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ANT FAUNA ASSOCIATED WITH AREAS UNDER THE DIRECT IMPACT OF SMALL HYDROPOWER PLANTS IN THE STATE OF PARANÁ, BRAZIL

MIRMECOFAUNA ASSOCIADA ÀS ÁREAS DE INFLUÊNCIA DIRETA DE PEQUENAS CENTRAIS HIDRELÉTRICAS NO ESTADO DO PARANÁ, BRASIL

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ABSTRACT

Ants can be important tools to assess the conditions of a given environment, as well as to monitor restoration of degraded areas. This study evaluated the richness and abundance of ant assemblages associated with areas directly impacted by the construction of small hydropower plants in the State of Paraná. To survey the ant fauna, samples were collected in September 2014 and January 2015 using pitfall and malaise traps. The association of the ant fauna composition with fragments and seasonality was analyzed by detrended correspondence. Fifty-eight species of ants were registered. The subfamily *Myrmicine* and the genus *Camponotus* were the most abundant (S= 25, S = 10, respectively). The removal of vegetation and formation of lakes in the directly affected area cause impacts that can be monitored based on the results of this study.

Keywords: ants; environment; environmental health; forests.

RESUMO

Formigas são importantes ferramentas para avaliar as condições de um determinado ambiente, bem como o acompanhamento da recuperação de áreas degradadas. O objetivo deste trabalho foi avaliar a riqueza e a abundância das assembleias de formigas associadas às Áreas de Influência Direta (AID) pela construção de pequenas Centrais Hidrelétricas (PCH) no estado do Paraná. Foram realizadas duas campanhas sazonais de amostragem, setembro de 2014 e janeiro de 2015. A amostragem foi realizada com armadilhas *pitfall* e *Malaise*. A relação da composição da mirmecofauna com os fragmentos e a sazonalidade foi avaliada a partir de uma análise de correspondência destendenciada. Foram registradas 58 espécies de formigas. A subfamília Mymicinae e o gênero *Camponotus* foram os mais ricos (S = 25; S = 10, respectivamente). A supressão da vegetação e a formação dos lagos na Área Diretamente afetada (ADA) causam impactos que poderão ser monitorados com base nos resultados deste estudo.

Palavras-chave: formigas; ambiente; saúde ambiental; florestas.

INTRODUCTION

Human activities and exploitation of natural resources pose threats to biodiversity conservation (DIAMOND, 2012). The transformation of natural environments into areas intended for human undertakings is the main cause of ecosystem fragmentation and a risk to the conservation of the diversity of organisms (GALINDO-LEAL; CÂMARA, 2003). There is a growing concern for environmental sustainability and the environmental impacts of the current energy matrix, based on the burning of fossil fuels (LUTINSKI *et al*., 2017). In this context, Small Hydropower Plants (SHP) represent an alternative of lower impact compared to large hydropower plants (KLIEMANN; DELARIVA, 2015).

During the construction of a SHP, the known impacts are related to the removal of vegetation in the directly affected area (DAA), construction of roads and power transmission networks, land compaction machines and, finally, the formation of the lake. During and especially after its implementation, the SHP can affect climate, temperature and local humidity and, consequently, the communities of organisms present in the areas under the direct impact (ADI) (BARBOSA FILHO, 2013; KLIEMANN; DELARIVA, 2015). However, little is known about the impact on the richness and abundance of invertebrate organisms living in these environments.

The study of organisms has been one of the techniques used to evaluate changes in the environment. Insects are ecological indicators to assess the impact that may occur in a given environment (LUTINSKI *et al*., 2013a). *Formicidae* is one of the most diverse insect taxa (HÖLLDOBLER; WILSON, 1990) and has wide distribution, high richness and abundance in terrestrial ecosystems (ALONSO; AGOSTI, 2000). For Jamison *et al*. (2016), ants are biodiversity indicators, as they are easy to collect, reach a wide range of herbivore hosts and indicate the conditions of plant communities. Ants are recognized as biological indicators, a tool to assess environmental conditions and monitoring degraded areas and the regeneration of forest areas (ILHA *et al*., 2009; ARENAS *et al*., 2015). These insects fulfill this role because they have a wide geographical distribution, are locally abundant, functionally important at all trophic levels and susceptible to ecological changes (HÖLLDOBLER; WILSON, 1990).

