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ECOLOGY

Man-made soil drainage alters the vegetation structure and woody species distribution in campo de murundus

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ABSTRACT. Campos de murundus work as recharge zones and are important for the maintenance of water resources in Brazilian Cerrado. However, with the expansion of the agricultural frontier, this ecosystem may disappear or suffer high anthropogenic disturbances. The aim of the study was to evaluate the structure and distribution of woody species, after the implantation of artificial drainage channels in campo de murundus, in plots near and distant of the drains in the soil. We sampled woody individuals with ⩾ 3 cm diameter at the base, and established 20 permanent plots of 20×50 m, 10 of which were between 0-20 m of the drains (edge) and 10 between 150-200 m distant from the drains (interior), totaling two hectares of survey. We recorded 47 species with total density of 230.5 ind.ha^{-1} and total basal area of 1.331 m^2 ha^{-1}. The diversity index of species was H' = 3.18. We recorded higher density and basal area in the edge, and differential distribution and occupation of woody species in the microrelief of the murundus. This provides us strong evidence that the drains have altered the vegetation structure, especially in the edge of the remnant campos de murundus turning the vegetation woodier and denser.

Keywords: Cerrado floodplain; Drainage channels or artificial grooves in the soil; Encroachment; Human disturbance; Wetlands.

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Introduction

Wetlands play an important role in ecosystem services (e.g. water maintenance), with high environmental complexity (e.g. diversity and endemism) and vulnerability (e.g. environmental degradation). As a consequence of the anthropogenic disturbance, these areas disappeared or were drastically decharacterized with edaphic changes and triggering erosive processes over the time (Ewing, Vepraskas, Broome, & White, 2012). In the wetlands of the Brazilian Cerrado, such as veredas, gallery forests, humid fields and campos de murundus (literally fields of earthmounds), the reality is the same (Rull & Montoya, 2014; Marimon et al., 2015).

Campos de murundus are characterized as savanna formations which occur in the Brazilian Central Plateau. These fields are important for the maintenance of the water flow, showing groundwater outcrops, especially during the rainy season (Resende, Araújo, Oliveira, Oliveira, & Ávila Júnior, 2004; Pinto, Mews, Jancoski, Marimon, & Bomfim, 2014; Marimon et al., 2015). Also known as parque de cerrado (*sensu* Ribeiro & Walter, 2008), varjão or covoais, the latter being the term popularly known in southwestern Goiás. This physiognomy is characterized by woody plants grouped in convex elevations in the terrain (mounds), which have regional denominations such as cocoruto, monchão or murundu, as adopted in this study. On the other hand, the murundus are surrounded by a wet grassland (grasses, sedges and herbaceous), where the water table reach the surface during the rainy season (Oliveira-Filho, 1992; Marimon et al., 2015).

Due to their environmental fragility, important role in the water maintenance and wildlife refuge, campos de murundus were defined as Permanent Preservation Area, by Goiás State Law - nº 16,513 (Goiás, 2007). However, the campos de murundus have been affected by anthropogenic disturbances due to the expansion of the agricultural frontier, and the construction of drainage channels to promote the subsurface outflow of soil water, making these ecosystems suitable for agriculture or pasture. Therefore, these areas were simply replaced by crops, or became very reduced and fragmented, since they are in flat relief, in fertile and wetter soils (Rosolen, Oliveira, & Bueno, 2015).

In recent years, some approaches on floristic composition, community structure and woody species distribution have been carried out in Brazilian campos de murundus. These studies were carried out in the Pantanal of the Araguaia floodplain, Mato Grosso state (Morais, Morais, & Lima, 2014; Marimon et al., 2012; 2015), in the Triângulo Mineiro region (Resende et al., 2004), and in southwestern Goiás state (Maricato, Guilherme, Gomes, Pereira, & Souza, 2017; Pereira, Souza, Guilherme, Freire, & Teles, 2019). In recent years the disturbance of agriculture on edaphic and microbiological properties were assessed in the studied area (Santos, Custódio Filho, Freitas, Correchel, & Carneiro, 2014; Gomes Filho et al., 2014; Assis et al., 2014; Carneiro et al., 2015; Rotta et al., 2015; Souza et al., 2016). However, little is known about the anthropogenic effects on the campos de murundus woody flora (Pinto et al., 2014). To our knowledge, no other study has investigated the flora composition and vegetation structure of campos de murundus in Goiás, especially when the surrounding matrix is dominated by monocultures and the land is intensively managed. Thus, this study may provide subsidies for future efforts to restore and manage these important wetlands.

