninae, and 6% of Formicinae and 14% was not known or was represented by other families present in less than 1%. The subfamilies Myrmicinae and Formicinae are cosmopolitan and of wide geographic distribution, besides sundry, are dominant in both numbers of "workers" and of colonies as in biomass, being frequent in diverse habitats (Coelho and Ribeiro, 2006). Furthermore, the presence of ants may be associated with degraded areas and disturbed environments as in urban

Table 3 – Relation quantitative of the taxonomic groups in the sampling methods carried out in UFCs.

Groups	Berlese				Pitfall		TSBF					
	PL	TL	PS1	TS1	P	T	PL	TL	PS1	TS1	PS2	TS2
Acari	62.31	49.67	71.75	67.96	33.77	24.71	0.00	0.00	0.00	0.00	0.00	0.00
Amphipoda	0.00	0.10	0.00	0.05	0.10	1.47	0.00	0.00	0.00	0.00	0.00	0.00
Araneae	0.57	1.33	0.38	0.44	0.89	1.31	6.11	6.52	2.22	1.90	0.00	0.00
Archaeognatha	0.11	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Blattodea	0.00	0.29	0.00	0.00	0.00	0.32	0.00	2.17	0.00	0.00	0.00	0.00
Chilopoda	0.23	0.19	0.15	0.05	0.05	0.11	4.63	1.45	2.22	0.00	1.00	0.00
Coleoptera	0.97	1.72	1.03	2.36	1.67	10.83	18.67	29.71	20.22	29.97	17.75	12.43
Collembola	32.38	36.32	23.64	18.76	59.25	51.79	0.00	0.00	0.00	0.00	0.00	0.00
Dermaptera	0.06	0.10	0.00	0.00	0.00	0.00	2.93	0.00	1.11	0.00	0.00	0.00
Diplopoda	0.29	0.10	0.08	0.00	0.57	0.37	14.48	3.62	14.11	10.99	5.70	1.43
Diplura	0.17	0.00	0.08	0.05	0.31	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Diptera	0.34	2.10	0.15	0.66	0.42	0.79	4.26	13.04	7.78	9.09	9.88	8.71
Earthworms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00	20.78	44.44	16.57
Enchytraeids	0.06	0.10	0.53	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteroptera	0.11	0.19	0.08	0.11	0.10	0.00	3.78	0.72	2.22	2.60	2.47	1.43
Homoptera	0.06	0.00	0.08	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00
Hymenoptera	0.68	6.67	0.65	7.68	1.20	6.78	16.93	30.43	5.57	6.49	2.47	50.00
Isopoda	0.68	0.29	0.46	0.05	0.47	0.11	11.04	2.90	11.44	2.60	13.28	1.43
Isoptera	0.00	0.19	0.00	0.71	0.00	0.00	0.00	0.00	0.00	11.69	0.00	8.00
Neuroptera	0.06	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opiliones	0.23	0.00	0.08	0.00	0.52	0.47	6.48	5.07	0.00	0.00	0.00	0.00
Orthoptera	0.07	0.10	0.00	0.05	0.16	0.68	8.70	4.35	3.11	3.90	1.00	0.00
Protura	0.17	0.10	0.15	0.00	0.21	0.16	0.00	0.00	0.00	0.00	0.00	0.00
Pscoptera	0.06	0.10	0.23	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudoscorpiones	0.29	0.00	0.15	0.00	0.31	0.05	1.00	0.00	0.00	0.00	0.00	0.00
Symphyla	0.06	0.10	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanoptera	0.06	0.19	0.15	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

P: Três Picos State Park; T: Taquara Municipal Natural Park; L: litter; S1: 0–10 cm depth; S2: 10–20 cm depth. The amount is expressed in percentage.

forests, once they are sensitive bioindicators of the environmental changes and play important roles in monitoring ecosystem functions, including interactions with other organisms at every trophic level (Alonso and Agosti, 2000). The greatest amount of ants was sampled by pitfall method, nevertheless the epigeic ants were better sampled by TSBF method.

