RAFAEL GONÇALVES CUISSI

USO DE FORMIGAS COMO BIOINDICADORAS PARA A AVALIAÇÃO DE ÁREAS DEGRADADAS EM RECUPERAÇÃO

LAVRAS – MG
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USE OF ANTS AS BIOINDICATORS FOR ASSESSMENT THE DEGRADED AREAS IN RECOVERING

Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos Naturais em Ecossistemas Fragmentados e Agrossistemas, para a obtenção do título de Mestre.

Orientadora

Profa. Dra. Carla Rodrigues Ribas

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Prof. Dr. Paulo dos Santos Pompeu	UFLA
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Orientadora

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2016

À minha família, em especial a Maria Aparecida
Gonçalves, minha querida mãe.
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"*Que as mãos da vida te conduzam pelo melhor caminho.*
Que a vida acaricie os teus cabelos.
Que a terra beije os teus pés.
Que o sol te abrace.
Que a chuva lave as tuas angústias.
Que as estrelas mimem o teu sono.
Que a paz sopre para longe as tuas dificuldades.
Que a fé fortifique as tuas metas.
Que a felicidade seja tua parceira.
Que o amor te leve no colo.
Que a tua obra seja maior que o teu sonho.
Que tu sejas luz no mundo."

(Lígia Guerra)

RESUMO GERAL

Os indicadores ambientais são instrumentos de gestão essenciais nas atividades de monitoramento e avaliação de ambientes degradados. Dentre estes indicadores, destacamos os bioindicadores. Neste sentido, este trabalho visa utilizar as formigas na avaliação e monitoramento de áreas degradadas pelo fogo, mineração e atividades agropecuárias. Para isto, esta dissertação foi dividida em dois capítulos na forma de artigos. No primeiro capítulo, em uma reserva natural do Parque Nacional das Emas, estado de Goiás, Brasil, o objetivo do trabalho foi avaliar o efeito do fogo em uma unidade de conservação no Cerrado brasileiro e a comunidade de formigas que habitam esses ambientes. Já no segundo, realizado em áreas da empresa VALE S.A. no município de Brumadinho, estado de Minas Gerais, Brasil, o objetivo foi verificar a resposta das formigas (diversidade e função ecológica – taxa de remoção de sementes) para diferentes tipos de recuperação de áreas degradadas (mineração e agricultura) e quais parâmetros da estrutura do habitat são importantes nestes processos de regulação da comunidade. De acordo com os resultados dois capítulos, existem algumas recomendações a serem feitas: a primeira se diz respeito a incluir, além de variáveis locais, também variáveis espaciais e temporais em programas de recuperação de áreas degradas. A segunda, se diz respeito a inclusão da vegetação natural para que o manejo e avaliação da recuperação sejam feitos com maior rigor. A terceira, relaciona-se a inclusão da avaliação do funcionamento do ecossistema dentro desses programas, representado neste caso pela remoção de sementes por formigas, pois demostra uma alternativa viável e interessante para estes tipos de estudos. Por fim, acredita-se que compreender os processos ecológicos envolvidos na recuperação de ambientes que sofreram com algum tipo de distúrbio, se torna uma estratégia interessante para o manejo áreas degradas.

Palavras-chave: Indicadores ecológicos. Formicidae. Riqueza e composição de espécies.

ABSTRACT

Environmental indicators are essential management tools in monitoring and evaluation activities of degraded environments. Among these indicators, we highlight the bioindicators. In this sense, this work aims to use the ants in the evaluation and monitoring of degraded areas by fire, mining and agricultural activities. For this, this work was divided into two sections in the form of chapters. The first chapter was conducted in a nature reserve of Emas National Park, State of Goias, Brazil. The objective of this study was to evaluate the effect of fire in a conservation unit in the Brazilian Cerrado and the community of ants that inhabit these environments. Already the second chapter was conducted in areas of the company Vale SA in the municipality of Brumadinho, state of Minas Gerais, Brazil. This study, the objective was evaluate the response of ants (diversity and ecological function - seed removal rate) for different degraded areas in recovery (mining and agriculture) and which habitat structure parameters are important in these community regulatory processes. According to the results of chapters, there are some recommendations to be made: the first with respect to include, in addition to local variables also spatial and temporal variables in recovery programs of degraded areas. The second concerns inclusion stricter of natural vegetation for the management and evaluation of recovering. The third relates to the inclusion the assessment of ecosystem functioning within these programs, represented through the seeds-removal by ants, demonstrating an viable and attractive alternative for these studies types. Finally, it is believed that understanding of the ecological processes involved in recovery environments that have suffered some type of disturbance becomes an interesting strategy for managing degraded areas.

Keywords: Ecological indicators. Fomicidae. Rrichness and composition species.

SUMÁRIO

1 INTRODUÇÃO GERAL

O avanço de atividades antrópicas atinge grandes escalas espaciais e ocorre em um período de tempo curto (ROCHA et al., 2006). Dentre estas, estão as atividades industriais (ROWELL e FLORENCE, 1993.), agrícolas (ALTIERI, 1999), de mineração (GARDNER, 2001) e crescimento urbano (UNEP, 2000).

A atividade de mineração pode resultar em mudanças drásticas na paisagem e consequentemente, na degradação do solo e perda de sua diversidade biológica (PARROTTA et al., 2001), devido ao processo de exploração intensiva de camadas subsuperficiais do solo. Já a agricultura, também devido ao manejo intensivo e inapropriado de camadas superficias do solo, altera significativamente a paisagem e sua biodiversidade associada (COLOMBAROLI et al., 2013). O fogo, quando de ocorrência natural, é importante para regular e manter as características de determinadas fitofisionomias como o Cerrado (Sanava brasileira) (TOWNSEND et al., 2010).

No entanto, o fogo de origem antrópica, devido a práticas de queimadas inadequadas (tanto em relação a sua intensidade quanto frequência) podem afetar negativamente a biodiversidade (PIVELLO, 2011). Dentro deste contexto, a recuperação de áreas degradadas tem por objetivo fornecer ao ambiente degradado, condições favoráveis a sua reestruturação (HOBBS and HARRIS, 2001).

O processo de recuperação de áreas degradadas se espelha nos ecossistemas nativos e tem como objetivo não somente a recuperação da vegetação perdida, mas também o retorno das espécies animais para a comunidade. Neste sentido, se faz necessário monitorar a eficácia da recuperação para obter uma avaliação concreta da qualidade desses ambientes (RIBAS et al., 2012).

A maioria dos estudos de técnicas de recuperação teve como objetivo avaliar da estrutura do habitat através de medidas quantitativas, como número de indivíduos, biomassa de plantas e peso da serapilheira (DIAS et al., 2012, PARROTTA e KNOWLESS, 2001). Ao longo do processo de recuperação, acredita-se que essas áreas apresentem um aumento no número de espécies, o qual favorece uma maior proximidade com a composição original de espécies e o consequente retorno das funções ecológicas anteriormente exercidas (MAJER et al., 2007). Entretanto, poucos estudos foram feitos com medidas que avaliam a efetividade do retorno dessas funções. Dentre os poucos exemplos, temos a avaliação das funções ecológicas desempenhadas pelos organismos que vivem nesses ambientes com o uso de bioindicadores (RABELLO et al., 2015; ANDERSEN e MORRISON, 1998; HOBBS e NORTON, 1996).