Here we seek to evaluate the impact of construction of soil drainage channels on the structure of the woody vegetation on the murundus (mounds) in a seasonal flooding area in southwestern Goiás. We compared the vegetation structure located near (edge) and away (interior) from the drains, and also by microenvironments, evaluated as a function of the murundu microrelief. In this context, we evaluated the effects of the drains in the distribution and abundance of the species. Since is notorious the anthropogenic impacts, especially near the drains, we work with the hypothesis that there are differences in the woody vegetation structure and species distribution between the edge and interior environments, and along the murundu's microrelief (summit, middle and base).

Material and methods

Study site

We conducted the study in a remnant of campo de murundus, located at *Fazenda Boa Vista*, municipality of Jataí, Goiás, Brazil (17°58'19" S and 52°04'39" W), area of 870 m, belonging to the Rio Claro basin, an important Paraná River tributary (Figure 1). The remnant has around 155 hectares and is immersed in an agricultural matrix (Figure 2-A). In order to allow the cultivation of grains (Santos et al., 2014), especially soybean and maize, drainage channels (drains), 1-1.5m deep and 1m wide, were dug throughout almost all of its surroundings. This artificial drainage system, installed two decades ago, facilitated the superficial flow of soil water and promoted the reduction of the water table level.

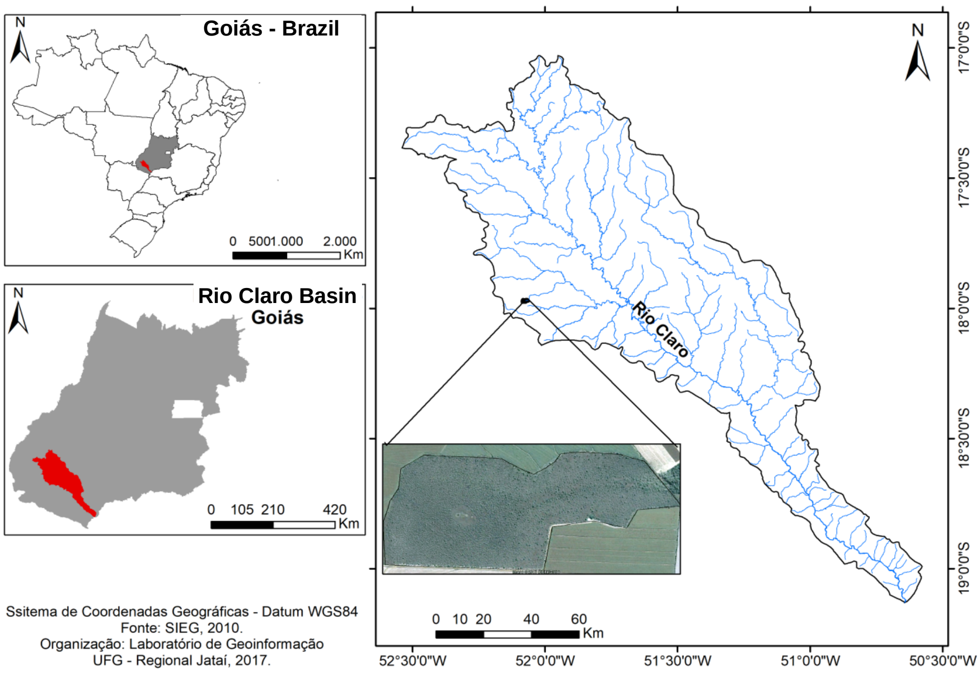

Figure 1. Location of the campo de murundus remnant in Boa Vista farm, Jataí, Goiás, Brazil.