In the state of Paraná, the pioneer entomofauna surveys were performed by Sakagami *et al.* (1967) and Gonçalves and Melo (2005). Such studies focused on the impact of deforestation, habitat fragmentation, introduction of exotic species, irrational agricultural practices and the reduction of native insect populations (LUTINSKI *et al*., 2017). Although the state of Paraná has stood out for being the first in southern Brazil demanding the investigation of invertebrate fauna in Environmental Impact Study/Environmental Impact Report (EIS/EIR), which is adding significant knowledge on the occurrence and distribution of entomofauna, the state still lacks studies on the ant fauna.

Considering that the state of Paraná has important production of energy from SHP (KLIEMANN; DELARIVA, 2015), this study aimed to:

- Evaluate the richness and abundance of ants assemblages associated with areas under the direct impact (ADI) from the construction of small hydropower plants, in the northeast region of the state of Paraná;
- Analyze the association between occurrences of ant species and the environments sampled and the sampling periods;
- Produce information about the existing ant fauna for monitoring in the period after the implementation of SHP.

MATERIAL AND METHODS

Study area

The study was developed in an ecotone, a transition region between the Atlantic Forest and Cerrado, along the banks of the Fortaleza River, municipalities of Piraí do Sul, Tibagi and Ventania, in the northeastern region of the state of Paraná (Figure 1). Five sampling sites were established in the river basin, where three SHP are projected to be implemented. The sites, located in the ADI of the undertakings, are composed of small forest fragments, located by the river:

- Site 1 (24º25’36” W; 50º13’54” S): 2 ha area, well-preserved environment, with well-formed litter and covered by dense vegetation. It is surrounded by crops of corn and soybeans, houses and pastures;
- Site 2 (24º25’28” W; 50º12’58” S): 6 ha area, forest fragment at advanced state of regeneration, with a well-formed litter and a dense understory. It is amidst crops, pastures and eucalyptus (*Eucalyptus* sp.) reforestation;
- Site 3 (24º25’55” W; 50°11’22” S): 2.5 ha area, amidst a pasture area with almost no litter and heavy trampling by cattle;
- Site 4 (24º25’34” W; 50º11’28” S): 4.5 ha area, at an intermediate stage of regeneration and is surrounded by eucalypt plantations, shrub and grasses. It does not have well-defined litter. It is also crossed by several roads and tracks used for silvicultural activities, logging and sand mining;
- Site 5 (24º25’17” W; 50º10’37” S): 4 ha area, presents the best preservation conditions. It is at an advanced stage of ecological succession, has a well-formed litter and dense vegetation. Traces of human action in this fragment are minimal.

Sampling

To survey the ant fauna in forest fragments, two seasonal samplings were performed, one on September 16-18, 2014 (winter) and another on January 13-15, 2015 (summer). Soil pitfall traps were used, which consisted of 500 mL plastic cups (7.5 cm diameter × 11.5 cm height), buried to the rim. Inside each trap, we added 150 mL water with a drop of detergent to break the surface tension of water. Ten pitfall traps were set at each site, in each