Os indicadores ambientais são instrumentos de gestão essenciais nas atividades de monitoramento e avaliação de ambientes degradados, pois permitem identificar avanços, melhorias de qualidade, correção de problemas ou até mesmo necessidades de mudança (THIVIERGE et al., 2014). Neste sentido, os indicadores fornecem informações quantitativas e qualitativas que podem representar ou resumir aspectos do estado do meio ambiente, dos recursos naturais e de atividades humanas relacionadas (VAN CAUWENBERGH et al., 2007). Atualmente, são utilizados vários indicadores ambientais. A exemplo, temos os indicadores do solo (GOMEZ et al., 1996), da água (MAYER et al., 2014), ar (SEGAWA et al., 2014) e/ou organismos (TARGETTI et al., 2014). Entretanto, a escolha do bom indicador vai depender do objetivo da pesquisa em questão (VAN CAUWENBERGH et al., 2007).

Dentre os indicadores ambientais, destacamos os bioindicadores. Estes organismos podem ser populações, espécies, grupos de espécies ou comunidades biológicas que a sua presença, abundância ou riqueza no ambiente pode indicar uma determinada condição ambiental (GARDNER, 2010). Sua importância se dá pelo fato de poder correlacionar uma determinada ação antrópica ou natural com seu potencial impactante, podendo identificar as causas e efeitos do impacto (NIEMI e MCDONALD, 2004). Neste sentido, os bioindicadores representam uma importante ferramenta na avaliação da integridade dos ecossistemas e ao mesmo tempo avaliam a efetividade das funções ecológicas exercidas pelos organismos ali existentes.

Muitos invertebrados do solo tem sido utilizados como indicadores de impacto provocado pelos distúrbios antrópicos (ANDERSEN, 2004; GERLACH et al. 2013). Em habitats alterados por processos antrópicos, os invertebrados do solo são os principais organismos afetados pelas mudanças das condições edáficas, onde na maioria das vezes ocorre um processo de alteração da diversidade e densidade populacional dos grupos em geral (KREMEN et al., 1993).

A exemplo, temos as formigas. Esses organismos vem demostrando ser um excelente grupo bioindicador (KASPERI e MAJER, 2000). Isso ocorre pelo fato da família Formicidae possuir alta diversidade de organismos, ampla distribuição geográfica, ecologia e taxonomia relativamente bem conhecidas, por desempenharem diversas funções ecológicas no ambiente e possuirem amostragem relativamente fácil e de baixo custo (ANDERSEN e MAJER, 2004; LACH et al., 2010) Neste sentindo, estudos que utilizem estes organismos como ferramenta de avaliação e/ou monitoramento de áreas degradadas em recuperação se torna interessante.

Vários estudos vem demonstrando a importância das formigas na avaliação de áreas degradadas por diversas atividades antrópicas, tais como: mineração (BISVAC e MAJER, 1999), fogo (ENDRINGER et al., 2008), agropecuária (PHILPOTT et al., 2010) e crescimento urbano (UNO et al., 2010).

Porém, ainda existem poucos estudos que fazem esse nível de abordagem, utilizando as formigas como bioindicadores em áreas degradadas, nos biomas Cerrado e Mata Atlântica.

Neste sentido, este trabalho visa utilizar as formigas na avaliação e monitoramento de áreas degradadas pelo fogo, mineração e atividades agropecuárias. Para isto, esta dissertação foi dividida em dois capítulos na forma de artigos a serem submetidos á periódico de alto fator de impacto. No primeiro capítulo o objetivo foi avaliar o efeito do fogo em uma unidade de conservação no Cerrado brasileiro e a comunidade de formigas que habitam esses ambientes.

Já no segundo foi verificar a resposta das formigas (diversidade e função ecológica – taxa de remoção de sementes) para diferentes tipos de recuperação de áreas degradadas (mineração e agricultura) e quais parâmetros da estrutura do habitat são importantes neste processo de regulação da comunidade. Através dos resultados obtidos, espera-se trazer soluções estratégicas para o manejo efetivo das áreas em questão visando sua recuperação, atendendo as diversas peculiaridades existentes.

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ARTIGO 1

WHAT REGULATES THE ANTS COMMUNITY OF CERRADO IN POST-FIRE RECOVERY: LOCAL ENVIRONMENTAL VARIABLES, DISTANCE OR RECOVERY TIME?

Preparado de acordo com as normas da revista *Journal of Insect Conservation*

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Abstract: Among the organisms that suffer with the effects of fire are soil invertebrates, especially ants. This work aimed to evaluate which variables are important for the regulation of the ant community of the savannah areas in post-fire recovery. The present study was conducted in the natural reserve called Emas National Park, located in Goiás state, Brazil. By means of transects with 100 meters and 10 sampling points, distant 10 meters between each other, were installed three pitfall traps by point in each microhabitat for collect of ants: arboreal, epigaeic and hypogaeic. Were also collected by point the environmental variables soil density (Dsoil), organic matter (OM), species richness (Splant) and tree density (Dplant). In addition, were calculated the time and average distance between the areas (Dist) in post-fire recovery. Among the variables analyzed, only the plant density and time were important to explain the change in species richness of epigaeic and hipogaeic ants, respectively. However, when we evaluate the species composition, it was observed that the soil density and the distance between areas in post-fire recovery were relevant to this change in all studied microhabitats. But the post-fire recovery time was also an important variable to change the composition of epigaeic and hipogaeic ants. The ants community in areas in post-fire recovery can be regulated by different variables. These include local, spatial and temporal variables. In this sense, management programs and biodiversity conservation, particularly for soil invertebrates, should include in their planning the landscape complexity in question.

Keywords: Brazilian savannah, Formicidae, burned areas, species richness and composition

INTRODUCTION

Considered one of the world's biodiversity hotspots, the Cerrado presents a great diversity of habitats, which determine a remarkable alternation of species between different vegetation types and consequently, presents a considerable abundance of endemic species (Ratter et al., 2003; Cavalcanti & Joly, 2002). However, due to various human actions, the Cerrado today suffers an exceptional loss of habitat and biological diversity (Machado et al., 2004; Baldin, 2011).

One such example is the effect of fire. It is know that, as a natural event, the fire is an important modulator agent of the structure and composition of the landscape (Townsend et al., 2010). : Nonetheless, as a human action, it affects the biological components of a given ecosystem in a negative way (Mistry, 1998). As the intensity and frequency of this impact varied, their actions on biodiversity as a result, ends up being unexpected (Pivello, 2011).

Among the organisms that suffer with the effects of fire are soil invertebrates (Vasconcelos et al, 2009; Moretti et al, 2006). These organisms play important ecological roles in the ecosystem (Anderson & Ingram, 1993) and ants are a good example of this. Due to its high diversity and biomass, the ants plays important functions in the environment: decomposing of organic matter (Coutinho, 1984), seed dispersal (Leal et al., 2015), nutrient cycling (Farji-Brener & Silva, 1995) and herbivory (Wirth et al., 2003).