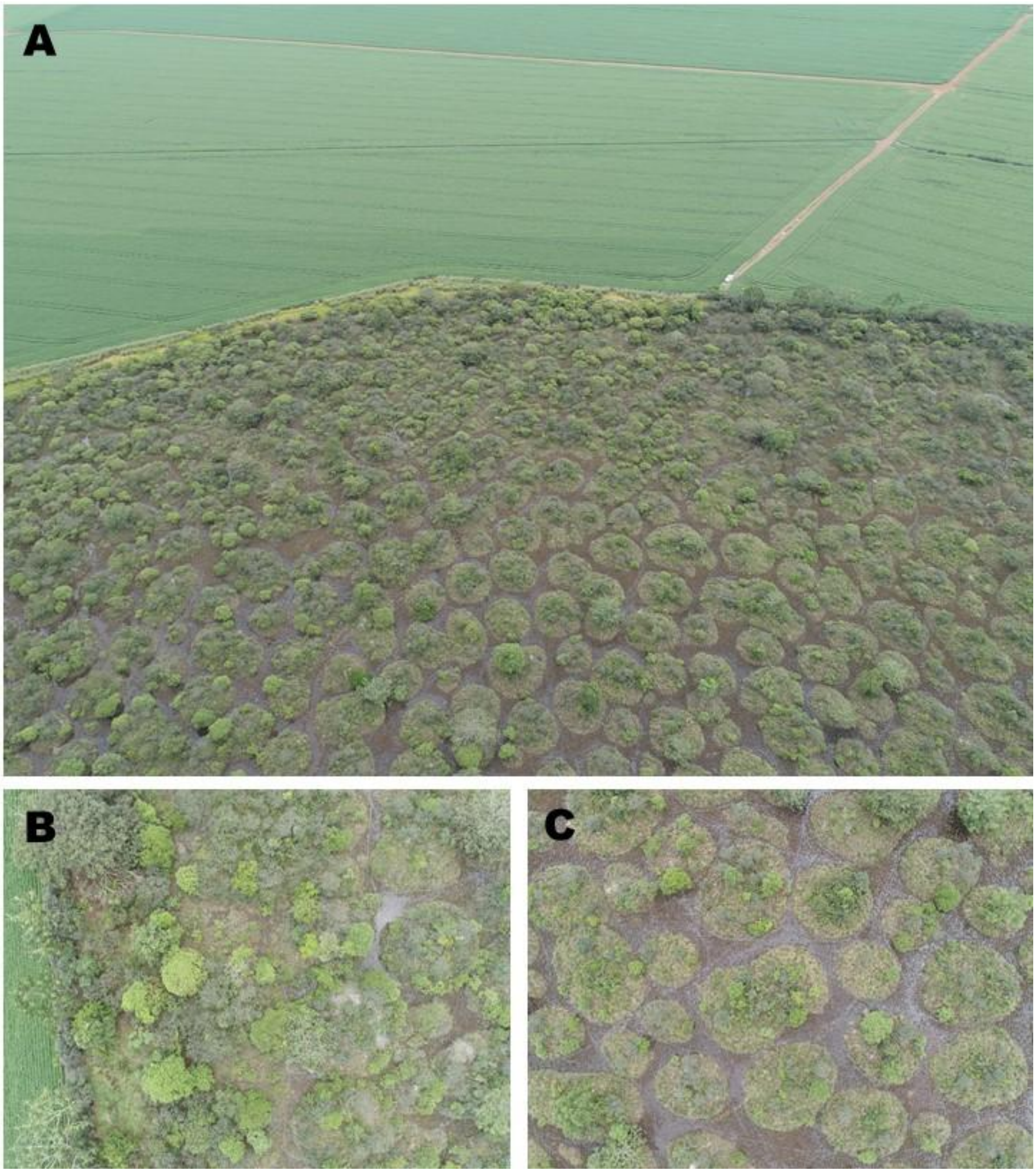

Figure 2. Overview of the campo de murundus showing the agricultural matrix (A), and the top view detail of murundus on the edge (B) and interior (C) of the remnant.