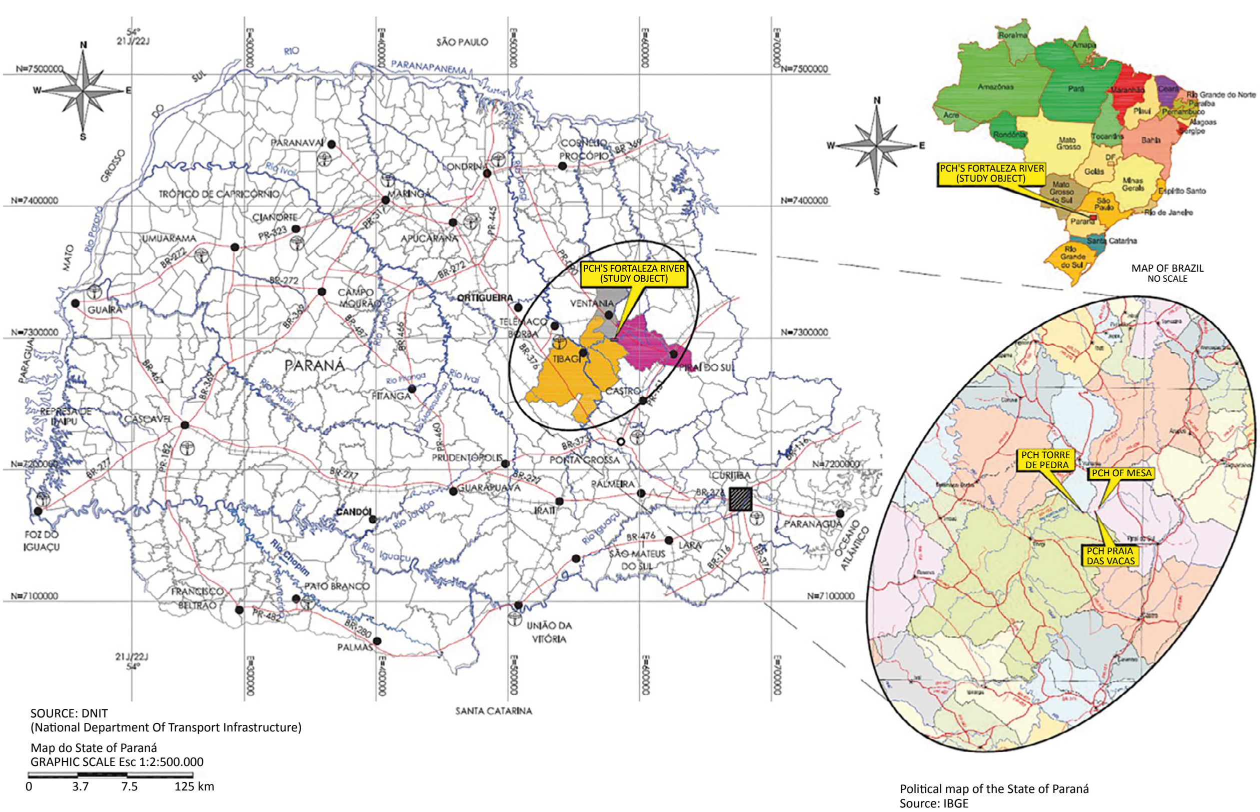

Figure 1 – Geographic location of three Small Hydroelectric Power Plants in Rio Fortaleza, Piraí do Sul, Tibagi and Ventania municipalities, Paraná, Brazil.

sampling. They were installed at an approximately central point, on a line transect, spaced apart by 10 meters (LUTINSKI *et al*., 2013b) and remained open for 48 hours.

Malaise traps were also used, one trap per site, in each sampling, totaling two samples for each site. The installation was carried out in transition environments between forest fragments and crops or grazing areas. The trap was made in white, with black septa and had a specific collector glass to 70% alcohol, used for fixing insects. The sampled specimens were collected at the end of 48 hours of trap exposure.

All specimens were transferred to vials containing 70% alcohol and taken to the laboratory of Entomology at the Community University of Chapecó Region (Unochapecó), where they were sorted and organized for identification according to the following literature: Fernández (2003) and Baccaro *et al*. (2015). The classification follows Bolton (2003).

Data analysis

Species richness was defined as the number of species of ants occurring in each sample. Abundance was determined based on the relative frequency (number of records of a given species in each trap) and not based on the number of sampled individuals (LUTINSKI *et al*., 2014). The percentage relative frequency was calculated for each species by the equation F(%) = Fi x 100 / Ft, where Fi is the number of occurrences of a given species in a given site and Ft is the total number of occurrences for this site.

The evaluation of diversity (richness and abundance) was performed using the Shannon-Weaver diversity index. This index allows estimating the local species diversity. The evenness is the contribution of each taxon in the community and was defined by the Pielou index (MAGURRAN, 1988). Both analyses were obtained using the software PAST (HAMMER *et al*., 2001).