Ants have been used as bioindicators of different disturbances (Ribas et al., 2012; Lach et al., 2010). Such perturbations can affect their species richness, composition and dominance (Andersen, 2008). Since these changes are linked to features such as environmental changes in their resources and conditions, ants easily respond to it (Ribas et al., 2007). The fire effects on the ants community varies according to their habitat peculiarities. For instance, it is known that ant richness response to fire may be positive (Folgarait, 1998), negative (York, 2000) or null (Hoffmann, 2003; Parr et al., 2004). This variation may be directly related to habitat complexity (Ratchford et al., 2005), since some environmental variables linked to soil and vegetation are important for regulation of ant community (Dauber et al., 2003; Folgarait et al., 2003; Luke et al., 2014).

Therefore, this study aimed to evaluate which variables are important for the regulation of the ant community of the savannah areas in post-fire recovery. For this, we verified at whether environmental variables, time since fire or distance between the areas in recovery are most important in explaining the change in ant species richness and composition.

MATERIALS AND METHODS

Study Area

We conducted the present study in 2008, in the natural reserve called Emas National Park, located in Goiás state, Brazil. The regional climate in this area is seasonal tropical with annual temperature range between 22 to 24ºC and the phytophysiognomy dominant is the Cerrado (França et al., 2007). We carried out the samples in six distinct areas of Cerrado in different times of post-fire recovery, ranging from one to nine years.

Ant sampling

We delineated a transect with 100 meters in each area, and marked 10 sampling points, distant 10 meters between each other. In each sampling point, we installed three pitfall traps in each habitat strata: arboreal, epigaeic and hypogaeic.

The pitfall traps were baited with sardine and honey and contained a solution with water, salt (1%) and detergent (5%), to kill and preserve the ants, which dropped into the traps. The arboreal traps were installed in a tree in the centre of the sampling point. They were tied at a height of 1, 30 meters above soil level (Ribas et al., 2003). Epigaeic traps were buried at the soil level (Bestelmeyer et al., 2000). The hypogaeic traps were capped and buried at 20 cm in the underground. These traps had four radial holes with 1 cm of diameter, where the ants had access to the interior traps (Schmidt & Solar, 2010).

The traps remained during 48h in field. The collected ants were taken to Community Ecology Lab in the Federal University of Viçosa, where they were identified to genus according to Bolton (1994) and Fernández (2003). Rodrigo Feitosa (UFPR) identified the ants at the species level and confirmed the morphospecies determined by the authors through the comparison with specimens in the reference collection of the São Paulo University (USP) Museum of Zoology.

Environmental variables, time post-fire and distance between areas

To understand the role of the environmental variables in the ant species richness and composition, we estimated in each sampling point: soil density (Dsoil), organic matter (OM), tree species richness (Splant) and tree density (Dplant). Samples of the soil were collected next to the epigaeic pitfall trap, then they were carried to the Federal University of Viçosa Soil Lab, where were determined the OM content and soil density. To quantify the tree species richness and tree density, we counted the number of the tree morphospecies and individuals, with trunk circumference equal or higher than 15 cm at 1.3 m height above the soil level, in a quadrant of 10 m^2 around the centre of the sampling point.

In addition, we used information provided by park staff who is responsible for fire brigade to infere the time post fire and calculated the average distance between the areas (Dist) in post-fire recovery with the aid of GPS by determining their geographical coordinates.

Data analysis

For statistical analyzes, we divided the set of variables into two groups.

This division is justified by fact we want to isolate previously the effect of environmental variables. The groups formed and analyzed sequentially were: a) richness and plant density, organic matter and soil density as local environmental variables and. b) the most important local environmental variable to ants selected by the previous analysis time of recovery after fire and distance between areas. Furthermore, the analyzes were separated for all three strata: arboreal, epigaeic and hipogaeic.

In order to check which variables are related to the change of species richness of ants, we made selections models based on Akaike criterion (AIC), with the help of the program R 2.15.1 (R Core Team, 2012). All created models were adjusted for the adequate errors distribution. We applied the IT –

Information-Theoretic approach based on the second-order Akaike's Information corrected for small sample size (AICc) (Burnham & Andersen, 2002).

For check which variables are related to the change in the composition of ant species, we conducted multivariate analyzes based on distance for linear models (DISTLM), with Primer v6 software and PERMANOVA + (Anderson, 2005). The tests were performed by using the Jaccard similarity index, suitable for presence and absence matrices.

RESULTS

We sampled 83 ant species and from these, 37 species were collected in arboreal microhabitat, 63 species were collected in epigaeic microhabitat and 33 species were collected in hypogaeic microhabitat.

Relationship between species richness and the variables

When analyzing the relationship of ant species richness with local environmental variables, we find that the model which best explains species richness is the null for the micro-habitat arboreal and epigaeic. However, for hipogaeic strata the best model that explains this change is plant density with a positive effect in the number of species (Table 1).

Table 1 - Selection of models for species richness of ants in relationship with local variables for three microhabitats. Dplant = plant density; Soil = soil density; OM = organic matter; Splant = plants richness.

Model	**Interc**	**Dplant**	**Dsoil**	**OM**	**Splant**	**df**	**logLik**	**AICc**	**Delta**	**Weight**
					Arboreal					
1	2.744					2	-70.287	144.9	0.00	0.231
5	1.774			0.1511		3	-69.243	145.1	0.23	0.206
9	2.519				0.1091	3	-70.114	146.8	1.97	0.086
					Epigaeic					
1	1.625					1	-108.056	218.2	0.00	0.234
9	1.487				0.06661	2	-107.497	219.2	1.05	0.138
2	1.539	0.0288				2	-107.532	219.3	1.12	0.133
5	1.489			0.021		2	-107.981	220.0	1.84	0.093
					Hipogaeic					
2	1.285	0.2039				3	-57.010	120.6	0.00	0.426

The same results (null model) were found for species richness in relationship to model selection with all variables (distance between areas in post-fire recovery and time) for arboreal stratum. Otherwise, when evaluated the epigaeic stratum, we found that time has a negative effect on the number of species. Already for the hipogaeic stratum only plant density presents a positive effect on the variation of richness (Table 2).

Table 2 - Selection of models for ant species richness in relationship to time post fire and distance between areas to the three strata. Dplant = plant density; Dist = distance between areas in post-fire recovery.

Model	**Interc**	**Dplant**	**Dist**	**Time**	**Df**	**logLik**	**AICc**	**Delta**	**Weight**
				Arboreal					
1	2.744				2	-70.287	144.9	0.00	0.519
3	2.980			-0.05726	3	-69.917	146.4	1.58	0.236
				Epigaeic					
3	1.819			-0.04849	2	-105.651	215.6	0.00	0.587
				Hipogaeic					
2	1.285	0.2039			3	-57.010	120.6	0.00	0.550

Relationship between species composition and the variables

When analyzing species composition, we find that among the local environmental variables, only soil density promotes change of species in the three strata (Table 3). Despite having been a significant change, the proportion of species composition explained is low.

Table 3 - Linear models based on distance (DistLM) to species composition in relationship to local environmental variables of three strata. Dplant = plant density; Dsoil = soil density; OM = organic matter; Splant = richness of plants.

