Differential effects of land use on ant and herbivore insect communities associated with *Caryocar brasiliense* (Caryocaraceae)

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Abstract: Simplification of natural habitats leads to a modification of the community associated with a host plant. Pequi trees (*Caryocar brasiliense*) are common to find in central Brazil, especially in the middle of monocultures, such as soy, corn, pasturelands or *Eucalyptus* plantations. On this scenario we hypothesized that habitat modification differentially affects the diversity of ants and herbivore insects associated with this species. The aim of the work was to test if C. brasiliense trees located in human modified habitats, support a lower species richness and abundance of ants, and a greater species richness and abundance of insect herbivores, compared to preserved cerrado habitats. The study was conducted in a Cerrado area located in Northern Minas Gerais State, Brazil. Ants and herbivore insects were collected monthly during 2005 using beating technique. The results showed that ant species richness was higher in pequi trees located in preserved Cerrado, followed by trees in pastureland and *Eucalyptus* plantation, respectively. The ant abundance was lower in the *Eucalyptus* plantation but no difference in ant abundance was observed between trees in pastureland and the preserved Cerrado. Moreover, herbivore insects exhibited lower number of species and individuals in trees located in the preserved Cerrado than in the pastureland and *Eucalyptus* plantation. We concluded that habitats simplified by human activities may result in diversity loss and may change species interactions. Rev. Biol. Trop. 60 (3): 1065-1073. Epub 2012 September 01.

Key words: environmental complexity, habitat management, insect diversity, pequi trees, tri-trophic interactions.

Understanding natural patterns of species distribution and mechanisms, which determine these patterns, constitute the basic information for biodiversity conservation (Basset *et al*. 2003, Samways 2007). In Brazil, studies that describe the patterns of species richness and distribution have primarily focused on the Amazon and Atlantic Forests (Myers *et al*. 2000). However, studies of this nature in the Brazilian cerrado (savanna) deserve special attention because it is considered a conservation priority biome (Silva & Bates 2002).

In fact, the cerrado represent around 1.5 to 2.0 million km^2 (approximately 20% of the country's surface) and less than 50% of cerrado's original area remains preserved, mainly because of agricultural expansion in central Brazil (Klink & Machado 2005).

Caryocar brasiliense Camb. (Caryocaraceae) is a typical tree of the Brazilian Cerrado and it can be found from the Southern of Pará State, along the edge of the Amazon region, until the South of Paraná State and also in Paraguay (Gribel & Hay 1993). The extraction

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of pequi fruits is considered an important economic activity in different regions of Brazil, since these fruits are used in preparation of dishes, condiments, oils and sweetened beverages (Almeida & Silva 1994). During the summer, in Northern Minas Gerais State, the pequi fruit collection engages approximately 50% of the population in rural areas, representing 54.7% of the annual income of these people (Fagundes *et al*. 2007).

The pequi tree is legally protected in Minas Gerais State (Law 10,883 of 02-20-1992), but their natural habitat has been constantly altered by different human land uses such as cattle-raising pasturelands and agroforestry systems. Thus these trees are commonly found isolated in these structurally simpler habitats (Fernandes *et al*. 2004). However, the pequi phenology change among different habitats (Fagundes *et al*. 2007) and recently, several herbivorous insects have been observed causing damage to the trees located in pasture (M.F. personal observation). In this system, ants are an important component controlling insect herbivores. In fact, extrafloral nectaries located on the pequi leaves serve as attractors to several ant species which can decrease herbivore abundance (Oliveira 1997).

Besides the direct negative effect of ants on herbivores, habitat structure can modify ant diversity, causing an indirect effect on herbivores (Hoffmann & Andersen 2003, Lassau & Hochuli 2004, Rosumek *et al*. 2009). Few studies have focused on insect diversity in human modified habitats, including both, *Eucalyptus* forests and agricultural systems (Szinicz *et al*. 2005, Tylianakis *et al*. 2007). In studies about moth species from forest fragments and from different surrounding agricultural habitats, the species richness decreased with increasing distance to the forest fragments. It was also found that the majority of moth species frequently moved between forest and agricultural habitats (Ricketts *et al*. 2001). Thus, habitat simplification around the pequi trees could decrease ant diversity and, consequently, decreases the pressure of this predator on the insect herbivore fauna associated with the same tree. Based on that, the aim of the present study was to test the hypothesis that pequi trees located in human modified habitats, which are structurally simpler, support a lower species richness and abundance of ants, and a greater species richness and abundance of insect herbivores, compared to more complex preserved cerrado habitats.