In order to assess sampling sufficiency (number of taxa according to the sampling sites), we constructed a species accumulation curve for the assemblage of ants in each site. We also obtained a richness estimate for each site and compared it with the respective observed richness. For this, we used the nonparametric Chao 1 estimator and estimates were generated by the software EstimateS 8.0 (COLWELL, 2006). The Chao 1 estimator essentially uses information about the species occurring in a sample (unicates) and those that occur in two samples (duplicates) (CHAO, 1987).

All data were tested for homoscedasticity (Levene's test) and normality (Kolmogorov-Smirnov test). Before the multivariate analysis, biotic and abiotic data were standardized and the values were transformed (root-square transformation) to minimize the effect of outliers. It was used Detrended correspondence analysis (DCA) to establish the relationship of the ant fauna composition with the sampling sites and seasonality. Axes with eigenvalues greater than 0.20 were retained for interpretation. To investigate the effects of the environment and seasons on the species composition, the scores of the first two significant axes of the DCA were tested using analysis of variance (ANOVA). For this analysis, we used the STATISTICA 8.0 software (STATSOFT, Inc., 2007).

RESULTS

In the ADI, 58 species of ants were recorded; 57 were caught in pitfall traps and eight in Malaise traps, only *Pachycondyla villosa* (Fabricius, 1804) was exclusive to this method of capture. The subfamily Mymicinae was the most species-rich (S = 25), followed by Formicinae (S = 13) and Ponerinae (S = 7). The genus *Camponotus* was the most representative, with 10 species, followed by *Pheidole* (S = 6), *Linepithema, Pachycondyla*, *Pseudomyrmex* and *Solenopsis* (S = 4). The highest richness was obtained in the winter (S = 45), followed by summer (S = 33) (Table 1).

As for the frequencies in the samples, *Gnamptogenys striatula* Mayr, 1884 and *Pheidole* sp. 4 were the most frequent species in site 1. In site 2, the frequency of *Pheidole* sp. 1 and *Pheidole* sp. 4 were the highest. In site 3, *Pheidole* sp. 1 and *Pheidole* sp. 6 and, in site 4, *Solenopsis saevissima* (F. Smith, 1855) and *Pachycondyla striata* (F. Smith, 1858) were the most frequent. Site 5 had *Pheidole* sp. 4 and *Linepithema* sp. 2 as the most frequent (Table 1). With the exception of site 4 (S'= 11), the other sites presented similar richness (Site 1: S = 24; Site 2: S = 25; Site 3: S = 25, and Site 5: S = 26). The higher diversity

Table 1 – Relative frequency (%) of occurrence of ant species in samples from five sites under the direct impact from small hydropower plants in the Fortaleza River, municipalities of Piraí do Sul, Tibagi and Ventania, state of Paraná, Brazil. September 2014 and January 2015.

Táxon	Sites				
	1	2	3	4	5
Subfamily Dolichoderinae					
Tribe Dolichoderini					
Dorymyrmex brunneus (Forel, 1908)	1.6	2.1		4.8	2.0
Dorymyrmex pyramicus (Roger, 1863)			4.7		2.0
Linepithema humile (Mayr, 1868)			4.7		3.9
Linepithema sp. 1	9.4	8.5	4.7	4.8	3.9
Linepithema sp. 2	3.1	2.1			9.8
Linepithema sp. 3		4.3			3.9
Subfamily Ectatomminae					
Tribe Ectatommini					
Gnamptogenys striatula Mayr, 1884	14.1	8.5	4.7		
Gnamptogenys sp.		4.3	4.7		
Subfamily Formicinae					
Tribe Camponotini					
Camponotus atriceps (F. Smith, 1858)		2.1		4.8	
Camponotus diversipalpus Santschi, 1922			4.7		5.9
Camponotus melanoticus Emery, 1894	3.1				2.0
Camponotus mus Roger, 1863	3.1	2.1	4.7		
Camponotus rufipes (Fabricius, 1775)	3.1	2.1	2.3	14.3	3.9
Camponotus sp. 1	1.6	2.1			
Camponotus sp. 2			2.3		
Camponotus sp. 3			2.3		
Camponotus sp. 4		2.1			
Camponotus sp. 5			2.3		
Tribe Plagiolepidini					
Brachymyrmex coactus Mayr, 1887		2.1			3.9
Brachymyrmex sp.		4.3			
Paratrechina longicornis (Latreille, 1802)	1.6				
Subfamily Heteroponerinae					
Tribe Heteroponerini					
Heteroponera flava Kempf, 1962	1.6				
Subfamily Myrmicinae					
Tribe Attini					
Acromyrmex niger (F. Smith, 1858)	1.6	2.1			2.0
Acromyrmex rugosus (F. Smith, 1858)	4.7	4.3	2.3		
Acromyrmex subterraneus (Forel, 1893)			2.3		
Cyphomyrmex strigatus Mayr, 1887			4.7	4.8	5.9
Mycocepurus goeldii (Forel, 1893)		2.1	4.7		