Although not present in larger proportions when compared to other taxonomic groups sampled by Pitfall, the specimens of Amphipoda were identified due the amount sampled and because they are common in the UFCs evaluated in this study. Therefore the amphipods were classified as the species *Talitroides topitotum* (Burt, 1934) belonged to the family Talitridae. Anthropogenic interferences in natural environments cause the breakage of spatial and competitive barriers, which may influence the spatial distribution of this exotic species (Matavelli et al., 2009; Uehara-Prado et al., 2009). On the other hand, Hurley (1968) mentions that the soil characteristics such as moisture, would be of greater influence in this order.

In the TSBF method, the population in the litter was similar in the two UFCs, although slightly higher in T, due to strong abundance of Coleoptera (≈30%) and of Hymenoptera (≈30%). In P the presence ≈ 9% of Orthoptera (80% composed by family Gryllidae) is highlighted. In the depths of the soil of 0 to 20 cm, the majority of the macrofauna found in P belonged to the taxonomic groups of Haplotaxida (37%), being composed exclusively of earthworms, Coleoptera (19%), Isopoda (12%) and Diplopoda (10%). In T the preeminent presence was of Hymenoptera 28% (formicidae), followed by Coleoptera ≈ 21%, Haplotaxida 19% (earthworms), Isoptera (10%) and Diptera (9%), according to Table 3.

In both UFCs the earthworms found belonged to the family Glossoscolecidae and all species were identified as *Pontoscolex corethrurus*. These endogeic earthworms are commonly found in forest soils of the state of Rio de Janeiro and have strong affinity for the anthropic environments, as urban and agricultural soils (Brown et al., 2006, 2010).

The families of Coleoptera found in P were Nitidulidae (13%), Scarabaeidae (12%), Chrysomelidae (11%), Geotropidae (10%), Scolytidae (10%), Tenebrionidae (9%), Staphylinidae (7%), Carabidae (7%), Coccinelidae (3%), Cantharidae (3%), Cerambycidae (2%), Corylophidae (2%), Curculionidae (2%), Elateridae (2%), Meloidae (2%), and Scydmaenidae (2%) and 3% was represented by other families present in less than 1%. In T Scarabaeidae (27%), Nitidulidae (23%), Geotropidae (20%), Staphylinidae (19%), and Tenebrionidae (7%) were found and 4% was represented by others families present in less than 1%. Scarabaeidae beetles have been widely proposed as cost effective bioindicators because they are sensitive to environmental imbalances, easily sampled, broadly distributed, and their taxonomy and ecology are relatively well known in tropical forests (Kadiri et al., 1997; Bett et al., 2014).

With regard to Isopoda, in P the following families were found: Porcellionidae (52%), Armadillidiidae (18%), Oniscidae (16%), Armadilidae (4%), and Philosciidae (4%) and 6% was not known or was represented by other families present in less than 1%. In T 89% corresponded to the Porcellionidae and

11% the Oniscidae. Some species as *Armadillidium vulgare* (of the family Armadillidiidae), *Armadillo* spp. (of the family Armadilidae) and *Porcelio scaber* (Porcellionidae) are found disseminated around the world, occurring in various habitat types (Correia et al., 2008), considered excellent bioindicators of soils, contaminated with pesticides and heavy metal (Vink et al., 1995).

The presence of the Diptera group in P was less than 2% in the Berlese and Pitfall sampling methods, and only in TSBF method was a population of 7% found, with all the specimens belonging to the family Calliphoridae. In contrast to that found in T, wherein 89% of these populations belonged to the superfamily Muscoidea (most of the family Calliphoridae) and 11% Drosophiloidea. The super family Muscoidea is commonly found in forest regions (Marinho et al., 2006) and it has great capacity of geographic expansion (Paraluppi and Castellon, 1994), beyond subtle ability to locate ephemeral resources in a long distance (Greenberg, 1973), being sensitive bioindicators of the anthropogenic interference (D'Almeida and Lopes, 1983) and with ecological importance in research medico-sanitary and forensic (Gomes and Zuben, 2005).