MATERIALS AND METHODS

Study area: The study was conducted in the Cerrado biome, in Morro Alto (16°53'17" S - 44°00'06" W), a district that belongs to Montes Claros municipality, Northern of Minas Gerais State (Brazil). The climate of the region is considered as tropical semi-arid (Peel *et al*. 2007), characterized by the existence of a severe dry season during the winter. The average temperature is 21°C and the annual rainfall is approximately 1 100mm, concentrated from November to January. To test the hypothesis, three adjacent habitats (500m), with similar soil characteristics and density of pequi trees, were chosen in the study area. Two habitats have been modified by human activities: cattle grazing pastureland and *Eucalyptus* plantation; and one preserved area (Cerrado *strictu sensu* physiognomy). In each habitat 15 trees of similar sizes (5-8m heights and diameter at breast height above 5cm) were marked in order to characterize the herbivore insects, and ant richness and abundance.

Sampling of ants and herbivore insects: The effects of human impact on insect fauna associated with pequi trees were evaluated monthly throughout 2005. Ants and herbivore insects were sampled (08:00-11:00am) using the beating technique (Neves *et al*. 2010): for each selected plant, a branch was chosen at random (selected branches in small and large trees had approximately the same amount of leaves), and the branch was hit ten times with a beating stick in order to dislodge the associated arthropods on to a tray placed beneath. The insects collected were taken to the laboratory and sorted to the lowest taxonomic level possible, and deposited at the Laboratório de Biologia

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A generalized linear model was used to verify the habitat effect on ant and insect herbivore richness and abundance. The mean number of species or individuals per tree over the 12 months of sampling was used as response variables in order to remove the temporal pseudoreplication. The habitats (preserved Cerrado, pastureland and *Eucalyptus* plantation) were used as explanatory variables. The minimal model was constructed from the junction of qualitative factors (habitat), which were statistically different from the full model (analysis of contrast) (Crawley 2007). Next, a residual analysis was conducted to check data adequacy for the assumed probability distribution (Crawley 2007). All analysis was performed using the statistical program R (R Development Core Team 2010).

RESULTS

A total of 2 827 ants belonging to 42 species, 12 genera and four subfamilies were collected from *C. brasiliense* trees (Table 1). The two richest ant genera were *Camponotus* and *Cephalotes*, with 13 and 10 species, respectively. The ant species richness associated with pequi trees varied among habitats (Table 2). The preserved Cerrado trees had a higher ant richness (p<0.05), followed by those in pastureland and *Eucalyptus* plantation (Fig. 1A). Higher ant abundance was found in trees of the preserved Cerrado and pastureland, with no significant difference between them. While trees from the *Eucalyptus* plantation observed the lowest ant abundance (Fig. 1B).

The herbivore insects sampled on *C. brasiliense* trees were composed by 1 666 individuals (877 chewing and 789 sap-sucking). All chewing herbivores belonged to the order Coleoptera (14 families). The families Curculionidae (50 morphospecies and 306 individuals) and Chrysomelidae (24 morphospecies and 262 individuals) resulted with the highest richness and abundance (Table 3). The richness and abundance of chewing insects associated with these trees differed significantly among habitats (Table 2): these were lower in pequi trees located in the preserved area (p<0.05) than those from either pastureland or *Eucalyptus* plantation (Fig. 1C, D).

The guild of sap-sucking insects sampled was grouped into 15 Hemiptera families. Aetalionidae (234 individuals) and Cicadellidae (21 morphospecies) were the most abundant and rich sap-sucking families (Table 3). Sap-sucking insects showed the same pattern observed for chewing insects, with the richness and abundance being lower in pequi trees from the preserved Cerrado (p<0.05) than those from pastureland and *Eucalyptus* plantation (Table 2, Fig. 1 E, F).

DISCUSSION

Many studies have shown a positive relationship between diversity of terrestrial arthropods and habitat heterogeneity (Lassau & Hochuli 2004, Sperber *et al*. 2004). Positive relations between ant diversity and habitat heterogeneity can be found in different Brazilian biomes, e.g: Amazon (Vasconcelos *et al*. 2000, Cerrado: Ribas *et al*. 2003), Pantanal (Ribas & Schoereder 2007) and Atlantic Subtropical forest (Silva *et al*. 2007). In our study, the ant richness was greater in trees located in preserved cerrado, which has more complex vegetation than trees found in a grassland pasture or *Eucalyptus* plantation. This result indicates that variations in habitats due human activity negatively affected the ant fauna associated with pequi trees. Thus, the removal of native vegetation to establish *Eucalyptus* plantation or pastureland may have caused the habitat simplification and, indirectly, a decrease on ant richness, probably due to a decrease in resource availability (e.g. food and nesting sites) in simplified habitats. This pattern supports the hypothesis that ant diversity is positively related to vegetation structural complexity due the classical niche diversification hypothesis.