		Arboreal		
Variables	SS(trace)	Pseudo-F	P	Prop.
Dsoil	9976	2,3691	0,001	5%
Dplant	5363,7	1,2407	0,204	3%
Splant	4797,4	1,1061	0,352	3%
MO	3496,8	0,80039	0,698	2%
		Epigaeic		
Variables	SS(trace)	Pseudo-F	P	Prop.
Dsoil	6436,1	1,5805	0,03	3%
MO	4560,9	1,1094	0,306	2%
Splant	4491,2	1,092	0,329	2%
Dplant	3843,4	0,93146	0,551	2%
		Hipogaeic		
Variable	SS(trace)	Pseudo-F	P	Prop.
Dsoil	12444	3,0643	0,004	7%
Dplant	5550	1,3148	0,166	3%
MO	4556,8	1,0736	0,348	2%
Splant	3237,9	0,75742	0,695	2%

When we analyzed with all variables, we find that distance between areas and soil density, both explain the change in the ant species composition in the three studied strata. Time post-fire just explained the change of ant species for epigaeic and hipogaeic strata (Table 4).

Table 4 - Linear models based on distance (DistLM) to species composition in relationship to time post fire and distance between areas for the three strata. Dist = distance between areas in post-fire recovery; Dsoil = soil density.

Variable	SS(trace)	Pseudo-F	P	Prop.
Arboreal				
Dist	12989	3,1395	0,001	7%
Dsoil	9976	2,3691	0,001	5%
Time	5315,7	1,2292	0,205	3%
Epigaeic				
Variable	SS(trace)	Pseudo-F	P	Prop.
Time	15660	4,036	0,001	8%
Dist	15594	4,0175	0,001	8%
Dsoil	6436,1	1,5805	0,044	3%
Hipogaeic				
Variable	SS(trace)	Pseudo-F	P	Prop.
Time	24155	6,3759	0,001	13%
Dsoil	12444	3,0643	0,001	7%
Dist	8779,6	2,1176	0,02	5%

DISCUSSION

In this work we find that, among the variables analyzed, only the plant density and time were important to explain the change in species richness of epigaeic and hipogaeic ants, respectively. However, when we evaluate the species composition, it was observed that the soil density and the distance between areas in post-fire recovery were important to this change in all studied microhabitats. But the post-fire recovery time was also an important variable to change the composition of epigaeic and hipogaeic ants.

Maintaining the ant community is very important in degraded areas of Cerrado in post-fire recovery process, since these organisms play important ecological roles for the environment in question, affecting directly and indirectly other species groups.

Relationship between species richness and the variables

According to our work the loss of epigaeic ant species is explained by the increase in the recovery time of areas. This result can be explained by the predominance of certain ant species with increasing post-fire recovery time. As the process of colonization by new species could be at random and suffers direct influence of anthropic surrounding regions, such mechanisms may favor the entry of dominant species in the area (Cerda et al., 2013; Tschinkel and King, 2013). It is known that a dominant species monopolizes resources and conditions, causing a loss of species richness (Lach et al., 2010).

The increase in the density of trees provides a gain in the number of hipogaeic ant species in post-fire recovery areas. The increase in the density of tree roots can provide an increased abundance of resources offered to these ants (Tawatao et al., 2014) as well as different conditions for establishing their nests, due to changes in the physical structure of the soil (Campos et al., 2003).

The arboreal ants were not sensitive to tested variables. Probably the colonization mechanisms these organisms on environmental in post-fire recovery are random due the microhabitat heterogeneity and high environmental variation.

The other variables also were not important for modification of species richness of ants in the three studied strata, which may indicate that in savanna areas in post-fire recovery process, these variables evaluated are not important to restructure the ant community.

Relationship between species composition and the variables

The density of the soil is an important local variable to determine the composition of ant species in areas in post-fire recovery, for the three strata studied. This variable can be considered an important condition to determine the environmental structure (Schmidt et al., 2013). The soil density represents its physical structure, consequently this variable also can determine the biotic community that lives in the soil and on its surface (Aquino et al., 2008). The reduction of soil organism activity due to fire effect causes an elevated compaction of soil (Barros et al., 2001) because these organisms can affect the nature and concentration of organic and inorganic cementing materials and responsible for soil structure (Dindal, 1990).

In turn, the distance between areas also is an important variable in determining the composition of ant species. Neighboring environments can share more species compared with more distant environments (Anjos et al., 2015). The surrounding areas has an important role in structuring the ant community in areas in post-fire recovery, since these areas are a direct source of species (Soininen et al., 2007). So, burned isolated areas are more dependent on this urburned environments of the surroundings (unburned Cerrado areas) for the return of the species and ant community restructuring.

Another important variable to species composition of epigaeic and hypogaeic ants is the post-fire recovery time. This variable is directly linked to structuring the ant community. The time can set the quantity and intensity the variables that influences the recovery process of degraded areas, which may reflect in communities more specialist and/or generalists (Schowalter, 2012).

Implications for the conservation of ant species in Cerrado areas

The Cerrado, due to its diversity of habitats, is shelter to a high diversity of species of ants, thus being considered as a biodiversity hotspot (Simon et al., 2009; Maravalhas & Vasconcelos, 2014). In this sense, conservation efforts and management strategies that avoid degradation of these environments should be prioritized (Durigan & Ratter, 2016), both in research activities, as in public policies for our managers.

According to this work, we conclude that a management plan for recovery of Cerrado areas degraded by fire should be based on certain principles. The first concerns the maintenance of the environment heterogeneity, since the soil density is an important factor in the regulation of the composition of ants. Environments with different soil densities provide different communities of ants. Therefore, this heterogeneous structure should be preserved.

Another important point concerns the environments that surrounding the areas affected by the fire. It is believed that these environments play a fundamental role in the regulation of ant community because they are direct donor sources of species for areas in post-fire recovery process. We saw that the distance between the burned areas is important in community regulation due to change in composition. That is, the farther away, the greater the dependence of the surrounding areas. In this sense, studies and practices that promote this idea should be valued.

Finally, we saw in this work that the community of ants in areas in post-fire recovery can be regulated by different variables. These include local, spatial and temporal variables. For this reason, management programs and biodiversity conservation, particularly for soil invertebrates, should include in their planning the landscape complexity in question.

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ARTIGO 2

DEGRADED AREAS ASSESSMENT: USE OF ANTS FOR THE BIOMONITORING

Preparado de acordo com as normas da revista *Restoration Ecology*

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Abstract: The aim of this study is to evaluate the response of ants (diversity and ecological function – seed removing rates) to different types of recovery of degraded areas and local environmental variables correlated. The work was carried out in Brumadinho, Minas Gerais state, southeastern Brazil, within one unit of the iron mining company Vale S.A. (Córrego do Feijão mine) and surrounding region. We collected inside the mine in three areas: a recovery with exotic plants (RES, Brachiaria decumbens and Melinis minutiflora), one area in natural recovery advanced stage of forestry formation (RF) and a control area (AR; Atlantic Rainforest). Out of the mine, we collected in four areas: an area in natural recovery (NR; without human intervention), one with exotic plants (RB; Brachiaria decumbens), one with invasive exotic grass (RNG; Andropogon bicornis L.) and a control area (CER; Cerrado). To sample the ants in each area, we established one transect positioned 50 m from the edge of each area. Each transect had ten independent sampling points at 20 m distant from each other. At each point, we installed one epigaeic trap. To measure seed-removing rates by ants, we installed in each area one transect with five independent points at 40 m distant from each other, where we offered 50 artificial lipid-rich fruits protected from vertebrate predation by a wire mesh (1.5 X 1.5 cm). To measure the environmental variation present in the environment, we marked quadrants of 6 x 6 m in each sample point used in ant sampling, where we measured the following variables: richness (TR), density (TD) and height (TH) of all plants with minimum circumference of 5 cm measured at 30 cm above ground level; weight (WL) and heterogeneity of the litter (HL) and canopy cover (CO). According to our aims, we saw that the response of ant diversity (richness and composition) and ecological function (seed removal rate) performed by ants are different for the microregions assessed. For species richness, only the areas collected inside the mine were different from each other. Already for removal rate, both regions had the same response regarding to recovery techniques. Concerning the environmental variables, we observed different responses depending on the microregion. The management of degraded areas under recovery becomes peculiar to the studied area, besides having a variety of methods employed, are obscure in recovery efficiency. In this sense, we observed that the natural environment is fundamental to the effectiveness of recovery efforts, because, from it, we can establish better criteria for recovery programs of degraded areas.