Approximately 79% of the population of Diplopoda sampled in P, belonged to the family Trigoniulidae, 13% to Spirostreptidae, 6% to Rhinocricidae and 2% to other families. In T there was a predominance of a single family, Trigoniulidae (100%). Hobbelen et al. (2006) showed that the soil pollution by Cd, Cu and Zn is a dominating factor to species richness and abundance, being still detritivore groups, as Isopoda and Diplopoda able to endure or resist the amount of metals in the organic matter.

The identification of the family of Isoptera was performed only in the specimens of T, because in P the population was less than 1%. In T 75% of the specimens belonged to the family Termitidae and 25% to Kalotermitidae. According to Eggleton (2000) the assemblages of termites (Isoptera) would be associated with environmental characteristics such as altitude, temperature, rainfall and vegetation type with the occurrence of other groups and orders of soil fauna. Further, tropical forests would be susceptible to changes in habitat.

The diversity indexes of Shannon (H) and Uniformity of Pielou (e), together with richness and abundance, were statistically distinct to the UFCs and showed higher values for P in the three sampling methods, with exception to the values of abundance and richness of the taxonomic groups that were similar in Pitfall method (Table 4). The diversity of the families also was significantly greater in P, in comparison to T.

The composition of the soil fauna reflects the functioning of the ecosystem due to their close association with the processes that occur in the litter–soil interface, being very sensitive to environmental changes (Correia and Pinheiro, 1999). Interventions in the vegetation cover will imply alterations in population density of certain taxonomic groups and in the diversity of these fauna, causing a decrease or disappearance of some groups, and depending on the group may be indicative of particular or environmental condition established (Büchs, 2003; Audino et al., 2014). Soil moisture content, nutrients, soil pH and organic matter are important factors for the distribution of soil arthropods (Kim and Jung, 2008). The results of the ecological indexes of the UFCs could be differing due to physical and chemical properties of soil, vegetation and altitude, but in this study these environmental variables are very similar, suggesting that such differences could be associated with the mercury deposition in soil and litter, as well as other factors not investigated, which could also influence.

2.4.2. Multivariate analysis

Multivariate statistical analysis has been reported as a powerful tool to investigate the main environmental variables that can be correlated with dispersion and association of taxonomic groups, be it in forests that have been devastated by fire (Kim and Jung, 2008), or in areas of different systems of agricultural crops (Alves et al., 2006), or still in forests that are prone or have suffered some level of contamination (Zaitsev et al., 2014).

The relationship between the soil fauna and the environment variables analyzed in this study can be visualized through the Principal Component Analysis (PCA). Axes 1 and 2 explained 48.4% and 24.5% of total data variability, respectively, by the Berlese method in litter (Table 5). In this sampling method (Fig. 1a), the taxonomic groups Hymenoptera and Diptera were positively correlated with the mercury concentration. For Pitfall method (Fig. 1c), the axis 1 explained 73.2% and the axis 2 5.9% (Table 5), and Amphipoda, Diptera and Coleoptera groups were

Table 4 – Ecological indexes to UFCs for the three sampling methods of soil edaphic fauna.

Method	UFC	Depth	Abundance [2]	Richness [3]	Shannon (H)	Pielou (e)
Berlese	P	Litter	46623 a [1]	23 a	1.80 a	0.51 a
	T		26089 b	21 b	1.38 b	0.31 b
	P	0–10 cm	68435 a	22 a	1.52 a	0.37 a
	T		45339 b	17 b	1.20 b	0.17 b
Pitfall	P	Litter	54 a	16 a	2.05 a	0.51 a
	T		49 a	16 a	1.18 b	0.45 a
TSBF	P	Litter	316 a	13 a	2.76 a	0.94 a
	T		216 b	11 b	1.40 b	0.41 b
	P	0–10 cm	190 a	11 a	2.79 a	0.81 a
	T		154 b	10 a	2.14 b	0.51 b
	P	10–20 cm	172 a	11 a	2.29 a	0.98 a
	T		140 b	8 b	1.65 b	0.52 b

[1] Average values followed by same letters in the same column do not differ from the Tukey ($p < 0.05$), for the same sampling methods.
[2] Abundance: number of individuals per m^2 for Berlese and TSBF methods, and number of individuals $trap^{-1}$ day^{-1} for Pitfall.
[3] Richness: total number of taxonomic groups.