Continue...

Table 1 – Continuation.

Táxon	Sites				
	1	2	3	4	5
Tribe Blepharidattini					
Wasmannia auropunctata (Roger, 1863)					2.0
Tribe Cephalotini					
Cephalotes pusillus (Klug, 1824)	1.6	2.1			
Cephalotes sp.		2.1			2.0
Tribe Crematogastrini					
Crematogaster corticicola (Mayr, 1887)	3.1		2.3		
Crematogaster sp. 1	1.6				
Crematogaster sp. 3				4.8	
Tribe Myrmicini					
Pogonomyrmex naegelii Forel, 1879			4.7		
Pogonomyrmex sp. 1		4.3			
Pogonomyrmex sp. 2					2.0
Tribe Pheidolini					
Pheidole sp. 1	9.4	10.6	9.3	9.5	5.9
Pheidole sp. 2		4.3			
Pheidole sp. 3	1.6				
Pheidole sp. 4	7.8	10.6	2.3	9.5	17.6
Pheidole sp. 5	1.6				
Pheidole sp. 6			4.7		2.0
Tribe Solenopsidini					
Solenopsis saevissima (F. Smith, 1855)	4.7			9.5	
Solenopsis sp. 1			2.3	9.5	2.0
Solenopsis sp. 2					
Solenopsis sp. 3			7.0		
Monomorium pharaonis (Linnaeus, 1758)					2.0
Subfamily Ponerinae					
Tribe Ponerini					
Hypoponera sp.		2.1			
Odontomachus chelifer (Latreille, 1802)	7.8		2.3		
Odontomachus sp.			7.0		
Pachycondyla crenata (Roger, 1858)		4.3			2.0
Pachycondyla striata F. Smith, 1858	9.4	2.1	2.3	14.3	7.8
Pachycondyla villosa (Fabricius, 1804)				4.8	
Pachycondyla sp.					2.0
Subfamily Pseudomyrmecinae					
Tribe Pseudomyrmecini					
Pseudomyrmex flavidulus (F. Smith, 1858)				4.8	2.0

was observed at site 2 (H'= 2.86), whereas the lowest, at site 4 (H'= 1.39). The same pattern was observed for the evenness, with the highest value recorded at site 2 (J'= 0.89) and the lowest, at site 4 (J' = 0.56) (Table 2).

The species accumulation curve showed the need for a more intensive sampling effort, because it did not reach the asymptote, both for observed and estimated richness (Chao 1). Except for site 4, where the estimated richness was considerably close to that observed, in the other sites sampled, the species richness recorded was far from the estimated values (Chao 1) (Figure 2).

The first two DCA axes had eigenvalues of 0.49 and 0.42, respectively (Figure 3). In the multivariate diagram, we observed the separation of summer and winter samples regarding the ant community composition in the fragments. The winter sample in site 4 segregated from the others by the lowest richness among all sampling sites and also the exclusive record of *Crematogaster* sp. 1 and almost exclusive of *S. saevissima*. However, evaluating the influence of seasons and sites on the ant fauna in the fragments, there was no significant difference in both axes ($p>0.05$).

Table 2 – Ecological indicators for ant assemblages in samples from five sites under the direct impact from small hydropower plants in the Fortaleza River, municipalities of Piraí do Sul, Tibagi and Ventania, state of Paraná, Brazil. September 2014 and January 2015.