We found that ant richness and abundance were smaller in *Eucalyptus* plantation than pasturelands. On the other hand, we did not

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TABLE 1

Occurrence of ants species associated to *Caryocar brasiliense* in three different habitats
(preserved Cerrado, pastureland and *Eucalyptus* plantation)

| Subfamily	Species	Cerrado	Pastureland	*Eucalyptus*
Dolichoderinae	*Azteca* sp. 1	X	X	X
	Azteca sp. 2	X	X	X
	Dolichoderus sp. 1		X	
	Dorymyrmex altlasanis	X	X	X
	Linepithema sp. 1	X		X
Ectatomminae	*Ectatomma tuberculatum*		X	
Formicinae	*Camponotus arboreus*	X	X	X
	Camponotus atriceps	X	X	
	Camponotus bidens	X		
	Camponotus blandus	X	X	X
	Camponotus crassus		X	X
	Camponotus melanoticus		X	
	Camponotus renggeri	X	X	
	Camponotus rufipes		X	X
	Camponotus sp. 1	X	X	X
	Camponotus sp. 2			X
	Camponotus sp. 3	X	X	X
	Camponotus sp. 4	X		
	Camponotus sp. 5		X	
Myrmicinae	*Cephalotes clypeatus*		X	
	Cephalotes grandinosus	X	X	
	Cephalotes pallens		X	
	Cephalotes pavonii	X	X	
	Cephalotes pusillus	X	X	X
	Cephalotes minutus	X	X	X
	Cephalotes simillimus	X		
	Cephalotes sp. 1	X		
	Cephalotes sp. 2	X		
	Cephalotes sp. 3		X	
	Crematogaster erecta			X
	Crematogaster crinosa	X	X	X
	Crematogaster sp. 1	X	X	X
	Pheidole sp. 1			X
	Solenopsis sp. 1		X	X
	Solenopsis sp. 2	X	X	X
	Tetramorium sp. 1			X
Pseudomyrmicinae	*Pseudomyrmex elongatus*	X		
	Pseudomyrmex gracilis	X	X	X
	Pseudomyrmex oculatus	X	X	X
	Pseudomyrmex sp. 1	X		X
	Pseudomyrmex sp. 2		X	X
	Pseudomyrmex sp. 4			X
Total	42	26	29	25
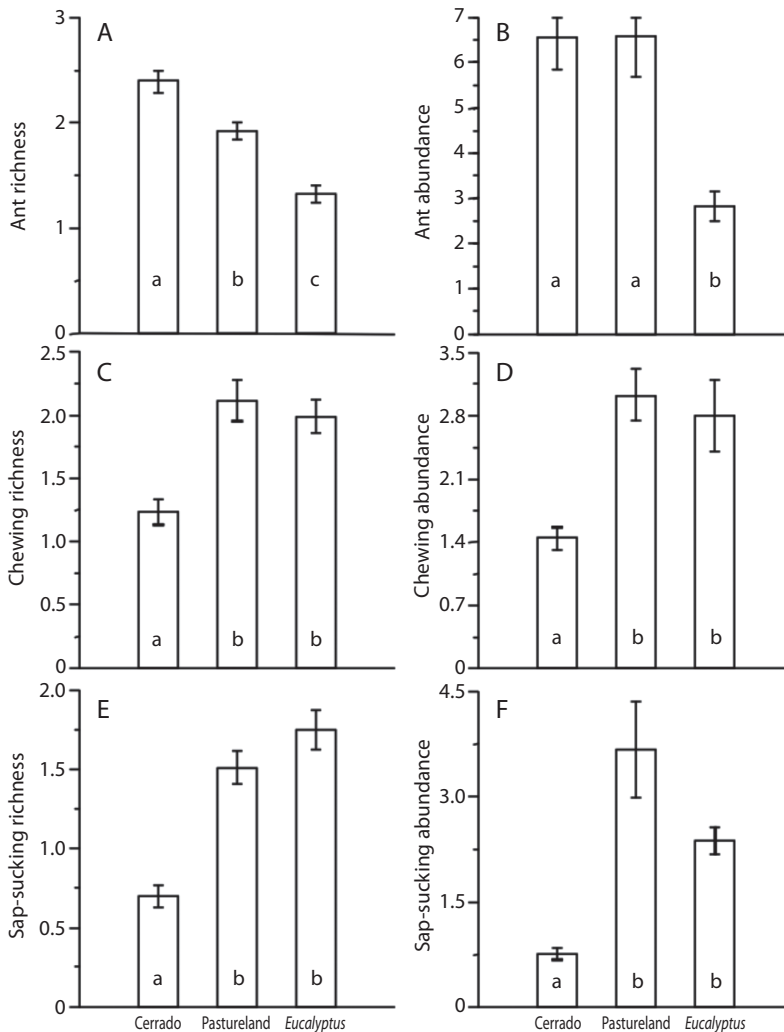
Fig. 1. Richness and abundance of ants (**A, B**), chewing (**C, D**) and sap-sucking insects (**E, F**) collected from pequi trees (*C. brasiliense*) in three habitats (preserved cerrado, pastureland and *Eucalyptus* plantation). The vertical bars represent the mean (±SE) number of species and individual per tree in 12 months of sampling. Different letters inside the vertical bars represent statistically distinct habitats (p<0.05) verified through the contrast analysis.