Table 5 – Correlation of environmental variables found in the sampling methods with PCA axes.

Depth	Variable	TSBF		Berlese		Pitfall	
		AX1	AX2	AX1	AX2	AX1	AX2
Litter	Hg	0.6477	0.4885	0.5233	−0.3260	0.9292	0.1716
	L	0.1370	0.5775	0.3394	−0.5222	0.6223	−0.2889
	F	0.5901	−0.0891	0.4269	−0.4895	0.4406	0.0735
	H	−0.6832	−0.1232	−0.1751	0.3346	−0.6354	−0.3793
	Relation*	47.4	71.4	48.4	72.9	73.2	79.1
Soil 0–10 cm	Hg	0.8071	0.1075	0.8318	−0.0586	–	–
	Moisture	0.7913	0.1604	0.6554	−0.0890	–	–
	C	0.0011	0.0013	0.0152	0.1270	–	–
	Al	0.1051	−0.1645	0.3052	−0.3238	–	–
	Mg	−0.3225	−0.4952	0.0715	−0.0526	–	–
	Ca	−0.5154	−0.1781	−0.3399	0.2349	–	–
	K	0.4760	−0.0084	0.4007	0.0137	–	–
	P	0.3662	0.1060	0.4846	0.0342	–	–
	H + Al	0.7037	0.2159	0.5740	−0.1386	–	–
	N	−0.1260	−0.1212	−0.2608	−0.4613	–	–
	Sand	0.2925	0.3977	0.4971	0.3708	–	–
	Silte	0.1047	−0.1990	0.1036	−0.3647	–	–
	Clay	−0.2782	−0.1762	−0.3027	−0.0229	–	–
	Relation*	52.1	63.7	40.0	54.9	–	–
Soil 10–20 cm	Hg	−0.7783	0.2079	–	–	–	–
	Moisture	−0.6929	0.0259	–	–	–	–
	C	−0.2231	−0.2410	–	–	–	–
	Al	−0.3110	0.0392	–	–	–	–
	Mg	−0.0443	−0.1363	–	–	–	–
	Ca	0.5190	−0.2206	–	–	–	–
	K	−0.5971	0.2877	–	–	–	–
	P	−0.2224	0.3526	–	–	–	–
	H + Al	−0.6687	0.2013	–	–	–	–
	N	−0.0477	−0.4514	–	–	–	–
	Sand	−0.4521	0.1087	–	–	–	–
	Silte	−0.0745	−0.3475	–	–	–	–
	Clay	0.2808	−0.0089	–	–	–	–
	Relation*	35.9	67.5	–	–	–	–

L: non-fragmented leaves; F: fragmented leaves; H: advanced stage of decomposition.
Relation*: Relation of the taxonomic groups with environment variables.

positively correlated with the mercury concentration in T. And the variable L, referring the stage of decomposition of litter of non-fragmented leaves, was positively correlated with the Hymenoptera group. While that in P, the H parameter (advanced stage of decomposition of litter) was positively correlated with the Pseudoscorpiones, Diplura and Isopoda groups. For this last group the association can be explained by its saprofagic activity, contributing significantly to the litter fragmentation and increment of the microbial colonization, regulating a fundamental stage of the decomposition process (Caseiro et al., 2000). In the TSBF method (Fig. 1d) axis 1 explained 47.4% and axis 2 24% (Table 5). The Blattodea and Coleoptera groups in T were strongly correlated with mercury concentration.

In soil of 0–10 cm depth, by the Berlese method (Fig. 1b) axes 1 and 2 explained 40% and 14.9%, respectively (Table 5), with the Isoptera group positively correlated with the variables of potential acidity (H + Al), moisture and mercury concentration. These same environment variables also showed positive correlation with the Blattodea group, in the TSBF method (Fig. 1e), in which axes 1 and 2 explained 52.1% and 11.6%, respectively (Table 5).