The climate is type Cw, according to the Köppen's classification, mesothermic, with well defined dry and rainy periods (Silva, Assad, & Evangelista, 2008). The temperature varies between 18-32°C throughout the year and the rainy season occurs between November and May, where more than 80% of the total annual rainfall is recorded. The average annual rainfall was 1600-1700 mm. According to the Brazilian System (Santos et al., 2014), the soil is classified as *Plintossolo háplico* of clayey texture, with restricted drainage and shallow water table, especially during rainfall, restriction to the water percolation and temporary (4-6 months) effect of flooding, with formation of plintite (Assis et al., 2014).

Survey and analysis of woody vegetation

We established 20 20×50 m (1,000 m^2 each) permanent and georeferenced plots. Ten of them were allocated between 0-20 m away from the drains (edge; Figure 2-B) and another 10 between 150-200 m from the drains (interior; Figure 2-C), totaling two hectares. We measured the height and diameter of all woody individuals with base diameter (0.3 m from the ground) ⩾ 3 cm and labelled with numbered aluminum tags for future monitoring. In the case of multiple stems, we measured only those greater than the inclusion limit. The botanical material with dubious identity was collect and herborized for later identification. Voucher specimens were deposited in the *Herbário Jataiense* (HJ) of the *Universidade Federal de Jataí*.

We compared the density and basal area of the species between edge and interior of the remnant applying Student

t-test, after evaluating the normality and homoscedasticity data assumptions (Zar, 2009), and using the BioEstat 5.0 Program (Ayres, Ayres Junior, Ayres, & Santos, 2007). The complete species list, as well as the authorship of scientific names, considering the relative density, dominance and frequency parameters and the importance value (VI), are found in Maricato et al. (2017). In this study we present a species list with more than five individuals throughout the survey and compared by means of the chi-square test (χ^2) if the abundances differed between the edge and interior of the earthmound. We evaluated the diversity of the woody vegetation using the Shannon index (H') and the evenness by the Pielou's index (J'). We compared the values of the diversity index between edge and interior by the Hutcheson *t* test at 5% significance (Zar, 2009).

In order to evaluate possible differential distributions of the woody component on the murundus, they were cut in three distinct microrelief: summit, middle and base. The adoption of this criterion was arbitrary, considering 1 3^{-1} of the murundus for each microrelief or microenvironment. The summit is located at the apex, and the base is located near the depressions, where there is an outcrop of the water table in the rainy season. The middle corresponds to the intermediate portion between the summit and the base. We did not record woody individuals in the depressions during the survey. Again, we used the chi-square test (χ^2) to evaluate the null hypothesis that the distribution of individuals is independent across the three microenvironments, both for edge and interior plots.

Results and discussion

We recorded a total density of 230 ind. ha^{-1} and basal area of 1.331 $m^2.ha^{-1}$. The species diversity for all the area was H'= 3.18 and evenness J' = 0.85 (Table 1). The values of H' found here are close to those recorded in other campos de murundus, such as in Mato Grosso, Minas Gerais, Goiás and Distrito Federal, ranging from 2.33 to 3.56 (Oliveira-Filho, 1992; Resende et al., 2004; Silva, Vale, Haidar, & Sternberg, 2010; Maricato et al., 2017). However, in general, species diversity in campos de murundus are lower than those recorded for woody vegetation in adjacent cerrado *sensu stricto*, probably due to the occurrence of woody plants being limited only to murundus (Oliveira-Filho, 1992). In a more general approach, murundus act essentially as islands of fertility and diversity, characterizing the spatial heterogeneity of vegetation in hyperseazonal savanna formations (Sileshi, Arshad, Konaté, & Nkunika, 2010).

Table 1. Diversity and woody vegetation structure of all area, edge and interior plots of the campo de murundus in Jataí, Goiás, Brazil. Different letters represent significant differences in *t* tests for density and basal area.