Keywords: mining, agriculture, Formicidae, richness, composition

INTRODUCTION

The various human activities have caused environmental disturbances that the environment alone has no means of natural regeneration. Among these, include industrial activities (Rayfield et al., 2005), agriculture (Gliessman, 2009), mining (Singh et al., 2006) and urban development (Oldfield et al., 2013). Within this context, the several degraded areas recovery techniques is intended to establish for the degraded environment favorable conditions for restructuring (Hobbs and Harris, 2001)

Through intensive land use, the impacts caused by mining generates significant loss of existing biodiversity (Miguel et al., 2014). Already agriculture, with using intensive management practices can also reduce the species diversity (Tejada et al., 2016). For this reason, some effort has been generated to recover these degraded areas (Sonter et al., 2014).

Many soil invertebrates have been used as indicators of impact caused by mining (Andersen, 2004; Gerlach et al., 2013). After the change of a natural habitat, soil invertebrates are the main bodies affected by changes in soil conditions. Most of the time, there is a change of diversity and population density of the groups in general (Kremen et al.,1993).

Currently, the ants have been shown to be an excellent bioindicator group (Kaspari and Majer, 2000; Queiroz et al., 2013). It happens because the family Formicidae has a high diversity of organisms, wide geographical distribution, ecology and taxonomy relatively well known, performing lots of important ecological functions and have sampling relatively easy and inexpensive (Andersen and Majer, 2004; Lach et al., 2010). In this aspect, studies that use these organisms, as tools of evaluation and/or monitoring of degraded areas in recovery, could be encouraged.

Several studies have shown the importance of ants in the evaluation of areas degraded by human activities such as mining (Bisvac and Majer, 1999), fire (Endringer et al., 2008), agriculture (Philpott et al., 2010) and urban growth (Uno et al., 2010). However, there are still few studies that use ants as bioindicators in recovery of degraded areas by mining for Cerrado and Atlantic Forest biomes (but see Ribas et al., 2012; Barros et al., 2010; Majer, 1992).

Another existing limitation in these studies involves the ecological functions performed by the ants. It is known that the functioning indicators of ecosystem can provide information on the resilience, productivity level and sustainability of habitats recovering (Grant et al., 2007). The seed removal rate by ants is an example of metrics that can be used for such purposes (Rabello et al., 2015), though, not yet widely used as a monitoring tool.

Another important point of monitoring is to find out which mechanisms are involved in the regulation of ant community, being that environmental variables can have great contributions in these processes. In natural environments and also in that modified by humans, some environmental variables linked to soil and vegetation are important for regulation of ant community (Luke et al., 2014; Dauber et al., 2003; Folgarait et al., 2003). These environmental variables may regulate the presence and the occurrence of particular ant species. Thus, it is necessary to include, in the monitoring of degraded areas into recovery, the environmental variables that can be directly linked to the change of ants diversity.

This study aimed to evaluate the response of ants (diversity and ecological function – seed removing rates) to different types of recovery degraded areas. Through these results, we can find which are the recovery types that most resemble the natural environment and which parameters of habitat structure are important for regulating ant community and should be included in management of degraded areas.

MATERIALS AND METHODS

Study area

The study was carried out in Brumadinho (20°08'34" S 44°12'00" O), Minas Gerais state, southeastern Brazil. The average altitude of the region is 1.571 m, annual average temperature is 20°C and local climate is characterized by dry winters (April to October) and rainy summers (November to March) (IBGE 2013). The vegetation is dominated by mountain fields, shrubby field and Cerrado areas, occurring traces of forests on the slopes, tops of mountains and galleries forests near the springs and streams (riparian vegetation). Our study sites are situated in a transition area between Atlantic Rainforest and Cerrado (Brazilian savanna) biomes.

The fieldwork was conducted in March (rainy season) of 2014 within one unit of the iron mining company Vale S.A. (*Córrego do Feijão* mine) and surrounding region. We collected inside the mine in three areas: a recovery with exotic plants (RES, *Brachiaria decumbens* and *Melinis minutiflora*), one area in natural recovery advanced stage of forestry formation (RF) and a control area (AR; Atlantic Rainforest). Out of the mine, we collected in four places: an area in natural recovery (NR; without human intervention), one with exotic plants (RB; *Brachiaria decumbens*), one with invasive exotic grass (RNG; *Andropogon bicornis* L.) and a control area (CER; Cerrado). The surrounding areas were regarded as compensation zone, where the company aims to recover its degraded areas, even if it has not developed mining activities. These sites have suffered degradation processes by farming and the VALE S.A., as a way of compensating the damage caused by mining itself, aims to recover them. This action is forecast for Art. 36 of the Act of Sistema Nacional de Unidades de Conservação (SNUC) and Decrees 6.848/09 e 4.340/02 the Brazilian Federal Constitution.

Ant sampling

To sample the ants in each area, we established one transect positioned 50 m from the edge of each area. Each transect had ten independent sampling points at 20 m distant from each other. At each point, we installed one epigaeic trap. These traps consisted of plastic pots (pitfall traps) with 8 cm in diameter and 12 cm in depth. Within contained a water (200 ml), detergent (0.6%) and salt (0.4%) solution (Canedo-Júnior et al., 2016). A cover was used to protect against sun and rain. The ants collected in pitfall traps were identified through keys in Palacio and Fernandez (2003) and Bolton (1994) all of them were separated to morphospecies.

Seed-removing rates

To measure seed-removing rates by ants, we installed in each area one transect with five independent points at 40 m distant from each other, where we offered 50 artificial lipid-rich fruits (based on Rabello et al., 2014 and 2015) protected from vertebrate predation by a wire mesh (1.5 X 1.5 cm). The artificial fruits contained one white fleshy part representing the elaiosome (part of natural fruits attractive for ants) and the ‘‘seed’’. The fleshy part consisted of vegetable fat (75 %), fructose (4.8 %), sucrose (0.5 %), glucose (4.7 %), casein (7 %), calcium carbonate (3 %), and maltodextrin (5 %), and was developed in the Laboratório de Química, Bioquímica e Análises de Alimentos (Departamento de Engenharia de Alimentos, Universidade Federal de Lavras). To represent the ‘‘seed’’, we used orange beads (0.03 g and 2 mm diameter) which were attached to the fleshy part. These characteristics place our fruits in the small and medium categories proposed by Pizo and Oliveira (2001). After 24 h from installation of the experiment, we recorded the number of seeds removed in order to calculate the removal rates in each area.