For the depth of 10–20 cm, in the TSBF method (Fig. 1f), axes 1 and 2 explained, respectively, 35.9% and 31.6% of total data variability (Table 5), showing a low correlation of the taxonomic groups with the variables, with exception of the Coleoptera, Isoptera and Diplopoda groups, which showed positive correlation with the variable of phosphorus (P). In turn, the Diptera group was negatively correlated with the variables N and C, possibly due to the stage of decomposition of the organic matter.

The results evidenced in this work showed a disproportion or even an imbalance between the UFCs assessed, already expected since it concerns forests with divergent anthropogenic interference, being T as an urban forest, receptive to anthropogenic actions, and P is practically free of these interferences. However, it is necessary to emphasize that although we cannot affirm that the disproportions of soil fauna have been occurring by the presence of mercury levels, since they are forests and there are many other interferences that cannot be isolated, or even we cannot find more areas with greater similarities in the same selection criteria (as mentioned in Section 1.1. Characterization of the forest areas), we cannot neglect that the presence of this trace-element in the

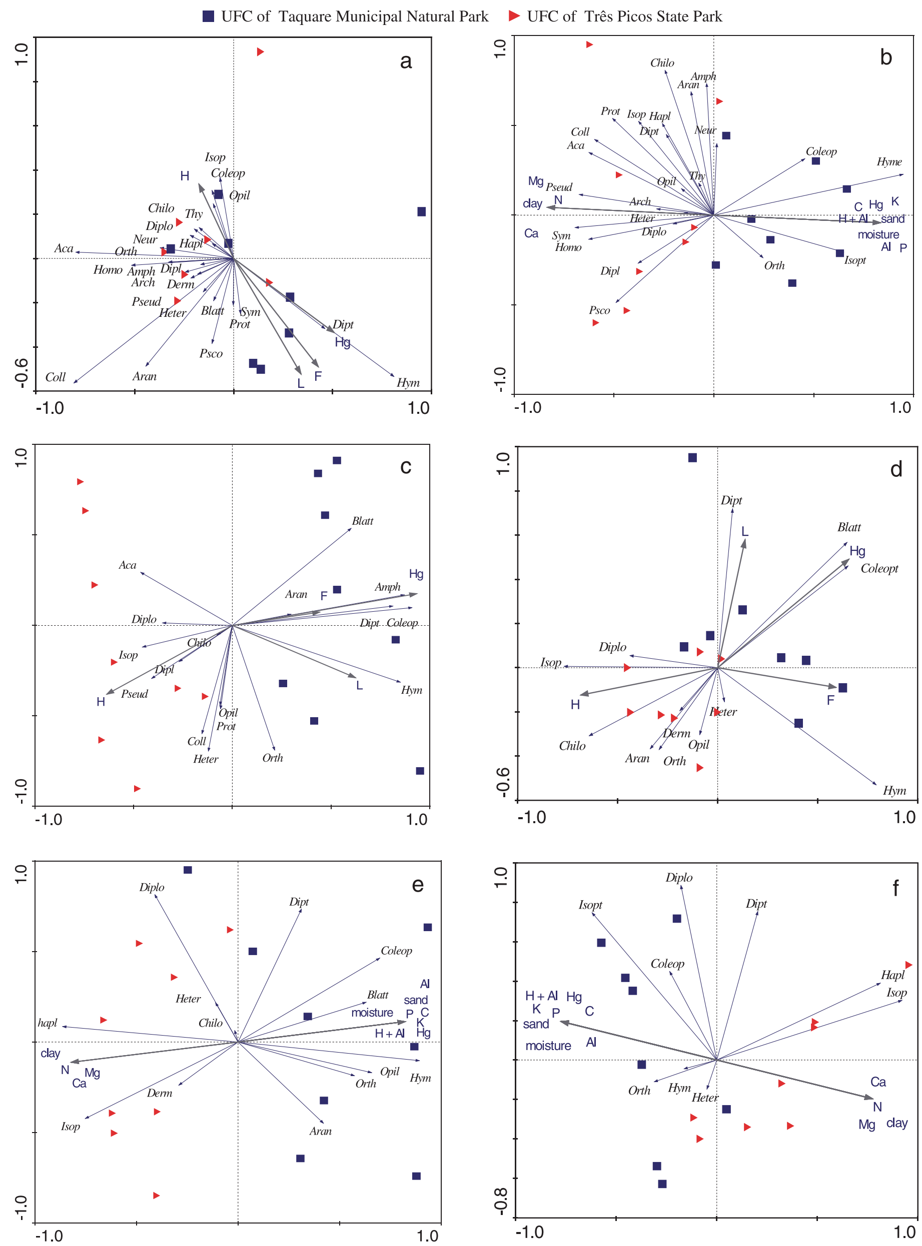

Fig. 1 – Graphical representation of the Principal Component Analysis (PCA) for the three sampling methods of soil fauna, employed in the two areas of UFC correlating with the environmental variables. (a) Berlese method for litter; (b) Berlese method for soil 0–10 cm depth; (c) Pitfalls method for litter; (d) TSBF method for litter; (e) TSBF method for soil 0–10 cm depth; (f) TSBF method for soil 10–20 cm depth Taxonomic groups: Aca (Acari), Amph (Amphipoda), Aran (Araneae), Arch (Archaeognatha), Blatt (Blattodea), Chilo (Chilopoda), Coleop (Coleoptera), Coll (Collembola), Derm (Dermaptera), Diplo (Diplopoda), Dipl (Diplura), Dipt (Diptera), Hapl (Haplotaxida—Earthworms), Haple (Haplotaxida—Enchytraeids), Heter (Heteroptera), Homo (Homoptera), Hyme (Hymenoptera), Isop (Isopoda), Isopt (Isoptera), Neur (Neuroptera), Opil (Opiliones), Orth (Orthoptera), Prot (Protura), Psco (Pscoptera), Pseud (Pseudoscorpiones), Sym (Symphyla), Thy (Thysanoptera). Environment variables: L: non-fragmented leaves; F: fragmented leaves; H: advanced stage of decomposition.