Parameters of woody plants	Total	Edge	Interior
Total number of individuals	461	278	183
Species number	43	37	32
Density (ind.ha^{-1})	230.5	278.0 a	183.0 b
Basal area ($m^2.ha^{-1}$)	1.331	0.857 a	0.474 b
Shannon diversity - H'(nat. ind^{-1})	3.18	2.83 a	2.89 a
Pielou eveness - J'	0.85	0.82	0.86

Species richness was similar between the edge and interior plots, and the values of H' did not differ statistically between both. On the other hand, both density (t = 2.23; p = 0.02; GL = 18) and basal area (t = 2.07; p = 0.04; GL = 18) were significantly higher in the edge plots than in the interior (Table 1). This agrees with this study hypothesis and suggests that the drains are influencing the woody vegetation density and biomass increase. With the drains, the water level is lower in the adjacent areas of the studied campo de murundus. Thus, the soil water saturation typical of these environments, ceases and promotes the growth of woody species. In this case, it is possible that the drains are causing a decharacterization of the original phytophysiognomy and, in the short or medium term, the area can become a typical cerrado.

Only four species showed significantly different abundances between edge and interior plots (Table 2), indicating that the hypothesis of differential species distribution was partially adopted. *Pleroma stenocarpum* showed higher abundance in the edge and below than expected in the interior, suggesting adaptation to grow near the drains, in drier sites. However, *Miconia rubiginosa*, *Maprounea guianensis* and *Myrcia splendens* were significantly more abundant in the interior, and the latter two were also significantly less abundant at the edge of the remnant. Therefore, these species may indicate preference for less disturbed environments, and still some waterlogging tolerance, even occurring on the murundus. Marimon et al. (2012) mention *Myrcia splendens* as frequent in campos *de* murundus, and the first author also describes the occurrence of *Miconia rubiginosa* in Amazonian savannas and veredas.

Table 2. Distribution of the species abundance that occurred in the edge (E) and interior (I) of the campos de murundus in Jataí, Goiás, Brazil. The χ^2 tests the null hypothesis that the species abundance is independent in relation to the evaluated environments. Values followed by positive (+) or negative (-) signs represent species abundance significantly above or below expected, respectively, in relation to the total of individuals in the area. ns = not significant.

Species	Number of individuals						
	Edge		Interior		χ^2 E	χ^2 I	*P*
Miconia albicans	42		30		0.02	0.03	ns
Davilla elliptica	29		16		0.07	0.10	ns
Pleroma stenocarpum	37	+	6	-	4.31	6.54	<0.05
Aegiphila verticillata	27		6		2.19	3.33	ns
Maprounea guianensis	3	-	29	+	12.93	19.65	<0.05
Byrsonima coriacea	15		7		0.11	0.17	ns
Miconia rubiginosa	4		12	+	2.75	4.17	<0.05
Heteropterys campestris	7		7		0.11	0.16	ns
Palicourea rigida	11		1		1.47	2.24	ns
Hortia oreadica	11		0		2.25	3.42	ns
Kielmeyera coriacea	9		2		0.53	0.80	ns
Leptolobium dasycarpum	7		3		0.04	0.06	ns
Bauhinia sp.	4		6		0.39	0.59	ns
Cecropia pachystachya	9		1		1.01	1.54	ns
Erythroxylum campestre	7		3		0.04	0.06	ns
Guapira opposita	5		5		0.05	0.07	ns
Kielmeyera speciosa	7		3		0.04	0.06	ns
Connarus suberosus	3		6		0.68	1.04	ns
Casearia sylvestris	7		1		0.58	0.88	ns
Tachigali vulgaris	5		3		0.02	0.03	ns
Banisteriopsis sp.	1		6		1.75	2.66	ns
Dimorphandra mollis	6		1		0.39	0.59	ns
Myrcia splendens	0	-	7	+	3.28	4.98	<0.05
Alchornea triplinervea	1		5		1.24	1.88	ns

Miconia albicans was the most important species (35% of total VI), occurring both on the edge and in the interior. This species can occupy both sunny and well drained environments, such as campo sujo, and those more shaded such as dense cerrado, may also predominate in secondary forests (Neri et al., 2005). This indicates the plasticity of some species in occupying environments on diverse soils and fertility conditions, as also observed by Moreno, Schiavini, and Haridasan (2008). Therefore, not only the genus *Miconia*, but the family Melastomataceae have woody species well represented and adapted to the campos de murundus, as also recorded by Marimon et al. (2012) in an extensive study conducted in the Araguaia River floodplain.