Sampling of environmental variables

To measure the environmental variation present in the environment, we marked quadrants of 6 x 6 m in each sample point used in ant sampling, where we measured the following variables: richness (TR), density (TD) and height (TH) of all plants with minimum circumference of 5 cm measured at 30 cm above ground level; weight (WL) and heterogeneity of the litter (HL) and canopy cover (CO).

To calculate the TR, TD and TH, we counted, measured the height and separated in morphospecies all the plants that were within the predetermined quadrant. For measured the WL and HL a sample of litter was collected inside the quadrant within a square of 25 x 25 cm, in which we counted all itens (e.g. leaves, stems, seeds, flowers etc.) and calculated the heterogeneity through the Simpson index (Queiroz et al., 2013) Posteriorly, this material was dried in one oven until reach constant weight and its weight measured. To calculate CO, was withdrawal a hemispheric digital photograph of the canopy with the aid of a camera with a lens-eye fish 0,20x coupled. The camera had been positioned 1.5 m from the ground in the center of the sample point. Through Gap Light Analyzer software (GLA), we measured the percentage of vegetation cover (Frazer et al., 1999).

Data analysis

The collected data were separated into two microregions for analysis: a) within the mine VALE S.A. and b) surrounding region.

In this sense, in order to verify whether there are differences in species richness of ants and seed-removing rates among types of recovery and among areas in recovery and their control areas (for both microregions), we conducted variance analysis followed by contrast analysis (when necessary) through generalized linear models (GLM). All models were adjusted to suitable distribution of errors for counting data. The tests were performed with R 2.15.1 software (R Core Team, 2014).

To check whether it occurs change in ant species composition in the evaluated areas (for both microregions), we used similarity analysis (ANOSIM), with Primer v6 software (Anderson, 2005). The tests were conducted using Jaccard similarity index, suitable for presence and absence matrices.

We conducted analysis of hierarchical partition (Chevan & Sutherland, 1991) to check if the change in the richness of ant species and seed removal rates are related to the measured environmental variables. We performed the analysis with R 2.15.1 (R Core Team, 2014), where the models were adjusted to suitable distribution of errors for counting data.

With the aim of check whether the change in the ant species composition can be explained by environmental variables measured, we used multivariate analysis based on distance for linear models (DISTLM). These analyzes were performed with Primer v6 software and PERMANOVA + (Anderson, 2005). All tests were performed using the Jaccard similarity index suitable for presence and absence matrices.

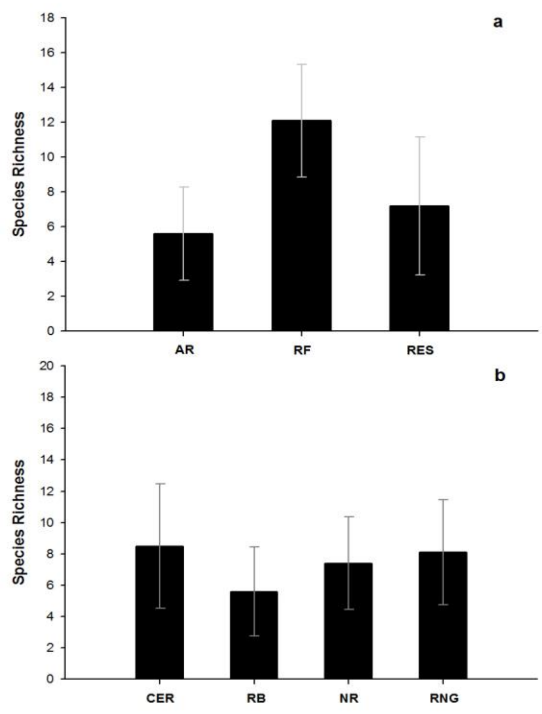
RESULTS

Altogether we collected 88 ant species from 32 genera, being *Camponotus* (sixteen), *Pheidole* (ten), *Crematogaster* (five), *Brachymyrmex* (four), *Pachycondyla* (four) and *Pseudomyrmex* (four), the genera most common in species number. Regarding the microregions, we collected a total of 59 species within the mine and 65 species in the surrounding region.

Species richness and recovery types

When we related the ant species richness with the types of recovery and their control areas inside the mine, we found difference in average richness per trap between areas sampled ($F_{2,27}$ = 10.292, p = 0.0005), being that the recovery with forestry formation has a higher species richness than the seasonal semideciduous forest ($F_{1\text{-}28}$ = 18.956, p = 0.0002) and recovery with exotic plant ($F_{1\text{-}28}$ = 10.772, p = 0.0029; Figure 1a). Seasonal semideciduous forest and recovery with exotic plant did not differentiate between them ($F_{1\text{-}28}$ = 1.1486, p = 0.2933; Figure 1a). In the surrounding microregion, we did not find difference in species richness between the sampled areas ($F_{3\text{-}36}$ = 1.5038, p = 0.2301; Figure1b).

Figure 1 - Mean species richness per trap for microregions inside the VALE S.A. mine (a) and surrounding areas (b). AR = seasonal semideciduous forest; RF = recovery with forestry formation; RES = recovery with exotic species; CER = Stricto sensu Cerrado; NR = natural recovery; RNG = recovery with invasive exotic grass; RB = recovery with *Brachiaria*. Error bars represents the mean standard deviation.



Species composition and recovery types

When we related the ant species composition with the types of recovery and their control areas, we found that all areas collected differ in species composition (within the mine: R = 0.48, p = 0.001; and surrounding region: R = 0:41, p = 0.001; Table 1).

Table 1 - Pairwise Comparison by the Similarity Analysis (ANOSIM) to two microregions.

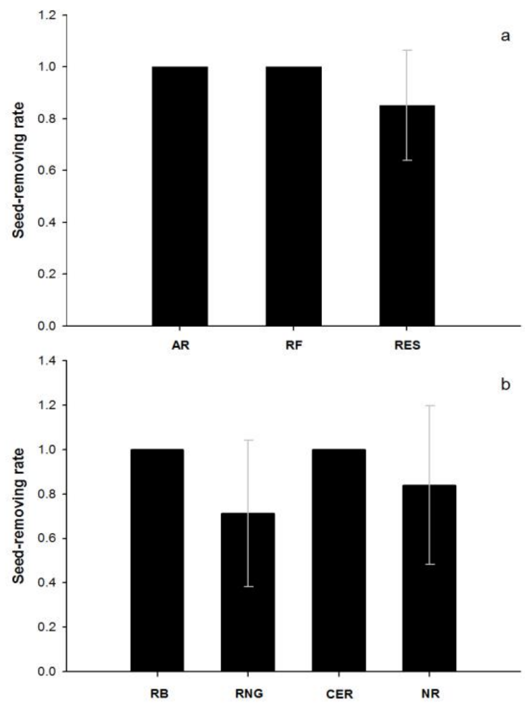
Groups	R Statistic	Significance Level %
Within the VALE/SA mine		
AR, RF	0.593	0.1
AR, RES	0.579	0.1
RF, RES	0.353	0.1
Surrounding areas		
Groups	R Statistic	Significance Level %
CER, RB	0.248	0.4
CER, NR	0.35	0.1
CER, RGN	0.644	0.1
RB, NR	0.24	0.1
RB, RGN	0.52	0.1
NR, RGN	0.421	0.1

* AR = seasonal semideciduous forest; RF = recovery with forestry formation; RES = recovery with exotic species; CER = Stricto sensu Cerrado; NR = natural recovery; RGN = recovery with invasive exotic grass; RB= recovery with Brachiaria. The higher the R value, the areas are dissimilar to each other in pairwise comparison within groups.