environmental compartments, litter and soil, can affect the soil fauna composition, interfering in the abundance and diversity of invertebrates. Ecotoxicological studies in laboratory have confirmed this, assessing the effect of Hg under the fauna in behavioral, acute and chronic tests, in short and long term, and demonstrated that even at low mercury concentrations there are effects of ecological risks to mesofauna (springtail and enchytraeids) and to macrofauna (earthworms) (Lock and Janssen, 2001). Furthermore, researches report that the presence of Hg in terrestrial ecosystems, results in bioaccumulation of this element to local fauna, due to its contact and food habitats, of fragment and decompose the litter, ingest soil and feed other micro-invertebrates (Boening, 2000; Ackerman et al., 2010; Tersic & Gosar, 2012; Guédron et al., 2014). Threating the health of whole food chain that integrates the other trophic levels of vertebrates, invertebrates, plants and human.

3. Conclusions

The results presented here provide a characterization of soil fauna of two Units of Forest Conservation of the State of Rio de Janeiro in order to collaborate with information about Brazilian biodiversity of fauna, especially the Atlantic Forest (biome), ensuring its preservation, conservation and valorization of a "hotspot" of the biodiversity. Still reporting on the additional role of tropical forests in atmospheric Hg transfer to litter and soils, this transfer will imply to soil fauna if the levels of mercury in these environmental compartments continue increasing. This work showed that the increase of Hg levels could be related not only to the quality of the terrestrial ecosystem, but specifically to the abundance and species richness of soil fauna, drastically altering its biological diversity. However, this study is just the beginning of ecological risk studies caused by atmospheric deposition of mercury, and it comes only with a characterization, once that the complexity of the interference from atmospheric deposition goes far beyond the cycle of this element and its answer to ecosystem biogeochemistry.

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