Ecological	Sites				
Indicators	1	2	3	4	5
Richness	24	25	25	11	26
Occurrences	252	78	123	75	102
Diversity (H')	2.35	2.86	2.60	1.39	2.16
Equitability (J')	0.74	0.89	0.81	0.58	0.66
Chao 1	33.3	38.7	31.4	13.0	37.4

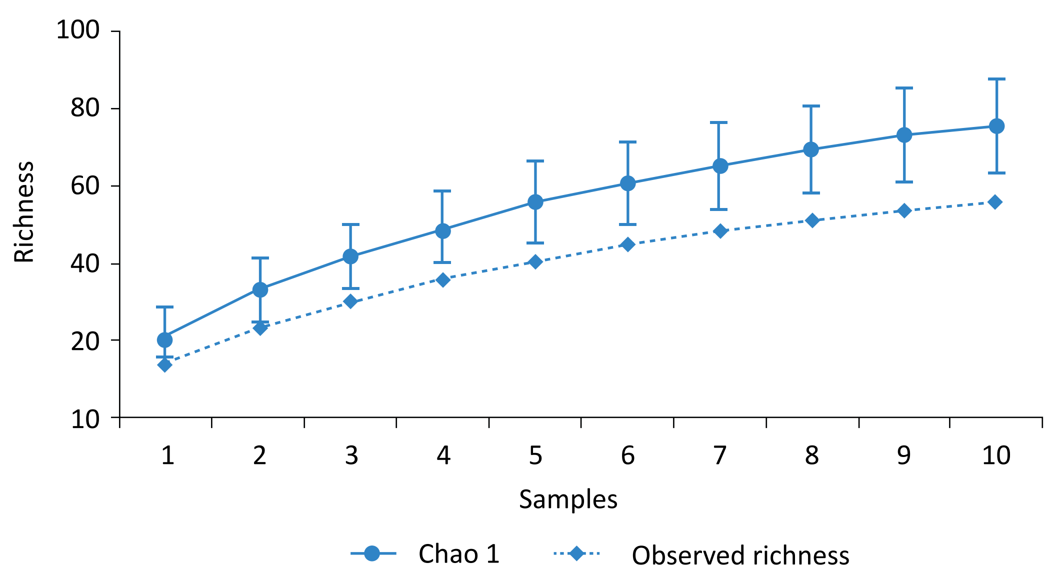

Figure 2 – Observed and estimated (Chao 1) richness of ants in samples from five sites under the direct impact from small hydropower plants in the Fortaleza River, municipalities of Piraí do Sul, Tibagi and Ventania, state of Paraná, Brazil. September 2014 and January 2015.