find differences in ant abundance between preserved Cerrado and pasturelands. Probably this result may be influenced by two main factors. First, structural complexity of the preserved Cerrado seems to be much more similar to pastureland than *Eucalyptus* plantation. Second, disturbance intensity due human activities is certainty bigger and more frequent in *Eucalyptus* plantation than in pastureland, which could

decrease ant species richness and abundance in *Eucalyptus* area. This is the first study that shows the negative effect of pastureland and *Eucalyptus* plantation on ant richness.

In contrast, pequi trees located in preserved Cerrado had lower richness and abundance of insect herbivores than those in pastureland or *Eucalyptus* plantation. A similar result was found for herbivores from distinct feeding

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TABLE 2
Analyses of deviance of the minimal adequate models showing the effects of the three habitats
(Cerrado, grassland pasture and *Eucalyptus* plantation) of ants and herbivore insects associated to *C. brasiliense*

Response variable	Error distribution	Deviance	p
Ant richness	Poisson	8.57	<0.01
Ant abundance	Quasipoisson	29.41	<0.01
Chewing insects richness	Poisson	6.67	<0.01
Chewing insects abundance	Poisson	21.59	<0.01
Sap-sucking insects richness	Poisson	8.66	<0.01
Sap-sucking insects abundance	Quasipoisson	26.95	<0.01

TABLE 3
Herbivore insect richness (ric) and abundance (ab) collected from pequi trees (*C. brasiliense*) in three habitats (preserved
Cerrado, pastureland and *Eucalyptus* plantation)

Taxa	Cerrado		Pastureland		*Eucayptus*	
	ric	ab	ric	ab	ric	ab
Coleoptera						
Bruchidae	1	1	12	20	9	17
Cerambycidae	2	2	0	0	3	3
Chrysomelidae	11	61	10	139	15	62
Curculionidae	25	55	27	124	27	127
Elateridae	2	2	1	1	2	2
Larvae	6	12	3	4	10	25
Hemiptera						
Nymphs	10	105	5	43	5	72
Auchenorrhyncha						
Aetalionidae	1	60	1	121	1	53
Cercopidae	0	0	1	1	0	0
Cicadellidae	14	44	13	35	13	30
Cicadidae	0	0	1	1	0	0
Flatidae	1	1	1	2	1	1
Fulgoridae	1	1	0	0	0	0
Membracidae	5	21	8	54	4	20
Nogodinidae	1	2	0	0	1	2
Sternorrhyncha						
Psyllidae	2	2	1	1	2	2
Heteroptera						
Alydidae	1	1	1	1	1	1
Largidae	1	1	2	4	1	1
Lygaeidae	2	76	1	14	1	62
Miridae	10	53	8	28	9	40
Pentatomidae	10	11	5	6	7	8
Rhopalidae	2	5	1	1	2	5
Scutelleridae	2	10	1	1	2	6
Total	110	526	103	601	116	539