Seed-removing rate and recovery types

When relating the removal rate with the recovery types inside the mine, we verified differences in mean removal rates of seed between the areas ($F_{2\text{-}12}$ = 7.144, p = 0.0090; Figure 2a), being that the seasonal semideciduous forest and recovery with forestry formation are similar presenting a 100% rate of seed removal ($F_{1\text{-}13}$ = 0, p = 1; Figure 2a). However, the recovery with exotic species show a lower average rate of seed removal than areas above ($F_{1\text{-}13}$ = 9.0972, p = 0.0107; Figure 2a). In the surrounding region, we also found differences in the removal rates between the areas ($F_{3\text{-}16}$ = 3.2725, p = 0.0486; Figure 2b), being that the recovery with *Brachiaria*, natural recovery and the Cerrado (control) are similar (RB and CER = 100% similarity; $F_{1\text{-}18}$ = 0, p = 1; Figure 2b) and different of recovery with invasive exotic grass.

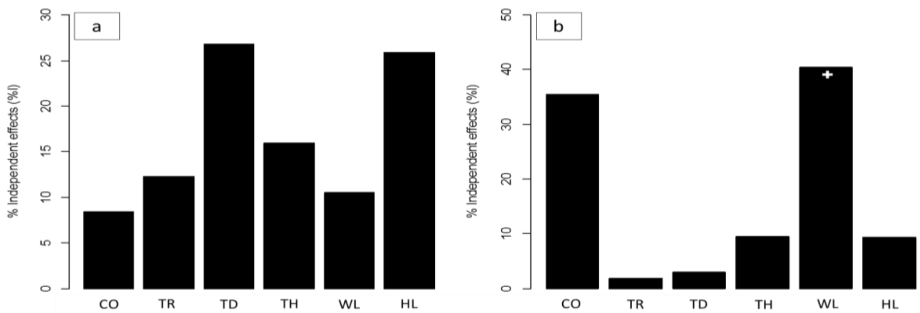
Figure 2 – Removal rate of seeds for microregions inside the VALE S.A. mine (a) and surrounding areas (b). AR = seasonal semideciduous forest; RF = recovery with forestry formation; RES = recovery with exotic species; CER = Stricto sensu Cerrado; NR = natural recovery; RNG = recovery with invasive exotic grass; RB = recovery with *Brachiaria*. Error bars represents the mean standard deviation.



Species richness and environmental variables

None environment variable influenced species richness inside the mine ($p > 0.05$; Figure 3a). However, when evaluating the surrounding areas, the litter dry weight positively influenced the ant species richness ($Z = 3.26$, $p = 0.05$; Figure 3b).

Figure 3 - Hierarchical partition for ant species richness in microregions inside the VALE S.A. mine (a) and surrounding areas (b). CO = canopy cover; TR = tree richness; TD = tree density; TH = tree height; WL = litter weight; HL = litter heterogeneity.



Species composition and environmental variables

When analyzing species composition, all variables influenced changes in species composition to both microregions (Table 2).

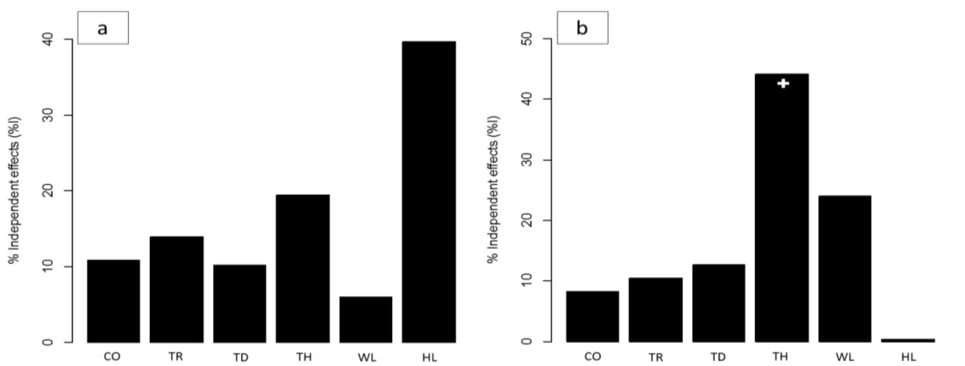
Table 2 - Multivariate Analysis Based on Distance for Linear Models (DistLM) to species composition in relationship to environmental variables of two microregions. CO = canopy cover; TR = tree richness; TD = tree density; TH = tree height; WL = litter weight; HL = litter heterogeneity.

Within the VALE/SA mine				
Variable	SS(trace)	Pseudo-F	p	Proportion (%)
CO	10859	3.2908	0.001	10.52
TR	10878	3.2973	0.001	10.54
TD	10141	3.0496	0.001	9.82
TH	13405	4.1775	0.001	12.98
WL	5838.5	1.6782	0.029	5.65
HL	6258.4	1.8066	0.021	6.06
Surrounding areas				
Variable	SS(trace)	Pseudo-F	p	Proportion (%)
CO	9972.3	2.7939	0.001	6.85
TR	10500	2.9532	0.001	7.21
TD	9251.7	2.5783	0.001	6.35
TH	9726.4	2.7201	0.001	6.68
WL	7794.3	2.1492	0.003	5.35
HL	6936.8	1.9009	0.007	4.76

Seed-removing rate and environmental variables

For seed removing rates, we found that in region inside of mine, none variable influenced the removal rate change ($p > 0.05$; Figure 4a). Otherwise, in the surrounding region, only the tree height showed a positive relationship with the seed removal rate ($Z = 1.71$, $p = 0.05$; Figure 4b).

Figure 4 – Hierarchical partition for seed-removing rates in microregions inside the VALE/SA mine (a) and surrounding areas (b). CO = canopy cover; TR = tree richness; TD = tree density; TH = tree height; WL = litter weight; HL = litter heterogeneity.



DISCUSSION

According to our aims, we saw that the response of ant diversity (richness and composition) and ecological function (seed removal rate) performed by ants are different for the microregions assessed. For species richness, only the areas collected inside the mine were different from each other.

Already for removal rate, both regions had the same response regarding to recovery techniques. Concerning the environmental variables, we observed different responses depending on the microregion.

These results show the importance that assessments of degraded areas recovery programs are made based on the natural environment in which these areas are located. Natural environments (control areas) function as a mirror of what potentially is expected to diversity, composition and ecological functions performed by the ants on a local scale.

Species richness

The fact of the area in recovery with forest formation have greater species richness when compared to the control area and recovery with exotic plants to the region inside the mine. It can be explained by intermediate disturbance hypothesis (Roxburgh et al., 2004). Environments with disturbance intermediate level have higher species richness, as found in other studies (Tonkin et al., 2013; Vonshak and Gordon, 2015). The recovery with forest formation is considered an intermediate disturbance area because it is already in an advanced stage of recovery compared with exotic species and also has a greater diversity of plant species (native and exotic), which makes this environment has a greater habitat diversity and consequently greater wealth, as stated by the theory of intermediate disturbance.