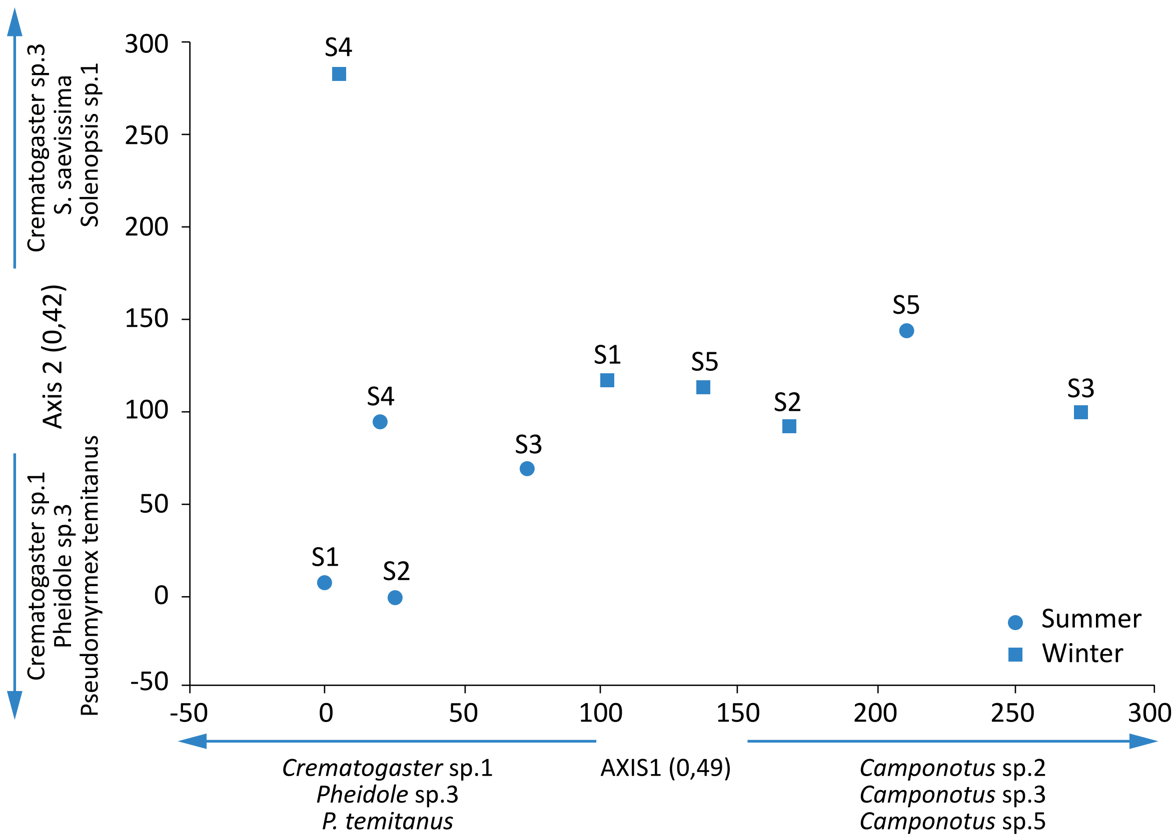

Figure 3 – Ordination of ant fauna composition by detrended correspondence analysis (DCA) in samples from five sites under the direct impact from small hydropower plants in the Fortaleza River, municipalities of Piraí do Sul, Tibagi and Ventania, state of Paraná, Brazil. September 2014 and January 2015.

DISCUSSION

The richness of ants recorded in this study was below other surveys performed in forested environments in southern Brazil (ULYSSÉA *et al*., 2011; LUTINSKI *et al*., 2014), however, is more than double the richness of ants verified by Maciel *et al*. (2011) in southern state of Paraná. The pattern of species composition was similar to other studies in Brazilian ecosystems with predominance of the subfamily Myrmicinae and the genera *Camponotus* and *Pheidole* (ILHA *et al*.,2009; LUTINSKI *et al*., 2013a). The fact that only two samplings were conducted may have influenced the richness, as indicated by the Chao1 estimator. The diversity (H') and evenness (J') represented the characteristics of the sites, since the highest values were obtained in those with the best conditions (plant community at a more advanced stage of succession and better formed litter) for the maintenance of ant fauna. It is noteworthy the difference in composition of ant fauna sampled in the two samplings and homogeneity among the assemblages in the five sites.

The subfamily Myrmecinae is dominant in Brazilian biomes, such as the Atlantic Forest and Cerrado, both in number of genera and species. Some characteristics are remarkable for the success of this subfamily, including the diversity of feeding and nesting habits (HÖLLDOBLER; WILSON, 1990). Additionally, the predominance of Myrmicinae can be because it is extremely adapted to changes in the different environmental conditions and can occupy various niches (GUZMÁN-MENDOZA *et al*., 2016).

The sampled sites have characteristics in common, such as the strong anthropic action in adjacent areas, where forest fragments are small and isolated by huge areas of agriculture and livestock. Environments with these characteristics allow species tolerant to alterations in environmental physical conditions, with ability to colonize environments disturbed by human activities, such as some species of *Camponotus*, *Crematogaster*, *Linepithema*, *Pheidole* and *Solenopsis*, to settle and become abundant and dominant in these environments (LUTINSKI *et al*., 2013a).