guilds between managed and conserved areas (Speight *et al*. 2003). Moreover, some studies indicate that insect herbivore's natural enemies are more effective in pristine areas (Altieri & Letourneau 1982). Normally, predators and parasitoid insects species show high diversity in forest than herbivore insects, that can be pest in agricultural areas (Szinicz *et al*. 2005). Predators and parasites have a stronger negative effects on herbivores associated with *Caryocar brasiliense* in Cerrado area. In this way, the decrease in ant diversity on *Eucalyptus* plantation and pastureland had positively affected the insect herbivore richness and abundance in these habitats. In contrast, tropical agroecosystems in Ecuador had a higher ratio of parasitoid to host species and increased parasitism rates (Tylianakis *et al*. 2007). In fact, many studies have reported high predation pressure by ants on arthropods (Heil & McKey 2003) while others showed that ant presence could reduce the herbivore insects abundance on their host plants (Oliveira 1997, Fagundes *et al*. 2005, Rosumek *et al*. 2009, Neves *et al*. 2011).

In addition to ants effects (Top-down effects), herbivore insects performance is also affected by host plant quality (Bottom-up effects) (Coley *et al*. 1985, Coley & Barone 1996). The resource availability hypothesis (Coley *et al*. 1985) predicts that plants with readily available light but low nutrient availability have elevated rates of carbon fixation and low investment in chemical defenses. In this study, isolated pequi trees in modified habitats should provide a high density of herbivores for the lack of chemical defense. Some authors have argued that higher selection pressure imposed by herbivores had resulted in plants evolving stronger chemical resistance to leaf herbivory in these environments (Coley & Barone 1996, Dirzo & Boege 2008).

The present study shows that the number of ant species on pequi trees decreases with habitat simplification. On the other hand, insect herbivore richness and abundance follows a reverse trend. From conservation point of view we could point out that natural habitat preservation in Cerrado could only benefit ants and at the same time the land use modification could benefit insect herbivore biodiversity. However this conclusion is wrong and must be carefully discussed. In fact, recent studies showed that some herbivore insects species have shown eruptive populations on trees located in disturbed habitats, affecting productivity and often plant survival (Fernandes *et al*. 2004, Fagundes *et al*. 2007). Moreover, networks structure can be altered by environmental change and these alterations may have important ecosystem-level consequences (Tylianakis *et al*. 2010). At this point is important to empathize the danger of use just a unique species in conservation programs, forgetting the role of species interaction to community organization and maintenance in space and time (Fagundes *et al*. 2005).

We suggest a decrease in the transformation of natural habitats in pastureland and *Eucalyptus* plantations, and in this way the ant top-down effects on herbivore insects. The natural habitat preservation of the Brazilian Cerrado is very important for biodiversity conservation and ecosystem optimum function. Experimental studies on tri-trophic interaction and food webs could be essential to elucidate the patterns of insect distribution and the effect of habitat modification on insect biodiversity and ecological processes.

RESUMEN

La simplificación de los hábitats naturales conduce a una modificación de la comunidad asociada con una planta huésped. En la región central de Brasil es muy común encontrar árboles aislados de "pequi" (*Caryocar brasiliense*) en medio de monocultivos de soya, maíz,

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pastos o plantaciones de eucalipto. Bajo este escenario, nosotros predecimos que la modificación del hábitat afecta diferencialmente la diversidad de hormigas y herbívoros asociados a árboles de "pequi". El objetivo de este artículo fue determinar que árboles de "pequi" localizados en hábitats modificados por actividades humanas (i.e. pastizales y plantaciones de *Eucalyptus*), soportan una menor abundancia y riqueza de especies de hormigas. Por el contrario, se espera una mayor abundancia y riqueza de especies de herbívoros en hábitats modificados. Este estudio fue realizado en un área de Cerrado (sabana brasileña) localizado en el Norte del estado de Minas Gerais, Brasil. Las hormigas y los herbívoros fueron muestreados usando técnicas de golpe. La riqueza de especies de hormigas fue mayor en árboles de "pequi" localizados en áreas preservadas de Cerrado, seguida por árboles de pastizales y finalmente por árboles de plantaciones de *Eucalyptus*. La abundancia de hormigas fue menor en plantaciones de *Eucalyptus*, pero no hubo diferencias en la abundancia de hormigas entre árboles de pastizales y áreas preservadas de cerrado. Por otra parte, el número de especies de insectos herbívoros fue menor en árboles de áreas preservadas de Cerrado que en pastizales y plantaciones de *Eucalyptus*. Concluimos que las actividades humanas reducen la complejidad del hábitat resultando en la pérdida de la diversidad de insectos y procesos ecológicos.

Palabras clave: complejidad ambiental, manejo de hábitat, diversidad de insectos, árboles de "pequi", interacciones tri-tróficas.

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