Already for the surrounding region, the fact that the areas are very near each other, justifies the richness between the areas being similar. The sharing of ant species between different areas is facilitated by the small distance between them (Soininen et al., 2007; Vasconcelos et al., 2010). Despite the recovery type being a factor that influences the ant species richness, the distance between areas is also an important regulatory factor as it homogenizes the richness between areas.

Therefore, the amount of resource available for ants is an important factor regulating species richness (Queiroz et al., 2013). This argument justifies the fact that the leaf litter weight is an important variable for the change of richness. The other variables were not important to richness for both regions, maybe due to this parameter being more sensitive to subtle changes of environment. However, as the mechanisms and ecological processes that occur in recovery of degraded areas are very singular, for further studies, other variables may be important in regulating the ant species richness.

Species composition

For the two microregions studied, the species composition was different for all areas assessed. These results demonstrate that even though the management plan for the recovery of degraded areas is appropriate, return to what it was before, is almost impossible or demand a lot of time (Ribas et al., 2012, Majer et al., 2013). This hypothesis is supported by the fact that the change in species composition may also be caused by disturbances which are subtle to environment (Campos et al., 2007; Anjos et al., 2015). These disorders can be natural or caused by man himself. The resilience of the environment to the state previously disturbed is a difficult task even for subtle changes (little or mean disturbance). So, when we highlight disturbance with a degrading factor (intense disturbance), turning back the species composition to that found in the control areas, it becomes a more difficult and complex work.

Regarding environmental variables, we could observe that all the variables are important for the maintenance and regulation of ant community, reaffirming that subtle environmental changes actually may cause significant changes in the composition of ant species (Williams et al., 2012; Queiroz et al., 2013).

Seed-removal rates

In this study, we saw that the environment in recovery with forest formation is more similar to the control area for the microregion inside the mine. This fact justifies the seed removal rate between these two areas being similar between them when compared with the recovery with exotic species. Recovery techniques that more closely resemble the structure of the natural environment (eg.: richness, density and plant height), may promote greater conservation of biodiversity and the functions carried out by them (Dominguez-Haydar & Armbrecht, 2011).

For the area outside the mine, the recovery with invader exotic grass presented lower removal rates. When we analyzed the areas of the surrounding region, we observed that besides the distance between areas influencing the removal rates (as also discussed for the species richness), the homogenization of species diversity within these environments causes loss of ecological functions (Suazo et al., 2013). In this work, the homogenization of environment was caused by the invader exotic grass *Andropogon bicornis* L.

Among the environmental variables analyzed, only plant height positively influences the seed removal rate in the areas in surrounding region. This result may be associated with one of the advantages that increasing the height of the trees has on the environment: microclimate change (Lessard et al., 2011). It is known that the temperature is a factor that regulates the activity of ants (Kaspari et al., 2015) and its reduction within the context of recovery, may provide a less stressful environment for the same and, consequently, favor seed removal function.

Implications for degraded areas management

According to the results of our work, we can discuss some implications for management of degraded areas. First, we conclude that in management of degraded areas is most importance in the studied area consider the natural environments (control areas) that these degraded areas are located. The greater proximity of the area in recovery with your natural environment provide one greater consistency to decision-making regarding the attributes evaluated in the evaluation of degraded areas programs, as it brings the regional context of habitat conservation.

Second, we can see that recovery with forestry formation proved to be a kind of interesting recovery for species richness and seeds-removal by ants.

Soon, it becomes interesting in recovery programs of degraded areas the planting of native tree species similar to its regional natural environment.

Third, we verified that in the surrounding region, the distance from the control area may have masked the effect of recovery types. In this sense, the distance proves to be an important regulating factor for ants species diversity and the functions performed by them, thus becoming one of the key instruments for recovery of degraded areas.

Fourth, among the environmental variables analyzed, all were important for the composition of ant species. These results demonstrate that the ants are highly sensitive to subtle environmental changes, hence being an excellent group to be included in evaluation programs of degraded areas. However, in this study, we brought focus on litter dry weight and plant height, since they were important for increasing species richness and seed removal rate by ants in areas inserted within the Cerrado context. For dry weight, our results demonstrate the importance of choosing plant species that have a greater accumulation of biomass in the soil. For plant height, we believe that it is important to accomplish planting tree species of fast-growing.

Finally, we can conclude that the management of degraded areas under recovery becomes peculiar to the studied area, besides having a variety of methods employed, are obscure in recovery efficiency. To sum up, we saw that the natural environment is fundamental to the effectiveness of recovery efforts, because from it we can establish better criteria for recovery programs of degraded areas.

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CONCLUSÃO GERAL

Atualmente, a recuperação de áreas degradadas se torna uma tarefa importante para manter minimamente o funcionamento dos ecossistemas. As atividades antrópicas são das mais variadas formas e provocam dados ao meio ambiente que precisam ser compensados. Neste sentido, é urgente a necessidade de estratégias de manejo que minimizem os impactos gerados por essas atividades.

No primeiro artigo deste manuscrito, avaliou-se o efeito do fogo em uma unidade de conservação no Cerrado brasileiro e a comunidade de formigas que habitam esses ambientes. Especificamente, vimos quais variáveis são importantes para a regulação da comunidade de formigas em áreas de Cerrado em recuperação pós-fogo. A partir dos nossos resultados, descobrimos que entre as variáveis analisadas, a densidade de plantas e o tempo de recuperação podem ser importantes para a regulação da riqueza, já a densidade do solo e a distância entre áreas são importantes para a composição de espécies de formigas. A partir desses resultados podemos perceber que além de variáveis locais, as variáveis espaciais e o tempo também regulam a comunidade de formigas em ambientes em recuperação pós-fogo. Recomendamos que essas variáveis sejam incluídas em programas de manejo para a recuperação de áreas degradadas.

No segundo artigo, verificamos a resposta das formigas (diversidade e função ecológica – taxa de remoção de sementes) para diferentes tipos de recuperação de áreas degradadas (mineração e agricultura) e quais parâmetros da estrutura do habitat são importantes nestes processos de regulação da comunidade. A partir dessas premissas, vimos que as respostas, tanto para a diversidade (riqueza e composição) quanto para a função ecológica (taxa de remoção de sementes) são diferentes para as microrregiões (Cerrado e Mata

Atlântica) avaliadas. Neste sentido, acredita-se ser importante considerar a singularidade do ambiente, atentando-se para a vegetação natural. Áreas controles devem sempre ser incluídas no desenho amostral em estudos de recuperação de áreas degradadas, pois são os melhores ambientes para comparações em relação aos serviços e funcionamentos dos ecossistemas.

De acordo com os dois capítulos, existem algumas recomendações a serem feitas: a primeira se diz respeito a incluir, além de variáveis locais, também variáveis espaciais e temporais em programas de recuperação de áreas degradas. A segunda se diz respeito á inclusão da vegetação natural para que o manejo e avaliação da recuperação sejam feitos com maior rigor. A terceira relaciona-se a inclusão da avaliação do funcionamento do ecossistema dentro desses programas, representado neste caso pela remoção de sementes, pois demostra uma alternativa viável e interessante para estes tipos de estudos. Por fim, acredita-se que compreender os processos ecológicos envolvidos na recuperação de ambientes que sofreram com algum tipo de distúrbio, se torna uma estratégia interessante para o manejo desses ambientes. A partir das respostas geradas pelos estudos desses mecanismos, podemos melhorar a eficiência do processo de recuperação.