It is important to emphasize the diversity of *Pachycondyla* and *Pseudomyrmex* in the samples, once these ants are associated with litter and vegetation, respectively, where they nest and find prey (BACCARO *et al*., 2015). The pseudomyrmecinae ants are agile and solitary patrol with well-developed vision and diurnal habits. Among the 180 species described for the Neotropics, most are associated with vegetation. Many of them are dependent on myrmecophilous plants (BACCARO *et al*., 2015). They visit nectaries and some predate on the ground. They prefer dense and humid forests although some can be found in open areas (WARD, 2003). The association of entomofauna with remnant forest fragments may also explain the occurrence of *Cephalotes* ants, whose species need shelter and nesting place in the vegetation. *Cephalotes* ants are essentially arboreal and rarely come down to the ground. They are associated with vegetation where they find a source of supply and place to build their nests, so they are very dependent on good local flora conditions in order to establish (FERNÁNDEZ, 2003).

The species richness and composition proved to be influenced by the habitat structure, mainly the site 4, which is an intermediate recovery area with little litter and no capacity to support a more diverse ant fauna, corroborating Arenas *et al*. (2015), who stated that simplified environments usually contain a lower richness and diversity of ants, with a fauna made up of generalist species. The other sites showed a more similar richness and composition, and probably have sufficient structural heterogeneity to allow a smaller niche overlap and therefore increase the number of ant species in these areas. According to Queiroz and Ribas (2016), the environmental heterogeneity is a determining factor for the coexistence of species and reduction in competition. Other factors that can act for the determination of this pattern are the size of the fragments and the conservation status. The occurrence of *Gnamptogenys* and *Hypoponera* is an important indicator of environmental conservation, because, in agreement with Valdés-Rodríguez *et al*. (2014), ants of these genera share, beyond the predatory habit, the habit of building nests in fallen logs, under rocks or on the litter, in general, that is, require environments with structure capable of sheltering these species.

The seasonal effect on the richness and composition of the ant community was remarkable, since species richness was higher in the winter. The temperature is limiting to the metabolism of insects in general, which are more active in periods of the year with higher temperatures (HÖLLDOBLER; WILSON, 1990). Nevertheless, in this study, this hypothesis was not confirmed, which can be attributed to rainfall registered in the field (~ 100 mm) during the sampling in January 2015 (summer).

The diversity index indicates that ant assemblages in the ADI are poor, equivalent to the insect fauna found in monoculture areas of the region, such as plantations of pine and eucalyptus, and is lower than that found in preserved areas (COSTA-MILANEZ *et al*., 2014). The highest values of Shannon found in site 2 are closely related to the preservation of the forest fragment. According to Peralta and Martínez (2013), evenness index ranges from zero to one, and a result greater than 0.5 indicates uniformity in the distribution of species in the evaluated location. The low frequency of most of the species of ants in the samples explains the high evenness of the assemblages, in each of the sites. As observed in this study, the presence of many uncommon species is a pattern well-documented for tropical and neotropical regions (CHACÓN DE ULLOA; ABADÍA, 2014).

In relation to sampling effort, the results indicate that the richness of ants of the AID may be higher than observed in the samples. The species accumulation curves of the five sites studied presented an upward trend at the end of the samplings. Given the diverse biological and ecological characteristics of ants (HÖLLDOBLER; WILSON, 1990), the sampling techniques used and the two samplings performed, the results allow us to infer sampling sufficiency. However, for the accumulation curves to reach a perfect asymptote, additional samples are required, using complementary techniques and for a longer period, to properly survey the diversity.

Although the DCA axes were not significant, there is a trend of seasonal influence on the species composition. The ant species evaluated may have different responses to variations in temperature and rainfall, typical of winter and summer seasons. These variations can affect nesting and foraging activity of ants (GALLEGO-ROPERO; RIVERA, 2015). Possibly, ants regulate the foraging activity based on these climate characteristics, thus explaining the difference in the composition between the seasons. Moreover, there are other variables related to the complexity of the environment, such as the presence of understory and litter, which can play a decisive role in structuring the ant community in the area under the impact from SHP.

The presence of ants indicates the existence of a complex fauna of prey and other organisms, in this way, the invertebrate richness of the AID can be considered significant, though poor when compared with preserved environments. This fauna keeps colonizing and using forest remnants in the AID as a refuge. The removal of vegetation and formation of lakes in the DAA, from the implementation of three SHP, may cause microclimate changes in the AID, which may impact the richness, abundance and composition of ant assemblages colonizing the forest remnants of the Fortaleza River basin. These impacts can be monitored based on the results of this study.

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