In general, the summit of the murundus had a higher woody vegetation density (289 individuals), followed by middle (129) and base (43), with lower abundance of individuals. In flooding sites, the low density of woody plants usually is associated with low species richness, as a natural process of selectivity due to the wetting condition of hydromorphic soils (Brito, Martins, Oliveira-Filho, Silva, & Silva, 2008), common in or near depressions, in campos de murundus (Oliveira-Filho, 1992). Marimon et al. (2015) observed that there is a strong gradient of species occurrence on the murundus and suggested that the vegetation can be hydrologically determined by the relief fine scale variation. In this case, soil water saturation is a limiting factor because it reduces the oxygen availability to the plant root system.

In edge plots the number of individuals was lower than expected for the summit (χ^2 = 27.3, p < 0.0001), whereas for the middle (χ^2 = 12.2, p < 0.001) and the base (χ^2 = 15.1, p < 0.001) of murundus, and abundance was higher than expected. Instead, in interior plots, abundance at the summit was higher than expected (χ^2 = 6.3, p < 0.02), while in the middle (χ^2 = 3.9, p < 0,05) and at the base (χ^2 = 12.4, p < 0.001) of murundus there were significantly fewer individuals. These findings suggest that the decreasing of the water table promoted by the drains is also contributing with the encroachment of the woody vegetation in the edges of the studied campo de murundus, agreeing with the study hypothesis. Furthermore, the best drainage at the summit of murundus is a condition that favors the occurrence of woody plants of the typical cerrado. Our study highlighted a strong evidence that, due to the implantation of drainage channels, a migration of woody plants to microenvironments near to the depression can occur, as observed for edges plots. The area available for the woody species to grow is restricted in campos de murundus, due to seasonal elevation of the water table. Once this factor is attenuated or removed from the environment by the action of the drains, there is a decrease in the environmental pressure limiting the species growth and increase in the space available for them to establish and develop. Future evaluations of the plant community dynamics of this campos de murundus will be able to prove the findings obtained in this study.

The woody vegetation increments and differential colonization in artificially drained areas can change the functioning and the ecosystem services of the environment over a medium to short term, with probable implications for the aquifers recharge, thus streamlining the processes of water loss in the ground. Naturally open ecosystems, such as campos de murundus, are more efficient in maintaining renewable water resources; however, disturbances of any nature, such as increased plant biomass, can lead to reduced water production (Honda & Durigan, 2017). Besides of the plant community, other components of the biota are also affected over time, with a conversion of campo de murundus into agriculture. Assis et al. (2014) verified changes in the occurrence and loss of arbuscular mycorrhizal fungi species in marginal cultivation areas in the same area studied here.

Brazilian wetlands, including campos de murundus, received special attention when the country became a signatory of the Ramsar Convention in 1993 (Junk et al., 2014). These areas are important, mainly because provides ecosystem services, contributing, for example, to the water table recharge, regulation of biogeochemical cycles, maintenance of biodiversity and even direct resources for human populations, such as fishing (Junk, Silva, Cunha, & Wantzen, 2011). Thus, it is extremely relevant to know the impacts that the anthropic actions cause to these areas. Only then we will be able to propose public policies to maintain the strength of the wetlands, guaranteeing water stability for future generations (Rosolen et al., 2015).

Conclusion

Greater density and basal area at the edge of the studied campos de murundus, differential woody species distribution and occupation on murundus microenvironments, provide us strong evidence that these man-made drainage channels modified the vegetation structure as a whole, especially in campos de murundus surroundings.

Several of these wetlands in southwestern Goiás have already been severely decimated in the recent past. However, the few remnants still found are under heavy pressure and need to be preserved, not only for the conservation of local biodiversity, but also, in particular, for the maintenance of water sources for future generations.

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